Evaluation of the Impact of Malaria Control Interventions on Malaria-Specific Morbidity and Mortality in All Ages in Ethiopia, 2000–2013

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Executive Summary

OBJECTIVE

This report was commissioned by the U.S. President's Malaria Initiative (PMI) on behalf of Ethiopia's Federal Ministry of Health (FMoH) and in support of the Roll Back Malaria (RBM) Partnership and the FMoH's monitoring and evaluation activities. The objective of this report is to evaluate the combined impact of progressively increasing coverage of malaria control interventions on malaria morbidity and mortality at the national level during the evaluation period 2000–2013.

DESIGN

The evaluation is based on a before-and-after assessment, which uses a plausibility evaluation design to measure the impact of changes in malaria intervention coverage on all-cause mortality in children under five years of age (ACCM) while considering other contextual factors that may have contributed to a decline in these outcomes.

DATA SOURCES

Several sources of data were accessed for use in this evaluation. Intervention coverage and ACCM were estimated from data obtained primarily from large population-based household surveys such as the Demographic and Health Surveys (DHS), and Malaria Indicator Surveys (MIS). These national survey data are supplemented, where relevant, by data from facility-based national health reporting systems such as the Health Management Information System (HMIS), the Integrated Disease Surveillance and Response (IDSR) system, and the Public Health Emergency Management (PHEM) system, and from data derived from annual malaria commodity micro-planning reports. Additional programmatic data such as district-level ITN distribution data, IRS program data, and availability of ACT commodities were included, when available. Data from the PMI-funded Ethiopia Malaria Epidemic Detection and Sentinel Surveillance Project, as well as research projects across the country, are included where possible to provide more in-depth assessment of trends in malaria-specific morbidity and mortality**.** Data from other published studies are cited where pertinent.

MALARIA IN ETHIOPIA

Malaria endemicity is low in Ethiopia, with 1.3% national malaria parasite prevalence in 2011. Despite the low prevalence, 60% of the population or 50.6 million people, were still at risk of malaria as of 2013. The most prevalent malaria pathogen is *Plasmodium falciparum (P. falciparum)*, but *Plasmodium vivax (P. vivax)* causes approximately 40% of outpatient malaria illnesses. In Ethiopia, unlike most of the rest of Africa, the majority of outpatient illnesses, hospitalizations, and deaths from malaria occur among persons greater than five years of age. Unstable transmission leads to low levels of immunity to malaria infection among all age groups. The instability of transmission is also associated with a constant threat of malaria outbreaks and associated case fatality rates of 5-10%. Large-scale malaria epidemics have historically occurred at 5 to 8-year cycles, possibly related to cyclical global weather events that influence local populations of malaria vectors.

IMPLEMENTATION OF MALARIA CONTROL INTERVENTIONS

Significant improvements in malaria control intervention coverage in Ethiopia have been achieved over the evaluation period. Between 2000 and 2011, more than 45 million insecticide treated nets (ITNs) were distributed, raising household ITN ownership from 4% in 2004 to 55% by 2011 in high-risk areas (rural households at elevations less than 2000 meters). The use of ITNs by children less than five years of age in these areas increased from 2% in 2005 to 30% in 2011. The use of ITNs by pregnant women in these areas also increased from 1% in 2005 to 29% in 2011. IRS protected fewer than 4.2 million people before 2005 but was expanded to protect 20 million (4.6 million households) in 2011. Households in areas of high malaria transmission owning at least one ITN or having received IRS increased from 12% in 2005 to 72% in 2011. Improvement was also noted in malaria case management and diagnosis over the evaluation period. Timely care seeking for fever in children less than five years of age in high transmission areas increased from 3% in 2005 to 51% in 2011 as did overall numbers of outpatient visits to public health facilities. The FMoH estimated that 92% of the population had access to primary care services in 2012, compared to only 64% in 2007 and 61% in 2004. This may be in part due to the increased numbers of public facilities constructed, including the establishment of 15,000 new rural health posts and training of 35,000 health extension workers (HEWs). Diagnostic testing for malaria also improved over this time period, with 83% of reported malaria cases parasitologically confirmed in 2012 compared to less than 25% in 2000. During this time period, first-line treatment for *P. falciparum* malaria transitioned from sulfadoxine pyrimethamine (SP) to artemether lumefantrine (AL).

IMPACT

Malaria morbidity mortality

National estimates of malaria parasitemia or anemia prevalence are not useful for analyzing trends in malaria morbidity over the evaluation period as they are not available from household surveys preceding the recent expansion of malaria interventions. Parasitemia data are available from two MIS conducted in 2007 and 2011. These data suggest sustained, low malaria prevalence in children less than five years of age living in malarious areas less than 2,000m elevation (1.0% in 2007 and 1.3% in 2011). Severe anemia prevalence, available from the two MIS as well as from the 2005 and 2011 DHS, did not decline over this time period. National systems for routine reporting of health facility data have collected malaria-specific morbidity and mortality data over the evaluation period, however, the quality and completeness of data reporting have changed dramatically during this time making counterfactual comparisons difficult. Several studies have analyzed health facility data from a fixed sample of facilities in order to have comparable baseline and endline data. Results from several of these studies show declines in annual malaria outpatient cases, reductions in slide positivity rates, malaria admissions, and monthly inpatient malaria deaths over the evaluation period. Taken in totality, existing evidence suggests that malaria cases and malaria deaths have declined over recent years, during the end of the evaluation period when malaria control interventions were widespread in the country; however, data are sparse or of questionable quality from the beginning of the evaluation period rendering longer term trends difficult to decipher with confidence.

All-cause child mortality

ACCM decreased by 47% from 1996–2000 to 2007–2011; the mortality rate of children less than five years of age was measured at 166 per 1,000 births in the 1996–2000 period, 123 per 1,000 in the 2001–2005 period, and 88 per 1,000 in the 2007–2011 period, indicating major progress in reducing ACCM.

Although the rapid expansion of malaria control activities in the malaria-endemic regions of the country likely contributed, patterns of decline in ACCM were similar in urban and rural areas and in areas of high and low elevation (a proxy for malaria risk). Significant declines also occurred before the period of greatest expansion in malaria control interventions.

Contextual Factors

Many other factors in addition to malaria control could have contributed to the overall decline in ACCM observed since 2000. Weather factors during the evaluation period favored malaria transmission during 2006-2010 compared to the earlier years, with warmer, wetter conditions observed. Thus, the declines in ACCM over this period appear to have occurred despite more favorable conditions for malaria transmission, suggesting that the impact of malaria control interventions may be underestimated if weather conditions are not taken into account. GDP per capita more than doubled during the evaluation period and household socioeconomic conditions also improved. These changes could help explain observed declines in ACCM. While improved access to health facilities is likely a major driver of the reduction in malaria morbidity and malaria mortality, improved access to care likely helped reduce ACCM by providing better clinical management of other treatable childhood illnesses. Other child health factors including nutrition and immunization coverage also improved during this period, which also could have contributed to the observed decline in ACCM since 2000. Many of the observed changes in contextual factors were not large in magnitude and thus are unlikely to fully explain the change decline of ACCM.

CONCLUSION

In summary, the majority of the improvements in coverage of vector control interventions were made between 2005 and 2007, which corresponds to periods of declining malaria morbidity and mortality according to the analyses from published studies summarized in this report. Major improvements in access to health facilities also occurred during the evaluation period which likely contributed to declines in ACCM by reducing both malaria and non-malaria deaths. Although ACCM declines were significant during the evaluation period, the rate of decline did not change after the dramatic expansion of vector control interventions and access to health services. Similarly, patterns of ACCM declines do not appear to be different in areas of high and low malaria risk as might be expected if change in malaria control was the major driver of ACCM declines. During the evaluation period there were also statistically significant improvements observed in the coverage of some non-malaria health interventions, as well as socio-economic improvements, which likely contributed in part to the reductions observed in ACCM from 2000 to 2011. Taken altogether, this evidence suggests that malaria control interventions in Ethiopia may have contributed to reductions in ACCM, particularly the reductions that were observed during the latter part of the evaluation period but that other factors likely played an important role as well.

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Abbreviations and Acronyms

AAU	Addis Ababa University
ACCM	All-cause Childhood Mortality
ACIPH	Addis Continental Institute for Public Health
ACT	Artemisinin-based Combination Therapy
AIDS	Acquired Immunodeficiency Syndrome
AL	Artemether-Lumefantrine
ALMA	African Leaders Malaria Alliance
ANC	Antenatal Care
API	Annual Parasite Incidence
ARI	Acute Respiratory Infection
ARV	Antiretroviral
BCC	Behavior Change Communication
BCG	Bacille Calmette-Guerin
CDC	U.S. Centers for Disease Control and Prevention
CHERG	Child Health Epidemiology Reference Group
CFR	Case Fatality Rate
CMR	Child Mortality Rate
CNHDE	Center for National Health Development in Ethiopia
CQ	Chloroquine
CSA	Central Statistics Agency
DHS	Demographic and Health Survey
dL	Deciliter
DPT	Diphtheria Pertussis Tetanus
DSS	Demographic Surveillance System
EC	Ethiopian Calendar (GC minus ~7 years)
EDS	Early Detection System
EFETP	Ethiopia Field Epidemiology Training Program
EFY	Ethiopian Fiscal Year (July-June in Western calendar)
EHNRI	Ethiopian Health & Nutrition Research Institute
ELISA	Enzyme-linked Immunosorbent Assay
ENSO	El Niño Southern Oscillation
EPHA	Ethiopian Public Health Association
EPHI	Ethiopian Public Health Institute (formerly EHNRI)
FDRE	Federal Democratic Republic of Ethiopia
FMoH	Federal Ministry of Health
FY	Fiscal Year
G6PD	Glucose-6-phosphate dehydrogenase

GC	Gregorian Calendar
GDP	Gross Domestic Product
GHI	U.S. Global Health Initiative
Global Fund or GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GoE	Government of Ethiopia
Hb	Hemoglobin
HBV	Hepatitis B Virus
HEP	Health Extension Program
HEW	Health Extension Workers
HiB	*Haemophilus influenzae* type B
HIV	Human Immunodeficiency Virus
HMIS	Health Management Information Systems
HSDP-IV	Health Sector Development Plan (number four)
ICAP	International Center for AIDS Care & Treatment Programs
iCCM	Integrated Community Case Management
IDSR	Integrated Disease Surveillance and Response System
IFA	Immuno-fluorescent Antibody
IEC	Information Education Communication
IGME	UN Inter-agency Group for Child Mortality Estimation
IHME	Institute for Health Metrics and Evaluation
IM	Intramuscular (injection)
IMCI	Integrated Management of Childhood Illnesses
IPB-AAU	Institute of Pathobiology- Addis Ababa University
IPD	Inpatient Department
IPTp	Intermittent Preventive Treatment in Pregnancy
IRS	Indoor Residual Spraying
ITN	Insecticide-Treated Bed Net
IV	Intravenous (injection)
LiST	Lives Saved Tool
LLIN	Long-lasting Insecticidal Net
MACEPA	Malaria Control & Evaluation Partnership in Africa
M&E	Monitoring and Evaluation
MCP	Malaria Control Program
MCST	Malaria Control Support Team
MDA	Mass Drug Administration
MDG	Millennium Development Goals
MERG	Monitoring and Evaluation Reference Group
MES	Malaria Eradication Service
MFTT	Mass Fever Testing and Treatment
MIS	Malaria Indicator Survey
MOVD	Malaria and Other Vector-borne Diseases
NMCP	National Malaria Control Program

NOCMVD	National Organization for the Control of Malaria and Other Vector-borne Diseases
NSP	National Strategic Plan
OPD	Outpatient Department
OPV	Oral Polio Vaccine
ORHB	Oromia Regional Health Bureau
ORS	Oral Rehydration Solution
PEPFAR	U.S. President's Emergency Program for AIDS Relief
P. f.	*Plasmodium falciparum*
PFSA	Pharmaceutical Fund and Supply Agency
PHCU	Primary Health Care Unit
PHEM	Public Health Emergency Management
PMI	U.S. President's Malaria Initiative
PMTCT	Preventing Mother-to-child Transmission of HIV
PQ	Primaquine
PSI	Population Services International
P.v.	*Plasmodium vivax*
RBM	Roll Back Malaria
RDT	Rapid Diagnostic Test
RHB	Regional Health Bureau
SIAPS	Systems for Improved Access to Pharmaceuticals and Services
SNNPR	Southern Nations Nationalities & Peoples Region
SP	Sulfadoxine-pyrimethamine
SPR	Slide Positivity Rate
TB	Tuberculosis
TCC	The Carter Center
TPR	Test positivity rate
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USP	United States Pharmacopeia
VA	Verbal Autopsy
WB	World Bank
WHO	World Health Organization
WHS	WHO World Health Statistics
WMR	WHO World Malaria Report

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Introduction

Purpose and Scope

Due to the serious disease burden caused by malaria, and the extensive funding, both internal and external, that has been devoted to malaria control in recent years, there is a growing demand from policy-makers, program managers, donors and researchers to measure the extent to which malaria control interventions have made an impact on malaria. This malaria impact evaluation was undertaken with the financial and technical support of the US President's Malaria Initiative (PMI) in collaboration with the Federal Ministry of Health (FMoH) and the Ethiopian Public Health Institute (EPHI) [formally the Ethiopian Health and Nutrition Research Institute (EHNRI)] together with input from other stakeholders and global institutions.

The main objective of the evaluation is to assess the impact of malaria control interventions on malaria morbidity and all-cause mortality in children under five years of age (ACCM) in Ethiopia during 2000–2013 using a compilation of national survey data and other nationally representative data sources. This report provides detailed descriptions of expansion and subnational variations in intervention coverage and considers other factors that might have contributed to decline in ACCM over the period.

This evaluation provides estimates and measurements of progress toward achieving national and international goals and targets that result from the combined efforts of the Government of Ethiopia (GoE) and other partners involved in malaria control in the country. The report does not present a critique of program implementation or of effectiveness of interventions. Although some estimates of lives saved due to specific interventions are included, the primary goal of the evaluation is not to quantify the impact of individual malaria control interventions (e.g., ITNs, IRS, or case management) or the relative impact of specific partners, programs and initiatives (e.g., Global Fund to Fight AIDS, Tuberculosis, and Malaria (Global Fund), PMI, World Bank Malaria Booster Program, Roll Back Malaria (RBM), World Health Organization (WHO), United Nations Children's Fund (UNICEF), and The Carter Center (TCC)) that also support malaria control in Ethiopia.

The evaluation focuses on the interval between 2000 and 2013 during which time there was a rapid change in malaria control interventions where proven malaria interventions were introduced or expanded and malaria data quality dramatically improved. During the same time, enabled by over $473 million in cumulative external malaria funding support from various donors, Ethiopia's malaria prevention and control capacity also increased drastically.

Evaluation Design

The evaluation was based on a before-and-after assessment, and employs a plausibility evaluation design that measures changes in malaria intervention coverage, malaria-related morbidity and ACCM. ACCM is typically used as a primary measure of impact in highly endemic countries because of the difficulty in directly measuring levels and trends in malaria-specific morbidity and mortality. In this evaluation, we assessed malaria-related morbidity because a relatively low proportion of under-five deaths are due to malaria in Ethiopia. The methodology also accounts for trends in other contextual

determinants that may have contributed to a decline in these outcomes [1, 2]. In pursuit of this objective, the evaluation describes in detail the levels and trends in malaria control interventions (e.g., ITNs, IRS, and case management) as well as levels and trends in outcomes such as malaria parasitemia, severe anemia, and ACCM using available data from household surveys, health information systems and published research. The plausibility of a cause and effect relationship is strengthened if:

- the magnitude of impact is consistent with intervention efficacy;
- the age-pattern of change is consistent with malaria-mediated morbidity and mortality;
- the timing of intervention expansion is consistent with trend change in impact, and
- there is an ecological association between malaria risk and the observed impact.

Data on contextual factors with the potential to influence changes in malaria-related morbidity and/or ACCM from household surveys, government reports and published research were also used. Examples include weather, socio-economic factors, educational levels, access to improved water and sanitation, access to health services and other predictors of maternal and child health such as nutrition, immunization and comorbidities.

The plausibility study design presents several challenges [3]. The main shortcoming of plausibility inferences, as compared to probability inferences (i.e., derived typically from randomized study designs), is that the observed difference and magnitude of changes in malaria morbidity and mortality may not be entirely attributable to the scale-up of malaria control interventions and the role of other contextual factors cannot be ruled out.

The Lives Saved Tool (LiST), created by the Child Health Epidemiology Reference Group (CHERG), was used to quantify the potential contribution of various health interventions (including, but not limited to malaria vector control) to changes in mortality of children aged less than five years between 2005 and 2011. Modeled estimates of trends in number of malaria cases from the World Malaria Report are also presented where relevant. These modeled analyses were only used to estimate the potential impact but should not be considered evidence of an impact.

Evaluation Objective

The Ethiopia malaria impact evaluation primarily aims to address changes in malaria morbidity and all-cause childhood mortality following the scale-up of malaria control interventions between 2000 and 2013. Additional information from 2013 and 2014 are mentioned to support the major study findings, to serve as a basis for future malaria impact evaluations, and to assist ongoing monitoring and evaluation activities.

Specific Objectives

- Measure the degree to which malaria control interventions have been implemented and expanded in Ethiopia;
- Assess malaria-related morbidity and mortality and ACCM before, during, and after expansion of malaria control interventions; and

- Assess the plausible attribution of the expansion of malaria control interventions on changes in malaria-related morbidity, mortality, and ACCM in the context of changing health and malaria transmission environments.

Evaluation Indicators

The selection and definition of indicators used in this evaluation for national-level analysis was guided by the recommendations of the RBM MERG and then modified to the Ethiopian context as shown in Table 1 and Table 2.

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

Indicator	Indicator Number and Description
Vector Control	1. Proportion of households with at least one ITN
	2. Proportion of the population that slept under an ITN the previous night
	3. Proportion of children under five years old who slept under an ITN the previous night
	4. Households covered by vector control: Proportion of households with at least one ITN and/or sprayed by IRS in the last 12 months
Diagnostics and case management	5. Proportion of children under five years old with fever in last two weeks for whom advice or treatment was sought
	6. Proportion of children under five years old with fever in last two weeks who had a finger or heel stick
Prevention and control of malaria in pregnant women	7. Proportion of pregnant women who slept under an ITN the previous night
Mortality	8. All-cause under five mortality rate
Morbidity	9. Parasitemia prevalence: proportion of individuals in all age groups with a positive RDT or microscopy result**
	10. Severe anemia prevalence: proportion of children aged 6-59 months with a haemoglobin measurement of <8 g/dL

***This is not a standard RBM MERG indicator but has been adapted to the Ethiopian context.*
Source: Household Survey Indicators for Malaria Control manual, 2013

Table 2: Facility-based Impact Indicators

Indicator	Indicator Number and Description
Morbidity	1. Confirmed malaria cases per 1,000 persons per year
	2. Inpatient malaria cases per 1,000 persons per year
	3. Malaria test positivity rate
	4. Number of malaria outbreaks
Mortality	5. Inpatient under-five malaria deaths per 1,000 persons per year
	6. Total inpatient malaria deaths per 1,000 persons per year

In line with the RBM MERG recommendations, the principal measure of impact used in this evaluation is ACCM because malaria-specific mortality cannot be reliably measured in most parts of sub-Saharan

Africa with the current sources of data. This measure is often preferable to malaria-attributable mortality for a number of reasons including: the lack of availability of national-level malaria-specific mortality; concerns about the sensitivity and specificity of the verbal autopsy method for detecting malaria deaths; 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 [4]. However, it should be noted that ACCM is typically recommended as the principal measure of impact in settings of moderate to high transmission intensity or where childhood parasite prevalence is greater than 25% [1]. In Ethiopia, only 2% of ACCM is due to malaria according to a study by the Child Health Epidemiology Reference Group (CHERG) of WHO and UNICEF [5].

Data Sources

No new primary data were collected for this evaluation. National household surveys, health management information system (HMIS) data, data from the PMI-funded Ethiopia Malaria Epidemic Detection and Sentinel Surveillance Project, Integrated Disease Surveillance and Response (IDSR) facility data, Public Health Emergency Management (PHEM) systems data, and annual malaria commodity micro-planning reports were the main sources of data used for this evaluation. Malaria outbreak investigation results were compiled through published reports or unpublished FMoH reports and presentations. All-cause child mortality, parasitemia prevalence estimates, and intervention coverage data were obtained primarily from large population-based household surveys such as the Demographic and Health Surveys (DHS) and Malaria Indicator Surveys (MIS). During the evaluation period (2000–2013), three DHS were conducted, in 2000, 2005, and 2011. The DHS conducted in 2000 did not collect malaria outcome indicator data such as parasitemia and anemia, therefore baseline national malaria indicators are not available for this evaluation. Malaria Indicator Surveys were conducted in 2007 and 2011. Both the DHS and MIS include detailed questions on other health programs and factors of interest, including socioeconomic status, health and nutritional indicators, coverage of health-care services, and immunization coverage. Other sources of these indicators include WHO and World Bank reports, UNICEF and country-specific reports, and other country-specific surveys and datasets, including the 2001 RBM baseline survey. A more detailed description of the data sets, survey methods, sample sizes and other statistical parameters can be found in Annex 1.

Country Context

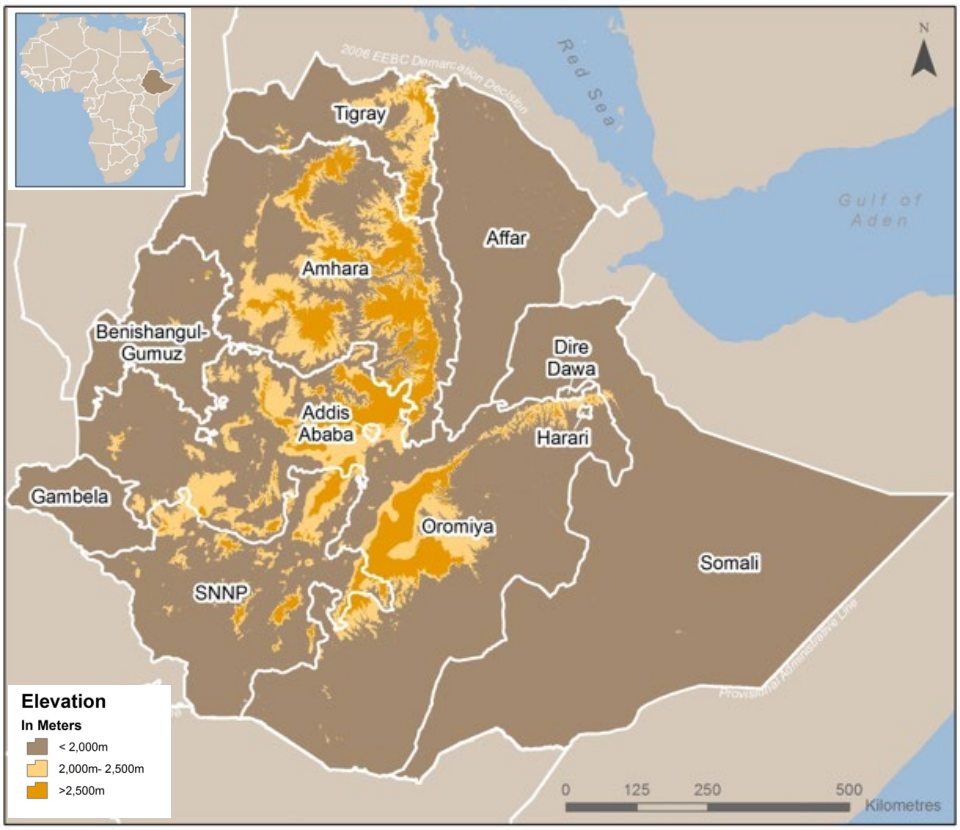
Background

Ethiopia is located in the Horn of Africa (3.30°–15°N, 33°–48°E) and has a total area of approximately 1.1 million square kilometers (Figure 1). It is landlocked between Eritrea to the north, and Djibouti and Somalia to the east, Kenya to the south, Sudan to the west, and South Sudan to the southwest. The country is administratively divided into nine Regional States and two city administrations, which are further sub-divided into 83 zones and 835 *woredas* (districts). A *woreda* is currently the basic unit of planning and political administration. The *woredas* are sub-divided into roughly 16,253 *kebeles* (census villages), of which around 87% are rural and 13% are urban [6]. There were about 622 *woredas* and

10,000 *kebeles* within the malarious areas of Ethiopia (i.e., below 2,000m) as of 2007; in 2014, the updated National Strategic Plan (NSP) for Malaria Prevention and Control and Elimination in Ethiopia [7] reduced the number of *woredas classified as* malarious to 545 based upon Annual Parasite Incidence (API) rates of more than 1 per 1,000 per year, and designated 290 *woredas* as malaria-free. Whereas in 2007, only 33% of Ethiopia's population was classified as living in malaria-free areas, 40% of Ethiopia's total population of approximately 84 million was classified as malaria-free based upon a complete analysis of all Ethiopian surveillance data sources from 2013 [7].

Ethiopia comprises complex geographic terrains ranging from 4,550m above sea level at the peak of the Ras Dashen Mountain to 125m below sea level in the Afar depression. More than half of the country lies above 1,500m. Topographically, the country is divided into the highlands and the lowlands. The highlands are generally at elevations higher than 1,500m above sea level. The highlands of Ethiopia cover about one-third of the country [8-10]. The highland plateaus are bisected by the Great Rift Valley from the northeast to the southwest. Numerous rivers cross the highland plateau, and the total landmass of the country is divided into 12 main water basins, eight of which are river basins, one lake basin and three dry basins (with no flow out of the drainage system) [11]. In Ethiopia, climate strongly interacts with terrain, and thus varies greatly with altitude. Figure 1 illustrates Ethiopia's elevation distribution, in meters, as categorized for analyses in the evaluation.

Figure 1: Map of Ethiopia showing administrative regions and territorial boundaries as well as elevation



Population and Socioeconomic Information

The majority (83%) of the population of Ethiopia lives in rural areas, making Ethiopia one of the least urbanized countries in the world. Ethiopia has an expanding population structure with 46% of the population under 15 years old and 14.6% under five years old [12, 13]. The FMoH and the accompanying Global Fund New Funding Mechanism application submitted in 2014 reported Ethiopia's total 2013 population as 84.2 million. Nationally, the average household size is 4.6 persons [14, 15].

Ethiopia's economy is based on agriculture, which employs 80% of the workforce, contributes over 80% to foreign exchange earnings, and accounts for over half of the GDP [16]. The agricultural sector generally suffers from frequent drought and poor cultivation practices.

Some basic development indicators for Ethiopia are presented in Table 3. According to the United Nations Development Program, Ethiopia ranked 174 out of 187 countries in 2011 in the Human Development Index (HDI), a composite measure of health, education, and income. Ethiopia's HDI score of 0.363 was below the 2011 regional average of 0.463 for sub-Saharan Africa and far below the global average of 0.682 [17]. As of 2012, life expectancy was 59.3 years, compared with 44 years in 1990 [18]. Maternal mortality ratio, though still high, decreased from 700 deaths per 100,000 live births in 2000 to 350 deaths per 100,000 births in 2010 [19].

In 2011, the adult (15–49 years) HIV prevalence rate was estimated at 1.5% (1.0% among males and 1.9% among females), with a higher burden in urban areas (4.2%) than rural areas (0.6%). Stunting amongst children less than five years of age was high in 2010 at 44%, and 10% of children less than five years of age were underweight [6].

Table 3: Basic development indicators for Ethiopia, 2011

Socioeconomic Indicators	
GDP per capita in current US$†	374
Rural population*	84%
Unemployment (% of total labor force)*	5.0%
Net primary school attendance rate (attended at least some primary school)	
Male	75.0%
Female	66.0%
Literacy	
Male	56.2 %
Female	38 %
Use of improved drinking water sources	34.3%
Maternal Health Indicators	
Total fertility rate (no. of children per woman)	4.8
% Births assisted by a skilled provider	10.0%
% HIV prevalence (women 15-49 years)	1.9%
Maternal mortality ratio (deaths per 100,000 live births) ††	350
Child Health Indicators	
Under five child mortality	88 per 1,000 live births
% Children under five years who are underweight	10.0%
% Children 12–23 months fully vaccinated	75.0%
% Children under five years who are stunted	44.0 %

**Data source: [20]; All other data are from the Ethiopia 2011 DHS.; †2011 estimate; ††2010 estimate [19]*

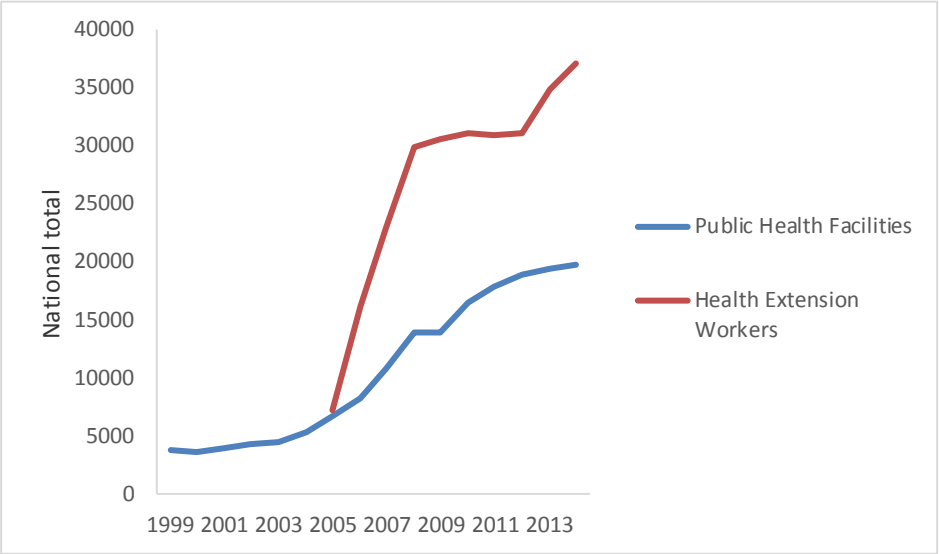
Health System Organization

A three-tier health care delivery system of primary, secondary and tertiary care was introduced following the 2007-08 Ethiopian business process re-engineering exercise. The lowest level of referral within each *woreda* is the Primary Health Care Unit (PHCU), with a primary *hospital*, a health center, and on average five satellite health posts. The primary hospital serves a population of between 60,000–100,000 people, the health centers cover a population of 15,000–25,000 people, and each of the satellite health posts is meant to serve a population of 3,000–5,000 people (approximately 1,000 households). A health post is typically staffed by two female salaried health extension workers (HEWs) who deliver services covering 16 different health intervention packages, including malaria prevention, diagnosis and treatment. Facilities within the PHCU are connected to each other by a referral system [6, 21]. By 2012, primary health service coverage reached 92% of the population with 125 hospitals, 2,999 health centers, 15,668 health posts and more than 4,000 private for-profit and not-for-profit clinics.

Secondary care is provided by general hospitals, which are often located in zonal capitals and cities and serve a population of 1–1.5 million people. Tertiary care is available at specialized hospitals that cover populations of 3.5–5 million. In addition, the private sector, nonprofit organizations, and other governmental agencies play significant roles in the expansion of health care coverage and utilization through establishing strong partnership with the public sector (see Annex A.2.1 for organizational structure).

As previously mentioned, a key element of the primary health care system in Ethiopia is the access to HEWs at health posts. These HEWs were trained through a Health Extension Program (HEP) launched in 2003 to improve access to basic health services. The program was intended for the rural population where access to clinicians and health officers trained in Integrated Management of Childhood Illness (IMCI) is rare. In 2009, a program of integrated community case management (iCCM) was launched with the goal of extending IMCI to the community level. The HEP began to be expanded in 2005, and the HEWs were trained in malaria community case management (CCM) and equipped with mono-species RDTs, ACTs and other malaria medicines. Currently, the HEWs are trained in iCCM, have the capacity to diagnose febrile cases with multi-species RDTs, and treat patients with ACTs (for *Plasmodium falciparum* or mixed infections) or chloroquine (CQ) (for *P. vivax* mono-infections), as per the national guidelines [22]. The HEWs have guidelines for stabilizing severe malaria illnesses with rectal artesunate and referring these cases for higher levels of care. The HEP has trained around 35,000 female HEWs to provide preventive and curative care for both adult and pediatric populations in communities. Although the HEP includes an urban program, the vast majority of HEWs work in rural areas. Figure 2 illustrates the increase in the number of public health facilities and trained HEWs from 1999 to 2012.

Figure 2: Availability of health services in Ethiopia, 1999–2013



Source: FMOH Annual Review Meetings and Health & Health Indicator Reports

Table 4 shows the rapid expansion of public sector health facilities since 2000, from 3,622 total health facilities in year 2000 to 19,716 total public health facilities in 2014. This expansion has been achieved predominantly by building rural health posts and by staffing each health post with two HEWs (Figure 2). The expansion has also included building an average of three new health centers in each rural district, with a 2-person inpatient capacity, staffed by a nurse, health officer, and pharmacist.

Table 4: Expansion of public health facilities in Ethiopia from 1998–2014

Western Calendar (GC)	Public Hospitals	Health Centers	Health Posts*	Total Public Health Facilities
1999-00	103	356	3,163	3,622
2000-01	110	382	3,416	3,908
2001-02	115	412	3,763	4,290
2002-03	119	451	3,828	4,398
2003-04	126	519	4,686	5,331
2004-05	138	600	5,873	6,611
2005-06	138	635	7,397	8,170
2006-07	149	690	9,904	10,743
2007-08	88	732	12,983	13,803
2008-09	100	1,362	12,488	13,950
2009-10	116	2,142	14,192	16,450
2010-11	122	2,660	15,095	17,877
2011-12	125	2,999	15,668	18,792
2012-13	127	3,245	16,048	19,420
2013-14	150	3,315	16,251	19,716

*Prior to 2007 health posts were referred to as health stations. Source: Annual Review Meeting and Health and Health Indicator Reports.

Malaria in Ethiopia

Geographical Distribution of Malaria

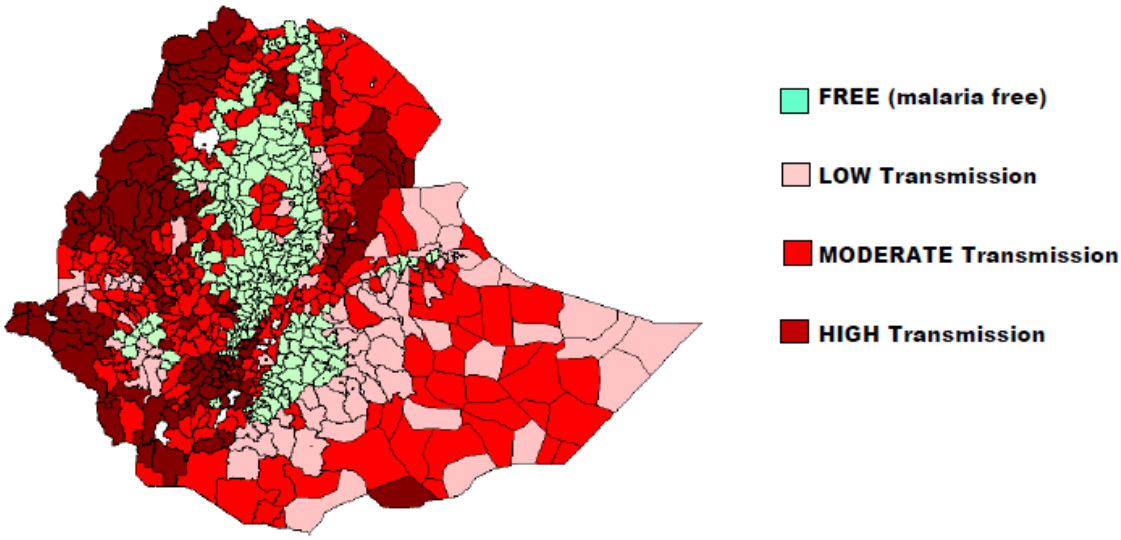
Malaria is endemic in Ethiopia with marked yearly, seasonal and geographical variations in transmission intensity. In general, malaria transmission throughout much of Ethiopia peaks from September to December, after the main rainy season (June–August); a smaller, second transmission season is observed in some parts of the country from April to May, after the short rainy season (February–March). Since malaria transmission is seasonal and unstable and overall there is low transmission intensity, the general population lacks protective immunity. Hence, unlike highly endemic malaria transmission settings in much of Africa, malaria tends to affect all age groups with almost equal intensity.

In Ethiopia, malaria transmission generally occurs at elevations below 2,000 m [23, 24]; however, higher elevations (up to 2,500 m) are considered epidemic-prone where anomalous weather conditions can be conducive to vector and parasite development [25-29]. An estimated 60% of the population

(approximately 51 million people in 2013) is at risk of malaria infection [7]. Altitude, climate, and proximity of villages to bodies of water such as lakes, wetlands, irrigation schemes, streams, and rivers are the most important determinants of malaria transmission risk [28, 30, 31]. As a result, malaria transmission is highly focal and variable within a given geographical range due to fluctuations in local vector population densities.

The 2014 NSP summarized all available malaria surveillance data in Ethiopia from 2013, and calculated Annual Parasite Incidence (API), per 1,000 population, per district (Figure 3). This analysis resulted in the following malaria transmission reclassifications of Ethiopian populations (percent of total) and *woreda* by API: High (API 100+) in 157 *woreda* (13% of the population); Medium (API 5-99.9) in 287 *woreda* (34% of the population); Low (API 0.1-4.9) in 101 *woreda* (13% of the population), and Malaria Free (API<0.1) in 290 *woreda* (40% of the population). Figure 3 displays risk strata at the *woreda* level.

Figure 3: FMOH malaria risk stratification map by district, 2014



Malaria Stratification and Proposed Interventions by Stratum

Malaria Strata	API	Elevation (m)	Population (2013)	% Population	No. of Woreda	% Woreda	Interventions					
							LLIN	IRS	Larval Control	Case Mx	Surveillance	IEC/ BCC
FREE	0	>= 2000 asl	33,639,639	40%	290	35%	-	-	-	x	x	X
LOW	>0 & <5	< 2000 asl	11,153,499	13%	101	12%	X	X*	WA	x	x	X
MODERATE	>=5 & <100		28,410,564	34%	287	34%	x	-	WA	x	x	X
HIGH	>=100		11,023,284	13%	157	19%	x	x	WA	x	x	X
Total			84,226,986	100%	835	100%						

*Only 32% of at risk population in highland fringe/epidemic-prone areas will be covered by IRS
WA: where applicable; asl: above sea level

Malaria Parasites

Plasmodium falciparum and *P. vivax* are the most prevalent malaria parasites in Ethiopia with annual national surveillance consistently showing 60–70% of the malaria outpatient cases are due to *P. falciparum* infection and 30–40% are due to *P. vivax*. FMoH data from July 2011-June 2012 show 59% of laboratory confirmed malaria cases were *P. falciparum* [32]. *P. malariae* and *P. ovale* account for less than 1% of the malaria infections. Mixed infections of both *P. falciparum* and *P. vivax* malaria are uncommon (1–5% by microscopy), but may increase during intense transmission seasons. Patients with *P. vivax* infections may experience several clinical relapses weeks to months after treatment, even if each clinical attack is treated with blood stage antimalarial medications such as CQ or artemether-lumefantrine (AL) [33-35] since anti-hypnozoite therapy with primaquine (PQ) has not been commonly administered in Ethiopia.

Malaria Vectors

Anopheles arabiensis is the principal malaria vector and has wide geographical distribution. Other species such as *An. funestus, An. pharoensis*, and *An. nili* are considered secondary malaria vectors. *An. pharoensis* has been shown to have high human biting rates but is more exophilic than *An. arabiensis* (92% captured in outdoor landing catches). *An. funestus* is highly anthropophilic but has limited geographical distributions around lake shores and swamps. *An. nili* may be an important vector in Gambella Region. *An. nili* may not be targeted by vector control interventions due to its tendency to bite indoors but rest outdoors.

Malaria Control Strategy and Program

IRS was first implemented in Ethiopia in 1955 in four pilot project areas [28]. Ethiopia established the Malaria Eradication Service (MES) in 1959 following the major malaria epidemic that hit the country in 1958. (See Table 5). Spraying with DDT and case treatment with CQ were the cornerstones of the malaria control activities during that time. Despite the periodic occurrence of malaria epidemics in many places, MES successfully reduced disease burden in most areas in most non-epidemic years for several decades [28, 36].

In 1971, the FMoH replaced the MES with the Malaria Control Program (MCP) using the same vertical organizational structures which were in line with the WHO recommendations. In 1985, the MCP was re-organized into the National Organization for the Control of Malaria and Other Vector Borne Diseases (NOCMVD). In 1993, following the new policy of decentralization and federalism in the country, the NOCMVD ceased to exist and the program was reorganized as malaria and other vector borne diseases prevention and control team (MOVD) at the federal level; malaria control efforts were then transferred to Regional Health Bureaus (RHBs). The FMoH recognized the importance of the accelerated implementation of malaria control activities during the mid-1990s, which was followed by an RBM initiative in 2000 aimed at strengthening malaria control in Ethiopia [37] (Table 5).

In 2006, the Ethiopian government reorganized the FMoH and agencies into eight core processes. The reorganization placed the national malaria control program (NMCP) and communicable disease prevention and control departments under the health promotion and disease prevention general directorate and in 2013 it became the disease prevention and control directorate. In 2013 the government underwent additional restructuring; this recently revised structure is included in Annex A.2.2.

Between 2000 and 2012, Ethiopia has developed three NSPs for malaria within the context of the Health Sector Development Plan (HSDP) and in line with the global and regional RBM goals and objectives. The first NSP (2000–2005) aimed to reduce the overall malaria burden (morbidity and mortality) by 25%, by the end of the year 2005 as compared to the 2000 baseline levels. The second (2006–2010) NSP was aimed at reducing the overall malaria burden (morbidity and mortality) by 50% by the end of 2010 as compared to the 2004-05 baseline level [38, 39] through rapidly scaling-up malaria control interventions including long-lasting insecticidal nets (LLINs), IRS, RDTs, and ACTs. A third (2011–2015) NSP [40], mainly focused on consolidating and building on the success achieved in the implementation of core malaria interventions. In addition, the third NSP aimed to build the platform from which the country can embark on the road to malaria elimination. Table 5 shows the milestones of the Ethiopian national malaria control program. On June 14, 2014, the fourth Ethiopian FMoH NSP, 2014-2020 was finalized in conjunction with the Global Fund New Funding Model grant application, and replaced the earlier NSPs.

Table 5: Milestones of the Ethiopian national malaria control program, 1955-2014

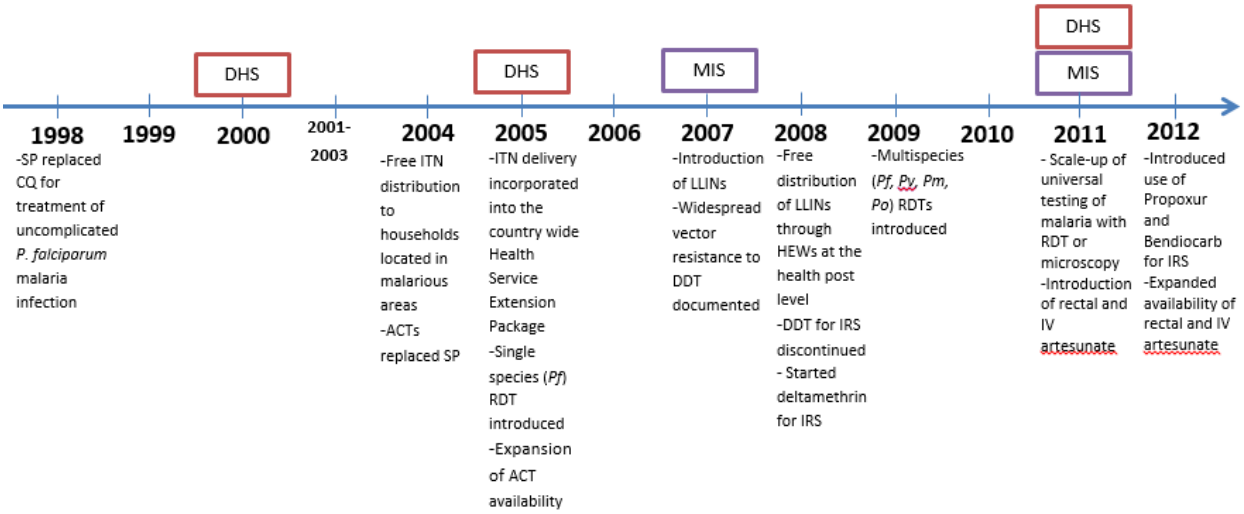
Gregorian calendar	Malaria control program events
1955	Initiated indoor residual spraying (IRS) with DDT and treatment with chloroquine (CQ) in four pilot project areas
1958	Occurrence of catastrophic nation-wide malaria epidemics with very high mortality
1959	Establishment of malaria eradication service (MES)
1970	WHO changed the strategy of eradication to control with four main objectives
1971	FMoH replaced the MES with MCP but with existing vertical structures
1985	FMoH re-organized the MCP into the NOCMVD
1988–89	Occurrence of malaria epidemics
1991–92	Occurrence of malaria epidemics
1993	Policy of decentralization adopted and NOCMVD became decentralized and integrated to the general health services
1997	Re-enforced the national malaria control program through the Accelerated Implementation of Malaria Control Program in Africa (ACIM) project of the WHO/AFRO
1997	ITNs introduced
1997–98	CQ treatment failure identified , widespread malaria epidemics with high mortality
1998	First malaria policy shift from CQ to SP for treatment of uncomplicated *P. falciparum* malaria
2000	Adopted the Abuja Declaration, RBM launch meeting in Addis Ababa
2001	Developed the first five year (2001–2005) National Strategic Plan for expansion of malaria control interventions in Ethiopia, decentralized malaria planning to district level
2003	SP treatment failure identified, widespread malaria epidemics HEP piloted
2003–04	Large scale malaria epidemics affecting 211 districts with high mortality
2004	Treatment policy shift from SP to ACT, Malaria diagnosis and treatment guidelines updated
2004–05	Expansion of malaria control interventions (LLIN, IRS, and diagnosis with RDT/Microscopy and treatment with ACT)
2005	Single species RDT introduced; 3.2 million ACT doses imported; pilot study of HEW use of artemether lumefantrine (Coartem) at community level, later scaled up nationally
2006	Second National strategic plan for malaria prevention and control 2006–2010 HMIS system assessed and designed
2007	Wide spread vector resistance to DDT documented HMIS implementation kicked off
2009	Use of DDT for IRS discontinued (start deltamethrin)

	Establishment for Public Health Emergency Management System (PHEM) replacing Integrated Disease Surveillance Reports (IDSR) for malaria surveillance and epidemic detection and response Multispecies RDTs introduced, replacing earlier RDTs that only identified *P. falciparum* Full scale of HEP achieved
2011	FMoH scaled up universal testing of malaria with RDT or microscopy and discouraged empirical treatment, increasing evidence of deltamethrin resistance
2011–12	Use of propoxur and bendiocarb for IRS introduced National diagnosis and treatment guideline updated & introduced Rectal and IV artesunate scaled up along with iCCM at 10,000 rural health posts, integrating malaria care with a diagnostic algorithm to manage acute febrile illnesses including possible use of antibiotics for pneumonia and ORS for diarrhea
2011–14	Third National Strategic Plan for malaria prevention, control and elimination in Ethiopia
2014	Fourth National Strategic Plan (2014-2020) & Global Fund New Funding Model application

MCP Malaria Control Program NOCMVD National Office of Control of Malaria and Vectorborne Diseases. ITN/LLIN insecticide treated nets. CQ=chloroquine, ACT= artemesinin-based combination therapy. IRS=indoor residual spray of insecticides. RDT=rapid diagnostic tests. iCCM=integrated community based case management

Figure 4 shows timelines for implementation of malaria control interventions, baseline, and follow-up surveys for the period in 1998 to 2012.

Figure 4: Timelines for the implementation of malaria control interventions and evaluation surveys with data sources in Ethiopia, 1998–2012



Financial Resources and Inputs

In Ethiopia, total health expenditures for malaria control came mainly from three sources: the GoE; external donors (Global Fund and PMI) (Table 6); and households. The list of partners working in malaria in Ethiopia is much longer (see Annex A.2.3). The significant boost in funding for malaria that began around 2004 came mainly from the Global Fund. Ethiopia received several rounds of Global Fund grants to fight malaria (2003, 2005, 2011 and transitional funding in 2012), totaling more than $430 million from 2006–2013. PMI has contributed close to $207 million for malaria activities in Ethiopia over the period 2006–2013. Table 7 shows the annual totals and percentages for key financial indicators for malaria (2001–2012). On average, between 2001–2010 US $59 million was spent annually in Ethiopia from all sources on malaria prevention and case management, accounting for 6.2% of all expenditures

on health in the country (Table 7). According to the fourth National Health Account report, 40% of the total health expenditures for malaria come from external donors, 37% from households, 21% from the government, and 2% from others [41].

Table 6: Distribution and commitments from Global Fund and PMI, 2006–2012 ($US)

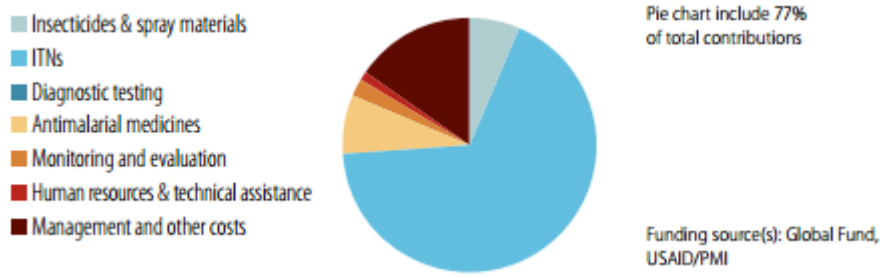
Source	2006	2007	2008	2009	2010	2011	2012	2013	Total
Global Fund (Rounds 2, 5,8, & TFM)*	70,074,800	17,480,252	3,138,583	121,481,761	28,254,185	51,910,538	23,762,673	114,020,000	430,122,792
PMI**	2,563,000	6,700,000	19,838,000	19,700,000	31,000,000	41,918,000	41,500,000	43,770,000	206,989,000
Total	72,637,800	24,180,252	22,976,583	141,181,761	59,254,185	93,828,538	65,262,673	157,790,000	637,111,792

*Disbursements, ** Commitments; TFM= transitional funding mechanism; Source: World Malaria Report 2012 and GFATM country representative personal communication, February 21, 2014

Note: Commitments and disbursements appear when they were made and appear in official documents. Amounts for commodities were counted in the calendar year in which they actually procured. It is possible that commitments and procurements may have occurred in different years for the same procurement.

The largest percentage of Global Fund and PMI procurements were expenditures for ITNs, procuring a total of 42 million ITNs. Since 2005, more than 48 million ACTs and a total of 38.7 million RDTs were procured for Ethiopia. In 2013, the largest proportion of Global Fund and PMI (~60%) funding went to purchase ITNs (Figure 5). Other significant spending went towards management, purchase of antimalarial medications and of insecticides and spray materials.

Figure 5: Financing by intervention in 2013



Source: World Malaria Report 2014 [42]

Table 7: Malaria health expenditure in Ethiopia, 2001–2012

\Indicators	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Total Population*	67.96	69.95	71.99	74.07	76.17	78.29	80.44	82.62	84.84	87.10	89.39	91.73	79.54
Population at risk*	47.11	48.33	49.55	50.77	51.98	53.20	54.40	55.61	56.83	58.06	57.75	61.42	53.75
GDP (current USD)*	8087	7714	8473	9954	12184	15014	18992	25609	28194	26311	29947	41605	19340
Total expenditure on health for malaria (USD) *	2.12	2.17	18.14	16.22	11.96	69.77	62.48	72.23	187.16	149.47	--	--	59.17**
Total expenditure on health for malaria as % of total health expenditure	0.60%	0.60%	4.30%	3.70%	2.40%	11.00%	6.80%	6.50%	14.80%	11.50%	10.03%	9.13%	6.22%
Per capita total expenditure on health for malaria	$0.04	$0.04	$0.37	$0.32	$0.23	$1.31	$1.15	$1.30	$3.29	$2.57	--	--	$1.06

*In millions; ** Per cap spending and the averages for 2001-2010

Source: World Bank report 2011; UNDP Human Development Index (HDI) 2012 [17] [43]; HSDP-IV Annual Performance Report EFY 2004 [44]

Expansion of Malaria Control Interventions

Insecticide treated Nets

ITN Implementation

ITNs are a highly effective tool for prevention of malaria both through direct insecticidal effects, and by reducing contact between vectors and humans, therefore lowering parasitemia prevalence at the community level [45-47]. Use of ITNs has been found to reduce all-cause child mortality by 15-20% [48], lower the risk of clinical malaria illness, reduce parasitemia prevalence and reduce the risk of high-density parasitemia [49]. ITN use also reduces the risk of severe anemia and splenomegaly and may improve anthropometric outcomes in children [50]. ITN use by pregnant women has been shown to reduce placental parasitemia, reduce low birth weight and reduce fetal loss and stillbirth [51, 52].

Focal distribution of ITNs in Ethiopia began in the mid-1990s. In 1996, distribution of ITNs was initiated in high malaria risk communities in Kafta-Humera District in northwestern Tigray Regional State under a community-financing scheme through the support of donors (WHO/Italian Cooperation) [53, 54]. During this period, 13,570 ITNs were distributed free of charge to 32,435 people to have at least one net per household [53]. Similar initiatives were undertaken in 1997 in selected high malaria risk districts in the three larger regional states (Amhara, Oromia, and SNNPR) with the support from the WHO Accelerated Implementation of Malaria Control Program in Africa [55].

In 2000, Ethiopia carried out a situational analysis, identified priorities, and developed the first 5-year (2001–2005) NSP that sought to achieve 60% ITN household ownership and use rates [38]. In 2001, the average cost of a bed net was estimated to be between US $3.43–10.6, and the re-treatment cost per bed net was between US $0.23–3.5 [56]. The high cost of ITNs had initially limited the rapid expansion of ITN implementation in Ethiopia. The ITN strategic plan was ratified by FMoH in 2004 and supported a market segmentation approach, with commercial sector distribution in urban areas complemented by free ITN distribution to vulnerable populations in rural areas through the public sector. Other partners used social marketing and distributed nets at subsidized prices in urban areas. A survey was conducted by NetMark in 2004, estimating that 86% of the population was at risk for malaria and indicating 25% national household ownership of any net and 11% national household ownership of ITNs [57].

In 2004, the country launched a program of free ITN distribution to households in malarious areas, prioritizing vulnerable groups such as pregnant women, children less than five years of age, people living with HIV/AIDS, resettled populations, and people under complex emergency situations. The ITNs were branded and heavily promoted to the public through a range of mass media and interpersonal communication channels. Delivery mechanisms included distribution through static health facilities and outreach services such as the Enhanced Outreach Strategy, National Immunization Days and other immunization activities. In 2005, ITN delivery was incorporated into the country-wide HEP, ensuring longer term sustainability. FMoH policies only supported ITN distributions to households below 2,000m since there was evidence of only limited malaria transmission at higher elevations.

A new generation of ITNs, long-lasting insecticide-treated nets (LLINs), was introduced in 2006 followed by an initial mass distribution campaign in 2006-07 in all regional states [58]. Between 2006 and 2007, approximately 16 million LLINs were distributed. Since that time, essentially all ITNs imported and distributed in Ethiopia have been LLINs, and these eventually replaced other types of older ITNs that had

needed periodic insecticide retreatment. Many of the LLINs from this first country-wide mass distribution campaign had been distributed just prior to the 2007 MIS that occurred between September and December 2007. There have been very few ITNs in Ethiopia that have been purchased, imported, or distributed through the private sector since 2007, and the earlier projects that involved purchasing nets with or without subsidized costs to at-risk households were discontinued. In 2008, a new LLIN strategy was developed to include free distribution of LLINs through HEWs at the health post level. This new policy supported national distribution campaigns every two to three years through catch-up and keep-up strategies. Figure 6 shows the ITN distribution timeline since 1996. Table 8 shows trends in the procurement and distribution of ITNs in Ethiopia from various sources from 2000 to 2012.

Figure 6: Timeline of national surveys and milestones in ITN strategy and interventions

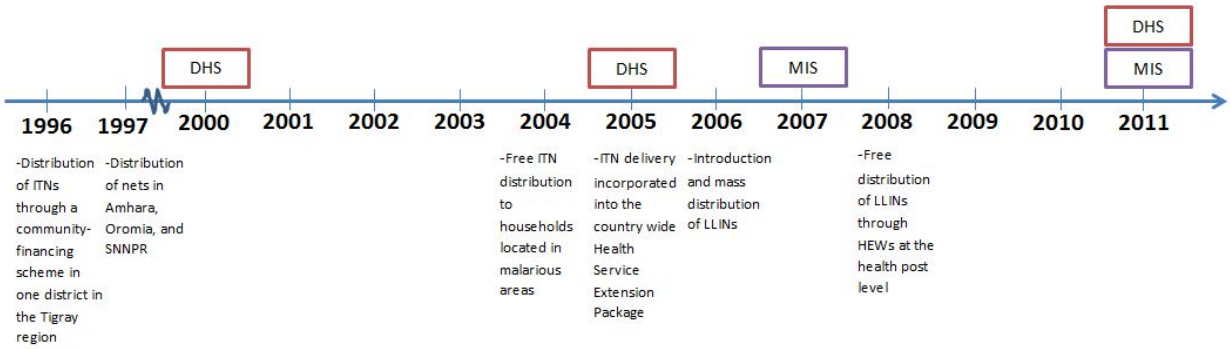


Table 8: ITN procurement and distribution in Ethiopia by year and source, 2000–2012

Year	UNICEF	Global Fund*	World Bank	TCC	PSI	MDG	PMI	Total ITNs
2000	250,000	-	-	-	-	-	-	250,000
2001	280,000	-	-	-	-	-	-	280,000
2002	320,000	-	-	-	-	-	-	320,000
2003	430,000	-	-	-	-	-	-	430,000
2004	550,000	-	-	-	30,000	-	-	580,000
2005	1,223,957	2,500,000	-	-	100,000	-	-	3,823,957
2006	354,750	3,825,500	-	-	300,000	-	-	4,480,250
2007	1,750,000	3,348,168	3,500,000	3,000,000	200,000	-	-	11,798,168
2008	-	778,423	1,600,000	-	-	-	-	2,378,423
2009	-	2,171,528	1,685,000	-	-	-	559,500	4,416,028
2010	180,000	11,350,000	114,600	2,958,897	-	-	1,000,000	15,603,497
2011	25,000	-	-	-	-	859,162	1,845,000	2,729,162
2012	-	1,000,000	2,700,000**	37,295	-	-	2,540,000	6,277,295
Total	**5,363,707**	**24,973,619**	**9,599,600**	**5,996,192**	**630,000**	**859,162**	**5,944,500**	**53,329,485**

Sources: PMI Needs Assessment Visit Report and UNICEF-Ethiopia GF=Global Fund.
TCC = The Carter Center; PSI = Population Services International; MDG = Millennium Development Goals
GF*= round 2, 5 and 8 are combined, and info from 2010 onward verified from GF TFM Grant Application. FMOH report of January 27, 2014, personal communication from HS: "In 2012, other than PMI and GF nets, an additional 2.7 million LLIN from World Bank were procured and distributed for a total of about 6.25 million nets distributed." Almost all PMI funded and purchased nets were distributed by UNICEF. ** Review by Global Fund officials of recent FMoH reports regarding World Bank funded ITNs suggest that the 2.7 million ITNs listed in 2012 may not have

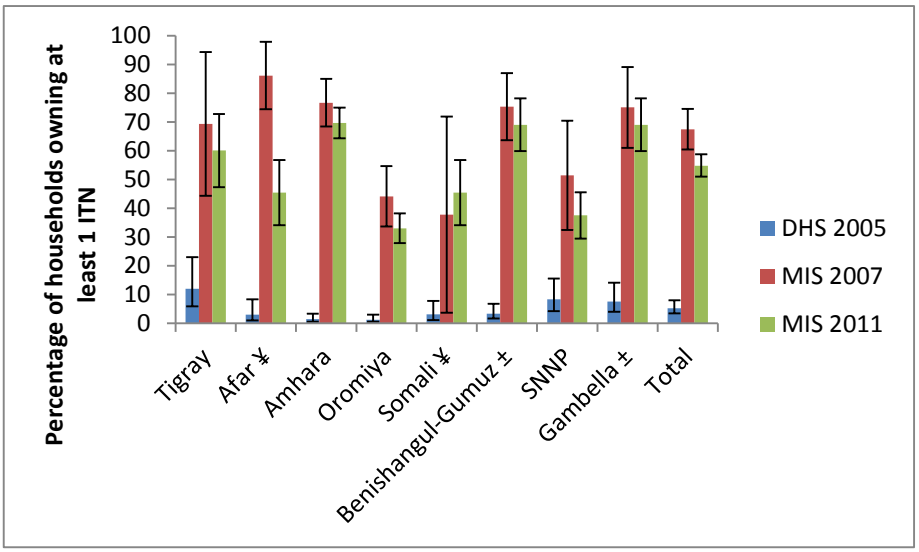
been purchased at that time. The Annual Review Meeting report for EFY2006 indicated that 58,676,866 ITNs were cumulatively distributed through June 2014 in Ethiopia, but distributions in year 2013 and stratifications of funding partners were not specified.

ITN Coverage Trends

Trends in national-level household survey data on ITN ownership and use between 2000 and 2011 were examined for rural household populations at elevations less than 2000m. According to the 2000 DHS, bednet ownership was very low, with only 1% of households owning a net and fewer owning nets that had ever been treated with insecticide. Questions on net use were not included in the 2000 DHS but given the low level of net ownership, usage can be assumed to be below 1%. As shown in Figure 7, ITN ownership trends indicate a dramatic increase over the past decade, especially between 2005 and 2007. The proportion of households in rural areas at elevations below 2,000m that owned at least one ITN increased from 5% in 2005 to 67% in 2007 and then decreased to 55% in 2011. The observed decline in 2011 may be a factor of the timing of distribution in relation to survey implementation; the 2007 MIS was conducted immediately after a mass distribution campaign, which would have led to the new nets being captured. The same level of accuracy in recording net ownership is not expected in the 2011 survey which did not immediately follow a distribution campaign. There is likely to be some level of recall bias about the number of nets owned and of details about the nets when they are not new. There is also likely to be decay (loss of effectiveness, holes, etc.) leading to nets being discarded or repurposed.

As seen in Figure 7, household ownership of ITNs varies greatly by region in rural areas at elevations below 2,000m. In 2011, households located in Oromia, Afar, and Somali at elevations less than 2000m had lower levels of household ownership than other regions (44%, 45%, and 45%, respectively compared to values between 57% and 74%), while in 2005 ITN ownership was uniformly low across regions (range: 1% to 15%). Household ITN ownership increased significantly between 2005 and 2011 in all regional states, but significant declines occurred between 2007 and 2011 in Tigray (88% to 66%) and Afar (86% to 45%). The observed decline in Afar could be a consequence of different sampling strategies between the two surveys; Afar and Somali regions were combined in the 2011 survey.

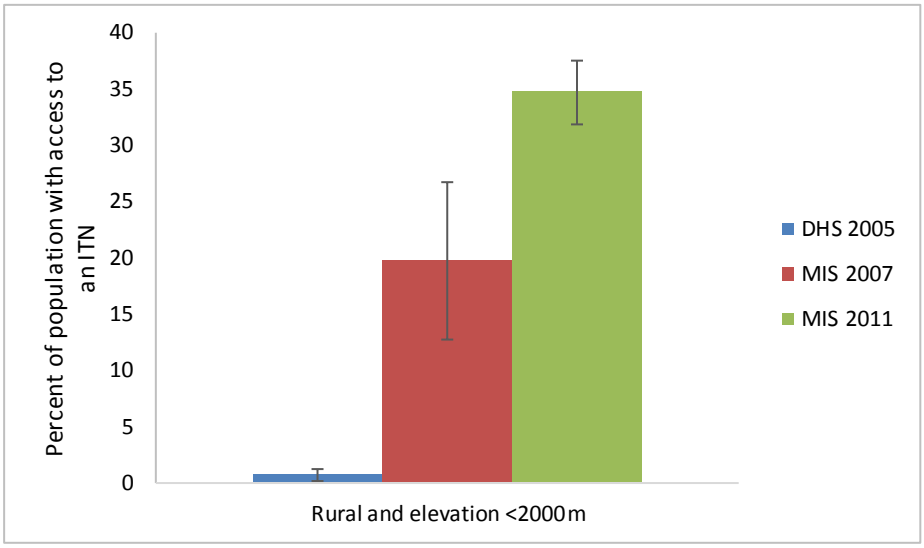
Figure 7: Household ownership of ITNs in rural households at elevations less than 2000 meters, by region, 2005–2011



¥ In the 2011 MIS the estimates are combined for Afar and Somali due to small sample size.
± In the 2011 MIS the estimates are combined for Benishangul-Gumuz and Gambella due to small sample size.

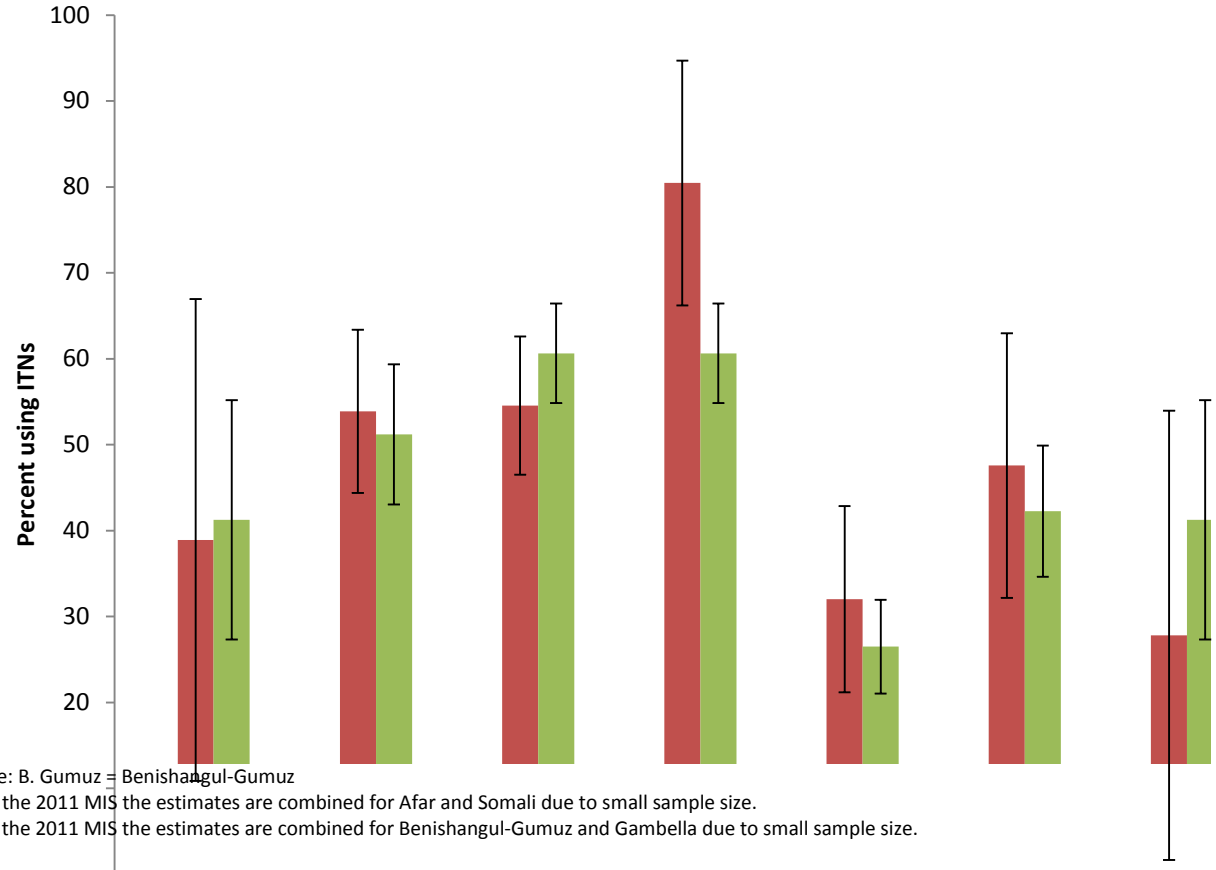
Access to ITNs is a population-level indicator measuring the proportion of the population that could sleep under an ITN assuming that each net can cover two people. In Ethiopia, in rural areas below 2000 m, 0.7% of the population had access to an ITN in 2005, 19.7% in 2007 and 34.7% in 2011 (Figure 8).

Figure 8: ITN access among population living in rural and area at elevations less than 2000 meters Ethiopia, 2005-2011



ITN use by children less than five years of age increased significantly between 2005 and 2011, from 3% to 38% (Figure 9). Large regional differences are apparent in ITN use by children less than five in 2007 and 2011 whereas ITN use was uniformly low in 2005 (Figure 9).

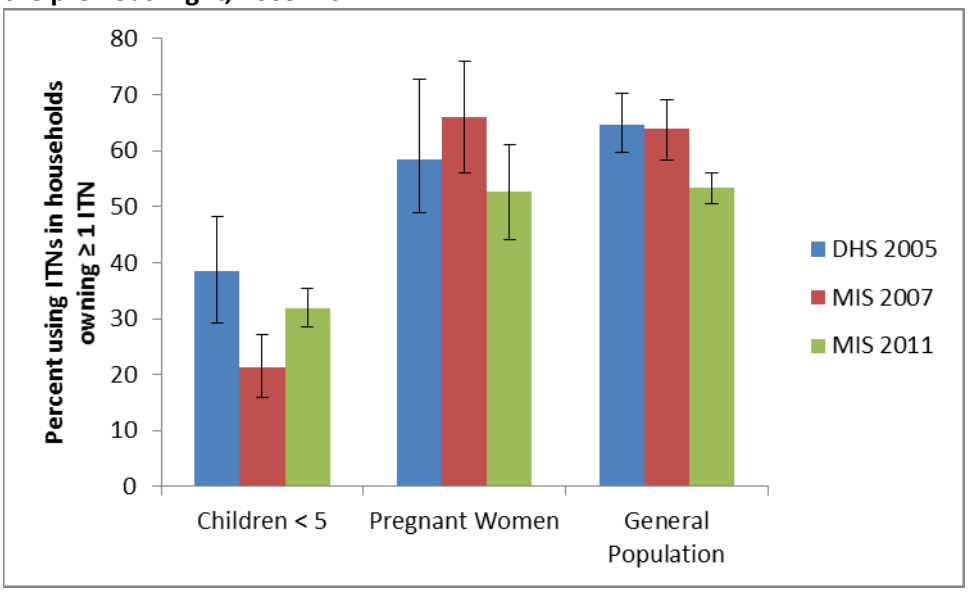
Figure 9: ITN use by children less than five in rural household at elevations less than 2,000m by regional state, 2005–2011



Note: B. Gumuz = Benishangul-Gumuz
¥ In the 2011 MIS the estimates are combined for Afar and Somali due to small sample size.
± In the 2011 MIS the estimates are combined for Benishangul-Gumuz and Gambella due to small sample size.

In rural households owning at least one ITN and living at elevations below 2,000m, the use of ITN among children less than five years of age decreased from 39% in 2005 to 21% in 2007, then increased to 35% in 2011. Among pregnant women, use was 58% in 2005, but increased to 64% in 2011 before declining to 53% in 2011, however, these changes are not statistically significant. Among the general population, us of ITN remained relatively high at 65% in 2005 and 64% in 2007 before declining to 53% in 2011 (Figure 10).

Figure 10: In rural households at elevations below 2,000m owning at least one ITN, the proportion of children less than five years and pregnant women and the entire population who slept under at ITN the previous night, 2005–2011



ITN Summary

In Ethiopia, there has been a rapid increase in ITN ownership and use since 2005. The various ITN campaigns during 2000 to 2012 have resulted in an increase in rural household ITN ownership (below 2,000m) from 5% in 2005 to 55% in 2011, despite an interim decline between 2007 and 2011. Despite the improvements, the level of ITN access indicates that the number of ITNs per household as of 2011 is insufficient for the number of residents. ITN use by children less than five years of age, in all households increased from 3% in 2005 to 38% in 2011. The use estimates indicate that when ITNs are available, they are being used by young children, pregnant women more and the general population even if use is lower among young children.

Indoor Residual Spraying

Background

In Ethiopia, IRS has been a major tool for malaria prevention and control for more than 50 years. Milestones in the Ethiopia IRS program are summarized in Figure 11. Since 1955, the insecticide DDT had been used for IRS [28, 30, 31]. From 1958 to 1971 the application of DDT for IRS was scaled up to cover all malarious areas targeted for eradication. However, following the failure of the national malaria eradication program in 1971, selective application of IRS was recommended by WHO, and Ethiopia adopted this strategy. Because of the emergence of vector-resistance to DDT, malathion (an organophosphate) was introduced as an alternative to DDT in the 1990s [22]. More recently, high levels of vector resistance to both insecticides has become widespread in the country; therefore, Ethiopia shifted from the use of DDT and malathion to deltamethrin (a pyrethroid) in 2010 [22]. In 2011, increased vector resistance to deltamethrin was identified, and currently, three insecticides, propoxur (a carbamate), bendiocarb (a carbamate), and fenithrion (an organophosphate), are recommended for IRS.

Compared to DDT, these insecticides have shorter residual efficacy (2–3 months) and are more expensive [59, 60]. According to the annual health report, in 2012 close to 46 million households, 73.1% of the households in areas at risk for malaria (<2,000 m), received IRS.

The 200 hotspot epidemic-prone districts, and potential for IRS, identified in 2012 are shown in Figure 12. High malaria risk areas to be covered by IRS are selected on a yearly basis based on epidemiological information, resource availability and expert opinion. Areas selected for IRS typically receive one round per year depending on the magnitude of the malaria burden and the type of insecticide being used, but malaria epidemics might prompt an additional emergency IRS spray round. Due to limited resources, only 20–47% of malaria epidemic prone areas are covered with IRS in a given year. Prior to 2004, the cost of IRS had been covered through government financing; however, since 2004, PMI and Global Fund resources have also supported IRS activities.

Figure 11: Timeline of national surveys and milestone in IRS strategy and interventions in Ethiopia

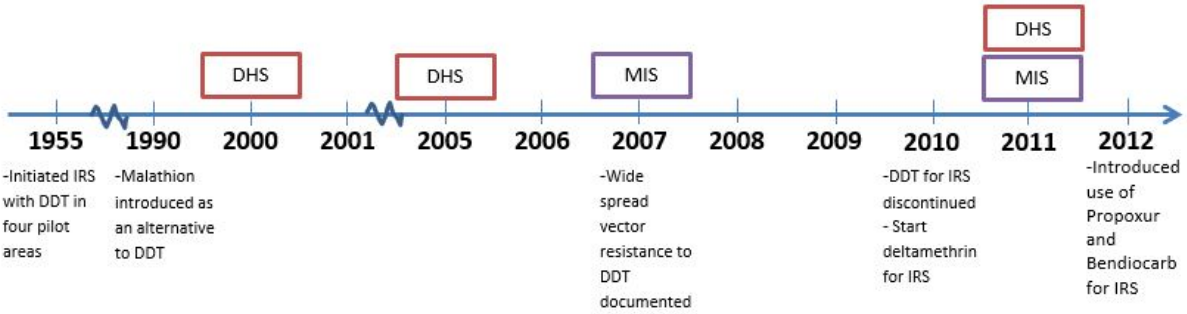
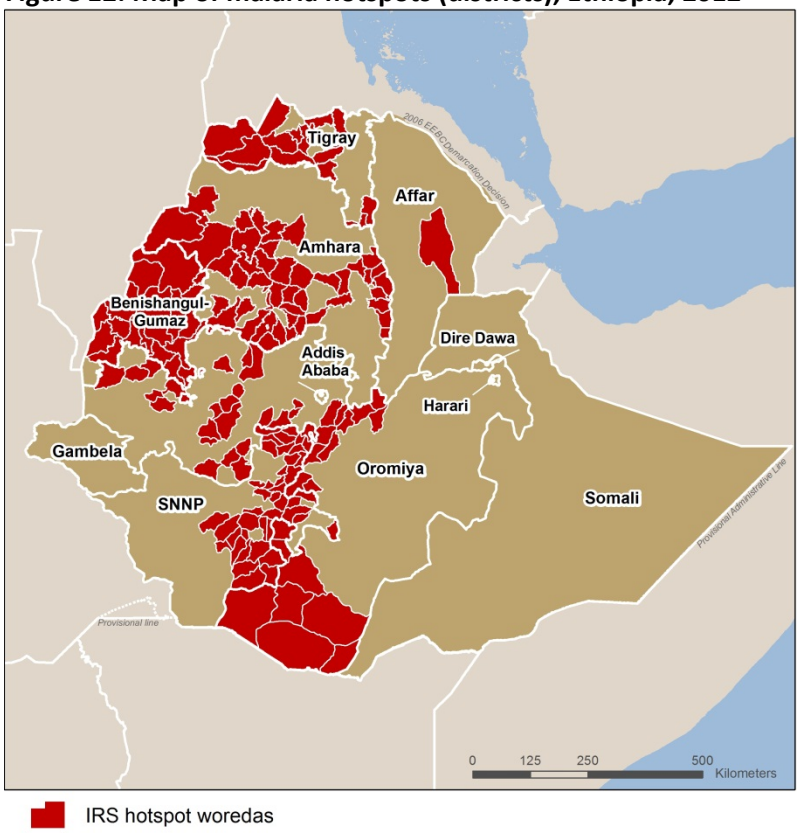


Figure 12: Map of malaria hotspots (districts), Ethiopia, 2012

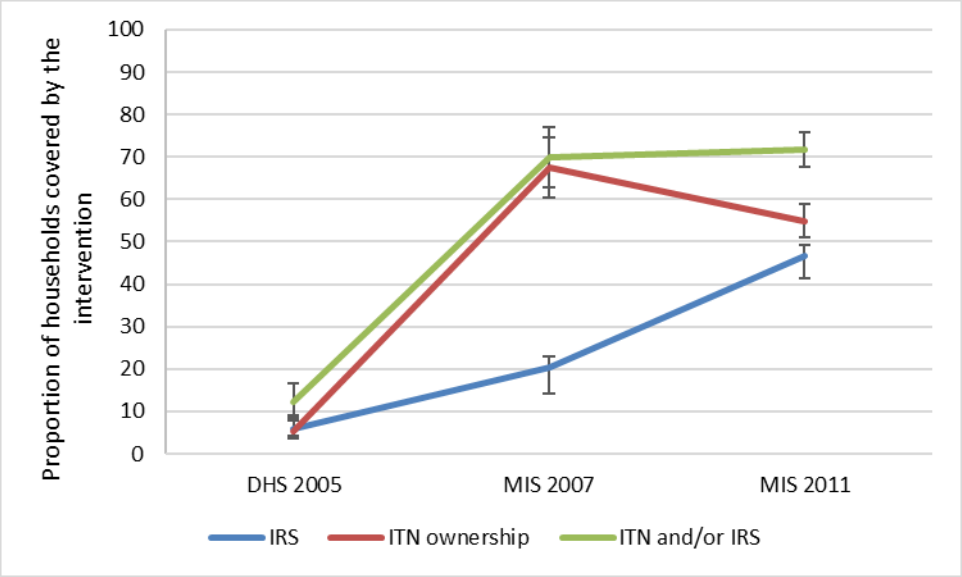


Source: Data from Dr. Daddi, EHNRI/EPHI, personal communication, 2012

IRS Implementation

According to the 2010 World Malaria Report (WMR), the population protected by IRS increased from 2.8 million in 2000, to 28.3 million in 2009, a 7-fold increase. The percentage of households sprayed with IRS in malaria endemic regions below 2,000m has also increased significantly from 8% in 2005 to 21% in 2007 to 47% according to self-report from the 2011 MIS (Figure 13). These estimates from household survey data approximate the estimates from administrative data showing 13% and 31% population coverage in 2005 and 2007 and 50% coverage in 2011. As both ITNs and IRS are effective malaria prevention strategies, it is useful to look at the proportion of households covered with either of the two interventions. The combined coverage with vector control interventions (i.e., either IRS, ITN ownership, or both) in the highest risk populations (below 2,000 m) has increased from 12% in 2005 to 72% in 2011 (Figure 13).

Figure 13: Trends in ITN and/or IRS coverage in rural households at elevations less than 2,000 m in Ethiopia, 2005–2011



Note: ITN ownership-=household ownership of at least one ITN.

IRS Summary

In Ethiopia between 2000 and 2013, an estimated 68% of the population lived in households at high risk of malaria including areas that were epidemic prone and those at altitudes below 2,000 m. Localities to be targeted for IRS are determined on a yearly basis using various parameters such as local epidemiological situation, local expert knowledge, and availability of resources. Most likely due to limited funding, the percentage of unit structures covered with IRS and population protected did not improve between 2000 and 2005, when only 18.6% of unit structures and 20% of the population in high malaria risk areas were covered. However, after significant financial investment in malaria prevention from Global Fund and PMI, IRS coverage rates increased to 40–50% of high risk populations in 2007 and 2011. By 2012, the combined coverage of ITNs and/or IRS protected 72% of the rural population living below 2000 m [61].

Prevention of Malaria in Pregnancy

Malaria prevention and control during pregnancy in most malaria endemic countries in Africa involves a three-pronged approach, including IPTp, ITN use, and diagnosis and treatment of clinical illness [62]. However, in Ethiopia, IPTp is not a part of the national malaria control strategy. Only 2.3 million people live within stable, high malaria transmission areas in Ethiopia, representing fewer than 5% of the population at significant malaria risk in Ethiopia. Despite the protection conferred by IPTp in moderate and high risk areas, this intervention is not recommended by WHO for areas of low transmission and thus has not been part of the national policy in Ethiopia. Malaria in pregnancy activities in Ethiopia focus on ITN use and prompt diagnosis and treatment of malaria cases when they occur. A review of the IDSR data through 2009 suggests that pregnant women constitute approximately 2% of outpatient malaria illnesses, 3% of total malaria admissions, and 2% of total reported malaria deaths among all age groups [63]. Trends in ITN use by pregnant women were presented in the ITN section. Data on case

management of clinical illness in pregnant women are not collected in national household-based surveys.

Malaria Case Management

Background

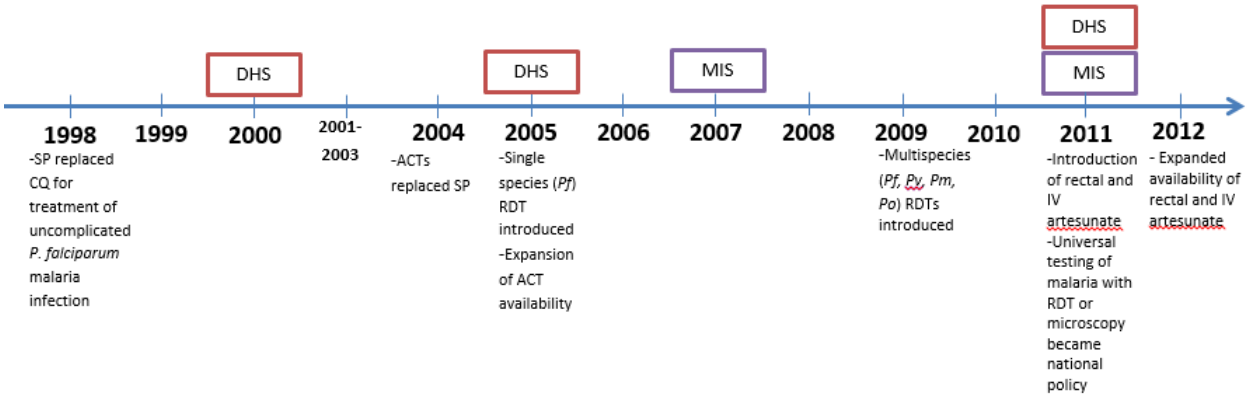
Ethiopia has embraced prompt and effective treatment of clinical malaria as one of the core malaria control strategies, as recommended by the WHO [64], and has also supported universal diagnostic testing of all suspected malaria cases. Provision of prompt diagnosis and treatment of malaria depends on factors including access to health facilities, proper diagnostic capacity, and availability of appropriate antimalarial treatments. In addition to the general malaria diagnosis and treatment guidelines, the Ethiopian National Malaria Guidelines provide special guidance on case management of febrile children and pregnant women [22]. All health workers at the health center level of care and above who are managing a sick child have been trained on the national algorithm of IMCI and HEWs have been trained in integrated community case management (iCCM) [22]. The treatment algorithm also provides guidance on managing a febrile child when parasitological tests are negative. During the evaluation period, data from the national surveys (both DHS and MIS) provide some insight into national trends in case management of children with malaria. These surveys reported on different RBM indicators, including the percentage of children less than five years of age with fever, and percentage of children that received a finger/heel stick (as a proxy for receiving a diagnostic test).

Diagnostic Policy

Prior to the expansion of malaria interventions, when there was only limited availability of microscopic confirmation in many health centers; presumptive treatment of all suspected cases of malaria with antimalarial medications was practiced widely in Ethiopia. Currently, microscopy remains the gold standard for malaria diagnostic confirmation and is preferentially used in all health centers and hospitals. In 2005, malaria *P. falciparum*-specific RDTs were introduced in Ethiopia. The mono-species *P. falciparum* RDTs are not capable of diagnosing *P. vivax* infections which account for 40% of malaria cases in Ethiopia. Due to the limited utility of a *Pf*-only diagnostic tool in the Ethiopian setting, health care providers continued to rely on presumptive treatment with ACTs, regardless of mono-species RDT results. In 2009, multi-species (Pan-specific) RDTs became available and were recommended for diagnosis when microscopy services were unavailable.

The policy of universal testing of all suspected malaria cases was adopted in 2011. Parasitological confirmation with RDTs and treatment with ACTs is provided free of charge to all suspected malaria cases in all public health facilities. In most cases, contingency supplies (between 15–25%) of RDTs and ACTs are reserved by the government in case of emergency situations. Figure 14 includes the timeline for testing and treatment policies in Ethiopia.

Figure 14: Timeline of national surveys and milestones in diagnostic and treatment strategy and interventions in Ethiopia



Diagnostic Capacity

Appropriate case management of malaria cases requires the ability to properly identify the malaria parasites and to provide malaria treatment promptly for the patient with acute malaria illness. The FMoH policy requires health centers and hospitals to diagnose malaria using microscopy, where health posts can use RDTs. The expansion of health centers from 356 to 2,999 between 2000 and 2012 came with the requirement for 1-2 microscopes and 1-2 microscopists to equip and staff each of these facilities. In 2001, only 15–25% of all reported malaria cases were confirmed (by microscopy) [65], but by 2011-12 83% of all malaria cases were confirmed with a diagnostic test.[1] According to annual micro-plan reports, 60% of these were confirmed by RDTs and 40% through microscopy. In addition, more than half of the confirmed malaria cases are now being reported from health posts rather than only from health centers and hospitals. According to the 2011 MIS, only 16.5% of children less than five years of age living in rural areas at elevations less than 2000m reported to have received a finger or heel stick (a proxy for malaria diagnostic testing) for a recent febrile illness episode. It is possible that low care seeking (51%) could be diluting this estimate.

Treatment

Antimalarial Drug Policy

Unlike most sub-Saharan countries, species differentiation in malaria diagnosis is of substantial clinical importance in Ethiopia where 40% of malaria cases are due to *P. vivax* infection. The national treatment guidelines recommend different treatment regimens for infection with *P. falciparum* and for infection with *P. vivax*. Since the introduction of malaria treatment in Ethiopia in the 1950s, the national malaria treatment policy has changed several times. The emergence and spread of *P. falciparum* resistance to CQ (65% treatment failure rate) was reported from 15 sentinel sites across the country in 1997 [66-68]. In 1998, the national treatment policy was revised, replacing CQ with sulfadoxine-pyrimethamine (SP) for treatment of uncomplicated *P. falciparum* malaria [66]. This policy change maintained CQ for treatment of uncomplicated *P. vivax* and quinine for treatment of complicated malaria. In 2004,

[1] UNICEF Micro-plan, unpublished and Annual Review Meeting reports

following strong scientific evidence of high rates of SP treatment failure (approximately 35% at 14 days and 75% by 28 days [69, 70]), the FMoH replaced SP with ACTs as the recommended first-line treatment for uncomplicated *Pf* malaria. Official FMoH guidelines have strongly discouraged the use of SP for malaria treatment since 2004, and artemisinin monotherapy is not permitted. While there is evidence that SP treatment for malaria is frequently prescribed in the private sector [71] the private sector is an uncommon source of treatment for malaria, particularly in rural areas.

Since early 2012, when the updated FMoH treatment guidelines were released, AL has been used for the treatment of uncomplicated *P. falciparum* malaria infections and CQ continues to be the primary preferred treatment for *P. vivax* infections [72]. Prior to 1990, CQ plus PQ treatment was first-line for both P. falciparum and *P. vivax* infection. No documentation of adverse effects due to PQ use is available from this period [73]. PQ was dropped from the recommended treatment regimen when SP was introduced. Currently, use of PQ is uncommon in clinical practice because of concerns about PQ safety and the lack of data on glucose-6-phosphate dehydrogenase (G6PD) deficiency distribution among the Ethiopian population. The current national guidelines restrict the use of PQ to health centers or hospitals and require further G6PD studies before wider use of PQ is permissible. In 2011, FMoH adopted the policy to replace injectable quinine with intravenous (IV) artesunate or intramuscular artemether for treatment of severe malaria. These treatments are mainly provided at health centers and hospitals with the capacity for supervised treatment and other supportive care. In addition, rectal artesunate is used as pre-referral treatment at the HP level.

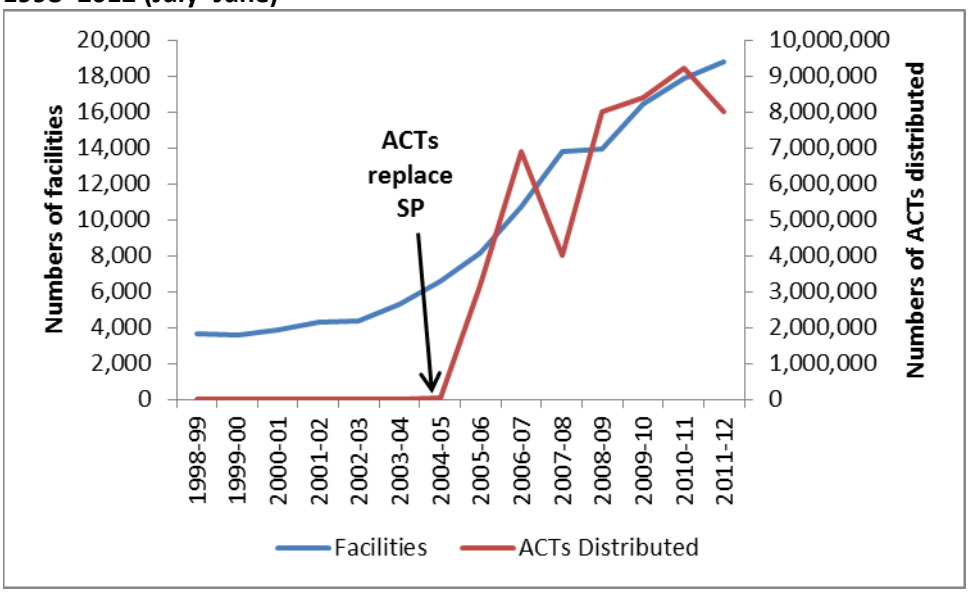
In addition to guidance on the recommended antimalarial regimens, training on basic case management for febrile illnesses is provided to health providers. Between 2012 and 2013, seven days of refresher training (including an RDT refresher training) and malaria job aids were provided to all rural HEWs through UNICEF, the FMoH, and various partners that included an evidence-based algorithm to manage acute febrile illnesses based upon the iCCM model.

Availability of Antimalarials and Diagnostic Commodities

Since 2006, ACT stocks have been sufficient at the national level to treat the likely national burden of *P. falciparum* infections based on estimated annual malaria cases and the assumption that at least 40% of these cases are due to *P. vivax* infections [74]. ACT requirements have decreased from 8–9 million doses per year in 2010-11 to between 5–7 million ACT doses per year in 2012-13 (even allowing for outbreak contingencies of 25%) due to increased use of parasitological testing and the concomitant reduction in presumptive treatment of fever. In 2011-12, 17.9 million RDTs were imported and distributed [75] and 18.3 million RDTs were imported and distributed during 2012-13 [76]. According to official policy, health centers, regional reference laboratories and hospitals must use microscopy for malaria diagnosis. PMI estimates that 70% of the suspected malaria fever cases will require an RDT for diagnosis when determining procurement needs. Figure 15 shows the rapid expansion of distribution of ACTs for over six years (2004–2012) in relation to the increase in the number of public health facilities since 1998. Adequate CQ supplies for the number of *P. vivax* cases have also been available in Ethiopia since 2010. Although RDTs and first-line antimalarial supplies have been sufficient at the national level, focal stock-outs of CQ, ACTs, and RDTs have occurred, either observed during health facility surveys or reported by

the districts. These have been caused by issues with the supply chain, health system weaknesses, and by distribution issues [77].

Figure 15: Annual increase in the number of public health facilities and ACT distribution in Ethiopia, 1998–2012 (July–June)



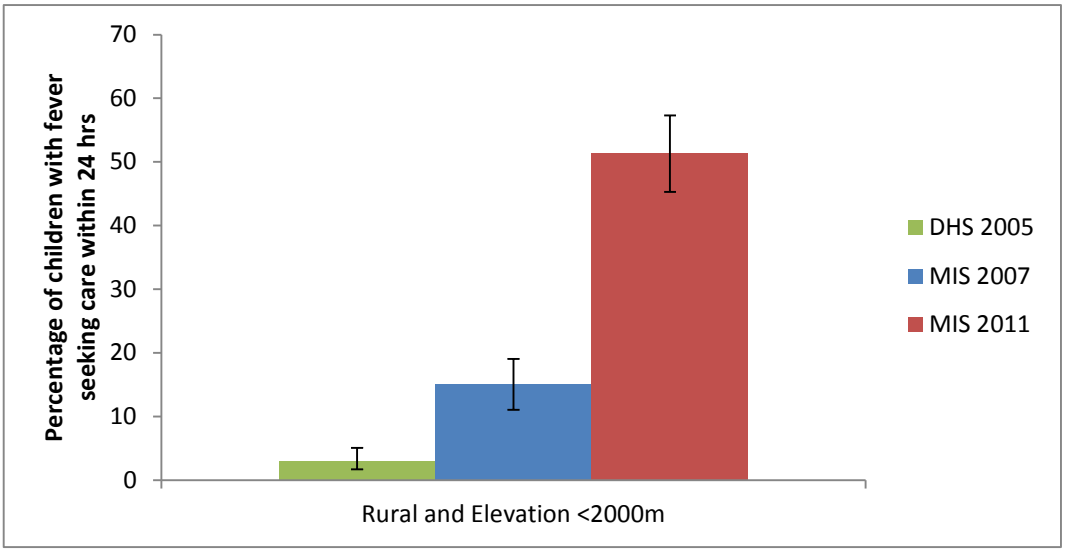
The expansion of HIV/AIDS, tuberculosis, and malaria interventions prompted Ethiopia to establish the Pharmaceutical Fund and Supply Agency (PFSA) in 2004, which procures and distributes most public sector health system items including malaria commodities such as LLINs, ACTs, RDTs, CQ, quinine, and IRS insecticides. Adequate supplies of appropriate antimalarials at access points are among the factors that influence trends in malaria case management indicators. Since the beginning of the expansion of malaria interventions in 2005, 48 million ACT treatment courses have been procured and distributed [40].

Malaria Case Management Coverage Trends

Provision of prompt diagnosis and treatment of malaria depends on factors such as access to health facilities, use of health facilities, proper diagnostic capacity, timely reporting, and availability of appropriate antimalarials. Access to health facilities has been increasing in Ethiopia over the evaluation period as more health posts have been constructed and staffed. The FMoH estimates that access to primary care services, defined as the percent of the population living within 2 hours walking distance of a facility, has increased from 61% in 2004 to 92% in 2012 [78].

In conjunction with the increase in total number of health facilities available, health facility use has also been increasing; survey data show that the percentage children less than five years of age living in households below 2,000m with fever in the two weeks preceding interview who reported seeking advice or treatment within 24 hours of fever onset increased from 3% in 2005 to 15% in 2007 and to 51% in 2011 (Figure 16).

Figure 16: Percentage of children less than five years of age with recent fever who sought advice or treatment within 24 hours of onset of fever, 2005–2011



Community Case Management of Malaria

Since 2004, Ethiopia constructed the majority of the currently existing community-level health posts and trained and equipped most of the HEWs. While malaria diagnosis and treatment was always at the core of the HEP at rural health posts, it was not until 2010 that multispecies RDTs were available in sufficient quantity to result in confirmatory diagnosis being obtained for most suspect malaria cases. Previously, a febrile patient with an RDT negative result would often receive empirical ACT treatment from HEWs. Several potential reasons for non-compliance with test results were limited supplies of CQ for treating *P. vivax*, inability to diagnose *P. vivax* as only mono-species *P. falciparum* RDTs were available, or doubts about overall RDT performance by clinicians. The introduction of iCCM in 2011 offered a major health system improvement allowing HEWs to provide cotrimoxazole for pneumonia, zinc and ORS for diarrhea, ready-to-use therapeutic foods for severe acute malnutrition, and the management of malaria with ACT, CQ or rectal artesunate as appropriate. The expansion of iCCM in Ethiopia was a rare example of rapid large-scale implementation of the program covering the large majority of the population [79]. Many resources have been invested in the iCCM program with the goal of increasing access to life-saving medical care and reducing child mortality.

Malaria Case Management Summary

In summary, during the evaluation period, Ethiopia made important malaria diagnostic and antimalarial treatment policy changes. Critical policy changes included replacing CQ with SP in 1998, and subsequently replacing SP with ACTs in 2004 as the first-line treatment of *P. falciparum* infections. In 2009, FMoH adopted a new policy to use multi-species RDTs and made a multispecies RDT available for diagnosing malaria at the health post level. Twenty million RDTs were delivered to health posts by late 2009. In 2011, another important policy was adopted that requires universal malaria testing for all febrile illnesses consistent with WHO malaria diagnosis and treatment guidelines. Finally, rectal and IV artesunate were recommended for treatment of severe malaria in 2012.

The expansion of malaria interventions including malaria parasitological diagnosis and use of effective antimalarials for treatment was observed during the evaluation period. National survey data show an increase in prompt care seeking for fever in children less than five years of age from 3% in 2005 to 51% in 2011. Among patients with fever seeking care, the proportion receiving parasitological tests to confirm malaria infection has also increased over the evaluation period; parasitological confirmation of reported malaria cases increased from less than 25% in 2001 to 83% in 2011-12[2].

Appropriate case management of confirmed malaria cases requires access to effective medications. Since 2006, at least 6 million ACT treatment doses per year have been procured and distributed to public health facilities, enough to meet the expected number of *P. falciparum* cases. Injectable quinine was used prior to 2011 for treatment of severe malaria but rectal and IV artesunate are now the recommended medications for severe disease. Since 2012, availability of these medications has increased. Although annual refresher training for HEW including malaria diagnosis and treatment have been a part of fever management services since the program began, the introduction of iCCM, in which diagnosis and treatment for pneumonia, diarrhea and malnutrition were included in HEW services, led to implementation of refresher training in 2012. These trainings reinforced HEW skills in malaria diagnosis and treatment, and led to improved stocks of essential antimalarials in rural health posts. Ultimately, these changes should lead to improvements in prompt access to malaria care among the population most at risk. However, the scale-up of severe malaria medications and iCCM occurred at the tail end of the evaluation period. The increase in species-specific parasitological testing also led to a clearer estimate of the *P. vivax* burden and treatment needs. More than 1.1 million diagnosed *P. vivax* cases were eligible for CQ therapy rather than AL in 2012, reducing the ACT requirement.

Parasitological confirmation at the community level by HEWs contributed to the improvement of access to malaria diagnosis, increased malaria case reporting, and improved access to prompt and effective treatment of malaria cases in Ethiopia. RDT-negative children may have also experienced improved care for their underlying illnesses once malaria was ruled out and clinical efforts could be diverted to other potential diagnoses. Improving diagnostic confirmation at the health centers and hospitals by decreasing the number of clinically diagnosed malaria cases improved the specificity of the malaria case data and maximized use of resources by reducing unnecessary treatment of presumptive cases.

Malaria Morbidity

Malaria Parasitemia

Parasitemia as an Impact Measure

Success of malaria interventions is measured by key malaria indicators collected at the community level. Malaria parasitemia prevalence is one of the standard outcomes that is used to measure impact of malaria control interventions. Reductions in parasitemia prevalence should have the effect of reducing malaria-attributable morbidity and mortality at the population level. In Ethiopia, prior to 2007, reliable national malaria parasitemia prevalence data was non-existent until national surveys were introduced as a means of monitoring malaria intervention expansion activities. Detection of meaningful change in parasitemia at the national level using survey data is challenging due to normal seasonal fluctuations in

[2] UNICEF Micro-plan, unpublished and Annual Review Meeting reports

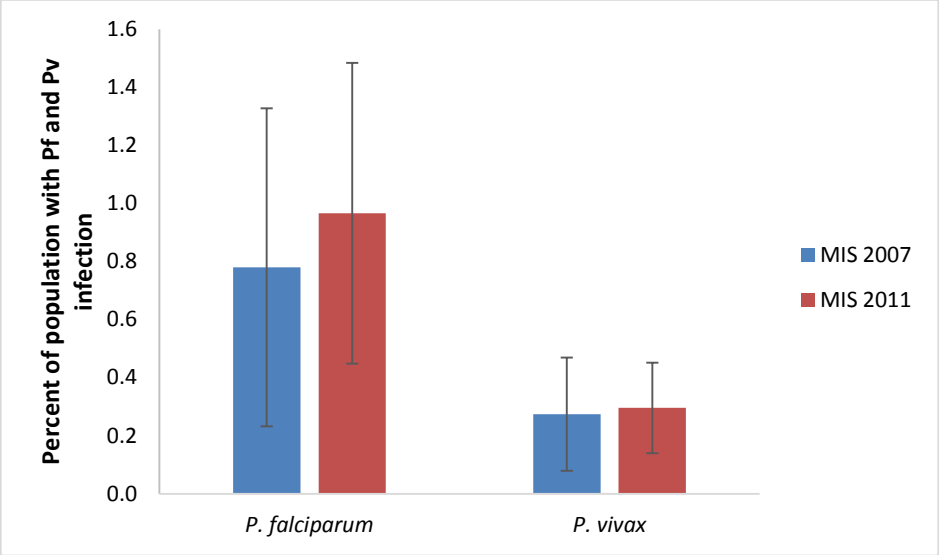
malaria transmission as well as the low overall malaria prevalence in Ethiopia [80]. Parasitemia prevalence can fluctuate drastically between seasons within a 1-year period [80, 81]. In addition to seasonal trends, changes in parasitemia levels over several years may be due to fluctuations in climate patterns rather than lapses or leaps in malaria control efforts [82, 83].

Malaria Parasitemia in Ethiopia

Estimates of national malaria parasitemia prevalence are not available before 2007 when the first MIS was implemented. This means that baseline estimates prior to intensification of malaria control activities are unavailable. However, a few studies provide parasitemia measures at a smaller scale. For example, a 2006 household survey in Amhara, Oromia and SSNPR Regional States found 4.1% parasitemia prevalence (4.6% in children less than five years of age) [84].

The 2007 MIS showed very low levels of parasitemia in all ages nationwide compared to most other sub-Saharan African countries. The survey revealed 1% malaria prevalence (0.8% *P. falciparum*, 0.3% *P. vivax*) by microscopy in all ages in rural areas below 2,000 meters during the peak transmission season (Figure 17). The 2011 MIS, which was also conducted during the peak transmission season, revealed a continued low parasite prevalence among all ages (1.3% by microscopy) in rural areas below 2,000m (1.0% *P. falciparum* and 0.3% *P. vivax*). Results from the 2007 and 2011 MIS indicate lower *P. falciparum* and *P. vivax* slide prevalence in populations living at elevations between 2,000 and 2,499m compared to populations in lower elevations in rural areas, indicating an inverse relationship between household altitude and local malaria transmission. In 2011, there was only 0.1% malaria slide prevalence by microscopy in areas above 2,000m and the great majority of these positive slides were *P. vivax*.

Figure 17: Prevalence of *Plasmodium falciparum* and *Plasmodium vivax* among all ages at altitudes less than 2000 m, Ethiopia, 2007–2011



A 2010 publication compared results of the aforementioned subnational household survey of malaria parasitemia conducted in 2006 in the three most populated Regional States of Ethiopia (Amhara, Oromia, and SNNPR) with a subset of data from the 2007 MIS restricted to malarious kebeles in the

same three Regional States [84]. These selected regions accounted for the majority of at-risk malaria populations and malaria burden in Ethiopia at that time. The study revealed a decrease in malaria parasitemia prevalence in 11,601 tested samples from 4.1% to 0.4% between 2006 and 2007 for all age groups, and among 1,960 children less than five years of age, a decrease from 4.6% (3.4–6.1) to 0.6% (0.2–1.7). Between 2006 and 2007 in the studied areas, ITN household ownership was shown to have increased from 20% in 2006 to 68% in 2007, suggesting a temporal association between significant parasitemia decline and malaria intervention program expansion.

Severe Anemia

Severe Anemia as an Impact Measure

Changes in severe anemia can potentially be used as an additional indicator to monitor malaria burden at the community level as malaria interventions are scaled up [85]. For malaria control monitoring and evaluation purposes, severe childhood anemia, defined as blood hemoglobin levels less than 8 g/dL[3] in children 6-59 months of age, is associated with malaria-related mortality, and it is measurable at the population level with less seasonal variability than parasitemia [87-89]. Declines in prevalence of severe childhood anemia have been found to be associated with malaria control interventions in other African countries [90, 91]. Severe childhood anemia prevalence has also been collected in many more population-level surveys than parasitemia, therefore trends are more easily established using retrospective survey data. In settings of low parasitemia prevalence, trends in childhood anemia are less likely to be driven by changes in parasitemia. For one, epidemiologic profiles shift in low burden settings such that children under five years old are not the group of highest risk of severe malaria. Second, other etiologies of childhood anemia may be more important than malaria in explaining trends where malaria cases are rare.

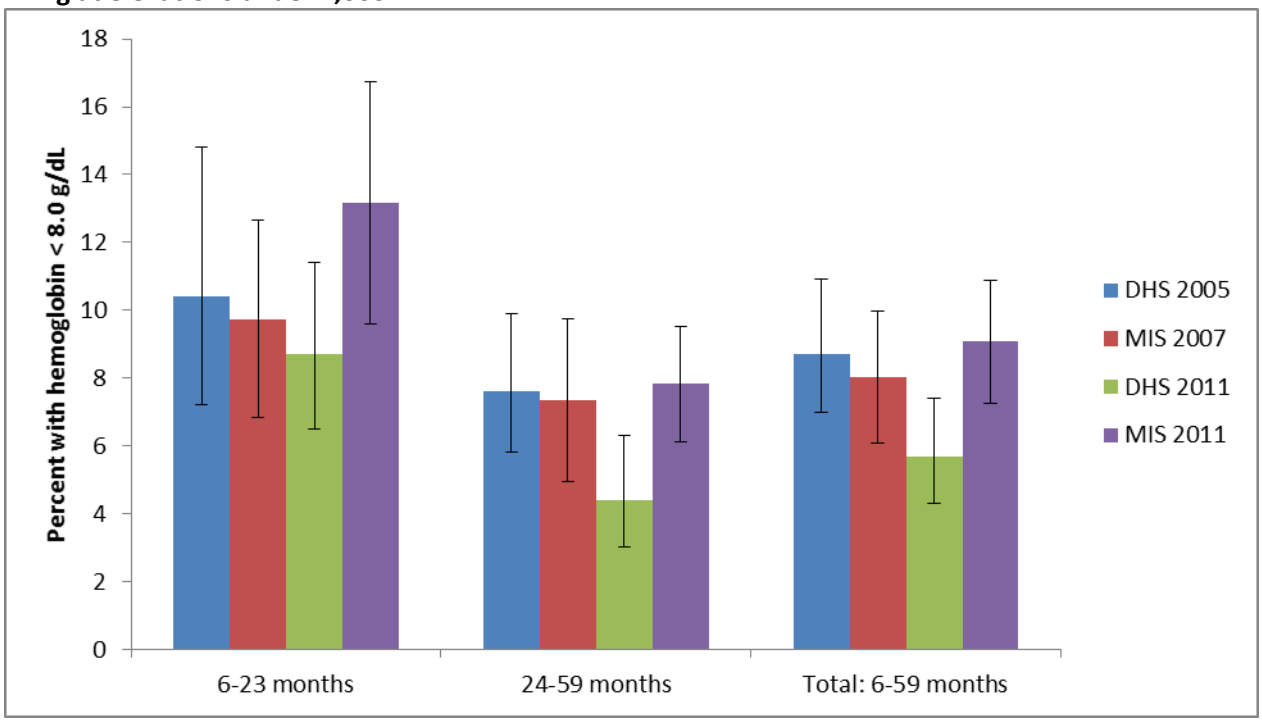
Severe Anemia in Ethiopia

In Ethiopia, using data from four national surveys (2005 DHS, 2007 MIS, 2011 DHS and 2011 MIS), altitude-adjusted rates of severe anemia (Hb <8g/dL) in children 6–59 months old has not significantly decreased from 2005 to 2011, nor was there any clear trend in stratified analyses of children above and below 24 months of age (Figure 18). There are no comparable baseline anemia data for the period of 2000–2004, before the expansion of malaria interventions. Although the presence of severe childhood anemia in low-transmission areas may suggest non-malarial etiologies, several studies suggest that malaria is an important cause of anemia even in low-endemicity settings [92, 93].

Figure 18 shows the prevalence of severe anemia in different age groups. Children 24–59 months of age were less likely to have severe anemia than were children 6–23 months of age in the 2011 MIS (8% vs. 13%) and the 2011 DHS (4% vs. 9%). No other statistically significant trends are apparent.

[3] A hemoglobin cutoff of <7 g/dL is used to classify severe nutritional anemia, whereas a cut off of <8g/dL is used to classify malaria-related anemia. Intervention trials have shown that malaria control interventions reduce moderate-to-severe anemia (Hb <8g/dL). These definitions refer to hemoglobin levels that have been adjusted for age, altitude and smoking habits as defined by CDC [86.Centers for Disease Control and Prevention, *Criteria for anemia in children and childbearing-aged women.* MMWR Morb Mortal Wkly Rep, 1989. **38**: p. 400–404.].

Figure 18: Trends in severe anemia (hemoglobin <8g/dL) prevalence in children aged 6–59 months living at elevations under 2,000m



Summary of Parasitemia and Anemia

Limited national level data prior to 2007 hampers analysis of trends in parasitemia and anemia prevalence over the evaluation period. Despite the lack of national survey data, a large sub-national survey suggested that malaria parasitemia in children less than five years of age in malarious areas of Amhara, Oromia, and SNNPR was 4.6% in 2006 [84]. By 2007, malaria parasitemia prevalence declined to approximately 1% of children less than five years of age in high risk areas (rural, <2,000m). The two surveys conducted in 2007 and 2011 occurred after malaria control intervention expansion was well underway and intervention coverage had increased, after which there was continued low malaria prevalence and low malaria transmission. National survey data do not show declines in malaria parasitemia prevalence between 2007 and 2011; however, the very low level of malaria prevalence in Ethiopia may make declines difficult to detect using the household survey platform. It is unclear whether additional declines in microscopy-detected parasitemia can be expected at current intervals of survey implementation under conditions of low transmission. .National-level childhood anemia data are unavailable before 2005; however, there have not been statistically significant changes in anemia prevalence between 2005 and 2011. It should be noted that the available national prevalence estimates are for children 6-59 months of age and that this age category is not the highest risk group for malaria in Ethiopia. Though limited, the available data concerning indirect indicators such as anemia and malaria parasitemia suggest that malaria intervention expansion has kept malaria prevalence low between 2005 and 2011 in Ethiopia.

Facility Data

Routinely-collected Facility-based Malaria Databases

There are many challenges in directly measuring malaria morbidity and mortality through surveillance. Certain populations may not have access to public health services (where measurement and reporting occur), parasitological confirmation of infection may be unavailable, and reporting may be imperfect. In Ethiopia, these challenges have been greatly mitigated since the pre-malaria intervention intensification period of 2000–2004 through health systems strengthening. Efforts have included improvements in access to prompt laboratory-based diagnosis and treatment, construction of new health facilities within a two hour walk from most households, and improvements in surveillance. The climate in which monitoring and evaluation of malaria control programs occur has starkly changed since pre-intervention times. Unfortunately, this reality makes measurement of trends over time challenging.

Attributes of major public health malaria surveillance systems in Ethiopia are presented in Table 9 with additional detail available in Annex A.1.1. There is considerable overlap in scope and redundant reporting among these systems.

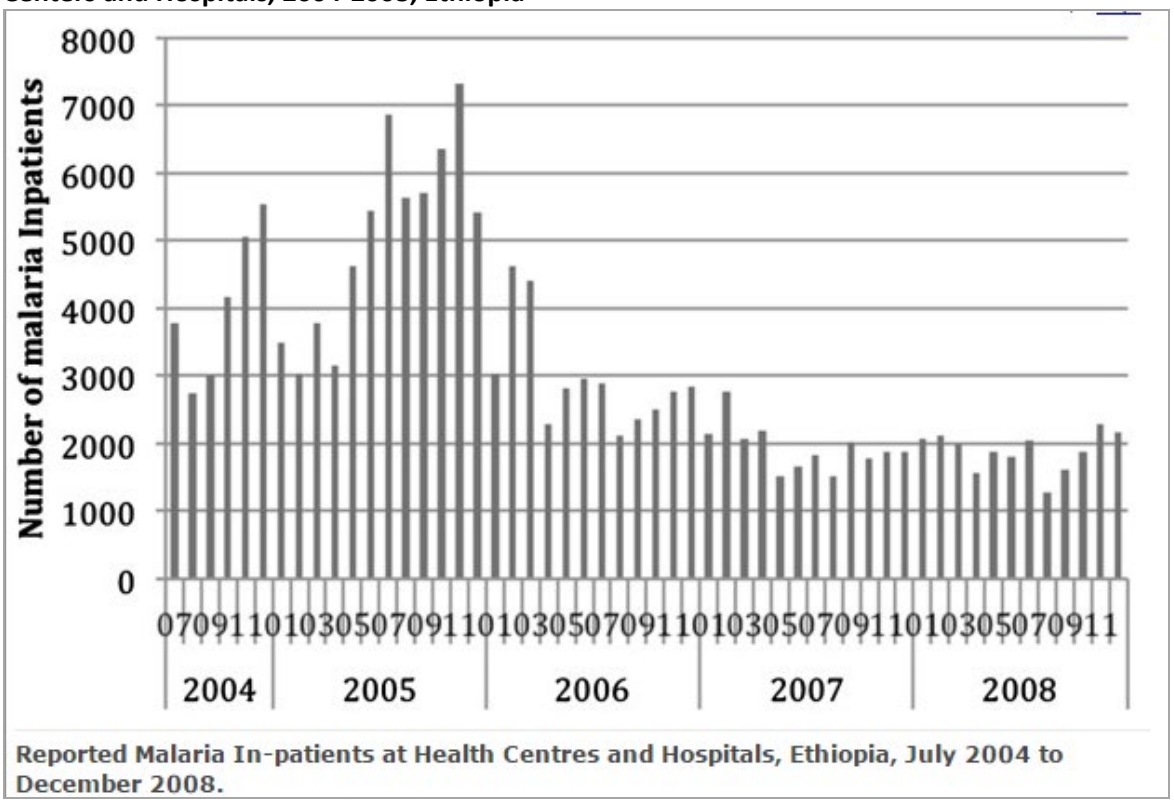
Table 9: Malaria Surveillance System Attributes, Public Sector, Ethiopia, 2000–2013

Surveillance System	Reporting Period	Facilities Reporting	Publications	Comment
Health Management Information System (HMIS)	Quarterly	Hospitals, Health Centers	Annual Health and Health-Related Indicators	Most complete for inpatient malaria reporting and inpatient deaths; some stratification of data by gender and for children. Prior to 2009 HMIS was the primary source of data for WHO's World Malaria Reports.
Integrated Disease Surveillance System (IDSR)	Monthly	Hospitals, Health Centers	Annual Health and Health Related Indicators, **until 2009**	Microscopy diagnostics; outpatient, inpatient deaths, children less than 5 years, malaria in pregnancy; IDSR malaria data have not been reported since 2009: folded into PHEM
Public Health Emergency Management (PHEM) System	Weekly	Hospitals, Health Centers, and Health Posts (includes HEW encounters)	Annual Review Meeting Report, and World Malaria Report	Timely, complete, designed for outbreak detection; **began in 2009** building upon former IDSR system; PHEM is the primary data source for Annual Review Meeting and the WHO's World Malaria Reports, Global Fund 2014 NFM application
Micro-plan	Annual	Hospitals, Health Centers, and Health Posts (includes HEW encounters)	Annual internal analysis, not published for public distribution	**Began national reporting in 2010**; Detects suspected malaria, most complete available reporting as of 2013, not stratified by age or gender; data are reported and analyzed by district while accounting for component health facilities; supplement to PHEM; reports number of persons tested, and clinically treated cases.

Malaria Morbidity Estimates – Integrated Diseases Surveillance Response (IDSR) Systems and Public Health Emergency Management System (PHEM)

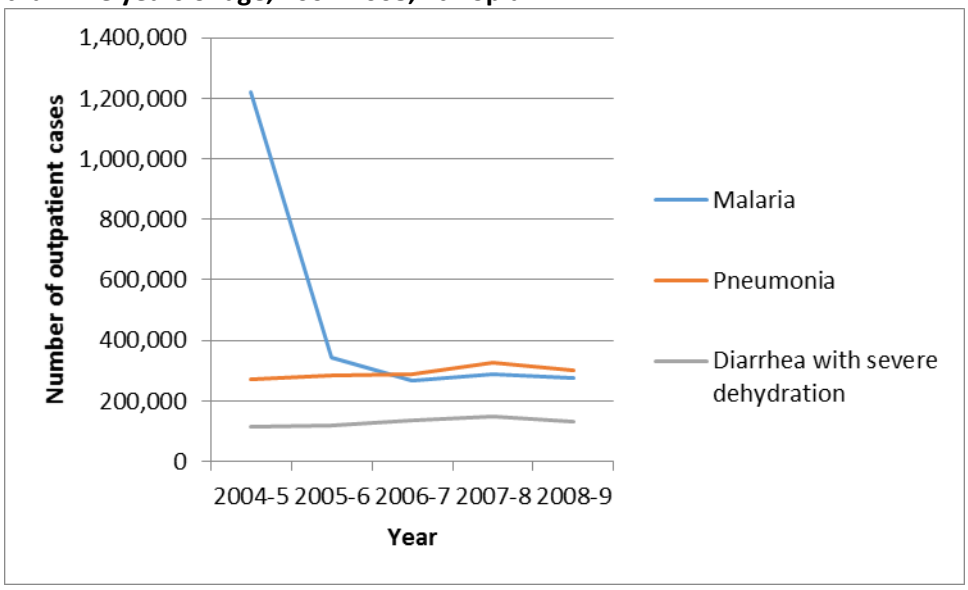
An analysis of Ethiopian IDSR surveillance trends from 2005 through 2009 (including compiled reports from most hospitals and health centers from nearly all zones and regional states, with over 80% completeness of reporting) found that there was no clear decline in outpatient malaria cases over this period with a calculated national average of 23.4 total malaria cases per 1,000 persons. Two-thirds of these cases were clinically diagnosed. The study also reported that malaria in-patient admissions averaged 6.4 per 10,000 per year. Finally, malaria inpatient admissions declined 2- to 3-fold from 2005 through 2009 [94]. These trends in malaria admissions are shown in Figure 19. Trends in malaria outpatient cases reported to IDSR compared with pneumonia and diarrhea cases are summarized in Figure 20. According to these data, malaria proportional morbidity in outpatients less than five years of age declined rapidly between 2005 and 2009. It should be noted, however, that a nation-wide malaria epidemic occurred in 2003-4 thus the observed declines may not reflect a meaningful reduction in inpatient admissions or in proportional malaria morbidity. These data are abstracted from national Health and Health Indicator Reports and trends have not been adjusted for reporting rates.

Figure 19: Integrated Disease Surveillance Report System Trends of Malaria Admissions to Health Centers and Hospitals, 2004-2008, Ethiopia



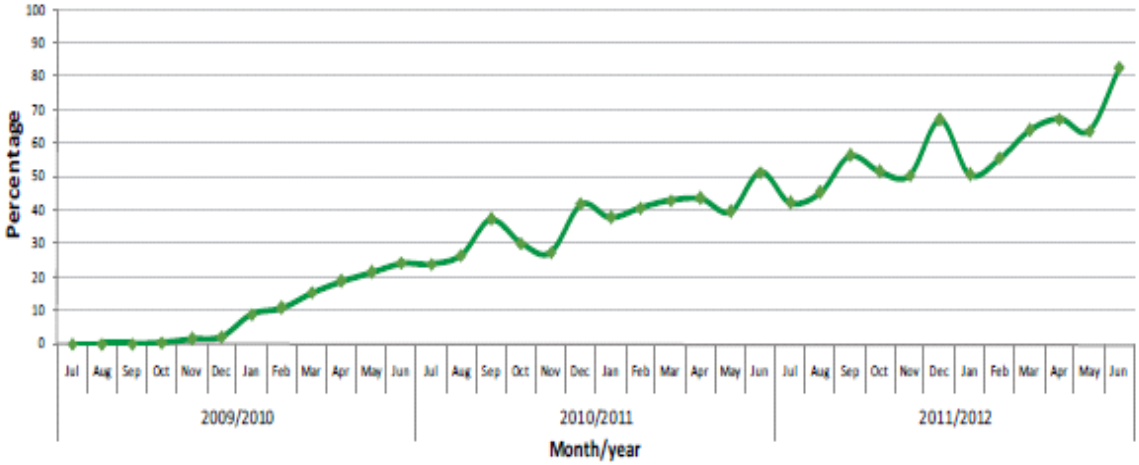
Source: Jima et al. (2012) [94]

Figure 20: Trends in outpatient malaria, pneumonia, and diarrhea cases from IDSR in children less than five years of age, 2004-2008, Ethiopia



The PHEM was created in 2009 as a means to rapidly detect and mitigate epidemics. The initial backbone of the PHEM system was the IDSR. Since malaria is the most commonly reported epidemic-prone disease in Ethiopia, malaria detection became a primary focus of the PHEM system. The strength of the system is its timeliness in detecting unusual excesses in outpatient malaria cases and other epidemic diseases within several weeks of onset. PHEM captures whether cases are from *P. vivax* or *P. falciparum* and records inpatient admissions and deaths. To do this PHEM requires weekly reports from all public health facilities, including hospitals, health centers, and health posts. Weekly reporting initially proved challenging for most health posts which typically do not have electricity or computers; health posts were more likely to provide monthly reports. Eventually, a PHEM officer was assigned to every district to report to Zonal and Regional Health officials and also to provide direct reports to the PHEM system at the Ethiopian Public Health Institute (EPHI) in Addis Ababa. The reporting completeness of the PHEM system increased from zero in late 2009 to 83% completeness in 2013 [7] (Figure 21). Results from the PHEM from 2010 onward are presented together with micro-plan data in the next section since those reports were comparable.

Figure 21: Trends in completeness of Public Health Emergency Management (PHEM) system reporting between 2009 and 2012



Source: Annual Performance Review Meeting page 36.

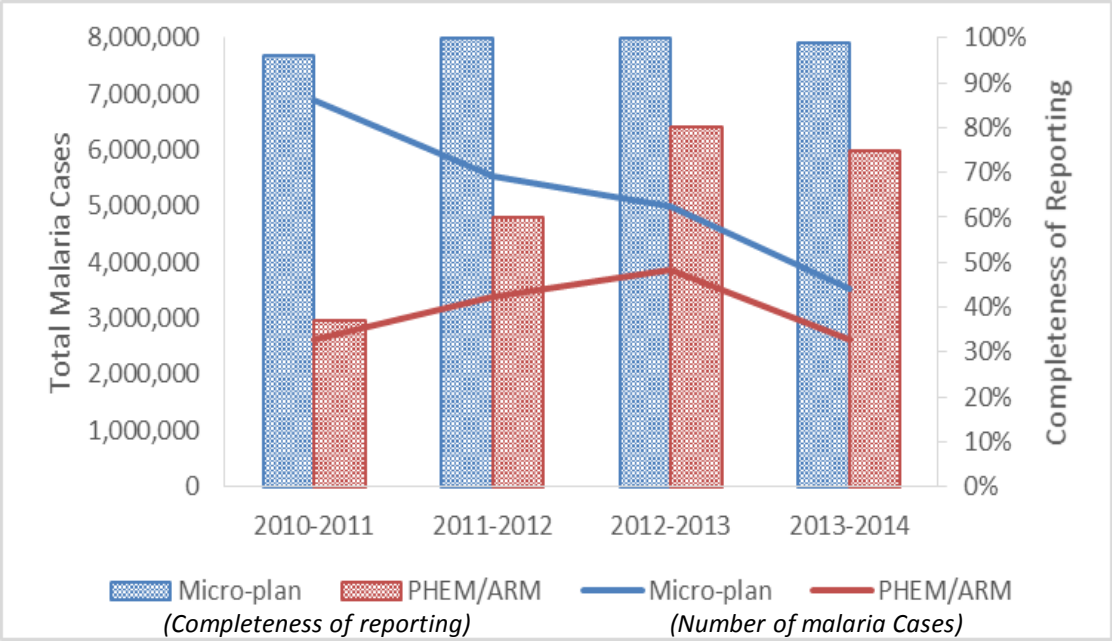
Malaria Morbidity Estimates – Micro-plan Annual Surveillance Data

Since 2010, the annual micro-plan has been an important and robust data reporting system that has complemented reporting from the emerging and rapidly improving surveillance systems in Ethiopia including HMIS, IDSR and PHEM, despite overlaps in the systems. The primary purpose of the annual micro-plan was to estimate commodity needs including RDTs, ACTs, CQ, and LLINs; however, the data on outpatient malaria visits generated from these (as a proxy for annual antimalarial medication consumption) has allowed an additional means of documenting rapid progress in HMIS and PHEM systems. Once yearly, district malaria health officers compile and report the malaria morbidity for their district, including data from health posts, health centers, and hospitals. The micro-plan system is still the only existing means to accurately calculate suspect malaria cases and RDT and microscopy requirements, essential pieces of information for malaria control. Since, in many cases, the same district health officers report the same types of malaria morbidity data to PHEM systems and HMIS, the data from these systems are becoming more consistent and estimates derived from each system are rapidly converging.

Summaries from both the micro-plan and PHEM from 2010 to 2014 are presented in Figure 22. Micro-plan reports that since 2010, malaria confirmatory testing rates have been higher at health posts than in health centers and hospitals. Between 2010 and 2014, reports of clinically treated malaria cases have declined, and malaria confirmatory testing has increased, exceeding 80%, especially at health posts. Approximately 10–12 million patients with acute febrile illnesses required case management in the public sector each year (i.e., suspected malaria cases), and total malaria cases diagnosed annually declined from 7 million to 3.5 million between 2010 and 2014. The annual burden of diagnostically-confirmed *P. falciparum* and *P. vivax* malaria cases reported in public health facilities increased between 2010 and 2013 with *P. vivax* representing between 30% and 40% of cases. Since 2010, there have been about 50,000 reported malaria hospitalizations annually. Using micro-planning reports to complement

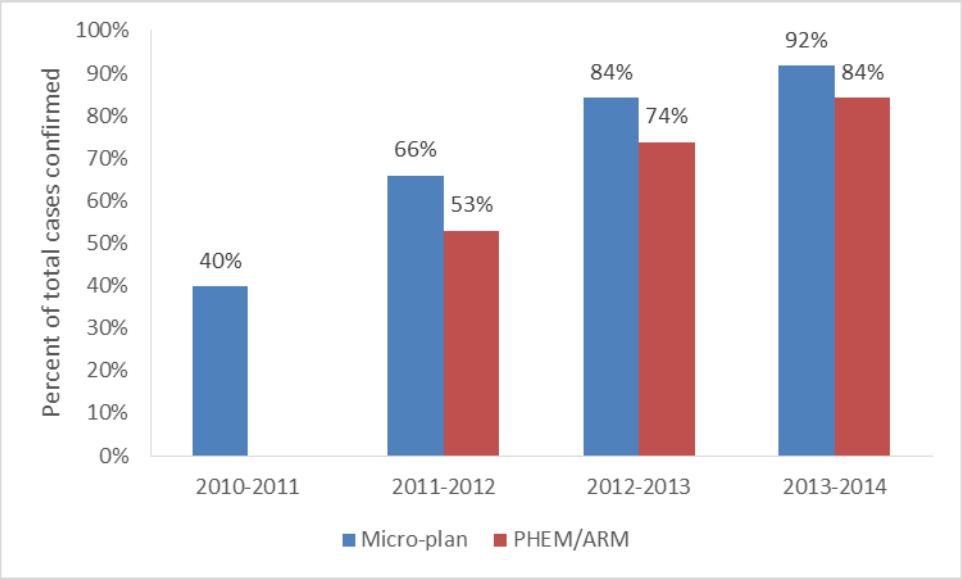
HMIS and PHEM surveillance data and making appropriate adjustments for 83% reporting completeness, the FMoH reported 5,277,554 total malaria cases for 2013 [7]. Surveillance data from 2013-2014 suggest that total outpatient malaria morbidity has declined to fewer than 4 million cases per year (**Error! Reference source not found.**). According to the micro-plan data, 97% of suspected cases were tested and 31.5% of those tested were positive. Similar trends in morbidity and in overall reporting were observed in an analysis of subnational data from Oromia Region (see Annex 6). These reported testing and test positivity rates are extraordinarily high for a low prevalence setting, which suggests that the reporting systems may not be capturing all of the suspected cases (fevers) that should be included in the denominator.

Figure: 22 Total malaria cases and completeness of reporting by micro-plan and PHEM/ARM reporting systems 2010-2014



Source: UNICEF Micro-plan, unpublished and Annual Review Meeting report.
Notes: Completeness of reporting for PHEM/ARM is estimated. The 100% of facilities reporting in the microplan is based upon 100% of malarious districts reporting data. The FMoH reported 5,277,554 total malaria cases in 2013 (January-December) in the National Malaria Strategic Plan (v. June 14, 2014). In the Micro-plan of 2013-2014, data were not included from the cities of Addis Ababa, Dire Dawa and Hareri, that according to the corresponding ARM report (EFY2006), experienced a combined total of about 15,000 total malaria cases.

Figure: Percentage of total malaria cases confirmed by diagnostic test as reported by micro-plan and PHEM/ARM reporting systems 2010-2014

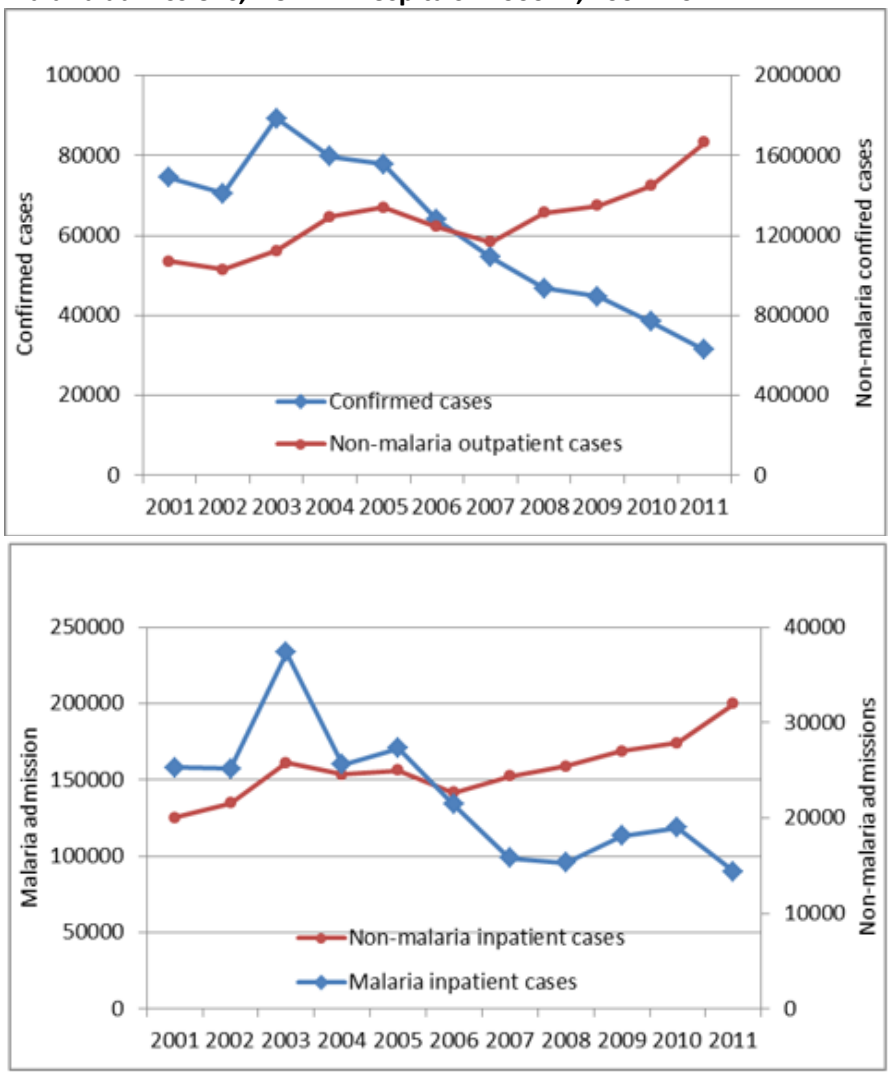


Source: UNICEF Micro-plan, unpublished and Annual Review Meeting report.
Notes: Laboratory confirmed cases includes clinical laboratory testing results by either malaria RDT or blood smear microscopy. In the Micro-plan of 2013-2014, data were not included from the cities of Addis Ababa, Dire Dawa and Hareri, that according to the corresponding ARM report (EFY2006), experienced a combined total of about 15,000 total malaria cases.

Malaria Morbidity Estimates – Health Facility Assessments

Several other published studies using health facility data provide evidence of decreasing malaria morbidity during the evaluation period. Although small in focus, one study evaluated malaria reports among children less than five years of age from a convenience sample of 13 health facilities in Ethiopia, and found that inpatient malaria admissions had declined by 73% when comparing the reporting periods 2001–2006 and 2007 [96]. Another recent analysis of data from 41 Ethiopian hospitals located at elevations below 2,000 m from 2001–2011, found that annual outpatient malaria cases peaked in these facilities in 2003 at 180,000 per year, then declined steadily through 2011 to 30,000 annual malaria outpatient cases. Changes in other factors such as use of health facilities (numbers of hospital visits), use of malaria diagnostic testing and climate (rainfall) did not explain the observed decrease in malaria cases. Also, seasonally-adjusted malaria slide positivity rates were higher during 2001–2004 at 23%, and declined to 15% during 2005–2011. Finally, monthly malaria admissions were higher during 2001–2004 compared to 2005–2011 (Figure 22) [97]. Overall, the observed number of confirmed malaria cases declined more than 60% and malaria inpatient cases declined more than 50% from the predicted values if 2001-2005 levels had persisted.

Figure 22: Confirmed cases versus non-malaria outpatient cases; malaria admissions versus non-malaria admissions, from 41 hospitals <2000 m, 2001–2011.



Source: Aregawi et al, 2014 [97].

Summary of Health-facility Based Morbidity

Estimates of trends in malaria morbidity from routinely collected health facility data must be interpreted with caution due to changes in the number of accessible health facilities, in patterns of use of health facilities, patterns of diagnosis and in numbers of health facilities reporting to the routine data collection systems over the evaluation period.

IDSR data show static outpatient malaria case numbers after the peak of malaria cases in 2004-5, but decreasing inpatient cases from 2005–2009 [94]. Proportionate malaria morbidity also declined over this period despite the lack of change in total reported malaria cases. The proportion of facilities reporting to IDSR varied over the evaluation period, complicating interpretation of trends. In addition, IDSR data are available only until 2009 at which point the PHEM data replaced IDSR. PHEM data are only available

from 2010 to 2014 and have the same issues with variable reporting rates over this short time period (0 to 83% from 2010 to 2013).

Data from the micro-plan system show significant declines in reported malaria cases from 6.9 million in 2010-11 to 3.5 million in 2013–14. Micro-plan data have the advantage of near 100% reporting and the inclusion of data from health posts (including HEW consultations) but the data are only available from 2010 to the present. The declines in numbers of malaria cases since 2010 are evident despite increasing access to health care (increasing numbers of health facilities available for use and expanded rural access to health facilities). During this time the proportion of presumed malaria cases confirmed with diagnostic tests also increased significantly which could partially explain the observed trends (a more specific definition of cases was used in the later years). It is not possible to conclude with certainty from these micro-plan reports that the observed trends are due to successful malaria control interventions because stable reporting conditions have not been present for a long enough period of time. Determining whether declines in malaria cases are real will require continued access to reliable data with which to examine unbiased trends.

Other attempts to examine recent trends in malaria morbidity used data from a specific set of hospitals in order to eliminate the bias of variable reporting rates and the increase in numbers of facilities reporting to the system over time, common to nationally representative datasets. These studies reported declines in outpatient malaria [98] as well as in admission rates [96, 98] in the studied hospitals. Although these studies are not nationally representative, they provide more stable conditions in which to make unbiased comparisons over time.

With the lack of comparable data over the entire evaluation period, definitive statements about trends in malaria cases are impossible; however, positive changes have occurred. More Ethiopians have access to health services and more are using these health services than ever before. In addition, more suspected malaria cases are being tested, either by microscopy or RDTs. This combination should lead to improved identification and treatment of cases thereby reducing morbidity and the infectious reservoir.

Successful malaria program expansion and health system strengthening efforts have resulted in robust Ethiopian surveillance systems that are well positioned to document trends in laboratory confirmed malaria cases in the future. The major limitation of these systems is they do not include cases being cared for in the private sector. Data from the 2011 DHS suggest that 21% of children with fever sought advice or treatment outside of public sector suggesting that while most cases are probably being captured and identified in the current data systems, a substantial proportion may not be.

Mortality

All-Cause Childhood Mortality

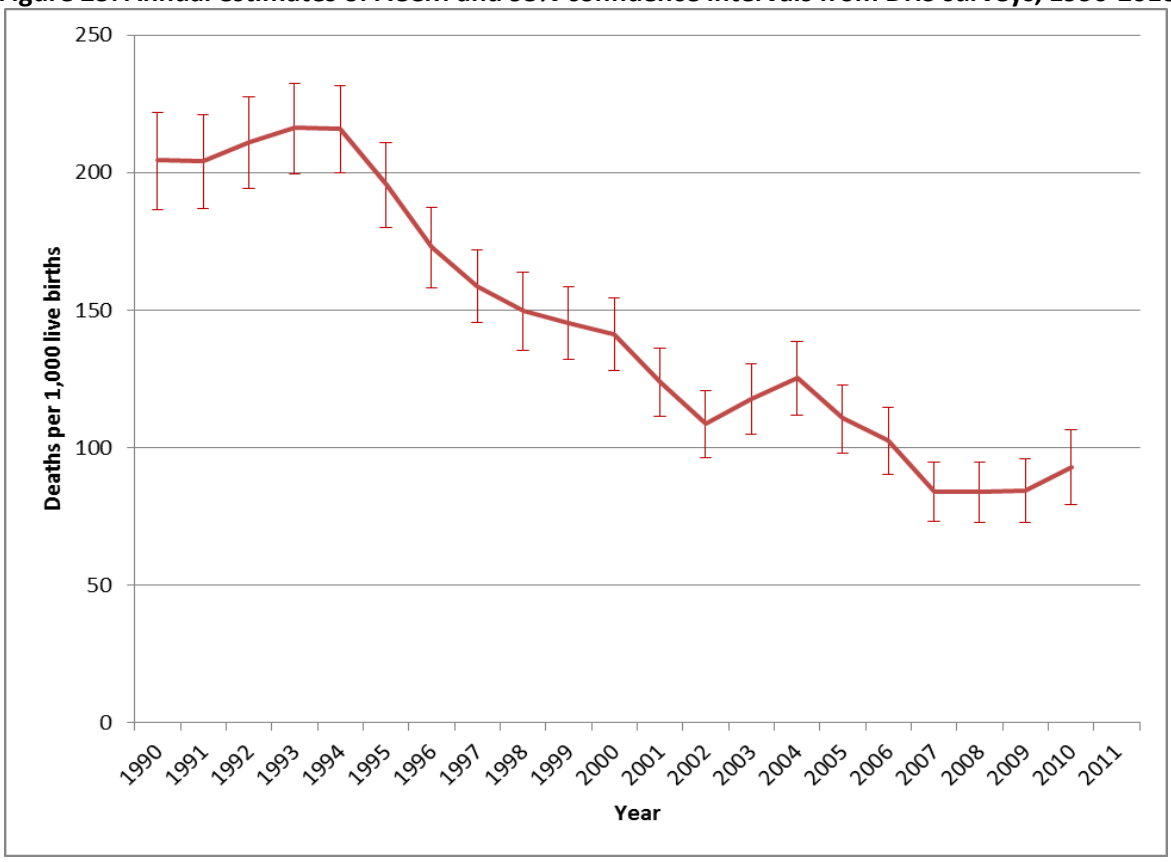
Malaria mortality is difficult to accurately measure given issues with vital registration systems, the lack of parasitological confirmation of many cases, and the number of deaths that occur outside of the formal health care setting. For this reason, all-cause under-five mortality (ACCM) has been used as an impact measure in similar evaluations in other countries. This section reviews recent trends in ACCM in Ethiopia, with a view to assessing the magnitude, timing, and age-pattern of change between the 2000

and 2011 surveys. Mortality estimates from successive DHS surveys conducted from 1992–2010 are included in some figures to put recent trends in a longer-term context. All mortality figures represent direct estimates, and unless otherwise stated, represent the period 0-4 years before each survey. The available national-level malaria-specific mortality data from routine systems and subnational data from demographic and health surveillance sites are then summarized.

Trends in All-Cause Childhood Mortality

Estimates of ACCM from successive DHS surveys conducted between 1992 and 2010 are presented in Figure 23. According to the DHS mortality estimates, ACCM has declined dramatically since 1990. Over the 20-year period depicted in Figure 23, ACCM declined by over 60%. Trends in ACCM showed a decrease from 166 deaths per 1,000 live births in 2000 to 88 deaths per 1,000 live births in 2011, a 47% relative reduction, while infant mortality decreased from 97 deaths per 1,000 live births in 2000 to 59 deaths per 1,000 live births in 2011, a 39% relative reduction.

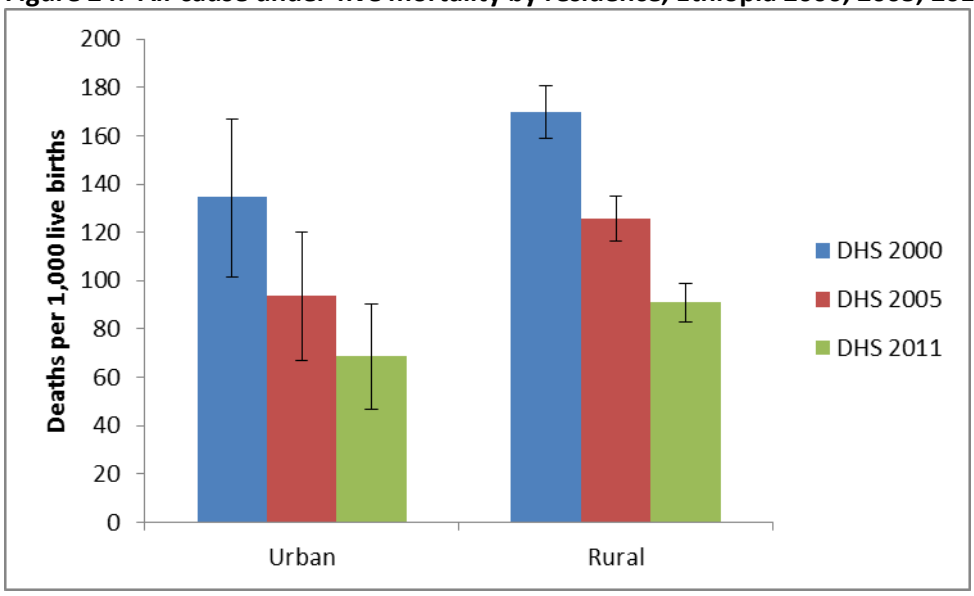
Figure 23: Annual estimates of ACCM and 95% confidence intervals from DHS surveys, 1990-2010



Note : Error bars represent 95% confidence intervals around each annual estimate of ACCM

Figure 24 shows trends in ACCM in urban and rural households. ACCM declined significantly from 1996-2000 to 2007–2011 in both urban (135 deaths per 1,000 live births to 69 deaths per 1,000 live births) and rural (170 deaths per 1,000 live births to 91 deaths per 1,000 live births) settings. Baseline mortality was higher in rural compared to urban settings (170 deaths per 1,000 to 135 deaths per 1,000) but relative declines in ACCM were similar.

Figure 24: All-cause under-five mortality by residence, Ethiopia 2000, 2005, 2011 DHS



Regional trends in ACCM at elevations less than 2,000m are shown in Figure 25. Some differences in ACCM are evident across regions. For example in 1996–2000, Amhara had the highest ACCM (222 deaths per 1,000 live births), significantly higher than Afar (145 deaths per 1,000 live births) and Benishangul-Gumuz (161 deaths per 1,000 live births). In 2001-2005 Benishangul-Gumuz had the highest ACCM (168 deaths per 1,000 live births), significantly higher than ACCM in Afar, Dire Dawa, and Gambela (82, 117, and 93 deaths per 1,000 live births, respectively). In 2007-2011 Harari had the highest ACCM (129 deaths per 1,000 live births), significantly higher than Benshangul-Gumuz (75 deaths per 1,000 live births). Declines in ACCM are evident in all regions between 1996–2000 and 2007–2011, although not all of the declines have been statistically significant.

Figure 25: All-cause under-five mortality at elevations below 2,000m, by region, Ethiopia 2000, 2005, 2011

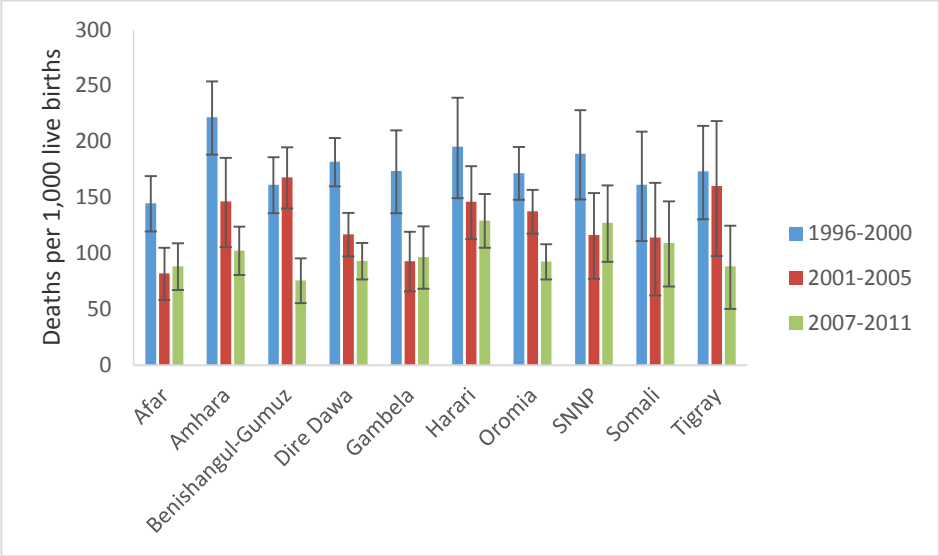
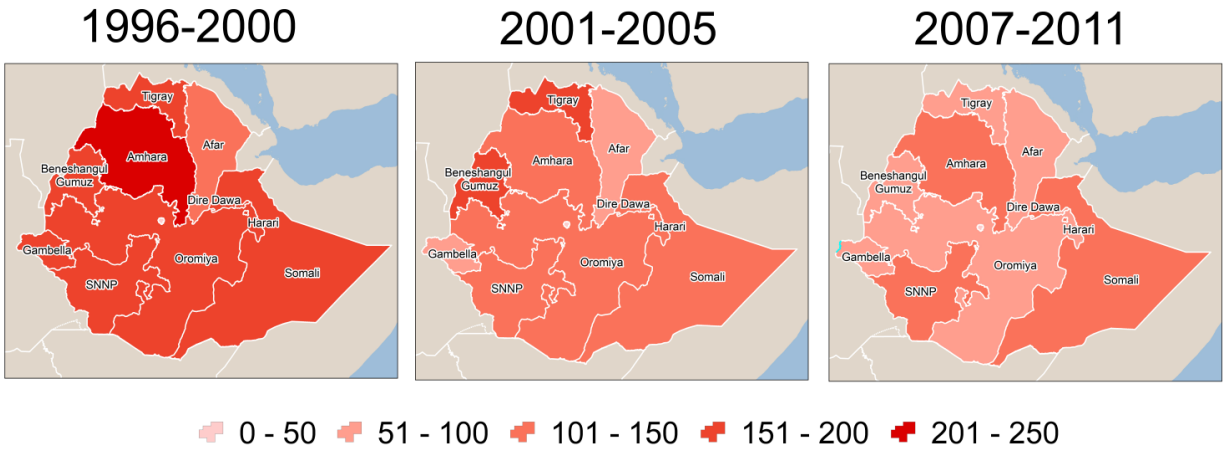


Figure 26: Regional maps of all-cause under-five mortality in Ethiopia for three 5-year periods for elevations below 2,000m



Note: Scale is deaths per 1,000 live births

Focusing on the areas of highest malaria burden (rural areas at elevations below 2,000 m) nationally-representative surveys from DHS 2000, 2005, and 2011 were also used to produce estimates of three categories of childhood mortality. Figure 27 shows estimates of mortality rates for different age categories of children for this time period. Significant declines in mortality are evident in every age group except for neonates between 1996–2000 and 2007–2011.

Figure 27: Childhood mortality in rural areas of Ethiopia at elevations below 2,000 m, 1996–2000, 2001–2005, and 2007–2011 DHS

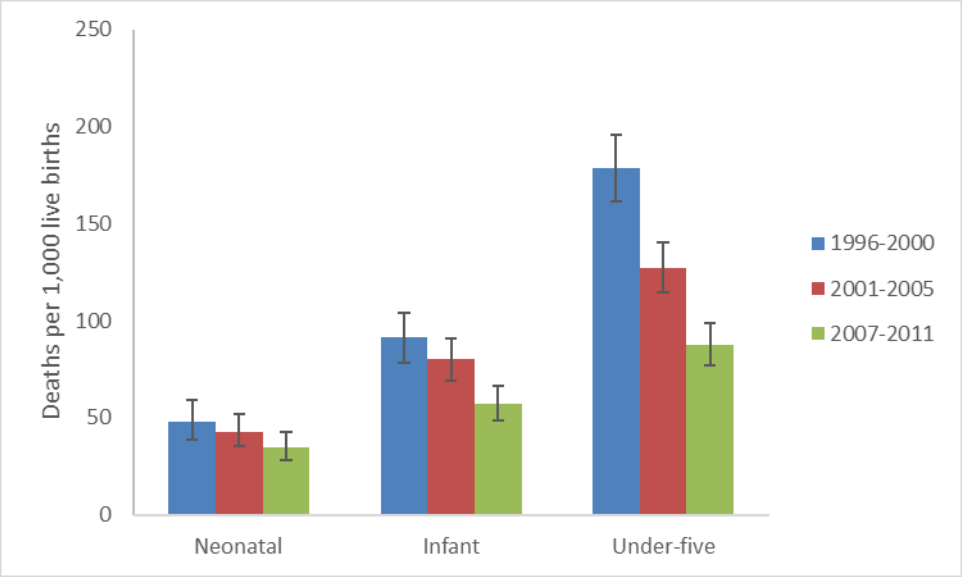
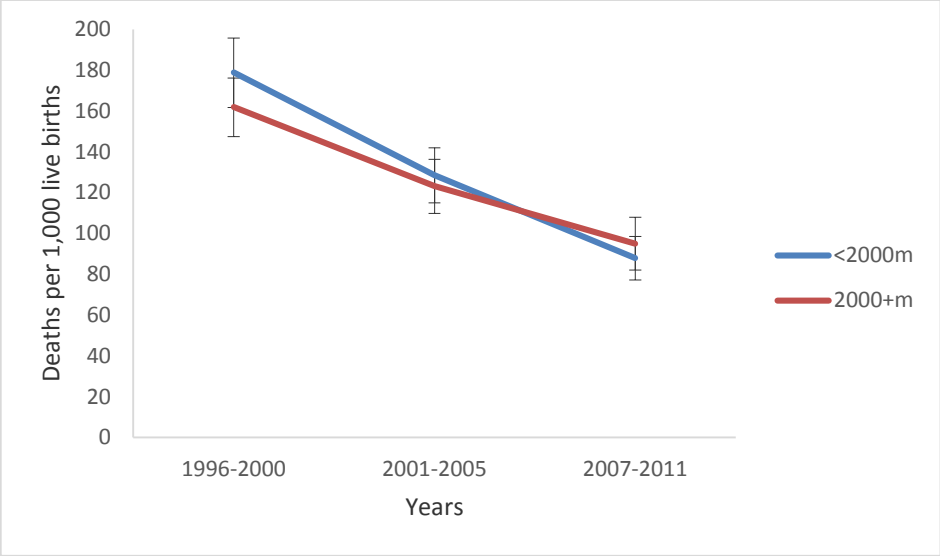


Figure 28 shows trends in all cause under-five mortality by elevation. Although under-five mortality declines over time are clearly evident in children living at both elevations, the decline observed between 1996–2000 and 2001–2005 above 2,000 m (165 deaths per 1,000 live births to 131 deaths per 1,000 live births) is only marginally significant. No significant differences in ACCM are seen between households at higher elevations and those below 2,000m for a given survey.

Figure 28: All-cause under-five mortality in rural areas by altitude, Ethiopia 1996–2000, 2001–2005, 2007–2011*

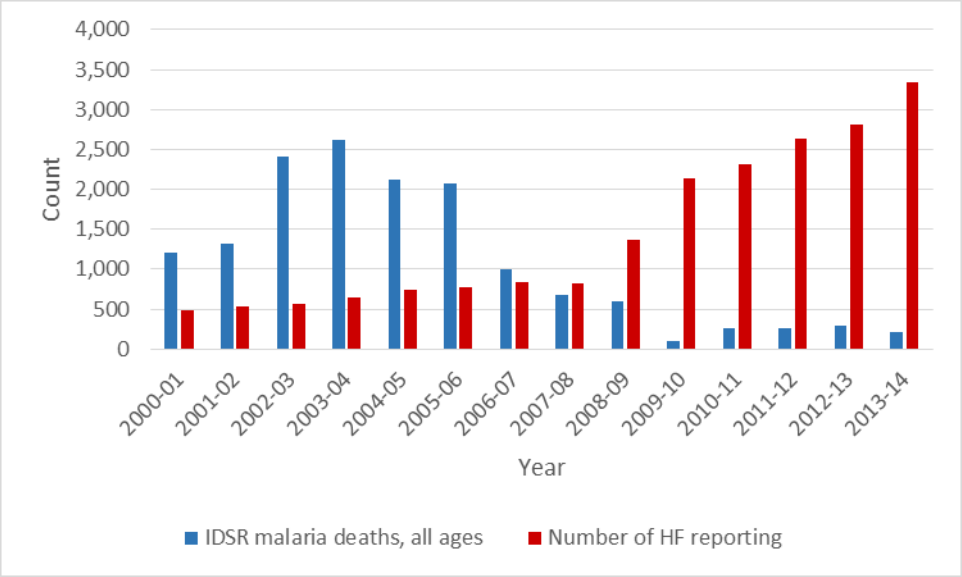


Malaria-specific Mortality from Health Facility Data

Malaria-specific Mortality from IDSR/PHEM

Malaria mortality trends from IDSR/PHEM are shown for Ethiopia in Figure 29. Data from the HMIS were determined not to be of sufficient quality to be presented (see Annex 5 for more details). IDSR/PHEM data show continued declines in malaria mortality after 2005-06. Similar patterns are seen at a subnational level in Oromia (see Annex 6). As previously noted, the completeness of reporting varies for these sources over time, which biases observed trends. Factors that likely affect trends in total malaria deaths include the number and type of health facilities reporting to each system, and the degree to which deaths can be accurately attributed to malaria (diagnostic capacity and testing rates). The number of health facilities has only clearly been documented since 2008 but has been estimated for earlier years. Reporting has been greater than 80% from all public health centers and hospitals since mid-2012 but was likely much lower in earlier years. Currently, the PHEM system is likely to detect most severe malaria cases, malaria hospitalizations, and deaths that are seen at public health facilities as reporting by hospitals and health centers is high.

Figure 29: Summary of malaria deaths reported to IDSR/PHEM and number of health facilities reporting in Ethiopia, 2000–2014

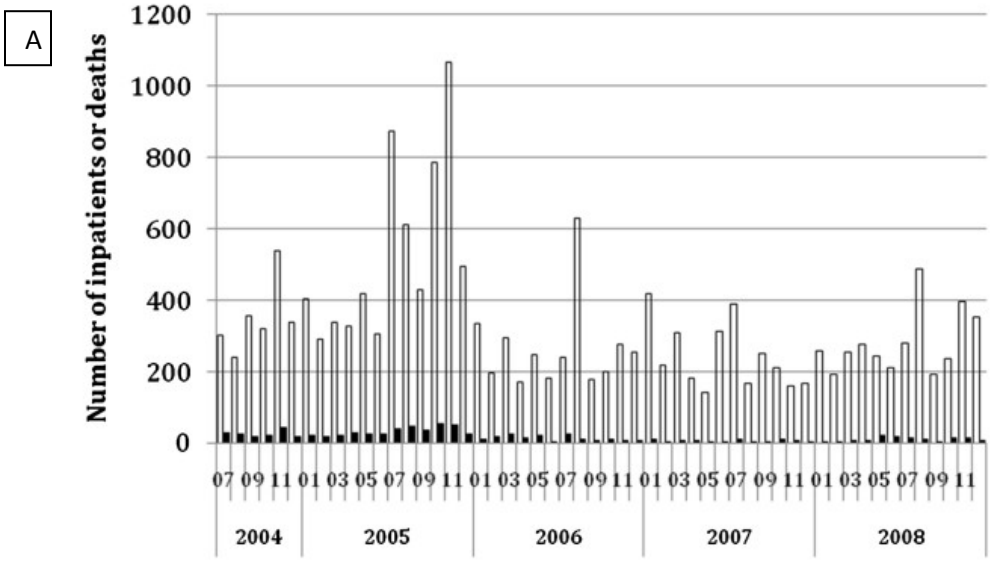


Malaria-specific Mortality from Published Health Facility Studies

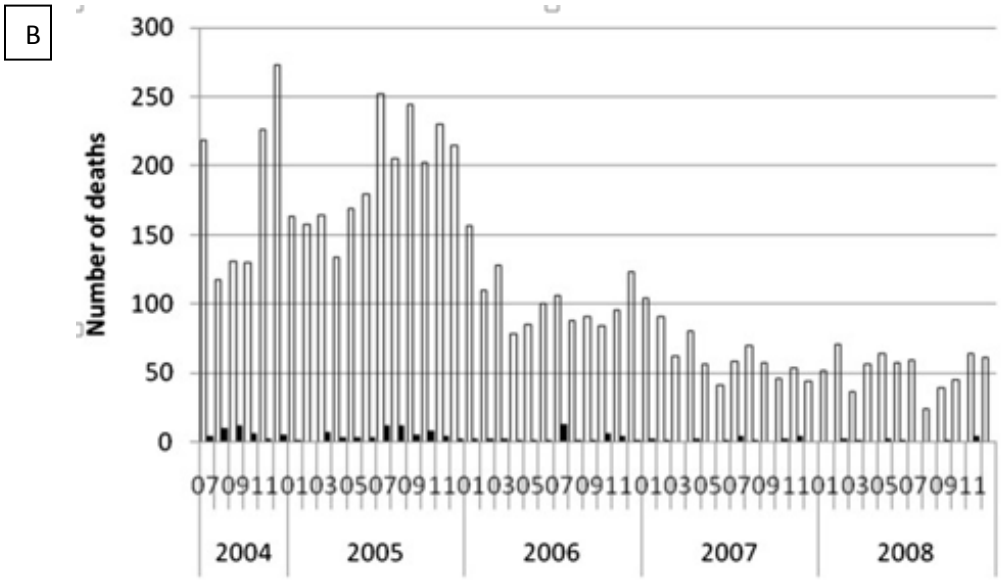
Another source of trend data for malaria mortality comes from published analyses of national data. A comprehensive study of inpatient IDSR health facility reports including nearly all existing public sector health centers and hospitals spanning 2004 through 2008 documented a 3-fold decline in mortality, as shown in Figure 30 [94]. The observed decline averaged 2.3 malaria inpatient deaths per 100,000 per year over the national population as estimated using 2007 census data. During this period, Ethiopia expanded the number of accessible health posts which became an increasingly important source of malaria diagnosis and treatment. While this increased access to health posts may have resulted in declining use of higher-level facilities for malaria outpatient services and a subsequent decline in reported outpatient malaria cases, authors note that mortality trends were unlikely to be similarly biased as health posts did not report to IDSR during this time period and were not sources of inpatient

care. However, increased access to timely and appropriate diagnosis and treatment of malaria infections through expansion of health posts and HEW programs could be a major contributor to a reduction in the incidence of severe malaria cases and a consequent reduction in hospital deaths. Aregawi and colleagues [97] studied a subsample of 41 facilities (all hospitals) that reported to IDSR/PHEM from 2001 through 2011. Fewer monthly inpatient malaria deaths (n=55) were documented during the interval from 2006–2011 compared to 2001–2005 (n=155), as shown in Figure 31.

Figure 30: A) Malaria with Severe Anemia In-patients and Deaths at Health Centers and Hospitals, B) overall malaria and malaria in pregnancy deaths, IDSR data, July 2004 to December 2008, Ethiopia

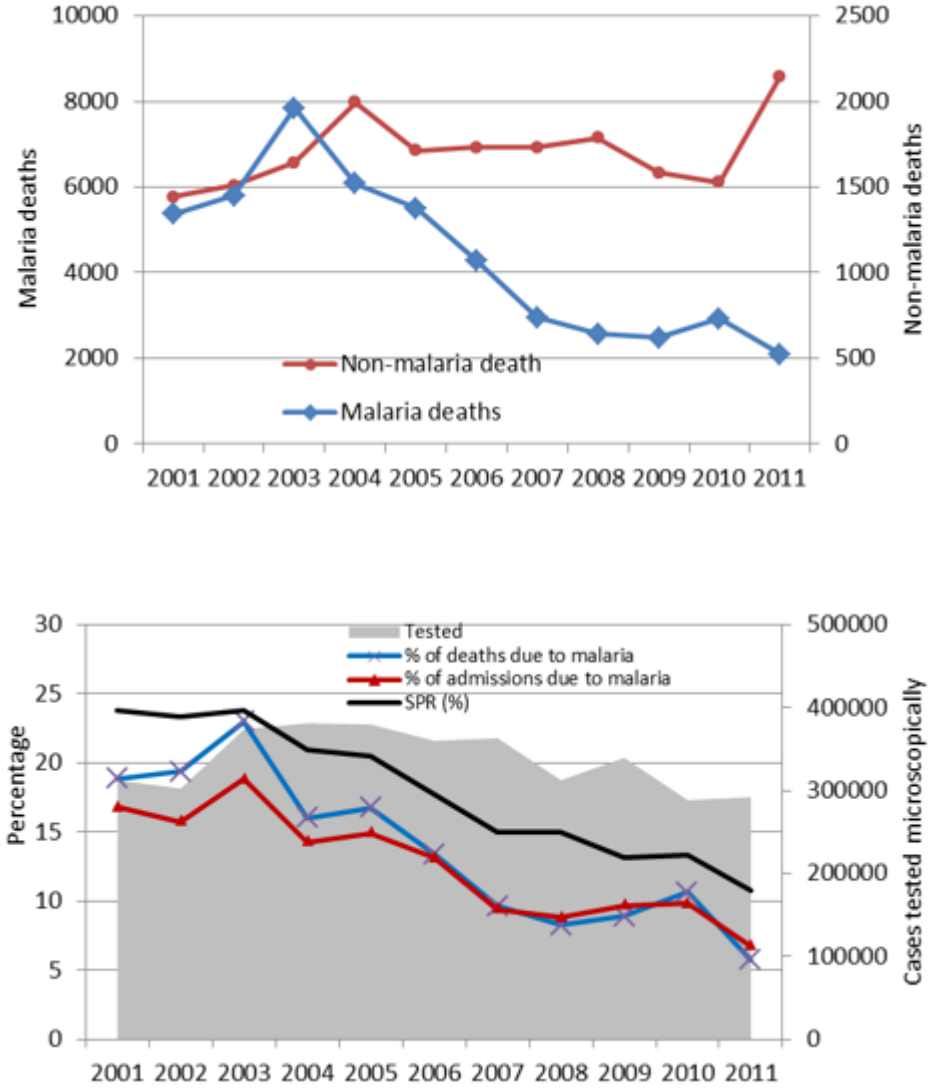


Open bars = inpatients with malaria and severe anemia, dark bars = deaths with malaria and severe anemia.



Open bars = malaria deaths, dark bars = malaria in pregnancy deaths.
Source: Jima D, Graves P, Malaria J 2012;11:330 [94].

Figure 31: Malaria and non-malaria deaths; Number of cases tested, slides positivity rate SPR, % admissions due to malaria, % of deaths due to malaria, 41 hospitals <2000 m, 2001–2011



Source: Aregawi, 2014 [97]

Malaria-specific Mortality from Verbal Autopsy in Demographic Surveillance System Sites

In addition to national data, published examples of analyses of subnational data from Demographic Surveillance System (DSS) sites can be used to look at trends in malaria-specific mortality. Verbal autopsy (VA) conducted at the Butajira DSS site between 2003 and 2011 showed a decreasing trend in the proportion of malaria deaths amongst the total all cause deaths in all age groups (Table 10). From August 2003 to July 2004 the proportion of malaria deaths for all age groups was 12.9% which decreased to 4.3% during the 2007-2011 period. A decrease from 9% at baseline to 3.3% at endline occurred among children less than five years of age [100]. Similar to national trends, in Butajira from 2007–2011 for children less than five years of age, malaria was the 10th leading cause of death, behind perinatal complications, pneumonia, diarrhea, tuberculosis, and HIV/AIDS. It is important to note that

data from DSS sites are not representative of the broader population of Ethiopia and VA methods have some challenges in sensitivity and specificity for malaria death.

Table 10: Mortality related to malaria by age from Butajira DSS site in Ethiopia, 2003–2011

Age Group	Malaria Proportional Mortality (VA)	
	2003-04 (1-year span)	2007–2011(4-year span*)
0–4 years of age	14/154 (9.0%)	12/369 (3.3%)
5–14 years	4/14 (29.0%)	2/38 (5.3%)
15–49 years	24/157 (15.2%)	24/472 (5.1%)
All ages	42/325 (12.9%)	38/879 (4.3%)

*Data were not available to disaggregate by year

Summary of Malaria Mortality

According to nationally-representative household survey data, there has been a significant decline in ACCM between 1996–2000 and 2007–2011, from 166 to 88 deaths per 1,000 live births, a 47% relative decrease from 2000 through 2011. This decline in ACCM occurred during a period of intense investment in malaria control interventions. This decline did not begin suddenly; ACCM in Ethiopia has been steadily decreasing over the past 20 years, from the 1990s through 2011. The decline in ACCM between 1996–2000 and 2007–2011 was significant in all age groups except neonates and was significant in children less than five years of age in both urban and rural areas (49% and 46% relative declines, respectively). Relative declines in ACCM during the most recent period 2001-2005 and 2007-2011 were of similar magnitude among children in urban and rural areas; however, declines were not significant in urban areas due to smaller sample sizes. Comparisons of ACCM in rural populations at lower elevations (<2000m) and higher elevations (2000m or greater) did not show significant differences.

Available data on trends in malaria mortality data from health facilities in Ethiopia suggest decreasing malaria mortality over the evaluation period. However, these data are difficult to interpret with confidence due to variable accessibility and use of health facilities by the at-risk population, and due to variable reporting of data from health facilities to the national level over the past decade. Various attempts to control for these factors have been made by researchers in peer-reviewed publications which are summarized here. Several peer-reviewed published studies of malaria mortality in Ethiopia have shown significant declines in malaria mortality. Jima and colleagues found a 3-fold decline in mortality trends between 2004 and 2007 [94]. Aregawi and colleagues compared periods pre- and post-expansion of malaria control interventions and observed a 50% decline in malaria mortality [98]. A smaller-scale study from a DSS in Butajira also reported declines in malaria proportional mortality; declines from 12.9% in 2003-04 to 4.3% in 2007-2011 were observed [100].

Despite the significant decline in ACCM observed during the evaluation period, the observed trends (timing, residence differentials, and relationship to malaria risk) are not consistent with the results that would be expected if improvements in malaria control were a major factor underlying the mortality change in Ethiopia: the relative decline in ACCM is similar during periods before and after intensification of malaria control interventions, the relative declines are similar in urban and rural areas, and the

relative decline is similar in areas of low and high malaria risk (<2000 m and 2000+ m). This evidence does not preclude improvements in malaria control from playing an important role in reducing child mortality, but it does suggest that other factors also must have contributed to the observed decline in ACCM. These factors are discussed in the next section. Published studies analyzing routinely reported facility data summarized here provide more convincing evidence of meaningful reductions in malaria mortality over the evaluation period.

Epidemic Malaria

As a country with varied topography and large areas of unstable malaria transmission, epidemics play an important role in the epidemiology of the disease in Ethiopia. Observations of the frequency and intensity of epidemics may be informative as to the successes of prevention and control efforts. To this end, available data on malaria epidemics in Ethiopia were examined and summarized. For the purpose of this report a malaria epidemic is defined generally as a sharp increase in the number of malaria cases in populations at risk of malaria at the national level. The term outbreak is used to define an abnormal rise in malaria cases as a smaller spatial scale (for example at the *woreda* or *kebele* level). More precise definitions of epidemics require high quality historical data on malaria incidence in order to establish normal baseline levels of infection and to determine thresholds that might be used to define abnormal transmission levels.

Periodic malaria epidemics have occurred since at least the 1930's in Ethiopia, although documentation is not widely available from the early 20th century (Table 11). The catastrophic 1958 malaria epidemic in Ethiopia has been well described [101]. In 1958, Ethiopia's total population was estimated at 18 million, of which 10 million were at risk for malaria. At least 3 million acute malaria infections (30% attack rate) and 150,000 malaria deaths (5% CFR, and 1,500 deaths per 100,000 of the at-risk population) were reported during this outbreak, and the majority of cases were due to *P. falciparum* infections.

Table 11: Major Malaria Epidemic Years, Ethiopia, 1930–2013

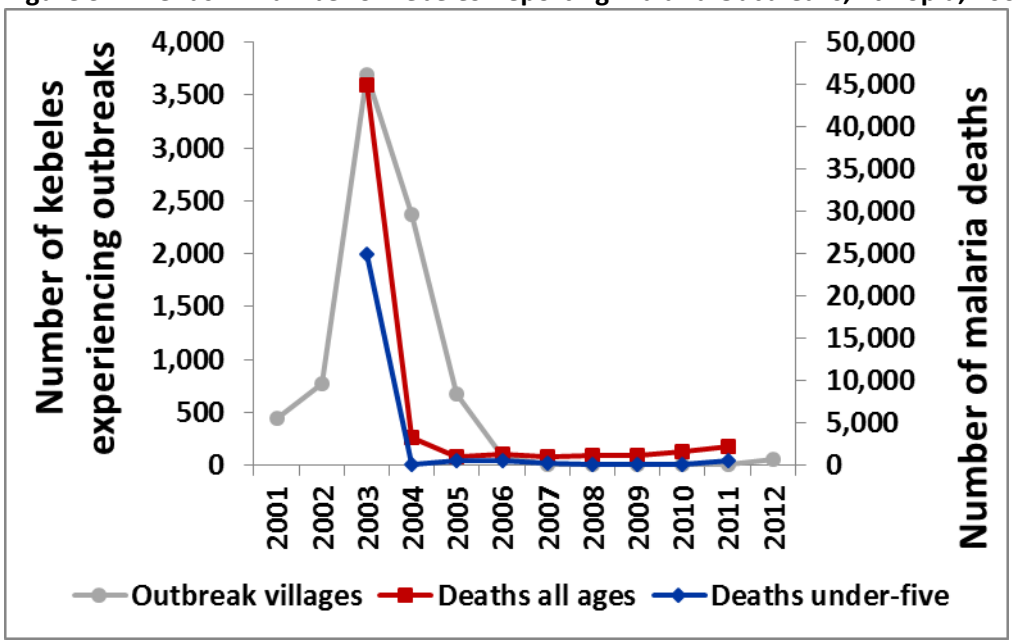
Year	Illnesses	Deaths	Comments
1930's			Italian investigators
1953		7,000	Covell, Demba plain[25],
1958	3,000,000	150,000	Excess rain, anomalous warm temperatures, high humidity [26]
1965			Outbreak occurred, but no case data available
1973			Outbreak occurred, but no case data available
1981			Outbreak occurred, but no case data available
1988			Outbreak occurred, but no case data available
1991	37,189	461	
1992			Outbreak occurred, but no case data available
1998	4,800,000	14,783	Chloroquine resistance
2003	6,100,000 - 15,000,000	45,000- 114,000	Midpoint SP resistance [102, 103]

Source: [30, 102, 104]

Since 1958, the historical pattern of malaria in Ethiopia has included epidemics approximately every five to eight years [101]. Especially large malaria epidemics were documented in 1988, 1991–1992, 1998, and 2003–2004. The 1998 epidemic affected more than 1 million individuals [105]. The 2003–2004 epidemic affected 6,100,000-15 million persons in 3 federal regions [102] in 211 of 700 malarious districts leading to an estimated 45,000-115,000 deaths. Population movements including seasonal migrant workers, local flooding, and famine conditions, and emerging resistance to antimalarial drugs and insecticides may also affect local communities' risks for local seasonal malaria transmission and for malaria epidemics.

Although there can be difficulties in distinguishing malaria seasonal transmission case counts from true epidemics, compared to reports prior to 2005, the magnitude and scale of identified malaria epidemics have dramatically decreased, and the outbreaks that have been reported have generally been limited to single districts or to two adjoining districts. These small, focal outbreaks have occurred in most years from 2005 through 2013 typically manifesting as exaggerated seasonal transmission episodes either in the minor transmission season of May or during peak major transmission season from September to December. Since 2006, fewer than 60 *kebeles* in 12 districts have reported outbreaks in any year. In 2012 and 2013 there were 12 and 3 districts with malaria outbreaks, respectively, with very few associated malaria deaths. The absence of major malaria epidemics for an entire decade is unprecedented, and provides support for the hypothesis that malaria control interventions are reducing the malaria burden in Ethiopia.

Figure 32: Trends in Number of *Kebeles* Reporting Malaria Outbreaks, Ethiopia, 2001–2012



Sources: Dr. Daddi Jima, PHEM data, 2012 and references [132] and [134]

The available evidence suggests that the expansion of malaria control efforts in Ethiopia may be associated with prevention of major malaria epidemics in Ethiopia. Although localized outbreaks have continued to occur since 2004, improvements in the quality and completeness of disease surveillance in

HMIS and PHEM systems have allowed for more rapid detection and response which could be responsible for the lack of a major epidemic. Response has also been aided by improvements in laboratory and human resource capacity, and by the availability of effective antimalarial medications compared to the pre-malaria intervention intensification period. Although CQ resistance and SP resistance were an issue during the 1998 and 2003 major malaria epidemics, respectively, drug resistance has not been a major problem in Ethiopia since ACTs were introduced in 2004 [106, 107]. Aside from local outbreaks in 1-2 contiguous woredas, malaria epidemics failed to materialize in 2009 and 2010 when weather conditions were favorable to increased malaria transmission [108, 109]. This suppression of major malaria epidemics since 2004 has likely reduced overall malaria mortality as higher than normal malaria mortality rates typically accompany malaria epidemics. See Annex 7 for a more detailed account of the history of malaria epidemics in Ethiopia.

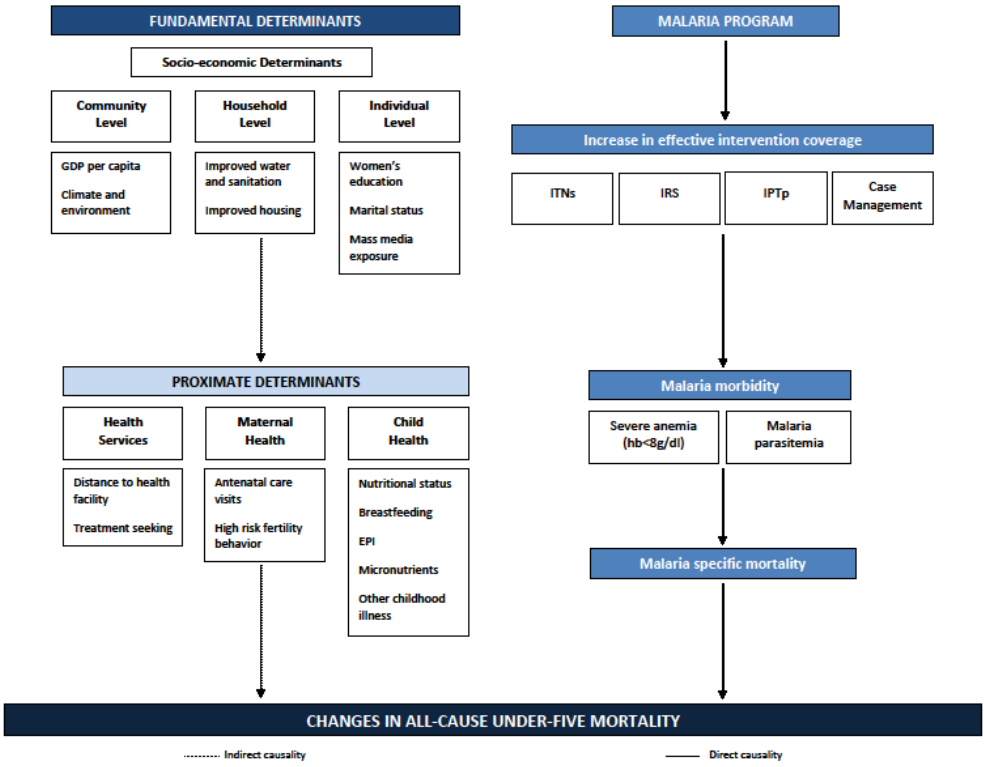
Contextual Factors

Accounting for Contextual Factors

Appropriate considerations of contextual factors are essential for ensuring the internal and external validity of evaluations of large-scale health programs [115], particularly for evaluations that are conducted when rapid changes are under way in many other aspects of socio-economic development and health services [116].

Contextual factors associated with childhood mortality and illness, including malaria, can be broadly categorized into the fundamental and proximate determinants of disease [117-124]. Fundamental determinants are the social and economic conditions under which people live, while proximate determinants are biological risks. The conceptual framework [116, 125-127] for the evaluation design in Ethiopia (Figure 33), incorporates numerous contextual factors. In the following sections, relevant information and levels and trends of various contextual determinants of childhood mortality and illness are reviewed. Data on contextual factors were obtained from large population-based household surveys (e.g., DHS, MIS), as well as other sources such as WHO, UNICEF, World Bank, and UNAIDS.

Figure 33: Conceptual framework for the evaluation of the malaria control program, Ethiopia, 2000–2012



Fundamental Determinants

Socioeconomic Factors

A range of socioeconomic determinants at the community, household, and individual level are associated with child survival [120, 128, 129], as shown in the conceptual framework in Figure 33. Poverty, either at the country or individual level, strongly correlates with poorer health outcomes [130] and is also frequently correlated with access to malaria control interventions. Thus, changes in economic conditions could influence the observed association between malaria control interventions and child survival and malaria-specific outcomes.

Socioeconomic determinants include Gross Domestic Product (GDP) per capita, household wealth and asset ownership, access to safe water and sanitary facilities, and measures of housing conditions. GDP, a measure of population wealth in a country, is considered to be a typical macroeconomic determinant of health [129]. In Ethiopia, the GDP per capita was US$ 123 in 2000, as compared to US$ 230 in 2011 [43], an increase that corresponds with the intensification period of modern malaria interventions and the simultaneous improvement in the malaria situation since 2003 in Ethiopia. Hence the improving malaria situation as a result of concerted malaria interventions could have contributed, in some way, to accelerated economic development since 2003, or alternatively, increased wealth might have helped to accelerate malaria control [131]. Household and microeconomic factors are also important

determinants of child health and malaria risk [128, 132]. Socio-economic differentials at the household level are associated with access to malaria interventions [133-135], thereby increasing the vulnerability of the poorest to malaria [136]. Levels and trends in household attributes and other proxies of socio-economic status are summarized in Table 12. In the 2011 MIS, households in the highest wealth quintile were significantly more likely to own at least one ITN than were those in the lowest wealth quintile (66% vs. 44%, see Annex Table A.4.1.1).

Safe water and sanitary facilities contribute to improved child health and survival [133]. Access to safe water and improved sanitation facilities increased over the evaluation period (safe water: from 12% to 54% and improved sanitation: from 0.3% to 8% of households) (Table 12). 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 [134, 135]. From 2000 to 2010, the proportion of households with an improved roof (i.e., not thatch, grass, or mud) and the proportion with modern floors both increased (32% to 51% and 7% to 15%, respectively (Table 12). 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 [137-140]. Also considered a socio-economic variable, maternal education is an important determinant of maternal and child health [129, 141-146]. Educational status and literacy of mothers both increased over the evaluation period (% of women with completed primary education 11% to 15%, and % literate from 24% to 38%) (Table 12).

Table 12: Distribution of socioeconomic factors, 2000–2011, Ethiopia

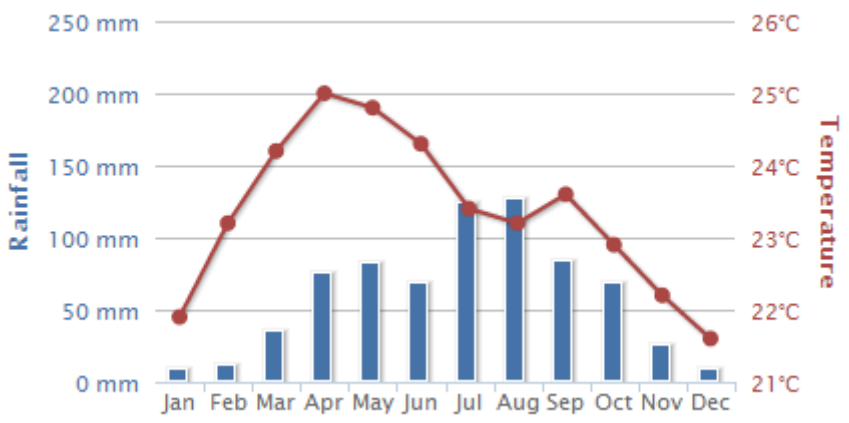
	2000			2011			Relative Change	
	%	95% CI	n	%	95% CI	n	% change	Sig.
Improved water source* (protected, borehole, piped), (% households)	12.4	10.5-14.6	14072	53.7	50.0-57.3	16702	333.1	S
Time to water source <15 min, (% households)	26.3	24.2-28.5	14072	31.2	28.5-33.9	16702	18.6	S
Access to improved toilet,**(% households)	0.3	0.2-0.4	14072	8.3	7.1-9.6	16702	2666.7	S
Improved roof (not thatch/grass/mud), (% households)	32.1	29.6-34.6	14072	51.3	48.3-54.4	16702	59.8	S
Modern floor material (not earth/sand/dung), (% households)	7.4	6.3-8.9	14072	15.3	13.4-17.3	16702	106.8	S
Electricity, (% households)	12.7	11.1-14.4	14072	23.0	20.5-25.8	16702	81.1	S
Telephone (landline or mobile), (% households)	1.3	1.0-1.7	14072	25.2	23.4-27.0	16702	1838.5	S
Completed primary education (%)~	10.7	9.5-12.0	15,367	15.2	14.0-16.5	16,515	42.1	S
Literacy (%)~	24.4	22.6-26.4	15,367	38.4	36.4-40.5	16,515	57.4	S

Sig.= Statistical significance. Statistics with non-overlapping 95% confidence intervals are considered significantly different. NS denotes not statistically significant; S denotes statistically significant. *Improved water sources include: piped water into dwelling/yard/plot; public tap/standpipe; tubewell/borehole; protected dug well; protected spring; rainwater; bottled water. ** Improved, Not Shared Toilet Facility includes: flush/pour flush to piped sewer system; flush/pour flush to septic tank; flush/pour flush to a pit latrine; ventilated improved pit (VIP) latrine; Pit latrine with a slab; Composting toilet; does not include any toilets that are shared with other households.
~For interviewed women aged 15-49 year.

Weather Variability

Weather is one of a number of possible confounders in the evaluation of malaria interventions. Malaria transmission in Ethiopia is characterized by distinct seasonal trends, dependent on patterns of rainfall and temperature. Ethiopia has two predominant rainy seasons including the main season (referred to as *Kiremt* and *Meher*) from June to September and the small season (also known as *Belg*) which occurs from February to May (Figure 34).

Figure 34: Average monthly temperature and rainfall for Ethiopia, from 1990–2009



Source: World Bank website [147]

In addition to annual seasonal fluctuations, inter-annual climatic drivers such as the *El Niño* Southern Oscillation (ENSO) can affect rainfall and temperature patterns in the region [148] within a given year, and longer-term patterns of climate change may influence rainfall and temperature patterns over many years or decades. It is important to consider and, where sufficient data exist, control for any inter-annual or longer term climate trends when evaluating trends in malaria morbidity and mortality. Changes in sea surface temperature, which affect ENSO, have also played a role in an extended period of drought (decreases in amounts of long rainy season precipitation over the past three decades with a more significant decline since 1999) in Ethiopia, in which widespread temperature increases and a 15–20% decline in rainfall have been observed [149, 150]. Associations have been shown between ENSO events and focal malaria epidemics in Ethiopia, such as the 1988–89 and the 1991–92 epidemics. Summarizing the effects of ENSO events on malaria transmission on a national scale is more challenging as the associations are not uniform across Ethiopian regions and heterogeneity exists in the impact on *Kiremt* and *Belg* seasons.

A recent comprehensive study conducted by the Earth Institute of Columbia University (International Research Institute for Climate and Society) stated that over 75% of Ethiopia's populated areas are climate-sensitive to malaria transmission due to the combined role of both temperature and rainfall [104, 148, 151-153], which qualifies Ethiopia as extremely climate-sensitive. In Oromia, Amhara and SNNPR, the baseline period from 2000–2005 was drier and cooler than the period from 2005–2010, thus the climate risk for malaria was higher during the end of the decade due to warmer and wetter weather. Longer-scale trends in Oromia and other highland areas show evidence of warming temperatures (approximately 0.3^{o}C per decade) which could contribute to potential increases in malaria observed at higher elevations [154, 155]. In Oromia, Amhara, and SNNPR, where most malaria cases occur, the

drought was worse during 2000–2005 than between 2006–2010 suggesting that decreases in rainfall were not the cause of reductions in malaria morbidity and mortality after the intervention intensification period [148]. An alternative explanation might be that weather conditions favorable to malaria transmission likely blunted the impact of malaria control interventions in the 2006–2010 period, thereby leading to an underestimate of the potential impact of malaria control.

Malaria resurgence has been observed in some areas following unusually high rainfall [157]. While the effect of weather conditions was less pronounced than expected, a community-based survey in the highland-fringe area of Butajira, south-central Ethiopia, showed increased prevalence of malaria following abnormal rainfall during the main rainy season: community surveys conducted every three months from October 2008 to June 2010 found 4.8% malaria prevalence in October 2009 in low-altitude regions compared to only 1.6% in October of 2008 [83]. A severe drought occurred in 2010, which may influence trends in 2011-12.

Proximate Determinants

Maternal and Child Health

Certain aspects of maternal and child health may influence risk of mortality in both women and their children. Attending antenatal care (ANC) visits is crucial for monitoring maternal health and providing interventions such as tetanus toxoid immunizations, folic acid and iron supplementation, and ITNs. In Ethiopia, increases were seen over the evaluation period in the proportion of women completing at least the recommended 4 ANC visits (10% to 19%), the proportion of women with at least two doses of tetanus toxoid (17% to 34%) and delivery in health facilities (5% to 10%) all increased over the evaluation period (Table 13 and Annex 4). Although improvements, these changes were small and the coverage of these important maternal health indicators remained low at the end of the evaluation period.

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 [158, 159]. Effective coverage of these vaccinations contributes substantially to reductions in ACCM. In Ethiopia, childhood vaccination rates (complete immunization in children 12-24 months) have increased over the evaluation period (14%-24%), but remain low, with measles coverage well below the level necessary for herd immunity (56% in 2011)(Table 13 and Annex 4). Prevalence of diarrhea in children less than five years of age decreased during the evaluation period (24%-13%) whereas care-seeking for diarrhea and use of ORS both increased (13%-32% and 13%-26%, respectively). Better prevention and management of bacterial and viral infections may lead to better survival in children, including when they become infected with malaria.

Undernutrition due to chronic dietary deficiency of protein, energy, essential vitamins, and minerals is an important determinant of maternal and child health [160]. Vitamin A deficiency has been implicated in increased morbidity and mortality from infectious diseases such as, measles, diarrhea, and acute respiratory infections, and results in up to 600,000 under-five deaths annually worldwide [161]. In 2013, the United States Department of Agriculture (USDA) report indicated that there were 35 million food-insecure people in Ethiopia and that 282,000 tons of food are needed annually to meet the recommended nutritional standards of the population. Although there are and have been focal food shortages and even focal famines, the food security situation has improved during 2000 – 2010, and is

expected to continue to improve despite the many challenges and expected continued population growth. DHS data show reductions in stunting (58%-44%), wasting (12%-10%) and underweight (41%-29%) in children less than five years of age but concomitant improvements in vitamin A supplementation were not seen (60%-53%) (Table 13).

Table 13: Distribution of maternal and child health factors, 2000-2011, Ethiopia

Indicators	DHS 2000			DHS 2011				
	%	95% CI	N	%	95% CI	N	% change	Sig
ANC visits 4+ (% women, most recent live birth, 0-2yrs)	**10.4**	8.9-12.1	7978	**19.1**	17.2-21.0	7908	**83.7**	S
Tetanus toxoid 2+ (% women, most recent live births, 0-2yrs)	**17.2**	15.5-19.0	7978	**33.8**	31.4-36.2	7908	**96.5**	S
Delivery at a health facility (% women, live births 0-4yrs)	**5.0**	4.0-6.3	12260	**9.9**	8.3-11.9	11872	**98.0**	S
Measles immunization*	**26.6**	23.3-30.2	2,143	**55.7**	51.3-60.1	1,930	**109.4**	S
Complete immunization (BCG, measles, DPT3, polio3)*	**14.3**	12.0-16.8	2,143	**24.3**	20.9-28.0	1,930	**69.9**	S
Children 0-4yrs with diarrhea in previous 2 weeks	**23.6**	22.1-25.3	10,753	**13.4**	12.2-14.7	11,042	**-43.2**	S
Children 0-4yrs with diarrhea sought treatment	**13.3**	11.3-15.6	2,540	**31.8**	27.8-36.1	1,483	**139.1**	S
Children 0-4yrs with diarrhea used ORS	**13.1**	11.0-15.5	2,540	**26.3**	23.0-29.9	1,483	**100.8**	S
Under-fives stunted (%) [&]	**57.7**	55.9-59.5	10,503	**44.4**	42.7-46.2	10,883	**-23.1**	S
Under-fives underweight (%) [$]	**41.3**	39.5-43.1	10,503	**28.7**	27.0-30.5	10,883	**-30.5**	S
Under-fives wasted (%)[#]	**12.2**	11.1-13.3	10,503	**9.7**	8.7-10.7	10,883	**-20.5**	S
Vitamin A supplementation within past 6 months (% children 6-59 months)	**59.9**	56.7-63.0	9,677	**53.1**	50.3-55.1	9,777	**-11.4**	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. *In children age 12-23 months; [&] **Stunted** : Children whose height-for-age Z-score is below minus two standard deviations (-2 SD) from the median of the reference population; [$] **Wasted:** Children whose weight-for-height Z-scores are below minus two standard deviations (-2 SD) from the median of the reference population; [#]**Underweight:** Children whose weight-for-age is below minus two standard deviations (2 SD) from the median of the reference population

Although population trends in prevalence of HIV infection among women aged 15–49 years in Ethiopia did not change between 2005 and 2011 according to the DHS data, with an estimated 1.9% infected, there was a rapid increase in the number of facilities providing prevention of mother-to-child transmission of HIV (PMTCT) services over the evaluation period. Population-based estimates of HIV infection in children less than five years of age 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 5% in 2000 as compared to 2% in 2011 [5, 162]. The 2012 WHO World Health Statistics Report estimated that there were 11,130 and 5,420 HIV-attributable deaths among children under the age of five years in years 2000 and 2010, respectively. Improvements in HIV prevention over the evaluation period may have contributed to observed reductions in ACCM.

Summary of Contextual Factors

Ethiopia experienced many positive developments during the evaluation period from years 2000 through 2013, many of which would be expected to lead to either direct or indirect improvements in malaria mortality. A summary of these changes and the expected relationship with malaria mortality in Ethiopia is presented in Table 14. In addition, detailed tables of trends for each indicator are included in Annex 4.

Table 14: Summary of evidence of changes in factors that could be associated with ACCM in Ethiopia, 2000–2014

	Evidence supporting lower mortality	No evidence suggesting change in mortality	Evidence supporting higher mortality
Malaria control interventions	• Household ownership of ITNs • ITN use by children under-five • ITN use by pregnant women • IRS (in selected areas) • Change from SP to ACTs • Improved diagnostics and increase in testing rate		
Other contextual determinants	Fundamental determinants • GDP per capita growth • Maternal education • Housing conditions • Access to safe water • Availability of health services Proximate determinants • Care seeking for fever • Increased access to care (more available health facilities and HEWs) • Antenatal Care attendances 4+ • Neonates protected from Tetanus • Birth at health facility • Hib vaccination • HepB vaccination • BCG, Polio, DPT, measles vaccinations • Diarrhea care seeking • Diarrhea prevalence • Diarrhea treatment (oral rehydration solution/extra fluids) • Low birth weight • Nutritional status • PMTCT, ART	Fundamental determinants • Women married • Food shortages Proximate determinants • Proportion of births that are high risk • Exclusive breastfeeding • HIV prevalence (female 15-49 years)	Fundamental determinants • Rainfall • Temperature Proximate determinants • Vitamin A supplementation • Early initiation of breastfeeding • Measles epidemic 2010/2011

Plausibility Argument

The objective of this malaria program impact evaluation is to assess the impact of malaria control interventions on ACCM in Ethiopia during and after expansion of malaria control interventions. In this section, the success of and impact of expansion of malaria control interventions and changes in ACCM and malaria-related outcomes in Ethiopia are summarized. The expansion of malaria interventions and changes in malaria-related outcomes and impact during the evaluation period is assessed.

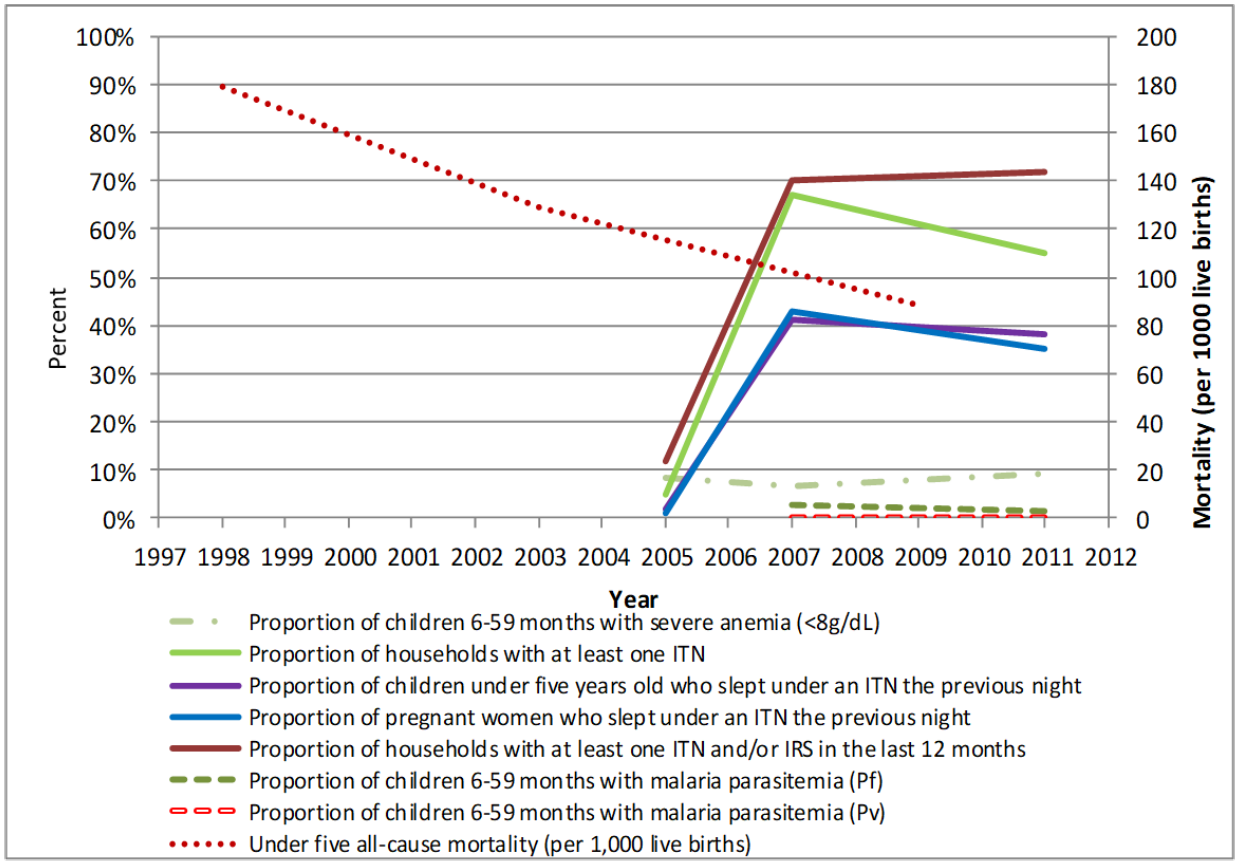
To determine whether the expansion of malaria control interventions could have contributed to the observed 47% reduction in ACCM and if so, to what extent, we examined the fundamental and proximate determinants of child mortality that were in the causal pathways of the conceptual framework (Table 14, Figure 33).

Coverage of Malaria Control Interventions has Expanded

There has been major expansion in malaria control interventions in Ethiopia (Figure 35). Between 2000 and 2011, more than 45 million ITNs were imported and distributed, raising household ITN ownership from 5% in 2005 to 55% by 2011. The use of ITNs by children less than five years of age increased from 2% in 2005 to 41% in 2007, but remained about the same (38%) in 2011. The use of ITNs by pregnant women also increased from 1% in 2005 to 43% in 2007, but decreased slightly (35%) in 2011. There was an increase in IRS coverage from protecting fewer than 4.2 million people annually before 2005, to protecting 20 million per year (4.6 million households) in 2011. Households owning at least one ITN or having received IRS increased from 12% in 2005 to 72% in 2011.

Improvement was also noted in malaria case management and diagnosis over the evaluation period. First, timely care seeking for fever in children less than five years of age increased from 3% in 2005 to 51% in 2011 and overall numbers of outpatient visits to public health facilities also increased dramatically. The FMoH estimates that 92% of the population has ready access to primary care services as of 2012, compared to only 64% in 2007, and 61% in 2004. This may be in part due to the increased numbers of public facilities constructed and to the establishment of 15,000 new rural health posts and training of 35,000 HEWs. Diagnostic testing for malaria also improved over this time period, with 83% of malaria cases parasitologically confirmed in 2012 compared to less than 25% in 2001. During this time period, first-line treatment for *Pf* malaria transitioned from SP to AL and no major stockouts of AL occurred.

Figure 35: Summary of trends in malaria control interventions and infant and all-cause mortality, severe anemia, and malaria parasitemia among children less than 5 years old, 1998–2011, Ethiopia



Note: For rural residences less than 2000m

Some Evidence that Malaria-specific Morbidity and Mortality Declined

Using available sources of data with varying degrees of consistency and completeness over the evaluation period, it is challenging to clearly deduce patterns in malaria morbidity; however, more robust data from the end of the evaluation period show trends of declining outpatient malaria cases and trends of declining malaria mortality. National survey data are not useful for monitoring these changes; these surveys do not contain estimates of malaria parasitemia or anemia prevalence for periods preceding the intensification of malaria interventions and they do not measure cause-specific mortality. National health facility-based reporting systems have collected malaria-specific morbidity and mortality data over the entirety of the evaluation period but the quality and completeness of data reporting have changed during this time making counterfactual comparisons difficult.

In order to adjust for these potential biases in the data from routine reporting systems, other researchers with access to the raw data have analyzed longitudinal trends in malaria morbidity and mortality from a fixed set of facilities in order to have more comparable baseline and endline data. Results from several of these studies show declines in annual malaria outpatient cases, slide positivity rates, malaria admissions, and monthly inpatient malaria deaths [94, 98].

Taken in totality, existing evidence suggests that malaria cases and malaria deaths declined during the end of the evaluation period, when malaria control interventions were widespread in the country; however, data are sparse or of questionable quality from the beginning of the evaluation period, rendering longer-term trends difficult to decipher with confidence.

All-cause Mortality in Children less than Five Years of Age Declined

The Ethiopian DHS data show that a significant decline in ACCM occurred between 2000 and 2011. Mortality in children under five years of age decreased by 47%, from 1996–2000 to 2007–2011; the mortality rate of children less than five years of age was measured at 166 per 1,000 births in the 1996–2000 period, 123 per 1,000 in the 2001–2005 period, and 88 per 1,000 in the 2007–2011 period, indicating major progress in reducing ACCM. Although the rapid expansion of malaria control activities in the malaria-endemic regions of the country likely contributed, patterns of decline in ACCM were similar in urban and rural areas and in areas of high and low elevation (a proxy for malaria risk). Significant declines also occurred before the period of greatest expansion in malaria control interventions. This suggests that factors other than malaria control are also important drivers of this reduction.

Contextual Factors

To examine whether the reduction in ACCM could be attributed to the expansion of malaria control interventions, other determinants of child survival that could offer alternate explanations for the observed reductions in mortality during 2000–2011 were assessed.

Socio-economic determinants of population health likely impact child health and survival in complex ways, including incidence and severity of malaria and non-malaria illnesses. Among the social and economic determinants of malaria, GDP per-capita doubled and women's education and literacy slightly improved. Access to healthcare and care-seeking among young children with fever increased dramatically. Access to improved water and sanitation also increased and housing conditions improved. These changes could have contributed to the decline in ACCM, as well as to malaria incidence and mortality rates, during the evaluation timeframe.

Other contextual factors significantly improved over the evaluation period such as ANC attendance, use of health facilities for childbirth, coverage of ORS, nutrition and vaccinations. Despite the observed increase, levels of facility births were low at endline. Trends in other contextual factors were not favorable to child survival; vitamin A coverage did not improve and parts of the country faced a measles epidemic.

Weather conditions such as rainfall and warming temperatures favored increased malaria trends in Ethiopia over the evaluation period. Increased temperatures and rainfall are favorable conditions for mosquito breeding and are often associated with increases in malaria morbidity and mortality as well as with malaria epidemics. Despite the favorable conditions, including several cycles of *El Niño* and *La Niña* that have contributed to local weather changes and focal famines and floods in Ethiopia, widespread malaria epidemics did not occur after 2004. Weather conditions in 2009 and 2010 were especially favorable for widespread malaria epidemics, but the malaria epidemics observed that year in Ethiopia were few in number and district-level in scope. It is possible that successful malaria control

interventions partnered with improved surveillance and reporting systems mitigated what would have otherwise been a widespread epidemic.

Plausibility

Evidence has clearly shown that malaria control interventions were rapidly expanded in Ethiopia from 2000 - 2013. ITN ownership and use, IRS coverage and access to malaria testing and effective treatments have all increased dramatically between 2005 and 2013. The number of public health facilities has grown and health extension workers trained in malaria diagnosis and treatment have greatly expanded the reach of services to rural populations. Policy changes mandating parasitological confirmation of infection and provision of ACTs for *Pf* infections have led to more efficient and accurate treatment of malaria cases. The increased distribution of malaria RDTs has allowed improved differential diagnosis of disease and use of the iCCM framework has allowed more efficient and cost-saving use of ACTs. Available stocks of multi-species RDTs, ACTs and rectal artesunate have been sufficient to meet need at the national level.

Using available primary sources of data on malaria morbidity and mortality, there is some evidence to suggest declining incidence and mortality rates over the evaluation period. However, due to the lack of data on the national anemia and parasitemia burden prior to 2004, and because of previous practices of clinically treating most acute febrile illnesses with malaria medicines combined with a previously weak surveillance system, establishing clear links between these substantial improvements in malaria control interventions and declines in malaria morbidity and mortality remains challenging. The rapid expansion of health facilities and outreach by health extension workers and the recent increase in diagnostic testing further complicate interpretation of trends in malaria morbidity. Results from subnational research studies presented in this report support the conclusions that inpatient malaria admissions, outpatient malaria cases, slide positivity rates and malaria mortality all decreased contemporarily with expansion of malaria control interventions. These studies present examples in which data from the same facilities were used in order to allow less biased comparisons of baseline and endline data; however, the subnational scale means that results may not be representative at the national level and suggest that future evaluation using the improved national data reporting systems will be required to draw more conclusive inference.

There clearly were many other factors that could have impacted ACCM during 2000 - 2013. Weather factors during the evaluation period favored malaria transmission during 2006-2010 compared to the earlier years, with warmer, wetter conditions observed. Thus, the declines in ACCM over this period appear to have occurred despite more favorable conditions for malaria transmission suggesting that the impact of malaria control interventions may be underestimated if weather conditions were not taken into account. GDP per capita more than doubled during the evaluation period and household socioeconomic conditions also improved. These changes could help explain observed declines in ACCM. While improved access to health facilities is likely a major driver of the reduction in malaria morbidities and malaria mortality, improved access to care may also have helped reduce ACCM by providing better clinical management of other treatable childhood illnesses. Other child health factors including nutrition and immunization coverage also improved during this period which also could have contributed to the observed decline in ACCM since 2000.

In summary, the majority of the improvements in coverage of vector control interventions were made between 2005 and 2007, which corresponds to periods of declining malaria morbidity and mortality according to the analyses from published studies summarized in this report. Major improvements in access to health facilities also occurred during the evaluation period, which likely contributed to declines in ACCM by reducing both malaria and non-malaria deaths. Although ACCM declines were significant during the evaluation period, the rate of decline did not change after the dramatic expansion of vector control interventions and access to health services. Similarly, patterns of ACCM declines do not appear to be different in areas of high and low malaria risk as might be expected if change in malaria control was the major driver of ACCM declines. During the evaluation period there were also significant improvements observed in the coverage of some non-malaria health interventions, as well as socio-economic improvements, which likely contributed in part to the reductions observed in ACCM from 2000 to 2011. Taken altogether, this evidence suggests that malaria control interventions in Ethiopia may have contributed to reductions in ACCM, particularly the reductions that were observed during the latter part of the evaluation period, but that other factors likely played an important role as well.

Limitations of Evaluation

This evaluation is constrained by a few important limitations. First, the evaluation relied solely upon secondary data sources, thus was limited by what data was available. For example, because most of the data about malaria control interventions (ITN ownership, ITN use, and IRS coverage) and morbidity (malaria parasitemia and severe anemia) were only available beginning in 2007, it was not possible to assess trends over the entire evaluation period. Second, there are known potential biases and limitations with many of the indicators that are reported and used to estimate intervention coverage, as well as malaria-related morbidity and ACCM. More detailed information on these potential biases and limitations for each of the indicators is presented within the annexes. As has been noted, the quality of the data from routine reporting systems presented in the report, particularly in terms of completeness, reliability and validity over the evaluation period, is varied and thus must be interpreted with caution. Finally, the plausibility approach to impact evaluation relying on ACCM as a primary measure of impact has been recommended in high prevalence settings (under-five malaria prevalence >25%). Although reliable baseline estimates are difficult to find, the Malaria Atlas Project models suggest that prevalence was much lower than that at baseline in Ethiopia ($Pf\mathrm{PR}_{2\text{-}10}$ was significantly below that in 2000 at baseline (3% nationally, 10% in highest risk region). Using malaria-specific mortality data to measure impact of malaria control is recommended in areas of low transmission and relatively few malaria deaths; however, this requires routine data that accurately captures a large majority of malaria deaths. In the Ethiopian context, another option may have been to conduct a subnational evaluation, limited to areas of highest malaria transmission.

References

1. Rowe, A.K., et al., *Viewpoint: evaluating the impact of malaria control efforts on mortality in sub-Saharan Africa.* Trop Med Int Health, 2007. **12**(12): p. 1524-39.
2. Habicht, J.P., C.G. Victora, and J.P. Vaughan, *Evaluation designs for adequacy, plausibility and probability of public health programme performance and impact.* Int J Epidemiol, 1999. **28**(1): p. 10-8.
3. Victora Cg Fau - Black, R.E., et al., *Measuring impact in the Millennium Development Goal era and beyond: a new approach to large-scale effectiveness evaluations.* (1474-547X (Electronic)).
4. Murphy, S.C. and J.G. Breman, *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, 2001. **64**(1-2 Suppl): p. 57-67.
5. Liu, L., et al., *Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000.* Lancet, 2012. **379**(9832): p. 2151-61.
6. Federal Democratic Republic of Ethiopia Ministry of Health, *Health Sector Development Program IV: Annual Performance Report 2010/11 - 2014/15*. 2012: Addis Ababa. p. 1-130.
7. Federal Ministry of Health Ethiopia, *National Five Year Strategic Plan for Malaria Prevention, Control, and Elimination in Ethiopia: 2014-2020*. 2014: Addis Ababa.
8. Cheung, W.H., G.B. Senay, and A. Singh, *Trends and spatial distribution of annual and seasonal rainfall in Ethiopia.* International Journal of Climatology, 2008. **28**(13): p. 1723-1734.

Estimated Deaths Prevented due to Expansion 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 during the evaluation period, we used The Lives Saved Tool (LiST) to estimate the deaths prevented due to the expansion of malaria control interventions (For more detailed information on LiST and the model presented see Annex 3).

It is estimated that over the period from 2005 to 2011, approximately **37,500** (range: 25,300-50,600) deaths were prevented in children 0-59 months, due to the expansion of ITN household ownership and IRS, compared to what would have happened if no vector control expansion had occurred. Under-five mortality is also affected by interventions to control malaria in pregnancy, including ITN use by pregnant women and IPTp during pregnancy. The LiST model estimated that **2,900** (range: 2,300-3,600) deaths in children 0-59 months were averted due to the expansion of ITN use by pregnant women in Ethiopia during the latter part of the evaluation period, from 2007 to 2011.

The LiST analysis presented here models the direct effect of malaria interventions on reducing malaria-specific mortality. Given the conservative nature of the LiST model, the estimates presented are likely to be underestimates. Overall, the LiST model conservatively estimates that the expansion of malaria control interventions during the latter part of the evaluation period (2005 to 2011) prevented at least 40,400 (27,600-54,200) deaths among children under five years of age in Ethiopia.

9. Cox, J., et al., *Mapping malaria risk in the highlands of Africa.* MARA/HIMAL Technical Report, 1999: p. 114.
10. Himeidan, Y.E. and E.J. Kweka, *Malaria in East African highlands during the past 30 years: impact of environmental changes.* Front Physiol, 2012. **3**: p. 315.
11. Federal Democratic Republic of Ethiopia Ministry of Water and Energy, *River Basins of Ethiopia*. Addis Ababa.
12. Federal Democratic Republic of Ethiopia, C.S.A.C., *Summary and statistical report of the 2007 population and housing census. Addis Ababa, Ethiopia:*. 2008: Addis Ababa, Ethiopia.
13. Federal Democratic Republic of Ethiopia Ministry of Health, *Health and Health Related Indicators*. 2011: Addis Ababa. p. 1-74.
14. Central Statistical Agency [Ethiopia] and ICF International, *Ethiopia demographic and health survey 2011*. 2012, Central Statistical Authority and ICF International: Addis Ababa, Ethiopia and Calverton, Maryland, USA.
15. Central Intelligence Agency. *The World Factbook*. 2013 [cited 2014 June 13]; Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/et.html.
16. UNDP, *United Nations Development Programme in Ethiopia Annual Report 2013*. 2014, UNDP.
17. UNDP. *Human Development Index (HDI) Methodology*. 2011; Available from: http://hdr.undp.org/en/statistics/hdi/.
18. World Health Organization., *World health statistics 2012*. 2012, Geneva: World Health Organization. 176 p.
19. *Trends in Maternal Mortality 1990 to 2010: WHO, UNICEF, UNFPA and The World Bank Estimates*. 2012, World Health Organization: Geneva, Switzerland.
20. United Nations. *UN Data: Ethiopia*. 2014; Available from: http://data.un.org/CountryProfile.aspx?crName=Ethiopia.
21. Federal Ministry of Health, *Health Sector Development Program IV 2010/11-2014/15*. 2010.
22. Federal Democratic Republic of Ethiopia Ministry of Health, *National Malaria Guidelines* 2012.
23. Melville, A.R., D.B. Wilson, and et al., *Malaria in Abyssinia.* East Afr Med J, 1945. **22**: p. 285-94.
24. Abeku, T.A., *Response to malaria epidemics in Africa.* Emerg Infect Dis, 2007. **13**(5): p. 681-6.
25. Covell, G., *Malaria in Ethiopia.* J Trop Med Hyg, 1957. **60**(1): p. 7-16.
26. Fontaine, R.E., A.E. Najjar, and J.S. Prince, *The 1958 malaria epidemic in Ethiopia.* Am J Trop Med Hyg, 1961. **10**: p. 795-803.
27. Kiszewski, A.E. and A. Teklehaimanot, *A review of the clinical and epidemiologic burdens of epidemic malaria.* Am J Trop Med Hyg, 2004. **71**(2 Suppl): p. 128-35.
28. Gebremariam, N., *Highlights of the malaria situation in Ethiopia. Proceedings of the workshop on promotion and strengthening of malaria control through the primary health care*. 1984: Nazareth Ethiopia.
29. Graves, P.M., et al., *Individual, household and environmental risk factors for malaria infection in Amhara, Oromia and SNNP regions of Ethiopia.* Trans R Soc Trop Med Hyg, 2009. **103**(12): p. 1211-20.
30. Kloos, H. and Z.A. Zein, *The ecology of health and disease in Ethiopia*. 1988.
31. Tulu, A., *The ecology of health and disease in Ethiopia*. 1993, Boulder and Oxford@ Westview Press. p. 341-352.
32. Presidents Malaria Initiative (PMI), *Malaria Operations Play FY 2014: Ethiopia*. 2014, PMI.
33. Yeshiwondim, A.K., et al., *Therapeutic efficacy of chloroquine and chloroquine plus primaquine for the treatment of Plasmodium vivax in Ethiopia.* Acta Trop, 2010. **113**(2): p. 105-13.

34. Schwartz, E. and G. Regev-Yochay, *Primaquine as prophylaxis for malaria for nonimmune travelers: a comparison with mefloquine and doxycycline.* Clinical infectious diseases, 1999. **29**(6): p. 1502-1506.
35. Schwartz, E., G. Regev-Yochay, and D. Kurnik, *Short report: a consideration of primaquine dose adjustment for radical cure of Plasmodium vivax malaria.* The American journal of tropical medicine and hygiene, 2000. **62**(3): p. 393-395.
36. Mekuria, Y. and G. Wolde Tsadik, *Malaria survey in north and north eastern Ethiopia.* Ethiopian medical journal, 1970. **8**(4): p. 201-6.
37. FMOH, *Malaria Profile*. 2000, Commercial Printing Press: Addis Ababa, Ethiopia.
38. Federal Democratic Republic of Ethiopia, M.o.H., *National Five-Year Strategic Plan for Malaria Control in Ethiopia: 2001- 2005*, D.P.a.C.D. Malaria and Other Vector Borne Diseases Prevention and Control Team, Editor. 2005: Addis Ababa.
39. Federal Democratic Republic of Ethiopia Ministry of Health, *National Five-Year Strategic Plan for Malaria Prevention and Control in Ethiopia: 2006- 2010*, D.P.a.C.D. Malaria and Other Vector Borne Diseases Prevention and Control Team, Editor. 2005: Addis Ababa. p. 1-52.
40. Ethiopia, F.M.o.H., *National Five Year Strategic Plan for Malaria Prevention, Control, and Elimination in Ethiopia: 2011-2015.* . 2011: Addis Ababa. p. 1-79.
41. Federal Democratic Republic of Ethiopia, M.o.H., *Ethiopia's Fourth National Health Accounts, 2007/2008*. 2010: Addis Ababa.
42. World Health Organization, *World malaria report 2014*. 2014: Geneva.
43. The World Bank. *The World Banks Data Ethiopia World Development Indicators*. 2013; Available from: http://data.worldbank.org/country/ethiopia?display=default#cp_wdi.
44. Federal Democratic Republic of Ethiopia Ministry of Health, *Health Sector Development Programme IV Annual Performance Report EFY 2004*. 2012.
45. Gimnig, J., et al., *Effect of permethrin-treated bed nets on the spatial distribution of malaria vectors in Western Kenya.* Am J Trop Med Hyg, 2003. **68(90040)**: p. 115-120.
46. Hawley, W.A., et al., *Community-wide effects of permethrin-treated bed nets on child mortality and malaria morbidity in western Kenya.* Am J Trop Med Hyg, 2003. **68**: p. 121 - 127.
47. Howard, S.C., et al., *Evidence for a mass community effect of insecticide-treated bednets on the incidence of malaria on the Kenyan coast.* Trans R Soc Trop Med Hyg, 2000. **94**(4): p. 357-60.
48. Alonso, P.L., et al., *A malaria control trial using insecticide-treated bed nets and targeted chemoprophylaxis in a rural area of The Gambia, west Africa. 6. The impact of the interventions on mortality and morbidity from malaria.* Trans R Soc Trop Med Hyg, 1993. **87 Suppl 2**: p. 37-44.
49. Lengeler, C., *Insecticide-treated bed nets and curtains for preventing malaria. .* Cochrane Database of Systematic Reviews, 2004(2).
50. Snow, R.W., et al., *The effects of malaria control on nutritional status in infancy.* Acta Trop, 1997. **65**(1): p. 1-10.
51. Ter Kuile, F., et al., *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, 2003. **68**(4 suppl): p. 68-77.
52. Gamble, C.L., J.P. Ekwaru, and F.O. ter Kuile, *Insecticide-treated nets for preventing malaria in pregnancy [Systematic Review].* Cochrane Database of Systematic Reviews, 2009. **1**: p. 1.
53. World Health Organization, *The Community-Based malaria Control Program in Tigray, northern Ethiopia: A Review of Program Setup, Activities, Outcomes and Impact*. 1999: Geneva.
54. Ghebreyesus, T., et al., *The community-based malaria control programme in Tigray, northern Ethiopia. A review of programme set-up, activities, outcomes and impact.* Parassitologia (Roma), 2000. **42**(3/4): p. 255-290.

55. African Heads of State and Government, *The Abuja Declaration on Roll Back Malaria in Africa. African Summit on Roll Back Malaria.* . 2000: Abuja.
56. FMOH, *The 2001 RBM baseline survey report*, D.P.a. Control, Editor. 2001: Addis Ababa, Ethiopia.
57. NetMark, *NetMark 2004 Survey on Insecticide Treated Nets (ITNs) in Ethiopia*. 2004: Addis Ababa.
58. National Malaria Control Programme, *Malaria Strategic Plan 2011-2015: Towards Universal Access*. 2010, Government of Malawi Ministry of Health.
59. Abate, A. and M. Hadis, *Susceptibility of Anopheles gambiae s.l. to DDT, malathion, permethrin and deltamethrin in Ethiopia.* Trop Med Int Health, 2011. **16**(4): p. 486-91.
60. Yewhalaw, D., et al., *First Evidence of High Knockdown Resistance Frequency in Anopheles arabiensis (Diptera: Culicidae) from Ethiopia.* The American Journal of Tropical Medicine and Hygiene, 2010. **83**(1): p. 122-125.
61. Ethiopian Health and Nutrition Research Institute, *Ethiopian Malaria Indicator Survey 2011* 2012, EHNRI: Addis Ababa. p. 1-71.
62. Falade, C.O., et al., *Intermittent preventive treatment with sulphadoxine-pyrimethamine is effective in preventing maternal and placental malaria in Ibadan, south-western Nigeria.* Malaria Journal, 2007. **6**(1): p. 88.
63. Federal Democratic Republic of Ethiopia Ministry of Health, *Health and Health Related Indicators E.C.2001*. 2010, Policy Plan Monitoring and Evaluation Directorate, MOH: Addis Ababa.
64. World Health Organization (WHO), *Guidelines for the Treatment of Malaria. Second edition.* 2010.
65. World Health Organization and UNICEF, *World malaria report 2012*. 2012: Geneva. p. 195.
66. Fedral Democratic Republic of Ethiopia Minstry of Health, *Therapeutic assessment of the eficacy of chloroqiuine in uncomplicated P. falciarum cases in Ethiopia*. 1999: Addis Ababa.
67. Organization, W.H., *Susceptibility of Plasmodium falciparum to antimalarial Drugs: Report on Global Monitoring:1996-2004*. 2005, WHO, Geneva, Switzerland.
68. Tulu, A.N., et al., *Failure of chloroquine treatment for malaria in the highlands of Ethiopia.* Trans R Soc Trop Med Hyg, 1996. **90**(5): p. 556-7.
69. Jima, D., et al., *Efficacy of sulfadoxine-pyrimethamine for the treatment of uncomplicated falciparum malaria in Ethiopia.* East Afr Med J, 2005. **82**(8): p. 391-5.
70. Federal Ministry of Health, *Malaria diagnosis and treatment guideline for health works in Ethiopia*. 2004, FMOH: Addis Ababa.
71. Jerene, D., et al., *The role of private health facilities in the provision of malaria case management and prevention services in four zones of Oromia Regional State, Ethiopia.* International Health, 2012. **4**(1): p. 70-73.
72. FMOH, *Ethiopia Malaria Program Performance Review*, Federal Ministry of Health, Editor. 2012, Federal Ministry of Health: Addis Abeba.
73. Eziefula, A., et al., *Rationale for short course primaquine in Africa to interrupt malaria transmission.* Malaria Journal, 2012. **11**(1): p. 360.
74. Ashton, R.A., *A retrospective analysis of routinely recorded health facility data from health post to hospital level in Oromia Regional State, 1998-2003 E.C and 2006-2010 G.C.* 2013, Malaria Consortium.
75. FMOH, *ARM Report EFY2004*. 2004. p. 35.
76. FMOH, *ARM Report EFY2005*. 2005. p. 31.

77. Daniel, G., et al., *Pilot assessment of supply chains for pharmaceuticals and medical commodities for malaria, tuberculosis and HIV infection in Ethiopia.* Transactions of The Royal Society of Tropical Medicine and Hygiene, 2012. **106**(1): p. 60-62.
78. Federal Democratic Republic of Ethiopia Ministry of Health, *Health and Health Related Indicators 2004 E.C.* 2012: Addis Ababa. p. 1-74.
79. Miller, M., *Assessment of ICCM implementation strength and quality of care in Oromia, Ethiopia*. 2013, Johns Hopkins Bloomberg School of Public Health, Institute for International Programs and UNICEF: Baltimore.
80. Ye, Y., et al., *Micro-epidemiology of Plasmodium falciparum malaria: Is there any difference in transmission risk between neighbouring villages?* Malaria Journal, 2007. **6**(1): p. 46.
81. Bejon, P., et al., *Stable and unstable malaria hotspots in longitudinal cohort studies in Kenya.* PLoS medicine, 2010. **7**(7): p. e1000304.
82. Githeko, A.K. and W. Ndegwa, *Predicting malaria epidemics in the Kenyan highlands using climate data: a tool for decision makers.* Global Change and Human Health, 2001. **2**(1): p. 54-63.
83. Woyessa, A., et al., *Prevalence of malaria infection in Butajira area, south-central Ethiopia.* Malaria Journal, 2012. **11**(84).
84. Shargie, E.B., et al., *Rapid increase in ownership and use of long-lasting insecticidal nets and decrease in prevalence of malaria in three regional States of ethiopia (2006-2007).* J Trop Med, 2010. **2010**.
85. Breman, J.G., *The ears of the hippopotamus: manifestations, determinants, and estimates of the malaria burden.* Am J Trop Med Hyg, 2001. **64**(1-2 Suppl): p. 1-11.
86. Centers for Disease Control and Prevention, *Criteria for anemia in children and childbearing-aged women.* MMWR Morb Mortal Wkly Rep, 1989. **38**: p. 400–404.
87. McElroy, P.D., et al., *Effect of Plasmodium falciparum parasitemia density on hemoglobin concentrations among full-term, normal birth weight children in western Kenya, IV. The Asembo Bay Cohort Project.* 2000(0002-9637 (Print)).
88. Menendez C Fau - Kahigwa, E., et al., *Randomised placebo-controlled trial of iron supplementation and malaria chemoprophylaxis for prevention of severe anaemia and malaria in Tanzanian infants.* (0140-6736 (Print)).
89. Snow, R.W., et al., *Relation between severe malaria morbidity in children and level of Plasmodium falciparum transmission in Africa.* 1997(0140-6736 (Print)).
90. Korenromp, E.L., et al., *Impact of malaria control on childhood anaemia in Africa -- a quantitative review.* Tropical Medicine & International Health: TM & IH, 2004. **9**(10): p. 1050-1065 %U http://www.ncbi.nlm.nih.gov/pubmed/15482397.
91. Florey, L., *Anemia as an Impact Measure of ITN Use among Young Children*, in *DHS Analytical Studies* 2012, ICF International: Calverton, Maryland, USA.
92. Reithinger, R., et al., *Risk factors for anemia in children under 6 years of age in Ethiopia: analysis of the data from the cross-sectional Malaria IndicatorSurvey, 2007.* Trans R Soc Trop Med Hyg, 2013. **107**(12): p. 769-76.
93. Noland, G.S., et al., *Decreased Prevalence of Anemia in Highland Areas of Low Malaria Transmission After a 1-Year Interruption of Transmission.* Clinical Infectious Diseases, 2012. **54**(2): p. 178-184.
94. Jima, D., et al., *Analysis of malaria surveillance data in Ethiopia: what can be learned from the Integrated Disease Surveillance and Response System?* Malaria Journal, 2012. **11**(1): p. 1-14.
95. World Health Organization., *World malaria report 2008*. 2008, Geneva: World Health Organization.

96. Otten, M., et al., *Initial evidence of reduction of malaria cases and deaths in Rwanda and Ethiopia due to rapid scale-up of malaria prevention and treatment.* Malar j, 2009. **8**(1): p. 14.
97. Aregawi, M., et al., *Time Series Analysis of Trends in Malaria Cases and Deaths at Hospitals and the Effect of Antimalarial Interventions, 2001–2011, Ethiopia.* PLoS ONE, 2014. **9**(11): p. e106359.
98. Aregawi, M., et al., *Measure of trends in malaria cases and deaths at hospitals, and the effect of antimalarial interventions, 2001-2011, Ethiopia.* PlosMed, 2014. **Under Review**
99. Murray, C.J.L., et al., *Global, regional, and national incidence and mortality for HIV, tuberculosis, and malaria during 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013.* The Lancet, 2014.
100. AAU School of Public Health, *Unpublished Butajira Demographic Surveillance Sites (DSS) report*. 2012.
101. Tulu, A.N., *Malaria*, in *The ecology of health and disease in Ethiopia*, H. Kloos and A.Z. Zein, Editors. 1993, West View Press: Boulder, San Francisco, Oxford. p. 341-352.
102. Negash, K., et al., *Malaria epidemics in the highlands of Ethiopia.* East Afr Med J, 2005. **82**(4): p. 186-92.
103. Das P, *Ethiopia faces severe malaria epidemic.* Lancet, 2003. **362**(2071).
104. Abeku, T.A., et al., *Spatial and temporal variations of malaria epidemic risk in Ethiopia: factors involved and implications.* Acta Trop, 2003. **87**(3): p. 331-40.
105. World Health Organization/UNICEF, *The Africa malaria report 2003*, WHO/Roll Back Malaria, Editor. 2003: Geneva.
106. Hwang, J., et al., *In Vivo Efficacy of Artemether-Lumefantrine and Chloroquine against Plasmodium vivax: A Randomized Open Label Trial in Central Ethiopia.* PLoS ONE, 2013. **8**(5): p. e63433.
107. Hwang J, et al., *In vivo efficacy of artemether-lumefantrine against uncomplicated Plasmodium falciparum malaria in Central Ethiopia.* Malaria J, 2011: p. 10-209.
108. Wimberly, M.C., et al., *Spatial synchrony of malaria outbreaks in a highland region of Ethiopia.* Tropical Medicine & International Health, 2012. **17**(10): p. 1192-1201.
109. HDAMA Ethiopia. *Early Warning System*. 2013; Available from: http://www.amaethiopia.org/early-warning-system/.
110. Korenromp, E., *Malaria incidence estimates at country level for the year.* 2005, World Health Organization: Geneva, Switzerland.
111. Johnson, H.L., et al., *Estimating the distribution of causes of death among children age 1-59 months in high-mortality countries with incomplete death certification. .* Int J Epidemiol, 2010. **39**(4): p. 1103-1114.
112. Black R.E., C.S., Johnson H.L., Lawn J.E., Rudan I., Bassani D.G. et al. , *Global, regional, and national causes of child mortality in 2008: A systematic analysis.* Lancet, 2010. **375**(9730): p. 1969-1987.
113. Liu, L., et al., *Global, regional, and national causes of child mortality in 2000–13, with projections to inform post-2015 priorities: an updated systematic analysis.* The Lancet.
114. Ross A., M.N., Molineaux L., Smith T. , *An epidemiologic model of severe morbidity and mortality caused by Plasmodium falciparum.* The American Journal of Tropical Medicine and Hygiene, 2006. **75**(2): p. 63-73.
115. Victora, C.G., et al., *Context matters: interpreting impact findings in child survival evaluations.* Health Policy and Planning, 2005. **20**(suppl 1): p. i18-i31.

116. Bryce, J., et al., *The Multi-Country Evaluation of the Integrated Management of Childhood Illness Strategy: Lessons for the Evaluation of Public Health Interventions.* Am J Public Health, 2004. **94**(3): p. 406-415.
117. Stratton, L., et al., *The persistent problem of malaria: addressing the fundamental causes of a global killer.* Soc Sci Med, 2008. **67**(5): p. 854-62.
118. Link, B. and J. Phelan, *Understanding sociodemographic differences in health--the role of fundamental social causes.* American journal of public health, 1996. **86**(4): p. 471-3.
119. Link, B.G. and J. Phelan, *Social conditions as fundamental causes of disease.* J Health Soc Behav, 1995. **Spec No**: p. 80-94.
120. Mosley WH and Chen LC, *An analytical framework for the study of child survival in developing countries.* Bull World Health Organ, 1984. **2003**(81): p. 2.
121. Inhorn M and Brown P, *Anthropology of Infectious Diseases.* Annual Reviews of Anthropology, 1990. **19**: p. 89-117.
122. Casman E, *Contextual determinants of Malaria.* Washington, DC: Resources for the Future, 2002.
123. Taylor C, Newman J, and Kelly N, *The child survival hypothesis.* Population Studies, 1978. **30**(2): p. 263-78.
124. Jones, G., et al., *How many child deaths can we prevent this year?* Lancet, 2003. **362**(9377): p. 65-71.
125. Bryce, J., et al., *WHO estimates of the causes of death in children.* Lancet, 2005. **365**(9465): p. 1147-52.
126. Rowe, A.K., et al., *Impact of a malaria-control project in Benin that included the integrated management of childhood illness strategy.* Am J Public Health, 2011. **101**(12): p. 2333-41.
127. Victora, C.G., et al., *Measuring impact in the Millennium Development Goal era and beyond: a new approach to large-scale effectiveness evaluations.* Lancet, 2011. **377**(9759): p. 85-95.
128. Wang, L., *Determinants of child mortality in LDCs: empirical findings from demographic and health surveys.* Health Policy, 2003. **65**(3): p. 277-99.
129. Boyle, M.H., et al., *The influence of economic development level, household wealth and maternal education on child health in the developing world.* Soc Sci Med, 2006. **63**(8): p. 2242-54.
130. Subramanian, S.V., P. Belli, and I. Kawachi, *The macroeconomic determinants of health.* Annu Rev Public Health, 2002. **23**: p. 287-302.
131. Gallup JL, S.J. *The Economic Burden of Malaria*. In: Breman JG, Egan A, Keusch GT, editors. The Intolerable Burden of Malaria: A New Look at the Numbers: Supplement to Volume 64(1) of the American Journal of Tropical Medicine and Hygiene; 2001 Jan. Available from: http://www.ncbi.nlm.nih.gov/books/NBK2624/ 2001.
132. Coleman, M., et al., *Household and microeconomic factors associated with malaria in Mpumalanga, South Africa.* Trans R Soc Trop Med Hyg, 2010. **104**(2): p. 143-7.
133. Günther, I. and G. Fink, *Water and Sanitation to Reduce Child Mortality:The Impact and Cost of Waterand Sanitation Infrastructure*. 2011, The World Bank: Washington DC.
134. Gamage-Mendis, A.C., et al., *Clustering of malaria infections within an endemic population: risk of malaria associated with the type of housing construction.* Am J Trop Med Hyg, 1991. **45**(1): p. 77-85.
135. Ye, Y., et al., *Housing conditions and Plasmodium falciparum infection: protective effect of iron-sheet roofed houses.* Malar J, 2006. **5**: p. 8.
136. Worrall, E., S. Basu, and K. Hanson, *Is malaria a disease of poverty? A review of the literature.* Trop Med Int Health, 2005. **10**(10): p. 1047-59.
137. Kirby, M., et al., *Risk factors for house-entry by culicine mosquitoes in a rural town and satellite villages in The Gambia.* Parasites & Vectors, 2008. **1**(1): p. 41.

138. Lindsay, S. and R. Snow, *The trouble with eaves; house entry by vectors of malaria.* Trans R Soc Trop Med Hyg, 1988. **82**(4): p. 645-6.
139. Lindsay, S.W., P.M. Emerson, and J.D. Charlwood, *Reducing malaria by mosquito-proofing houses.* Trends in Parasitology, 2002. **18**(11): p. 510-514.
140. Ogoma, S., et al., *Window screening, ceilings and closed eaves as sustainable ways to control malaria in Dar es Salaam, Tanzania.* Malaria Journal, 2009. **8**(1): p. 221.
141. Gakidou, E., et al., *Increased educational attainment and its effect on child mortality in 175 countries between 1970 and 2009: a systematic analysis.* Lancet, 2010. **376**(9745): p. 959-74.
142. Sandiford, P., et al., *The Impact of Women's Literacy on Child Health and its Interaction with Access to Health Services.* Population Studies, 1995. **49**(1): p. 5-17.
143. Jejeebhoy, S., *Women's education, autonomy and reproductive behaviour:experience from developing countries*. 1995: Oxford:Clarendon Press.
144. Hobcraft, J., *Women's education, child welfare and child survival: a review of the evidence.* Health Transit Rev, 1993. **3**(2): p. 159-75.
145. Cleland, J.G. and J.K. van Ginneken, *Maternal education and child survival in developing countries: The search for pathways of influence.* Social Science & Medicine, 1988. **27**(12): p. 1357-1368.
146. Becker, G., *Demographic and Economic Change in Developed Countries*. 1960, Princeton: Princeton University Press. p. 209–240.
147. The World Bank. *Ethiopia Historical Climate*. Available from: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Africa&ThisCCode=ETH.
148. Thomson, M.C., *Development of Climate Analysis Section for the President's Malaria Initiative Impact Evaluation: Reports for Ethiopia and Tanzania*, C.U. International Research Institute for Climate and Society/Mailman School of Public Health/The Earth Institute, Editor. 2012.
149. Williams, A.P.a.C.F., *A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa.* Climate Dynamics, 2011. **37**: p. 2417-2435.
150. Lyon, B.a.D.G.D., *A recent and abrupt decline in the East African long rains.* Geophysical Research Letters, 2012. **39**.
151. Teklehaimanot, H.D., et al., *Weather-based prediction of Plasmodium falciparum malaria in epidemic-prone regions of Ethiopia II. Weather-based prediction systems perform comparably to early detection systems in identifying times for interventions.* Malar J, 2004. **3**: p. 44.
152. Teklehaimanot, H.D., et al., *Weather-based prediction of Plasmodium falciparum malaria in epidemic-prone regions of Ethiopia I. Patterns of lagged weather effects reflect biological mechanisms.* Malar J, 2004. **3**: p. 41.
153. Abeku, T.A., et al., *Effects of meteorological factors on epidemic malaria in Ethiopia: a statistical modelling approach based on theoretical reasoning.* Parasitology, 2004. **128**(Pt 6): p. 585-93.
154. Siraj, A.S., et al., *Altitudinal Changes in Malaria Incidence in Highlands of Ethiopia and Colombia.* Science, 2014. **343**(6175): p. 1154-1158.
155. Alonso, D., M.J. Bouma, and M. Pascual, *Epidemic malaria and warmer temperatures in recent decades in an East African highland*. 2010.
156. US Department of Interior. *USGS Science Supports Early Humanitarian Response to Famine Conditions in East Africa*. 2011; Graphic illustrates 2010/2011 rainfall compared to historical totals (since 1950/1951) in select pastoral areas of Kenya and Ethiopia (analysis by U.S. Geological Survey's Famine Early Warning Systems Network).]. Available from: http://eros.usgs.gov/doi-remote-sensing-activities/2011/usgs-science-supports-early-humanitarian-response-famine-conditions-east-africa.

157. World Health Organization and UNICEF, *World malaria report 2011*. 2011, Geneva: World Health Organization. xii, 246 p.
158 World Development Report 1993: Investing in Health, Volume1, June 1993 ISBN: 978-0-19-520890-0 https://doi.org/10.1596/0-1952-0890-0
159. World Health Organization, The world health report 2002 - Reducing Risks, Promoting Healthy Life. Geneva: World Health Organization.
160. West, J., KP, B. Caballero, and R. Black, *Nutrition*, in *International Public Health: Diseases, Programs, Systems, and Policies* M. Merson, R. Black, and A. Mills, Editors. 2001, Aspen Publishers, Inc.
161. Black, R.E., et al., *Maternal and child undernutrition: global and regional exposures and health consequences.* Lancet, 2008. **371**(9608): p. 243-60.
162. UNICEF, *Progress Report: Committing to Child Survival: a promise renewed*. 2012: New York.