Epidemiology and control profile of malaria in

Malawi

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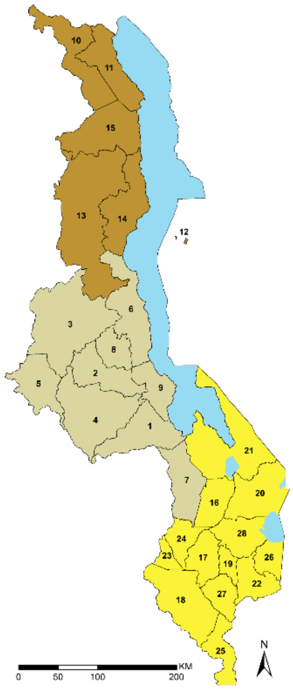
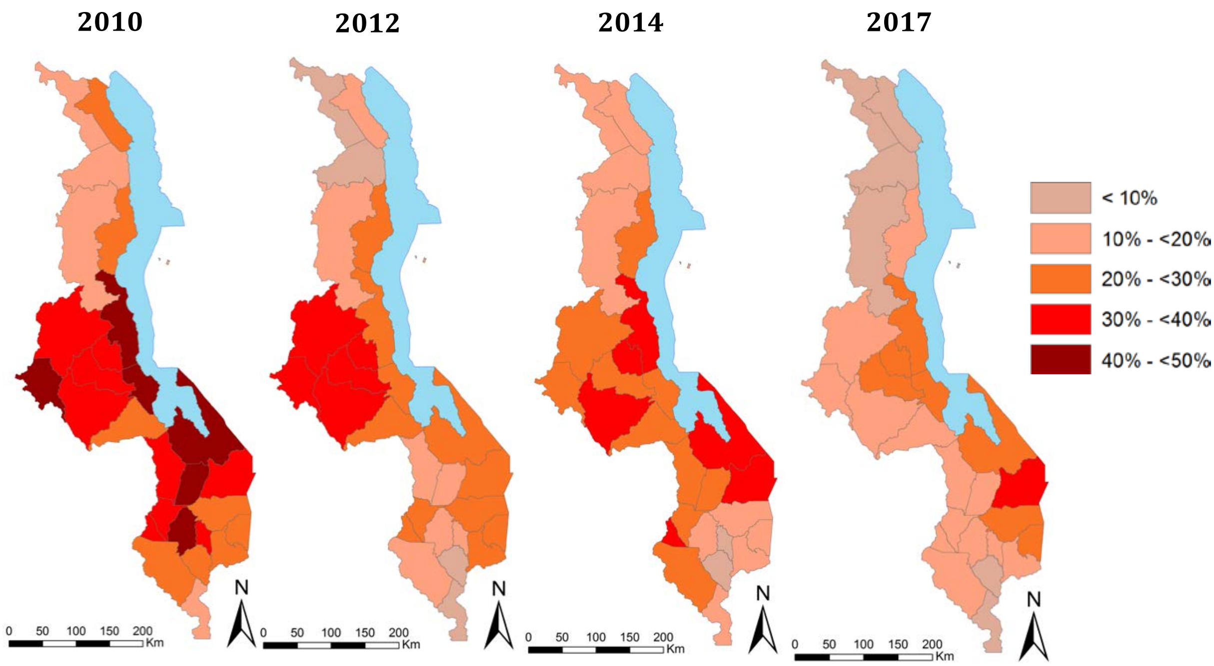
28 health districts of Malawi within three regions



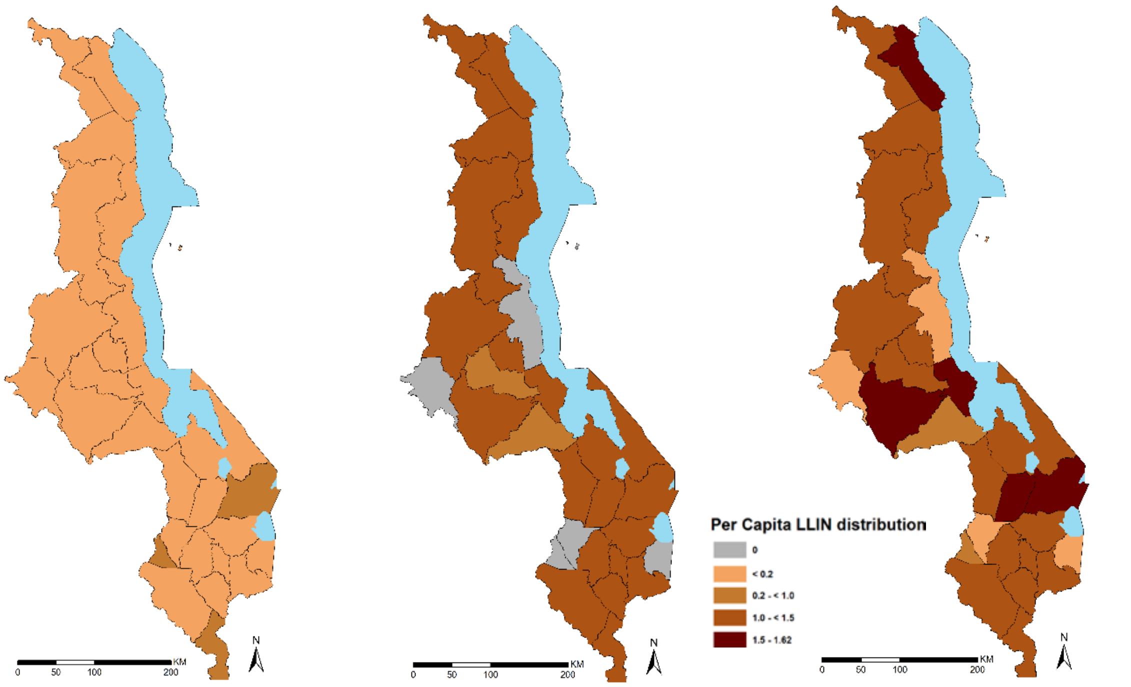
Map code	District	Map code	District
Central Region		Southern Region	
1	Dedza	16	Balaka
2	Dowa	17	Blantyre
3	Kasungu	18	Chikwawa
4	Lilongwe	19	Chiradzulu
5	Mchinji	20	Machinga
6	Nkhotakota	21	Mangochi
7	Ntcheu	22	Mulanje
8	Ntchisi	23	Mwanza
9	Salima	24	Neno
Northern Region		25	Nsanje
10	Chitipa	26	Phalombe
11	Karonga	27	Thyolo
12	Likoma	28	Zomba
13	Mzimba		
14	Nkhata Bay		
15	Rumphi		

Predicted distribution of *Pf*PR$_{2\text{-}10}$ in 2010, 2012, 2014 and 2017



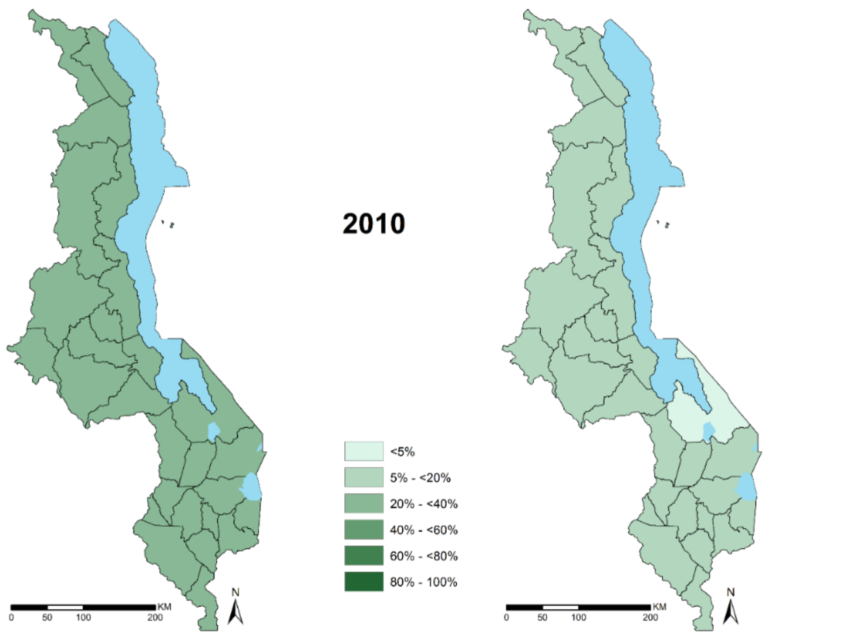
Per capita 2015-2017 LLIN summed distribution per 2017 projected population (left: by routine distribution; centre: by mass distribution; right: by mass and routine distribution)

By routine distribution* **By mass distribution*** **By routine and mass distribution***



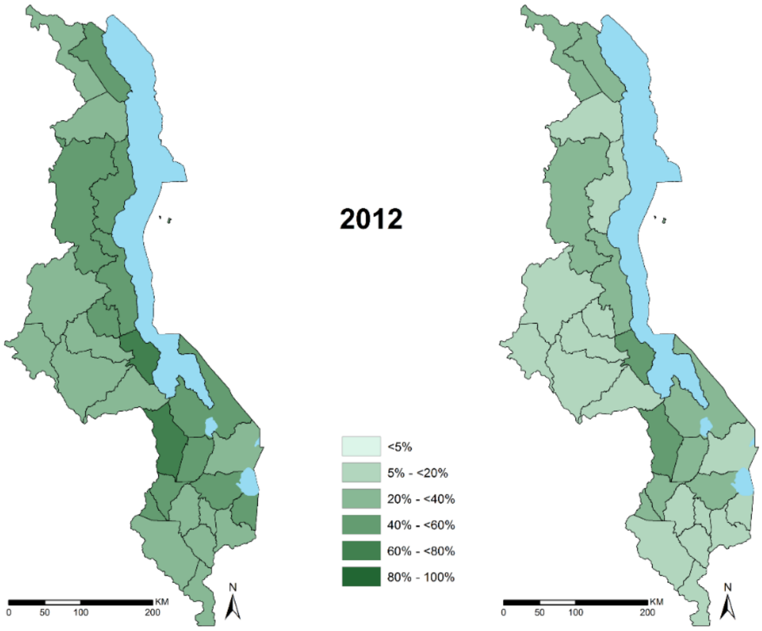
*Excluding routine distribution to infants

LLIN coverage from survey data



Proportion of population sleeping under LLIN

Proportion of households with at least one LLIN for every 2 persons



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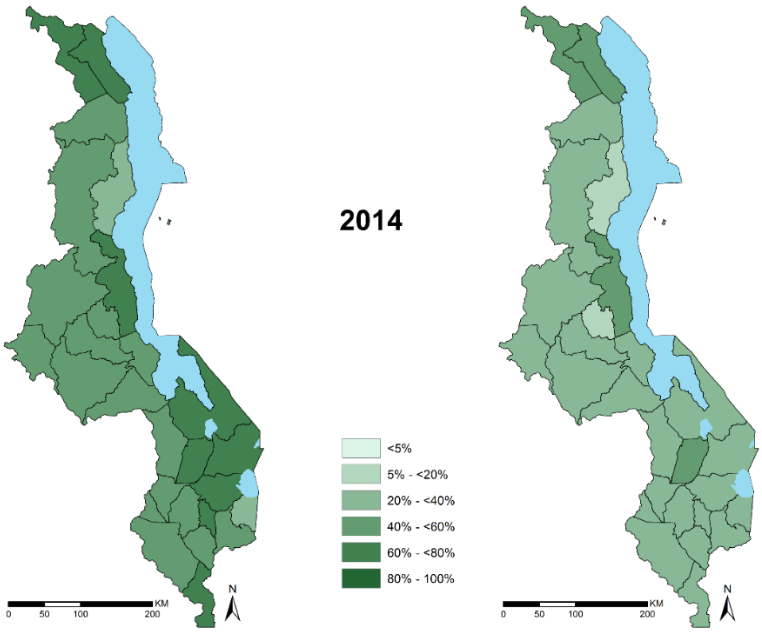

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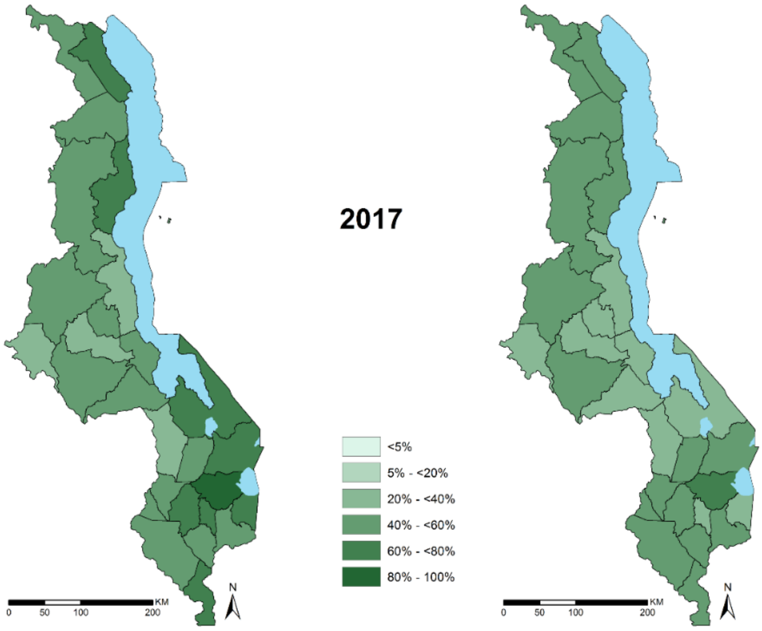
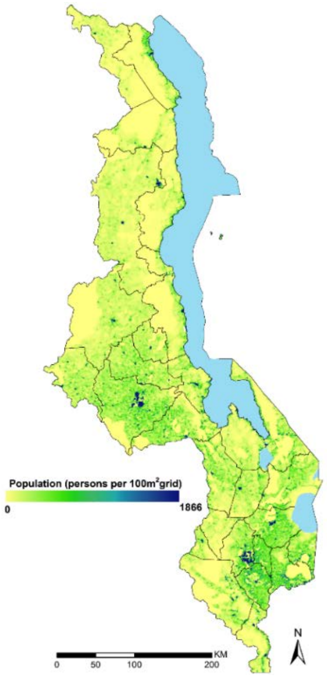


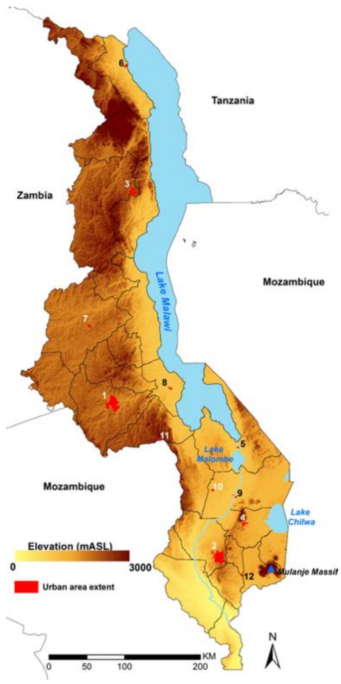
Proportion of population sleeping under LLIN

Proportion of households with at least one LLIN for every 2 persons

Modelled population density per 100 m²



Major relief features, rivers and lakes



Acronyms

ACT	Artemisinin-based combination therapies
AERC	African Economic Research Consortium
AFRO	WHO Regional Office for Africa
AL	Artemether-lumefantrine
ALMA	African Leaders Malaria Alliance
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BIMI	Blantyre Integrated Malaria Initiative
BITNet	Blantyre Insecticide Treated Net Project
BLM	Banja la Mtsogolo
CDF	Colonial Development Fund
CHAM	Christian Health Association of Malawi
CMED	Central Monitoring and Evaluation Department
CQ	Chloroquine
DA	District Assemblies
DFID	Department for International Development
DHMT	District Health Management Teams
DHS	Demographic Health Survey
DRC	Democratic Republic of the Congo
EHP	Essential Health Package
EHRP	Emergency Human Resource Programme
EP	Exceedance probability
EPI	Expanded Programme on Immunisation
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GIS	Geographic Information Systems
GMEP	Global Malaria Eradication Programme
GPS	Global Positioning Systems
HDI	Human Development Index
HIS	Health Information Systems
HISP	Health Information Systems Programme
HMIS	Health management information system
HSA	Health surveillance assistants
HSSP	Health Sector Strategic Plan
HTSS	Health Technical Support Services

iCCM	Integrated community case management for childhood illnesses
ICEMR	International Centres of Excellence for Malaria Research
IHME	Institute for Health Metrics and Evaluation
IMCI	Integrated management of childhood illness
IMF	International Monetary Fund
IPTp	Intermittent preventive treatment in pregnant women
IRS	Indoor Residual Spraying
ITN	Insecticide-treated net
IVM	Integrated vector management
JICA	Japan International Cooperation Agency
KAP	Knowledge attitude and practice
KWTRP	KEMRI-Wellcome Research Trust Programme
LLIN	Long-lasting Insecticidal Net
LMIS	Logistics management information system
LSHTM	London School of Hygiene & Tropical Medicine
M&E	Monitoring and Evaluation
MAC	Malaria Alert Centre
MAP	Malaria Atlas Project
MARA	Malaria Risk in Africa
MBG	Model-based geo-statistics
MCMC	Markov Chain Monte Carlo
MCP	Malawi Congress Party
MDG	Millennium Development Goals
MDHS	Malawi Demographic and Health Survey
MGDS	Malawi's Third Growth and Development Strategy
MICS	Multiple Indicator Cluster Survey
MiP	Malaria in Pregnancy
MIS	Malaria Indicator Survey
MMR	Maternal mortality ratio
MoH	Ministry of Health
MPR	Malaria Programme Performance Review
MPRS	Malawi Poverty Reduction Strategy
MSP	Malaria Strategic Plan
MSPA	Malawi Service Provision Assessment
NAC	Nyasaland African Congress
NGO	Non-governmental organisations

NMCP	National Malaria Control Programme
NSO	National Statistics Office
ODA	Overseas development assistance
OPD	Outpatient department
PCR	Polymerase Chain Reaction
PHC	Primary Health Care
PNFP	Private-for-profit, and private-not-for-profit
POW	Programme of Work
RBM	Roll Back Malaria
RDT	Rapid diagnostic tests
mMIS	"Rolling" MIS
SAE	Small Area Estimation
SLA	Service-Level Agreements
SMC	Seasonal malaria chemoprevention
SP	Sulfadoxine-pyrimethamine
SWAp	Sector-wide approach
UDF	United Democratic Front
UNDP	United Nations Development Programme
UNWPF	United National World Population Fund
VHC	Village Health Communities
WaSH	Water, sanitation and hygiene

Executive summary

This epidemiological profile represents a collaboration between the Malawi National Malaria Control Programme (NMCP), NMCP partners, WHO Regional Office for Africa and the LINK Programme (London School of Hygiene & Tropical Medicine [LSHTM] and KEMRI-Wellcome Research Trust Programme [KWTRP]). The profile was developed to support national- and district-level malaria control actors to align most-recent malaria burden data and intervention coverage data with efforts to improve the impact of malaria reduction interventions, in line with the country's National Malaria Strategic Plan.

This report builds upon work produced in 2014 by the KWTRP to develop an epidemiological profile of malaria at district levels. Subsequent mass Long-lasting Insecticidal Net (LLIN) campaigns across the country have altered the landscape of intervention coverage and possibly malaria risk since the first profile was developed. At the same time, new sources of data have become available, namely a Demographic Health Survey (DHS) with a malaria module in 2015 and a national Malaria Indicator Survey (MIS) in 2017. These surveys are designed to provide highly accurate results at the regional and national level; however, district-level estimates are best-suited for national planning. Therefore, we apply model-based geospatial (MBG) techniques to render district-level estimates using the data available from nationally-representative surveys and small studies.

This report updates national spatially-defined data on malaria parasite prevalence, vector species occurrence, human population settlements and vector control coverage. The updated databases for this profile are owned by the NMCP and Ministry of Health as part of a national data repository. Using MBG methods, this report presents maps of malaria risks in Malawi for 2010, 2012, 2014 and 2017. The maps are based on parasite prevalence among children aged two to ten years ($Pf\mathrm{PR}_{2\text{-}10}$) and are transformed into district-level estimates of risk to review burden and change over time across 28 health districts to support the planning of resources. These maps were produced by a Malawian researcher with technical training from KWTRP. Moving forward, these maps can be generated within Malawi, allowing for a timely and country-driven mapping portfolio.

Malaria transmission in Malawi is best described as hyperendemic. Transmission occurs throughout the year in most areas but is highest during the rainy seasons from November to April. The entire population is at risk of the disease. The presence of the *An. gambiae* complex and the *An. funestus* group are sympatric in the entire country. *An. funestus* is the primary vector of Malawi, but *An. gambiae s.s.* and *An. arabiensis* may predominate in some areas at certain times of the year. *Plasmodium falciparum* (P. *falciparum*) is the dominant malaria infection in Malawi.

LLIN use is the dominant vector control strategy in Malawi. IRS was challenged by high levels of pyrethroid and carbamate resistance in *An. funestus* in 2011; the country is exploring how to re-initiate IRS in suitable epidemiological areas using non-pyrethroid, non-carbamate insecticides. Survey data shows that LLIN coverage has increased over time through their mass and routine distribution. The 2014 MIS found that 30% of households reported having met the global standard of at least one ITN for every two persons sleeping in the house, while the 2017 found that this had increased to 42%.

Resistance to insecticides is a growing concern in Malawi and more broadly, in the region. In particular, there is widespread permethrin resistance in the Democratic Republic of the Congo (DRC).[1] Between 2009 and 2014, consistently high levels of *An. funestus* resistance to pyrethroid (permethrin and deltamethrin) and carbamate insecticides were recorded throughout Malawi. *An. funestus* remains susceptible to the organophosphate malathion and DDT.

Since 2007, Malawi's policy has been to treat uncomplicated malaria with artemisinin-based combination therapy (ACT). This policy was created following the identification of increasing resistance to sulfadoxine-pyrimethamine (SP). In 2007, Malawi became one of the first countries to adopt integrated community case management for childhood illnesses (iCCM), which the country implements through community health workers, called Health Surveillance Assistants (HSAs). By 2010 all districts were implementing iCCM. Since 2003, Malawi has implemented Malaria in Pregnancy (MiP) through focused antenatal care using a three-pronged approach: 1) health facility-based use of intermittent preventive treatment in pregnant women (IPTp) using at least three doses of SP; 2) distribution of LLINs to pregnant women; and 3) effective case management of malarial illness and anaemia.

The Malaria Strategic Plan (MSP) 2017-22 aims to reduce malaria incidence by at least 50% from a 2015 baseline of 386 per 1,000 population to 193 per 1,000 and malaria deaths by at least 50% from 23 per 100,000 population to 12 per 100,000 population by 2022. Malawi's Mid-term Programme Review in 2016 identified that malaria incidence reduced by 20% (from 484 per 1000 in 2010 to 386 per 1000 population in 2015) and that malaria deaths reduced by 61% (from 59 per 100,000 population to 23 per 100,000 population). These indicators show significant progress toward the goals of the MSP. The MSP identified that strengthening epidemiological and entomological vector surveillance would create opportunity increase the impact of interventions.

The geospatial maps in this profile, alongside geospatially-represented LLIN coverage and use maps can assist the NMCP to identify sub-national targeting of interventions to promote progress towards its 2022 targets and beyond.

1. Introduction

1. 1 History of malariometric data, maps and epidemiological intelligence in malaria control

The use of survey data, maps and epidemiological intelligence was a routine feature of control planning across most African countries during the Global Malaria Eradication Programme (GMEP) era from the mid-1950s. Data included epidemiological descriptions of transmission, vectors, topography and climate. Over 50 years ago, the infection prevalence among children aged two to ten years ($Pf\mathrm{PR}_{2-10}$) was recognised as one important source of planning and used to define categories of endemic risk. This special epidemiology was used to guide and monitor progress toward malaria elimination targets.

The art and skills necessary to design malaria control programmes based on an understanding of the spatial epidemiology were lost during the 1970s when the agenda for malaria control fell under a less specialised, integrated primary care mandate focused on managing fevers.

In 1996, a renewed appeal for better malaria cartography to guide malaria control in Africa was made.[2,3] Over the last decade there was enormous growth in spatial data on malaria and populations which had not been available to malariologists or programme control managers 60 years ago. The growth in data was accompanied by the development of statistical approaches to model and map risk and intervention access in space and in time using model-based geostatistics (MBG).[4]

At the launch of the Roll Back Malaria (RBM) partnership in 1998, calls for universal coverage of all available interventions were likely an appropriate response to the epidemic that affected most of sub-Saharan Africa during this period.[5,6] A decade on, the international donor community is constrained by the global financial crisis; accessing overseas development assistance (ODA) and using limited national domestic funding for malaria control now requires a much stronger evidence-based business case. These business cases must increasingly be grounded in the best possible epidemiological evidence to predict the likely impact of future interventions, assess the impact of current investment and, equally important, demonstrate what might happen should funding and intervention coverage decline.

1.2 Purpose of this profile

Malawi undertook its second National Malaria Programme Performance Review (MPR)[1] in 2016 to support the development of the Malaria Strategic Plan 2017-22. The MPR, which examined the years 2011-15, identified the need to strengthen epidemiological and entomological surveillance, as well as to ensure proper monitoring of interventions and measure their impact. To this end, the MPR made the recommendation to strengthen malaria surveillance and operational research capacity through the interfacing of the Health management information system (HMIS) with other complementary systems for interoperability and to build capacity in surveillance and data use for decision-making at the district and sub-district level.[7]

This profile was developed to support national-level planning in Malawi through the assemblage of an epidemiological evidence base required for a more targeted approach to

[1] In 2011, the WHO Office for the Africa Region (AFRO) developed a manual to assist countries in developing their National Malaria Strategic Plan including, as a prelude, the undertaking of a National MPR. It is recommended that the MPR should include a detailed review of the malaria epidemiology and stratification including the geographical distribution of malaria burden, parasite prevalence and parasite species.

malaria control. This report builds upon a profile produced in 2014 by INFORM (KEMRI-Welcome Trust) which sought to develop an epidemiological profile of malaria at district levels. The 2014 analysis allowed for a description of malaria risk based on parasite prevalence data throughout Malawi predicting to the most recent periods for which the majority of data were available (2000 and 2010). The 2014 profile identified high rates of morbidity and parasite transmission intensity and no significant changes in malaria transmission between 2000 and 2010. Following the release of the original profile in 2014, subsequent mass long-lasting insecticidal net (LLIN) campaigns, Indoor Residual Spraying (IRS) campaigns and emerging insecticide resistance have altered the landscape of intervention coverage and possibly malaria risk. Concurrently, new sources of data have become available, namely a DHS with a malaria module in 2015, and Malaria Indicator Surveys (MIS) in 2014 and 2017.

This updated epidemiological profile unites the latest evidence of parasite transmission risk and data on the distribution of dominant vector species. Risk is described at the level of Malawi's health districts; offering data at a unit most useful for targeting sub-national control efforts toward the targets of the national malaria strategic plan. Importantly, this work is intended to support the NMCP's strategic planning and ongoing M&E efforts.

2. Country context

2.1 Geographic location

Malawi, referred to as “The Warm Heart of Africa,” is a small, narrow, landlocked country that shares boundaries with Zambia in the west; Mozambique in the east, south and southwest; and Tanzania in the north. It has a surface area of 118,484 km^2, of which 94,276 km^2 is water.[8] The country’s five lakes (Lakes Malawi, Malombe, Chilwa, Chiuta, Kazuni and Kaulime) comprise 21% of Malawi's territorial surface area.

Malawi’s landscape is highly varied. Four basic regions can be identified: the Great Rift Valley, the central plateaus, the highlands, and the isolated mountains. Malawi’s most striking topographic feature is the Rift Valley, which runs the entire length of the country, passing through Lake Malawi in the Northern and Central Regions and stretching to the Shire Valley in the south.

The Shire River drains into the Zambezi River in Mozambique from Lake Malawi. To the west and south of Lake Malawi lie fertile plains and mountain ranges whose peaks range from 1,700 to 3,000 m above sea level. The isolated massifs of Mulanje, which reach 3,002 m above sea level, are the highest points in the country. Lake Malawi is 457.2 m above sea level and acts as an important transport route, source of food, source of income and a tourist attraction.

Figure 1 presents a geospatial map of the major relief features, rivers, lakes and major urban areas.[2] The urban areas were identified according the National Statistics Office (NSO)’s definition of “urban” areas. Malawi’s 2008 Population Census[9] separates urban centres into three categories: (i) primary centres, (ii) secondary centres and (iii) other centres. This classification is not based solely on population size, but rather on an urban centre’s orientation towards non-agricultural activities, its population density, and availability of services. Since other urban centres’ geographic extents are too small to be visualised at national map scale, the map shows only the 12 primary and secondary urban centres’ extents, digitised in Google Earth (Google Inc., California, USA), namely – Lilongwe [1], Blantyre [2], Mzuzu [3], Zomba [4], Mangochi [5], Karonga [6], Kasungu [7], Salima [8], Liwonde [9], Balaka [10], Dedza [11] and Luchenza [12].

[2] The Digital Elevation Model presented used the 30m resolution Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) accessed at (https://gdex.cr.usgs.gov/gdex/) on 16/03/18.

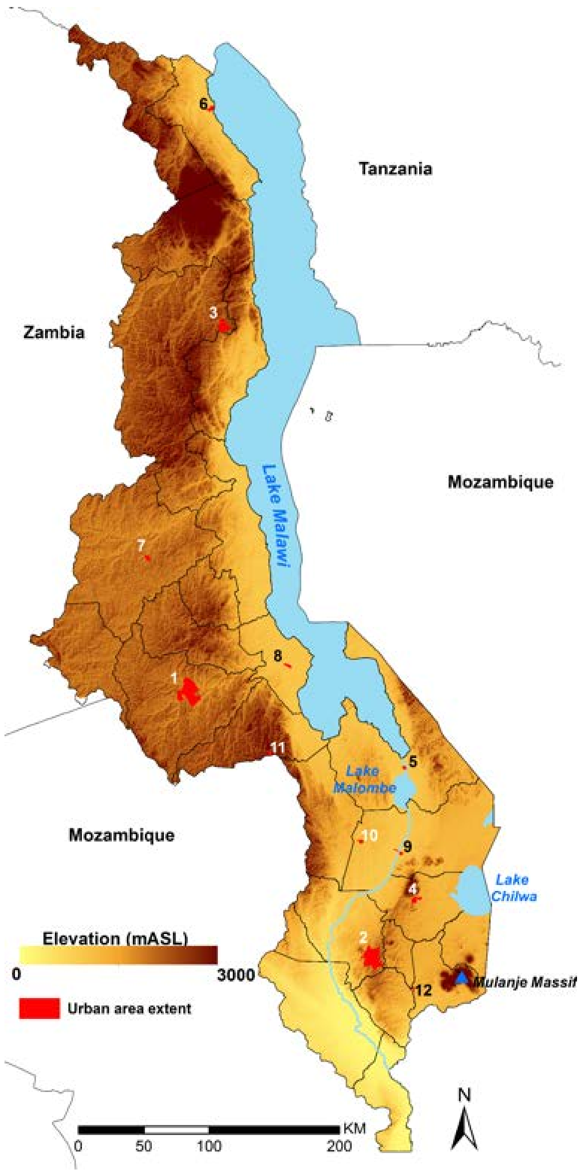


Figure 1. Major relief features, rivers and lakes and indication of major urban areas (highlighted in red)

Malawi's terrain is made up of woodlands, tropical rainforests, open savannah high altitude grasslands and scrub. Malawi's climate is subtropical with the three distinct seasons: rainy season extending from November to April, the cool-cold and dry season from May to mid-August (temperatures at night reaching as low as 10-14^{o} C) and the hot and dry season from between mid-August and November. Generally, the highlands are cooler and wetter while the low-lying regions of the Shire Valley are hotter and more humid. The rains are more prolonged in the north.

Malaria transmission is greatest during the rainy season, from November to April, when breeding sites are more abundant. Low-lying areas with hot temperatures are favourable to mosquito breeding, so transmission is highest in these areas.

2.2 Social and political evolution

The country now known as Malawi has been heavily influenced by large human migrations over the course of hundreds of years. The region was once part of the Maravi Empire, a dynasty thought to have been founded in the late 15th century by the unification of several Bantu-speaking tribes who migrated into area which later became Malawi. It is thought that the name "Malawi" is derived from the word "Maravi", meaning "flames." The Maravi attacked the original inhabitants of the region, the Akafula, and took hold of their land. The kingdom included most of modern Malawi, as well as parts of present day Mozambique and Zambia. The region remained under Maravi control until the arrival of Arab traders and slavery in the mid-19th century.[10] The Maravi Empire had access to the coast of modern day Mozambique, used for trade purposes..

Portuguese explorers arrived from the present-day coast of Mozambique in the 17th century. The 18th and 19th centuries witnessed dramatic increases in the slave trade, where Malawian tribes traded slaves with the Portuguese. By the 19th century the Maravi Empire's power base began to decline and the state was attacked by the Ngoni and the Yao. During this period of instability, Arab traders penetrated the interior during the 1870s and formed trade alliances with the Yao. Conflict ensued for many years between the Yao and Angoni in an attempt to gain authority over the region.[10]

In 1850, the Scottish Presbyterian missionary David Livingstone led an exploration of the region, initiating the entry of missionaries, European adventurers and traders. Livingstone arrived at Lake Nyasa in 1858 and he led the Scottish church's mission against slavery thereafter. In 1876, the city of Blantyre was established in the southern region and served as a headquarters in the continuing fight against slavery. Livingstone's presence, until his death in 1873, was a key factor in attracting British trading companies to Malawi and its subsequent colonisation. In 1881, a British consul was appointed and by 1891, the British formally established the Nyasaland and District Protectorate, later renamed the British Central African Protectorate. In 1907, the British Central African Protectorate was later renamed Nyasaland.

Resistance to colonial rule began in 1915 when the Reverend John Chilembwe led a revolt against British rule, killing white managers of a farming estate. This was a prelude to a long period of discontent that led to the formation of the Nyasaland African Congress (NAC) by Nationalists in 1944, inspired by similar movements in South Africa.[11] Despite strong opposition from the NAC and white liberal activists, Britain combined Nyasaland in a Federation with Northern and Southern Rhodesia (now Zambia and Zimbabwe respectively) in 1953.

In 1958, Dr Hastings Kamuzu Banda returned to Nyasaland having spent time both in England and in the United States[12] to denounce the Federation. He then assumed leadership of the NAC which eventually became the Malawi Congress Party (MCP). The colonial authorities banned the MCP in 1959 and arrested Banda and members of the MCP's leadership. A state of emergency was declared between 1959 and 1960 when Banda led protests against the British.

The MCP won elections to the legislative council in 1961. The British then agreed to Malawi's independence in the following year. In 1963, Nyasaland was granted self-governing status shortly before the Federation dissolved, and Banda became the prime minister despite control of financial, security, and judicial systems by the British. Nyasaland declared independence as Malawi on the 6th July 1964 and became a republic two years later with a multiparty system of governance.

In 1966, the constitution of Malawi was changed to a one-party state under President's Banda's leadership. Opposition movements were suppressed and their leaders detained. Banda was voted President for Life of the MCP in 1970 and assumed this role from 1971.[11,13]

During the 1980s, there was political unrest and by 1992 several donor countries suspended aid to the country. When donor countries suspended bilateral aid, Banda conceded to a national referendum in 1993, which resulted in an overwhelming support for multi-party elections.

Democratic, multi-party elections were held on the 17 May 1994. These were won by Bakili Muluzi of the United Democratic Front (UDF). In 1999, Muluzi was re-elected to a second five-year term, during which his government had to contend with the famine of 2002 and allegations of corruption.[14] In May 2004, Bingu wa Mutharika from the UDF party was elected President. Mutharika was elected for a second term in May 2009 but died while in office in 2012. He was subsequently succeeded by his vice-president, Joyce Banda. In 2014, Peter Mutharika, Bingu wa Matharika's brother, won the presidency in the country's first tripartite elections (ie., local government, parliament, and the presidency were voted on in the same election).

3. Population and economy

3.1 Population

The first "census" was conducted in 1891 when Malawi was a British Protectorate; however, the head counts were restricted only to the European population. The second population census was conducted in 1901 and included Malawians. Additional pre-independence censuses were conducted in the years 1911, 1921, 1926, 1931, and 1945. The most comprehensive censuses using modern demographic methods started shortly after independence in 1966. These censuses are repeated approximately every ten years. The latest census was undertaken in June 2008.[15]

Malawi's population is growing rapidly. Malawi's population increased 3.3-fold from 4 million people in 1966 to 13 million in 2008. The average inter-censal annual growth rate has been 2.9% since 1966, with the highest rate of 3.7% observed between 1977 and 1987. Between 1998 and 2008, this rate declined to 2.8%. According to the United Nations Population Fund (UNPF), 44% of the population of Malawi was under the age of 14 in 2017.[16] Malawi's population will double within the next 30 years if it follows the current growth trend.[15]

The crude population density for Malawi was 85 persons per km^2 in 1987 and 139 per km^2 in 2008. However, this average masks distribution diversity, as population density ranges from 35 to 3,007 inhabitants per km^2.[15] About 45% of the total population lives in the Southern Region of the country with the highest population densities (185 per km^2) compared to Central Region (154 per km^2) and Northern Region (63 per km^2) regions.

To improve our understanding of human settlement patterns in Malawi, spatial modelling techniques have been developed to reallocate populations captured by censuses to finer-gridded surfaces.[17] In brief, a daysymmetric modelling technique[18] was used to redistribute population counts within the 28 spatially defined districts used during the 2008 national census and land cover data sets derived from satellite imagery. A different population weight was assigned to each land cover class to shift populations away from areas unlikely to be inhabited (e.g. game reserves or arid deserts) and concentrate populations in built-up areas.

The net result was a gridded dataset of population distribution (counts) at 0.1 x 0.1 km resolution (Figure 2). The population distribution datasets were projected to years used to predict malaria risk and LLIN coverage using UN national rural and urban growth rates[19] and made to match the total national population estimates provided by the UN Population Division[20] for these years.

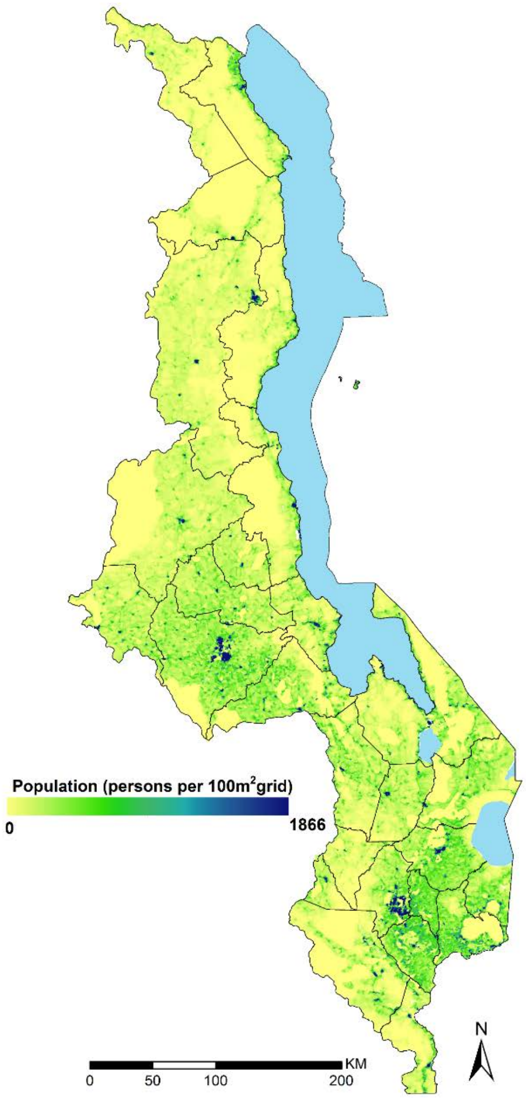


Figure 2. Modelled 2015 population density per 100 m^2

Urbanisation

The first post-independence census in 1966 showed that Malawi's urbanisation was one of the lowest in Africa. Approximately 5% of the population lived in urban areas, 54% of whom were in Blantyre.[21] At the time, only four towns (Blantyre, Lilongwe, Zomba and Mzuzu) had populations greater than 5,000 people. To promote greater regional equity in growth acting as a counter to the commercial capital of Blantyre, Lilongwe was designated as the new capital, replacing the colonial capital Zomba post-independence. Lilongwe grew at an average rate of 16% per year up to 1977. The growth in Blantyre (100,000 at independence) during the same period was much slower at 6.4% per year.[21]

In 2008, Malawi remained one of the least urbanised countries in the world, with an estimated urban population of two million.[15,22,23] Malawi has seemingly undergone relatively little rural-urban transformation, with its urban population increasing from 10.7% in 1987 to 15.3% in 2008 at a rate slower than other African countries.[24] At this rate, about 20% of the population will live in an urban area by 2030.[24]

Migration

Large, unplanned movements of people increase the risk of malaria transmission and malaria epidemics. Such movement also strains the health system, which in turn affects the capacity for detection, treatment and surveillance.[25]

In the 1980s and 1990s, Malawi received over a million refugees from Mozambique due to the civil war. More recently, Malawi has received an influx of Mozambicans due to the Reanmo insurgency which began in 2013.

3.2 Economy

The pre-colonial economy of Malawi was largely based on the agricultural production of millet and sorghum. The Maravi Empire established ivory, iron and slave trading links with the Portuguese and Arabs of the Mozambican coast. During the period when Malawi was a British protectorate, local industrialisation was limited and the cash economy depended on agriculture (i.e. coffee, tea, tobacco and cotton) due to the dearth of oil or mineral natural resources. The landlocked position of Malawi posed a serious challenge for economic development by restricting access to trade.

Upon the country's independence in 1964, Malawi faced several economic challenges. The 1963 dissolution of the federation of Nyasaland and Rhodesia, or the Central African Federation, shifted the burden of funding public services from the Federation (based in what is now Harare) to the Malawian government. Therefore, at the time of independence Malawi was left with limited infrastructure and public services, no central banking system and limited tools to develop its institutions. As mentioned previously, the country's geographic placement was not a strategic location for trade, and the lack of natural resources like minerals or gas failed to bolster the economy.

Following independence, President Banda embarked on a unique economic development strategy. While neighbouring post-colonial countries like Zambia and Tanzania adopted Afro-socialism economic policies, post-colonial Malawi adopted an approach of "pragmatic unilateral capitalism."[26] The pragmatic nature was embodied in the country's decision to maintain trade relationships with Portuguese East Africa, Southern Rhodesia and throughout all of the apartheid years (1948-1991), the Republic of South Africa. The economic approach also focused on capital development and the expansion of the agriculture sector. Finally, the government suppressed trade unions and enforced low wage policies as a way to encourage industry growth. The economy experienced rapid growth in gross domestic product (GDP) during the late 1960s well into the 1980s (Figure 3).[27]

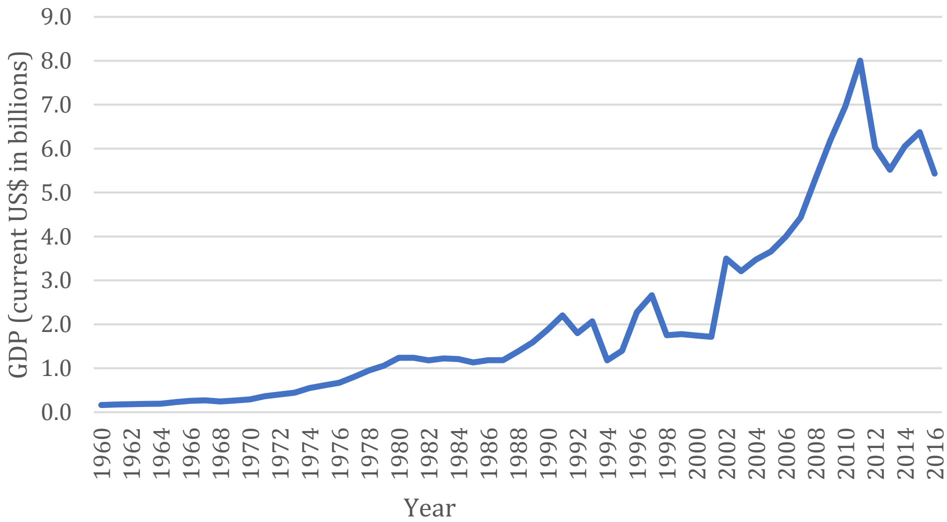


Figure 3. Malawi's Gross Domestic Product (GDP) from 1960-2016 in billions USD[28]

In 1981, Malawi became one of the first countries in sub-Saharan Africa to implement structural adjustment programmes under the direction of the World Bank and the International Monetary Fund (IMF). These adjustment programmes were aimed at the following: 1) diversifying the economic base; 2) ensuring appropriate price and incomes policy; 3) increasing the efficiency and incomes of smallholder farmers; 4) improving the policy environment for manufacturing and trade; and 5) restructuring fiscal budgetary allocation and expenditure.[29–31]

From 1989 to 2004, Malawi's economic was highly unstable. Inflation peaked at 83% in 1995, droughts occurred in 1992 and again in 1994, and an influx of Mozambican refugees entered the country through the late 1980s. Bingu wa Mutharika assumed the presidency in 2004 and implemented various policies to encourage economic growth. These policies were directed towards sectors and areas where the poor work and live, fertiliser subsidies and improved relations with the donor community. Despite early economic growth, GDP has slowed and stagnated since 2008; with a 2.5% estimated growth rate in 2016, compared to an 9.6% growth in 2007 (Figure 4).[28] These recent trends mirror the trends seen across sub-Saharan Africa (Figure 4).

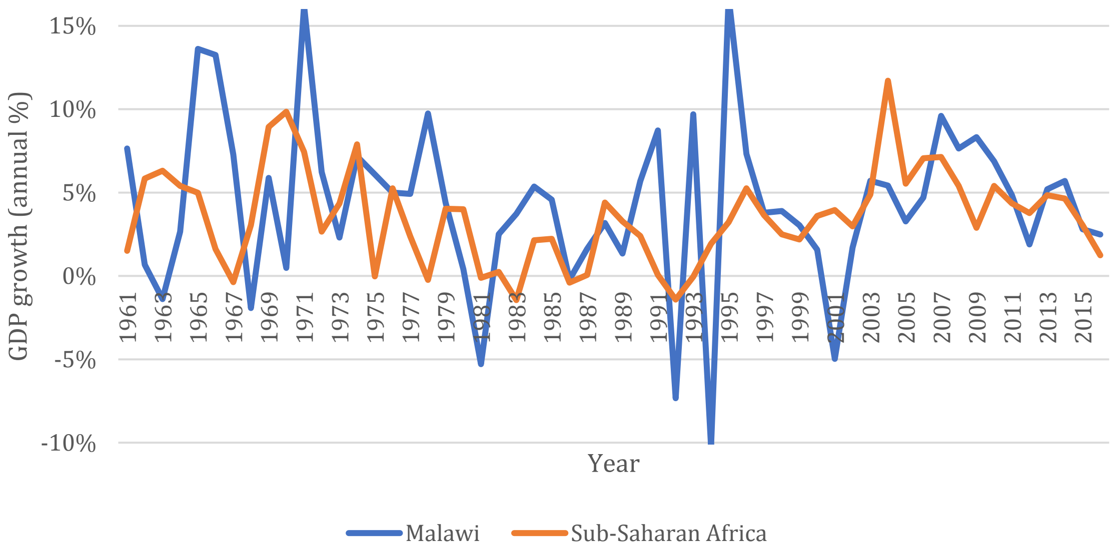


Figure 4. Percent growth in GDP for Malawi (blue) and sub-Saharan Africa (orange), 1960-2016

By 2010, there were foreign exchange, fuel and electricity supply shortages. These led to major restrictions on local businesses and escalated the cost of living for the average Malawian. Inflation has been above 20% since 2012;[28] this is in part due to the 2012 devaluation of the kwacha currency by a third to satisfy IMF requirements, as well as drought. Malawi's Third Growth and Development Strategy (MGDS III) covers 2017 to 2022[32] and aims to improve productivity and transform the country into a competitive nation resilient to shocks.

Despite long-term visions and medium-term action plans, Malawi remains one of poorest countries in the world, with a per capita income of only USD 300 in 2016.[28] Per capita incomes have fallen since 2011 and are lower than the per capita income of neighbouring countries and the average per capita income for sub-Saharan Africa.[28]

Industry

Agriculture drives Malawi's economy, with nearly 85% of the labour force working within the industry.[33]. However, its role in contribution to GDP has decreased as the manufacturing industry has somewhat expanded (Figure 5).[33] Agriculture currently accounts for 28% of the GDP, compared to 44% in 1980.[28] Tobacco production alone accounts for 60% of the country's exports.[33] Tea, coffee and sugarcane account for a further 10% of GDP.

There are few natural mineral resources in Malawi, leaving the agriculture-reliant GDP vulnerable to climate shocks, most recently the 2015 drought. In 2009 a uranium mine was opened by Paladin Energy Ltd at Kayelekera in the Northern region of the country. By 2013, revenues had contributed to 2.6% of the GDP, but production was suspended in 2014 due to the global plummet of uranium prices following the Fukushima nuclear crisis. The mines have since been under care and maintenance.[34]

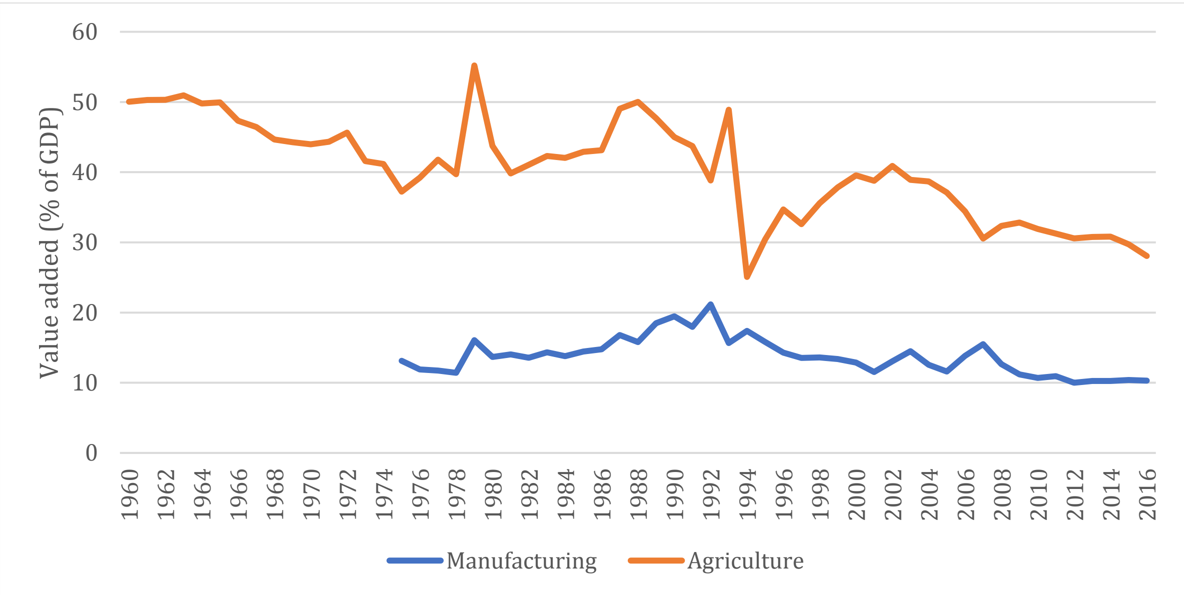


Figure 5. Percent of GDP accounted for by manufacturing (blue) and agriculture (orange) in Malawi, 1960-2016

Poverty

In 1998, Malawi's first Integrated Household Survey (IHS)[35] identified that 65% of the population was classified as "poor" and 29% of the population was living in "extreme poverty"(Figure 6).[36] In an effort to address poverty, Malawi prepared a long-term framework for development planning and management, Vision 2020. Vision 2020 presents the long-term development goal that "*By the year 2020, Malawi, as a God-fearing nation will be secure,* *democratically mature, environmentally sustainable, self -reliant with equal opportunities for and active participation by all, having social services, vibrant culture and religious values and a technologically driven middle-income economy*".[37] The vision has nine core themes which included "*fair and equitable distribution of income.*"

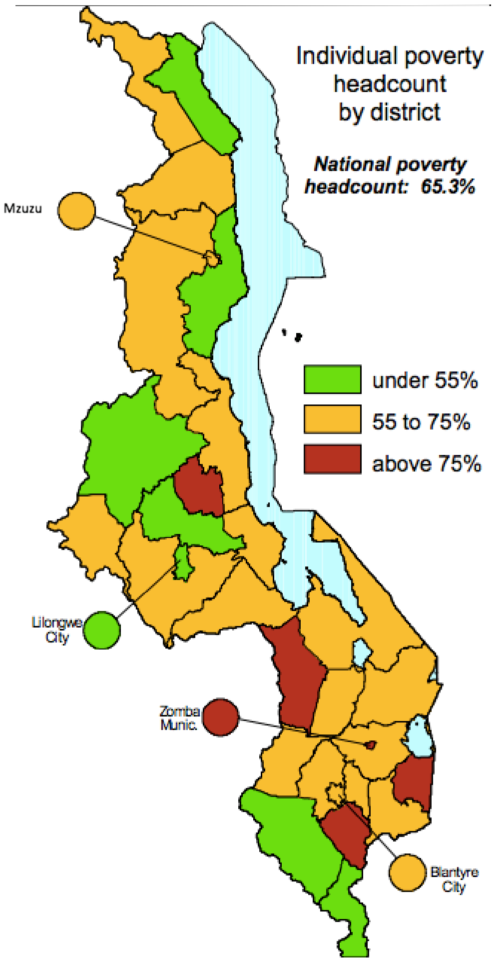


Figure 6. Individual poverty headcount by district from the 1997-98 Malawi Integrated Household Survey

In May 2002, the government launched the Malawi Poverty Reduction Strategy (MPRS) to translate the long-term strategy of the Vision 2020 into medium-term action plans.[38] The goal of the MPRS was to achieve "*sustainable poverty reduction through empowerment of the poor.*"[39] The MPRS was built around four strategic pillars: sustainable pro-poor growth, human capital development, improving the quality of life of the most vulnerable and governance.[40] Three Growth and Development Strategies have laid out five-year plans to achieve these goals by 2020.

From the 1998 Integrated Household Survey, IHSs have provided an empirical update on the population's socio-economic situation. The IHS was performed from 2004 to 2005[41], 2010 to 2011,[42] and most recently from 2016 to 2017[43]. The 2010 to 2011 survey showed that 25% of the population are defined as ultra-poor[3] which showed relatively little change from the

[3] Poverty in Malawi is defined as having a total household consumption per year which is below the poverty line. The poverty line is a measure of the total Malawi Kwacha per person per year required to obtain a minimum level of living which is inclusive of enough food to reach a specific number of calories;

previous survey. However, the 2016 to 2017 survey measured only the perception of economic status. Consequently, while it identified that 36% of households perceived themselves as "very poor," the measure cannot be directly compared to previous surveys.

According to UNDP, Malawi's Human Development Index (HDI) rose by 47% from 0.325 to 0.476 between 1990 and 2015, ranking the country at 170 out of 188 countries with comparable data in 2015, placing Malawi below the average HDI for sub-Saharan Africa of 0.523.[44] Malawi therefore falls into the "low development" classification, based on life expectancy, educational attainment and gross national product.[44]

3.3 National health overview

Life expectancy at birth in Malawi was 64 years of age in 2016, compared to 46 years of age in 2000.[45] The adult mortality rate (probability of dying between 15 and 60 years of age per 1,000 population) in 2016 was 255 per 1,000 population, a 30% decrease from the 2010 rate of 366 per 1,000 population.[45]

A greater proportion of deaths are incrementally attributable to injuries and non-communicable diseases rather than communicable, maternal, neonatal and nutritional diseases. By major cause group, 72% of deaths were due to communicable diseases, 23% were due to non-communicable diseases, and 5% were due to injuries in 2010.[46] In 2016, 64% of deaths in 2016 were due to communicable diseases, 6% were due to injuries, and 30% were due to non-communicable diseases.[46]

The maternal mortality ratio (MMR) is high but decreasing. The MMR witnessed a 29% decrease from 890 deaths per 10,000 live births in 2000 to 634 deaths per 100,000 live births in 2015.[45] A study examining trends across the DHS and other surveys concluded that MMR rose rapidly in the 1980s to mid-1990s and has since gradually reduced.[47] However, an assessment of DHS data quality suggested that these numbers are not representative.[48]

Malawi was one of the few countries in sub-Saharan Africa which met the MDG 4 target of reducing under-5 mortality by two-thirds between 1990 and 2015.[49] Estimates from the UN Interagency Group on Mortality Estimation show that there have been substantial declines in infant (birth to first year of life), neonatal (first 28 days of life) and under-five (birth to 5 years of age) mortalities since the 1960s (Figure 7).[50] Mortality in the first month of life has decreased 55%, from 51 to 23 deaths per 1,000 live births between 1990 and 2016, while mortality in the first year of life has fallen 71% from 137 to 39 between 1990 and 2016.

It is thought that these decreases were achieved by improvements in access to high-impact interventions to address major childhood killers like pneumonia, diarrhoea and malaria.[49] It is also thought that these intervention scale-ups were successful due to strengthened leadership and partner coordination.[49] Decreases in neonatal mortality may be driven by a significant increase in facility births among other systems changes like the scaling-up of Kangaroo Mother Care.[51]

necessary energy requirement per person per day and a non-food component of basic goods and services. Persons living below the poverty line are considered poor while people living below the minimum food level consumption are referred to as ultra-poor.[42] In the 2010/11 IH
S, the poverty lines were defined as: those below MK 37002 – Poor while those below MK 22956 were defined as ultra-Poor

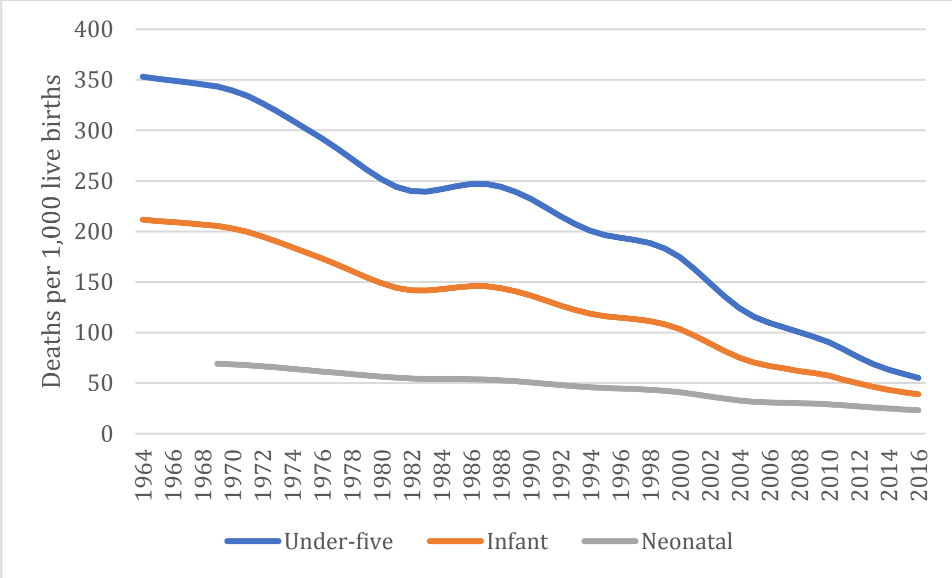


Figure 7. UN Interagency Group for Child Mortality estimates for infant, neonatal and under-five deaths and mortality rates since the 1960s

3.4 Administration and policies

Government

Malawi is a democratic, multi-party government with executive, legislative and judicial branches. The president leads the executive branch and acts as chief of state and head of government. The legislative branch has 193 members who represent the districts; elections for seats are also held every five years. Elections for the presidency and the legislature are held every five years by universal suffrage. The judicial branch consists of a Supreme Court of Appeal, a High Court and subordinate courts. Local government is administered by regional administrators and district commissioners who are appointed by the central government.

Administrative divisions

The 1995 Constitution and the 1998 Local Government Act (LGA) devolved political and administrative authority to the unitary local governments, which have elected local council and popular participation.[52] The National Centralisation Policy was approved in 1998 to lay out how the LGA would be implemented. [53] Political decentralisation stalled in 2005 when the president cancelled local council elections. However, administrative and fiscal decentralisation commenced in the health and education sectors in 2004 when the government started implementing a health sector-wide approach (SWAp), guided by a six-year joint Programme of Work (POW) 2004-2010.[54]

Malawi is composed of three administrative regions (the Northern, Central and Southern regions) (Figure 8). The regions are subdivided into 28 districts, which constitute the country's local government units.[55] These districts are administered by district assemblies. Below the district level, Malawi operates 250 traditional authorities, sub-traditional authorities (or sub-chiefs) while the urban areas are divided into 110 wards. Some traditional authorities straddle district borders, so these subsidiary divisions do not fit precisely into a hierarchical scheme.

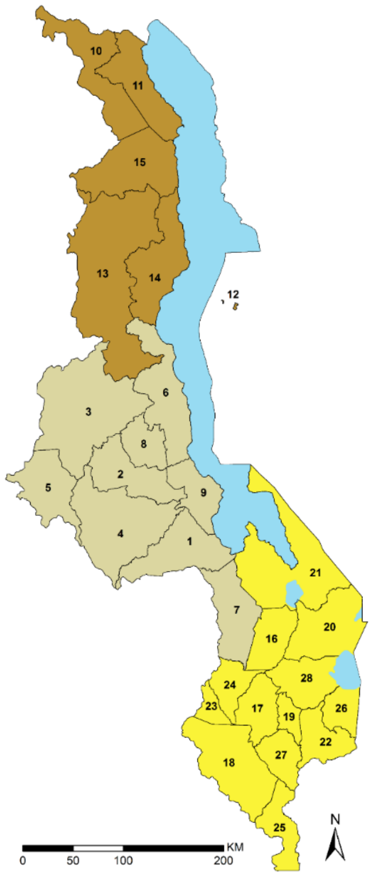


Figure 8. Twenty-eight health administration districts across three regions in Malawi

Table 1. District codes by region

Map code	District	Map code	District
Central Region		Southern Region	
1	Dedza	16	Balaka
2	Dowa	17	Blantyre
3	Kasungu	18	Chikwawa
4	Lilongwe	19	Chiradzulu
5	Mchinji	20	Machinga
6	Nkhotakota	21	Mangochi
7	Ntcheu	22	Mulanje
8	Ntchisi	23	Mwanza
9	Salima	24	Neno
Northern Region		25	Nsanje
10	Chitipa	26	Phalombe
11	Karonga	27	Thyolo
12	Likoma	28	Zomba
13	Mzimba		
14	Nkhata Bay		
15	Rumphi		

Levels of decision making

Political and administrative decentralisation is being strengthened with common funding mechanisms and the institution of local government civil service.[56] The health system in Malawi is district-based, with each district responsible for supervising its preventive and promotive activities. District boundaries match local government administrative boundaries, as visualised in Figure 8.[55,57]

The LGA and National Decentralisation Policy give councils the power to make decisions on local government and development strategies. They oversee planning, resource mobilisation, and financial management of locally generated revenue and central government transfers, staff employment, law enforcement, business administration and inspection, and the delivery of essential local services.

In terms of health, the local government is responsible for planning and budgeting, recurrent expenditure and procurement for district hospitals and public clinics (except for drugs), data collection, monitoring standards, water, sanitation and hygiene (WaSH), and contracting of Christian Health Service of Malawi facilities.[52] Meanwhile, the national government is responsible for setting policy and standards, regulation, monitoring, inspection and evaluation, national projects and referral hospitals, human resources (salaries, hiring and firing, promotion and transfers), capital investment, donor fund management, drug budgeting, procurement and distribution, and Health Zonal Offices (which offer technical support to district health management teams).[52]

Health System

Historical perspective

Early history
In the early 1900s, Malawi was ravaged by several epidemics including plague outbreaks in 1904 and 1906, smallpox, and the influenza pandemic which followed the First World War. These medical crises prompted the expansion of government medical services and facilities which had been established in the early 1980s under the British Protectorate.[58] By 1911 there were government facilities at Zomba (European and African hospitals), Karonga (dispensary), Port Herald (Nsanje) (dispensary), Fort Johnson (Mangochi) (European and African hospitals) and Blantyre (European and African hospitals) but clinical services continued to be focused on the health of government officials.[59,60] The government health services had modest staffing which was complemented by mission doctors, nurses and medical facilities that were more established in some areas owing to their earlier founding in 1876.[58]

It was not until the late 1920s that the health policy expanded the provision of medical services from government officials to the rest of the population.[58] Twelve district hospitals and 90 rural dispensaries were established, more medical staff were deployed, and an increasing amount of money was spent on healthcare by the 1930s. By 1937, there were 15 African hospitals, two European hospitals, 706 hospital beds and 93 dispensaries.[59]

By 1938, the number of people with access to health care, especially in the rural areas, had risen. In the years following the Second World War, increasing funds from the Colonial Development fund led to further expansion of health services nationwide. A medical assistant training school, a mental hospital and a leprosy settlement were established and other facilities and dispensaries were improved, with low level facilities being upgraded to rural health units.[60] In 1954, the medical department became the responsibility of the federal government; but there were concerns about inadequate medical facilities to serve the population, discrimination against African staff and a low number of medical specialists. The medical department became the sole responsibility of the Malawi government in 1963, after the termination of the Federation.[58]

By 1974, 10 years after independence, medical services significantly expanded, with a 50% increase in medical staff and increase in health expenditure to more than 10% of the total budget as compared to 1964.[58] A cholera outbreak in the early 1970s prompted the establishment of Village Health Communities (VHCs) which utilised the services of village volunteers and trained health assistants, also called cholera assistants.[61] By 1995, their scope of work was expanded to provide health care to people in communities, their positions were made permanent and they were henceforth referred to as Health Surveillance Assistants (HSAs).[62]

1980s and 1990s: Decentralised and expanded health care
The health policy was revised in the 1980s to focus on raising the level and quality of health for all Malawians with an emphasis on Primary Health Care (PHC). The PHC approach was adopted in 1978 and it encouraged the participation of communities in catering for their health needs and the development of a basic health infrastructure to provide health care, especially in rural and inaccessible areas. This policy shifted care from hospitals to the community, where the care was focused on maternal and child health care. However, implementation of PHC was slow owing to the shortage of qualified personnel, inadequate funding and lack of coordination from the government.[62]

The country continued to expand the medical department and by 1995, 71% of the population lived within a 5 km radius of a health unit.[62] Populations living in hard-to-reach areas, particularly in rural areas and in households more than 8 km from a health unit, were served by HSAs through village clinics.

In 1994, a District Focus policy was issued to increased development at district level, but it was not until 1998 that decentralisation of health care was fully implemented.[63] Decentralisation was prompted by the establishment of Local Assemblies, which received money allocations rather than the Ministry of Health (MoH). Health care management was then devolved from the central government to the district level, managed by District Health Management Teams (DHMTs).[64]

2000s: Towards an essential health package

In the early 2000s, Malawi became a signatory in a number of international conventions, particularly the 2000 Millennium Declaration and the Abuja Declaration, which became the basis for health care policy formulation in the country. The launch of the Malawi Poverty Reduction Strategy Paper in 2002 prioritised health care provisions in the already implemented Essential Health Package (EHP). The *Bakili Muluzi Health Initiative*, launched in 1999, focused on ensuring the availability of basic essential drugs as part of the EHP within walking distance of rural populations' homes. This package addressed the provision of affordable health care to every individual in Malawi, especially the poor and vulnerable populations.[62] This primary health care strategy focused on the priority areas to achieve not only national goals set in the MPRS, Malawi Growth and Development Strategy (MGDS), but also global goals such as the Millennium Development Goals (MDGs).

In 2004, the government implemented a health SWAp guided by a six-year joint programme of work (POW) 2004-2010. The POW priorities revolved around the provision of the EHP, with its implementation through the decentralisation framework and District Assemblies (DAs) responsible for health service delivery. Additionally, the MoU between the government and the Christian Health Association of Malawi (CHAM) increased access to health care, as these Christian-owned facilities also emphasised EHP. SWAp-PoW was complemented by the Service-Level Agreements (SLAs), which were further agreements between the government and CHAM where facilities under CHAM offered free health care services and received government reimbursement. Still facing a national shortage of health care workers, Malawi launched an Emergency Human Resource Programme (EHRP) to train and deploy health workers and doctors between 2004 and 2009.

The period after 2004 was characterised by improvements in the health sector. Decentralisation continued while health care and medical facilities improved health care provisions (measured through the reduction in maternal mortality ratio and infant mortality ratio). There was also an increase in the commitment of the government towards health care provision, with health sector expenditure increasing from 11.1% in 2005 to 12.4% from 2009 to 2010.[62,65]

2010 onwards: implementing Health Sector Strategic Plans

In 2010, the government launched the Health Sector Strategic Plan (HSSP) 2011–2016 which replaced the SWAp–PoW with a more strategic emphasis on health promotion, disease prevention and increased community participation. A core group chaired by the Director of SWAp with membership from all departments of the MoH, health worker training institutions and the private sector, was established to steer the formulation of the HSSP, which in turn would guide interventions in the health sector. Following the outcomes of the SWAp–PoW, the core group, with assistance from stakeholders, was to revise the EHP according to the burden of disease and address critical issues on non-EHP conditions, especially funding. The government also started the implementation of sectoral technical working groups in all government ministries to encourage better coordination in alignment of government systems, reduce duplication of data reporting and enhance efficiency and effectiveness with a view to improve health systems.[65]

The Health Sector Strategic Plan II (HSPPII) was launched in 2017 and is in effect until 2022. It incorporates the SDGs and builds upon the health successes achieved under the previous plan in the areas, notably the reduction of child mortality, malaria, and HIV and AIDS.[55] The current HSSP focuses on delivering the revised EHP through health systems strengthening, which includes addressing health financing and shortages in the health workforce and essential medical products and technologies.

Health system governance

The MoH is overseen by the Office of the Minister, which seats the Minister of Health and Honorary State Ministers for Health. The Ministry has 14 directorates under the Ministry Headquarters:

1. Directorate of Administration
2. Directorate of Finance
3. Directorate of Human Resources
4. Directorate of Clinical Services
5. Directorate of Nursing & Midwifery Services
6. Directorate of Preventive Health Services
7. National Public Health Institute of Malawi
8. Directorate of Health Technical Support Services (HTTS)
9. Directorate of Planning & Policy Development (P&PD)
10. Directorate of Health Research
11. Directorate of Reproductive Health
12. Directorate of Safe Motherhood
13. Directorate of Nutrition
14. Quality Management Directorate

Service provision hierarchy

Health services in Malawi are provided by public, private-for-profit, and private-not-for-profit (PNFP) sectors. The public sector includes government health facilities at the district, town and city council level. The private sector contains private hospitals, clinics, and laboratories, as well as traditional healers. The PNFP sector includes religious organisations, non-governmental organisations (NGOs). The most prominent religious healthcare provider in Malawi is CHAM, which has agreements with the government and provides about 30% of services in the country.[55] Health services in the public sector are free-of-charge at the point of use, but private services typically charge fees.

The health care system in Malawi is composed of four levels which are connected through a referral system: primary (health posts – level 1, health centres – level 2, community/rural hospitals – level 3), secondary (district hospitals – level 4) and tertiary (national and specialist hospitals – level 5). In the public health system, services are delivered at primary, secondary, and tertiary levels. The community, primary, and secondary levels are overseen by the District Councils, which are headed by a District Health Officer who reports to the District Commissioner who oversees the public institutions of the district.

The levels of service provision are described below and depicted in Figure 9.

Primary level: This level comprises community initiatives, health posts, dispensaries, maternity facilities, health centres, and community/rural hospitals. Service delivery at this level is done mostly by community-based cadres such as health surveillance assistants, community-based distributing agents, village health committees and other volunteers. These cadres provide a range of mostly promotive and preventable services and some curative services.

Secondary level: Secondary level services are delivered by district hospitals. These are referral facilities for the primary level of care and provide both inpatient and outpatient services for their target populations.

Tertiary level: Tertiary level services are provided by the central hospitals. These institutions also act as referral facilities for the district hospitals while providing services in their regions. Central hospitals also have the mandate to offer professional training, conduct research, and provide support to the districts.[66]

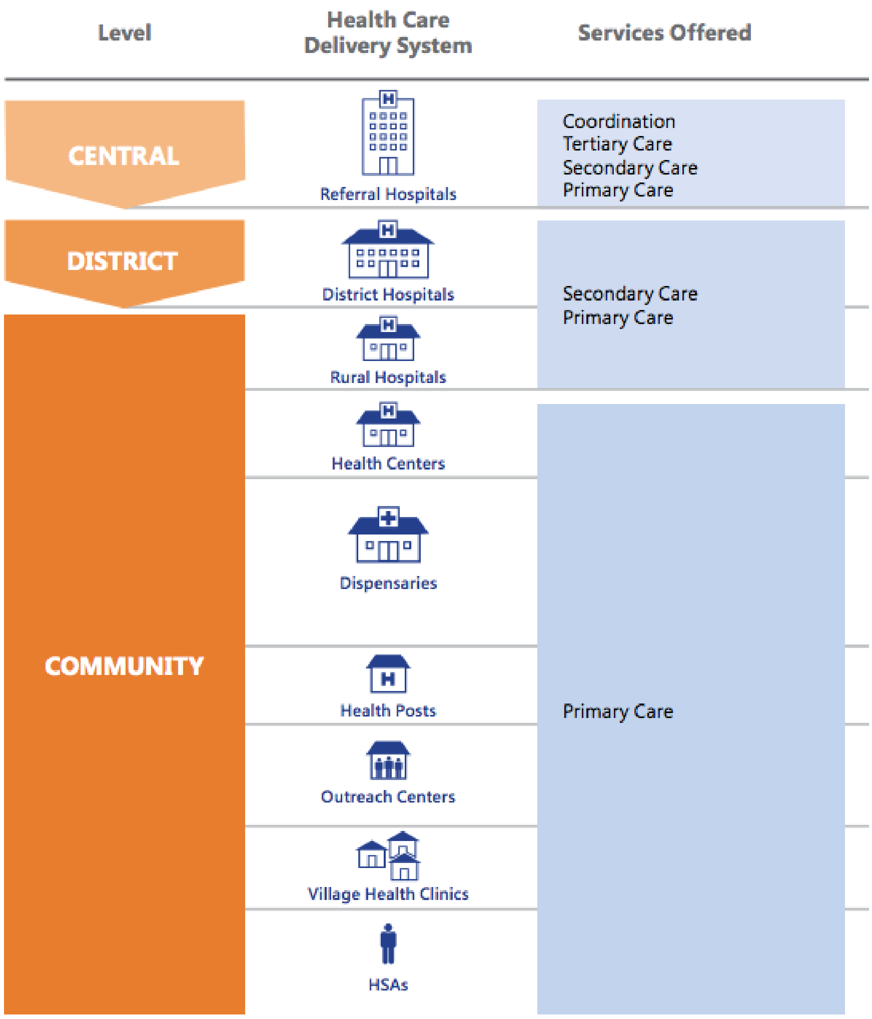


Figure 9. Malawi's public health system[67]
This figure is from Devlin et al. (2017), Malawi's Community-based Health System Model: Structure, Strategies, and Learning

Health facility mapping

Accurate health information is the cornerstone of effective decision-making and reliable assessment of disease burden and resource needs.[68,69] Efforts to tackle the enormous burden of ill-health in low-income countries are hampered by the lack of functioning health information structures to provide reliable health statistics.[70–72] Central to a fully operational Health Information Systems (HIS) is a basic inventory of all functioning health facilities and the services they provide. Such an inventory requires a spatial dimension, allowing facilities to be linked to the populations they serve by level of care and other proximate determinants of health such as environment, poverty and education. This spatial linkage can be provided by geographic information systems (GIS). The use of GIS for health services planning is widespread in developed countries[73,74] but there are few examples of their development and operational use in resource-poor settings in Africa.[75–77]

Health facility locations in Malawi, both public and private, were comprehensively surveyed in 2002 by the Japan International Cooperation Agency (JICA). The geo-coordinates for each facility, its type, ownership and funding source were included in the original database compiled in 2013.[78] Accompanying this epidemiological profile is an updated health facility database which additionally includes data from: a 2010 MoH survey of health facilities; a 2016 inventory of CHAM facilities;[79] a 2017 inventory of facilities from the Malawi Health Information Systems Programe;[80] the United Nations Office for the Coordination of Humanitarian Affairs database;[81] and the 2014 Malawi Service Provision Assessment (MSPA).[66]

The final database had 648 public health facilities, of which 639 were geocoded[4] (Figure 10). Nine public health facilities had missing coordinates. Excluded from the original data sources were three private facilities[5] and 121 facilities that provided specialist services (eg. maternity, sexual and reproductive health, Banja la Mtsogolo (BLM), dental, nursing home, rehab, etc.) or facilities that provided services to a subset of the population (eg. police, prisons, military, schools etc.). The facilities were re-coded into three tiers of Hospitals (Rural or community hospitals, District hospitals, and central hospitals), Health Centres and Health Posts (Dispensary, Health Post, and Clinic).

The current HSSP II[55] reports a total of 738 public health facilities which includes facilities offering specialist services. This database could be up to date but needs to be cross-checked with Malawi HISP's DHIS 2 facility list.

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[4] Data points were geolocated using: GPS sources (615), Google Earth (5), Encarta (2), Geonames (7), other sources (4) and a combination of sources (6).

[5] These facilities were accessible only to those able to afford care and do not often feature in anti-malarial and net distribution supply management systems.

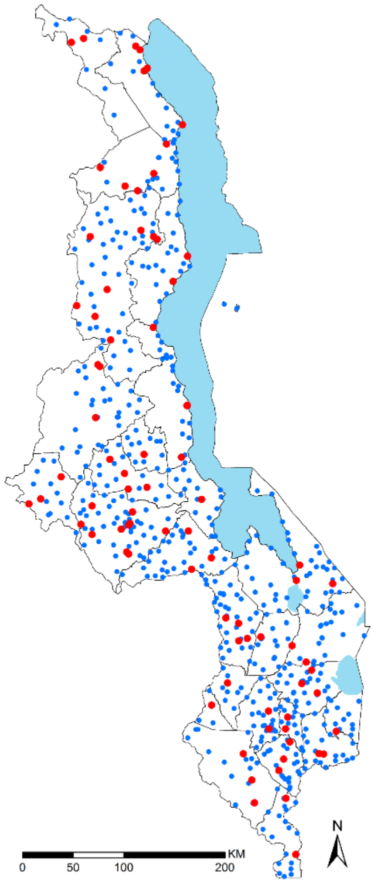

Figure 10. Malawi: Distribution of 639 public health facilities. 82 hospitals (red), 451 health centres, 86 health posts/dispensaries and 20 clinics (blue)

Health context and priorities

Malawi released its the most recent Health Sector Strategic Plan II (2017-2022) (HSSPII) in 2017; it is the second and final medium-term development plan aimed toward achieving Malawi's Vision 2020. The HSSPII also aims to operationalise the National Health Policy to improve health status, increase client satisfaction and increase client satisfaction and increase financial risk protection with the goal of attaining Universal Health Coverage and the 2030 SDGs.

Under the first HSSP, Malawi made notable gains, in particular improvements in child and maternal survival. The HSSP focuses on accelerating movement toward universal health coverage by strengthening health systems for the delivery of an essential health package and tackling social determinants of health. To this end, there are eight objectives:

1) Increase equitable access to and improve quality of health care services
2) Reduce environmental and social risk factors that have direct impact on health
3) Improve the availability and quality of health infrastructure and medical equipment
4) Improve availability, retention, performance and motivation of human resources for health for effective, efficient and equitable health service delivery

5) Improve the availability, quality and utilisation of medicines and medical supplies

6) Generate quality information and make it accessible to all intended users for evidence-based decision-making, through standardised and harmonised tools across all programmes

7) Improve leadership and governance (particularly setting direction and regulation) across the health sector and at all levels of health system

3.5 Malaria in Malawi

Malaria is hyperendemic in Malawi. Transmission occurs throughout the year in most areas, and the entire population is at risk of the disease.

An. funestus is the primary vector of Malawi, but *An. gambiae s.s.* and *An. arabiensis* may predominate in some areas at certain times of the year.[82,83] Plasmodium *falciparum* (P. *falciparum*) is the most common malaria species in Malawi.

WHO reported in 2017 that Malawi accounted for 2% of the global cases of malaria, and 10% of all cases within East and Southern Africa. [84] However, this is a significant improvement from 2010, when estimated cases were placed at 13.4 million and estimated deaths at 25,370.[85]

Malaria control is a long-standing priority of the government's health agenda. The 2006 Malawi Growth and Development Strategy up to the 2017 MGDS all identify malaria as a priority disease. Malawi is also a member of the African Leaders Malaria Alliance (ALMA), an organisation of African Heads of State which endeavours to end malaria-related deaths.

National Malaria Strategic Plan

The HSPP II places emphasis on malaria as a priority disease and stresses that improved malaria prevention and treatment through the EHP will contribute to the achievement of SDG3. In an effort to align national strategic plans, Malawi developed the Malaria Strategic Plan (MSP) 2017-2022 to align with the national and international development agenda. The MSP 2017-22, the country's fourth strategic plan for malaria, aims to reduce malaria incidence by at least 50% from a 2015 baseline of 386 per 1,000 population to 193 per 1,000 and malaria deaths by at least 50% from 23 per 100,000 population to 12 per 100,000 population by 2022. To achieve these strategic goals, the plan states the following objectives:

1. By 2022, at least 90% of the population use one or more malaria preventative interventions.
2. At least 95% of suspected malaria cases will be tested and 100% of confirmed cases treated by 2022.
3. To increase uptake of at least three doses of Intermittent Preventive Treatment (IPTp) from 12% to 60% by 2022
4. To reduce annual average stock out rate of all LA (lumefantrine-artemether) from 7% in 2016 to 3% by 2022.
5. To increase proportion of caregivers of under-five children who take action to seek appropriate malaria treatment within 24 hours of the onset of fever from 31.2% to 50% by 2022
6. To improve data quality by increasing accuracy from 7% to 60% by 2022
7. To improve programme performance in implementing planned MSP activities from 43% to at least 90% by 2022.

An overview of current malaria interventions

Vector control

Vector control is a cornerstone of Malawi's efforts to control malaria. The distribution and promotion of ITNs[6] are a primary malaria control intervention. The country began to transition to the use of LLINs, which are a type of ITN treated to maintain effective levels of insecticide for at least three years, even after repeated washing, in 2007.[86] The country aspires to achieve universal coverage, defined as one LLIN per 1.8 people. These nets are distributed through mass campaigns at three-year intervals, and continuously through antenatal care clinics (ANC) and Expanded Programme on Immunisation (EPI) centres. This routine distribution is implemented in coordination with the Directorate of Reproductive Health.

IRS activities are guided by the Malawi Integrated Vector Management Strategy. PMI piloted IRS with a pyrethroid insecticide in two high-transmission districts in 2007, and the country later supported IRS in five more districts in 2010. However, IRS was met by high levels of pyrethroid and carbamate resistance in *An. funestus*. It was then decided to shift insecticides to a short-acting organophosphate. However, given the high cost, IRS was suspended after 2011. The country's current malaria control strategy states that it will implement IRS in suitable epidemiological areas using non-pyrethroid, non-carbamate insecticides. However, there are no operational indicators specified in the current MSP.

The 2017-20 MSP and integrated vector management (IVM) strategy also propose larval source management in targeted communities; however, as of 2016 there were no such activities. Larval source management entails use of bio-larvicides on mosquito breeding sites and environmental modification to impact the development and survival of vectors. These activities are intended to be performed in collaboration with other sectors such as the Ministry of Public Works, Ministry of Natural Resources Management, Ministry of Agriculture, the city, town and district councils and including the community themselves.

Treatment and case management

Malawi was the first country in sub-Saharan African to switch from CQ (chloroquine) to SP for treatment of uncomplicated malaria.[87] Due to growing resistance to SP, the first-line drug policy for uncomplicated malaria (confirmed and unconfirmed) was again changed to artemether-lumefantrine (LA).

In 2007, Malawi also became one of the first countries to adopt integrated community case management for childhood illnesses (iCCM).[88,89] iCCM is implemented by government employed community health workers, called health surveillance assistants (HSAs), who are trained to treat children (with ACT) for malaria. These HSAs are stationed in hard-to-reach areas which are defined as areas more than five kilometres from a healthcare facility. By the end of 2010, all districts in Malawi had adopted iCCM.

For the management of patients with severe malaria, parenteral artesunate is administered for pre-referral treatment in health centres while rectal artesunate is a recommended pre-referral treatment for suspected severe malaria cases in children under five years of age at the community level. In 2013, the new Malawi national malaria treatment policy recommended that RDTs and pre-referral rectal artesunate be integrated into iCCM.[90]

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[6] Net brands distributed by the NMCP include: PermaNet® 2.0 (Vestergaard Frandsen, Lausanne, Switzerland), Olyset® Net (Sumitomo Chemical Company, Tokyo, Japan), and as of 2016, Royal Sentry® (Disease Control Technologies, USA).[142]

Malaria in Pregnancy

In 2003, Malawi established guidelines for Malaria in Pregnancy (MiP) prevention and treatment in alignment with WHO's three-pronged approach. This approach is focused antenatal care using a three-pronged approach: 1) health facility-based use of intermittent preventive treatment in pregnant women (IPTp) using at least three doses of SP at ANC (antenatal care) appointments; 2) distribution of LLINs to pregnant women free of charge at ANC visits; and 3) effective case management of malarial illness and anaemia. MiP work is carried out in coordination with the Malawi Reproductive Health Unit.

Structure and function of National Malaria Control Programme

The NMCP is a sub-unit within the Directorate of Preventative Health Services. Figure 11 shows the structure of the NMCP and governmental and non-governmental partners.[91]

The NMCP is housed under the Department of National Disease Control and it is led by the Programme Manager, who reports to the head of the director of Preventative Services (

Figure 12). The NMCP is responsible for setting policies and strategies, coordinating national activities among districts, and providing technical guidance and leadership. The districts operate under the leadership of a District Malaria Coordinator and a District ITN Coordinator. District Malaria Coordinator positions are full-time, and the ITN Coordinator positions are held by staff who also operate other roles within the district office.

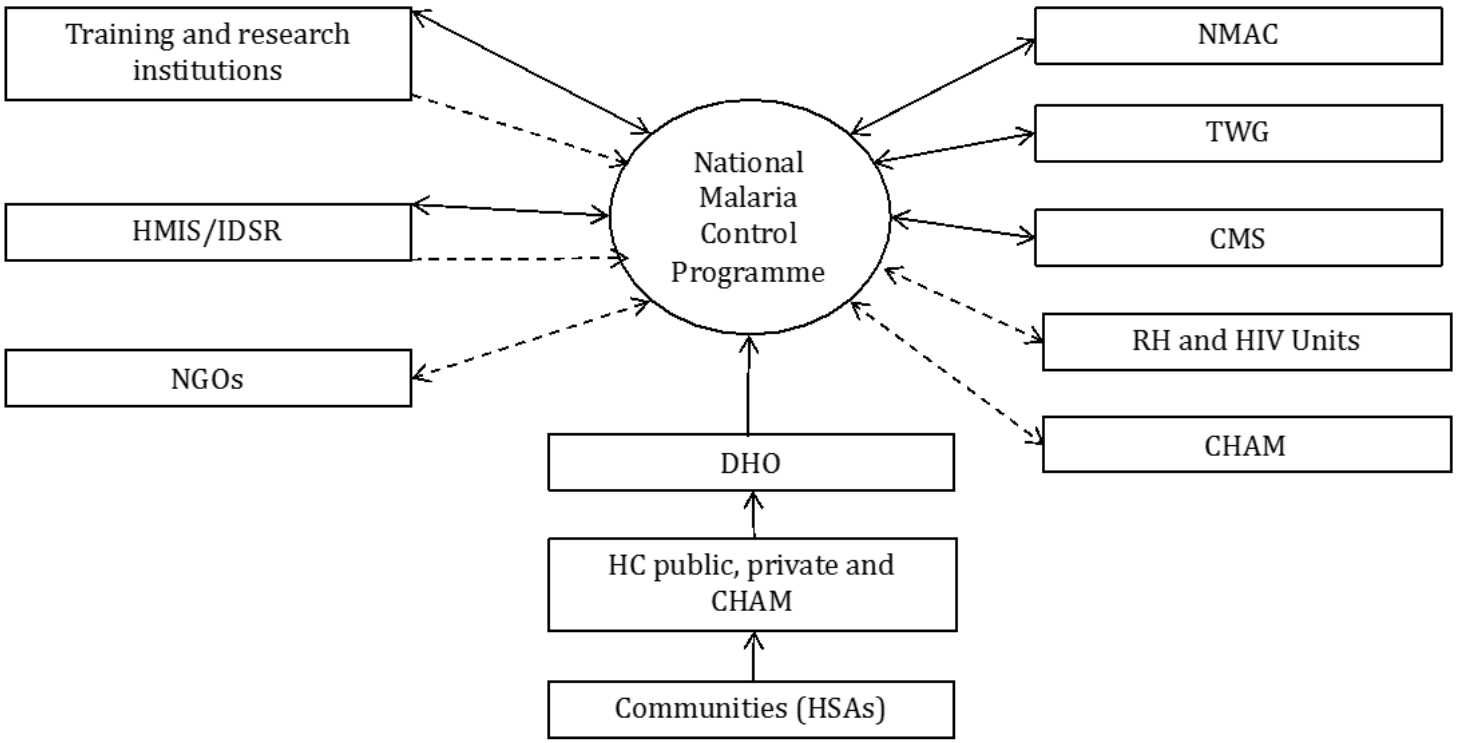
A timeline of malaria control in Malawi

As part of the earlier 2014 malaria risk profile,[92] a comprehensive written history of malaria control in Malawi was prepared. To ground the discussion of malaria control in Malawi, this report summarises major events between the 1900s and present day. Readers are encouraged to reference the written history in full,[92] and to view the Malawi Malaria Control Timeline which is online at www.linkmalaria.org.

Year	Event
1899	British government sent Stevens and Christophers to Blantyre in response to malaria outbreaks
1900	Dr Daniel of Liverpool School of Tropical Medicine discovered Anopheline larvae at 5,000 feet
1902	First detailed mosquito breeding maps made in Likoma island
1902	First malaria risk mapping at Kota-Kota and Malindi performed
1913	Environmental control, personal prophylaxis with quinine, and use of mosquito nets practiced by Europeans
1913	Anti-malarial gangs used until 1925
1921	Brick and cement drainage established by the Mudi Stream
1930	Sanitary Board Ordinance introduced, leading to the establishment of sanitary boards in six districts
1930	Sanitary Inspector appointed at Zomba and managed an anti-malaria gang
1931	Colonial Development Fund (CDF) finances environmental work by town councils in Blantyre and Limbe and use medical officer visits to rural districts
1931	Chief of Sanitary department added mosquito avoidance education to schools in townships
1933	Post Offices used to provide quinine to the general public, continuing until the 1950s
1935	Zomba reported to be free of mosquitoes
1935	Jeane's School at Zomba becomes training centre for sanitary staff, with funding from the Carnegie Trust
1935	Sanitation department merged into Medical Department
1935	Sentinel site system established to document the climate, living conditions and health status of communities in 12 districts
1950	In addition to quinine, mepacrine and paludrine sold at General Post Offices
1950	Gammexane was introduced to tackle epidemics of relapsing fever in the Central and Northern Provinces
1952	Vector Control Units established to carry out spraying of houses in densely populated areas
1956	Spray operations began using gammexane in Zomba and Chiradzulu, covering 230 miles squared and over 43,000 houses
1957	Spraying expanded to Domasi area until 1960
1959	Inter-country malaria eradication project for southern African (South-East African Malaria Eradication Project) formed
1973	WHO sends a mission to Malawi to review disease burden, urban malaria control, and efficacy of pyrithiamine
1973	WHO mission findings spurred recommendation for national expansion of prophylaxis and replacement of pyrithiamine with CQ
1974	Larviciding with malariol used in Lilongwe
1984	Africa Child Survival Initiative-Combatting Childhood Communicable Disease programme starts to research declining CQ efficacy through to 1998
1984	National Malaria Control Programme (NMCP) created under the Division of Preventive Health services through the formation of a National Malaria Control Committee

1984 National Malaria Strategic Plan 1984-1989 released
1984 Efficacy of CQ was assessed at six sites across the country; positive outcomes resulted in CQ being selected as first-line therapy
1986 *In vivo* studies at six sentinel sites revealed deteriorating efficacy of CQ
1987 First national malaria control manager appointed
1990 National Malaria Strategic Plan 1990-1994 released
1990 Health services in Malawi decentralised from the central level to the district level
1990 Studies conducted at Karonga District Hospital and Mangochi found that more than 90% of children treated with CQ remained parasitemic
1990 Trials in Mangochi and Chikwawa showed that SP reduced placental malaria and maternal anaemia
1990 Illovo sugar companies begin IRS twice a year using rotating organophosphates and pyrethroids and later supported pilot activities in Nkhotakota District
1992 Nationwide knowledge attitude and practice (KAP) malaria survey conducted
1992 First Demographic and Health Survey (DHS) conducted
1993 Mangochi Malaria Research Project established
1993 Central Medical Stores purchased and distributed sufficient amounts of SP for use in the health system
1993 NMCP launches malaria treatment guidelines, making Malawi the first country to switch from CQ to sulfadoxine-pyrimethamine (SP) and to recommend SP for pregnant women
1995 Malawi-Liverpool-Wellcome Trust Clinical Research Programme (MLW) established
1995 First Multiple Indicator Cluster Survey (MICS) conducted
1996 Second DHS conducted
1997 Ekwendeni Malaria Control Programme targeted ITNs to 6,000 children under-five and pregnant women
1998 Blantyre Integrated Malaria Initiative (BIMI) launched to improve demand and use of IPTp and ITNs and improve management of paediatric fever and anaemia
1998 Blantyre Insecticide Treated Net Project (BITNet) launched to do social marketing of ITNs, selling more than 90,000 nets
1998 Tests at Salima District Hospital indicated SP resistance
1998 Studies in Machinga showed evidence of early treatment failure to SP and mefloquine (MQ) in children.
1998 Ongoing monitoring of *Plasmodium falciparum* drug resistance in Blantyre showed diminishing clinical and parasitological efficacy of SP
1998 NCMP adopts integrated management of childhood illness (IMCI) strategy
1999 Roll Back Malaria global strategy for the scale-up of malaria control activities adopted
2000 Third DHS conducted
2000 Malawi signed the Abuja Declaration to provide a minimum coverage of 60% protection to vulnerable populations by 2005 and halve the malaria burden by 2010
2001 National Malaria Strategy 2001-2005 launched
2002 NMCP develops guidelines for ITN distribution and use
2002 NMCP launches annual ITN re-treatment campaigns
2002 MoH launches an integrated routine Health Information Management System (HMIS) across the country
2005 National Malaria Strategy 2005-2010 launched
2005 Drug efficacy studies showed that SP had lower clinical and parasitological response than other drug combinations
2006 Second MICS conducted
2006 Integration of free LLINs into routine Expanded Programme on Immunisation (EPI) piloted in Mwanza and Phalombe

2006	Small scale IRS with pyrethroids conducted in Ntchisi
2006	Malaria Alert Centre (MAC) establishes sentinel sites for entomological indices monitoring
2006	NMCP changed drug policy, replacing SP with AL (artemether-lumefantrine) as the first-line treatment, AQ+AS as second-line, and quinine for severe malaria and special cases, SP was retained for IPTp, and ACTs for febrile children under the age of 5
2006	NCMP distributes 660,000 ITNs to extremely poor households
2007	Malawi ITN policy changed to focus on LLIN distribution and scaling coverage
2007	NMCP launches first IRS pilot in Nkhotakota using lambda-cyhalothrin slow-release capsule suspension, protecting 500,000 people
2007	National Malaria Monitoring and Evaluation (M&E) Plan 2007 – 2011 launched
2008	Mid-term review conducted
2008	First mass LLIN campaign launched, distributing 1.1 million nets in total
2008	Routine LLIN distribution through EPI facilities went to scale
2008	IMCI unit rolls out integrated community case management (iCCM) to 4,000 hard-to-reach villages protecting an estimated 10% of population
2009	IRS programme established within Lilongwe district through Nkhoma Mission Hospital and partners
2009	IRS with pyrethroids carried out in Nkhotakota, Salima, Karonga, Nkhata Bay, Mangochi, Chikwawa and Nsanje, covering more than 3 million people
2010	Fourth DHS conducted
2010	PMI initiates sentinel surveillance sites at four hospitals to track changes in morbidity indicators including the testing all fever presentation for parasitaemia using microscopy
2010	MLW establishes a continuous (rolling) Malaria Indicator Survey in Chikwawa district to monitor malaria burden
2010	NMCP conducts a universal net access campaign in six districts
2010	MoH launches a quality assurance programme for both clinical and diagnostic testing for malaria case management in 16 districts
2011	International Centres of Excellence for Malaria Research (ICEMR) establishes sites to collect malaria morbidity and entomology data
2011	Rapid diagnostic tests (RDTs) for malaria diagnosis introduced, phased roll-out of RDTs to health facilities continued through 2016
2011	National Malaria Strategic plan 2011-2016 launched
2011	High levels of pyrethroid and carbamate resistance in *An. funestus* necessitated a shift to organophosphates for IRS
2012	First Malaria Indicator Survey (MIS) conducted
2012	NMCP launches Universal Access Campaign, conducting mass LLIN campaign reaching 5.6 million people
2013	Third MICS conducted
2014	Second MIS conducted
2014	Mass campaign distributed nearly 7 million nets nationally
2014	NMCP conducts Mid-term Programme Review
2015	Fifth DHS conducted, with a separate Micronutrient Survey
2015	Malawi Vector Control Strategy 2015-2019 launched
2015	NMCP launches Malaria Communication Strategy (2015-2020) and a committee to support behavioural change interventions
2015	Health Surveillance Assistants (HSAs) trained on the use of RDTs and pre-referral use of rectal artesunate
2016	Mass LLIN campaign, distributing 8 million nets
2017	Third MIS conducted
2017	Malaria Strategic Plan 2017-2022 launched
2018	Mass LLIN campaign launched, distributing 10.9 million nets



Acronyms

NMCP	National Malaria Control Programme
HMIS	Health information management system
IDSR	Integrated Disease Surveillance and Response
DHO	District Health Office
HSA	Health Surveillance Assistants
NGO	Non-governmental Organisation
CMS	Central Medical Stores
CMS	Central Medical Stores
TWG	Technical Working Group
NMAC	National Malaria Advisory Group
RH	Reproductive Health
HIV	Human Immunodeficiency Virus
CHAM	Christian Health Association of Malawi
- - - - -	Liaison/Consulting
———	Direct reporting

Figure 11. NMCP Coordination structure

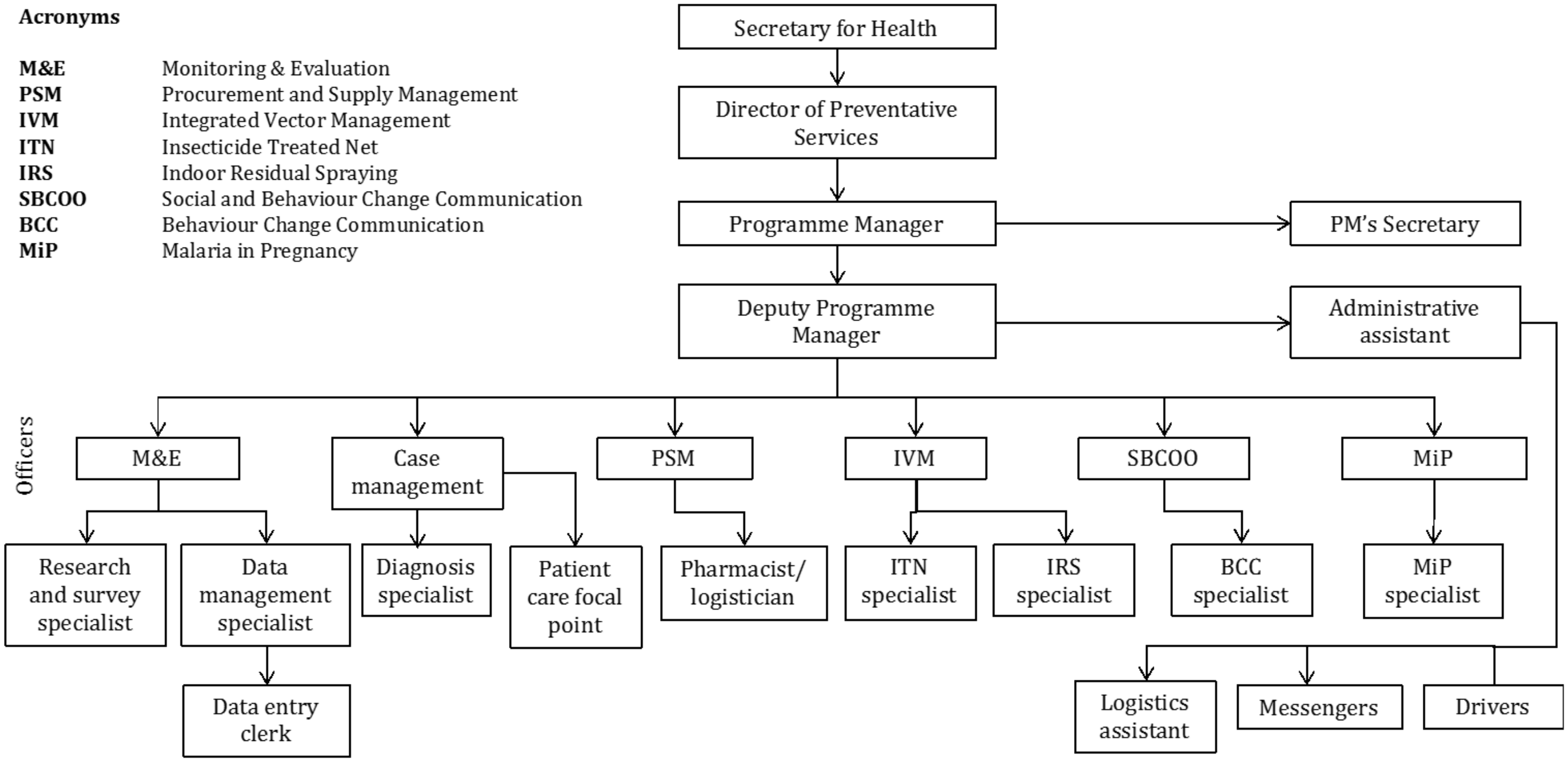


Figure 12. National Malaria Control Programme Organogram (adapted from MSP 2017-22)

Financing malaria control

It is estimated that between 2014 and 2016, less than USD 3 per person at-risk per year was spent on malaria control in Malawi.[84] The majority of funding for malaria prevention, control and treatment came from external donors, as reported by the country in the 2017 WHO World Malaria Report (Figure 12).[85] Though the Malawian government has increased its health spending as a percentage of total national health expenditure (from 22% in 2012 to 28% in 2015), out-of-pocket payments as a percent of current health expenditure have recently increased, from 6% in 2000 to 11% in 2015.[93]

Major external funders are the Global Fund to Fight HIV, Tuberculosis and Malaria (GTFAM) and PMI/USAID. Despite contributions from both the government and external funders, the 2016 MPR reported that the malaria control programme operated on a financial gap throughout the life of the most recent MSP.[7]

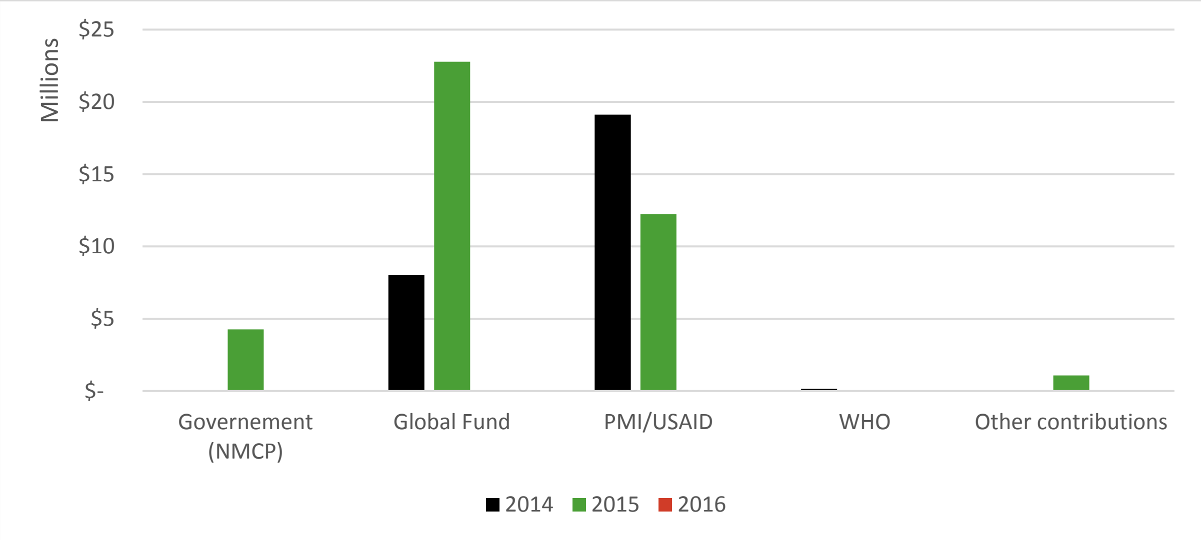


Figure 13. Estimated contributions for malaria reported by Malawi, 2013-2015

Data relevant for malaria control

The 2017-2020 Malaria Strategic Plan calls for improved malaria monitoring and evaluation systems towards achieving enhanced data and programme accountability by 2022. To this end, the NMCP developed the 2011-2015 Malaria Monitoring and Evaluation Plan,[94] which is a sub-system of the Monitoring and Evaluation Plan of the MoH's Health Sector Strategic Plans. The goal of this plan was to provide a comprehensive framework for obtaining reliable and consistent data for assessing progress in universal coverage of malaria interventions and disease burden reduction.

The Central Monitoring and Evaluation Department (CMED) is responsible for all information systems within the MoH. Its statistical responsibilities include:

1. Designing, developing and improving data collection tools for all levels of the health care systems.
2. Establishing and maintaining central and district level databases and to network with other M&E/research organisations/institutions/networks and sharing information and lessons learnt
3. Linking with the National Statistics Office during major surveys to ensure collection of relevant monitoring indicators.

Routine health information systems

Health Management Information System (HMIS)

HMIS, which has been operated through the District Health Information System 2 (DHIS 2) since 2012, is the country's main tool for collecting data for the NMCP monitoring and evaluation framework. The HMIS system is harmonised and centrally-operated by CMED. Eighty-four core indicators are collected and reported from community, facility, district and national level through routine reports (
Figure 14).

At the community level, HSAs collect data for the HMIS using a paper form and send these forms to the respective health facility. At the health facility level, data is initially captured in individual registers where patient-level data is recorded; a focal person compiles data from the register to prepare an HMIS form with summary measures. In 2017, the revised HMIS outpatient department registries and malaria reporting forms for malaria were rolled-out.[95] In 15 districts, health facilities are using DHIS 2 Mobile, a module within DHIS 2 which allows data capture into DHIS 2 through mobile phones at the data collection point.[96] Facilities using DHIS 2 Mobile continue to use paper reporting system as a back-up.

Health facilities submit data (from the community and health facility levels) to the district health programme coordinator in paper format. For districts using DHIS 2 Mobile, this is also done electronically. Central hospitals collect data for the HMIS using a paper form and submit this to the district level.

Aggregated data from the health facilities are received at the district level, where HMIS officers verify the data before capturing the data into DHIS 2.

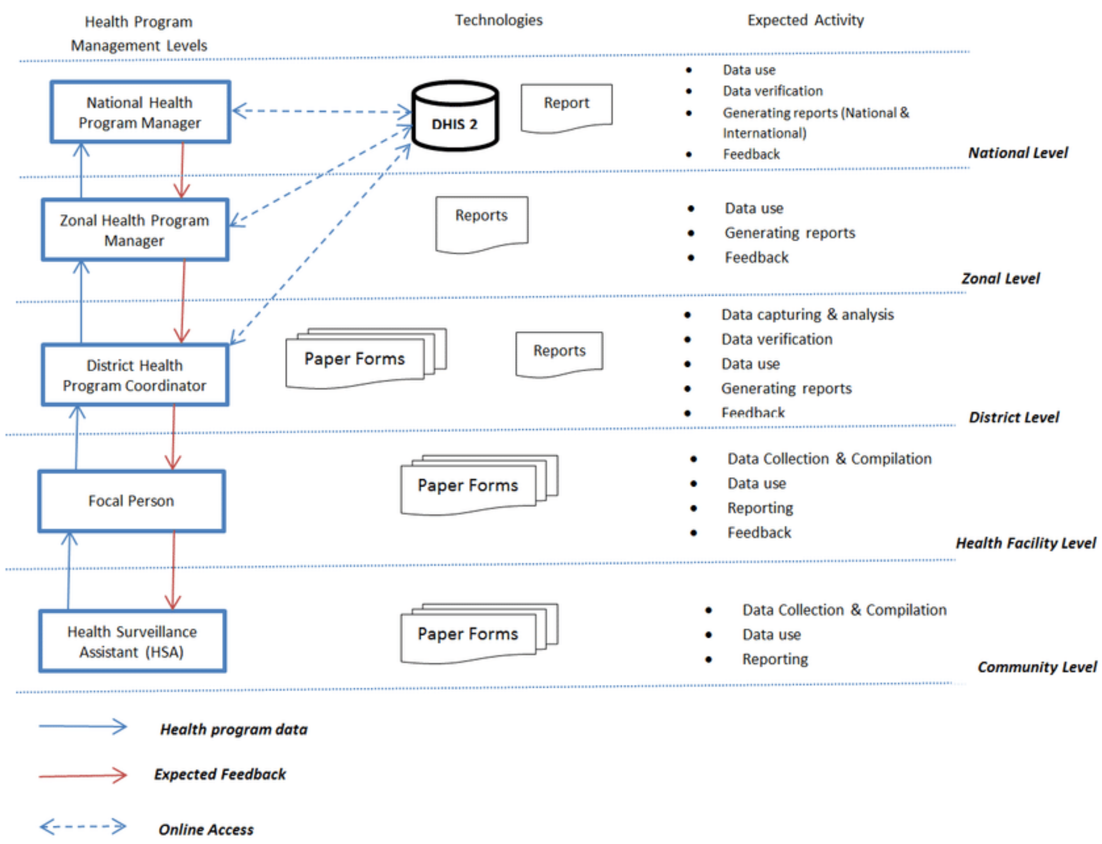


Figure 14. Expected data flow in Malawi HMIS and position of DHIS 2[96]
Figure from Chikumba, P.A., 2017. Management of Health Information in Malawi: Role of Technology. *Advances in Science, Technology and Engineering Systems Journal*, 2(1), pp.157–166.

The malaria measures in the DHIS 2 are Out-Patient Department (OPD) malaria cases and inpatient malaria deaths, disaggregated by age (under five years of age or 5 years or older). In 2012, CMED and the NMCP made plans to integrate additional malaria-specific indicators into the DHIS 2. These indicators are: number of suspected malaria cases tested by microscopy or RDTs, number of confirmed malaria cases at OPD, number of clinical in-patient malaria cases, number of confirmed in-patient malaria cases, and number of malaria deaths. For pregnant women, data is collected on numbers receiving two or more doses of IPTp, antenatal attendance, and test positivity rates among pregnant women. A mobile/web-based platform collects data on drug distribution to community outlets and stock-outs of AL.[97] Data elements for malaria are disaggregated by age (ie, under five years and five years or more).

Health Technical Support Services (HTSS) within the MoH is the unit responsible for the management of the logistics management information system (LMIS) for all health products in the country. This system monitors the movement of health commodities, including malaria drugs. The LMIS is currently not linked to DHIS 2 (it operates off of a single-user Microsoft Access Database).

Integrated Disease Surveillance and Response

Intagrated Disease Surveillance and Response (IDSR) is a sub-system of the HMIS system which was introduced in 2002[98] to improve surveillance of emerging public health threats. IDSR collects data on clinical outpatient department (OPD) malaria cases, number of suspected malaria cases tested by microscopy, number of OPD malaria in pregnancy cases, number of inpatient malaria in pregnancy cases, number of in-patient malaria cases, and number of malaria deaths. IDSR is managed by the Epidemiology Department of the MoH; at the district level it is overseen by an IDSR Focal Person.

Sentinel sites

The NMCP maintains sentinel surveillance sites for monitoring drug efficacy, entomological studies and malaria morbidity trends. These sites are located in Chikwawa, Karonga, Lilongwe, Machinga, Mangochi, Mwanza, Nkhotakota, and Rumphi. Sites in Karonga, Lilongwe, Machinga, Mangochi, Nkhotakota, and Rumphi capture data on antimalarial drug efficacy and effectiveness every two years. In districts where IRS is planned or ongoing (Nsanje, Chikwawa, Machinga, Salima, Mchinji, Nkhotakota, Nkhatabay and Karonga), sentinel sites conduct entomologic surveillance, measuring insecticide resistance to organophosphate and a pyrethroid insecticides among *Anopheles* populations. Entomologic surveillance includes vector abundance monitoring in three villages in each of the seven IRS districts.

Finally, since 2008 in collaboration with the Malaria Alert Centre (MAC) and with funding from PMI, a selection of sites (Bolero Rural Hospital in Rumphi, Mitundu Community Hospital in Lilongwe, Mwanza District Hospital and Matiki Health Centre in Nkhota Kota) have collected data on number of fever cases, number of fever cases tested for malaria with either RDT or microscopy, and treatment practices. These data are used by the NMCP, MAC and other malaria partnersto examine trends in malaria morbidity.[99]

Between 2005 and 2009, MAC also conducted repeated surveys at several sites to measure malaria parasitaemia and prevalence of anaemia in children 6-30 months old in six districts, with four from the Southern Region (Chiradzulu, Mwanza, Phalombe, and Blantyre), and one each from the Central Region (Lilongwe) and the Northern Region (Rumphi). This strategy was extended to include two additional districts (Nkhotakhota in the Central Region and Karonga in the Northern Region) in 2007, 2008 and 2009. These surveys were conducted in April of each year at the end of the wet, high transmission season.

From 2010 to 2013, PMI established sentinel surveillance sites at four hospitals (Mwanza district Hospital, Mitundi Hospital, Rumphi District Hospital and Nkhotakota hospital) to track changes in morbidity indicators, which involved microscopy testing of all fever presentations for parasitaemia.

In 2010 the Malawi-Liverpool-Wellcome Trust Clinical Research Programme in Malawi introduced a continuous ("rolling") MIS (rMIS) as part of a randomised, controlled trial to monitor the malaria burden in Chikwawa district by sampling 50 villages at least once every six months. The rMIS collects data on the prevalence of anaemia and parasitaemia, as well as LLIN and IRS coverage and access to treatment among children ages six to 59 months.

Since 2010, International Centres of Excellence for Malaria Research (ICEMR) have operated sites in Blantyre city, Chikwawa and Thylo districts where malaria morbidity and entomology data are collected biannually in the dry and rainy seasons.

Large-scale household surveys

Large-scale household and health facility surveys are a major source of malaria data in Malawi. The Demographic and Health Surveys (DHS) are nationally-representative household surveys, typically sampling between 5,000 and 30,000 households every five years. These surveys are designed to provide reliable estimates of malaria prevalence at regional and national level only. Malaria-relevant data collected by DHS are: ownership and use of mosquito nets, prevalence and treatment of fever in the past two weeks and IRS. Sometimes these surveys include malaria-specific modules which include additional questions on IRS, as well as biomarker testing for anaemia and malaria. The DHS is carried out throughout both rainy and dry seasons, therefore not accounting for seasonality.

The MIS is a stand-alone household survey that collects national, regional, and/or provincial data. These surveys are timed to malaria transmission seasons and collect data for a set of malaria indicators. The household questionnaire collects data on household ownership and use of mosquito nets, and identifies children ages 6 to 59 months who are eligible for the biomarker test, which includes an RDT and microscopy (think and thick blood smears which were sent to the national laboratory). All children found to be positive for malaria though this test are offered a full course of malaria treatment in accordance with national guidelines. A women's questionnaire includes questions about access of IPTp, about the prevalence and treatment of fever among children under five, and about knowledge about malaria

Results of recent major household surveys

In 2012,[100] 2014[101] and 2017[102] MIS surveys were conducted to measure coverage and use of malaria control interventions. In 1992,[103] 2000,[104] 2004,[105] 2010[86] and most recently in 2015-6[106] the DHS was conducted. The 2000, 2010 and 2015 surveys included questions on anaemia and the 2010 and 2015 surveys included a malaria module with a ITN/LLIN inventory. The findings of these surveys are summarised below.

2010 DHS

The 2010 DHS found that severe anaemia prevalence (haemoglobin [hb]<8.0 g/dl) among children 6-59 months was 9%. Fifty-five percent of women age 15-49 with a live birth in the two years preceding the survey had received at least two or more doses of SP at an ANC visit.

This survey indicated that 57% of households owned at least 1 ITN, and 41% owned at least one LLIN. Twenty-nine percent of households reported sleeping under an ITN the preceding night, and 19% reported sleeping under an LLIN. Of households that had reported owning at least one ITN, 48% reported sleeping under the net the previous night.

Thirty-five percent of children under five slept under an ITN the preceding night, and of households reporting owning at least one ITN, 59% of children slept under an ITN the previous night. Thirty-five percent of pregnant women slept under an ITN the preceding night, and of households reporting owning at least one ITN, 57% of pregnant women slept under an ITN the previous night.

2012 MIS
The 2012 MIS found that *Pf*PR among children ages six to 59 months of age was 43% by RDT and 28% by microscopy. Severe anaemia prevalence (hb<8.0 g/dl) among children ages 6-59 months was 9%.

The survey found that 54% of women aged 15-49 with a live birth in the two years preceding the survey had received at least two or more doses of SP.

Nineteen percent of households reported having at least one ITN or LLIN for every two persons staying in the household the previous night. Overall, 40.4% of the population reported sleeping under an ITN the previous night, and 40% reported sleeping under an LLIN. Of households with at least one ITN nearly 70% reported sleeping under an ITN the previous night.

The survey found that 55% of all children under the age of five slept under an ITN the preceding night, and 51% of all pregnant women ages 15-49 surveyed had slept under an ITN the preceding night.

2014 MIS
The 2012 MIS found that *Pf*PR among children ages six to 59 months of age was 37% by RDT and 33% by microscopy. Severe anaemia prevalence (hb<8.0 g/dl) among children ages 6-59 months was 6%.

The survey found that 64% of women aged 15-49 with a live birth in the two years preceding the survey had received at least two or more doses of SP.

Thirty percent of households reported having at least one ITN or LLIN for every two persons staying in the household the previous night. Overall, 53% of the population reported sleeping under an ITN the previous night, and 52% reported sleeping under an LLIN. Of households with at least one ITN nearly 72% reported sleeping under an ITN the previous night.

The survey found that 67% of all children under the age of five slept under an ITN the preceding night, and 62% of all pregnant women ages 15-49 surveyed had slept under an ITN the preceding night.

2015 DHS
The 2015 DHS did not measure *Pf*PR, but the Malawi Micronutrient Survey 2015-6 did collect this information. The Malawi Micronutrient Survey found that *Pf*PR among children ages six to 59 months of age was 27% by RDT (and 42% for children ages 5 to 14 years). The 2015 DHS found that severe anaemia prevalence (hb<8.0 g/dl) among children ages 6-59 months was 6%.

The survey found that 63% of women aged 15-49 with a live birth in the two years preceding the survey had received at least two or more doses of SP.

Twenty-four percent of households reported having at least one ITN for every two persons staying in the household the previous night and 23% reported having at least one LLIN for every two persons. Overall, 34% of the population reported sleeping under an ITN the previous night, and 30% reported sleeping under an LLIN. Of households with at least one ITN 59% reported sleeping under an ITN the previous night.

The survey found that 43% of all children under the age of five slept under an ITN the preceding night, and 44% of all pregnant women ages 15-49 surveyed had slept under an ITN the preceding night.

2017 MIS
The 2017 MIS found that *Pf*PR among children ages six to 59 months of age was 36% by RDT and 24% by microscopy. Severe anaemia prevalence (hb<8.0 g/dl) among children ages 6-59 months was 5%.

The survey found that 76% of women aged 15-49 with a live birth in the two years preceding the survey had received at least two or more doses of SP.

Forty-two percent of households reported having at least one ITN for every two persons staying in the household the previous night. Overall, 55% of the population reported sleeping under an ITN the previous night and of households with at least one ITN 66% reported sleeping under an ITN the previous night.

The survey found that 67% of all children under the age of five slept under an ITN the preceding night, and 63% of all pregnant women ages 15-49 surveyed had slept under an ITN the preceding night

*Pf*PR in children is heterogeneous in Malawi. The 2017 MIS found that childhood prevalence of malaria was higher in rural areas (4% urban, 28% rural), and higher in the Central (26%) and Southern (26%) regions than the Northern region (11%).

Progress with control is not expected to be homogeneous and it will become increasingly important to understand variations in malaria epidemiology with greater spatial resolution. DHS, MIS and other nationally representative household surveys are designed to be representative at the regional level (though domains contain districts which share similar malaria burden or have a shared malaria intervention). The modelling methods presented in Sections 4 and 6 offer an approach to leverage data from these nationally representative surveys to offer district-level estimates.

3.6 Drug and insecticide resistance

Drug resistance

In 1993, Malawi became one of the first countries to adopt IPT-SP following increasing evidence of CQ resistance.[107,108] SP has remained the only available treatment for uncomplicated malaria in government facilities since the early 1990s.

By 2007, SP efficacy was failing which compelled the country to switch from SP to ACTs as the first-line treatment for uncomplicated P. *falciparum* malaria, though SP continued to be used for IPTp.[109–111] Five years after the removal of SP for uncomplicated malaria, SP-resistant malaria persisted and that the genetic nature of the resistance meant it was unlikely a return of SP-susceptibility would be observed in the absence of SP pressure.[110]

Insecticide resistance

In 2007, WHO phenotypic resistance assays found that *An. funestus* and *An. gambiae s.l.* were susceptible to all insecticides, but by 2010 resistance of both species to pyrethroids was had been detected.[112,113] Between 2007 and 2015, *An. funestus* resistance to pyrethroid (permethrin and deltamethrin) and carbamate (bendiocarb and propoxur)insecticides were recorded in multiple locations across Malawi. [114,115] *An. funestus* remains susceptible to the organophosphate malathion and DDT were confirmed (as of 2012).[114,115]

3.7 History of risk mapping in Malawi

In 2006, model-based geostatistical (MBG) methods using empirical P. *falciparum* parasite prevalence data was used for the first time in Malawi to predict malaria risk across the country.[116] The output of this work, performed by Kazembe et al. (2006), is presented in

Figure *15* and shows malaria prevalence data among children aged 1-10 year from 73 survey locations sampled between 1970 and 2001. Mean annual maximum temperature, rainfall, potential evapotranspiration and elevation were all used as covariates to predict P. *falciparum* prevalence at unsampled locations using information and correlates from sampled locations. Bayesian statistical inference was used to predict estimations using prior distributions around each of the parameters. The P. *falciparum* map produced by Kazembe et al. (2006) (

Figure *15*) was not used in any NMCP products until the MPR in 2010.[117]

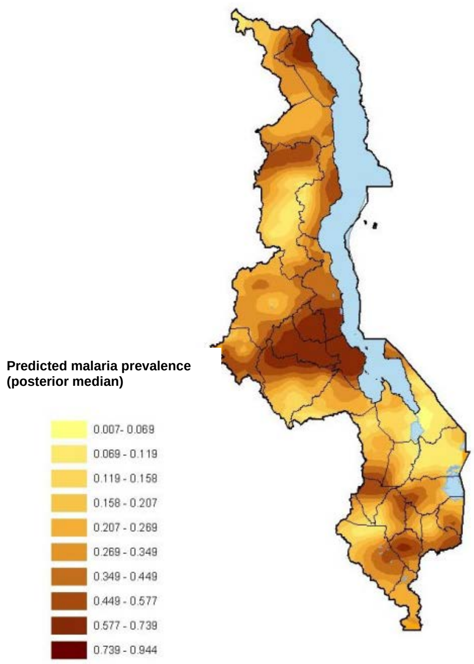


Figure 15. Posterior predicted malaria prevalence among children aged one to ten years based on a MBG approach to interpolating risk from 73 empirical survey data points[116]

The *P. falciparum* map produced by Kazembe et al. (2006) was presented in the 2010 MPR and later used in the NMSP III (2011-2015). In the NMSP III, a confirmation of dominant vectors and variation in risk across the country was made for the first time.[91]

The first seasonal profiles for malaria risk were developed in the early 2000s by the Mapping Malaria Risk in Africa (MARA/ARMA) collaboration. These climate suitability maps were based on the likelihood of stable transmission using a rules-based approach.[118,119]

A more recent attempt at using empirical data to define extremes of seasonality for seasonal malaria chemoprevention (SMC) was done in 2012 by Cairns et al. (2012)[120] using Fourier processed daily rainfall data 100 [http://www.cpc.noaa.gov/products/fews/rfe.shtml] since 2000 and tested against monthly clinical incidence data from 55 sites across sub-Saharan Africa. The optimal model was one where 60% of annual rainfall occurred within 3 months and best fitted the seasonal clinical profiles of >60% of cumulative cases occurring in 4 consecutive months. Using this rainfall, profile areas with incidence patterns suitable for SMC were identified, with a sensitivity of 95.0% and a specificity of 73.5%.[120]

Other mapped products available between 2000 and 2012 included a climate suitability map developed by the MARA collaboration (based on the likelihood of stable transmission using a rules-based approach[118]), as well as an MBG model of risk using 396 data points and a Markov Chain Monte Carlo (MCMC) Bayesian model to produce an interpolated map of childhood malaria prevalence for the year 2010 as part of the Malaria Atlas Project (MAP). Both of these maps were not resolved to district-level, rather to a 30 by 30km[118] and the 3·75° by 2·5°[119] resolution, which is below the district-level.

Other mapped products available to the NMCP between 2000 and 2012, but not used, included a climate suitability map developed by the MARA collaboration, based on the likelihood of stable transmission using a rules-based approach [Craig et al., 1999]13 and a MBG model of risk using 396 data points and a Markov Chain Monte Carlo (MCMC) Bayesian

By 2010, there was a growing desire to use epidemiological stratification in the design of malaria control interventions in Malawi. The MPR made three specific recommendations: a) malaria prevalence survey sampling should powered estimate prevalence at district level; b) there is a need for detailed analysis and triangulation of different data sources to determine the current epidemiological situation and update the malaria epidemiology map; and c) decisions on scaling-up of malaria control interventions should be based on points a) and b).[117]

Between 2011 and 2012, two approaches to using empirical parasite prevalence data from 2009 to 2010[121] and subsequently from 2000 to 2010[122] produced updated MBG mapped products of P. *falciparum* prevalence in Malawi. The process of developing these maps included national partners and information that was resolved to district-levels. These initial models did not include all available parasite prevalence data, including the national Malaria Indicator Survey of 2012, and use either simple interpolation methods[121] or more complex MCMC methods.[122] In 2014, the LINK programme conducted a detailed assembly of data, using simpler adaptations of MBG to make predictions in time and space, and resolve all information to district-level decision-making units.

4. Malaria prevalence mapping

P. falciparum is the most common malaria species in Malawi. In this report, where it is not specified, readers should take prevalence to mean P. *falciparum* prevalence.

Typically, national household surveys are designed to estimate P. *falciparum* prevalence at national and regional levels and rarely representative of lower levels such as districts. Therefore, simply aggregating survey data to provide district level estimates of an outcome of interest result in estimates with wide confidence intervals or low precision. Additionally, while smaller prevalence studies offer a detailed picture of malaria burden in an area, they do not alone offer insight into burden across a district or within a country.

This profile builds upon survey and prevalence study data already available, using model-based geostatistical methods to generate district-level estimates which are more reliable and which are comparable over time.[123,124] Here we detail how the models of malaria prevalence in Malawi were assembled and validated. We will also present the maps of prevalence models which were produced through these modelling methods.

4.1 Assembling malaria survey data into a single geocoded repository

Data searches

Methods to identify sources of information have been opportunistic, cascaded approaches and included the use of personal contacts among the research communities in Malawi. More traditional peer-reviewed publication searches were also performed, including: PubMed, Google Scholar, the WHO Library Database and African Journals Online. In all digital electronic database searches for published work the free text keywords "*malaria*" and "*Malawi*" were used. The last electronic search was completed in September 2018. Finally, survey data from the national household surveys in 2010, 2012, 2015 and 2017 were also identified. A full description of survey data assembly methods is provided elsewhere.[125] All those who aided in locating survey reports, university theses and unpublished data or provided help in geo-coding of the survey data are listed in the front of the report.

Data extraction

From each of the survey reports the minimum required data fields for each record were: description of the study area (name, administrative divisions and geographical coordinates, if available), start and end of survey dates (month and year) and information about blood examination (number of individuals tested, number positive for *Plasmodium* infections by species), the methods used to detect infection (microscopy, RDTs, Polymerase Chain Reaction [PCR] or Loop-mediated isothermal amplification [LAMP]) and the lowest and highest age in the surveyed population (decimal years). For data derived from randomised controlled intervention trials, data were only selected when described for baseline, pre-intervention and subsequent follow-up cross-sectional surveys among control populations. The month of survey was occasionally not possible to define from the survey report. Descriptions of "wet" and "dry" season, first or second school term or other information was used to make an approximation of the month of survey.

Where age was not specified in the report but a statement was made that the entire village or primary school children examined the age ranges to be 0-99 years or 5-14 years were assumed respectively. Surveys covered many different age ranges, to make meaningful comparisons in time and space, a single standardised age range is required. Correction to a standard age for *P. falciparum* was done using adapted catalytic conversion Muench models, into static equations in

R-script that uses the lower and upper range of the sample and the overall prevalence to transform into a predicted estimate in children aged two to ten years, $PfPR_{2-10}$.[126]

Geocoding locations of each survey

During data extraction, each data point was recorded with as much geographic information from the source as possible and this was used during the geo-positioning, for example checking the geo-coding placed the survey location in the administrative units described in the report or corresponded to other details in the report on distance to rivers or towns when displayed on Google Earth. According to their spatial representation, data were classified as individual villages, communities or schools or a collection of communities within an area covering a 5 km grid or approximately 0.05 decimal degrees at the equator (point). Preference was given to point data, however, areas more than 5 km^2 were classified as "wide-areas" (<10 km^2), and those where data was only available across larger administrative units included as "polygons," and excluded from the analysis.

More recent use of Global Positioning Systems (GPS) during survey work enabled a re-aggregation of household survey data, to increase the sampling precision by combining clusters of small sample sizes in space, while maintaining the 5 km grid criteria. While in theory GPS coordinates should represent an unambiguous spatial location, these required careful re-checking to ensure that the survey location matched the GPS coordinates and all coordinates located on populated communities. To position each survey location where GPS coordinates were not available, a variety of digital resources were used: Microsoft Encarta Encyclopaedia, Google Earth, Fallingrain, African Data Sampler and digital place name gazetteers of schools and health centres in Malawi.

We have restricted the data reference period between 2000 and 2017. This period includes the maximal amount of data and includes years when national household surveys were conducted. Between 2000 and 2017, a total of 2,237 independent survey data points were identified at 1,834 unique locations, representing a total population of 59,920. To note, the 2017 MIS was based on 150 clusters, 3,729 households and 16,755 respondents. All data points were geocoded (Figure 16).

Eighty-three percent of the surveys used microscopy for parasite detection and 17% used RDT. Of the surveys which used RDT, 57.9% used SD Bioline, 6.1% used immunochromatographic test (ICT) Malaria PF, 8.4% used First Response and 27.6% were not known. 86.3% of the surveys were geocoded using GPS, 0.8% by Google Earth/Encarta, 0.5% by personal communication and 12.4% by other methods. The maximum $PfPR_{2-10}$ value identified was 99.79%, the minimum was 0.0%, and the median value was 21.08% (IQR:39.88%). A complete, geocoded database of survey data (2000-2017) is provided to the NMCP with this report.

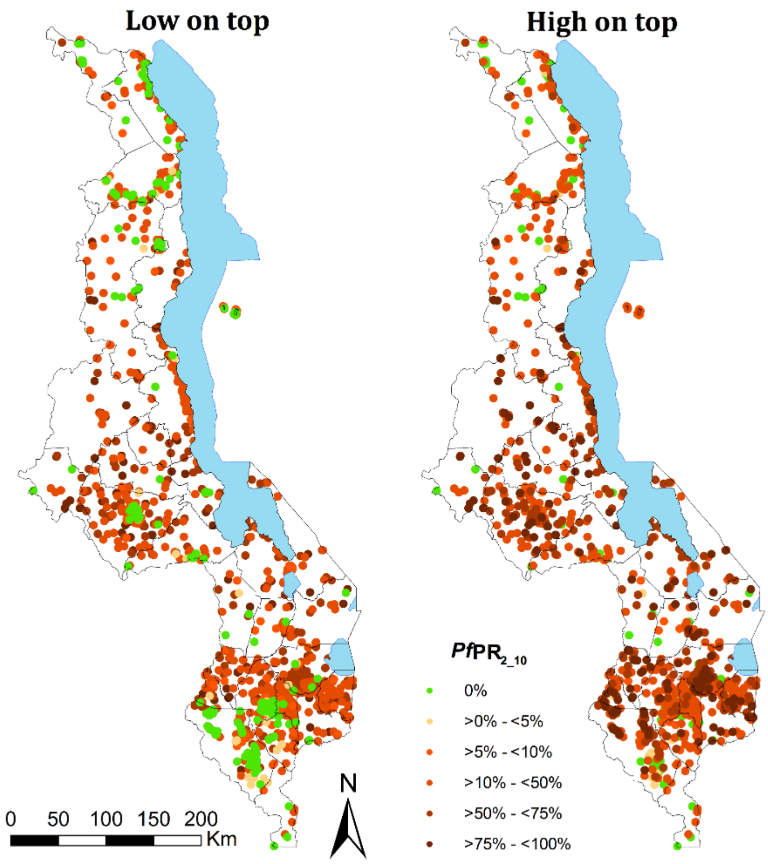


Figure 16. The age-corrected *P. falciparum* infection rates at 1,834 unique locations between 2000 and 2017, showing the lowest values on-top among 2,237 survey points 2000-17 (L) and highest values on top (R)

4.2 Statistical approaches to locality risk mapping

Model form

The analysis of research data undertaken in different parts of the country, regional school surveys and national household survey in one combined way, requires MBG. MBG is a modelling framework that allows us to make the best possible use of the data by providing a statistically principled approach that deals with uncertainty. These statistical methods draw on the basic principle that things that are close in space and time are more related than distant things (also known as the first law of geography) (i.e. surveys conducted in the same district will have a more similar measure of malaria risk than surveys in different districts far from each other, or surveys that are one year apart will have a more similar malaria risk than surveys undertaken decades apart).[127] The mathematical details that translate the first law of geography into geo-statistical models are described elsewhere[128] and used recently to provide malaria risk maps in Somalia.[129]

In the current modelling exercise, no environmental or ecological covariates are used to assist in malaria predictions. These become important when data are very sparse, and there is a well-defined biological relationship in each setting with the covariates selected. For the current modelling exercise in Malawi, it is simply assumed that the parasite prevalence at a given location is a product of its climate and control environment, without presuming the biology of climate to infection prevalence.

The spatio-temporal variation in *Pf*$PR_{2\text{-}10}$ was modelled using geostatistical methods[128–130] to borrow strength of information across time and space. Let *x* be the location of a surveyed community in year *t*. We then use *S(x,t)* to denote the variation in malaria risk between communities (e.g. variation due to different environmental conditions) and *Z(x,t)* the variation within communities (i.e. genetic and behavioural traits). In statistical jargon, *S(x,t)* and *Z(x,t)* are so-called random effects that are used in a model in order to capture the effects of unmeasured malaria risk factors.

The input data was the observed *Pf*$PR_{2\text{-}10}$ values at location *x* (n=1,834) and year *t*. We defined a logit-linear model for *Pf*$PR_{2\text{-}10}$ as*:*

$$log\left\{\frac{PfPR(x,t)}{1-PfPR(x,t)}\right\} = \alpha + \beta * mA + \gamma * MA + S(x,t) + Z(x,t),$$

where mA and MA are the min and max age among the sampled individuals at location x*.*

The model parameters were estimated via maximum likelihood in the R software environment (version 3.4.1) using logit-transformed prevalence.[131] The targets for the predictions were *Pf*$PR_{2\text{-}10}$ over the 1 x 1 km regular grid surface covering the whole of Malawi. Maps of malaria risk were generated for the years 2010, 2012, 2014 and 2017 in ArcMap version 10.5 (ESRI Inc., Redlands, CA, USA) (Figure 20) and average *Pf*$PR_{2\text{-}10}$ binned to six classes of risk per district (Figure 18). The prevalence values represented in the map are presented in Table 2.

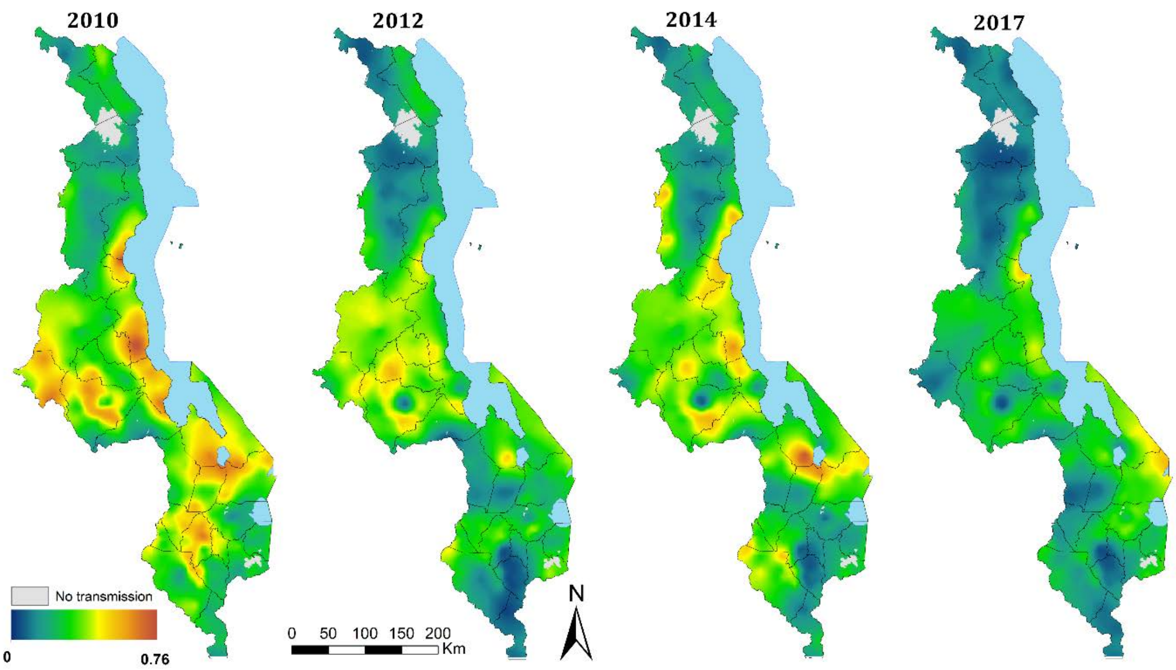


Figure 17. Continuous predicted *Pf*$PR_{2\text{-}10}$ estimates for Malawi in 2010, 2012, 2014 and 2017 *Ranging from yellow low to red high through intermediary prevalence blue. Grey masks shows areas unable to support stable transmission.*[132]

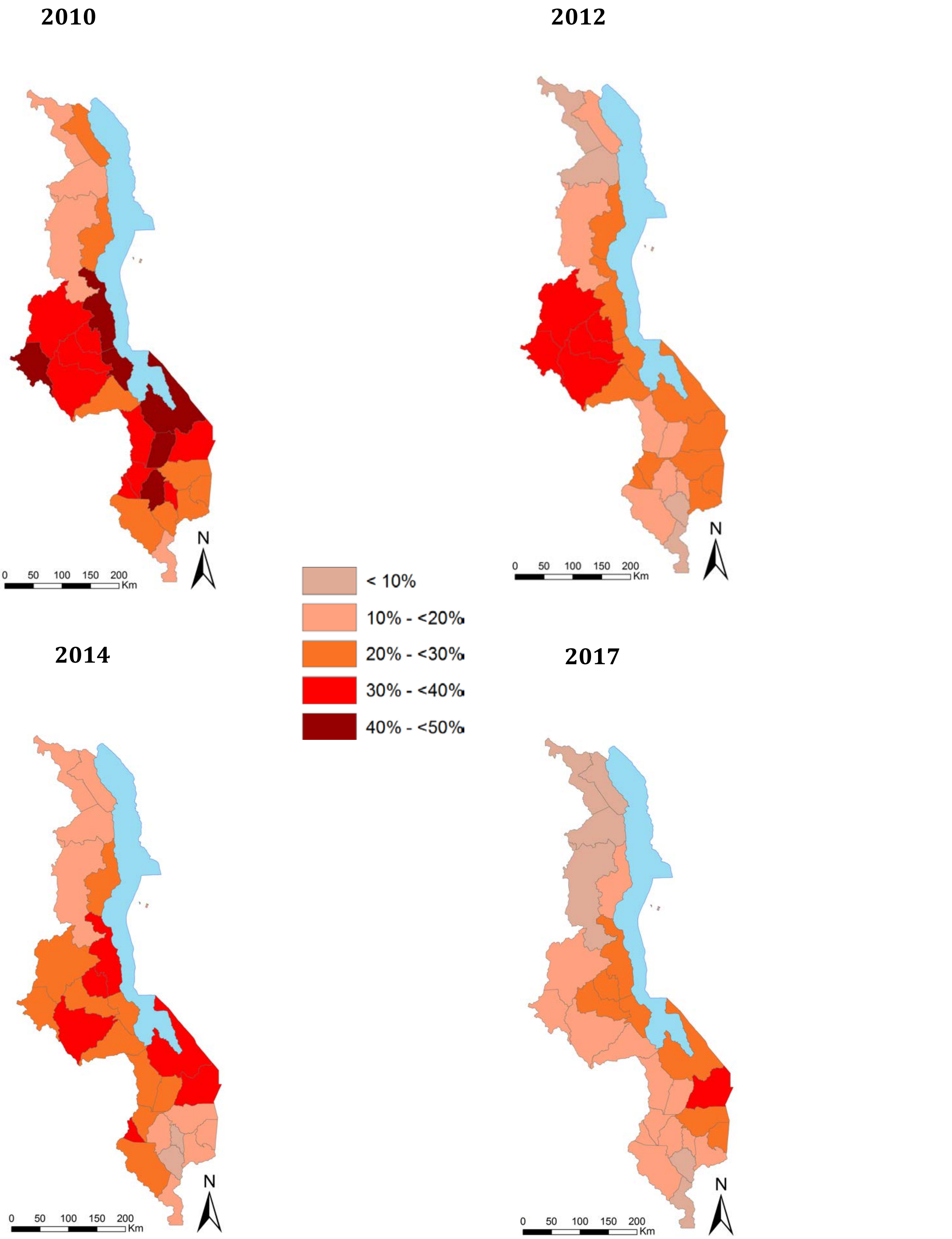


Figure 18. Binned predicted average quantities of *Pf*PR$_{2-10}$ by district in 2010, 2012, 2014 and 2017: <10%, 10-<20%, 20-<30%, 40-<50%

In general, malaria incidence has decreased throughout Malawi since 2010, except for Zomba district, where prevalence increased by nearly 25% since 2010. Prevalence in Zomba in 2017 was estimated at 25% where prevalence had been estimated at 20% in 2010 and 15% in 2014. In Mchinji, prevalence decreased by nearly 80%. Similarly, prevalence decreased by more than 50% in 13 additional districts. In Lilongwe and Chikwawa, prevalence dropped by nearly 50% since 2010.

In seven districts, prevalence fell to below 10% in 2017 (Rumpi, Nsanje, Likoma, Chitipa, Karonga and Thyolo). The districts with the highest estimated prevalence in 2010 were Manoguchi (41%), Balaka (41%), Blantyre (44%), Nkhotakota (45%), Mchinji (47%) and Salima (49%). By 2017, Mchinji had decreased prevalence by 79%, Balaka by 67%, Blantyre by 15%, Salima by 22%, Mangochi by 28% and Nkhotakota by 45%.

Table 2. Predicted average $Pf\mathrm{PR}_{2-10}$ in 28 districts in 2010, 2012, 2014 and 2017

District	2010	2012	2014	2017	Estimated % change relative to 2010
Mchinji	47.3	31.7	24.8	10.4	-77.9
Neno	39.1	22.5	23.0	12.0	-69.4
Blantyre	44.0	18.8	18.3	14.5	-67.0
Balaka	40.9	14.2	25.0	13.7	-66.6
Karonga	20.6	18.2	14.1	7.4	-63.8
Chiradzulu	33.0	12.1	8.4	12.2	-63.2
Thyolo	20.5	4.6	8.7	7.7	-62.5
Nsanje	16.6	5.4	13.0	6.6	-60.2
Ntcheu	32.0	12.2	22.6	12.8	-59.9
Mwanza	30.7	25.7	30.1	12.7	-58.5
Rumphi	12.8	9.0	12.5	5.4	-57.6
Chitipa	16.0	9.0	11.3	7.2	-54.7
Salima	49.1	27.4	29.7	22.6	-53.9
Likoma	14.1	10.1	15.8	6.8	-52.1
Mzimba	18.1	15.7	20.0	9.0	-50.4
Chikwawa	27.1	14.2	26.7	14.0	-48.1
Lilongwe	36.5	31.9	31.0	19.1	-47.6
Nkhata Bay	28.0	20.1	26.1	17.1	-38.8
Ntchisi	38.3	36.5	33.9	24.0	-37.5
Nkhotakota	45.4	29.1	38.9	28.9	-36.3
Kasungu	30.3	33.5	29.4	19.7	-35.2
Mangochi	40.7	27.6	31.4	28.0	-31.2
Dowa	30.2	36.8	29.8	21.3	-29.3
Dedza	22.1	20.3	27.7	19.0	-13.8
Machinga	35.0	21.0	33.5	32.6	-6.8
Mulanje	20.0	22.6	16.8	18.8	-6.1
Phalombe	20.5	21.3	16.0	20.4	-0.4
Zomba	20.4	20.4	14.9	25.5	24.6

4.3 How certain are we in our estimates of malaria prevalence?

One of the objectives of this profile is to identify areas that are below a certain policy relevant malaria prevalence threshold. In countries where areas are transitioning to lower transmission, as in Malawi, identifying areas which are below a particular threshold support the need for considering how to adapt strategies from those that demand universal coverage to a more nuanced, cost-efficient and efficacious combination of interventions.[129]

However, classifying geographical areas into different endemic levels by estimated parasite prevalence creates an oversimplified picture of the malaria situation in that area.[128] As with any data measurement or modelling, we are making an estimate of malaria prevalence for a population in a certain place at a specific time. This estimate falls within a range of values that are likely to encompass the true prevalence of malaria.

Box A
Estimates of *Pf*PR$_{2\text{-}10}$ at location *x* and time *t*, (*Pf*PR$_{2\text{-}10(x,t)}$) have uncertainties that need to be taken into account when determining whether the prevalence in that area falls below a certain threshold, say *l*. We use the geostatistical model to derive a distribution of the most likely values that *Pf*PR$_{2\text{-}10}$(x,t) can take. We then use this distribution to quantify how likely *Pf*PR$_{2\text{-}10}$*(x,t)* is to be below a threshold *l* through a non-exceedance probability (NEPs), formally expressed as:

$$NEP = Probability\{ PfPR_{2\text{-}10}(x,t) < l \mid data\}$$

where *l* is the prevalence threshold which we set to ≤ 20%. In other words, NEP expresses how likely *Pf*PR$_{2\text{-}10}$ is to be below the threshold *l* based on the available survey data.

To address the uncertainty of our estimates, we have estimated a 'non-exceedance probability (NEP)' that the prevalence of malaria in a given area falls below the threshold of 10 and 20%, based on available survey data (the method by which we do this is described in Box A). A NEP close to 100% indicates that *Pf*PR$_{2\text{-}10}$, is highly likely to be below the threshold *l*; if close to 0%, *Pf*PR$_{2\text{-}10}$, is highly likely to be above the threshold *l*; finally, if close to 50%, *Pf*PR$_{2\text{-}10}$, is equally likely to be above or below the threshold *l*, this corresponds to the highest level of uncertainty.

Figure 19 indicates areas where the model allows for are 80% or 90% certain that the *Pf*PR$_{2\text{-}10}$ does not exceed 10% in 2010, 2012, 2014 and 2017 based on the available data. Similarly, Figure 20 indicates areas where the model allows for are 80% or 90% certain that the *Pf*PR$_{2\text{-}10}$ does not exceed 20% in 2010, 2012, 2014 and 2017 based on the available data.

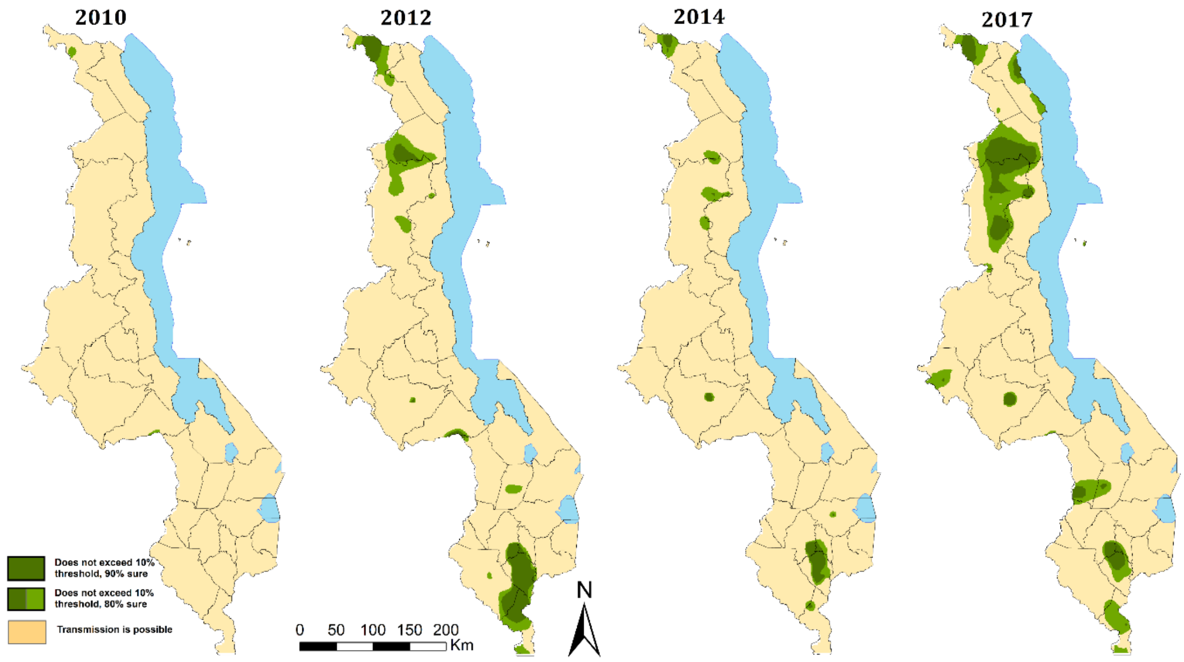


Figure 19. Areas in Malawi where *Pf*PR$_{2\text{-}10}$ does not exceed 10% and the model allows for either 80% certainty (bi-colour of green) or 90% certainty (dark green)

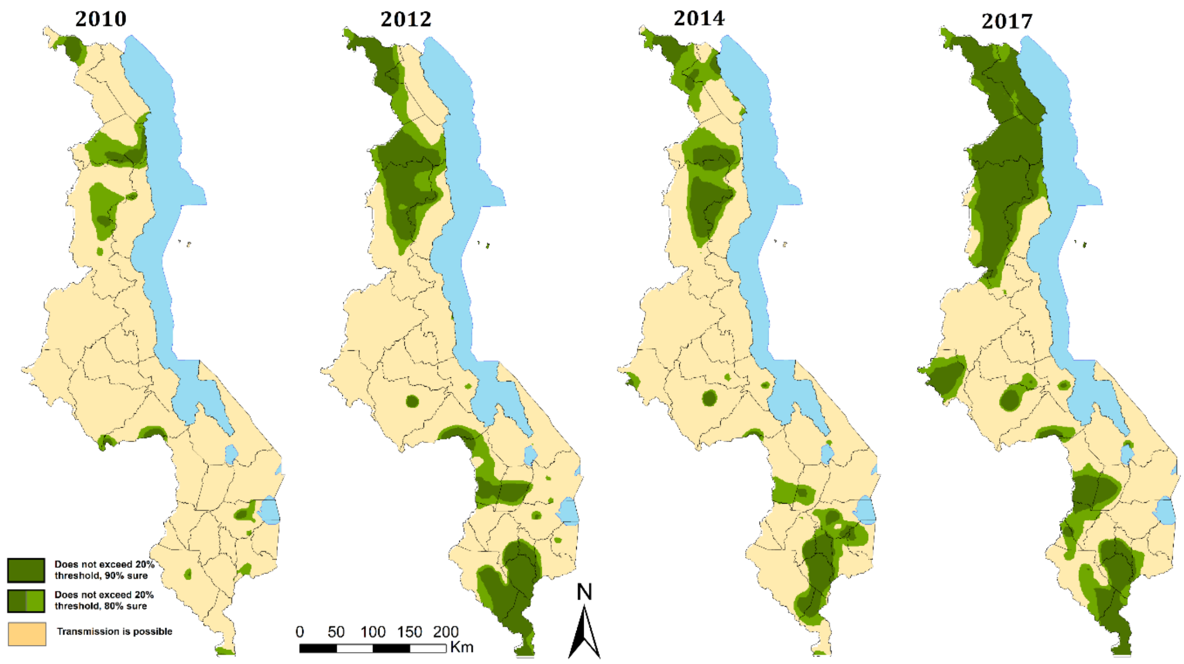


Figure 20. Areas in Malawi where *Pf*PR$_{2\text{-}10}$ does not exceed 20% and the model allows for either 80% certainty (bi-colour of green) or 90% certainty (dark green)

5. Entomological profile

In the recent past, most of vector sampling has been conducted in the sentinel sites located in Central and Southern regions.[113] A repository of data on malaria vectors using historical archives, published sources, unpublished data from researchers and malaria control agencies working in Malawi. Full details of the data assembly, geo-coding methods and classifications of species according to their role in malaria transmission are detailed elsewhere.[133]

The database has been arranged as a site-specific, referenced inventory to capture details of species identification recorded since the earliest surveys in 1900 through to the latest records in 2015. A full digital PDF library, database and bibliography were developed for the National Malaria Control Programme and were delivered along with this profile.

From each identified report, data extraction included whether a species was identified at a given site, methods used to capture adults or larvae and methods used to speciate each anopheline collection. "Y" was recorded if species was identified and "N" was only recorded when the true absence of the species was reported. The database is therefore one of species presence, not absence and nor proportional presence of various vectors. The final database contained 225 site specific reports of anopheline vectors in Malawi, all of which we managed to geo-locate the survey site (
Figure 21).

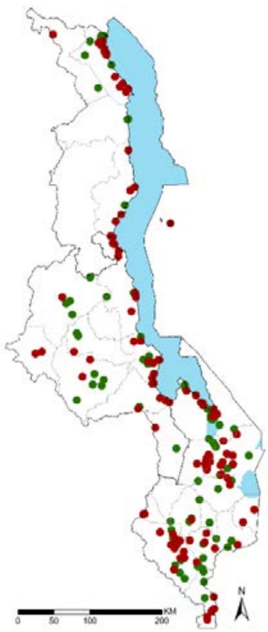


Figure 21. Distribution of Anopheline survey 225 locations sampled between 1900 and 2015 (133 red locations are sites sampled 2005-2015, green are 92 sites sampled before 2005)

An. gambiae complex and the *An. funestus* group are sympatric in Malawi (Figure 22). *An. gambiae* complex comprises of *An. arabiensis* and *An. gambiae s.s* (S form) (
Figure 23). *An. gambiae s.s* occurs relatively in fewer numbers and locations , with the S form being recorded in only 4 locations in Southern Region.[134,135] Among the members of *An. funestus* group, *An funestus s.s* has been fairly well described across the country (Figure 24), while *An. rivulorum* and *An. parensis* have been recorded in 9 and 3 locations respectively. Within the *funestus* group, only *An. funestus s.s* has been implicated as a malaria vector in Malawi, while *An. rivulorum* is suspected to play a secondary role.[136] *An. nili* and *An. moucheti* have never been described in Malawi.

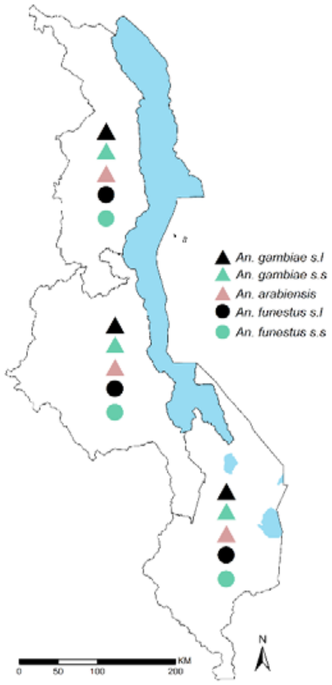


Figure 22. Distribution of documented dominant malaria vector species per region in Malawi

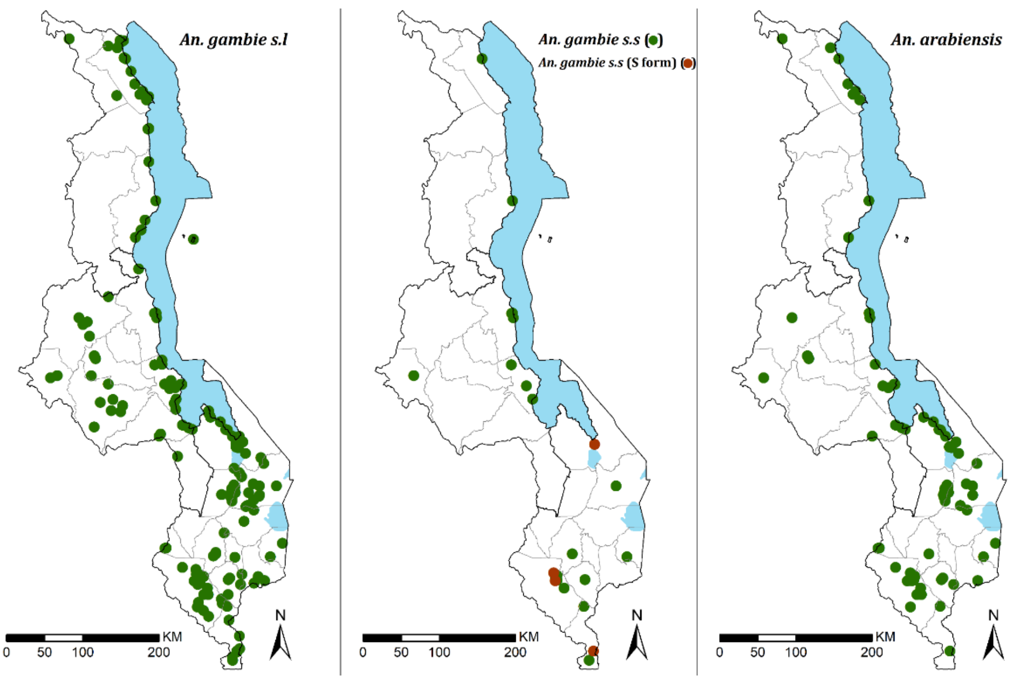


Figure 23. Location of members of *An. gambiae* complex
An gambiae s.l. = 175; *An gambiae s.s.* = 24; *An gambiae s.s.* (S form) = 4; *An arabiensis* = 89

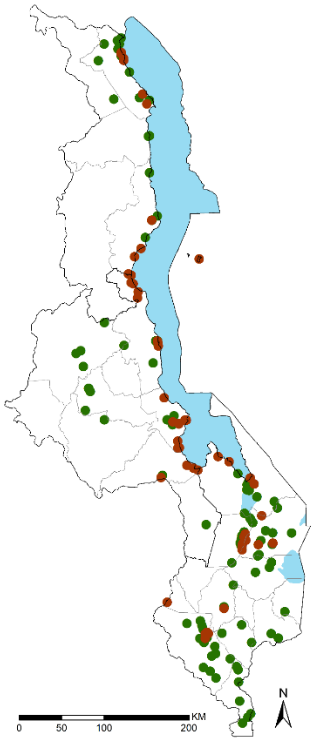


Figure 24. Distribution of location of *An. funestus s.l*. and *An. funestus s.s.*
An. funestus s.l. (n=171), *An. funestus s.s.* (n=56)

Other anophelines reported in Malawi since 1900 but not implicated in malaria transmission include: *An. coustani, An. pharoensis, An. rufipes, An. seydeli, An. tenebrosus, An. ziemanni.*

6. Malaria vector control mapping

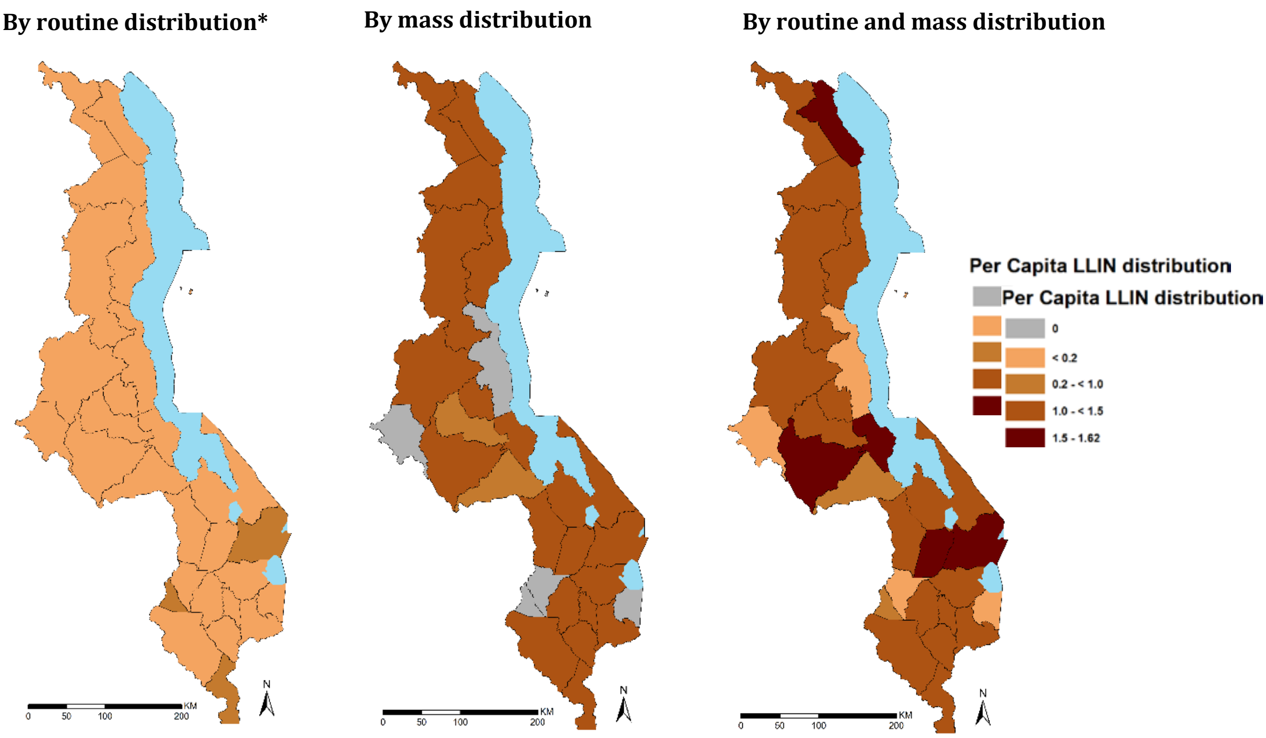
6.1 Distribution of LLINs

Data provided by the NMCP in the report *2014-2016 Mass Distribution Campaign of Long Lasting Insecticidal Treated Mosquito Nets in Twenty-three Districts,*[137] described the numbers of predicted net needs and those distributed during the 2014 and 2015 mini-campaigns. These campaigns delivered nets to ten districts in total in 2014/2015 and to 19 districts in 2016. Data were also provided on routine LLIN distributions through ANC and MCH clinics between 2013 and 2017.

We have used 2017 projected population from 2015 100-metre spatial resolution Worldpop population dataset to render a map of net distributions per district between 2015 and 2017 expressed per person (Figure 25). A complete database accompanies this report.

Under the current National Malaria Control Strategy, the NMCP aimed to distribute 1 LLIN per 1.8 people between 2016 and 2022. Using routine data of mass and routine distribution between 2015 and 2017, Figure 25 presents:

1. Per capita LLIN routine distribution between 2015-7 (left)
2. Per capita LLIN mass distribution between 2015-7 (center); and
3. Per capita LLIN mass and routine distribution between 2015-7 (right).



** Excluding routine distribution for infants; at the time of this profile routine distribution for infants was not yet available.*

Figure 25. Per capita 2015-2017 LLIN summed distribution per 2017 projected population (Left: by routine; center: by mass; right: mass and routine combined)

We have used geocoded household data from the 2010, 2012, 2014, and 2017 national surveys to provide information on coverage and reported LLIN use for each of the 28 districts using Small Area Estimation (SAE) methods. Here we have used hierarchical Bayesian spatial and temporal SAE techniques using a geo-additive regression approach.[138,139] This method uses survey data from a health district and neighbourhood information from adjacent districts to smooth values at the health district. Importantly we predict quantities among all age groups, as this now represents the important indicator for universal coverage and necessary when computing likely impacts on malaria transmission[140,141]. In addition, WHO recommended targets for universal coverage have been defined as at least 2 people per LLIN per household.[7]

Using these modelling methods, Figure 27 presents the percent of households with universal coverage of ITNs, defined here as at least one ITN for every two people. By 2017. 16 of the 28 districts had achieved between 40 and 60% coverage, compared to zero districts in 2010, two districts in 2012 and four districts in 2014. These findings match the history of malaria control in Malawi; major mass distributions began in in 2014.

We also provide maps of net utilisation through the proportion of the population sleeping under an LLIN. Increasing LLIN utilisation falls under the remit of the SBCC Communications Sub-Committee, which designed and implemented community-based communications for behaviour change alongside distribution campaigns. Again, the maps produced through the modelling exercise of household data (Figure 27) indicate that there were country-wide improvements in net use by district. In 2010 all districts reported that less than 40% of the population were sleeping under LLINs. By 2012, 12 districts reported between 40 and 60% coverage, and 2 districts had achieved between 60 and 80%. In 2014, 16 districts reported between 40 and 60% coverage, and 10 districts had achieved between 60 to 80%. By 2017, 14 districts reported between 40 and 60% coverage, nine districts had achieved between 60 to 80% and one district (Zomba) had achieved between 80 and 100% coverage.

[7] To note: modelling for 2010 DHS[86] was based on 849 clusters, 24,825 households and 118,850 respondents; modelling for 2012 MIS[100] based on 140 clusters, 3,404 households and 14,290 respondents; modelling for 2014 MIS[101] based on 140 clusters, 3,405 households and 14,327 respondents; and modelling for 2017 MIS[102] based on 150 clusters, 3,729 households and 16,755 respondents.

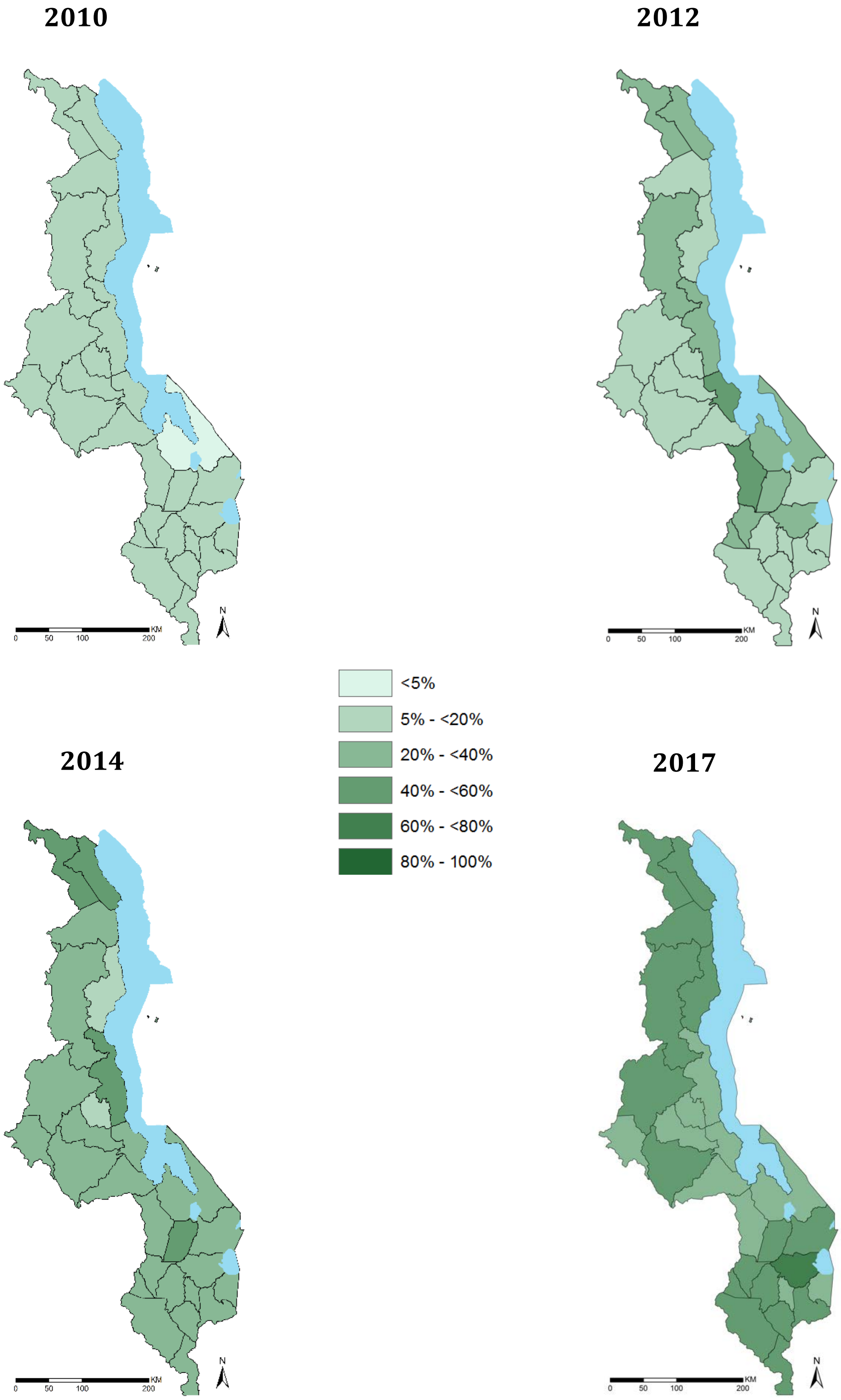


Figure 26. Percent of households with at least one LLIN for every 2 persons in 2010, 2012, 2014 and 2017

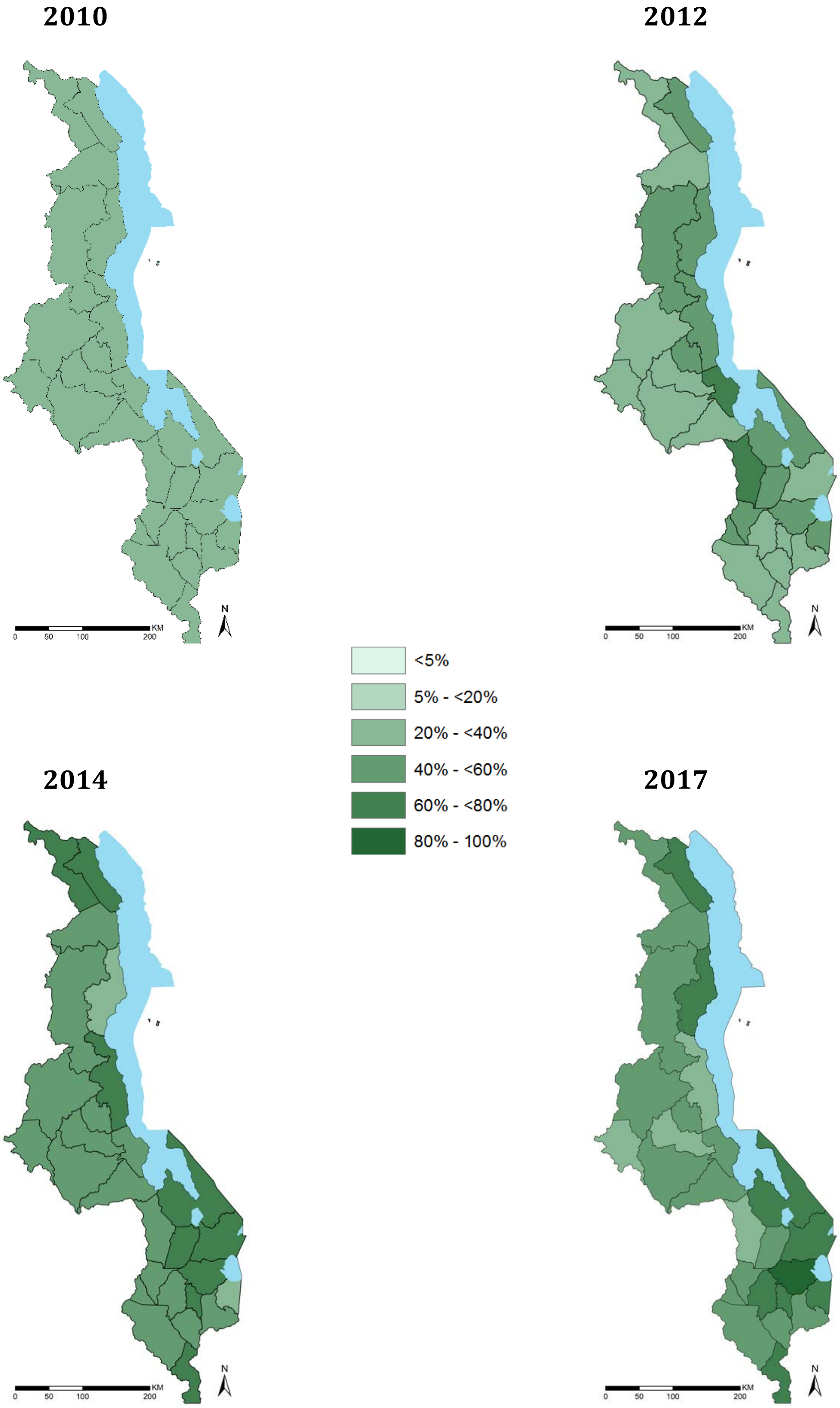


Figure 27. Percent of households sleeping under an LLIN in 2010, 2012, 2014 and 2017

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