Epidemiology and control profile of malaria in

Uganda: Evidence for a targeted malaria response

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Preface

Uganda is a malaria endemic country. Over the past decade, significant investment and gains have been made in malaria reduction efforts. Malaria prevalence has decreased markedly from 42% in 2009 to the current level of 19%, malaria deaths have been halved from 2012 levels and malaria testing in the public sector has also improved from 60% to over 90%. Access to ACTs has been improved, with less than 5% of facilities reporting stock outs. Over 26 million nets were distributed in the last universal campaign in 2017.

In 2017, Uganda had the ninth highest mortality and tenth highest morbidity due to malaria worldwide. The theme for this Uganda Malaria Reduction Strategic Plan (UMRSP), 2014-2020, is "*Accelerated nationwide scale up to achieve universal coverage of cost effective malaria prevention and treatment interventions."* The aim of this strategy is to rapidly increase access of malaria control interventions to the population. However, the strategy is pursued in the context of a changing epidemiology of malaria in the country and limited resources for malaria control. This context has necessitated the use of evidence to stratify the country and target interventions to the most affected groups to accelerate elimination efforts.

The UK-DFID supported WHO AFRO/DFID *"Strengthening the Use of Data for Malaria Decision Making and Action in the African Region"* and LINK project in collaboration with other partners and key stakeholders have supported the Uganda National Malaria Control Programme to document the fight against malaria in Uganda from precolonial times, as well as support the programme to develop a malaria risk stratification map.

This evidence will not only guide the current ongoing Uganda Malaria Policy review for an accelerated implementation approach to achieve 2020 UMRSP stated goals but also the development of a new malaria strategy beyond 2020.

We pledge to use this information and update it routinely to guide our decision making.

I am grateful to all, WHO, DFID, London School of Tropical Medicine & Hygiene, KEMRI and Ugandan malaria implementing partners that have contributed towards the production of this vital product.

Dr Jimmy Opigo
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Abbreviations

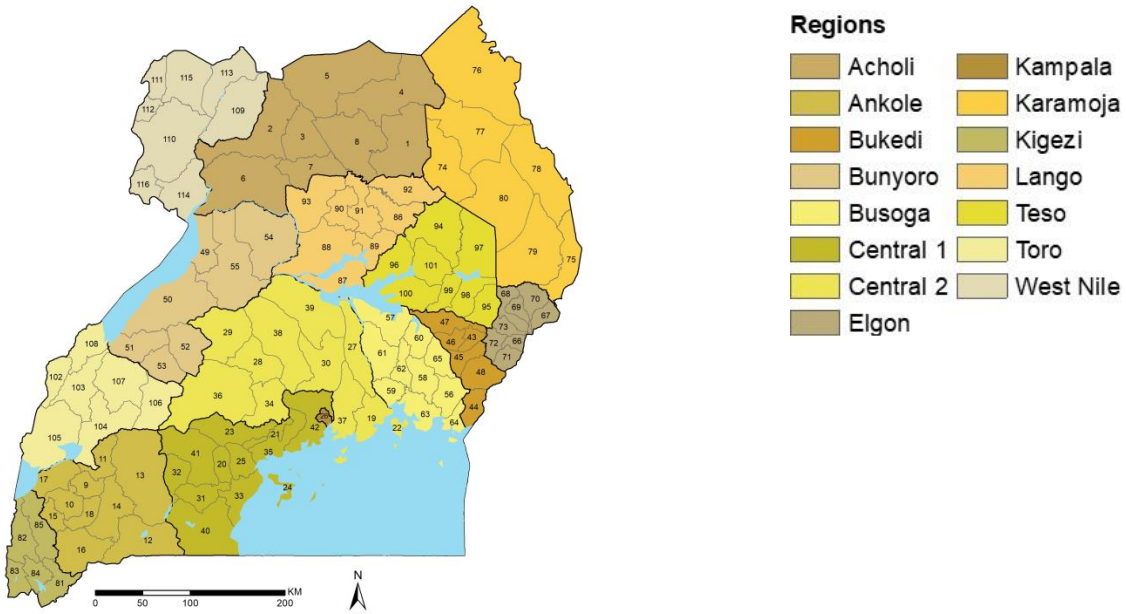
ACT	Artemisinin-based combination therapies
AL	Artemether-lumefantrine
AMIS	Agricultural Market Information System
ANC	Antenatal care
AQ	Amodiaquine
BMGF	Bill & Melinda Gates Foundation
CDD	Community Drug Distributors
CMD	Community Medicine Distributors
CMS	Church Missionary Society
CQ	Chloroquine
DFID	Department for International Development
DHS	Demographic Health Survey
DRC	Democratic Republic of the Congo
EANMAT	East African Network for Monitoring Antimalarial Treatment
EP	Exceedance probability
EPI	Expanded Programme for Immunisation
GAUL	Global Administrative Unit Layers
GFATM	Global Fund to Fight AIDS, Tuberculosis and Malaria
GIS	Geographic Information Systems
GMEP	Global Malaria Eradication Programme
GPS	Global Positioning Systems
HBMF	Home-based management of malaria fevers
HC I	Health Centre level 1
HC II	Health Centre level 2
HC III	Health Centre level 3
HC IV	Health Centre level 4, or general hospital
HIPC	Heavily Indebted Poor Countries
HIS	Health Information Systems
HMIS	Health management information system
HSD	Health Sub-district
IBEA	Indian British East Africa
ICT	Information and communication technologies
IDP	Internally displaced people
IDRC	Infectious Disease Research Collaboration
IHME	Institute for Health Metrics and Evaluation
IOM	International Organization for Migration
IMF	International Monetary Fund
IRS	Indoor Residual Spraying
ITN	Insecticide-treated net
IVM	Integrated vector management
LAMP	Loop-mediated isothermal amplification

LLIN	Long-lasting insecticidal net
M&E	Monitoring and evaluation
MAE	Mean absolute error
MAPD	Malaria Action Programme for Districts
MBG	Model-Based Geo-statistics
MC	Malaria Consortium
MCU	Malaria Control Unit
MDA	Mass drug administration
MIS	Malaria Indicator Survey
MMR	Maternal mortality ratio
MoH	Ministry of Health
MPR	Malaria Programme Performance Review
MRC	Malaria Research Centre
MSF	Médecins Sans Frontières
MTR	Mid-term Review
NDA	National Drug Authority
NGO	Non-governmental organisation
NMCP	National Malaria Control Programme
UMRSP	Uganda Malaria Reduction Strategic Plan
NRA	National Resistance Army
ODA	Overseas development assistance
PCR	Polymerase Chain Reaction
PMI	President's Malaria Initiative
PRISM	Programme for Resistance, Immunology, Surveillance and Modelling
QoD	Quality of Data
RBM	Roll Back Malaria
RDT	Rapid diagnostic test
SAM	Service Availability Mapping
SBCC	Social mobilisation and behaviour change communication
SMC	Seasonal malaria control
SMEOR	Surveillance, Monitoring, Evaluation and Operational Research
SP	Sulphadoxine-pyrimethamine
TTT	Test, Treat and Track
UBOS	Uganda Bureau of Statistics
UMSP	Uganda Malaria Surveillance Project
UNHCR	United Nations High Commissioner for Refugees
UNLA	Uganda National Liberation Army
UNLF	Uganda National Liberation Front
USAID	United States Agency for International Development
WHO	World Health Organization

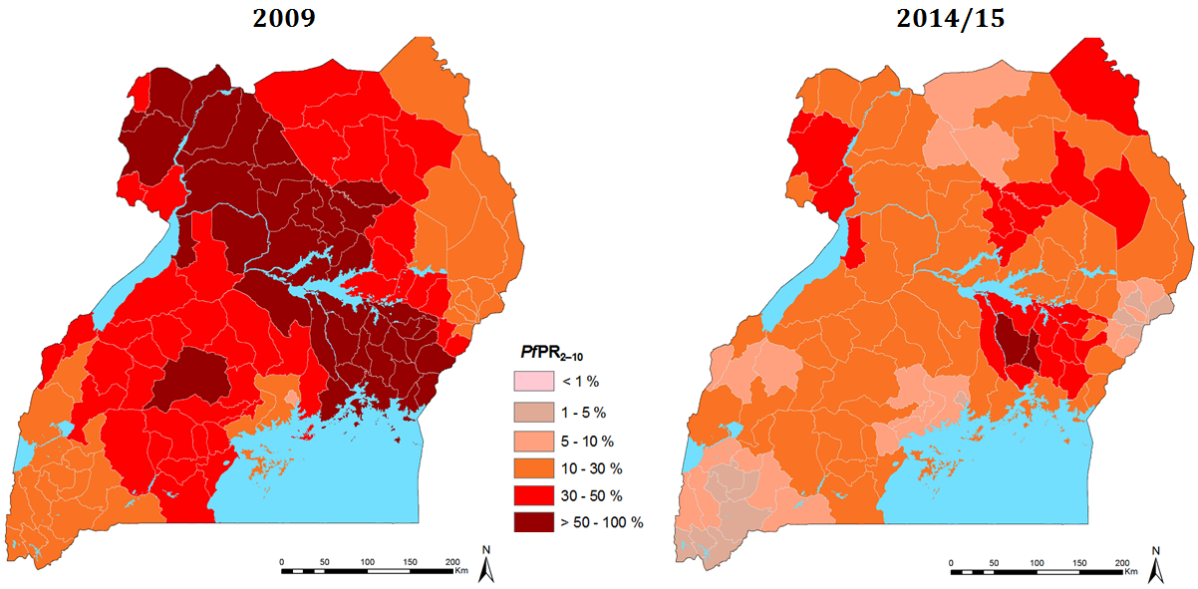
Map overview

This profile represents data about malaria control in Uganda using a series of maps, using 2009 and 2014/15 as two comparator points in time. The maps and the underlying data were delivered to the National Malaria Control Programme (NMCP) along with this profile in 2018; the figures and data may be requested by contacting the NMCP. A sampling of the maps found within this report may be found in the panel below.

Map 1. 116 health districts of Uganda within 15 nominal regions

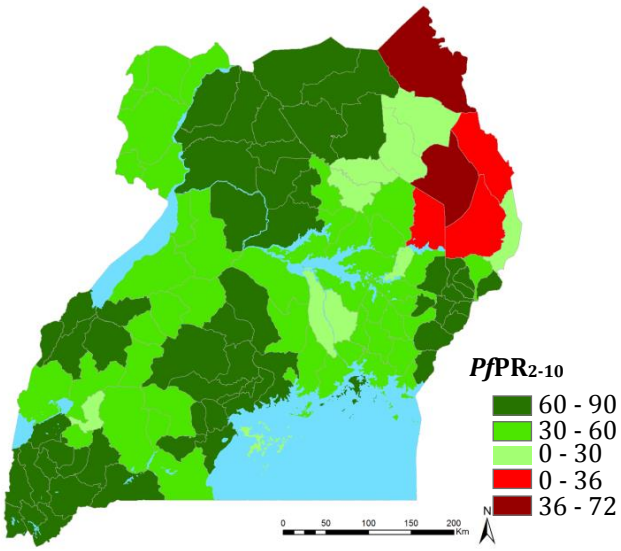


Map 2: Predicted distribution of *Pf*PR$_{2-10}$ in 2009 and 2014/15



Map 3. Percent prevalence increase or decrease by district between 2009 and 2014/15

Green shades indicate decrease in prevalence, red shades indicate increases in prevalence



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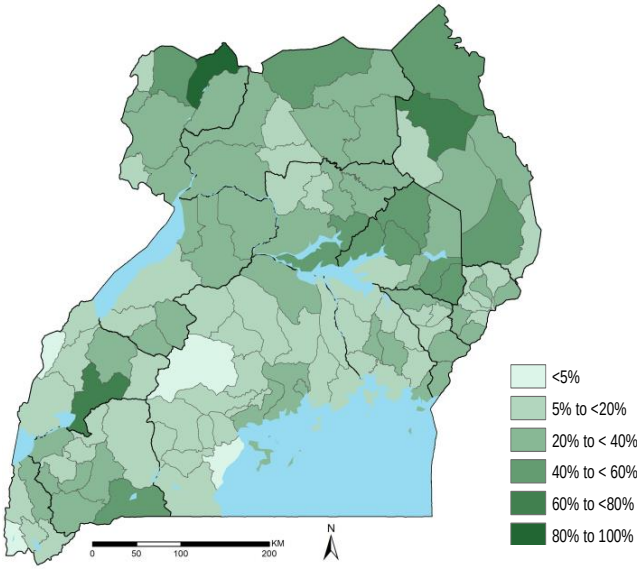
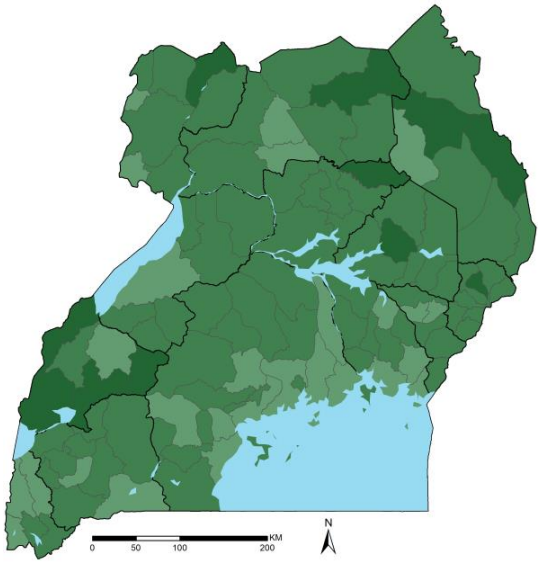


Map 5. Proportion of the population sleeping under an ITN in 2014/15



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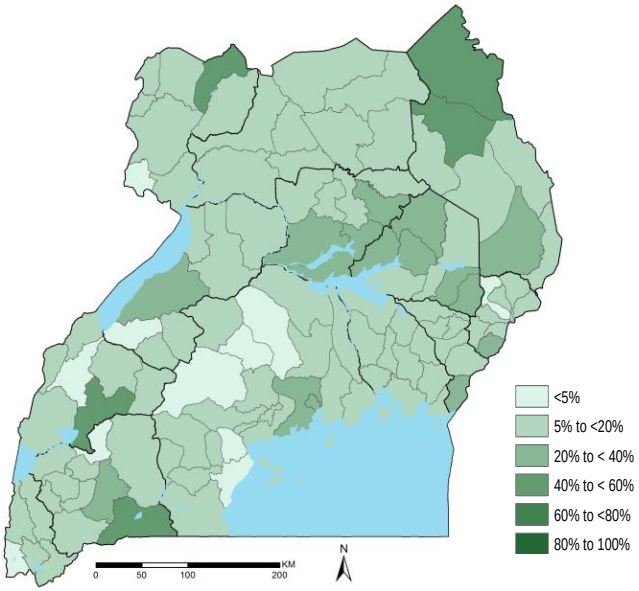
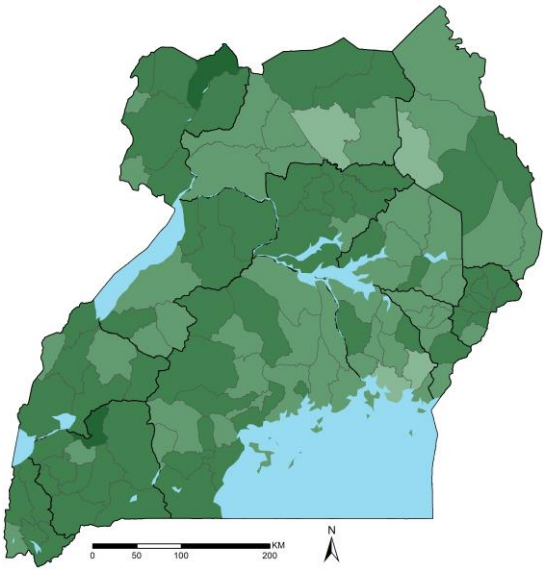


Map 7. Proportion of households with at least one ITN for every two persons in 2014/15



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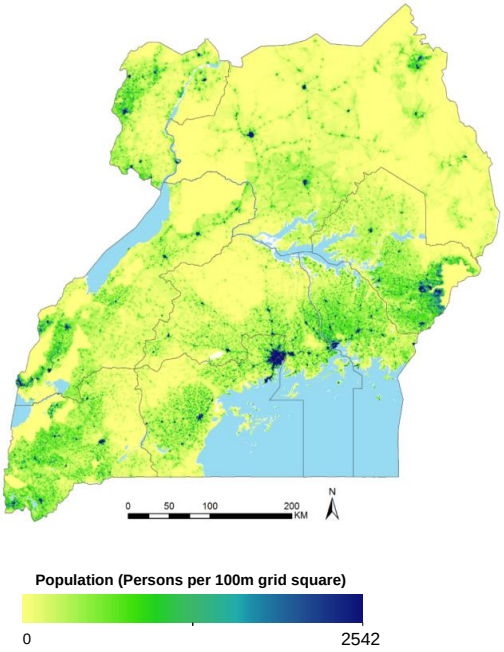

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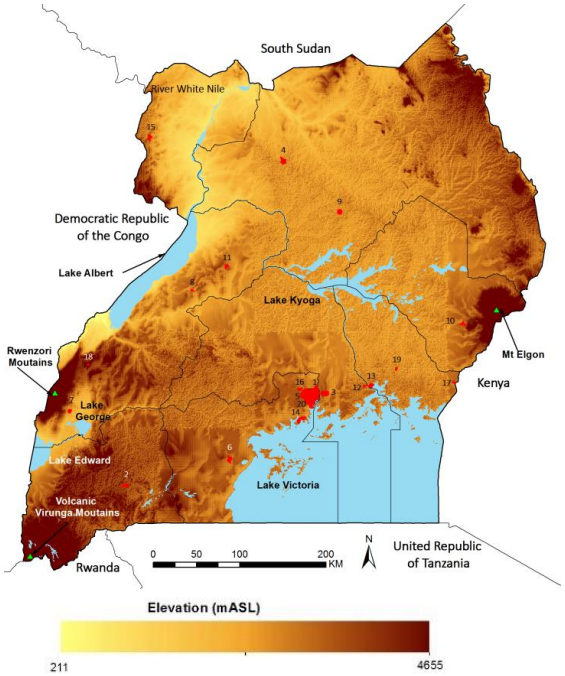


Executive summary

This epidemiological profile results from a collaboration between the NMCP, NMCP partners, WHO 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 in aligning most recent malaria burden data and intervention coverage data with efforts to "accelerate nationwide scale-up of evidence-led malaria reduction interventions," in line with the National Malaria Strategic Plan 2014-20.

This report builds upon work produced in 2013 by the KWTRP to develop an epidemiological profile of malaria at district levels. Subsequent mass long-lasting insecticidal net (LLIN) campaigns across the country and malaria epidemics in the north have altered the landscape of intervention coverage and possibly malaria risk since the 2013 profile was developed. At the same time, new sources of data have become available, namely a national Malaria Indicator Survey (MIS) in 2014, a Demographic Health Survey (DHS) with a malaria module in 2016, and an MIS to be conducted in Novebmer 2018. 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 techniques to render district-level estimates from the data available in nationally-representative surveys and small studies.

This report updates national spatially-defined data on malaria parasite prevalence, vector species occurrence, human population settlement, health service location 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 the model-based geo-statistical (MBG) methods, this report presents maps of malaria risks in Uganda for 2000 and 2014-15. The maps are based on parasite prevalence among children aged two to ten years ($Pf\text{PR}_{2\text{-}10}$) and are transformed into district population-adjusted estimates of risks to review burden and change over time across 116 health districts to support the planning of resources. The maps in this profile do not incorporate DHS 2016 data. However, through the LINK programme, two Ugandan malaria scientists, Dr Damian Rutazaana and Mr Paul Mbaka, received training with KWTRP in July 2018 to learn how to execute geospatial models of malaria. A prevalence map for 2016 which includes DHS 2016 data, along with the modelling methods, is provided in Annex C. In the future, geospatial prevalence maps may be generated from within Uganda and in alignment with national planning needs.

Malaria transmission in Uganda is best described as meso-hyperendemic, though there is much variation within the country. The presence of the *An. gambiae* complex and the *An. funestus* group are sympatric across the entire county. *An. funestus* are limited to areas of higher elevations, around permanent bodies of water, and to the short dry seasons of September to November. In contrast *An. gambiae* are found more ubiquitously throughout Uganda. Among the *An. gambiae* complex, *An. gambiae ss* and *An. arabiensis* have been recorded in all regions of Uganda. *Plasmodium falciparum* (*Pf*) is the dominant malaria infection. Transmission is largely perennial with relatively little seasonal variability, so no areas within Uganda lend themselves to targeted seasonal malaria control (SMC). There has been a modest change in the national intensity of *P. falciparum* transmission over the last decade.

LLIN use is the dominant vector control strategy in Uganda, with Indoor Residual Spraying (IRS) and larval source management used to supplement net distribution. Survey data shows that LLIN coverage has increased over time through their mass and routine distribution. The 2000-1 DHS found that 12.5% of households had at least one mosquito net while the 2016 DHS reported that nearly 80% of households had at least one insecticide-treated net (ITN) and more than 50% of households met the global standard of at least one ITN for every two persons sleeping in the house.

A national IRS strategy which started in 2009 achieved positive results in ten mid-north region districts by 2014.[1] After 2014, the NMCP and supporting agencies planned to transition to LLIN-only coverage in these 10 districts and focus IRS strategy on 14 other districts in northern and eastern Uganda. In mid-2015, a rebound of malaria was detected in those northern areas, thought to have occurred because of the removal of IRS. The Ministry of Health (MoH) re-initiated IRS in these districts in 2016. By 2017, IRS was being conducted in 25 districts (11 of the previously discontinued districts and 14 districts targeted for reduction).

Resistance to insecticides is a growing concern in Uganda and more broadly, in the region. In particular, there is widespread permethrin (of the pyrethroid family) resistance in the Democratic Republic of the Congo (DRC).[2] In 2016, sentinel site surveillance Uganda identified that vectors were sensitive to organophosphates and carbamates, but that vectors were resistant to pyrethroids and DDT, a type of organochlorine. Through its Mid-term Programme Review, the NMCP identified that improved entomological research is needed to guide the design, planning and implementation of future control efforts.

The 2014-2020 Uganda Malaria Reduction Strategic Plan (UMRSP) aims to adopt integrated vector management (IVM) including a rapid and sustained scale-up of LLIN distribution and IRS coverage. The plan also includes goals to scale-up malaria diagnostics using microscopy and rapid diagnostic tests (RDTs) and treatment with effective antimalarials, increase social mobilisation and behaviour change communication (SBCC) and strengthen existing malaria surveillance, monitoring and evaluation systems. To this end, the country finalised an IVM strategy in 2017, launched a Behaviour Change and Communication Strategy in 2017,[3] expanded IRS to new districts, carried out a mass distribution of 25 million LLINs in 2016, scaled-up testing and integrated community case management (iCCM) of malaria, and introduced weekly surveillance from health facilities using an SMS-based system in 2014.

The UMRSP 2014-2020 aimed to reduce malaria parasite prevalence from 19% in 2013 to less than 7% by 2020. However, the most recent Mid-term Review (MTR) concluded that the country will fall short of its 2020 targets and therefore should revisit its strategies. The geospatial parasite prevalence estimates presented in this report confirm what the MTR concluded using MIS and DHS data.

The geospatial maps in this profile, alongside geospatially-represented LLIN and IRS coverage maps can assist the NMCP to identify sub-national targeting of interventions to promote progress towards its 2020 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 of 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 ($Pf PR_{2-10}$) was recognised as an important source of planning data and used to define categories of endemic risk. This categorisation of endemic risk was used to guide and monitor progress toward malaria elimination targets.

In the 1970s, personnel with skills to design malaria control programmes were integrated into a less specialised, integrated primary care mandate which focused on managing fevers. As a result, efforts to design malaria control programmes based on an understanding of the spatial epidemiology eroded.

In 1996, a renewed appeal for better malaria cartography to guide malaria control in Africa was made.[4,5] 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 MBG.[6]

At the launch of the Roll Back Malaria (RBM) partnership in 1998, there were calls for universal coverage of all available interventions in response to the epidemic that affected most of sub-Saharan Africa during this period.[7,8] 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 future business cases must 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

Uganda undertook its first National Malaria Programme Performance Review (MPR)[i] in 2011 to support the development of the UMRSP. The MPR, which assessed programme performance between the years 2000-10, identified that "the lack of risk mapping (including using routine data) makes it difficult to identify populations at highest risk and targeting of interventions to these populations."

Subsequently, the MPR formed a key action point: “the malaria programme should plan for and conduct periodic risk assessments and mapping in order to assist intervention targeting."[9] The MOH has since institutionalised Quality of Data (QoD) surveys, and is prolific in map production using routine data (eg. test positivity rate by district and malaria incidence by district). Additionally, the NMCP prioritised risk mapping for Uganda through to 2014 for the purposes of

[i] In 2011, WHO developed a manual to assist countries in developing their NMSP 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.

the MPR in 2017. The MPR in 2017 drew upon routine health data, as well as geospatial prevalence maps and entomological survey maps from the 2013 LINK profile.

This profile was developed to support national-level planning, through the assemblage of an epidemiological evidence base required for a more targeted approach to malaria control in Uganda. This report builds upon a previous profile produced in 2013 by INFORM (KEMRI-Welcome Trust) which sought to develop an epidemiological profile of malaria at district levels. The 2013 analysis allowed for a description of malaria risk based on parasite prevalence data from across Uganda predicting to the most recent period for which the majority of data were available (2009/2010). The 2013 profile identified weaknesses in certain data domains, including the absence of parasite prevalence surveys in some areas of the country (especially in the eastern region and throughout the eastern districts of the northern region), identified weaknesses in vector data and updated information on LLIN coverage and distribution.

Following the release of the previous profile (2013), mass LLIN campaigns across the country and malaria outbreaks in the north have altered the landscape of intervention coverage and possibly malaria risk. Concurrently, new sources of data have become available, namely a national MIS in 2014 and a DHS with a malaria module in 2016.

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 Uganda's health districts; offering data at a unit most useful for targeting sub-national control toward the achievement of the targets of the national malaria strategic plan. Importantly, this work is intended to support the NMCP's strategic planning and ongoing monitoring and evaluation (M&E) efforts.

2. Country context

2.1 Geographic location

Uganda, referred to as the "Pearl of Africa", is located along the central African Rift Valley within the Nile basin. It shares borders with Kenya in the east, South Sudan to the north, the DRC to the west, Rwanda in the south west and Tanzania to the south.

Uganda varies in topography, ranging from high altitude areas including the Rwenzori Mountains (5100 m), Mount Elgon (4300 m) and the volcanic Virunga Mountains (> 4000 m) to the low-lying Sudanese Plain in the north (Figure 1). The central region is dominated by the large shallow, inland Lake Kyoga, surrounded by extensive marshy areas. The Nile drains from Lake Victoria into Lake Kyoga and from there to Lake Albert on the DRC border. Other lakes include Lake Edward in the South West and Lake George. A small area on the eastern edge of Uganda is drained by the Turkwel River, part of the internal drainage basin of Lake Turkana. The north eastern Karamoja region has the driest climate and is prone to droughts. The climate in the south is heavily influenced by Lake Victoria, preventing temperatures from varying significantly but increasing cloudiness and rainfall.

There are a series of islands within Lake Victoria, including the archipelago of inhabited Ssese islands in the northwest. These islands are part of Kalangala district in southern central Uganda.

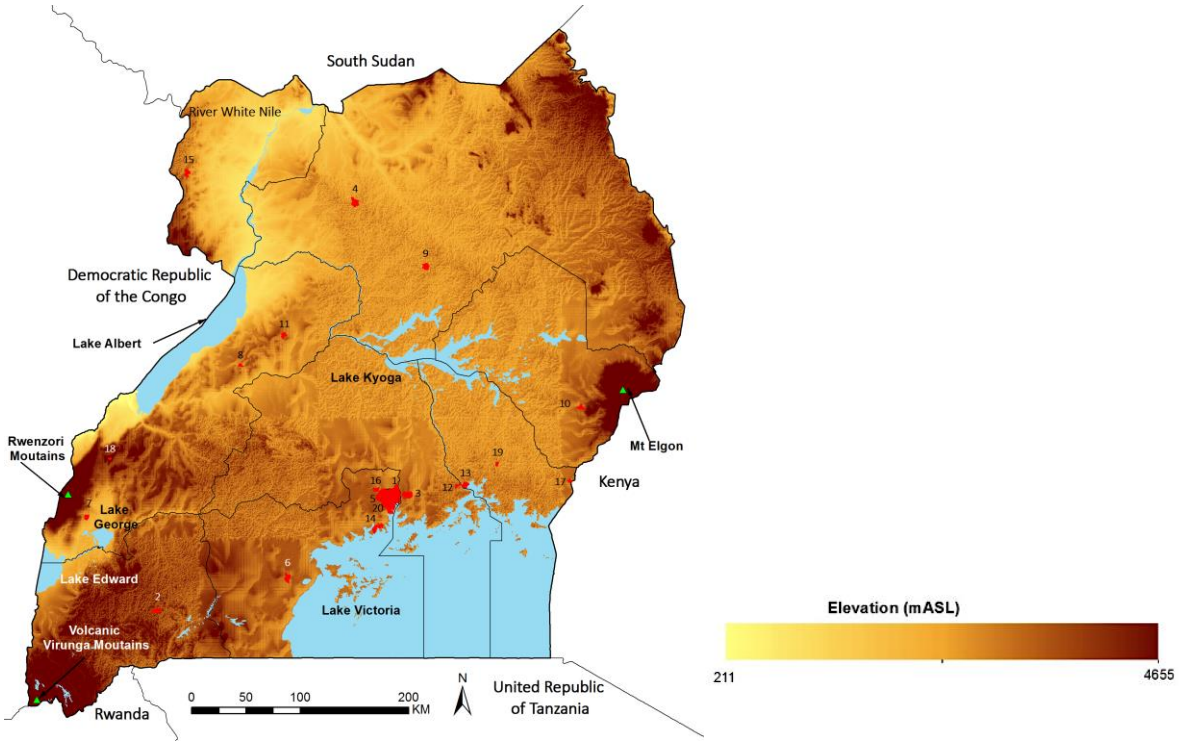


Figure 1. Major relief features, rivers and lakes and indication of major urban areas (highlighted in red)[ii]

[ii] Urban areas are numbered as follows: 1. Kampala 2. Mbarara 3. Nakawa 4. Gulu 5. Rubaga 6. 7. Kasese 8. Hoima 9. Lira 10. Mbale 11. Masindi 12. Njeru 13. Jinja 14. Mutungo 15. Arua 16. Kawmpe 17. Busia 18. Kikorba 19. Bugiri 20. Makindye

2.2 Political and social evolution

Uganda hosts more than 40 ethnic groups, some of which flow between the porous borders of Uganda and its neighbouring countries.[10] The cultural richness of Uganda dates back to Bantu migration from the west in 400 BC, followed by centuries of pastoral rule by the Chwezi,[11] who were displaced to the south in the 15th century by the Nilotic-speaking pastoral group called the Bito. As part of the Chwezi southward migration, the Banyoro arrived in Buganda early in the 15th century.[12]

Protestant and Catholic missionaries entered Uganda between 1877 and 1879. The United Kingdom placed the area under the charter of the Indian British East Africa Company (IBEA) in 1888.[13] Uganda was declared a British protectorate in 1894, and by 1918, the British Protectorate of Uganda had attained its present shape and boundaries.

In 1921, a legislative council was set up to serve as the parliament of Uganda, but it was not until 1946 that the first Africans had any council presence; by 1956 this grew to 30 African representatives elected from all districts of Uganda. Uganda's approach to independence was unique from other colonial territories; in Uganda inter-party cooperation was compelled, with future independence already assured.[12]

Uganda gained independence from Britain on 9 October 1962. The first President of Uganda was King Mutesa of Buganda, with Milton Obote serving as the prime minister of a loose coalition. Obote seized the presidency in a coup in 1966, after which followed a series of coups which escalated to political violence, ethnic violence, conflict with Tanzania and the collapse of industries under martial law and African socialism under President Amin. In 1979, President Nyerere of Tanzania, in combination with Ugandan exiles united as the Uganda National Liberation Army (UNLA) and troops provided by Libya's Qadhafit, took Kampala from Amin.

An interim government was established as the Uganda National Liberation Front (UNLF) in April 1979. By 1979 military leaders began to enrol thousands of recruits into private armies, and a 1980 military coup overthrew the UNLF president Binaisa. Contentious elections of December 1980 returned Obote to power. In February 1981, the National Resistance Army (NRA) was established to overthrow Obote by means of a popular rebellion.

The following four years resulted in vast areas of devastation and more deaths than under the Amin regime, with an estimated 500,000 deaths claimed by conflict between 1981 and 1985. The conflict also led to economic failures, and in 1985, Obote fled the country for Zambia along with much of the national treasury.

A military government under the direction of General Tito Lutwa Okello ruled from July 1985 to 1986. On 26 January 1986, Yoweri Museveni moved against Kampala. Museveni was formally sworn in as president on 29 January 1986. Museveni restricted political parties from 1986 to a non-party "Movement" system where political parties continued to exist but could only operate a headquarters office. A constitutional referendum cancelled this ban on multiparty politics in July 2005; however, the term limit for president was changed in the constitution from the two-term limit in September 2005, enabling the current president to continue with his political activity. Museveni was re-elected in 2006 and again in 2011 after 24 years of rule.

2.3 Population and economy

Population

The first censuses in Uganda were conducted in 1911, 1921 and 1931 (Figure 2). These used counts by 'huts' rather than by individuals.[14] Slow growth rate in the first decade may have been

explained by a series of sleeping sickness epidemics that were estimated to have killed more than 250,000 people; about two-thirds of the population in the lakeshore areas were affected.

Censuses undertaken in 1948 and in 1959 used modern *de facto* demographic methods following the formation of the East African Statistical Department, despite divisions into two separate enumerations (ie. one enumeration for Africans, and one for the non-Africans). The censuses since independence were undertaken in 1969, 1980[iii], 1990-91, 2002, 2012 and 2014.[15]

The average annual population growth rate between 1980 and 1991 was 2.5%, and 3.2% between 1991 and 2002. The more recent higher growth rate was explained by declining mortality and high fertility rates. The growth rate has since declined to 3.0%, with the population recorded at 34.6 million in 2014.

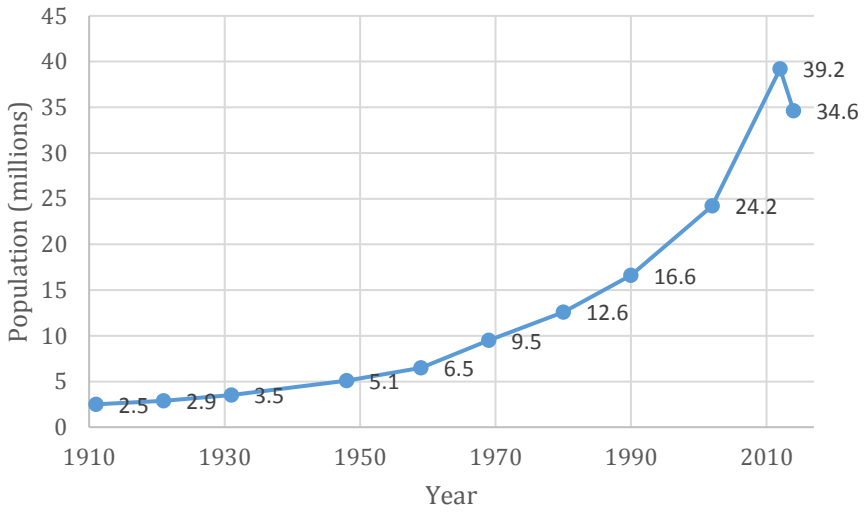


Figure 2. Population estimates from censuses in Uganda, 2011 to 2014

To improve our understanding of human settlement patterns in Uganda, spatial modelling techniques have been developed to reallocate populations within censuses to finer-gridded surfaces.[16] In brief, a day symetric modelling technique[17] was used to redistribute population counts within the 5,180 spatially defined parishes used during the 2002 national census as well as land cover data sets derived from satellite images. A different population weight was assigned to each land cover class to shift populations away from areas unlikely to be inhabited (eg. game reserves or arid deserts) and concentrate populations in built-up areas. The net result was a gridded dataset of population distribution (counts) at a 0.1 by 0.1 km^2 resolution (Figure 3). The population distribution datasets were projected to years used to predict malaria risk and LLIN coverage using UN national rural and urban growth rates[18] and made to match the total national population estimates provided by the UN Population division for these years. The population density map (Figure 3) was produced in 2013 using 2002 census data. Population distribution mapping and malaria prevalence estimations could be improved using the 2014 national census data Uganda Bureau of Statistics (unreleased as of 2018).

[iii] This census had significant uncertainty due to the loss of census data in subsequent outbreaks of violence.

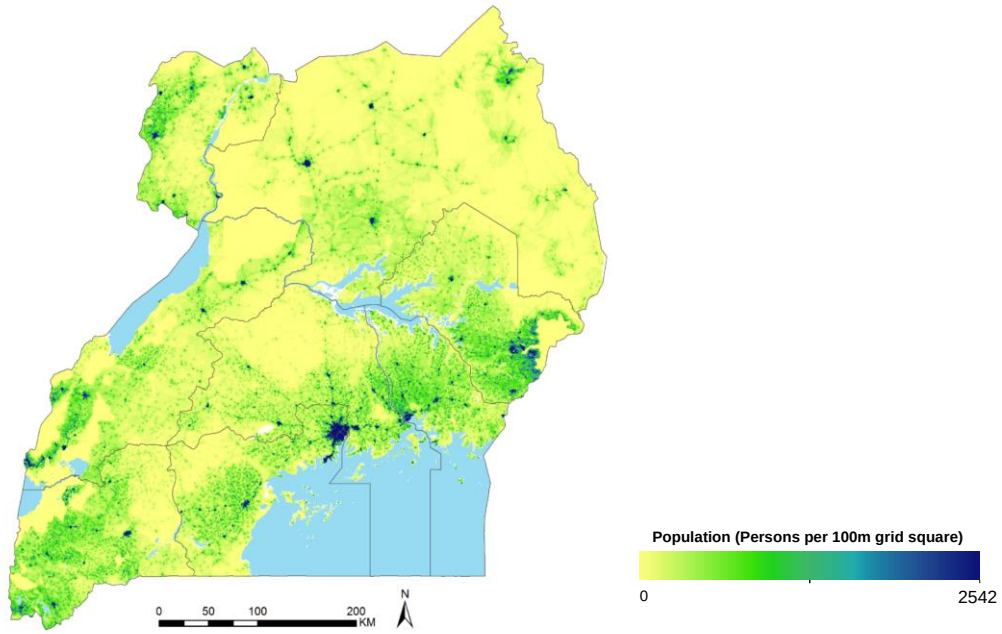


Figure 3. Modelled population density per 100 m^2

In 2014, Uganda's population density was relatively high in comparison with most of Africa, estimated to be 172 persons per km^2 (Table 1[19–21]). Uganda's population density is higher than that of Kenya and Tanzania, but lower than Rwanda and Burundi. The relatively high population density masks a range from less than 29 persons per km^2 for Moroto district to 7,928 persons per km^2 in Kampala district.

Table 1. Population density of Uganda and selected districts and neighbouring countries, 2014

Country, *district*	**1991**	**2002**	**2014**
Uganda	85	123	173
Moroto	11	22	29
Tororo	241	330	433
Mbale	371	534	943
Wakiso	338	545	1,060
Kamapla	4,726	7,259	7,928
Kenya	27	54	74
Tanzania	26	39	54
Rwanda	285	281	421
Burundi	216	243	377

Urbanisation

The definition of urban areas in Uganda has changed over the years. In the 1969 and 1989 census, trading centres with 100 and 400 people respectively were considered urban. In the 1991 census, the classification was revised to include all cities, municipalities, town councils, town boards and trading centres with a population of over 1,000 persons. However, the 2002 and 2014 population census did not include a population threshold and instead only included cities, municipalities and town councils gazetted in the Local Government Act of 2000.[19]

Most of Uganda's population lives in rural areas, though the proportion of the population living in urban areas has increased with each census year from 6.6% in 1969 to 21% in 2014 (Figure 4).[22] Rural-to-urban migration declined during the 1970s as a result of deteriorating security

and economic conditions. During the 1980s, Kampala accounted for almost 50% of the total urban population but recorded a population increase of only 3%. Jinja is the main industrial centre and second largest city; six other cities (Kabale, Fort Portal, Entebbe, Masaka, Mbarara and Mbale) had populations of more than 20,000 in 1989. The urban growth rate has remained relatively stable since 2004 at about 5.5%.[23]

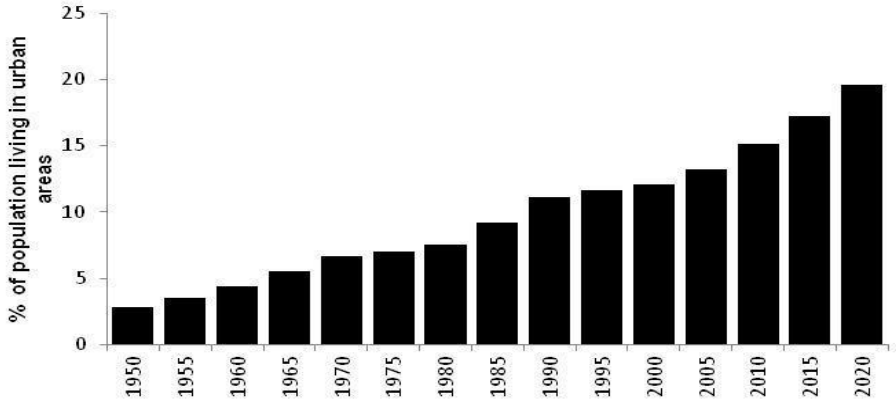


Figure 4. Percentage of population residing in urban areas of Uganda between 1950 and 2020

Population movement

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.[24] Bordered by five countries, some with unstable political and economic situations, Uganda was the focus of migration from surrounding African countries until 1970, with most immigrants coming from Rwanda, Burundi and Sudan. In the 1970s, immigrants were estimated to make up 11% of the population. Emigration increased dramatically during the 1970s and was believed to slow during the 1980s. About 23,000 Ugandans were living in Kenya, and a smaller number had fled to other neighbouring countries.

In 1989, Uganda reported 163,000 refugees to the United Nations High Commissioner for Refugees (UNHCR). Most of these were from Rwanda, but several other neighbouring countries were also represented. At the same time, Zaire and Sudan registered a total of nearly 250,000 refugees from Uganda. The effects of the war in the north waged by the Lord's Resistance Army for over a decade from the mid-1990s led to large scale massacres, population displacement and refugee camp establishment.

The effects of population movent on human settlement have yet to be properly enumerated. In 2011, there was a surge in the number of refugees fleeing violence in the eastern parts of the DRC and by 2012, had resulted in more than 40,000 persons seeking safety in Uganda. They joined other new arrivals, notably from South Sudan, Somalia, Burundi, Rwanda, Ethiopia and Eritrea, who were entering at a slower rate. In 2012, Uganda registered more than 190,0000 refugees and asylum seekers.[10]

Economy

The period of colonial rule (1895 to 1962) saw a rapid expansion in the agricultural economy of Uganda, mainly cotton, coffee, rubber, sugarcane and tobacco. The rail line, completed in 1901, allowed for the movement of crops within the country and to neighbouring Kenya for export. Between 1948 and 1954, the Owens Falls Dam was constructed, but the expected dramatic growth of industries around Jinja did not take place and the electrical supply exceeded the demand until the 1980s.[25]

Agriculture continues to be the major source of foreign exchange; however, Uganda's mineral potential remains undeveloped. Areas identified for priority attention include the Busia goldfields in south-east Uganda, the area around Tororo and Mbale, and the Buhweju and Kigezi goldfields. A Canadian company, Uganda Gold Mining, has also claimed that there are diamond reserves in Bushenyi district. Mining for phosphates at Sukulu in eastern Uganda is ongoing, and drilling for oil began in 2002 near Lake Albert.

During the decades of civil war and political strife, the country's economy was paralysed and Uganda was regarded as one of the poorest countries in the world. Agriculture still dominated the economy in 1986, with coffee as Uganda's main export. The government, with donor assistance, rehabilitated the economy. Inflation ran at 240% in 1987, but was reduced to 42% by 1992, and further reduced to 5.1% in 2003. By 2007, the services sector had surpassed agriculture and accounted for 52% of gross domestic product (GDP).

In 2000, Uganda was included in the Heavily Indebted Poor Countries (HIPC) debt relief initiative worth USD 1.3 billion and Paris Club debt relief worth USD 145 million. The country was hailed by the International Monetary Fund (IMF) and the World Bank as a paragon of economic reform leading to substantive growth. In 2006 the Ugandan Government successfully paid all their debts to the Paris Club, which meant that it was no longer on the HIPC list.

In 2008, Uganda recorded 7% growth despite its global downturn and regional instability. Uganda depends on Kenya for access to international markets via its rail and road networks, a dependence acutely felt during the post-election violence in Kenya in 2007-8 when market access was virtually cut off.

In 2007, the government approved the Comprehensive National Development Planning Framework. This framework provided for the development of a 30-year vision to be implemented through National Development Plans, Sector Investment Plans and Local Government Development Plans.

The Uganda Vision 2040 was launched in April 2013 and articulated strategies and policy directions to transform the country into a lower middle-income country with a per capita income of USD 1,033. The vision incorporates emerging development prospects including the discovery of oil and gas reserves, green economy, e-revolution, globalisation and regional economic integration among others. The governmental cabinet approved the Uganda Vision 2040 Statement: "a transformed Ugandan Society from a peasant to a modern and prosperous country within 30 years" upon its introduction.[26]

In 2015 the country released its Second National Development Plan (NDPII), which proposed heavy investments in industry and infrastructure to drive a growth rate of 6.3% toward a per capita income of USD 1,039 by 2020.

The country has rapidly decreased rates of impoverishment over the past two decades. The proportion of people living below the poverty line declined from 56% in 1992 to 20% in 2013.[27] Though the percentage of the population living on less than USD 1.90 purchasing power parity (PPP) per day has decreased from 53.2% 2006, more than a third (34.6%) of the population lives below the extreme international poverty line.[27]

The per capita income was USD 580 in 2016, USD 122 lower than only two years before due to volatility from the election and global market and lowered oil and commodity prices on the global market.[28] Despite this, the National Planning Authority reiterated that the 2020 goal was attainable in its 2017 Roadmap to Attaining Middle Income Status if the NDPII was implemented well.[29]

The MoH is expected to contribute to this goal by working to improve the health status and life expectancy of the people of Uganda. In particular, the NDPII emphasises that mass management of malaria, among a wider set of areas, is a key part of the plan's focus to improve development through health.

Health in Uganda

Life expectancy at birth in Uganda was 62 years of age in 2015, compared to 47 years of age in 2000.[30] The adult mortality rate (probability of dying between 15 and 60 years of age per 1,000 population) in 2015 was 291 per 1,000 population, a 20% decrease from the 2010 rate of 362 per 1,000 population.[30] 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, 71% of deaths were due to communicable diseases, 23% were due to non-communicable diseases, and 6% were due to injuries in 2010.[31] In 2016, 63% of deaths in 2016 were due to communicable diseases, 8% were due to injuries, and 29% were due to non-communicable diseases.[31]

The maternal mortality ratio (MMR) fell from 780 deaths per 100,00 live births in 1990 to 343 deaths per 100,000 live births in 2015 (a 56% decrease). Similarly, the recent 2016 DHS suggests that the MMR during the seven years preceding the 2016 survey was 336 deaths per 100,00 live births.[32]

Substantial declines in both infant and under-five mortality were measured from 1960 through to the early 1970s afterwhich modelled household survey data show the stagnation of progress and periods of high mortality over the two decades of civil strife and war and the emerging HIV epidemic.[33] By the mid-1990s, infant and child mortality began to decline significantly.[33] Under-five mortality decreased from 170 deaths per 1,000 live births in 1990 to 53 deaths per 1,000 live births in 2016, according to UN population data.[30] Most recently, the 2016 DHS suggests that under-five mortality 64 per 1000 live births and infant mortality (1q0) is 43 per 1000 live births.[32]

By 2016, Uganda had fallen short of achieving Millennium Development Goal (MDG) 5, target 5A: Reduce by three quarters between 1990 and 2015, the MMR, but only narrowly missed MDG5, target 4A: reduce by two thirds, between 1990 and 2015, the under-five mortality rate.[34] Despite improvements in child and maternal survival, these figures remain high.

2.4 Administration and policies

Government

Uganda is a democratic republic ruled by a president, who elected by a majority popular vote for a five-year term. President Museveni has ruled the country since his ascension to power in 1986 (see Section 9.2). The executive branch of the government is occupied by the President, Vice President, Prime Minister and the Cabinet. The President serves as the head of state and government, and appoints all members of the Cabinet, subject to parliamentary approval.

The Legislature, which contains Parliament, consists of 375 members, known as MPs, elected to a five-year term to represent counties. Parliament is responsible for passing legislation, scrutinising government spending and operation and vetting nominees of the president.
The third branch of government, the Judiciary, is responsible for resolving disputes, interpreting the constitution, upholding democratic principles, promoting the law and maintain societal order and protecting human rights.

Administrative divisions

The country has 15 nominal regions (Figure 5),[35] which contain sets of districts (Table 2). In 2015, Parliament approved the creation of 23 new districts throughout the country. The districts will be introduced in phases between 2016 and 2019.[36,iv] Presently, there are 116 districts in Uganda. Each district is subdivided into counties and municipalities or towns, which are defined by the Ministry of Local Government. Counties are further divided to sub-countries and municipalities are subdivided into divisions. Sub-counties, divisions and towns are further divided into parishes and wards, which are finally subdivided into villages, which are the lowest administrative level.

Levels of decision-making

The Ministry of Local Government oversees the administration of local government and is empowered through the Local Governments Act 1997 (Cap. 243). The Ministry of Local Government is responsible for formulating and supervising national policy and legislation on local government.[37] Each level of local government is led by councillors who are elected locally at each level from the village to the district/city. Local governments have legislative, financial and administrative powers.[37]

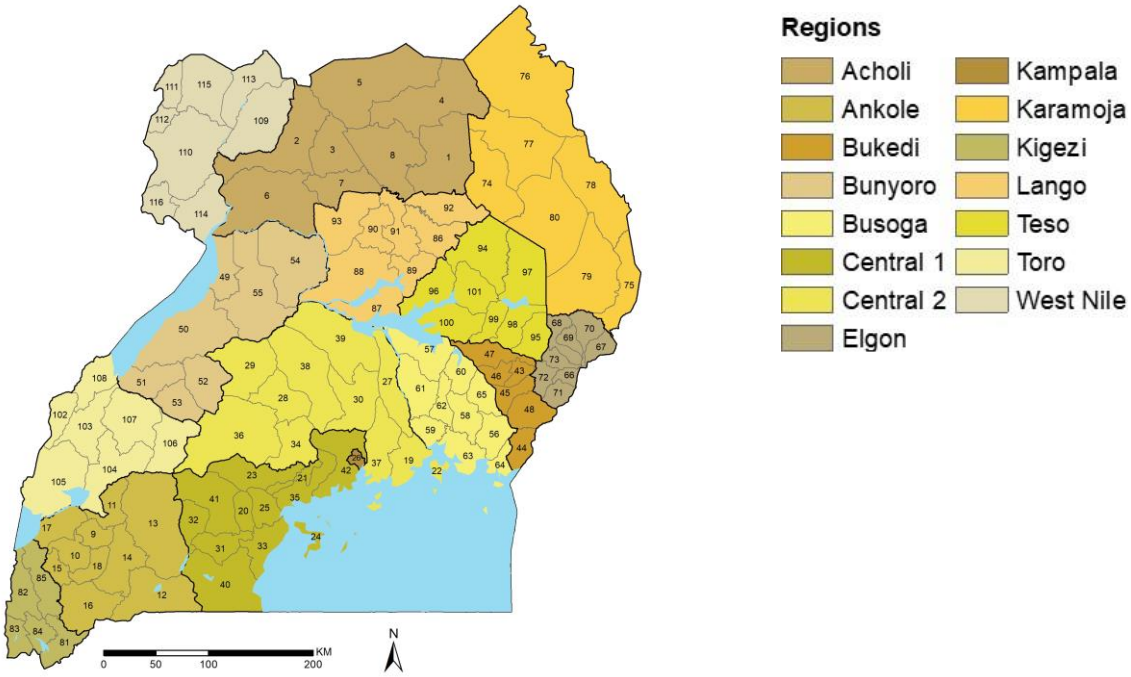


Figure 5. 116 districts of Uganda within 15 nominal regions.
The methods for validating and preparing this figure are provided in Annex A.

[iv] Kagadi, Kakumiro, Omoro and Rubanda will become effective in July 2016, Namisindwa, Pakwach, Butebo, Rukiga, Kyotera and Bunyangabu will become effective in July 2017, Nabilatuk, Bugweri, Kasanda, Kwania, Kapelebyong and Kikuube will become effective in July 2018 and Obongi, Kazo, Rwampara, Kitagwenda, Madi-Okollo, Karenga and Lusot will become effective in July 2019

Table 2. 116 Districts by region for Uganda

District	Map code	District	Map code	District	Map code
Acholi		**Central 1**		**Kigezi**	
Agago	1	Bukomansimbi	20	Kabale	81
Amuru	2	Butambala	21	Kanungu	82
Gulu	3	Gomba	23	Kisoro	83
Kitgum	4	Kalangala	24	Rubanda	84
Lamwo	5	Kalungu	25	Rukungiri	85
Nwoya	6	Lwengo	31	**Lango**	
Omoro	7	Lyantonde	32	Alebtong	86
Pader	8	Masaka	33	Amolatar	87
Ankole		Mpigi	35	Apac	88
Buhweju	9	Rakai	40	Dokolo	89
Bushenyi	10	Sembabule	41	Kole	90
Ibanda	11	Wakiso	42	Lira	91
Isingiro	12	**Central 2**		Otuke	92
Kiruhura	13	Buikwe	19	Oyam	93
Mbarara	14	Buvuma	22	**Teso**	
Mitooma	15	Kayunga	27	Amuria	94
Ntungamo	16	Kiboga	28	Bukedea	95
Rubirizi	17	Kyankwanzi	29	Kaberamaido	96
Sheema	18	Luwero	30	Katakwi	97
Bukedi		Mityana	34	Kumi	98
Budaka	43	Mubende	36	Ngora	99
Busia	44	Mukono	37	Serere	100
Butaleja	45	Nakaseke	38	Soroti	101
Kibuku	46	Nakasongola	39	**Toro**	
Pallisa	47	Elgon		Bundibugyo	102
Tororo	48	Bududa	66	Kabarole	103
Bunyoro		Bukwo	67	Kamwenge	104
Buliisa	49	Bulambuli	68	Kasese	105
Hoima	50	Kapchorwa	69	Kyegegwa	106
Kagadi	51	Kween	70	Kyenjojo	107
Kakumiro	52	Manafwa	71	Ntoroko	108
Kibaale	53	Mbale	72	**West Nile**	
Kiryandongo	54	Sironko	73	Adjumani	109
Masindi	55	**Kampala**		Arua	110
Busoga		Kampala	26	Koboko	111
Bugiri	56	**Karamoja**		Maracha	112
Buyende	57	Abim	74	Moyo	113
Iganga	58	Amudat	75	Nebbi	114
Jinja	59	Kaabong	76	Yumbe	115
Kaliro	60	Kotido	77	Zombo	116
Kamuli	61	Moroto	78		
Luuka	62	Nakapiripirit	79		
Mayuge	63	Napak	80		
Namayingo	64				
Namutumba	65				

Health system

Historical perspective of the health system

Formalised medical services in Uganda were established by the Imperial British East Africa (IBEA) Company in 1888 when it needed medical doctors for its employees. When the IBEA transferred its functions and assets to the British Foreign Office in 1985, it also transferred its medical services. The Foreign Office restructured the company's medical services into the medical department of the protectorates. The medical department was primarily focused on preventing health hazards for Europeans; second in priority were Indians who were building the railway and promoting trade. In 1901, there were seven doctors, seven hospital assistants and three nurses serving the medical department. The medical department in Uganda faced numerous challenges that ultimately led to a merger of the Kenyan and Ugandan medical departments in 1903, with a principal medical officer for Kenya and Uganda. The combined medical staff at this time comprised of 26 doctors, seven European dispensers, and six nurses.[38]

The first missionary hospital, Mengo Hospital, was established in 1897 by the Church Missionary Society (CMS) through Sir Albert Cook. The hospital had 70 beds, serving 1,070 inpatients and 76,840 out-patients by 1901. It was at Mengo Hospital that the first case of sleeping sickness was diagnosed in 1901.[39] The missionary work introduced western medicine and accelerated its acceptance by local populations. World War I saw the formation of the Uganda Medical Corps consisting of volunteers drawn from high schools and a government medical training centre in Kampala. By 1915, the Uganda Medical Corps consisted of 1000 assistants.[39] Between 1919 and 1925, the missions trained 60 hospital assistants and several "native" medical attendants at Makerere Technical College. Makerere College started in Kampala in 1921 as a technical college and changed its curriculum in 1922 when it began to teach medical courses formerly given at Mengo Hospital by CMS.[38] A dispensary system was introduced in 1924, later upgraded to modern health centres.[38]

Re-organisation of medical services continued after the Second World War (1939–45). In 1955, a committee was set up to review and examine health services in Uganda. The committee reported that a lack of funds hindered expansion of medical services and recommended the introduction of user fees, adoption of a common policy to coordinate all medical resources in the country and to accelerate the training of African personnel. The report also encouraged closer relationships between the medical department and mission medical work.[38]

After many years of training medical auxiliaries and laboratory technicians, Makerere College became a University College for East Africa which provided medical degrees from the University of London, and eventually in 1963 fully fledged regional degrees. The University was therefore responsible for the first cohorts of qualified doctors from Tanzania, Kenya and Uganda upon the country's independence.[38]

The first decade following independence saw the growth of a national public health system but by 1986 the health sector was in a state of near collapse, with dilapidated and very poorly equipped public health facilities. The country was dependent on foreign aid, and donors and aid agencies influenced both health and development policy as a result.[40] There was strong regional pressure for the role of user fees in encouraging community participation and ownership and as a means to generate revenue, in line with the Bamako Initiative. In the late 1980s, user fees were introduced into the public sector against a backdrop of poor health system but did not spread widely until the early 1990s. The fees were later abolished in 2001as part of a health sector reform strategy.[41]

Uganda embarked on major reforms from 1986 onwards both in the health sector and wider public arena. The immediate emphasis was a rehabilitation of the existing facilities to restore functional capacity and a shift of emphasis to primary health care.

In the early 1990s the Ugandan government decentralised its services as part of a cross-cutting public-sector reform which was part of a regional push for structural adjustment. Through this, the central government's role for health was through the MoH mandate and consisted of policy formulation, standard-setting, quality assurance, resource mobilisation, capacity development, technical support, the provision of nationally coordinated services such as epidemic control, the coordination of health research and monitoring, and evaluation of overall sector performance. Local governments were mandated to provide curative and rehabilitative services, vector/communicable disease control, health education, safe water and sanitation, and additional resources at the local (district) level.

Health system administrative boundaries

Districts and counties have played a key role in the delivery and management of health services since the early 1990s. There is almost no regional level planning other than the regional referral hospital care system. The 1995 Constitution and the 1997 Local Government Act mandates the District Local Government to plan, budget and implement health policies and health sector plans.[42] The healthcare delivery system in Uganda is parcelled into districts. According to health sector strategic plans since 2008,[43] the District Health System comprises:

> "*…a well-defined population living within a clearly delineated administrative and geographic boundary and includes all actors in the recognised spheres of health within the district. It is expected that the activities of the diverse partners in health are reflected in the District Health Sector Strategic Plan, which in turn is an integral part of the rolling District Development Plan. The National Health System established the Health Sub-District (HSD) as a functional subdivision or service zone of the district health system to bring good quality essential care closer to the people, allow for identification of local priorities, involve communities in the planning and management of health services, and increase the responsiveness to local needs*"

Districts are subdivided into counties and then into sub-counties. The sub-counties are self-contained service zones headed by a medical officer, but they are not considered distinct administrative units. According to the 1999 National Health Policy, the sub-counties are primarily responsible for health service delivery.[44] Sub-counties are further divided into parishes and parishes into villages.

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. They oversee accounting officers (the Permancy Secretary and Under Secretary) in the Permanent Secretary.

The Director General, who sits beneath the Permanent Secretary, oversees the six major Departments: Finance and Administration; Planning, Quality Assurance, Nursing, Community Health, Clinical Service, National Disease Control and Human Resources. Each department is overseen by a commissioner. The National Malaria Control Programme sits beneath the Department of National Disease Control. Figure 6 depicts the broad organisation of the health system.

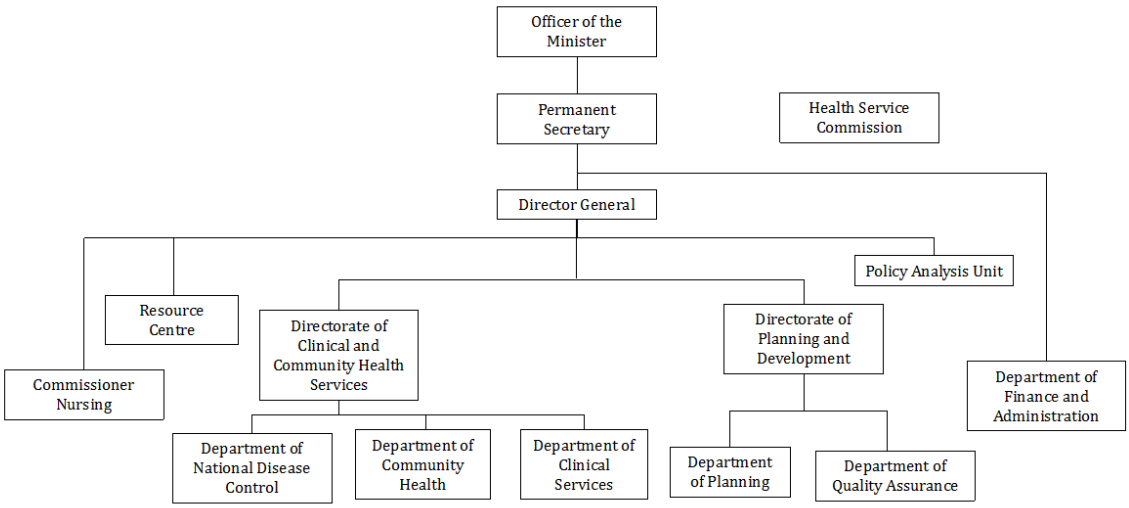


Figure 6. Uganda health system structure

Service provision hierarchy

Beyond the central administration of the health system, Uganda's decentralised health system is governed through District Health Systems, which are under the leadership of the District Directorate of Health Services. The District Directors for Health Services are responsible for the planning, management, monitoring and coordination of all district-level and lower health facilities.[45]

Healthcare provision in Uganda is delivered through a tiered structure of facilities based on the services that they provide and catchment area they are intended to serve.[46,47] The facilities are designated as Health Centre level one (HC I) to Health Centre level four (HC IV or general hospital); Regional Referral Hospital and National Referral Hospital (Figure 7).

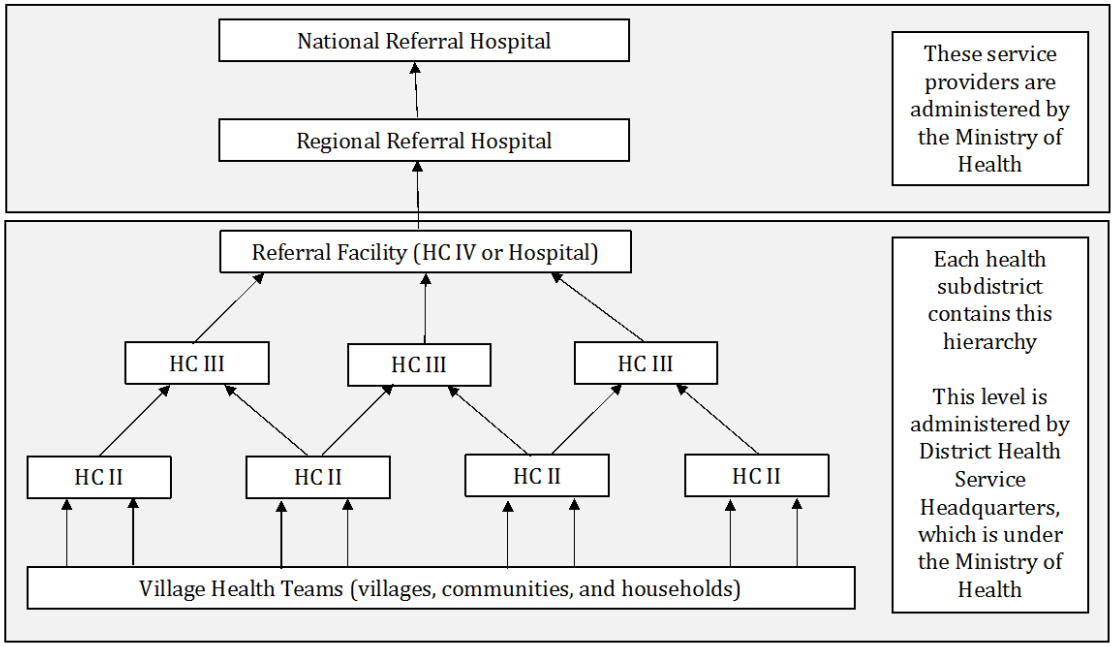


Figure 7. Uganda health system structure (adapted from health system profile for Uganda 2005 and from PRIMASYS - Primary Care Systems Profile and Performance by the WHO/Alliance for health policy and systems research with support from Bill & Melinda Gates Foundation [BMGF] [under review])

The lowest level of a HSD and first point of contact for someone living in a rural area is Health Centre I (HC I). These are owned by village health teams (VHT)/community medicine distributors who are largely volunteers targeting smaller populations of 1,000 persons. In most cases, they do not exist or do not have basic drugs for diseases such as malaria.

According to Uganda's health policy, every parish is supposed to have a HC II facility serving a target of about 5,000 people. A HC II is supposed to be staffed by an enrolled nurse, working with a midwife, two nursing assistants and a health assistant. It runs an outpatient clinic, treating common diseases (including malaria) and offering antenatal care.

A HC III facility should be found in every sub-county in Uganda serving a target population of 20,000 people. These centres should have about 18 staff, led by a senior clinical officer, who runs a general outpatient clinic, inpatient health services and a maternity ward. HC IIIs should also have a functioning laboratory for diagnosis (though the 2007 DHS Service Provision Assessment found that only 35% of HC IIIs reported capacity for blood smears and only 1% reported capacity for RDTs).

A HC IV serves counties and is the main facility for seven sub-counties. As a mini-hospital, a HC IV serves a target population of about 100,000 persons and provides all HC III services as well as emergency surgery and blood transfusion. HC IV facilities must have a senior medical officer and another doctor as well as a theatre for carrying out emergency operations. Each district is ideally supposed to have a hospital, which should have all the services offered at a HC IV, plus specialised clinics – such as those for mental health and dentistry – and consultant physicians.

Hospitals are grouped into three categories: general, serving a population of 100,000 – 1,000,000; regional, serving a population of 1 to 2 million; and national, serving population of over 24 million. There are two National Referral Hospitals and 11 regional referral hospitals, which are semi-autonomous. Soroti's district hospital, in Soroti town, is also a regional referral hospital as it caters for the Teso and Karamoja regions, meaning it gets cases referred from other district hospitals. At the top of the healthcare chain is the national referral hospital located at Mulago in the capital Kampala. Other national referral hospitals include Butabika, and more recently Gulu and Mbarara.

Health facility mapping

Accurate health information is the cornerstone of effective decision-making and reliable assessment of disease burden and resource needs.[48,49] 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.[50–52] 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[53,54] but there are few examples of their development and operational use in resource-poor settings in Africa.[55–57]

The first health facility mapping exercise began before independence by the medical department in 1956 and then soon after independence in 1968 by the MoH with the assistance of WHO.[58] The 1956 health facility map provided the positions of 33 hospitals and 142 maternity centres and dispensaries with beds. Of the 33 hospitals, 24 were maintained by the government while nine by missionaries. Of the 142 maternity centres and dispensaries with beds, 115 were maintained by the government while 27 were maintained by missionaries. To produce maps of health facilities, the project has mapped project recorded the facilities into Hospitals and HC IIIs (maternity centres and dispensaries with beds) for purposes of consistency with current service provision levels (Figure 8).

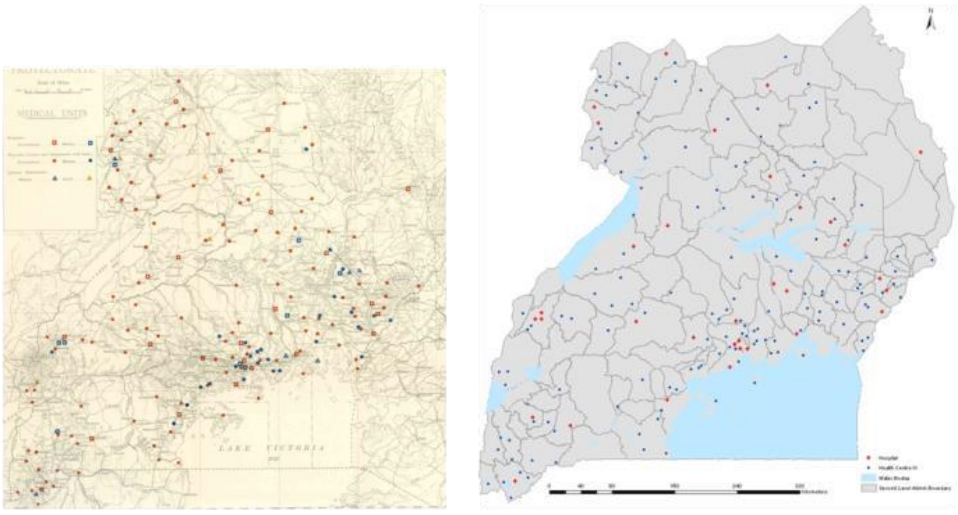


Figure 8. 1,956 health service distribution a) The original maps and b) digitised by importing each of the recoded 175 facilities (leprosy settlements excluded) using ArcGIS [ArcMap 10.1, Esri Systems, Redlands, CA, USA]

The 1968 health facility map provided 29 government hospitals, 17 planned government hospitals, 21 mission hospitals, 18 health centres, 79 dispensaries/maternity units, 77 dispensaries, 92 sub-dispensaries, 154 aid posts, 37 mission units and four private industry hospitals. This report recoded the facilities into hospitals (government hospital, government planned hospitals, mission hospitals and private industry hospitals); HC IV (health centre and mission Unit); HC III (dispensary and dispensary/maternity unit) and HC II (Aid post and Sub-dispensary) (Figure 9).

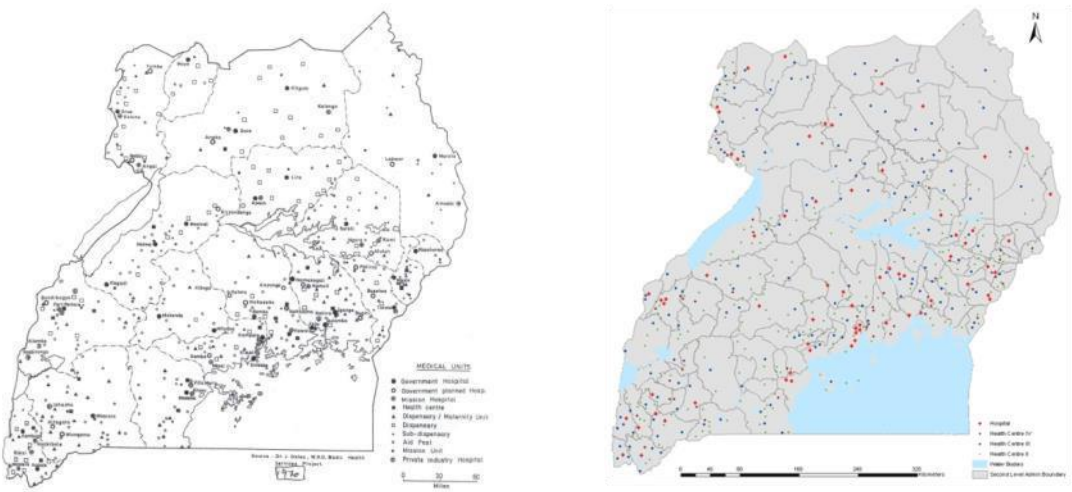


Figure 9. 1,968 health service distribution a) The original maps and b) digitised by importing each of the recoded 504 recoded facilities (note four industry-owned facilities excluded) using ArcGIS [ArcMap 10.1, Esri Systems, Redlands, CA, USA]

In 2004, a service availability mapping survey was carried out by the MoH and WHO which estimated the total number of health facilities, indicating that there were 2,731 managed by government, non-governmental organisation (NGO) and private sectors. The composition of facilities included 108 hospitals, 160 HC IVs, 873 HC IIIs and 1,593 HC IIs.[46]

The MoH maintains a master health facility list using information supplied from district medical officers and partners in the health sector. This list was most recently updated in 2017. The 2013 LINK profile provides detailed methods of how health facility mapping was previously conducted in Uganda (Figure 10).[59]

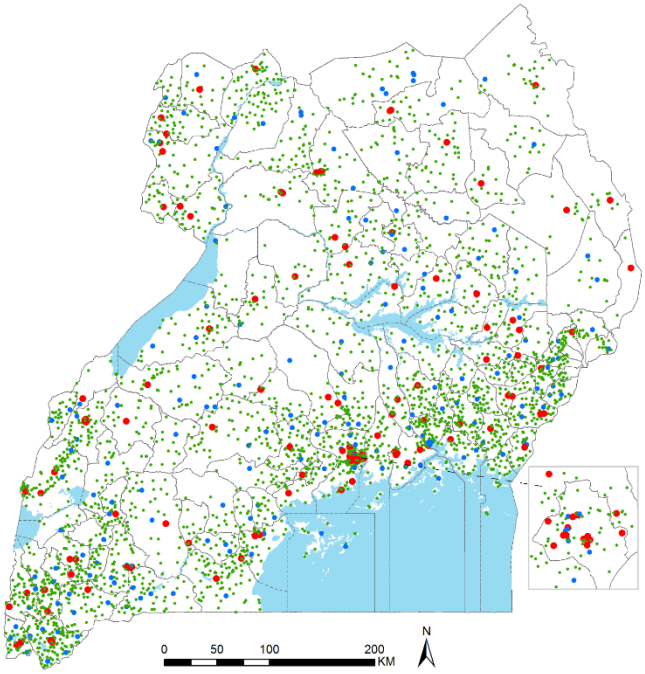


Figure 10. Distribution of 3357 public health facilities: Hospitals (115 red), Health Centres (184 blue) and Health Posts (3058 green)

Health context and priorities

Uganda released its the most recent Health Sector Development Plan (HSSIP) (2015-20) in 2015; it is the second in a series of six development plans aimed at achieving Uganda Vision 2040. Similar to vision 2040, the country's 2010 National Health Policy II vision is to achieve a "healthy and productive population that contributes to socio-economic growth and national development," and additionally establishes a focus on primary health care delivery and the decentralisation of the health system.

Under previous HSSIPs, Uganda had made notable gains, in particular improvements in child and maternal survival and a national transition to the District Health Information System (DHIS-2). The current Health Sector Development Plan focuses on accelerating movement toward universal health coverage. To this end, there are four objectives:

1) To contribute to the production of a healthy human capital for wealth creation through provision of equitable, safe and sustainable health services
2) To increase financial risk protection of households against impoverishment due to health expenditure
3) To address the key determinants of health through strengthening intersectoral collaboration and partnerships; and
4) To enhance health sector competitiveness in the region and globally.

To achieve these objectives, the government will work towards strengthening the health system in the areas of governance; disease prevention, mitigation and control; health education and promotion, curative services; rehabilitation services; palliative services; and health infrastructure development.

eHealth

The MoH recognises eHealth as essential to improve health outcomes though its promise to improve delivery of health services. To this end, it developed a national eHealth policy in 2013.[60] This policy provides guidance on how to use information and communication technologies (ICT) to improve the flow of information through electronic means, support delivery of services and facilitate long-term goals that include health sector efficiency, social transformation and universal access to care.[60]

The MoH operates an eHealth Technical Working Group (eHTWG), which is chaired by the Resource Centre. Present governance and leadership in this area is unclear at the district and community level. There is no special budget to improve ICT, so work in this area is dominated by various donor-driven projects that are not interoperable with government technologies. Currently there are no national standards for the management of secure electronic health information.

Presently, data connectivity and networking in Uganda covers 100% of the country, made possible through fibre for major towns and wireless (mobile phone) connectivity in districts. The National Backbone Infrastructure, implemented through the National Information Technology Authority and owned by the Government of Uganda, is expanding access between all major towns by building an extensive network infrastructure.

2.5 Malaria in Uganda

According to the 2014 UMRSP, malaria is endemic in approximately 95% of Uganda and affects over 90% of the population.[61] In non-endemic areas, transition is unstable and epidemic-prone; these areas are in the highlands of the south- and mid-west, along the eastern border with Rwanda, and the north-eastern border with Sudan.[61] In 2015, WHO reported that nearly 40 million people were at high risk of malaria.[62]

In 2016, Uganda accounted for 4% of global malaria cases.[63] In 2017, the country had the seventh highest number of malaria cases in Africa, with 7.7 million cases, and had the tenth highest number of annual malarial deaths in 2016, with 12,060 deaths.[62] However, this is a significant improvement from 2010, when estimated cases were placed at 13.4 million and estimated deaths at 25,370.[63]

Malaria control is a long-standing priority of the government's health agenda. The Constitution of the Republic of Uganda, the National Development Plan (2010/11-2014/15) and the Second National Health Policy (NHP II, 2010) emphasise that malaria control is of national interest (NMSP 2014-15). National policies are in place to promote malaria control and access to services: in 2001 user fees for malaria care were eliminated at all public facilities and government taxes on ITNs, medicines and laboratory supplies were waived.

National Malaria Strategic Plan

The 2014-20 National Malaria Strategic Plan envisions a "malaria free Uganda." It aims to, by 2020, reduce annual malaria deaths from the 2013 levels to near zero, reduce malaria morbidity to 30 cases per 1,000 population and reduce the malaria parasite prevalence to less than 7%.[64] To achieve these strategic goals, the plan states the following objectives:

1) Achieve and sustain protection of at least 85% of the population at risk through recommended malaria prevention measures, by 2016;
2) Achieve and sustain at least 90% of malaria cases in the public and private sectors and community level receive prompt treatment according to national guidelines, by 2018;
3) At least 85% of the population practices correct malaria prevention and management measures, by 2017;
4) The programme is able to manage and coordinate multi-sectoral malaria reduction efforts at all levels, by 2016;
5) All health facilities and District Health Offices report routinely and timely on malaria programme performance, by 2017; and
6) All malaria epidemic prone districts have the capacity for epidemic preparedness and response, by 2017.

A timeline of malaria control in Uganda

As part of the earlier 2013 malaria risk profile,[59] a comprehensive written history of malaria control in Uganda was prepared. In addition, the history of malaria control was presented in a paper by Talisuna et al.[65] To ground the discussion of malaria control in Uganda, this report summarises major events between the 1900s and present day. Readers are encouraged to reference the written history in full[59,65] and to view the Uganda Malaria Control Timeline which is online at www.linkmalaria.org.

Year	Event
1917	"Anti-Malarial Gangs" used in major towns of the protectorate for drainage and filling in of breeding sites
1920	Major Nakivubo Swamp reclamation project in Kampala
	IRS conducted with DDT in Lake Mutanda (current Kisoro district) in Kigezi Routine distribution of quinine for prophylaxis in Uganda, but most among Europeans
1928	Increasing use of oil and Paris green as larvicides in urban centres
1929	Colonel SP James visited to provide advice on malaria control, leading to establishment of Malaria Survey Unit and a malaria engineer
1931	Malaria ordinance passed, malaria engineer employed and Paris green widely used in towns
1933	Government-appointed entomologist appointed to work under Agriculture Department
1945	Field trials of DDT undertaken through to the 1950s by the Colonial Insecticides Research Unit
1948	Gammexane powder sprayed on backwaters and spraying oil along the lake edges around Jinja
1950	First malaria conference in Equatorial Africa held in Kampala, convened by theWHO Most control continued from 1950s to 1983 in urban areas under the Ministry of Sanitation's Vector Control Units and included improving drainage and using larviciding in Kampala and other municipalities
	Experimental eradication pilot projects with vector- and parasite-based control conducted in Kigezi, Masaka, Lugazi and Kakira IRS implemented at a larger scale as part of the WHO pilot programme 1959-1963 in Kigezi and Masaka
	Malaria eradication experiments successfully carried out with IRS spraying and mass drug administration (MDA) in northern Kigezi and expanded to region by 1964 IRS with DDT and MDA with Chloriquine (CQ) and pyrimethamine (P) at Kigezi district Malaria eradication pilot projects; Comprehensive human- and vector-based studies undertaken to characterise the epidemiology of malaria in a government resettlement scheme of approximately 50,000 people in northern Kigezi
	WHO Malaria Eradication Technical Committee Meeting held in Brazzaville
1962	Independence from Britain IRS with DDT plus MDA with CQ+P expanded across Kigezi highlands and Lake Bunyonyi area
1963	Large-scale field trial of malathion carried out in Masaka district with support of WHO
	Malathion IRS conducted in Masaka district, protecting 26,000 people

	Uganda pre-eradication programme conducted survey of 120,000 to produce first malaria risk map
1964	Ugandan Malaria Pre-eradication service established with headquarters at Jinja
	CQ-medicated salt project at sugar estates in Lugazi & Kakira conducted until 1965 under malaria eradication experimental pilot project
1969	CQ fully sensitive at Kuluva in West Nile
1976	Civil war, war with Tanzania and political turmoil continued until 1986, hindered malaria control efforts and collapsed health system
1985	First health information system designed, focused on specific diseases
1988	CQ parasitological failure rates exceed 25%
	Uganda DHS conducted
1990	Isolated studies of malaria epidemiology carried out in Kabarole and Bundibugyo until 1996
	Small ITN trials and projects and district-based net sales through NGOs and bilaterals distributed several thousand nets per year
1992	HMIS developed to include management data
1993	Adoption of decentralised health care system
	National Medical Store established under the MoH
1994	Severe epidemics in Kabale district, increasing across the highlands in frequency and severity in three year intervals
1995	MoH established the MCU
	Uganda DHS conducted
	MCU established office in Entebbe
1996	MCU restructured
	National Intensified Malaria Action Plan launched through to 2000 MoH hosts workshop to improve the management of severe malaria at the health facility and hospital level
1997	HMIS system rolled out nationally
	EANMAT a sub-regional network of ministries of health and research agencies, established Large outbreak in south-western Uganda associated with El Niño begins in February and peaks in March
1998	MoH established sentinel sites with support of EANMAT and WHO
	Anti-malaria policy passed by parliament
	EANMAT begins standardised testing of CQ, SP and AQ in Uganda at eight epidemiologically representative sites ITNs included as key preventative strategy for the first time as part of the national malaria control policy EANMAT sentinel sites show evidence of CQ resistance exceeded WHO-recommended threshold
	WHO training materials on management of severe malaria were adapted for Uganda and a first round of training workshops for physicians carried out in the districts
1999	MCU, along with entire MoH headquarters, relocated to current offices in Kampala International Committee of the Red Cross operated a distribution of nets among internally displaced population in Kabarole, neighbouring district to Bundibugyo, and adherence was estimated to be sufficient
2000	CQ clinical failure had reached 33%; SP failure rates 5-12% across the country
	CQ+SP replaced CQ as first line treatment

	Total of nets sold/distributed through all channels increases from 100,000/year in 2010 to 815,000 in the first half of 2005 alone
	Between 2000 and 2005, mass ITN distribution delayed due to change in implementation plan and GFATM procurement process
	HMIS revised to capture indicators to support national monitoring and planning
	Uganda DHS conducted
	Adoption of Integrated Disease Surveillance and Response
	Malaria in Pregnancy Control Strategic Plan launched, emphasizing IPTp, clinical case management and prevention with ITNs
	National Malaria Strategy launched through to 2005
	Intermittent preventative treatment IPTp (two SP doses) policy rolled out
2001	Uganda Malaria Surveillance Programme (UMSP) founded Médecins Sans Frontières (MSF) conducted mass distribution of ITN, distributing 25,552 nets to 16,687 households in internally displaced people (IDP) camps in Bundibugyo district
	UMSP and the MoH established a sentinel malaria surveillance system
	Results of ongoing efficacy studies showed widespread resistance to CQ/SP
	Small-scale IRS carried out in communities in the southwest
2002	Urban malaria vector control projects started in Jinja and Kampala
	ITN policy and strategy document finalisation, waiver of taxes and tariffs on nets and insecticides and establishment of quality standards for the project through the Uganda National Bureau of Standards created an enabling environment for ITN
	MoH adopted WHO LLIN policy to target distribution to pregnant women and children in areas of high risk and began implementation of policy
	User charges in government health facilities abolished Home-based management of [malaria] fever (HBMF) for children less than five years of age via Village Health Teams introduced in ten districts to complement availability of free malaria treatment at public facilities
2003	Subsidised nets made available in economically disadvantaged areas of the North
2004	IRS policy and implementation guidelines finalised as part of IVM approach
	Uganda Malaria Research Centre established by President Museveni
	Decision to change first line treatment policy to artemether/lumefantrin, with artesunate + amodiaquine defined as an alternative first line treatment
	2,150 health workers in 80 hospitals (30 districts) trained in severe malaria management using an updated training manual Availability of oral and injectable quinine improved through development partner support for procurement In addition to the epidemic preparedness approach used in all epidemic prone areas, an extended monitoring and early warning system for malaria epidemics introduced and operated in Kabale and Rukungir
2005	National Malaria Strategy launched through to 2010
	CQ+SP 12% clinical failure rates
	PMI began seed funding for national control, leading to large scale funding in 2006 and following years
2006	Global Fund approved Round 4 funding
	ACT policy implemented following 2004 announcement and preparation period
	Uganda DHS conducted

	IRS with lambda-cyhalothrin began in Kabale district and expanded to Kanungu district in 2007
2007	"ITN mixed model" approach between private and public sector delivery adopted Pilot study conducted by Malaria Consortium in five districts to inform rollout of mRDTs in all lower health facilities
	MoH developed the Resource Centre
2008	IDRC created from the UMSP Home-based management pilot projects conducted in Kamuli, Kaliro, Pallisa and Budaka districts Mass screening and treatment using artemisinin-napthaquone, then dihydroartemisinin–piperaquine conducted, alongside larval control and IRS implemented in Katakwi district, later repeated in Kumi district
	MCU developed its first ever M&E plan
2009	IRS conducted in Apac and Oyam using Alpha-cypermethrin following proven resistance to DDT, MoH conducts IRS in Kumi and Ngora through to 2012
	Global Fund approved Round 7 funding
	DDT and pyrethroid resistance described
	MIS conducted
	Evidence of rising rates of malaria hospitalisation across Uganda since 1999, despite distribution of over 15 million ITNs since 2005
	mRDTs rolled out to 21 districts
2010	MoH officially launched iCCM
	Global Fund Round 10 approved
	IRS switched to use of carbamate (bendiocarb), covering 10 northern districts, protecting circa 3 million people by 2013 With GFATM funding, NMCP carries out its first targeted community mass distribution campaign
	Mass free ITN distribution campaign had distributed circa 7.2 million nets to children under five and pregnant women
	iCCM rolled out
	HBMF with ACTs rolled out to more than 39 districts Programme for Resistance, Immunology, Surveillance and Modelling (PRISM) of malaria established
2011	DHIS 2 was nationally adopted into the HMIS system
	National Malaria Strategy launched through to 2015
	Widespread DDT, permethrin, deltamethrin lambda-cyhalothrin, DDT and carbamate resistance described; pirimiphos–methyl 0.25% sensitive at all sentinel sites Affordable Medicines Facility - malaria (AMFm) to provide ACT in private sector with Global Fund support
	Policy changed to support the use of artesunate injectable as the preferred first line treatment in management of severe malaria from injectable quinine
	First MPR conducted
	Uganda DHS conducted
	iCCM pilot project conducted in private sector in Kaliro and Kamuli districts Survey records dating back to early 1950s destroyed at eradication headquarters in Jinja town in eastern Uganda
	Development of Uganda epidemic preparedness guide
2012	IRS with carbamatebendiocarb conducted in 10 districts-Acholi and Lango subregion

2013	National diagnostic (microscopy & malaria rapid diagnostic test [mRDT]) policy launched
	IPTp policy changed to include three doses of SP, but was not implemented through to 2015
2014	Test, Treat and Track Initiative adopted
	IRS expanded to 14 districts in Eastern and Northern Uganda
	National Malaria Strategy launched through to 2020
	IRS scaled down in northern districts and phased out in Amuru, Kitgum, Lamwo, Nwoya and Agago which ended in May while in the districts of Apac, Kole, Oyam, Gulu and Pader IRS activities ended in October 2014
	IRS switched to seven eastern districts Alebtong, Amolator, Dokolo, Kabaremaido, Lira, Otuke and Tororo in December using Bendiocarb protecting circa 2,551,123 people
	Vector control needs assessment undertaken to prepare an Integrated Vector Control Strategy
	iCCM with malaria treatment expanded in 34 hard-to-reach districts
	mTrac (weekly surveillance) rolled out, using a SMS-based system
	MIS conducted
2015	iCCM scaled up in 33 additional districts
	Up detected in 10 phased-out IRS districts and Arua district in April; epidemic surges continued through to 2016, affecting over 1 million people; NMCP responded by sending 370 health workers to region and improved supply of effective medicines.
	IPTp policy with three doses of SP approved but not implemented
	Additional seven districts added to IRS strategy using pirimiphos methyl protecting circa 2,061,057 people
	iCCM, including malaria, expanded to an additional 18 districts
2016	USAID and PMI support IRS project expanded to additional 14 districts
	Uganda DHS conducted
	Assessment of Malaria Surveillance, Monitoring, Evaluation and Operational Research (SMEOR) capacity conducted
	Staffing in NMCP increased from 9 to 33 staff with support of partners
	Global Fund bridge funding approved
	Malaria Action Programme for Districts Project (MAPD) launched, covering 43 districts
2017	IRS conducted 14 districts under USAID/PMI and USAID; IRS in 11 former IRS districts conducted under Global Fund
	Mass distribution of 25 million LLINs launched by the MoH
	IVM strategy and implementation guidelines approved
	IPTp3 policy launched
	BCC strategy launched
	Global Fund Application for 2018-2020 approved
	PILGRIM study launched to measure impact of population-based IRS and MDA in high transmission setting
	School-based LLIN distribution Guidelines approved
	IVM Strategy approved
	Parasite-Based Diagnostic Guidelines approved
	National Framework for Strengthening SMEOR System developed
	Malaria Indicator Framework developed

An overview of current national malaria interventions

Vector control

Vector control is a cornerstone of Uganda's efforts to control malaria. The country implements IRS, ITNs, and since 2002, LLINs. LLIN and IRS interventions are supported by intensive social mobilisation and behaviour change efforts.[66]

Uganda has a policy of universal coverage (ie. "universal access to, and use of, LLINs", actualised in Uganda as one net per two persons in the population) of LLINs as its primary vector control intervention. From 2010, targeted distributions of LLINs were carried out nationally to children under five years of age and pregnant women. Continuous distribution has been maintained through antenatal care (ANC), Expanded Programme for Immunisation (EPI) and schools. Most recently, the NMCP initiated a 2017 campaign to deliver more than 25 million prequalified LLINs through a mass campaign. Of those LLINs, five million were impregnated with piperonylbutoxide (PBO) synergist to address insecticide resistance through a trial in 48 districts of Uganda.[67]

In 2006 Kabale district adopted IRS using lambda-cyhalothrin, which expanded to an additional five districts (Kanungu, Apac, Kitgum, Gulu, Pader) in 2007. In 2008, IRS was implemented in only two districts, Katakwi and Kumi still using lambda-cyhalothrin there is insufficient detail on whether this continued through to 2009 (Figure 31). The current national strategic plan builds upon this previous work.

The National Strategic Plan states that IRS is to be used as a complementary intervention to LLINs. Between 2009 and 2014, two IRS rounds were conducted annually in ten districts (Kitgum, Agago, Lamwo, Pader, Amuru, Nwoya, Gulu, Oyam, Kole and Apac), covering 500,000 structures and protecting more than 2.6 million people.[68] A marked declined in malaria prevalence was observed in the mid-North region, where prevalence reduced from 63% in 2009 to 20% in 2014.[69,70] IRS was subsequently withdrawn from the ten northern districts in 2014 with the expectation that LLINs would maintain progress. IRS was transitioned to other districts (Alebtong, Amolator, Dokolo, Kabaremaido, Lira, Otuke and Tororo). A year later, malaria epidemics broke out in the ten suspended IRS districts, affecting over one million people.

The NMCP responded by activating the National Task Force, involving all stakeholders and ramping up weekly and daily surveillance.[70] It also sent hundreds of health workers and medicines to the region. At the request of the MoH, WHO delivered technical assistance involving the World Health Organization (WHO). Recently, the NMCP and partners expanded an IRS project to additional districts. In 2017, 25 districts were receiving IRS. A consulting firm, Abt Associates, with support from USAID PMI, was spraying 14 districts, the '*Pilgrim Project'* sprayed one county in Katakwi district and the NMCP sprayed 11 districts, including the ten where the 2015 malaria epidemics had occurred: Kole, Kitgum, Oyam, Nwoya, Gulu, Omoro, Apac, Lamwo, Pader, Amuru and Agago.[71]

While the MoH plans to implement larval source management in urban or peri-urban sites and dry areas, there are currently no activities in that area.[68]

Following the 2011 MTR, which found that vector control interventions were not implemented in an integrated manner,[66] a vector control needs assessment was conducted in 2012. As a result, the NMCP led efforts to develop a national strategy for IVM, the recommended approach

for controlling some vector-borne diseases.[v] The UMRSP 2014–20 incorporated an IVM approach for vector control. In 2014 the country received a Vector Control Needs Assessment according to WHO standards, and used this to inform the development of IVM strategic guidelines in 2015 (finalised in 2017).[66,68]

Treatment and case management

Drug policy

Uganda's first antimalarial drug policy recommended CQ as the first line regimen and sulphadoxine-pyrimethamine (SP) as the second line regimen, with quinine recommended for severe malaria and in case of resistance to CQ or SP. In 2004, the country switched the first line drugs from CQ+SP to artemether-lumefantrine (AL), a WHO-recommended artemisinin-based combination therapy (ACT), for uncomplicated malaria in response to growing CQ+SP resistance. Since 2005, Uganda's second-line drug has been dihydroartemisnin-piperaquine (DHA/PPQ) since 2005.[61,70] For severe malaria, quinine IV is used as an alternative to injectable artesunate.[70]

In 2014, the country adopted the WHO's Test, Treat and Track (TTT) initiative, which mandates that every suspected malaria case should be tested, every confirmed case should be treated with a quality-assured antimalarial medicine, and the disease should be tracked through a timely and accurate surveillance system. To support this, Uganda began to supply all public health facilities with RDTs. The NMCP mandates parasitological diagnosis and treatment with ACTs for all patients with confirmed malaria.

Community-based management

After conducting several studies to increase the quality of home-based malaria case management[72–74] a WHO Special Programme for Research and Training in Tropical Disease (TDR) spearheaded pilot studies in 1998 to assess the feasibility of using pre-packaged medicines for home-based management of malaria fevers (HBMF).

The first pilot countries were Ghana, Nigeria and Uganda. In Uganda the pilot studies were conducted in three sub-counties in Masaka, Mubende and Mpigi districts between 1998 and 2000; the studies demonstrated that HBMF was feasible and could improve access to malaria treatment.[75] HBMF was adopted as a policy in 2001, and it was introduced in 2002 as part of the Integrated Management of Childhood Illnesses.[76] In order to complement the availability of free malaria treatment through public health facilities and bring it closer to the home, the programme of HBMF for children less than five years of age was introduced initially in ten districts in 2002.[77] The blister-packed combination treatment of CQ+SP was developed in two age-dependent and colour-coded packages; one for children six months to two years of age and another for the two to five-year olds. The then-first-line treatment was called "HOMAPAK" and was produced by a local pharmaceutical company. The medicines were initially distributed directly to the districts by the MCU but delivery was later integrated into the existing essential medicines supply system. Caretakers of children with fever accessed the treatment through volunteers called Community Drug Distributors (CDD) or Community Medicine Distributors (CMD), two of whom were selected and trained per village. These CDDs/CMDs reported to and received supplies from the nearest health facility which was also responsible for supervision.

[v] IVM is defined by WHO as "a rational decision-making process for the optimal use of resources for vector control". WHO states that "Implementation of IVM requires institutional arrangements, regulatory frameworks, decision-making criteria, and procedures that can be applied at the lowest administrative level. It also requires decision-making skills that support intersectoral action and are able to establish vector control and health-based targets."[172]

In 2006, the HBMF programme stalled due to shortages in supply.[78] During this time, policy focus shifted to in Integrated Community Case Management (iCCM). In 2010, Uganda introduced a more comprehensive scheme which build upon the country's Village Health Team (VHT) strategy to deliver iCCM, which is the treatment of uncomplicated childhood illness (pneumonia, diarrhoea and malaria) by Community Health Workers (CHWs) and referral of complicated cases. iCCM is hosted by the Department of Child Health and is implemented at HC I level. Through iCCM, CHWs test children under five for malaria using an RDT and treat positive cases of uncomplicated malaria with ACTs. CHWs also offer LLINs and intermittent preventive treatment of malaria during pregnancy.

Malaria in pregnancy
Malaria in pregnancy is managed through the Reproductive Health Division. Malaria in pregnancy is addressed through a policy of intermittent preventative therapy in pregnancy (IPTp), clinical case management and delivery of treated nets through ANC visits. All women are to have one dose of SP as IPTp during both the second and third trimesters.

Structure and function of the National Malaria Control Programme

The MoH delegates responsibilities of management and coordination of the country's malaria programme to the NMCP. The NMCP is responsible for planning, coordinating, implementing and monitoring malaria control interventions. 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 Department of Disease Control (Figure 11).

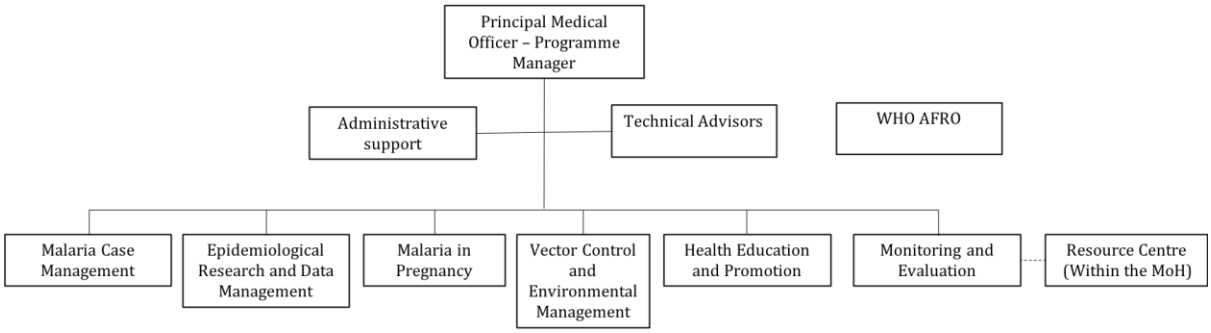


Figure 11. Simplified organisational structure of NMCP, circa 2011

Since 1998 Uganda has aspired to use a zonal coordination system. Therefore, the NMCP coordinates a national strategy through decentralised district offices, which operate District Health Management Teams and which should house a district malaria focal person. National policies operate at the district level.

Financing malaria control

It is estimated that between 2012 and 2015, USD 3 per at-risk capita per year was spent on malaria control in Uganda.[62] The majority (95%) 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).[63] Major funders include the Global Fund to Fight HIV, Tuberculosis and Malaria (GTFAM), PMI/USAID, DIFD, WHO and other bilateral organisations.

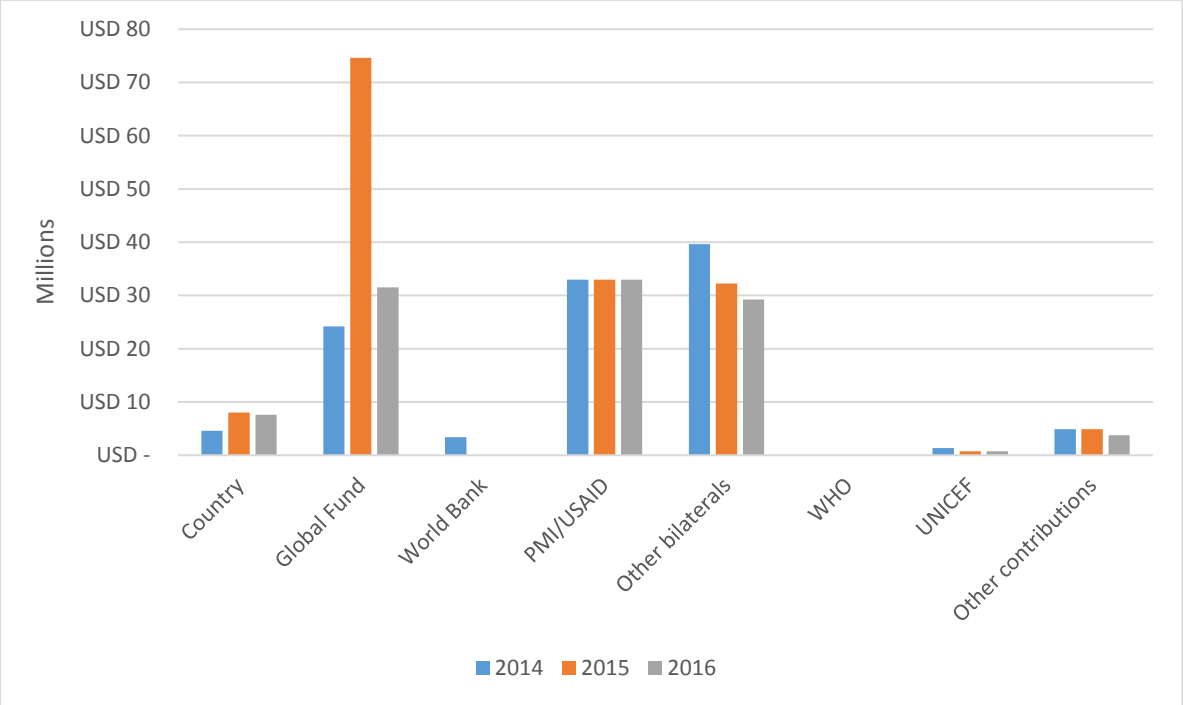


Figure 12. Estimated contributions for malaria reported by Uganda, 2013-5

The budget for implementation of the 2014-2020 UMRSP for the period of 2014 to 2017 was USD 1.2 billion. More than half of budget allocations were for IVM (specifically for LLIN and IRS activities), case management was allocated nearly 40% of the budget, while less than 10% of the remaining budget was allocated to programme management, surveillance, monitoring and evaluation, and operational research, advocacy, communication and social mobilisation. Most the budget is dedicated to the purchase of commodities, specifically LLINs, chemicals for IRS, drugs, and RDTs; the remainder is for operational and research expenses that support implementation.

Though there is global and national momentum for the control and prevention of malaria, government spending on health as a proportion of the national budget is 7% (the Abjua Declaration recommends 15%) and has gradually decreased since 2010,[79] making ongoing support from partners crucial.[80] At the same time, ongoing changes in the malaria funding landscape are leading to an increased demand for detailed epidemiological evidence as the basis for support and targeting of interventions.

Data relevant for malaria control

Data used to inform malaria control in Uganda primarily comes from four sources: (i) routine health information, which gathers data from the public health system and may be complemented by other types of official data such as socio-demographic information; (ii) data from sentinel surveillance sites; (iii) large-scale household and health facility surveys; and (iv) operational research and intervention studies.

This report briefly describes the routine health information system and sentinel sites and give examples of data generated through operational research.

Routine Health Information Systems

In 2007, the MoH established a Resource Centre, which sits under the Director General (Figure 6). The Resource Centre is responsible for the management of public sector health data, including malaria data, through its National Health Data Bank. Routine malaria data are captured through two platforms: mTrac and DHIS 2.[vi] Beginning in 2016, all facilities, including private not-for-profit and private-for-profit, are required to submit routine health data on a weekly and monthly basis to the Resource Centre using a uniform reporting tool (DHIS 2 and mTrac). The routine health information system is depicted in Figure 13.[81–83]

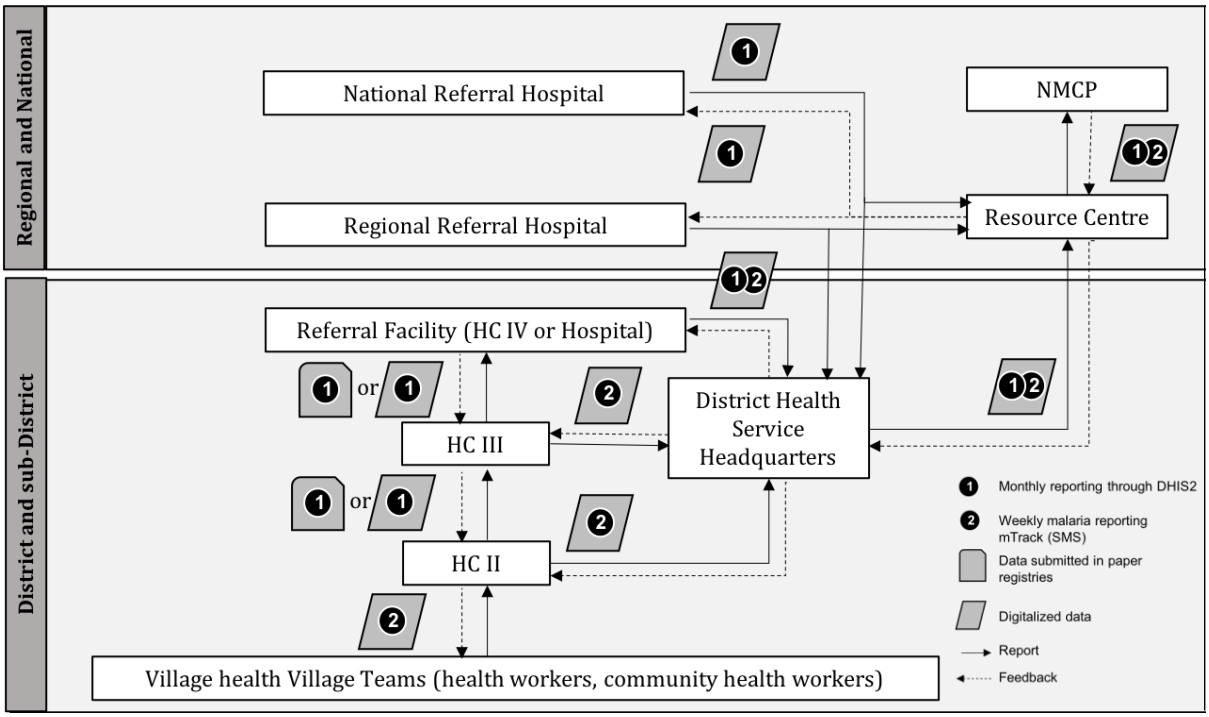


Figure 13. Routine health information system for malaria in Uganda

Uganda nationally adopted the District Health Management Information Software System version 2 (DHIS 2) in 2011 after the evolution of several health information system systems dating back to 1985.[84] Prior to 2010, earlier versions of the HIS were in place, but they were not fully operational and the system continued to be largely paper-based.[84] DHIS 2 was found to improve the timeliness and completeness in reporting of outpatient, inpatient and health service usage data.[84] DHIS 2 in Uganda was customised by a technical team comprised of DHIS 2-trained MoH staff and University of Oslo staff.

[vi] In parallel to DHIS 2 is the hospital medical records system, called UgandaEMR, which uses OpenMRS. However, this system is primarily used for HIV patients receiving inpatient care.

The DHIS 2 system is centrally operated by the Resource Centre. On a monthly and quarterly basis, primary data from lower-level facilities is delivered (electronically, or for facilities without computers, on paper registers) to HC IVs, where trained staff enter in data to submit to the District Health Service Headquarters.

The primary Health Management Information System (HMIS) forms which are submitted by facilities for inclusion in DHIS 2 are:

1) **Outpatient monthly reports.** This form is submitted by HC IIs and above. It captures monthly attendance figures for outpatient department, OPD diagnoses, maternal and child health, HIV/AIDS service data, lab data, stock outs of essential drugs and supplies and financial data. Malaria specific data are: RDT supply, malaria tests and diagnoses by microscopy and RDT, number of malaria in pregnancy cases. It is submitted by each health unit in-charge to the district and to the health sub-district (HC IV). General Hospitals (HC IV) and Regional and National Referral Hospitals send this data to the respective district and the MoH Resource Centre.

2) **Inpatient monthly reports.** This form is submitted by HC III and all levels above, including hospitals. It summarises inpatient services; relevant malaria data include: total and confirmed malaria cases (microscopy and RDT), malaria in pregnancy cases and blood transfusions due to severe malaria. It is submitted by each health unit in-charge to the District and to the health sub-district. However, for general hospitals (HC IV) and regional and national referral hospitals, this is sent to the respective district and the MoH Resource Centre.

3) **Health Unit Weekly Epidemiological Surveillance Report through mTrac (system has interoperability with DHIS 2)**. This is submitted by HC II and above, including government, private health providers and private not-for-profit providers. It reports cases of notifiable diseases The data is retained at the health unit and is also transmitted (in paper form or electronically) to the health sub-district and then to the District Health Headquarters and the Resource Centre. General hospitals, Regional Referral Hospitals and National Referral Centres sent this data to the Resource Centre. To increase the timeliness and reduce the burden of submitting this data, mTrac was introduced; this tool is described below.

Operating alongside DHIS 2 is mTrac, a government-led initiative which digitises the transfer of weekly-reported HMIS data via mobile phones. Adopted in 2011, the primary focus of mTrac is to strengthen disease surveillance and the national medicines monitoring system at the facility and community level. mTrac has interoperability with DHIS 2 and enables paperless, real-time reporting at the district level. mTrac is used to collect data from VHTs/community health workers and from health workers at HC IIs and HC IIIs. Data reported through mTrac mirrors the DHIS 2 Health Unit Weekly Epidemiological Surveillance Form, which collects data on malaria cases suspected, tested (RDT, microscopy) and treated as well as artemisinin-based ACT and RDT stock. SMS-submitted reports are aggregated, tabulated and graphed onto an online dashboard for District Health Teams, which then reviews, approves and submits the data to the Resource Centre. This data is also regularly submitted to the DHIS 2 for analysis of all aggregate HMIS data.

Data regarding ACT stock outs are submitted back to the district health teams and to an action centre which includes the National Medical Stores, the MoH and the Medicines and Health Medicines Delivery Monitoring Unit (a government-mandated group outside of the MOH which was founded in 2009 to investigate management of health resources) for follow-up.

The Resource Centre provides support for district and sub-district level to maintain the DHIS 2 and mTrac systems. It reviews monthly data submissions for quality and requests updated information from facilities when anomalies are detected. It also conducts monthly and quarterly analyses of data and provides feedback to district-level statisticians, who should disseminate to facilities in their catchment areas. When resources allow, the Resource Centre conducts data quality audits. There is a joint quarterly review between the MoH and all partners operating in the health sector who review the data. However, data generated through HMIS is of variable quality.[85,86]

Sentinel sites

The UMSP - later named Infectious Disease Research Collaboration (IDRC) - established six sentinel surveillance sites in 2006 to complement HMIS surveillance; these sites were located in Apac, Mubende, Kanugu, Kabale, Jinja and Tororo.

The sentinel sites operated until 2014, when funding restrictions forced their closure. More recently, investments in response to the epidemics of the north have supported the re-opening and expansion of sentinel surveillance in the north of Uganda. Currently there are 21 sites operating, mostly in the north. Most of these collect outpatient data, but the six original sites additionally collect inpatient data at hospitals in the district, which includes a more detailed module for children.

Large-scale household and health facility surveys

Large-scale household and health facility surveys are a major source of malaria data in Uganda. The DHS are nationally-representative household surveys, typically sampling between 5,000 and 30,000 households, which are conducted every five years. These surveys are designed to be precise at the regional and national level, but are less precise in providing district or sub-district-level estimates. Malaria-relevant data collected by DHS are: ownership and use of mosquito nets, prevalence and treatment of fever, indoor residual spraying for mosquitoes, prevalence of anaemia. 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 at various times in the year, not accounting specifically for malaria seasonality.

The MIS is a stand-alone household survey collecting national, regional, and/or provincial data. These surveys are timed to malaria transmission seasons and collect data for a set of malaria indicators:

- Household ownership of ITNs and their use, especially by children under five years of age and pregnant women
- Intermittent preventive treatment against malaria during pregnancy
- The type and timing of treatment of high fever in children under five years of age
- IRS of insecticide to kill mosquitoes
- Diagnostic blood testing of children under five with fever.

The MIS can also collect data on malaria parasites and anaemia using RDTs or field microscopy.

Results of recent major household surveys
In 2009 and 2014 the MIS[87,88] was conducted to measure coverage and use of malaria control interventions. In 2016 the standard DHS[89] was conducted, which included questions about RDTs for malaria and a malaria module.

The 2016 DHS identified a 30.4% prevalence of malaria by RDT. The most recent MIS indicated a decreased prevalence of parasitaemia by microscopy among children under five years of age (19%), compared to 42% identified by the 2009 MIS.

Malaria can cause anaemia; for this reason anaemia findings are reported alongside malaria findings. The 2016 DHS reported a prevalence of severe anaemia (<7.0 g/dl) among children (6-59 months of age) of 2.3%. The 2014-15 MIS found a prevalence of severe anaemia of nearly 5% among children (Hb<8.0 g/dl), improved from 10% found in the 2009 MIS. Most children surveyed who tested positive by microscopy for malaria for the MIS 2014-15 were infected with *P. falciparum* (97% of all infections).[vii]

Geographically, malaria prevalence among children is varied. The 2016 DHS found that childhood prevalence of malaria was higher in rural areas (11.5% urban, 32.9% rural), and much higher prevalence in Karamoja (70.3%), Lango (62.2%) and Acholi (62.8%) compared to the national average of 30.4%. Similarly, the 2014-15 MIS found that there was much a higher prevalence of malaria infection among children in rural areas (6% urban v. 21% rural, by microscopy) and higher prevalence in east central (36%) and north east (27%) regions.

The 2016 DHS found that 78.4% percent of surveyed households reported having at least one mosquito net, while 51.1% reported having at least one net for every two persons who stayed in the house the preceding night. This indicates a decrease since the 2014-15 MIS, which found that 90% of surveyed households reported having at least one mosquito net, while 62% reported having at least one net for every two persons who stayed in the house the preceding night. There was little difference between coverage in rural and urban areas.

The 2016 DHS found that 64% of all pregnant women surveyed had slept under an ITN the previous night, and that 45% of pregnant women surveyed had received at least two or more doses of SP. This indicates improvements from the 2009 MIS, but not the more recent 2014-15 MIS. In 2009, the MIS found that 44% of pregnant women were sleeping under an LLIN the previous night and that 32% of pregnant women had received at least two doses of IPTp (at least one during ANC); the 2014-15 MIS indicated that this had increased to 75% and 45%, respectively.

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 which is to be investigated). However, the operational unit for malaria control is the district and ensuring the availability of key information on malaria risk at this level is important.

2.6 Drug and insecticide resistance and response

Drug resistance

The first study of drug efficacy in Uganda took place in 1969, following reports of reduced CQ response at the missionary hospital at Kuluva in West Nile. This study, which tested nearly 450 children for the presence of parasites daily following standard body weight CQ three-day dosing, found that CQ eliminated parasitaemia before the fifth day post-treatment with a large majority clearing parasites on the third day, suggesting normal sensitivity to CQ in Kuluva.[90]

[vii] The 2016 DHS used a RDT which detected evidence of *P. falciparum* and *P. vivax* infections, but did not distinguish the parasite.

Beyond this work, few other studies were conducted in Uganda to explore drug efficacy and resistance until the late 1980s. In the late 1980s until the early 2000s, several *in vivo* efficacy studies were conducted, but used different protocols, different study populations and different outcome measures (Table 3). Namely, most studies conducted before 1996 followed WHO recommendations to use asymptomatic subjects attending school, but studies beyond this increasingly recruited symptomatic patients aged between six and 59 months of age or all age groups.

Table 3. CQ and SP resistance studies among children in Uganda (1988-2001)

Study districts	Year	Subjects recruited	Age group (years)	Follow-up duration (days)	Parasitological failure (%)		Clinical Treatment failure (%)	
					CQ	SP	CQ	SP
Kampala[91]	1988	Asymptomatic	5 to 15	7	39	0		
Jinja[91]	1988	Asymptomatic	5 to 15	7	23	0		
Masaka[91]	1988	Asymptomatic	5 to 15	7	38	0		
Masindi[91]	1988	Asymptomatic	5 to 15	7	29	0		
Kasese[91]	1988	Asymptomatic	5 to 15	7	21	0		
Arua[91]	1988	Asymptomatic	5 to 15	7	3	0		
Kabarole[92]	1992	Asymptomatic and uncomplicated	0.5 to 60	7	16	5		
Kampala[93]	1993	Uncomplicated	0.5 to 5	14	12	2		
Apac[93]	1993	Uncomplicated	0.5 to 5	14	2	0		
Tororo[93]	1993	Uncomplicated	0.5 to 5	14	8	0		
Hoima[94]	1995	Asymptomatic	7 to 10	7	58	4		
Jinja[95]	1996	Uncomplicated	0.5 to 5	14	36	5	12	6
Bundibugyo[96]	1996	Uncomplicated	0.5 to 5	14	40	13	33	5
Kabarole[96]	1996	Uncomplicated	0.5 to 5	14	77	7	58	4
Jinja[97]	1996	Uncomplicated	0.5 to 5	14	36	6	12	6
Jinja[98]	1996	Uncomplicated	0.5 to 5	14	33	3	28	2.4
Tororo[98]	1998	Uncomplicated	0.5 to 5	14	88	72	21	15
Arua[98]	1999	Uncomplicated	0.5 to 5	14	43	19	21	10
Apac[98]	1999	Uncomplicated	0.5 to 5	14	41	14	15	10
Rukungiri[98]	1998/99	Uncomplicated	0.5 to 5	14	10	0	10	0
Kabarole[98]	1998/99	Uncomplicated	0.5 to 5	14	81	20	44	13
Moroto[98]	1998/99	Uncomplicated	0.5 to 5	14			48	12
Moroto[99]	1999	Uncomplicated	0.5 to 5	14			21	17
Hoima[100]	1998	Asymptomatic	4 to 10	7	28	1	1	
Mbarara[101]	1998/99	Uncomplicated	0.5 to 5	14		28	81	25
Kampala[102]	1998/99	Uncomplicated	0.5 to 5	14	83		62	
Kampala[103]	1999	Uncomplicated	0.5 to 5	14	96	33	76	11
Kampala[104]	1999/2000	Uncomplicated	0.5 to 5	14			26	14

In response to the need for additional and standardised data on resistance and drug efficacy, the East African Network for Monitoring Antimalarial Treatment (EANMAT) was formed in 1997. The purpose of EANMAT was to facilitate research on drug sensitivity of malaria parasites to antimalarial drugs to support rational and evidence-based malaria treatment policies were implemented in the East African region. Initially EANMAT included Kenya, Uganda and mainland Tanzania, but was later expanded to include Rwanda, Burundi and Zanzibar in 2003.

The Malaria Control Unit (MCU) conducted most of the testing, data collection and analysis in collaboration with staff at the sentinel health facilities in Aduku in Apac, Nangogera in Tororo, Kyenjojo in Kabarole (now Kenjojo), Cilio in Arua, Kihihi in Rukungiri (now Kanungu), Kasabya in Mubende, Mulago in Kampala and Walukuba in Jinja district (Figure 14).[98,105] IDRC was later formed to conduct ongoing drug efficacy studies using a new model of collaboration with local research partners; this groups has produced the largest volume of drug efficacy studies since 2005.

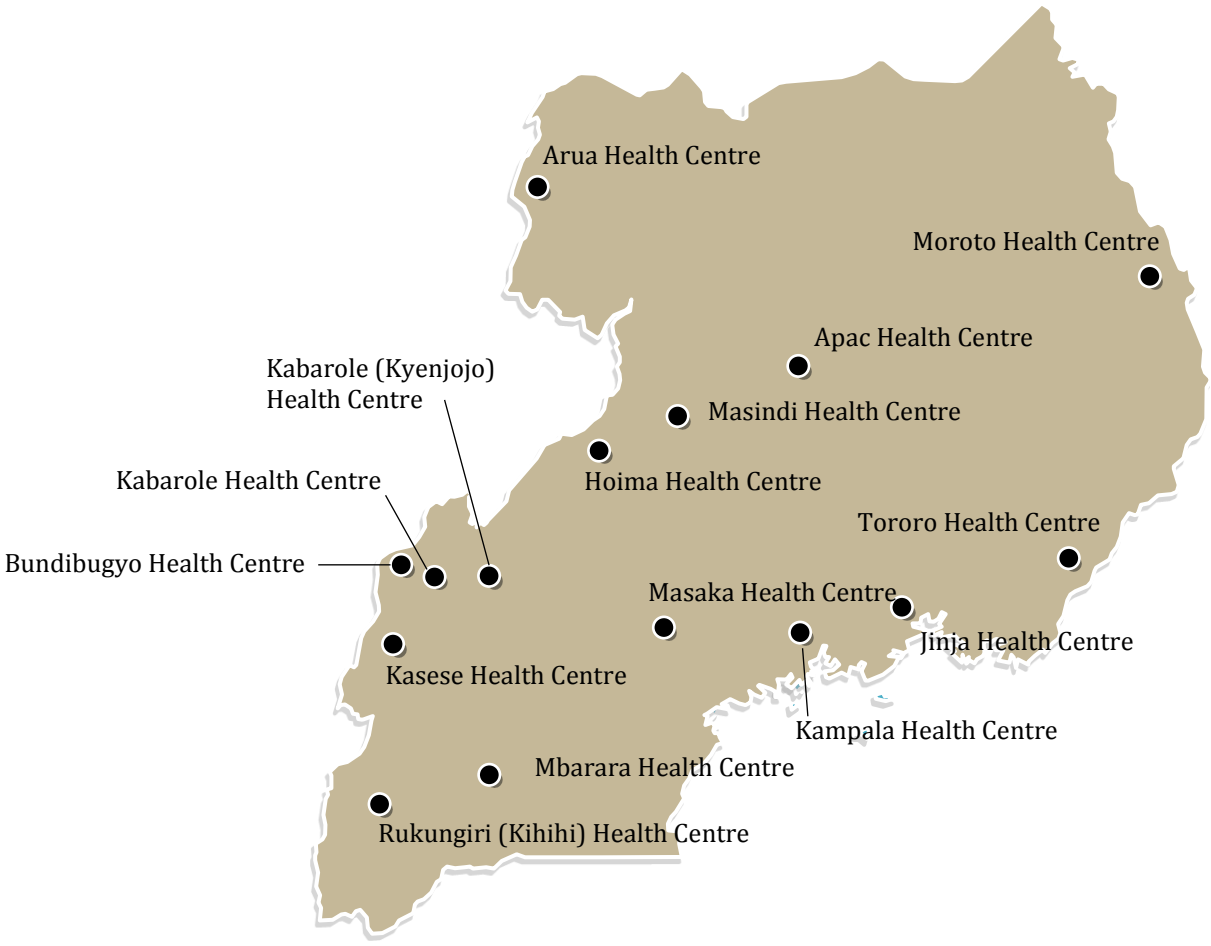


Figure 14. Location of sites generating information on CQ and SP resistance 1988-2000

The data generated by the EANMAT/UMSP sentinel surveillance and several other studies conducted in Uganda confirmed that the prevalence of CQ resistance had become a major problem. For the period 1999-2001, CQ treatment failures had reached an average of 33% in the country, based on a 14 day follow up in children less than five years of age. While SP mono-therapy treatment failure had increased from 5.5% to 12% for the period 1995-98. Paradoxically, faced with these data MoH changed the first-line treatment policy at the end of 2000 to the combination of CQ+SP,[106,107] which had an average failure rate of 7% at the time the policy was launched.

This interim solution was selected because there was a perceived lack of practical alternatives. Treatment guidelines and other training and communication materials were updated, supplies of SP increased to support CQ co-administration and all health staff in the public sector trained on the new treatment guidelines. Following the 2000 decision, the actual launch of the policy took place in April 2002 and almost all government health facilities used CQ+SP for malaria treatment by 2003. In contrast, uptake was significantly slower in the private sector where in September 2002 only 15% of all shops had both, CQ and SP available.[108]

A further growing concern during this period was the quality of medicines available in the private sector. In 1997, the drug regulatory body, the National Drug Authority (NDA), sampled 12 quinine mixtures/syrups from nine local manufacturers and found that none of them had the correct amount of active ingredient (ie. 100-mg quinine base/5 ml).[109] A study on the quality of

CQ reported that up to 30% of the tablet samples and 33% of the injectable CQ samples contained less than the required amount of active ingredient; only 45% of tablet samples and 38% of injectable samples of CQ contained the required amount of active ingredient.[110] A major challenge identified at that time was the inadequacy of the system for post-marketing surveillance and pharmacovigilance.[111]

Insecticide resistance

Studies have identified progressively widespread insecticide resistance in Uganda since 2009.[112–118] In addition, since 2009, the NMCP has conducted biennial national insecticide vector susceptibility monitoring studies using the WHO tube assay in six sentinel sites (Apac, Kitgum, Hoima, Wakiso, Tororo and Kanugu). The NMCP and the Vector Control Division of the MoH receive technical, implementation and financial support for this insecticide resistance monitoring from the Uganda IRS Project/Abt Inc. Associates supported by USAID-PMI, IDRC supported by a consortium of partners; the Malaria Consortium (MC) and the Malaria Research Centre (MRC). Government monitoring for insecticide resistance has identified resistance to dichloro-diphenyl-trichloroethane (DDT) in all six sites. Though there is presently no established process for collating and reporting insecticide resistance between all partners, the IVM Technical Working Group established an ad-hoc Insecticide Resistance Data Management Committee in 2017 to create such a coordination mechanism.[67]

Between 2013 and 2016, resistance to pyrethroids was observed in all the study districts. In 2009, there was full susceptibility to carbamates in the study districts, but between 2011 and 2015 the NMCP identified probable resistance to carbamates in all surveillance districts but Kitgum. Later, carbamate resistance was confirmed in Tororo (in 2011) and Wakiso (2013). Full susceptibility to organophosphates has been identified in all sites up to 2016.

Two sentinel sites in Arua and Katakwi were added in 2016, and the country proposed to expand monitoring to sites in Jinja, Tororo, Mubende, Kanungu, Kabale, Amolatar, Kole, Lamwo, Agago, Arua, Otuke, Moroto, Mbale, Kampala, Kyenjonjo, Katakwi and Kalangala in 2017.

2.7 History of risk mapping in Uganda

One of the objectives of the malaria pre-eradication programme in Uganda was to assess the national malaria situation and investigate the epidemiological conditions prevailing in the country. Malariometric surveys were undertaken to provide a profile of risk, epidemiology and seasonality in preparation for the design of national elimination.

This was one of the most significant national examinations of the epidemiology of malaria risk in Africa at the time. Surveys were undertaken across Uganda, covering the examination of over 120,000 people between 1963 and 1967 (Figure 15).[119] The activities were conducted in all the regions of the country, except the central region.[90,120–123] Malaria endemicity was recorded following classifications formulated at the Malaria Conference in Equatorial Africa held in Kampala in 1950 and later revised from spleen rates to parasite rates in children aged two to nine years.[124]

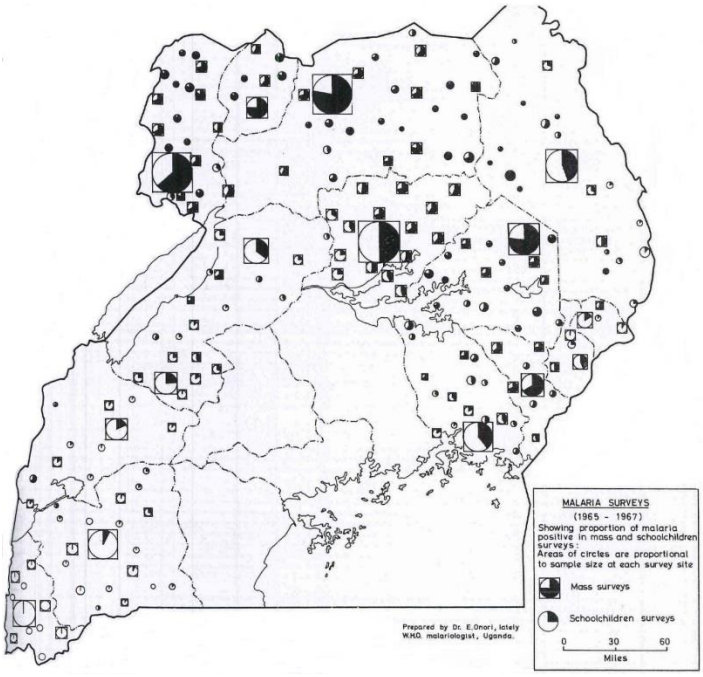


Figure 15. Proportion of malaria prevalence surveys conducted in Uganda, 1965-7

The eradication headquarters at Jinja housed all the survey records until 2011 when they were destroyed. The assembled data provided an information platform necessary to produce a cartography of risk used for many years after data were assembled (Figure 16).[125,126]

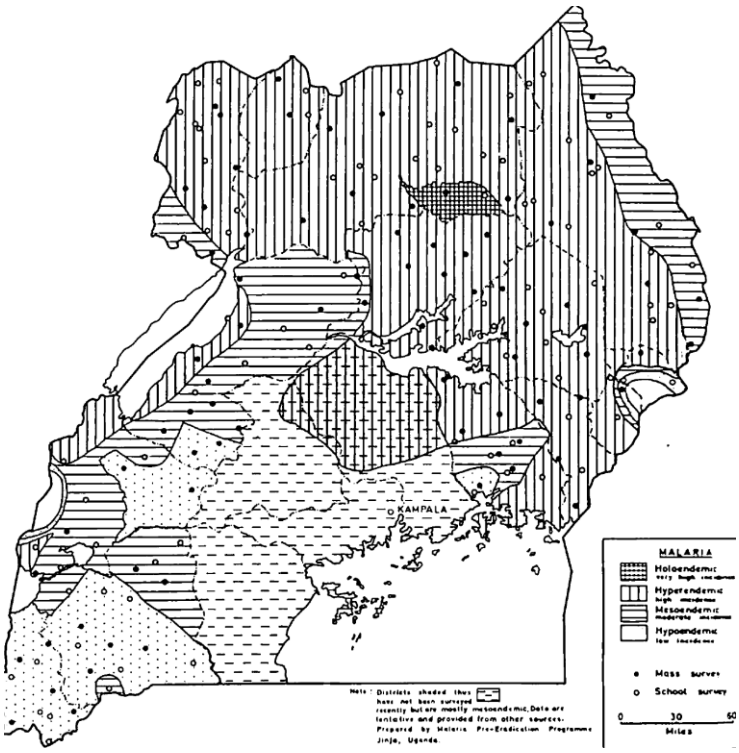
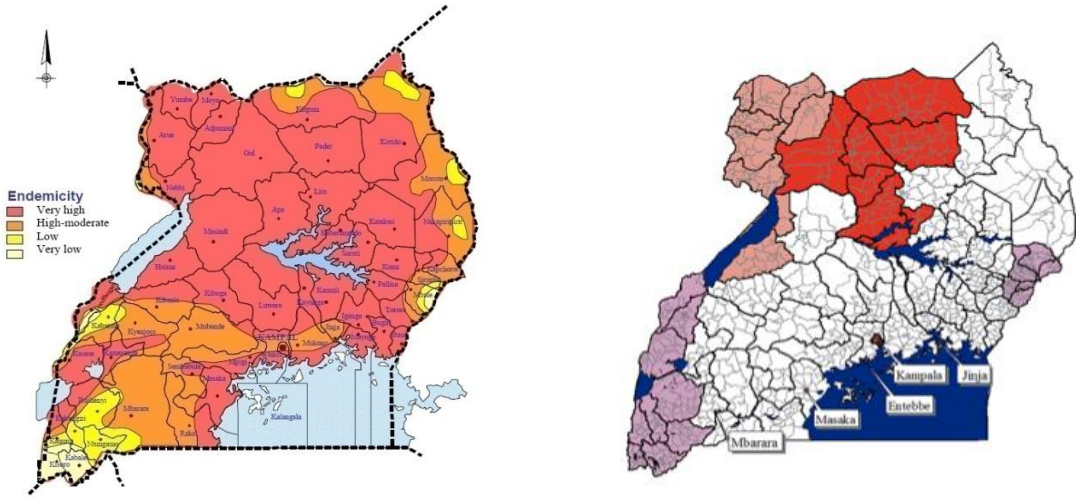


Figure 16. Atlas of malaria risk, 1970s

The map of contemporary risk used in the 2005-10 UMRSP is shown in Figure 17a. No quantification or description of high to very high, high, medium to high, low and very low no transmission was provided. This same figure has been used in various subsequent documents developed by the NMCP and partners, including the monitoring and evaluation plan 2007-12,[127] PMI annual programme annual reviews 2007-12,[128] the Global Fund Round 7 submission to scale up LLINs in 2007,[129] publications considering the potential for malaria elimination,[130] Malaria Programme Reviews in 2011,[131] (which also provided a map summarising the parasite prevalence among children aged less than five years across the nine regions recorded during the national MIS in 2009), and the National Malaria Strategy 2011-2015.[132]

The strategic plan 2011-5 did begin to spatially target interventions in areas requiring special attention, including the historic epidemic-prone areas, border/conflict districts, urban areas and areas where IRS was to be targeted (Figure 17b).[132] This is the first evidence of spatial targeting of intervention, however few details are provided on how the cartography of risk was likely to guide intervention selection.

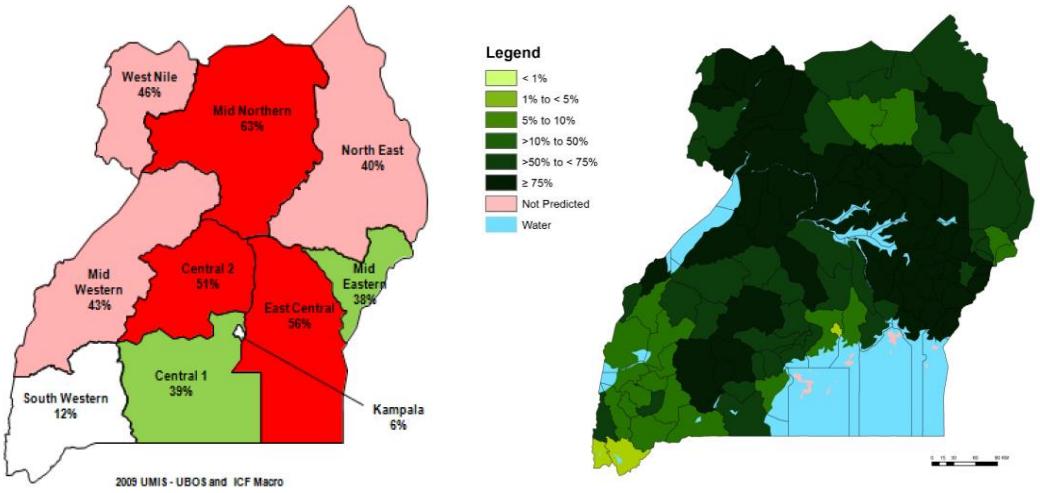


a) b)

Figure 17. Contemporary malaria risk maps

a) Malaria risk map used in national malaria strategies and other MoH documents from 2007; b) Map showing targeted control/special areas used in 2011-15 national malaria strategy. Red indicates IRS districts, brown urban settlements, light purple epidemic prone areas and orange border/conflict areas.[132]

The National Malaria Strategic Plan 2014-20[133] used two maps. The first is a simple presentation of the regional summaries of the MIS in 2009 (Figure 18a) and second is the first use of a modelled parasite prevalence map predicted to the year 2010 (Figure 18b). In 2013, the INFORM project and NMCP and other partners developed a malaria risk map using all available parasite prevalence data from 1980 to 2012 to generate a provisional malaria risk map for malaria planning purposes.[134] Population adjusted mean *Pf*PR_{2-10} in 2010 was computed using methods described in the 2013 malaria epidemiological profile for Uganda[134] with covariates that included temperature suitability index, precipitation, enhanced vegetation index and urbanisation.



a) b)

Figure 18. Latest malaria risk maps used by NMCP in 2014-20 National Strategic Plan
a) Malaria prevalence by region for 2009 MIS; b) INFORM Phase I product developed for NMCP in 2013

3. Malaria prevalence mapping using model-based geostatistics

Typically, national household surveys are designed to be precise at national and regional levels and rarely at lower levels such as districts. Therefore, simply aggregating survey data to provide district level estimates of an outcome of interest will lead to values of low precision. Additionally, while smaller prevalence studies offer a detailed picture of malaria burden in a particular area, they do not alone offer insight to burden across a district or 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.[135,136] Here we detail how the models of malaria prevalence in Uganda were assembled and validated. We will also present the maps of prevalence models which were produced through these modelling methods.

3.1 Assembling malaria survey data into a single geo-coded 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 Uganda. 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 "*Uganda*" were used. The last electronic search was completed in December 2017. Finally, survey data from the national household surveys in 2009 and 2014-15 were also identified. A full description of survey data assembly methods is provided elsewhere.[137] 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, *Pf*$PR_{2\text{-}10}$.[138]

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 Uganda.

We have selected as a data reference period 2006-2016, where data can be used to make a prediction to the years when national household sampling was undertaken in 2009 and 2014/15. Between 2006-2016, a total of 1,503 independent survey data points, 2006-2016, were identified at 1,278 unique locations. All data points were geocoded (Figure 19). There were no "polygon" data during this period. 1,267 (84%) surveys used microscopy for parasite detection, 5 (0.3%) used microscopy in combination with PCR confirmation, 60 (4%) used RDT (Paracheck) with microscopy confirmation, 170 used RDTs alone (11.3%) (Paracheck, Paracheck Pf (Device), SD Bioline or CareStart) and one used LAMP. 759 (50.4%) were geo-coded using GPS, 14 (1%) using Geonames, 35 (2.3%) using Encarta, 129 (8.6%) using Google Earth and 566 (38%) using national digital place names, many of which were derived from GPS. A complete, geocoded database of survey data (1980-2016) is provided to the NMCP with this report.

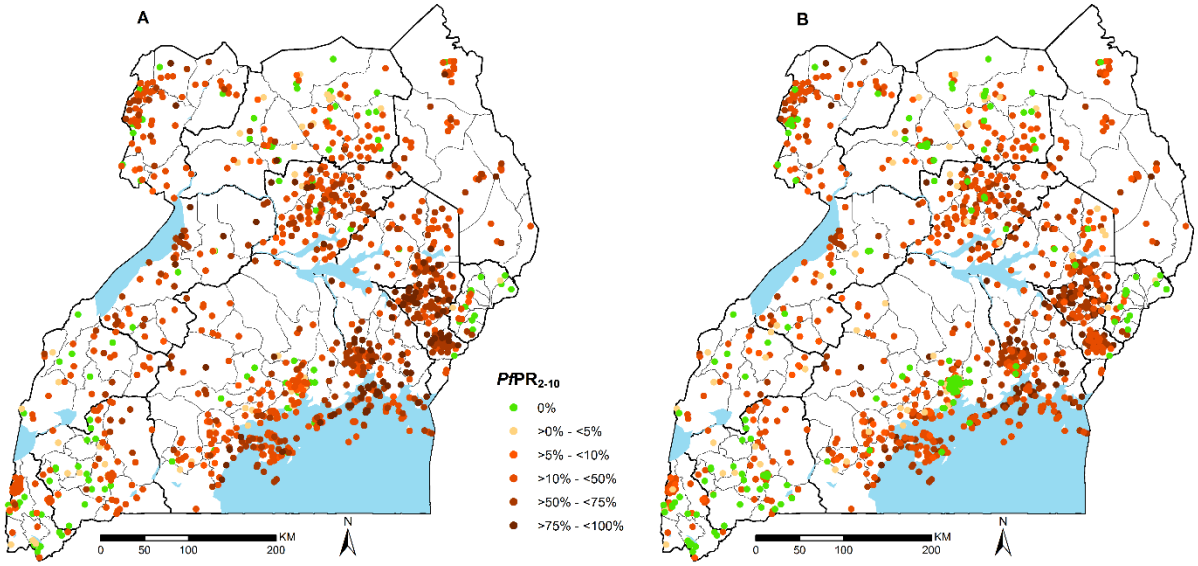


Figure 19. The age-corrected *P. falciparum* infection rates at 1,278 locations 2006-16 showing the highest values on-top among 1,503 surveys 2000-16 (A) and lowest values on top (B)

3.2 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) (ie. 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).[139] The mathematical details that translate the first law of geography into geo-statistical models are described elsewhere[140] and used recently to provide malaria risk maps in Somalia.[141]

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 Uganda, 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$_{2-10}$ was modelled using geostatistical methods[140–142] 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 (eg. variation due to different environmental conditions) and $Z(x,t)$ the variation within communities (ie. 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$_{2-10}$ values at location x (n=1,503) and year t. We defined a logit-linear model for *Pf*PR$_{2-10}$ as:

$$log\{PfPR_{2-10}(x,t)/[1-PfPR_{2-10}(x,t)]\} = \beta + S(x,t) + Z(x,t)$$

The $S(x,t)$ was modelled as a stationary and isotropic Gaussian process with spatio-temporal correlation function given by:

$$corr\{S(x,t),S(x',t')\} = exp\{-||x-x'||/\phi\}exp\{-|t-t'|/\psi\}$$

where ϕ and ψ are scale parameters which regulate the rate of decay of the spatial and temporal correlation for increasing distance and time separation, respectively. The notation ||x-x'|| represents the distance in space between the locations of two communities, one at x and the other at x'. The above equation then indicates that as the distance between x and x' increases, the spatial correlation will decay at a rate ϕ. A similar argument applies to $|t-t'|$ which represents the time separation between two surveys.

The model parameters were estimated via maximum likelihood in the R software environment (version 3.4.1) using logit-transformed prevalence.[143] The targets for the predictions were *Pf*PR_{2-10} over the 1 x 1 km regular grid surface covering the whole of Uganda. Maps of malaria risk were generated for the years 2009 and 2014/15 in ArcMap version 10.5 (ESRI Inc., Redlands, CA, USA) (Figure 20) and average *Pf*PR_{2-10} binned to six classes of risk per district (Figure 21). The prevalence values represented in the map are presented in Table 4.

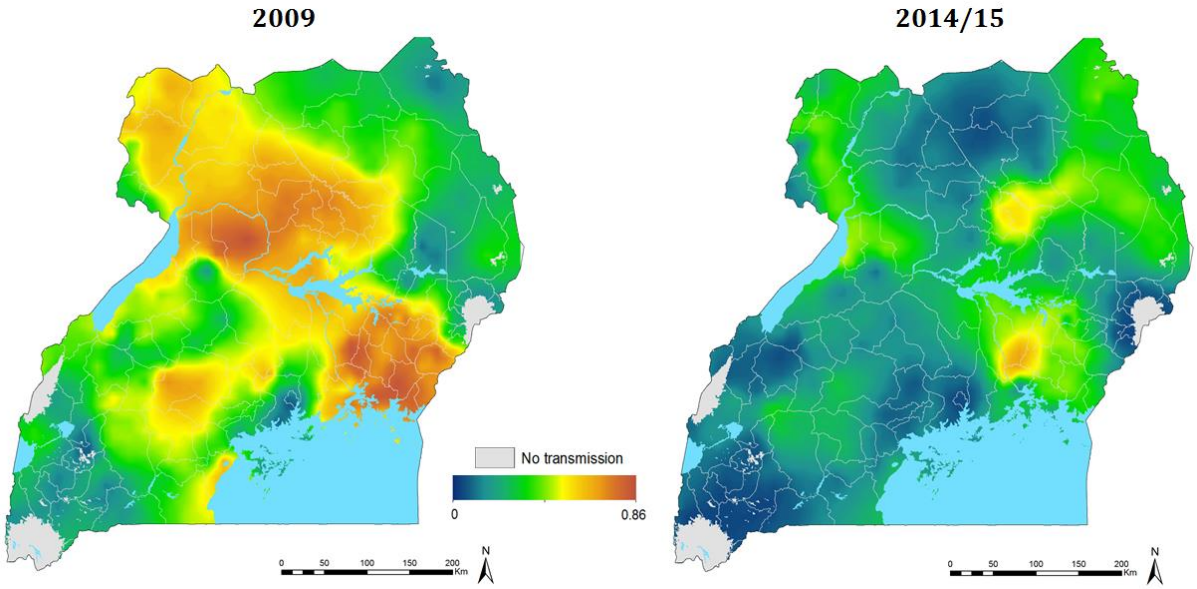


Figure 20. Continuous predicted *Pf*PR_{2-10} estimates for Uganda in 2009 (left) and 2014-15 (right) *Ranging from yellow low to red high through intermediary prevalence blue. Grey masks shows areas unable to support stable transmission based on low temperature in the South West and Mount Elgon.*[144]

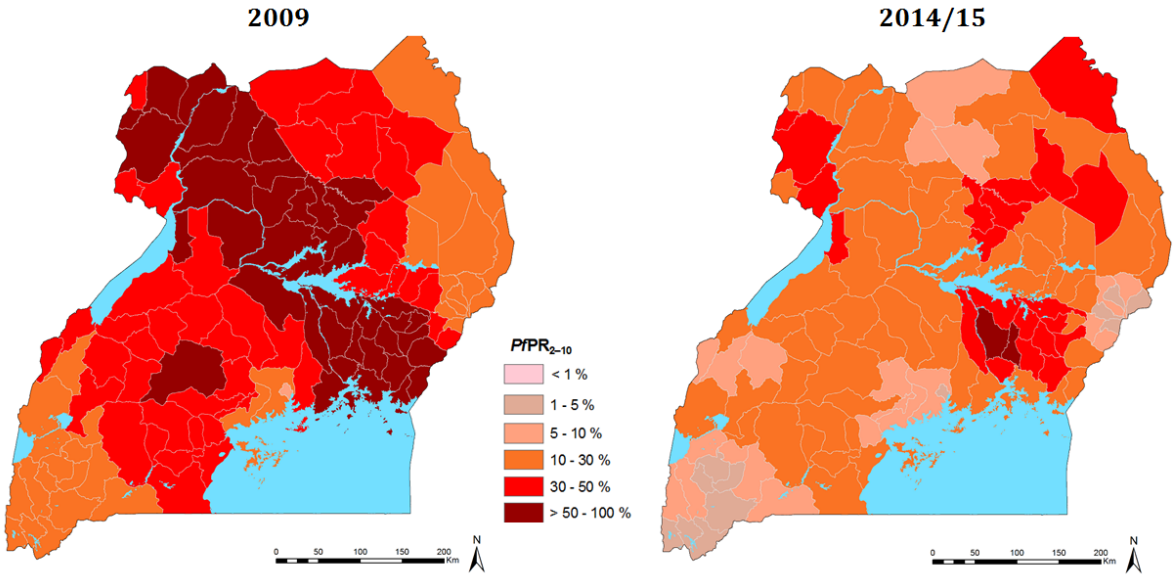


Figure 21. Binned predicted average quantities of *Pf*PR$_{2\text{-}10}$ in 116 districts in 2009 and 2014-15: <1%, 1-4.9%, 5-9.9%, 10-29.9%, 30-49.9% and ≥10%

We present a map indicating the percent change of malaria prevalence between 2009 and 2014-15 (Figure 22). The values represented in this map are provided in Table 4. Section 1.9 provides a discussion of the meaning and implications of the percent changes over time identified through the model.

In general, malaria incidence decreased throughout all of Uganda, except for five districts in the North. In 15 districts, the decrease in malaria prevalence was more than 75%.

In 2015, a malaria epidemic was confirmed in ten northern districts: Lamwo, Kitgum, Gulu, Nwoya, Amuru, Pader, Agago, Apac, Oyam and Kole.[145] These models do not reflect survey data which was collected after the 2015 epidemic. The models indicate that malaria burden increased by 72% in Kaabong, a district in the northern region. This district is a northern district which had not received IRS in the efforts prior to 2015.[145] Prevalence also increased by 33% in Katakwi. Notably, the models indicated that the burden in Napak, a northern district of Karamoja, had increased by 54% between 2009 and 2014-15.

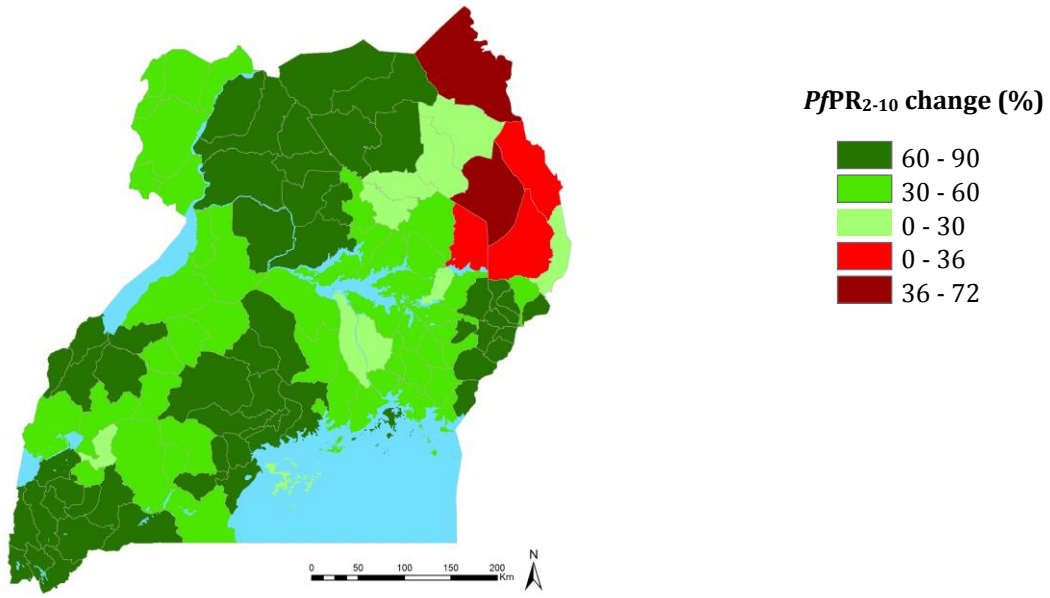


Figure 22. District-level prevalence change between 2009 and 2014-15

Table 4. Predicted average *Pf*PR$_{2-10}$ in 116 districts in 2009 and 2014-15

	***Pf*PR$_{2-10}$ 2009 (%)**		
District	**2009**	**2014-15**	**Estimated % change relative to 2009**
Kaabong	18.4	31.6	+71.9
Napak	22.6	34.9	+54.6
Katakwi	15.2	20.2	+32.7
Moroto	23.3	29.4	+26.5
Nakapiripirit	25.2	26.1	+3.3
Kotido	32.5	29.6	-9.0
Amudat	26.5	23.5	-11.4
Ngora	30.2	26.3	-12.7
Abim	41.2	35.9	-12.9
Kamuli	64.7	50.6	-21.8
Otuke	59.1	43.9	-25.7
Alebtong	65.1	48.4	-25.7
Kalangala	25.0	18.0	-28.2
Kayunga	53.9	38.6	-28.3
Ibanda	17.0	12.1	-28.6
Luuka	77.5	54.0	-30.3
Nebbi	49.4	33.3	-32.6
Buyende	59.9	39.6	-33.9
Buliisa	60.8	40.0	-34.2
Kaliro	70.4	44.8	-36.3
Amuria	41.4	26.2	-36.8
Maracha	57.6	35.5	-38.3
Jinja	68.0	41.8	-38.6
Kumi	33.9	20.6	-39.3

Serere	47.3	28.5	-39.9
Dokolo	56.0	33.0	-41.1
Iganga	72.0	41.6	-42.2
Namutumba	70.7	40.4	-42.9
Kaberamaido	50.4	28.5	-43.5
Lira	68.4	38.6	-43.5
Arua	55.8	30.6	-45.2
Koboko	49.6	26.2	-47.1
Pallisa	65.7	34.7	-47.2
Kamwenge	30.3	15.9	-47.4
Soroti	33.9	17.7	-47.8
Kasese	24.2	12.5	-48.3
Kiruhura	34.9	17.9	-48.6
Masindi	48.6	24.6	-49.4
Yumbe	58.3	29.2	-50.0
Kibuku	69.0	33.1	-52.0
Bugiri	79.4	37.8	-52.4
Moyo	52.6	25.0	-52.5
Amolatar	62.1	29.1	-53.1
Butaleja	72.7	33.4	-54.0
Kyankwanzi	32.1	14.6	-54.4
Buhweju	11.6	5.3	-54.5
Lyantonde	41.8	18.9	-54.7
Kampala	7.4	3.4	-54.8
Nakasongola	54.4	24.5	-55.1
Kakumiro	36.9	16.5	-55.3
Zombo	32.0	13.8	-56.8
Hoima	45.8	19.6	-57.1
Mukono	32.7	14.0	-57.2
Ssembabule	49.2	20.7	-57.9
Kyegegwa	42.5	17.7	-58.4
Kibaale	31.4	13.0	-58.5
Luwero	44.1	18.1	-59.0
Buikwe	58.4	23.9	-59.1
Rakai	39.3	15.8	-59.7
Mayuge	72.1	29.0	-59.7
Namayingo	70.4	28.3	-59.8
Kween	16.1	6.5	-59.8
Rubirizi	21.9	8.7	-60.1
Mpigi	24.0	9.5	-60.4
Busia	72.3	27.5	-61.9
Kiryandongo	74.7	28.0	-62.5
Kitgum	30.2	11.3	-62.6
Isingiro	19.8	7.3	-63.0
Buvuma	60.1	22.1	-63.3
Lwengo	37.5	13.7	-63.5

Kisoro	13.5	4.9	-63.7
Nakaseke	42.4	15.4	-63.8
Bushenyi	13.4	4.9	-63.8
Masaka	48.1	17.3	-64.1
Budaka	64.1	23.0	-64.1
Agago	39.0	14.0	-64.1
Adjumani	53.0	18.4	-65.2
Mbarara	16.8	5.8	-65.5
Mubende	53.8	18.1	-66.4
Tororo	70.6	23.3	-67.1
Nwoya	60.6	19.8	-67.4
Wakiso	22.6	7.3	-67.5
Kanungu	17.2	5.4	-68.3
Kiboga	41.1	12.9	-68.5
Bukedea	39.6	12.4	-68.7
Mitooma	14.1	4.4	-68.8
Lamwo	31.2	9.7	-68.9
Bukomansimbi	41.6	12.8	-69.3
Kagadi	36.6	11.1	-69.8
Rukungiri	17.7	5.2	-70.9
Rubanda	10.4	3.0	-71.2
Butambala	30.7	8.8	-71.4
Apac	65.4	18.6	-71.6
Bulambuli	21.3	5.9	-72.5
Sheema	16.5	4.4	-73.1
Kalungu	36.8	9.9	-73.2
Kabarole	28.6	7.6	-73.5
Ntoroko	39.3	10.2	-73.9
Kole	70.0	18.0	-74.3
Bukwo	14.6	3.7	-74.3
Kabale	14.2	3.6	-74.6
Amuru	51.9	12.9	-75.1
Bundibugyo	35.9	8.8	-75.4
Gomba	49.7	12.2	-75.5
Kapchorwa	17.6	4.0	-77.2
Kyenjojo	32.8	7.3	-77.7
Pader	48.4	9.6	-80.2
Mbale	44.2	8.6	-80.5
Oyam	71.1	13.0	-81.7
Ntungamo	18.1	3.3	-81.9
Sironko	23.8	4.2	-82.6
Mityana	44.7	7.7	-82.9
Gulu	55.4	9.2	-83.4
Omoro	66.3	10.6	-84.1
Manafwa	46.4	5.9	-87.2
Bududa	24.5	2.8	-88.6

3.3 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 malaria prevalence threshold. In countries where areas are transitioning to lower transmission, as in Uganda, identifying areas which are below a particular threshold support considering how to adapt strategies that demand universal coverage to a more nuanced, cost-efficient and efficacious combination of interventions.[141]

However, classifying geographical areas into different endemic levels by estimated parasite prevalence creates an oversimplified picture of the malaria situation in that area.[140] 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.

To address the uncertainty of our estimates, we have estimated an 'exceedance probability (EP)' that the prevalence of malaria in a given area falls below the threshold of 30%, based on available survey data (the method by which we do this is described in Box A). An EP close to 100% indicates that *Pf*PR$_{2\text{-}10}$, is highly likely to be above the threshold *l*; if close to 0%, *Pf*PR$_{2\text{-}10}$, is high likely to be below 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.

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 an exceedance probability (EPs), formally expressed as:

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

where *l* is the prevalence threshold which we set to ≥ 30%. In other words, EP expresses how likely *Pf*PR$_{2\text{-}10}$ is to be above the threshold *l* based on the available survey data.

This is important when defining the level of certainty an area is above 30% and therefore proves highly intractable to interventions applied in that area to-date. Below we show areas where we are 80% certain that an area has 30% *Pf*PR$_{2\text{-}10}$ in 2014-15 based on the available data (Figure 23). These cover 13 districts in five regions: Buikwe, Kayunga, Buliisa, Iganga, Jinja, Kaliro, Kamuli, Luuka, Abim, Alebtong, Dokolo, Lira and Otuke.

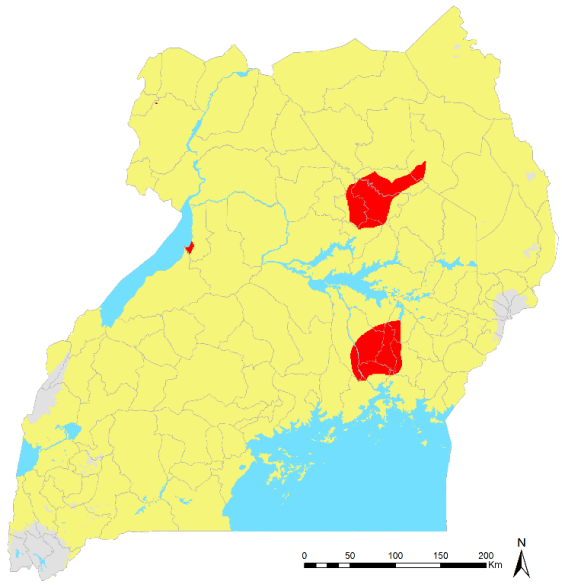


Figure 23. Areas in Uganda (red) where *Pf*PR$_{2-10}$ is estimated (with 80% certainty) to be less than or equal to 30%

3.4 Model validation

The models presented in this profile were cross-validated by holding out 142 (9.5%) surveys randomly selected between 2000 to 2016. The predictive performance of the model through the bias (how much the model over or underestimates the actual prevalence), the mean absolute error (MAE) (how accurate the model is in predicting, the spread around the true values) and the correlation between the estimated and observed *Pf*PR$_{2-10}$ were computed. The validation showed a good correlation, r^2=0.81 (Figure 24), with a slight overestimation (bias) of 2% and a MAE of 12%.

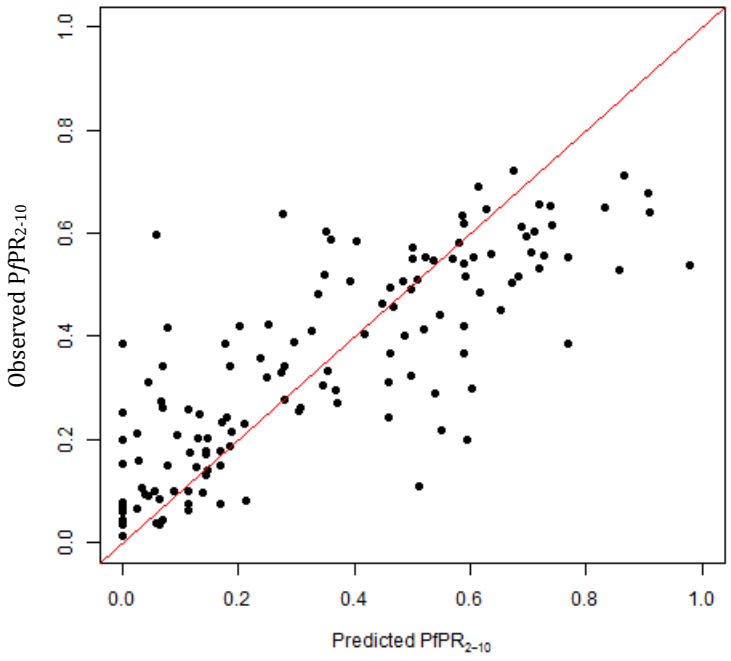


Figure 24. Correlation between predicted and held out 142 observed *Pf*PR$_{2-10}$ estimates

4. Entomological profile

4.1 Mosquito sampling sites

This report used historical archives and published sources, increased the documentation of potential secondary vectors and sourced more recent unpublished data from scientists and control agencies working in Uganda. Full details of the data assembly, geo-coding methods and classifications of species according to their role in malaria transmission are provided elsewhere.[146] The database has been arranged as a site-specific, referenced inventory to capture details of species identification recorded since the earliest surveys in 1902 through to the latest records in 2013. The full digital Pdf library, database and bibliography accompanies this report.

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 latter is not possible given the wide variation in collection methods between surveys and an inability to standardise between sampling methods.

The final database contained 438 site/time specific reports of anopheline vectors in Uganda occurrence between 1902 and 2013 for which it was possible to geo-locate the survey site (Figure 25). One-hundred and forty-nine of these 438 surveys were undertaken since 2005 (Figure 26). Much of this recent survey data does not have sibling species PCR and therefore, the following figures are limited in their ability to show reliable distributions of ss. V. *An arabiensis*.

It was not possible to geo-locate five (1.1%) of the survey sites. The database includes some of the earliest inventories of anophelines in Uganda, undertaken by the colonial government's entomologist EG Gibbins,[147] the national vector surveys undertaken in the 1960s and compiled as part of a national disease atlas[119] (Figure 27) and several wide-ranging reconnaissance surveys among the islands of Lake Victoria.[148–150]

This report has not assembled geo-coded information related to vector resistance, these data have been carefully curated, validated and mapped by the IRBase initiative.[151,152]

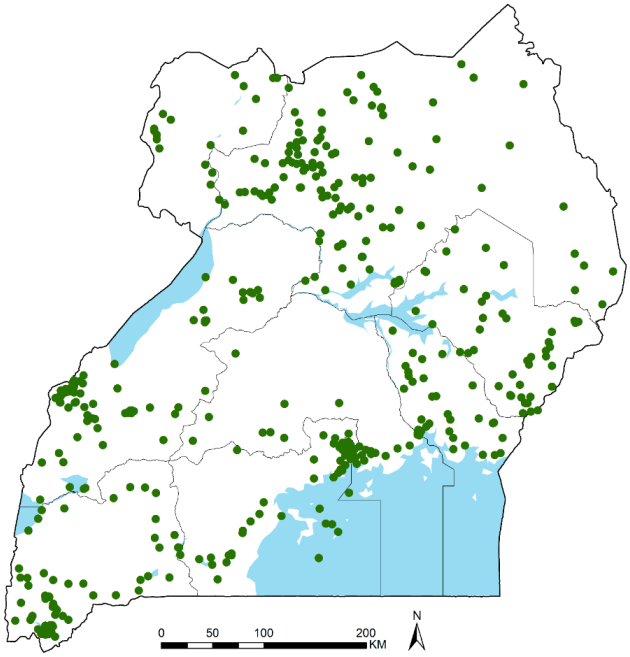


Figure 25. Location of mosquito sampling sites for 438 surveys undertaken between 1902 and 2013

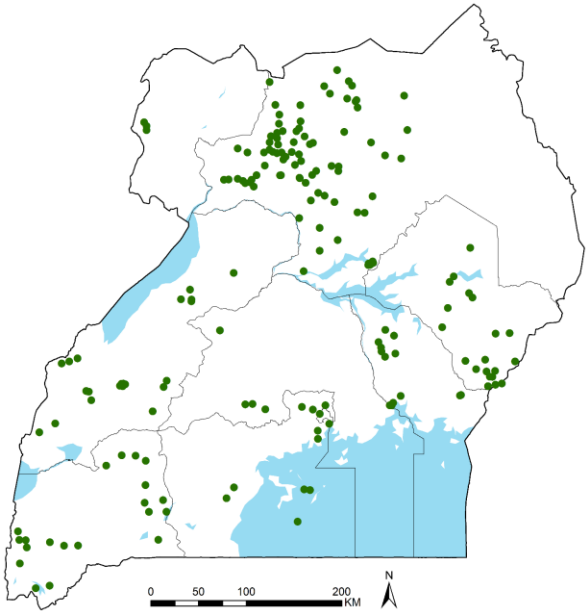


Figure 26. Location of mosquito sampling sites for 179 surveys undertaken since 2005

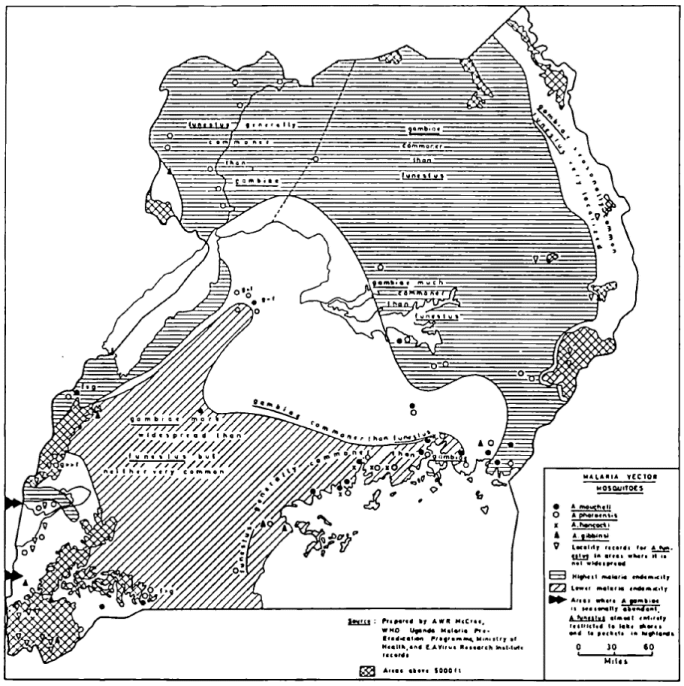


Figure 27. Previous national malaria vectors maps derived from survey data, 1950-70

4.2 Identified species

The presence of the *An. gambiae* complex and the *An. funestus* group are sympatric across the entire county (Figure 28). Among the *An. gambiae* complex, *An. gambiae ss An. arabiensis* have been recorded in all the regions of Uganda (Figure 30), while salt water breeding members of the *An. gambiae* complex have never been identified in Uganda. Characterisation of the *An. gambiae s.s* into M and S forms is poor for Uganda, only the S form has been reported in Uganda.[117]

An. bwambae, a member of *Anopheles gambiae* complex was first described in Uganda and restricted to a small ecological niche around geothermal springs on the north western fringe of the Ruwenzori Mountains (Figure 29).[153,154] The species was probably first described by Haddow and colleagues in 1944 in Bwamba forest.[155]

An. rivulorum, a member of *An. funestus* group, has been described in the western regions of Uganda (Figure 28). *An. moucheti* and *An. hancocki* have only been described in the southern half of the country (Figure 28), while *An. nili* has been recorded only in a few places near Arua in the West Nile region, in Lake Victoria Islands and in Jinja. These three vectors have all been implicated in malaria transmission in different parts of the country.[156–158] *An. pharoensis* has been found in all the regions, but it has not been implicated in transmission of malaria in Uganda.

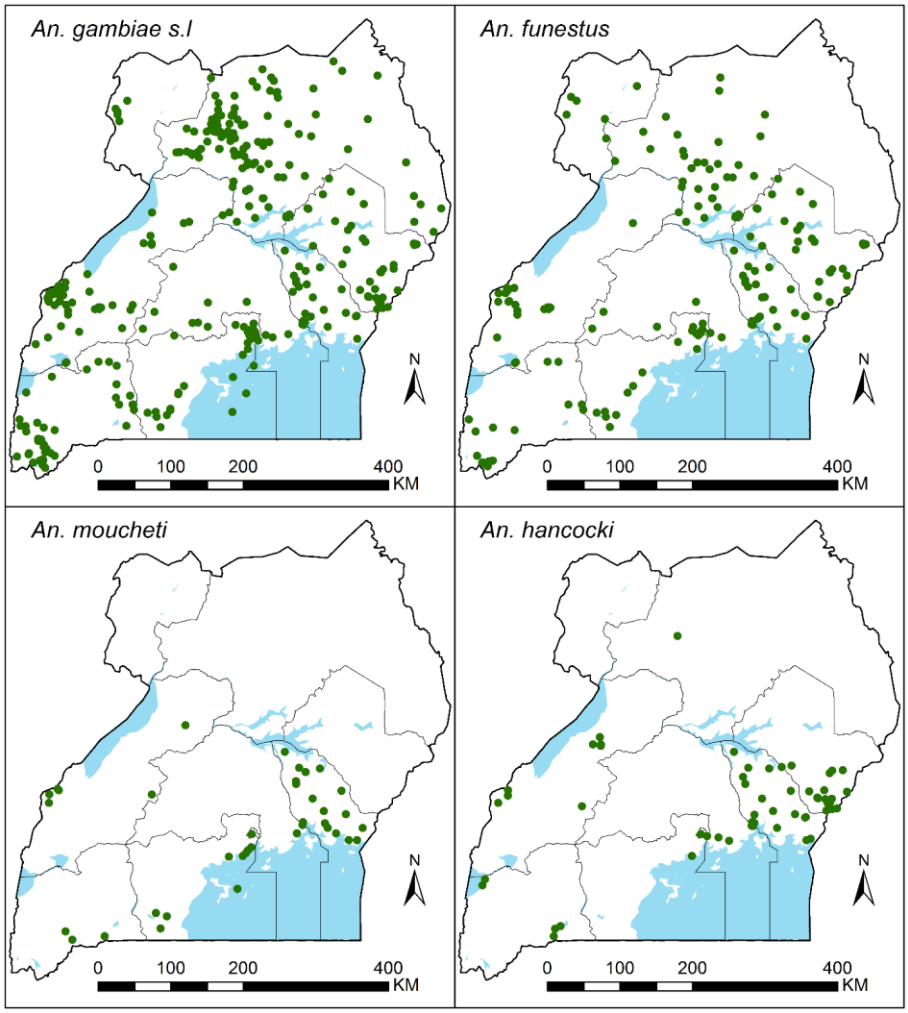


Figure 28. Recorded species identifications across all surveys by region

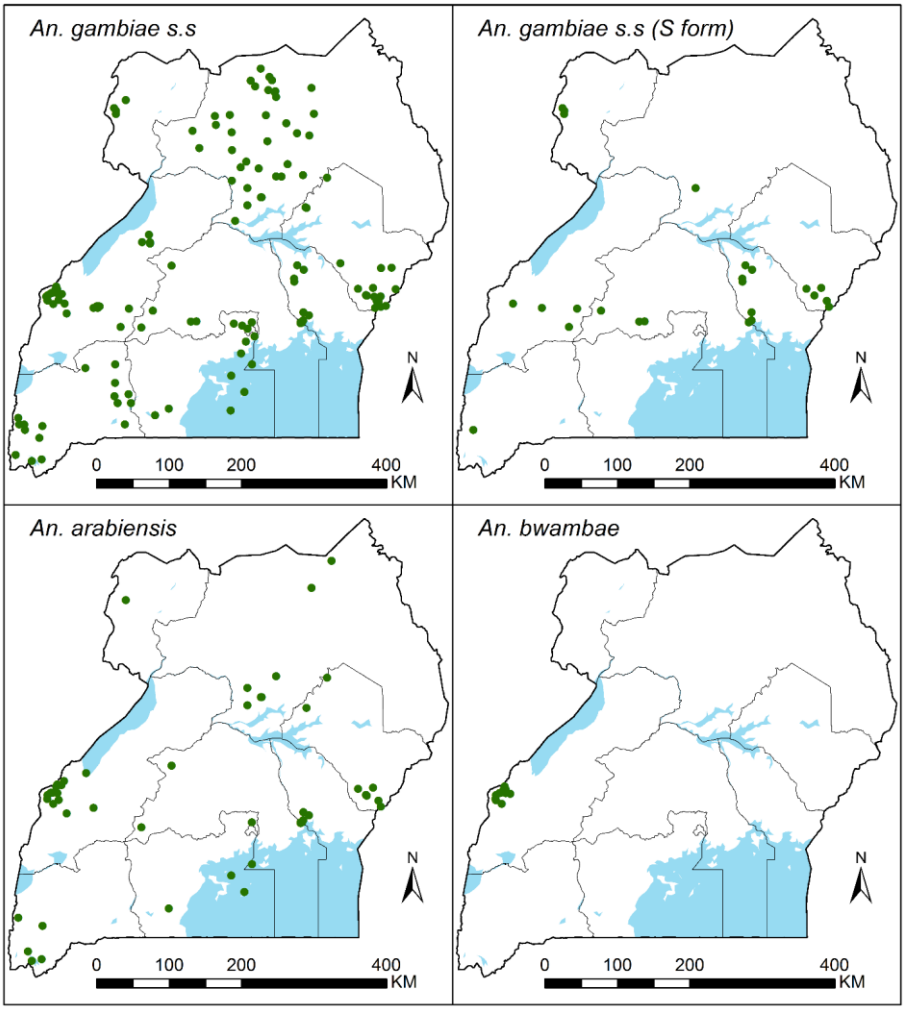


Figure 29. Location of members of *An. gambiae* complex by region

Taxonomy

Anopheles gambiae complex has undergone numerous transitions in taxonomy through time. The earliest descriptions of the *An. gambiae* complex referred to a single species, *An. costalis*, during the first decade of the last century. Following the Liverpool School visit to The Gambia in 1902, this species was named *An. gambiensis* Giles. In 1940s, *An. melas* (West Africa) and *An. merus* (East Africa) were confirmed as sibling species of the gambiae complex through observations on salinity tolerance and slight morphological variations.[159,160] In the 1950s and 1960s, the innovation of new hybridisation methods (cross-mating) made it possible to distinguish three fresh-water breeding species of *An. gambiae* (A-C). At around the same time, a morphologically unique sibling [Species D] was identified in the mineral springs of the Semliki National Park, Bwamba district, Uganda, and later named *An. bwambae* White.[155,161,162] Chromosomal investigations of species A and B were undertaken in the late 1960s and this led to the ability to distinguish between *An. gambiae sensu stricto* and *An. arabiensis* respectively.[163] The zoophilic *An. quadriannulatus* A and *An. quadriannulatus* B were described as sibling-species of the *An. gambiae* complex (previously species C) in the early 1980s but not regarded as vectors of malaria within their geographic ranges of southern Africa and Ethiopia.[164,165] *An. quadriannulatus* B from Ethiopia was later renamed *An. amharicus* Hunt, Wilkerson & Coetzee sp. n. while the name *An. quadriannulatus* was retained for the southern African form.[166,167]

In early 2000s, *An. gambiae s.s* was genetically distinguished as *An. gambiae* s.s. S form (Savanna/ Bamako) and M form (Mopti).[168,169] In 2013, the "M form" was re-named *An. coluzzii* Coetzee & Wilkerson sp. n while the "S form" retained the name *An. gambiae s.s.*[167]

All the records of *An. gambies s.s* species (or Species A) before the invention of genetic tools referred to either the M or S forms or both, but not solely the S form, as is now defined. For this reason, that the name "*An. gambiae s.s"* was retained to include both species that formerly belonged to the *sensu stricto,* and only indicated the S form when specifically recorded as so.

***Anopheles gambiae s.s (S form)*:** despite the fact that characterisation of the *An. gambiae s.s* into M and S forms is poor for Uganda, there has been no record of the M form (*An. colluzii*) in the country.[117,170] *Anopheles gambiae* s.s larvae typically inhabit sunlit, shallow, temporary bodies of fresh water such as round depressions, puddles, pools and hoof prints. This aspect of their bionomics might help members of the *An. gambiae* complex avoid most predators, and the larvae are able to develop very quickly (circa six days from egg to adult under optimal conditions). *An. gambiae* s.s has been reported from habitats containing floating and submerged algae, emergent grass, rice, or 'short plants' in roadside ditches and from sites devoid of any vegetation. It is considered to be highly anthropophilic, with many studies finding a marked preference for human hosts, typically feeds late at night and is often described as an endophagic and endophilic species, ie. biting and resting mostly indoors. The species is considered to be one of the most efficient vectors of malaria in the world.

Anopheles arabiensis: *Anopheles arabiensis* is considered a species of dry, savannah environments or sparse woodland. Evidence is growing of a more ubiquitous range of *An. arabiensis* across Africa. Its larval habitats are generally small, temporary, sunlit, clear and shallow fresh water pools, although *An. arabiensis* is able to utilise a variety of habitats including slow flowing, partially shaded streams, large and small natural and man-made habitats, turbid waters and there are reports of larval identification in brackish habitats. *Anopheles arabiensis* is described as a zoophilic, exophagic and exophilic species but has a wide range of feeding and resting patterns, depending on geographical location. This behavioural plasticity allows *An. arabiensis* to adapt quickly to counter IRS control showing behavioural avoidance of sprayed surfaces depending on the type of insecticide used. Blood feeding times also vary in frequency; peak evening biting times can begin in the early evening (19:00) or early morning (03:00). This species usually has a greater tendency than *An. gambiae s.s.* to bite animals and rest outdoors.

Anopheles bwambae: *Anopheles bwambae* is an endemic species of Uganda whose larvae developed in mineral springs of the Semliki National Park[154] and abundant in Bwamba District, particularly anthropophilic but did not appear to play an important role in transmission.

Records of other anopheline species, either non-vectors or considered incidental vectors of malaria since 1907:

> *An. bervoetsi, An. christyi, An. coustani, An. coustani var. tenebrosus, An. coustani var. ziemanni, An. demeilloni, An. domicola, An. garnhami, An. gibbinsi, An. hargreavesi, An. harperi, An. implexus, An. keniensis, An. kingi, An. leesoni, An. longipalpis, An. maculipalpis, An. marshalli, An. marshalli var. gibbinsi, An. marshalli var. hargreavesi, An. mauritianus, An. obscurus, An. paludis, An. parensis, An. pretoriensis, An. rhodesiensis, An. squamosus, An. symesi, An. tenebrosus, An. transvaalensis, An. vinckei, An. wellcomei, An. Ziemanni*

Figure 30 depicts the distribution of recorded species across all surveys by state.

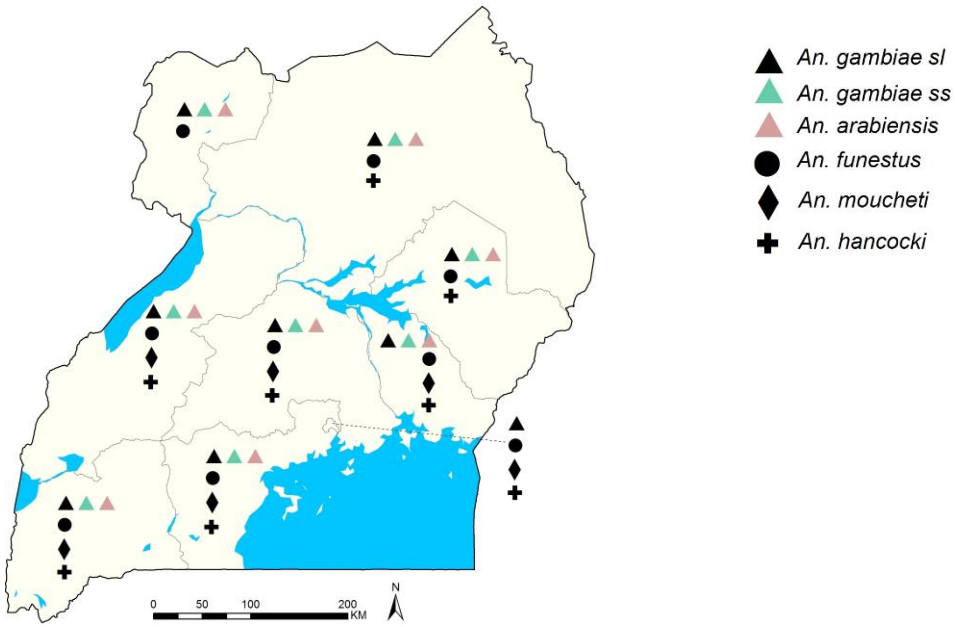


Figure 30. Recorded species identification across all surveys by region

5. Malaria vector control mapping

5.1 Indoor Residual Spraying

We have geographically depicted all IRS undertaken in Uganda since 2006. A narrative of this work is included in the Vector Control chapter (pp 40). From 2008 to 2009, the larvicide used in the eastern part of the Eastern region was lambda-cyhalothrin, from 2010 to 2015, bendiocarb was the primary larvicide used in the central northern region, and from 2014 to 2015, pirimiphos-methyl was the primary chemical used in the districts throughout the central corridor of the eastern region and in the heart of the northern region.

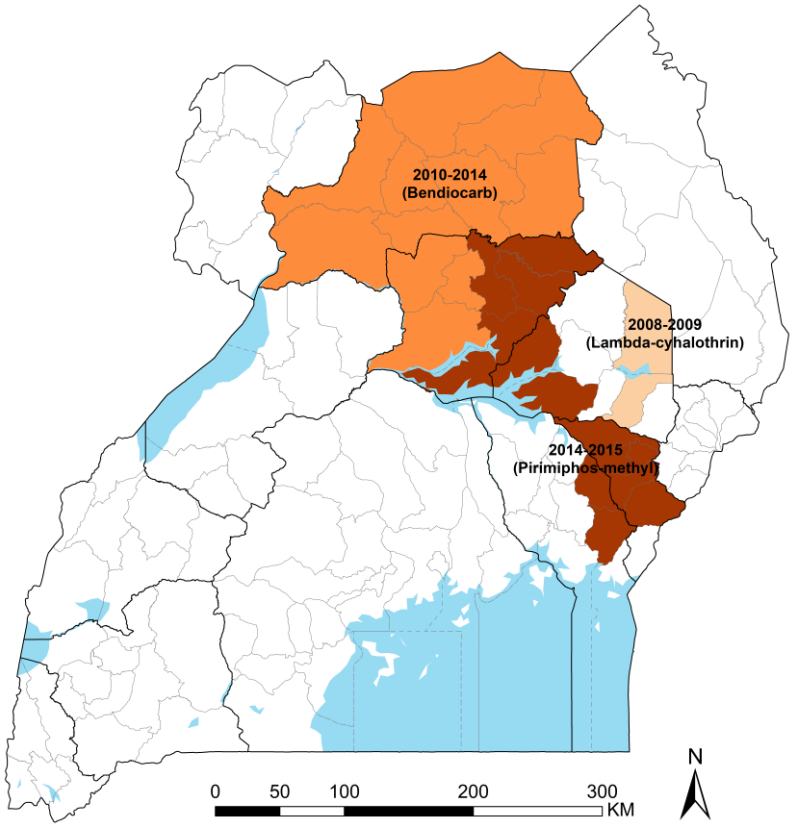


Figure 31. IRS spraying 2008-15

5.2 Distribution of ITNs and LLINs

Data provided by the NMCP covered the numbers of predicted net needs and those distributed during the 2010 mass distribution campaign and the much larger campaign in 2013-4. In addition, data were provided on routine LLIN distributions through ANC and MCH clinics between the period 2013-15. The data were re-organised per district. One district, Buliisa, did not have any information on mass distribution in 2010, though the same document indicates that it had universal coverage in 2010. Other districts which had universal coverage in 2010 were Kibogo, Kyankwanzi and Hoima.

We have used 2004 population census data from the Uganda Bureau of Statistics and NMCP distribution data to render a map of net distributions per district between 2012 and 2014 expressed per person (Figure 32). A complete database accompanies this report.

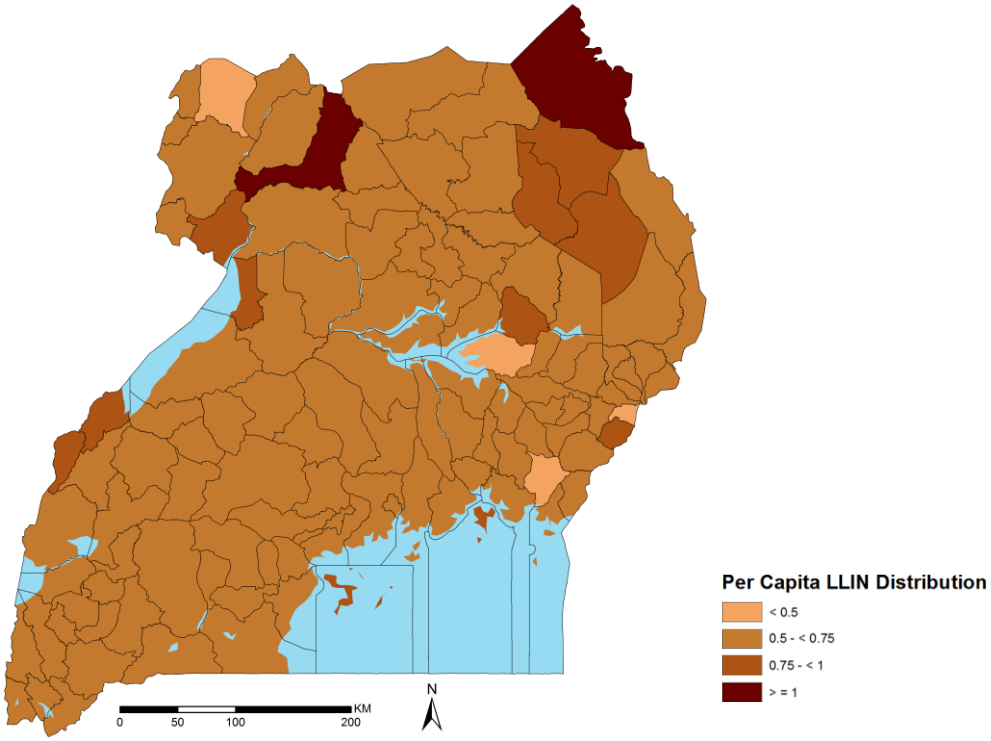


Figure 32. Net distributions per district 2012-4 expressed per person (2014)

We have used the geo-coded household data from the 2009 and 2014-15 national sample[87,88] to provide information coverage and reported LLIN use for each of the 116 health districts using MBG methods. We present the percent of population sleeping under an ITN the preceding night (Figure 33).

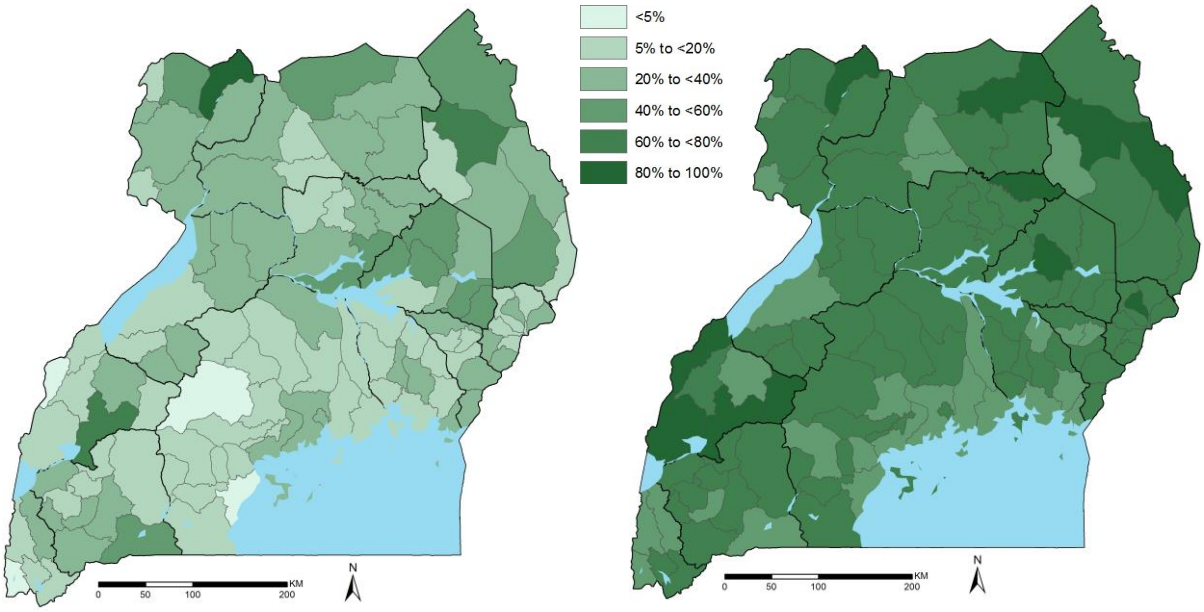


Figure 33. Percentage of the population sleeping under an ITN (left: 2009; right: 2014-15)

Overall, the proportion of the population sleeping under an ITN has increased throughout the country, but especially in the Western Region and in Mubende district, where the indicator has increased from less than 5% to more than 40%.

In addition, WHO recommended targets for universal coverage have been defined as at least two people per LLIN per household. We therefore present the proportion of households with at least one ITN for every two persons using the geo-coded household data from the 2009 and 2014-15 national sample (Figure 34).[87,88]

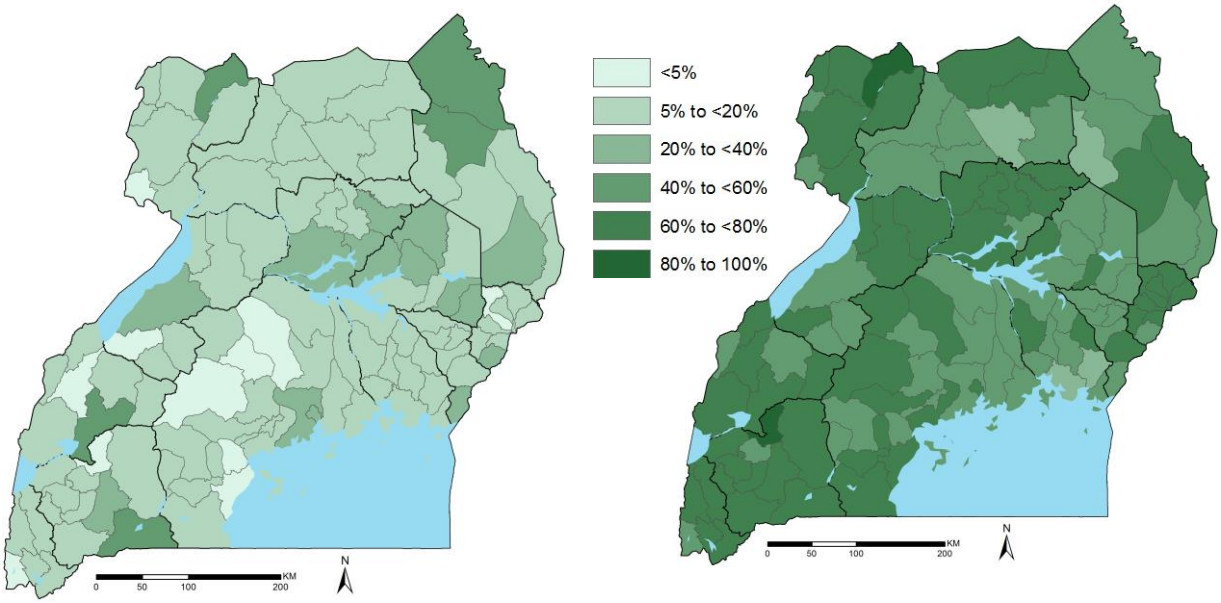


Figure 34. Proportion of households with at least one net for every two persons (left: 2009; right: 2014/15)

The proportion of households with at least one net for every two persons gives some indication to how well the achievement of universal LLIN coverage has been achieved. In Uganda, there have been improvements in most districts since 2009. However, only Moyo and Ibanda districts have achieved greater than 80% of universal coverage, though most districts have achieved between 60 to 80% universal coverage.

6. Interrogation of results

This profile was disseminated on 14 June 2018 at the WHO Uganda Offices in Kampala. The meeting was chaired by Dr Daniel Kyabayinze on behalf of Dr Damian Rutazaana and the NMCP. Dr Jimmy Opigo, NMCP Programme Manager offered opening remarks, which were followed by a presentation on regional malaria control by Dr Bayo Fatunmbi, WHO Malaria Technical Officer. The meeting was well-attended by the NMCP and Uganda malaria control partners. Partner institutions in attendance included IDRC, the Clinton Health Access Initiative (CHAI), USAID (Regional Health Integration to Enhance Services in Eastern Uganda [RHITE-E]), Medlink, Makerere School of Public Health, Pilgrim Africa, DFID and Malaria Consortium.

In his opening remarks, Dr Opigo emphasied the need to understand where malaria burden is concentrated in Uganda. Malaria burden data allows for contextualisation and determining where and how interventions should be implemented. Updated malaria burden will allow for the revising of current malaria policy so that actions in the next strategic plan are synconised with elimination targets.

The group identified the need to build up a culture of data use. One way to do this is to promote the use all data from academic and routine health information sources for malaria stratifications. Malaria prevalence data, both measured from surveys and modelled, offer one perspective of malaria burden. Other indicators from routine data collection, like test positivity rate, offer an indication of malaria incidence. Comparing data sources to understand the balance between prevalence and incidence will allow for a better understanding of how to adjust control strategies. It is critical that the NMCP and partners have regular opportunities to interrogate DHIS 2 data, modelled data and survey data together.

Timely access to data was identified as an important componenet of triangulating malaria burden data regularly. The NMCP identified the value of getting timely access to national survey data from UBOS. Additionaly, through the LINK programme, two Ugandan malaria scientists, Dr Damian Rutazaana and Mr Paul Mbaka, received training with KWTRP in July 2018 to learn how to execute geospatial models of malaria. In the future, geospatial prevalence maps may be generated from within Uganda and in alignment with national planning needs. The methods and outputs of the modelling work done by Dr Damian Rutazaana and Mr Paul Mbaka are laid out in Annex C.

Finally, the meeting identified the need to make malaria data available and accessable in a national repository.

6.1 Knowledge and research gaps

Operational research on data use and data capacity in Uganda could help fill knowledge gaps and existing weakness in the health system to promote malaria control activities. This report highlights areas where future research might be well-directed:[viii]

- **Routine health data management.** The MoH receives data from facilities across the health system, including private for-profit and private not-for-profit, but data management capacity is an ongoing challenge at all levels. Operational research might explore the utility of using mTrac to submit weekly digitised reports to DHIS 2,

[viii] This section was developed in consultation with Dr James Kuule of the Uganda Malaria Research Centre and Freddy Eric Kitutu of Uppsala University and Makerere University.

characterise data quality challenges related to management capacity, or explore the influence of health worker training deficiencies on data management.

- **Data use at the district and sub-district level.** Technical workers collect and transmit data at the sub-district level, but they typically do not further engage with the data. Operational research might explore sub-district capacities and incentives to use routine health data for malaria programme management. Additionally, research might explore the usefulness of collaborative activities with routine health data use between academic and implementing agencies at the national and district level.
- **DHIS 2.** Operational research might characterise the use of DHIS 2 across the MoH and partners at the national and sub-national levels.
- **Fragmented data systems.** In 2016 the MoH required that all health facilities, private and public, submit data through DHIS 2. However, a map of the various data systems in Uganda might reveal opportunities to improve use of existing data (ie. HMIS data used to measure consumption, but partner data is used for procurement planning).

7. Annex A: Health administrative unit mapping

The second-level health administrative units shapefile used for mapping (112 districts) was provided by Didas Namanya (didas.namanya@health.go.ug) of Uganda Bureau of Statistics (UBOS). This digital shapefile was compared to the Global Administrative Unit Layers (GAUL).[171,ix] The UBOS district boundary had several anomalies at the national boundary and was re-digitised in ArcGIS to provide an exact match with approved global boundaries.

In February 2017, a new shapefile of 116 districts currently used by Uganda NMCP was sent to Lauren Hashiguchi (Lauren.Hashiguchi@lshtm.ac.uk) from Uganda NMCP. This shapefile had four newly created districts, namely Kagadi, Kakumiro, Omoro and Rubanda though boundaries have not changed for the 112 matching districts, just slight mismatches. Also Nsiika, Katerere and Kibingo districts from the old shapefile have been renamed to Buhweju, Rubirizi and Sheema respectively. The shapefile was checked for errors mainly sliver polygons and a few were corrected, and the outer district boundaries were aligned to the GAUL adm0 boundary for Uganda.

The regional distinctions were re-done in August 2018 to reflect the 15 nominal regions laid out in the 2017 Health Status and Associated Factors Thematic Series produced by the Uganda Bureau of Statistics.

[ix] The Global Administrative Unit Layers (GAUL) is an initiative implemented by FAO within the Bill & Melinda Gates Foundation, Agricultural Market Information System (AMIS) and AfricaFertilizer.org projects. The GAUL compiles and disseminates the best available information on administrative units for all the countries in the world, providing a contribution to the standardisation of the spatial dataset representing administrative units.

8. Annex B: Uganda prevalance bibliography

The EMBLEM Study (https://emblem.cancer.gov/), which is funded by the US Department of Health and Human Services. Contributing individuals were: Maziarz M, Kinyera T, Otim I, Kagwa P, Nabalende H, Legason ID, Ogwang MD, Kirimunda S, Emmanuel B, Reynolds SJ, Kerchan P, Joloba MM, Bergen AW, Bhatia K, Talisuna AO, Biggar RJ, Goedert JJ, Pfeiffer RM, Mbulaiteye SM, as well as Lawler-Heavner J, Sunday E, Nyegenye W, Buck L, Giffen C, Rydzak G and Lyman J.

The PRIME study in Tororo, part of the ACT Consortium. Contributing individuals were Sarah Staedke, Catherine Maiteki-Sebuguzi, Deborah DiLiberto, Emily Webb, Lei Mugenyi, Edith Mbabazi, Samuel Gonahasa, Simon Kigozi, Barbara Willey, Grant Dorsey, Moses Kamya, Clare Chandler, Philip Rosenthal and Paul Snell.

Abeku TA, Helinski MEH, Kirby MJ (2015). Monitoring malaria epidemiology and control in Ethiopia and Uganda: Baseline survey October-November 2012. Malaria Consortium, London

Al-Shehri H, Stanton MC, LaCourse J, Atuhaire A, Arinaitwe M, Wamboko A, Adriko M, Kabatereine NB, Stothard JR (2016). An extensive burden of giardiasis associated with intestinal schistosomiasis and anaemia in school children on the shoreline of Lake Albert, Uganda. Transactions of the Royal Society of Tropical Medicine & Hygiene, 110: 597-603

Bakaki P (1995). Childhood anaemia in a rural Ugandan community: Kiyeyi target area. Thesis, Makerere University, Kampala, Uganda

Betson M, Sousa-Figueiredo JC, Atuhaire A, Arinaitwe M, Adriko M, Besigye F, Mwesigwa G, Sutherland CJ, Kabatereine NB, Stothard R (2011). Investigating the poor parasitological performance of artemether-lumefantrine against malaria in Bukoba village, Mayuge district, Uganda. American Society of Tropical Medicine & Hygiene, 60th annual meeting program, December 4-6 2011, Philadelphia Marriott Downtown, 85:6 supplement

Betson M, Sousa-Figueiredo JC, Rowell C, Kabatereine NB, Stothard R (2010). Intestinal schistosomiasis in mothers and young children in Uganda: investigation of field-applicable markers of bowel morbidity. American Journal of Tropical Medicine & Hygiene, 83: 1048-1055

Coldiron ME, Lasry E, Bouhenia M, Das D, Okui P, Nyehangane D, Mwanga J, Langendorf C, Elder G, Salumu L, Grais RF (2017). Intermittent preventive treatment for malaria among children in a refugee camp in Northern Uganda: lessons learned. Malaria Journal, 16: 218

Communicable Disease Control Division (CDCD) (1992). Malaria situation analysis in Apac, Kabarole, Kampala and Rukingiri Districts: January to May 1992. Communicable Diseases Control Division, Ministry of Health, Uganda/UNICEF/WHO; MoH Archives, Entebbe

Davis JC, Clark TD, Kemble SK, Talemwa N, Njama-Meya D, Staedke SG, Dorsey G (2006). Longitudinal study of urban malaria in a cohort of Ugandan children: description of study site, census and recruitment. Malaria Journal, 5: 18

De Beaudrap P, Nabasumba C, Grandesso F, Turyakira E, Schramm B, Boum Y, Etard J (2011). Heterogeneous decrease in malaria prevalence in children over six-year period in South-western Uganda. Malaria Journal, 10: 132

Echodu R, Okello-Onen J, Lutwama JJ, Enyaru J, Ocan R, Asaba RB, Ajuga F, Akikii R, Bradley D, Mutero C, Kabonesa C, Olobo J (2010). Plasmodium falciparium transmission intensity in

Nyabushozi County, Kiruhura district, Uganda. Journal of Parasitology & Vector Biology, 2: 35-43

Egwang TG, Apio B, Riley E, Okello D (2000). Plasmodium falciparum malariometric indices in Apac district, northern Uganda. East African Medical Journal, 77: 413-416

Grandesso F (2004). Malarial morbidity in Mbarara district, Uganda a cross-sectional population-based survey, January 2004, Épicentre Épidemiologie, Médicins Sans Frontières

Green HK, Sousa-Figueiredo JC, Basanez MG, Betson M, Kabatereine NB, Fenwick A, Stothard JR (2011). Anaemia in Ugandan preschool-aged children: the relative contribution of intestinal parasites and malaria. Parasitology, 138: 1534-1545

Igune M (1984). Malaria study in children 0-14 years at Atutur, Kumi district-Uganda. A dissertation submitted for the academic post-graduate diploma in public health. Makerere University, Institute of Public Health, Medical School, Kampala, Uganda (No PDF)

Igune M (1987). Malaria study in children 0-14 years at Atutur, Kumi District, Uganda. Diploma in Public Health thesis. Makerere University (Full PDF not provided, only the annex)

Imani GW (1981). A survey of health problems among children in Igara county, Bushenyi District Uganda - A dissertation submitted for the academic post-graduate diploma in public health. Makerere University, Institute of Public Health (No PDF)

Kabatereine NB, Standley CJ, Sousa-Fugueiredo JC, Fleming RM, Stothard JR, Talisuna A and Fenwick A (2011). Integrated prevalence mapping of schistosomiasis, soil-transmitted helminthiasis and malaria in lakeside and island communities in Lake Victoria, Uganda. Parasites & Vectors, 4: 232

Katrak S, Day N, Ssemmondo E, Kwarisiima D, Midekisa A, Greenhouse B, Kamya M, Havlir D, Dorsey G (2016). Community-wide prevalence of malaria parasitemia in HIV-infected and uninfected populations in a high transmission setting in Uganda. Journal of Infectious Diseases, 213: 1971-1978

Kilian A (1995). Malaria control in Kabarole and Bundibugyo Districts-Western Uganda. International Support Programme for Malaria Control in the Framework of PHL, University of Munich and German Agency for Technical Co-operation (GTZ); Ministry of Health Archive, Entebbe

Kolaczinski JH, Reithinger R, Worku DT, Ocheng A, Kasimiro J, Kabatereine N, Brooker S (2008). Risk factors of visceral leishmaniasis in East Africa: a case-control study in Pokot territory of Kenya and Uganda. International Journal of Epidemiology, 37: 344-352

Legason ID, Atiku A, Ssenyonga R, Olupot-Olupot P, Barugahare JB (2017). Prevalence of anaemia and associated risk factors among children in North-Western Uganda: a cross sectional study. BMC Hematology, 17: 10

Lewnard JA, Berrang-Ford L, Lwasa S, Namanya DB, Patterson KA, Donnelly B, Kulkarni MA, Harper SL, Ogden NH, Carcamo CP (2014). Relative undernourishment and food insecurity associations with Plasmodium falciparum among Batwa pygmies in Uganda: Evidence from a cross-sectional survey. American Journal of Tropical Medicine & Hygiene, 91: 39-49

Lindsay S, Egwang T, Kebba A, Oyena D, Matwale G (2003). First year summary report: Development of a community-based environmental management program for malaria control in Kampala and Jinja, Uganda. Environmental Health Project, Activity Report no. 122

Lynch C, Cooke S, Nanyunja S, Corran P, Drakeley C, Bruce J, Bhasin A, Roper C, Pearce R, Rwakimari JB, Abeku TA, Cox J (2009). Determining the association between lifetime migration and malaria transmission intensity in highland areas, southwest Uganda [MIM16696398]. 5th MIM Pan-African Malaria Conference, Nairobi, Kenya

Maziarz M, Kinyera T, Otim I, Kagwa P, Nabalende H, Legason ID, Ogwang MD , Kirimunda S, Emmanuel B, Reynolds SJ, Kerchan P, Joloba MM, Bergen AW, Bhatia K, Talisuna AO, Biggar RJ, Goedert JJ, Pfeiffer RM, Mbulaiteye SM (2017). Age and geographic patterns of Plasmodium falciparum malaria infection in a representative sample of children living in Burkitt lymphoma‐endemic areas of northern Uganda. Malaria Journal, 16: 124

Maziarz M, Kinyera T, Otim I, Kagwa P, Nabalende H, Legason ID, Ogwang MD, Kirimunda S, Emmanuel B, Reynolds SJ, Kerchan P, Joloba MM, Bergen AW, Bhatia K, Talisuna AO, Biggar RJ, Goedert JJ, Pfeiffer RM, Mbulaiteye SM (2017). Age and geographic patterns of Plasmodium falciparum malaria infection in a representative sample of children living in Burkitt lymphoma‐endemic areas of northern Uganda. Malaria Journal, 16: 124

Nabukenya I, Kaddu-Mulindwa D, Nasinyama GW (2013). Survey of Brucella infection and malaria among Abattoir workers in Kampala and Mbarara Districts, Uganda. BMC Public Health, 13: 901

Nankabirwa JI, Wandera B, Staedke SG, Kamya M, Brooker S (2012). Asymptomatic Plasmodium Spp. Infection and cognition among Primary School children aged 6-14 years in a high malaria transmission setting on Uganda. American Journal of Tropical Medicine & Hygiene, 87 Supplement 5, abstract 380, Proceedings of 61st Annual Conference, Atlanta, Georgia, USA November 11-15 2012

National Malaria Control Programme, Uganda Malaria Surveillance Project, Uganda Bureau of Statistics, with support from PMI (2011). Malaria intervention coverage and associated morbidity survey in children under five years: Indoor residual spraying in northern Uganda and LLIN coverage in Central Uganda. MoH Report, December 2011

Naus CW, Jones FM, Satti MZ, Joseph S, Riley EM, Kimani G, Mwatha JK, Kariuki CH, Ouma JH, Kabatereine NB, Vennervald BJ, Dunne DW (2003). Serological responses among individuals in areas where both schistosomiasis and malaria are endemic: cross-reactivity between Schistosoma mansoni and Plasmodium falciparum. Journal of Infectious Diseases, 187: 1272-1282

Ndyomugyenyi R & Magnussen P (1997). In vivo sensitivity of Plasmodium falciparum to chloroquine and sulfadoxine-pyrimethamine in school children in Hoima district, western Uganda. Acta Tropica, 66: 137-143

Onapa AW, Simonsen PE, Baehr I, Pedersen EM (2005). Rapid assessment of the geographical distribution of Mansonella perstans infections in Uganda, by screening schoolchildren for microfilariae. Annals of Tropical Medicine & Parasitology, 99: 383-393

Oyet C, Roh ME, Kiwanuka GN, Orikiriza P, Wade M, Parikh S et al (2017). Evaluation of the Deki Reader™, an automated RDT reader and data management device, in a household survey setting in low malaria endemic southwestern Uganda. Malaria Journal. 16:450

Proietti C, Pettinato DD, Kanoi BN, Ntege E, Crisanti A, Riley EM, Egwang TG, Drakeley C, Bousema T (2011). Continuing intense malaria transmission in northern Uganda. American Journal Tropical Medicine & Hygiene, 84: 830-837

Rek J, Katrak S, Obasi H, Nayebare P, Katureebe A, Kakande E, Arinaitwe E, Nankabirwa JI, Jagannathan P, Drakeley C, Staedke SG, Smith DL, Bousema T, Kamya M, Rosenthal PJ, Dorsey G, Greenhouse B (2016). Characterizing microscopic and submicroscopic malaria parasitaemia at three sites with varied transmission intensity in Uganda. Malaria Journal, 15: 470

Saran I & Cohen J (2017). Disparities between malaria infection and treatment rates: Evidence from a crosssectional analysis of households in Uganda. PLoS ONE, 12: e0171835

Seal A, Creek P, Mirghani Z, Abdalla F, McBurney R, Pratt L, Brookes D, Ruth L, Marchand E (2005). Iron and vitamin A deficiency in long-term African refugees. Journal of Nutrition, 135: 808-813

Ssali G (1987). Prevalence of malaria in two peri-urban villages of Masaka town. Institute of Public Health, Makerere University, Kampala, Uganda

Staedke SG & Mugenyi L (2015). Data from START-IPT study registered at Clinicaltrials.gov (NCT02009215). The trial was funded by the Joint Global Health Trials Scheme (Medical Research Council, Wellcome Trust, and UK Department for International Development) (No PDF)

Staedke SG, Mwebaza N, Kamya MR, Clark TD, Dorsey G, Rosenthal PJ, Whitty CJ (2009). Home management of malaria with artemether-lumefantrine compared with standard care in urban Ugandan children: a randomised controlled trial. Lancet, 373: 1623-1631

Talisuna AO, Langi P, Bakyaita N, Egwang T, Mutabingwa TK, Watkins W, Van Marck E, D'Alessandro U (2002). Intensity of malaria transmission, antimalarial-drug use and resistance in Uganda: what is the relationship between these three factors? Transactions of the Royal Society of Tropical Medicine & Hygiene, 96: 310-317

Uganda Bureau of Statistics (UBOS) & ICF International (2015). Uganda Malaria Indicator Survey 2014-15. Kampala, Uganda, and Rockville, Maryland, USA: UBOS and ICF International

Uganda Bureau of Statistics (UBOS) & ICF Macro (2010). Uganda Malaria Indicator Survey 2009. Calverton, Maryland, USA

Wanzirah H, Tusting LS, Arinaitwe E, Katureebe A, Maxwell K, Rek J, Bottomley C, Staedke SG, Kamya M, Dorsey G, Lindsay SW (2015). Mind the gap: house structure and the risk of malaria in Uganda. PLoS One, 10: e0117396

Yeka A, Nankabirwa J, Okui P, Katamba H, Talisuna AO (2014). Prevalence of malaria infection and bed net coverage among school going children in Uganda. Survey undertaken using RBM-DFID support and data provided to INFORM on 1st August 2014 (No PDF)

Yeka A, Nankabirwa J, Mpimbaza A, Kigozi R, Arinaitwe E, Drakeley C, Greenhouse B, Kamya MR, Dorsey G, Staedke SG (2015). Factors associated with malaria parasitemia, anemia and serological responses in a spectrum of epidemiological settings in Uganda. PLoS One, 10: e0118901

9. Annex C: Light modelling methods

9.1 Background

In July 2018, two Ugandan malaria scientists, Dr Damian Rutazaana and Mr Paul Mbaka, received training with the KWRTP in Nairobi to learn how to execute geospatial models of malaria. Through this work, a prevalence map for 2016 which includes DHS 2016 data were produced. In the future, geospatial prevalence maps may be generated from within Uganda and in alignment with national planning needs.

Below we overview the methods of the modelling approach used to produce these new maps, and present the maps (Section 9.4).

9.2 Frequently asked questions on geospatial modelling of malaria prevalence

Data input into the models

- **What is the measure of risk we use?**

To characterise malaria risk, we use parasite prevalence, which is the proportion of a random sample of population with malaria parasites in their peripheral blood. It has been used to define transmission since 1900 in sub-Saharan Africa.

- **What are the minimum data requirements?**

For each community survey, the minimum data requirements are: the year of the survey; sample size; age range of the sample (ie. lowest and highest age in the sample); numbers reported positive for *P falciparum* infection; method(s) used to detect the infection (ie. microscopy, if RDT, type of RDT used); and coordinates of the surveyed location. In addition, boundaries of subnational units (eg. districts, counties, localities etc.) are needed because they form the health decision-making units which the prevalence estimates will be matched to. Depending on the model specifications, any covariates may be required (ie. environmental and socio-economic characteristics) when data are very sparse, and there is a well-defined biological relationship in each setting with the covariates selected.

- **What are the data quality checks employed?**

We confirm that the coordinates of each data point fall within national boarder and subnational units, as indicated in their originating source. We also check that the number of positive subjects are not greater than number of subjects examined, that the age ranges in the survey community are logical and that there are no unusual outliers. For the subnational boundaries we confirm the boundaries are complete and that there is no double-digitisation of the boundary lines.

- **What type of geospatial model is used estimate malaria risk?**

Model form

Model based geostatistics (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 (ie. 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 reflect more similar malaria risk than surveys undertaken decades apart).

We have two types of models that we use to estimate malaria prevalence in a country. The first model was used in the earlier malaria profile (called Model A), after which the KWRT migrated to the second version of the model (called Model B).

Model A
We incorporated data on parasite prevalence and environmental variables (covariates) that affect the transmission of the malaria through a well-defined biological relationship in each setting. These covariates include precipitation, vegetation, temperature suitability index and urbanisation. We estimate risk at every 1 km^2 in a country using the principles of model based geostatistics. In this model, covariates are used to improve predictions in areas where there is no data (sparse data) since no country has malaria prevalence data for each km^2.

The model is non-stationary and implemented through Stochastic Partial Differential Equations (SPDE) approach using Integrated Nested Laplace Approximations (INLA) in R-INLA library. The results generated include surfaces showing the mean, the upper and lower credible intervals, and standard deviation all at a 1 by 1 km resolution covering a range of years specified in the model. The mean is then averaged per each subnational unit.

Model B
The second model uses the same framework of model based geostatistics, however, covariates are not used. Instead, it is 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 model is stationary and is implemented in R software environment using Monte Carlo maximum likelihood under the PrevMap package. The outputs generated in this model (eg. mean parasite prevalence, credible intervals) generated by Model B are same as the same as Model A.

The main distinction between Model A and Model B is anchored on the stationarity property, where some properties of the distribution such as variance and covariance are either assumed to be constant or not over time. Model A is modelled as non-stationary (assuming that the properties are not constant over time) while Model B is assumed to be stationary (assuming that the properties are constant over time). The formulation of Model A is motivated by computational benefits and the marginal gains (intangible difference in terms of the predictions) that comes with Model A given that the binomial prevalence data available carry very weak information on non-stationary patterns and a potential of over fitting in Model A.

- ## What are the policy relevant thresholds?

One of the objectives of malaria risk mapping profile is to identify areas that are below or above a certain policy relevant malaria prevalence threshold (X). In addition to optimising Model B and dropping covariates, we added an extra component to allow better characterisation of (un)certainty. Classifying areas into different endemic levels purely based on predicted prevalence may lead to policy decisions that have not fully accounted for certainty of the predicted risk. Estimates of malaria risk ($Pf\text{PR}_{2\text{-}10}$) at every location have uncertainties that need to be considered when determining whether the prevalence in that area falls below a certain threshold.

Consequently, Model B allows us to characterize the level of certainty we have that either a subnational unit and or 1 by 1 km grid is either above or below the chosen threshold using an 'exceedance probability (EP)' metric. This is based on a probability calculated based on number of times a simulation predicts a prevalence measure below or above this threshold. An EP close

to 100% indicates that *Pf*PR$_{2-10}$ is highly likely to be above the threshold X; if close to 0%, *Pf*PR$_{2-10}$ is high likely to be below the threshold X; finally, if close to 50%, *Pf*PR$_{2-10}$ is equally likely to be above or below the threshold X, and this corresponds to the highest level of uncertainty.

- **Can NMCP undertake the modelling themselves?**

We have developed a web application that incorporates a user-friendly interface with which to implement Model B. The platform is a standardised and simplified form of the model that operates outside the R environment with predefined model parameters. Within this platform the user can upload and visualise country specific prevalence data and subnational boundaries and execute the model and visualise specific results: mean parasite prevalence and credible intervals at each health unit and the accompany exceedance probability values for the predefined policy relevant malaria prevalence threshold.

- **What is the difference between the web-platform and the execution of the Model B in R environment?**

In comparison to the execution of Model B in R where continuous maps at 1 by 1 km grid and predictions to multiple years can be produced, the web platform produces mean prevalence, 95% credible intervals and exceedance probabilities resolved at the subnational unit of a country. In addition, predictions can only be made to a single year during each model run. The two limitations are necessary to balance model running times and the needs of the NMCPs to have outputs anchored on the subnational unit of decision making. However, the app is still under development and will allow for greater flexibility in the future.

Interpretation of the maps from Model A and B

- **Are there any differences between mean prevalence from Model A and B?**

The differences are minimal and occasioned by the use of the covariates in Model A and not in Model B. However, the credible intervals in most instances will overlap. The means from Model A have incorporated the effect of covariates while the means from Model B are without the effect of covariates, and any difference observed is due to this difference.

Advantages and disadvantages of Model A v Model B.

- **What are the advantages and disadvantages of the two different models you use to estimate malaria prevalence risk?**

Model A required enormous amount of processing power using cloud-based servers and took substantially longer to get results up to three weeks. The model paradigm used covariates to improve predictions in areas where data were sparse and was implemented in INLA. The model did not allow the new measure of certainty around set policy thresholds.

The specification of Model B allows it to run on a desktop computer between 0.75 -5 hours depending on the amount of data available, the size of the country and the prediction resolution. It does not use covariates and allows for the evaluation of certainty around set policy thresholds.

- **What are the limitations of the models?**

Models are necessitated by the paucity and limitation of the available data. As such they only provide approximations. With sufficient data the use of models to produce estimates is negated.

- **What if my routine data shows something different?**

Routine data typically measures malaria disease among people who are symptomatic and use public health facilities, while the models described here rely on interpolation of parasite prevalence from community surveys in asymptomatic individuals. One limitation is that these surveys do not capture the intra-annual and seasonal variation of malaria risk and

heterogeneity at sub-national scale which routine data does. Additionally, as malaria prevalence declines, large sampling is required to capture the variation in rates of infection at sub-national levels hence the need to replace surveys with the use of routine data and using Test Positivity Rates (TPR) in place of parasite prevalence.

However, for many malaria endemic countries in sub-Saharan Africa, the surveillance systems do not capture all malaria cases, and data often come from the public health sector only. Not all cases in the public sector are reported consistently and, even where cases are reported, a proportion of them may not be parasitologically confirmed. Additionally, many patients do not have adequate access to health care and therefore do not seek treatment from formal health providers and or often use the private providers or buy medicines from retail stores. Hence in most cases, the routine data remain unreliable for estimating malaria burden. Additional the reliability of routine data is also much worse going further back in time. Improvements to routine data will be necessary to increase its utility.

Accuracy, representation of reality and quality assurance

- **Does Model A have similar accuracy as Model B?**

Models are assessed based on two things: 1) whether adopted modelling framework is suitable for the kind of data at hand; and 2) through cross validation that is comparison of the predicted values against the observed values. Each model should be assed individually because the input data are different.

- **How confident can we be in the geospatial maps that you produce (ie. How do we know if the maps reflect reality?)**

Estimates of malaria risk ($Pf\text{PR}_{2\text{-}10}$) at every location have a measure of the level of certainty that need to be considered when determining whether the prevalence in that area falls below a certain threshold. Additional the maps should be interpreted based on what is known about the spatial epidemiology of malaria in the country of interest and the practiced knowledge of the NMCP staff. The maps are also a reflection of the amount of data available for the modelling exercise.

- **The models are run by KWTRP; what kind of quality assurance is done?**

The quality of input data is checked as defined under section 1b. The modelling strategy is validated as described in section 4a.

- **What to assess if data is entered correctly and the generated are correct?**

This is a combination of section 1a, section 4a and section 4b.

9.3 Model summary

Category	Model A	Model B
Data input	Examined, positive, age range, year coordinates and covariates	Examined, positive, age range, year, and coordinates
Type	Geo-statistical	Geo-statistical
Space-time	Space-time Binomial	Space-time Binomial
Stationarity	Non-Stationary	Stationary
Inference method	Through Stochastic Partial Differential Equations (SPDE) using Integrated Nested Laplace Approximations (INLA) in R-INLA library	Through Monte Carlo maximum likelihood (MCML) in the PrevMap library
Covariates used	Precipitation, Enhanced Vegetation Index, Temperature Suitability Index, Precipitation and Urbanisation	No covariates used
Assumption	Covariates improve predictions where there are no data any location and time	The observed prevalence is product of all the covariates at any location and time
(Non) Exceedance Probability	Not generated	Generated for any specified threshold at both gridded and subnational level
Validation	Cross validation using a holdout set	Cross validation using a holdout set and a variogram based algorithm to test the adopted spatio-temporal structure
Resolution of output	Gridded output and/or subnational aggregates	Gridded output and/or subnational aggregates

9.4 NMCP-produced prevalence maps by Model B

Prevalence map produced by Model B for 2016.

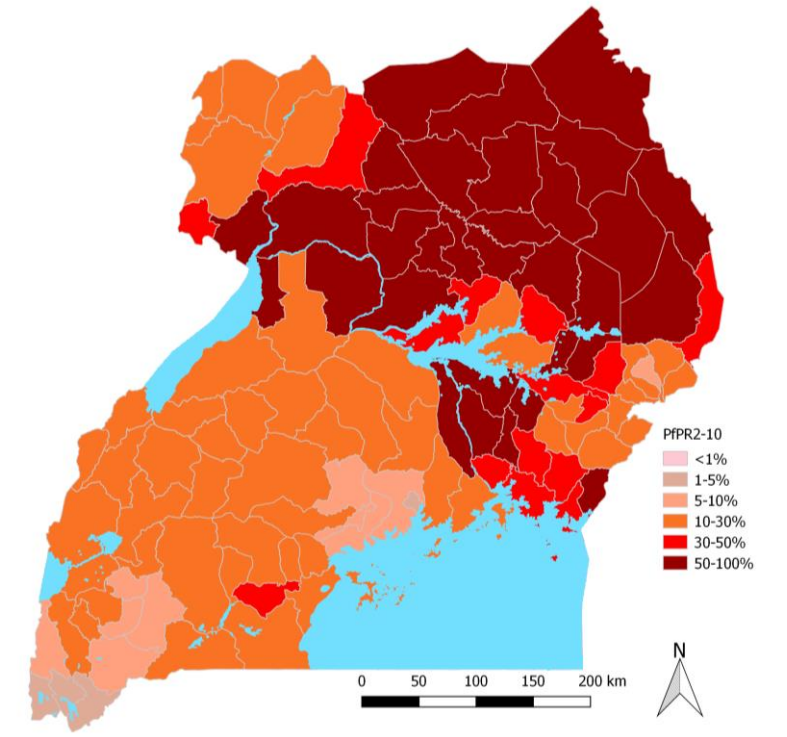


Figure 35. Predicted distribution of *Pf*PR$_{2\text{-}10}$ in 2016 by Model B

10. References

1. Kigozi, R. *et al.* Indoor Residual Spraying of Insecticide and Malaria Morbidity in a High Transmission Intensity Area of Uganda. *PLoS One* **7,** e42857 (2012).
2. Wat'senga, F. *et al.* Nationwide insecticide resistance status and biting behaviour of malaria vector species in the Democratic Republic of Congo. *Malar. J.* **17,** 129 (2018).
3. Roll Back Malaria Partnership to End Malaria (RBMP Partnership). *The Strategic Framework for Malaria Social and Behaviour Change Communication 2018-2030*. (2017).
4. Snow, R., Marsh, K. & Le Sueur, D. The need for maps of transmission intensity to guide malaria control in Africa. *Parasitol. Today* **12,** 455–457 (1996).
5. Snow, R. W. & Noor, A. M. Malaria risk mapping in Africa. 1–21 (2015).
6. Diggle, P. & Ribeiro, P. J. *Model-based Geostatistics*. (Springer, 2007).
7. World Health Organization/Roll Back Malaria Partnership Secretariat. The Abuja Declaration and the Plan of Action. in *An extract from The African Summit on Roll Back Malaria, Abuja, 25 April 2000 (WHO/CDS/RBM/2000.17)* **2000,** (2000).
8. Snow, R. W., Amratia, P., Kabaria, C. W. & Noor, A. M. *Europe PMC Funders Group The Changing Limits and Incidence of Malaria in Africa : 1939 – 2009*. (2012). doi:10.1016/B978-0-12-394303-3.00010-4.
9. Republic of Uganda Ministry of Health. *Uganda Malaria Program Review Report, 2001-2010*. (2011).
10. International Organization for Migration (IOM). *Migration in Uganda: a rapid country profile in 2013*. (2013).
11. Kesby, J. *The cultural regions of East Africa*. (Academic Press, 1977).
12. Byrnes, R. *Uganda: A Country Study*. (GPO for the Library of Congress, 1990).
13. Harlow, V., Chilver, E. & Smith, A. *History of East Africa; Volume II*. (Claredon Press, 1965).
14. Kuncyzinski, R. *A demographic survey of the British Colonial Empire*. (Oxford University Press, 1948).
15. Uganda Bureau of Statistics (UBOS). *Uganda National Population and Household Census 2014 Final Report*. (2014).
16. Linard, C., Gilbert, M., Snow, R. W., Noor, A. M. & Tatem, A. J. Population Distribution, Settlement Patterns and Accessibility across Africa in 2010. *PLoS One* **7,** e31743 (2012).
17. Mennis, J. Dasymetric Mapping for Estimating Population in Small Areas. *Geogr. Compass* **3,** 727–745 (2009).
18. United Nations Population Division. *World Urbanization Prospects: the 2011 Revision*. (2011).
19. Uganda Bureau of Statistics (UBOS). *Uganda Population and Housing Census Analytical Report*. (2006).
20. Uganda Bureau of Statistics (UBOS). *2002 Uganda Housing and Population Census*. (2002).
21. Uganda Bureau of Statistics (UBOS). *Uganda National Population and Housing Census 2014*. (2014).
22. United Nations. *World Urbanization Prospects: the 2011 Revision*. (2012).
23. World Bank. World Bank databank: Uganda. (2017). Available at: http://data.worldbank.org/country/uganda. (Accessed: 8th May 2017)
24. National Research Council. *Malaria Control During Mass Population Movements*

and Natural Disasters. (National Academies Press, 2003).
25. Harlow, V., Chilver, E., Smith, A. & Perham, M. *History of East Africa; Volume II*. (Claredon Press, 1965).
26. National Planning Authority. *Uganda Vision 2040*. (2013).
27. World Bank. *The Uganda poverty assessment report*. (2016).
28. World Bank. Uganda Economic Update: Fact Sheet. (2016).
29. Uganda National Planning Authority. *Roadmap to attaining middle income status for Uganda*. (2017).
30. World Health Organization. African Health Observatory. (2014). Available at: http://www.aho.afro.who.int/en/data-statistics. (Accessed: 21st March 2018)
31. Institute for Health Metrics and Evaluation (IHME) University of Washington. GBD Compare. (2015). Available at: http://ihmeuw.org/4d0t%0A. (Accessed: 18th March 2018)
32. Uganda Bureau of Statistics [UBOS]. *Uganda 2016 Demographic and Health Survey, Key Indicators (provisional)*. (2016).
33. UNICEF-IGME. *Level and Trends in child mortality, Report 2010*. (2011).
34. Republic of Uganda. *Millennium Development Goals Report for Uganda 2015*. (2015).
35. National Malaria Control Programme, Abt Associates & INFORM Project. *An Epidemiological Profile of Malaria and Its Control in Uganda. A report prepared for the Ministry of Health, the Roll Back Malaria Partnership and the Department for International Development, UK*. (2013).
36. Parliament of the Republic of Uganda. Parliament creates 23 new districts. (2015). Available at: http://tinyurl.com/zpl9dq7.
37. United Nations. *Republic of Uganda: Public Administration Country Profile*. (2004).
38. Beck, A. A History of the British medical administration of East Africa, 1900-1950. (Harvard University, 1970).
39. Berrang-Ford, L., Odiit, M., Maiso, F., Waltner-Toews, D. & McDermott, J. Sleeping sickness in Uganda: revisiting current and historical distributions. *Afr. Health Sci.* **6,** 223–231 (2007).
40. Okuonzi, S. & Macrae, J. Whose policy anyway? International and National Policies on Health policy Development in Uganda. *Heal. Policy Plan.* **10,** 122–132 (1995).
41. Kipp, W., Kamugisha, J., Jacob, P., Burnham, G. & Rubaale, T. Cost sharing In Kabarole District, Western Uganda: communities' and health professionals perceptions about health financing. *J. Heal. Popul. Dev. Ctries.* 30–38 (1999).
42. Ministry of Health. *Health Sector Quality Improvement Framework and Strategic Plan, 2010/11-2014/15*. (2011).
43. Ministry of Health (MOH) & Macro International Inc. *Uganda Service Provision Assessment Survey 2007*. (2008).
44. Hutchinson, P., Habte, D. & Mulusa, M. *Health Care in Uganda: Selected Issues. World Bank Discussion Paper No. 404. The World Bank, Washington DC.* (1999).
45. WHO/Alliance for Health Policy and Systems Research with Support from BMGF. *PRIMASYS - Primary Care Systems Profile and Performance (under review)*. (2017).
46. Ministry of Health (MoH). *Service Availability Mapping (SAM)*. (2006).
47. Ministry of Health. *Health sector strategic plan III 2010/11-2014/15*. (2010).
48. Detmer, D. Building the national health information infrastructure for personal health, health care services, public health and research. *BMC Med. Inf. Decis. Mak.* **3,** 1–12 (2003).
49. World Health Organization. *60th World Health Assembly, Resolution 60.27*

Strengthening of health information systems. (2007).
50. Osiobe, S. Health information imperatives for third world countries. *Soc. Sci. Med.* **28,** 9–12 (1989).
51. Boerma, J. & Stansfield, S. Health statistics now: are we making the right investments? *Lancet* **369,** 779–786 (2007).
52. World Health Organization. *The Health Metrics Network Framework. 2nd edition.* (2008).
53. Bullen, N., Moon, G. & Jones, K. Defining localities for health planning: a GIS approach. *Soc. Sci. Med.* **42,** (1996).
54. Gatrell, A. & Markku, L. *GIS and health*. (Taylor and Francis, 1998).
55. Noor, A., Gikandi, P., Hay, S., Muga, R. & Snow, R. Creating spatially defined databases for health service planning in resource poor countries: The example of Kenya. *Acta Trop.* **91,** 239–251 (2004).
56. Kazembe, L., Appleton, C. & Kleinschmidt, I. Geographical disparities in core population coverage indicators for Roll Back Malaria in Malawi. *Int. J. Equity Heal.* **6,** (2007).
57. Lozano-Fuentes, S. *et al.* Use of Google Earth™ to strengthen public health capacity and facilitate management of vector-borne diseases in resource-poor environments. *Bull. World Heal. Organ.* **86,** 718–723 (2008).
58. Galea, J. *Uganda Atlas of Disease Distribution*. (1968).
59. National Malaria Control Programme, Abt Associates & INFORM Project. *An Epidemiological Profile of Malaria and Its Control in Uganda. A report prepared for the Ministry of Health, the Roll Back Malaria Partnership and the Department for International Development, UK*. (2013).
60. Omaswa, C. *Uganda National E-Health Policy*. (2013).
61. Ministry of Health. *The Uganda Malaria Reduction Strategic Plan 2014-2020*. (2014).
62. World Health Organization. *World Malaria Report 2016*. *World Health Organization* (2016). doi:10.1071/EC12504
63. Organization, W. H. *2017 World Malaria Report*. (2017).
64. Government of the Republic of South Sudan. National Malaria Strategic Plan 2014/15-2020/21. (2014).
65. Talisuna, A. O., Noor, A. M., Okui, A. P. & Snow, R. W. The past, present and future use of epidemiological intelligence to plan malaria vector control and parasite prevention in Uganda. *Malar. J.* **14,** 158 (2015).
66. Uganda National Malaria Control Programme. *Mid Term Review of the 2010 – 2015 Malaria Strategic Plan*. (2014).
67. Uganda National Malaria Control Program. *Insecticide resistance management plan for malaria vectors in Uganda*. (2017).
68. Okia, M. *et al.* Consolidating tactical planning and implementation frameworks for integrated vector management in Uganda. *Malar. J.* **15,** 214 (2016).
69. Uganda Bureau of Statistics (UBOS) & ICF International. *Uganda Malaria Indicator Survey 2014-15*. (2015).
70. Uganda Ministry of Health & World Health Organization. *Malaria Epidemic Assessment Report*. (2015).
71. Rutazaana, D. Conversation with Dr Damian Rutazaana of the NMCP. (2017).
72. Kengeya-Kayondo, J. F. *et al.* Recognition, treatment seeking behaviour and perception of cause of malaria among rural women in Uganda. *Acta Trop.* **58,** 267–273 (1994).

73. Kidane, G. & Morrow, R. H. Teaching mothers to provide home treatment of malaria in Tigray, Ethiopia: a randomised trial. *Lancet* **356,** 550–555 (2000).
74. Ghebreyesus, T. A. *et al.* Community-based malaria control in Tigray, Northern Ethiopia. *Parassitologia* **41,** 367–371 (1999).
75. Mpeka, B., Tugume, B., Kigongo, C., Lutalo, T. & Lubang, R. *Developing and piloting interventions for appropriate home management of childhood fevers in Uganda.* (2000).
76. Ministry of Health. *Malaria Control Strategic Plan, 2001/02 - 2004/05*. (2001).
77. Ministry of Health. *Health sector strategic plan II, 2005/06-2010/11*. (2005).
78. Batwala, V., Magnussen, P. & Nuwaha, F. Challenges to implementation of artemisinin combination therapy policy in Uganda. *Int. Health* **2,** 262–268 (2010).
79. Government of South Sudan. *Health Policy for the Government of Southern Sudan, 2006-2011*. (2011).
80. Government of South Sudan. *Health Sector Development Plan, 2011-2015*. (2011).
81. World Health Organization. *Developing Health Management Information Systems: a Practical Guide for Developing Countries*. (2004).
82. Ministry of Health. *The Health Management Information System, Health Unit Procedure Manual, Vol. 1*. (2010).
83. Ogwal, J. Interview with Mr Jimmy Ogwal, Uganda Ministry of Health Resource Centre. (2017).
84. Kiberu, V. M. *et al.* Strengthening district-based health reporting through the district health management information software system: the Ugandan experience. *BMC Med. Inform. Decis. Mak.* **14,** 40 (2014).
85. Uganda Ministry of Health. Uganda HMIS Knowledge Management Portal. Available at: http://library.health.go.ug/publications/health-information-systems/hmis. (Accessed: 1st May 2018)
86. World Health Organization. *Assessment of health facility data quality in Uganda, 2010-1*. (2011).
87. Uganda Bureau of Statistics (UBOS) & ICF Macro. *Uganda Malaria Indicator Survey 2009*. (2010).
88. Uganda Bureau of Statistics [UBOS]. *2014-2015 Uganda Malaria Indicator Survey (MIS)*. (2016).
89. Uganda Bureau of Statistics & DHS Program. *Uganda Demographic and Health Survey: Key Indicators*. (2017).
90. Onori, E. & Benthein, F. Investigation of alleged Chloroquine resistance of malaria parasites in Westnile district of Uganda. *Parasitologia* **3,** 225–234 (1969).
91. Sezi, C., Nevil, C., Ochen, K., Munafu, C. & Bek'obita, D. The response of plasmodium to 4 aminoquinolines and pyrimethamine sulfadoxine at six sites scattered throughout Uganda. *Uganda Med. J.* **8,** 33–46 (1991).
92. Kamugisha, J., Kipp, W. & Burnham, G. In vivo sensitivity of Plasmodium falciparum to chloroquine, amodiaquine and sulfadoxine-pyrimethamine in western Uganda. *Trop. Geogr. Med.* **46,** 364–365 (1994).
93. Uganda Ministry of Health. *Report on the sensitivity of Chloroquine and Sulphadoxine-Pyrimethamine. [Unpublished document]*. (1993).
94. Ndyomugyenyi, R. & Magnussen, P. In vivo sensitivity of plasmodium falciparum to chloroquine and sulfadoxine-pyrimethamine in school children in Hoima district, western Uganda. *Acta Trop.* **66,** 137–143 (1997).
95. Uganda Ministry of Health. *Uganda Intensified Malaria Control Initiative*. (1996).
96. Kilian, A. *Unpublished drug sensitivity data*. (1998).

97. Mpeka & Ndezi. Unpublished drug sensitivity data report. *1996*
98. Talisuna, A. O. *et al.* Intensity of malaria transmission, antimalarial-drug use and resistance in uganda: What is the relationship between these three factors? *Trans. R. Soc. Trop. Med. Hyg.* **96,** 310–317 (2002).
99. Rapuoda, B. *et al.* The efficacy of antimalarial monotherapies, sulphadoxine-pyrimethamine and amodiaquine in East Africa: Implications for sub-regional policy. *Trop. Med. Int. Heal.* **8,** 860–867 (2003).
100. Ndyomugyenyi, R. & Magnussen, P. In vivo sensitivity of Plasmodium falciparum to chloroquine and sulfadoxine-pyrimethamine among schoolchildren in rural Uganda: A comparison between 1995 and 1998. *Acta Trop.* **76,** 265–270 (2000).
101. Legros, D. *et al.* Clinical efficacy of chloroquine or sulfadoxine-pyrimethamine in children under five from south-western Uganda with uncomplicated falciparum malaria. *Trans. R. Soc. Trop. Med. Hyg.* **96,** 199–201 (2002).
102. Dorsey, G. *et al.* Predictors of chloroquine treatment failure in children and adults with falciparum malaria in Kampala, Uganda. *Am. J. Trop. Med. Hyg.* **62,** 686–92 (2000).
103. Kamya, M. R. *et al.* The comparative efficacy of chloroquine and sulfadoxine-pyrimethamine for the treatment of uncomplicated falciparum malaria in Kampala, Uganda. *Trans. R. Soc. Trop. Med. Hyg.* **95,** 50–55 (2001).
104. Staedke, S. *et al.* Amodiaquine, sulfadoxine/pyrimethamine, and combination therapy for treatment of uncomplicated falciparum malaria in Kampala, Uganda: a randomised trial. *Lancet* **358,** (2001).
105. Bakyaita, N. *et al.* Sulfadoxine-pyrimethamine plus chloroquine or amodiaquine for uncomplicated falciparum malaria: A randomized, multisite trial to guide national policy in Uganda. *Am. J. Trop. Med. Hyg.* **72,** 573–580 (2005).
106. Ministry of Health. *National Policy on Malaria Treatment*. (2000).
107. Kamya, M. R., Bakyaita, N. N., Talisuna, A. O., Were, W. M. & Staedke, S. G. Increasing antimalarial drug resistance in Uganda and revision of the national drug policy. *Tropical Medicine and International Health* **7,** 1031–1041 (2002).
108. Commercial Market Strategies-CMS. *Availability and pricing of Anti-malarials in the private Sector in Uganda: A study by the Commercial Market Strategies Project*. (2003).
109. National Drug Authority (NDA). *Survey of quinine mixtures available on the market*. (1997).
110. Ogwal-Okeng, J. W., Okello, D. O. & Odyek, O. Quality of oral and parenteral chloroquine in Kampala. *East Afr. Med. J.* **75,** 692–694 (1998).
111. Talisuna, A. O., Staedke, S. G. & D'Alessandro, U. Pharmacovigilance of antimalarial treatment in Africa: is it possible? *Malar. J.* **5,** 50 (2006).
112. Abeku, T. A. *et al.* Monitoring changes in malaria epidemiology and effectiveness of interventions in Ethiopia and Uganda: Beyond Garki Project baseline survey. *Malar. J.* **14,** 337 (2015).
113. Abeku, T. A. *et al.* Insecticide resistance patterns in Uganda and the effect of indoor residual spraying with bendiocarb on kdr L1014S frequencies in Anopheles gambiae s.s. *Malar. J.* **16,** 156 (2017).
114. Mulamba, C. *et al.* Widespread Pyrethroid and DDT Resistance in the Major Malaria Vector Anopheles funestus in East Africa Is Driven by Metabolic Resistance Mechanisms. *PLoS One* **9,** e110058 (2014).
115. Mawejje, H. D. *et al.* Insecticide resistance monitoring of field-collected Anopheles gambiae s.l. populations from Jinja, eastern Uganda, identifies high levels of

pyrethroid resistance. *Med. Vet. Entomol.* **27,** 276–283 (2013).
116. Morgan, J. C., Irving, H., Okedi, L. M., Steven, A. & Wondji, C. S. Pyrethroid Resistance in an Anopheles funestus Population from Uganda. *PLoS One* **5,** e11872 (2010).
117. Verhaeghen, K. *et al.* Spatio-Temporal Patterns in kdr Frequency in Permethrin and DDT Resistant Anopheles gambiae s.s. from Uganda. *Am. J. Trop. Med. Hyg.* **82,** 566–573 (2010).
118. Ramphul, U. *et al.* Insecticide resistance and its association with target-site mutations in natural populations of Anopheles gambiae from eastern Uganda. *Trans. R. Soc. Trop. Med. Hyg.* **103,** 1121–1126 (2009).
119. McCrae, A. *In Uganda Atlas of Disease Distribution*. (East African Publishing House, 1975).
120. De Zulueta, J. *et al.* A malaria eradication experiment in the highlands of Kigezi (Uganda). *East Afr. Med. J.* **41,** 102–120 (1964).
121. De Zulueta, J., Kafuko, G. W., Cullen, J. R. & Pedersen, C. K. The results of the first year of a malaria eradication pilot project in Northern Kigezi (Uganda). *East Afr. Med. J.* **38,** 1–26 (1961).
122. De Zulueta, J., Kafuko, G. W. & Cullen, J. R. An investigation of the annual cycle of malaria in Masaka district (Uganda). *East Afr. Med. J.* **40,** 469–488 (1963).
123. Onori, E. & Benthein, F. *An investigation of the annual cycle of malaria in an area of Uganda.* (1967).
124. Metselaar, D. & Thiel, P. van. Classification of malaria. in *Trop Geogr Med 11* 157–16 (1959).
125. McCrae, A. in *Malaria* (eds. Hall, S. & Langlands, B.) 55–60 (Makerere University College, 1968).
126. McCrae, A. in *Malaria* (eds. Hall, S. & Langlands, B.) (East African Publishing House, 1975).
127. Ministry of Health. *National Malaria Prevention and Control Monitoring and Evaluation Plan 2007-2012*. (2007).
128. President's Malaria Initiative (PMI). *Malaria Operational Plans for Uganda, 2007, 2008, 2009, 2010, 2011 and 2012*.
129. Global Fund to Fight AIDS Tuberculosis and Malaria. Round 7 Malaria component submission to the Global Fund: Scaling up Long Lasting Insecticidal Net (LLIN) ownership and use in Uganda. *2007*
130. Yeka, A. *et al.* Malaria in Uganda: Challenges to control on the long road to elimination. *Acta Trop.* **121,** 184–195 (2012).
131. Ministry of Health. *Uganda Malaria Programme Review Report 2001-2010*. (2011).
132. Ministry of Health. *Uganda Malaria Control Strategic Plan 2011-2015*. (2011).
133. Ministry of Health. *National malaria strategic plan 2014-2020 (UMRSP)*. (2015).
134. National Malaria Control Programme, Associates, A. & Project, I. *An epidemiological profile of malaria and its control in Uganda*. (2013).
135. Rao, J. *Small Area Estimation*. (John Wiley & Sons, Inc., 2003).
136. BIAS. Introduction to Bayesian Small Area Estimation. (2007). Available at: http://www.bias-project.org.uk/software/SAE.pdf.
137. Snow, R. W. *et al.* The prevalence of Plasmodium falciparum in sub-Saharan Africa since 1900. *Nature* **550,** 515–518 (2017).
138. Smith, D. L., Guerra, C. A., Snow, R. W. & Hay, S. I. Standardizing estimates of the Plasmodium falciparum parasite rate. *Malar. J.* **6,** 131 (2007).
139. Tobler, W. A Computer Movie Simulating Urban Growth in the Detroit Region.

Econ. Geogr. **46,** 234–240 (1970).
140. Giorgi, E., Diggle, P., Snow, R. & Noor, A. Disease mapping and visualization using data from spatiotemporally referenced prevalence surveys [in press]. *Int. Stat. Rev.*
141. Giorgi, E. *et al.* Using non-exceedance probabilities of policy-relevant prevalence thresholds to identify areas of low malaria transmission in Somalia. *Malar. J.* 88 (2018).
142. Diggle, P., Moyeed, R., Rowlingson, B. & Thomson, M. Childhood malaria in the Gambia: a case-study in model-based geostatistics. *J. R. Stat. Soc. Ser. C (Applied Stat.* **51,** 493–506 (2002).
143. Stanton, M. C. & Diggle, P. J. Geostatistical analysis of binomial data: generalised linear or transformed Gaussian modelling? *Environmetrics* **24,** 158–171 (2013).
144. Gething, P. W., Patil, A. P. & Hay, S. I. Quantifying aggregated uncertainty in Plasmodium falciparum malaria prevalence and populations at risk via efficient space-time geostatistical joint simulation. *PLoS Comput Biol* **6,** (2010).
145. Okullo, A. E. *et al.* Malaria incidence among children less than 5 years during and after cessation of indoor residual spraying in Northern Uganda. *Malar. J.* **16,** 319 (2017).
146. Snow, R. *et al. Assembling a geo-coded repository of malaria infection prevalence survey data in Africa 1900-2014.* (2015).
147. Gibbins, E. Natural malaria infection of house frequenting anopheles mosquitoes in Uganda. *Ann. Trop. Med. Parasitol.* **26,** (1932).
148. White, B. J. *et al.* Molecular karyotyping of the 2La inversion in Anopheles gambiae. *Am. J. Trop. Med. Hyg.* **76,** 334–339 (2007).
149. Kayondo, J. K. *et al.* Genetic structure of Anopheles gambiae populations on islands in northwestern Lake Victoria, Uganda. *Malar. J.* **4,** (2005).
150. Kengne, P. *et al.* Molecular differentiation of three closely related members of the mosquito species complex, Anopheles moucheti, by mitochondrial and ribosomal DNA polymorphism. *Med. Vet. Entomol.* **21,** 177–182 (2007).
151. IRBase.
152. Knox, T. B. *et al.* An online tool for mapping insecticide resistance in major Anopheles vectors of human malaria parasites and review of resistance status for the Afrotropical region. *Parasit. Vectors* **7,** 76 (2014).
153. Haddow, A. & Ssenkubuge, Y. The mosquitoes of Bwamba County, Uganda. X. Observations on the biting behavior of Anopheles spp. other than A. gambiae Giles, with notes on the behaviour of these species in the Entebbe area. *Bull. Entomol. Res.* **64,** 45–51 (1974).
154. Harbach, R., Townson, H., Mukwaya, L. & Adeniran, T. Use of rDNA-PCR to investigate the ecological distribution of Anopheles bwambae in relation to other members of the An.gambiae complex of mosquitoes in Bwamba County, Uganda. *Med. Vet. Entomol.* **11,** 329–334 (1997).
155. Haddow, Ab. of E. R., VanSomeren, E., Lumsden, W., Harper, J. & Gillett, J. The mosquitoes of Bwamba County, Uganda. III. Records of occurence, behaviour and habitat. *Bull. Entomol. Res.* 207–238 (1947).
156. Gillies, M. & DeMeillon, B. *The Anophelinae of Africa South of the Sahara*. (1968).
157. Antonio-Nkondjio, C. *et al.* Population structure of the malaria vector Anopheles moucheti in the equatorial forest region of Africa. *Malar. J.* **7,** (2008).
158. Okello, P. E. *et al.* Variation in malaria transmission intensity in seven sites throughout Uganda. *Am. J. Trop. Med. Hyg.* **75,** 219–225 (2006).

159. Ribbands, C. R. Differences between anopheles melas and anopheles gambiae. *Ann. Trop. Med. Parasitol.* **38,** 87–99 (1944).
160. Muirhead Thomson, R. C. Studies on Salt-Water and Fresh-Water Anopheles gambiae on the East African Coast. *Bull. Entomol. Res.* **41,** 487–502 (1951).
161. WHITE, G. B. Anopheles bwambae sp.n., a malaria vector in the Semliki Valley, Uganda, and its relationships with other sibling species of the An.gambiae complex (Diptera: Culicidae). *Syst. Entomol.* **10,** 501–522 (1985).
162. Harbach, R. E. Review of the internal classification of the genus Anopheles (Diptera: Culicidae): The foundation for comparative systematics and phylogenetic research. *Bull. Entomol. Res.* **84,** 331–342 (1994).
163. Coluzzi, M. & Sabatini, A. Cytogenetic observation on species A and B of the Anopheles gambiae complex. *Parasitologia* 73–88 (1967).
164. Coluzzi, M. Heterogeneities of the malaria vectorial system in tropical Africa and their significance in malaria epidemiology and control. *Bull. World Health Organ.* **62,** 107–113 (1984).
165. COETZEE, M. A taxonomic description of Anopheles quadriannulatus Theobald (Diptera: Culicidae) from southern Africa. *Syst. Entomol.* **12,** 305–312 (1987).
166. Hunt, R. H., Coetzee, M. & Fettene, M. The Anopheles gambiae complex: a new species from Ethiopia. *Trans. R. Soc. Trop. Med. Hyg.* **92,** 231–235 (1998).
167. Coetzee, M. & Koekemoer, L. L. Molecular systematics and insecticide resistance in the major African malaria vector, Anopheles funestus. *Annu Rev Entomol* **58,** (2013).
168. Della Torre, A. *et al.* Molecular evidence of incipient speciation within Anopheles gambiae s.s. in West africa. *Insect Mol. Biol.* **10,** 9–18 (2001).
169. Della Torre, A. *et al.* Speciation within Anopheles gambiae--the glass is half full. *Science (80-.).* **298,** 115–117 (2002).
170. Kabbale, F. *et al.* Molecular identification of Anopheles gambiae sensu stricto Giles (formerly Anopheles gambiae Savannah Form) in Kamuli District, Uganda. *African J. Biotechnol.* **15,** 2124–2131 (2016).
171. Food and Agriculture Organization of the United Nations. Global Administrative Unit Layers (GAUL). (2014). Available at: http://www.fao.org/geonetwork/srv/en/metadata.show?currTab=simple&id=12691.
172. World Health Organization. *WHO position statement on integrated vector management*. (2008).

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