Understanding the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa

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Tables & Figures

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List of acronyms

ABMs	Agent-based models
ACT	Artemisinin-based combination therapy
BMGF	Bill & Melinda Gates Foundation
CAR	Conditional autoregressive model
CBPR	Community-based participatory research
CDC	U.S. Centers for Disease Control
CHW	Community health worker
CM	Case management
DHES	Directorate of Health and Epidemiological Surveillance, Madagascar Ministry of Health
DHS	The Demographic and Health Surveys Program
DIS	Directorate of Information Systems, Madagascar Ministry of Health
DSP	Directorate of Studies and Planning, Madagascar Ministry of Health
EHR	Electronic health record
EIR	Entomological inoculation rate
FBO	Faith based organization
Gavi	Global Alliance for Vaccines and Immunization
GBD	*Global Burden of Disease* Study, Lancet
GF	Global Fund to Fight AIDS, Tuberculosis, and Malaria
GIS	Geographic Information Systems
GMP	Global Malaria Programme, World Health Organization
GPS	Global Positioning Systems
GTS	Global Technical Strategy for Malaria 2016–2030, World Health Organization
HCD	Human-centred design
HEP	Health Emergencies Programme, World Health Organization
HF	Health facility
HIS	Health Information System
HMIS	Health Management Information System
iCCM	Integrated community case management
IDI	In-depth interview
IDSRS	Integrated Diseases Surveillance and Response System
IEC	Information, education and communication
IPTC	International Treatment Preparedness Coalition
IPTp	Intermittent preventive treatment of pregnant women
IPTp3+	Intermittent preventive treatment of pregnant women, with coverage of at least three doses
IRS	Indoor residual spraying
ITN	Insecticide-treated mosquito net
LCLU	Land cover/land use
LLIN	Long-lasting insecticidal net
M&E	National monitoring and evaluation
MACEPA	Malaria Control and Elimination Partnership in Africa
MAP	Malaria Atlas Project
MARA/AMRA	Mapping Malaria Risk in Africa / «Atlas du Risque de la Malaria en Afrique»
MBG	Model-based geostatistics

MCDA	Multi-criteria decision analysis
MDAST	Malaria Decision Analysis Support Tool
MECAT	Monitoring and Evaluation Capacity Assessment Toolkit
MEWS	Malaria early warning system
MICS	Multiple Indicator Cluster Surveys
MIS	Malaria Indicator Survey
MoH	Ministry of Health
MPAG	Malaria Policy Advisory Group, World Health Organization
MPR	Malaria Programme Performance Review
MSP	Malaria Strategic Plan
NCD	Non-communicable disease
NDM	Nuffield Department of Medicine, Oxford University
NGO	Non-governmental organisation
NMCP	National Malaria Control Programme
NMS	National Malaria Strategy
ODA	Overseas Development Assistance
OSM	OpenStreetMap
PBO	Piperonyl butoxide
*Pf*PR	*Plasmodium falciparum* prevalence rate
PGIS	Participatory GIS
PMI	President's Malaria Initiative, U.S. Agency for International Development
R_0	Basic reproductive number
RBM	Roll Back Malaria Partnership to End Malaria
RDT	Rapid diagnostic test
SAR	Spatial Annual Report, The Demographic and Health Surveys Program
SDG	Sustainable Development Goal
SDR	Spatial Data Repository Program, The Demographic and Health Surveys Program
SMC	Season malaria chemoprophylaxis
SMS	Short message services
SRTM	Shuttle Radar Topography Mission
TPI	Pasteur Institute of Madagascar
UNICEF	United Nations Children's Fund
USAID	U.S. Agency for International Development
VGI	Volunteered geographic information
WHO	World Health Organization
WHO-AFRO	Regional Office for Africa, World Health Organization
WHO-EMRO	Regional Office for the Eastern Mediterranean, World Health Organization
WMR	*World Malaria Report*, World Health Organization

List of acronym translations

Campagne d'aspersion intradomiciliaire (CAID)	Indoor residual spraying (IRS)
Centre de Santé de Bases (CSB)	Basic Health Centre
Centre hospitalier (CH)	Hospital center
Combinaison artésunate amodiaquine (ASAQ)	Artesunate–amodiaquine
Direction de lutte contre le paludisme (DLP)	National malaria control programme (NMCP)
Direction des Études et de la Planification (DEP)	Directorate of Studies and Planning (DSP)
Direction des formation sanitaires et surveillance épidémiologique (DFSSE)	Directorate of Health and Epidemiological Surveillance (DHES)
Direction du Système d'Information (DSI)	Directorate of Information Systems (DIS)
Enquête sur les indicateurs du paludisme (EIPM)	Malaria Indicator Surveys (MIS)
Fonds Mondial (FM)	Global Fund (GF)
Formation sanitaire	Health locality
Institut Pasteur de Madagascar (IPM)	Pasteur Institute of Madagascar (TPI)
Ministère de la Santé Publique (MSNP)	Ministry of Health (MoH)
Moustiquaire Imprégnée d'Insecticide (MID)	Insecticide-treated mosquito net (ITN)
Organisation Mondiale de la Santé (OMS)	World Health Organization (WHO)
Plan de Riposte aux épidémies (PRE)	Epidemic Response Plan
Plan stratégique nationale (PSN)	National malaria strategy (NMS)
Responsable Paludisme de District (RPD)	Responsible party at the District level
Responsable Paludisme Régional (RPR)	Responsible party at the Region level
Suivi et évaluation des performances	Monitoring and evaluation (M&E)
Test de diagnostic rapide (TDR)	Rapid Diagnostic Test (RDT)

*Non-exhaustive

Overview

Abstract

'Understanding the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa'

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Malaria risk maps are a critical tool to assist national malaria programmes in the prioritization and targeting of their malaria control activities to maximize efficacy and equity, especially under conditions of resource constraint. The research study sets out to answer a core series of questions pertaining to the use of malaria mapping, the actors involved, the mapped outputs produced, and approaches for their improvement and knowledge translation.

The research study conducts a narrative literature review and an audit of over 100 control programme documents from 47 malaria-endemic sub-Saharan African countries to better understand the typologies malaria risk maps, their development, their applications, and their potential value across different decision-making levels. The research study then conducts a thematic analysis of 17 qualitative, in-depth interviews held with malaria control stakeholders in Madagascar in order to identify current-state use cases, perceived utility, perceived limitations, and future-state use cases of malaria risk mapping in the country. Finally, the study evaluates the results of a modelled map workshop organized by The Demographic and Health

Surveys Program and conducted with technical malaria stakeholders in Madagascar to assess methods for capacity-strengthening and knowledge translation in malaria risk mapping.

The research study finds that malaria risk maps are increasingly used in national and sub-national fora, and have perceived value across a range of use cases, including surveillance, intervention stratification, logistics, descriptive epidemiological or climatic visualizations, and predictive analyses. Further explorations of stakeholder perceptions can help to better understand the decision points and trade-offs faced by health policymakers in malaria elimination and control when considering the use of malaria risk maps.

Word Count: 262

Chapters included in thesis

I. Narrative literature review of the potential value and applications of malaria risk maps in global malaria control and elimination efforts.

II. Auditing the inclusion of malaria risk maps in national malaria strategies and financing documents in sub-Saharan Africa.

III. Stakeholder views on malaria risk maps in Madagascar.

IV. Findings from a stakeholder workshop by The Demographic and Health Surveys Program about modelled maps of identified key malaria indicators in Madagascar.

V. Recommendations for future research.

Statement of contributions

I, **Mr. Kaleem Hawa** (KH), confirm that this thesis is wholly my own work. Some parts of the chapters have been necessarily assisted by other individuals – where this is the case, initials are used. Their contributions include:

Dr. Rosalind Howes (RH), acted as a co-investigator for **Chapter 3** and **Chapter 4**, assisted with the development of the methodology for **Chapter 3**, co-designed the workshop in **Chapter 4**, and reviewed a draft of thesis during the dissertation process. For more details about RH's contributions in **Chapter 4**, please refer to the '**Note on contribution**'.

Ms. Cameron Taylor (CT), a researcher at The Demographic and Health Surveys Program, co-designed the workshop in **Chapter 4** and designed one of the questionnaires in **Chapter 4**. For more details about CT's contributions in **Chapter 4**, please refer to the '**Note on contribution**'.

Publications authored during the course of thesis

The following publication was authored during the course of this research thesis. It is attached in full in **Appendix A.2**.

Howes, R., Hawa, K., *et al*. A stakeholder workshop about modelled maps of key malaria indicator survey indicators in Madagascar. *Malaria Journal* **18**, 90. (2019).

Chapter 1

Narrative literature review of the potential value and applications of malaria risk maps in global malaria control and elimination efforts

Research question

Given the long history and increased use of malaria risk maps, it merits examining a variety of phenomena, including their inputs, outputs, and use cases. This Chapter conducts a narrative literature review to understand existing malaria risk map typologies and develops a framework for understanding their development and use in malaria control and elimination.

1.1 Introduction

Despite encouraging progress in reducing the prevalence and incidence of malaria in recent years, infections with *Plasmodium falciparum* malaria caused an estimated 229 million new malaria cases in Africa in 2019 and led to approximately 409,000 deaths, more than two thirds of which occurred in children under five.[1] Malaria is also one of the leading contributors to years lived with disability in low socio-demographic index countries, according to the 2019 *Global Burden of Disease* (*GBD*) study.[2]

In attempting to evaluate progress towards international targets in malaria control, policymakers increasingly have taken an interest in standardized methodologies that would allow meaningful country-to-country comparison and risk prediction across space and time.[3] In a landmark report, the Bill & Melinda Gates Foundation (BMGF) highlighted five key principles that comprise the cornerstone of malaria elimination and control strategy: (1) 'finding and curing all infections, not just clinical cases'; (2) 'making surveillance the backbone of elimination'; (3) 'thinking regionally and acting nationally'; (4) 'taking adaptive approaches to combatting malaria'; and (5) 'integrating malaria elimination into effective health systems'.[4] Within the second strategy, there are at least four areas where malaria risk mapping can have an influence: (1) 'the collection of accurate epidemiological data to help countries determine the size and location of parasite reservoirs, implement appropriate interventions, and forecast commodity demand'; (2) 'the development of effective health information systems to analyze epidemiological data and make it available in real time to local response teams'; (3) 'the analysis of human mobility

patterns to understand the spatial dimensions of malaria transmission and help program managers prevent reintroduction in cleared areas'; and (4) 'the analysis of entomological data on the transmission potential of mosquitoes and insecticide resistance patterns to help countries design appropriate control efforts'.[4]

Given the outsize potential importance of risk mapping in malaria policy, it is useful to systematically understand the perceived value and present applications of malaria risk maps, and to link them to the stated approaches and preferences of national malaria control programmes (NMCPs), international governance bodies, and financing authorities.

1.1.1 History of malaria risk mapping

There is a deep history of the use of geographical information systems (GIS) in disease control. At the normative level, GIS applications in disease control rely on a series of interrelated processes, including collection of epidemiological data, visualization (e.g., through maps), exploratory analysis using spatial statistics, and modelling.[5] GIS systems have been used to inform disease control efforts in malaria, tuberculosis, HIV/AIDS, and in pandemic-related response efforts, following Zika, SARS, Ebola, and, most recently, COVID-19. GIS-informed modelling has also been used to examine the intersecting effects of these diseases; consider, for example, a 2020 analysis (published in 2021) of the indirect effects of the COVID-19 pandemic on malaria intervention coverage, morbidity, and mortality in sub-Saharan Africa.[6]

Specifically for malaria, epidemiological models have been used for over 100 years,[7,8] and have remained an essential part of the toolkit used to understand the dynamics of one of the world's most debilitating infectious diseases.[9] Since the 1972 World Health Organization (WHO) Brazzaville conference, which declared malaria control a short-term strategic goal and eradication a long-term strategic goal, risk maps to support tailored, country-specific, and programmatically-informed malaria policy have emerged as an important focus.[10]

Since then, the technical sophistication of mapping has improved, concurrently with enhanced computing capacities and data collection techniques. Malaria risk maps have come to be used in a multiplicity of ways, at the international, national, and sub-national levels, and to evaluate disease burden, transmission, intervention coverage, cost-effectiveness, or to conduct predictive analyses.[11] This will be evaluated in greater depth in **Chapter 1.3** and **Chapter 1.4**.

1.1.2 Understanding implications of malaria maps in malaria policy

Part of this Chapter's intention is to link the use of malaria risk maps across its various dimensions to the wider malaria policy and programming landscape. Broadly, this understanding of malaria mapping utility can be constructed in a variety of different ways, answering discrete questions: which metrics or indicators are being mapped, for what purpose, and by which actors? These distinctions are, of course, themselves malleable, with certain categories transcending multiple buckets; financing, for instance,

constitutes both an objective in its own right as well as a superstructure of actors responsible for the provision of services.

Therefore, it is important to begin with examining both the proximate objectives and ultimate objectives in malaria risk mapping for elimination and control. Reflecting the WHO consensus position at the time, the BMGF identified ultimate objectives as falling into one of three categories in their 2011 'Malaria strategy overview': (1) malaria control, which is defined as 'reducing the malaria disease burden to a level at which it is no longer a public health problem'; (2) malaria elimination, which is defined as 'the interruption of local mosquito borne malaria transmission for at least three consecutive years'; and (3) malaria eradication, which is defined as 'permanent reduction to zero of the worldwide incidence of infection caused by a particular malaria parasite species'.[12] Since then, however, the WHO has moved away from seeing these as spanning discrete phases, preferring to understand the objectives as falling along a continuum.[13] Proximate objectives can constitute any variety of international, national, or sub-national goals that contribute to the ultimate objectives of malaria elimination or control, and which can be visualized in a geographically-stratified manner using maps. These can include, but are not limited to: lowering local incidence; lowering infection importation; lowering infection duration; reducing the parasitic reservoir; and reducing the entomological potential.[11] Malaria risk maps can play a role in setting targets for or evaluating progress towards achieving these proximate objectives.

There exist a variety of technical and operational factors that help predict the feasibility of achieving these ultimate and proximate objectives

globally.[14] These include epidemiological factors like intensity of endemic transmission and malaria importation rates as well as operational factors including: government stability (e.g., effectiveness and commitment; 'absence of internal and external conflicts'; 'good organisational and technical infrastructure'; 'firm political and financial commitment to malaria elimination'); health systems (e.g., 'fully developed, functional general health services'; 'high quality of training and personnel'); and populations at risk (e.g., 'size of total population at risk'; 'at-risk population as a proportion of total population'; 'access to populations at risk').[14,15] Spatial data can be used to help describe these factors, and can be integrated into mapping products to help policymakers in elimination and control efforts.

1.1.3 Trends facilitating greater use of malaria risk maps

The WHO Global Malaria Programme's (GMP) 2017 'Framework for malaria elimination' identifies a variety of key policy changes that have occurred since 2007 that help provide underlying context for greater use of geospatial analyses in malaria elimination and control.[16] These include, among others: the 2007 recommendation of universal coverage of insecticide-treated mosquito nets (ITNs); the 2010 recommendation of parasitological confirmation through microscopy or rapid diagnostic test (RDT) before treatment; and the 2012 recommendation of the use of primaquine with artemisinin-based combination therapy (ACT) for all patients (excluding pregnant women and infants) in low transmission areas.[16]

Mapping in resource constrained settings is also a trend with predictive salience. In the last few decades, financial investments towards malaria burden reduction grew significantly, but have shown greater constriction in recent years, which has necessitated NMCP focus on cost-efficiency.[17,18] For their part, international financing authorities aiming to assist NMCPs in achieving a variety of objectives related to malaria control and elimination have shown an increased willingness to integrate modelled surfaces in their evaluations of national financing applications.[4]

Finally, increasing sophistication of methods, tools, and capabilities has contributed to stronger perceived value of malaria risk mapping. An example of this can be observed in South Africa's Mpumalanga province, where malaria control planning has been limited by a case surveillance system for malaria that was only able to provide risk assessments at the magisterial district level (a subdivision of a province).[19] A dedicated geographical information system introduced by the WHO in partnership with the Ministry of Health (MoH) allowed estimates at the town and village level to be ascertained, improving the sophistication of the malaria control strategies.[19]

1.1.3.1 Increased use of data systems and analysis in healthcare delivery

Finally, while the focus of this Chapter is understanding the use of modelled data surfaces and cartographic visualizations of malaria, it is valuable to review the high-level context of how data systems are used and perceived in healthcare delivery, which also serves as a key trend informing

international, national, and sub-national authorities investing in the data analysis techniques discussed in this narrative review.

Data is an integral part of any healthcare system. Over the years the volume, variety and veracity of health data – generated both by hospitals and at the community- and primary care-level – has continued to increase. Within health centres, key examples of data include: electronic health records (EHRs); medical imaging data; clinical trial data; patient-reported data; medical claim records; and biomarker data, among others.[20] The use cases for these data primarily include: predictive modelling for risk and resource use; population management; drug and medical device surveillance; disease treatment and heterogeneity; precision medicine and decision-support; quality of care and performance management; public health; and research.[21]

However, health data pose unique challenges for decision-makers, including the preservation of patient privacy, the risk of misuse, and the absence of data sharing incentives leading to siloed repositories of highly-structured data.[22] As a result, questions of how to capture, store, analyse, and visualize this data in a way that more accurately reflects the real world have become central.[23] Using information systems to move from data to actionable intelligence has become a central goal for MoHs beset by a host of challenges, including aging populations,[24] growing non-communicable disease (NCD) burdens,[25] infectious disease outbreaks,[26] and higher costs of care.[27]

MoHs and disease control programmes have adapted to such advancements through investments in predictive analytics and GIS modelling, which are increasingly being used for health and medical science

applications.[28] This has led to burgeoning investment in health information systems (HIS) – a collection of data, processes, tools, and individuals that can help convert health data into actionable intelligence[29] – which the WHO has designated as one of six fundamental building blocks of a strong health system.[30] Importantly, health intelligence advances the notion that structured datasets are 'necessary but not sufficient' to improving human health, and that the analysis of health data must be in service to patients and communities.[31]

Health intelligence can effectively support a variety of key stakeholders in their efforts to improve outcomes: for health professionals, it can lead to better outcomes at lower cost as well as more meaningful information about what is needed by their patients and community members;[32] for individuals, it can drive better health, better care experiences, and greater transparency in treatment;[33] and for policymakers looking at larger regional or national contexts, it can improve population health by allow more targeted and effective use of limited resources across the entire system.

1.2 Methods

1.2.1 Narrative review approach

This chapter consists of a narrative literature review, with the results consolidated into thematic categories as well as a use case table. Narrative review investigative strategies have been shown to increase the comprehensiveness of overall findings by allowing for a flexible exploration of a complex issue area, and less dis-inclusion of potentially valuable insights.[34] The review was completed using publicly-available research articles, white papers, policy reports, programme reports, and regulatory guidance. The review sought to ascertain various salient details about the use of model-based and non-model-based malaria risk maps, including: (1) scale and nature of malaria indicators in risk maps; (2) risk maps use cases, applications, and linkages to stated pillars of the WHO's 'Global Technical Strategy (GTS) for Malaria 2016–2030'[13] as well as its 2021 update;[35] and (3) trends in the development of risk maps.

Ultimately, some of the materials that were most valuable to understanding this topic were difficult to capture through traditional search methodologies, and would be most commonly found in programmatic reports and assessments released by international stakeholders (e.g., global technical strategies) or NMCPs (e.g., National Malaria Strategies (NMSs)). These were occasionally captured by the search criteria but no systematic methodology was used to collect additional documents (see more limitations in **Chapter 1.4.1**).

1.2.2 Literature search methodology

The narrative review was conducted in 2018 and built on a previous narrative review search that was conducted in 2017. Some results published in 2019–2021 were updated and included in the Chapter analysis after a refresh was done in 2021. Search methodology relied on three major databases: PubMed, SCOPUS, and Web of Science for access to published academic literature. To capture insights from governments, non-governmental organisations (NGOs), international organisations, financing authorities, and regulatory agencies, additional searches were conducted through their public websites.

Finally, a few seminal policy documents guiding practitioner understandings of malaria risk mapping were also consulted for the review. These include the WHO's *World Malaria Report* (*WMR*) (latest as of 2020),[1,36,37] the WHO's Malaria Policy Advisory Group (MPAG) reports (published bi-annually; latest as of April 2021),[38,39] and the Roll Back Malaria (RBM) Partnership to End Malaria guidance on malaria elimination, 'High Burden to High Impact' (latest as of 2018).[40]

The academic search strategy was informed by the literature. Search results were exported into Mendeley 1.19.4 (Glyph & Cog, LLC) for processing, removal of duplicates, analysis, and synthesis. The Boolean logic for the searches was as follows:

PubMed:

("malaria"[Title]) AND ("risk*") AND ("map*" OR "geospatial" OR "geograph*")

SCOPUS:

(TITLE ("malaria") AND TITLE-ABS-KEY ("risk*") AND TITLE-ABS-KEY ("map*" OR "geospatial" OR "geograph*"))

Web of Science:

TI=("malaria") AND TS=("risk*") AND TS=("map*" OR "geospatial" OR "geograph*")

Inclusion and exclusion criteria were applied by reading titles and abstracts (where available) of articles and reports. Full-text review was initiated if necessary. Articles and reports were excluded if they could not be reasonably attributed to reference mapping or geographically-informed risk stratification in pursuit of malaria knowledge. Results pertaining to co-infection with other diseases were also excluded if the primary disease of interest was not malaria.

Ultimately, 603 articles were chosen for review prior to the refresh, published between 1999 and 2018. Articles and reports were then binned thematically into categories for narrative review. The defined categories focused on the related data inputs or visualized outputs of the maps, and were as follows: (1) data inputs (i.e., data types); (2) data outputs (i.e., types of risk map); and (3) data use (i.e., objectives). Data inputs were further categorized as: (1a) environmental (e.g., climatic, socio-demographic, and other covariates); (1b) disease-related (e.g., incidence, prevalence, cases, burden, transmission, importation, entomological); and (1c) operational (e.g., vector control, other intervention coverage, costs, stock-outs). These

were not mutually exclusive categories – certain articles could fall into multiple bins – but were intended to assist in understanding thematic linkages. A schematic of the narrative search methodology is depicted in **Figure 1.1**.

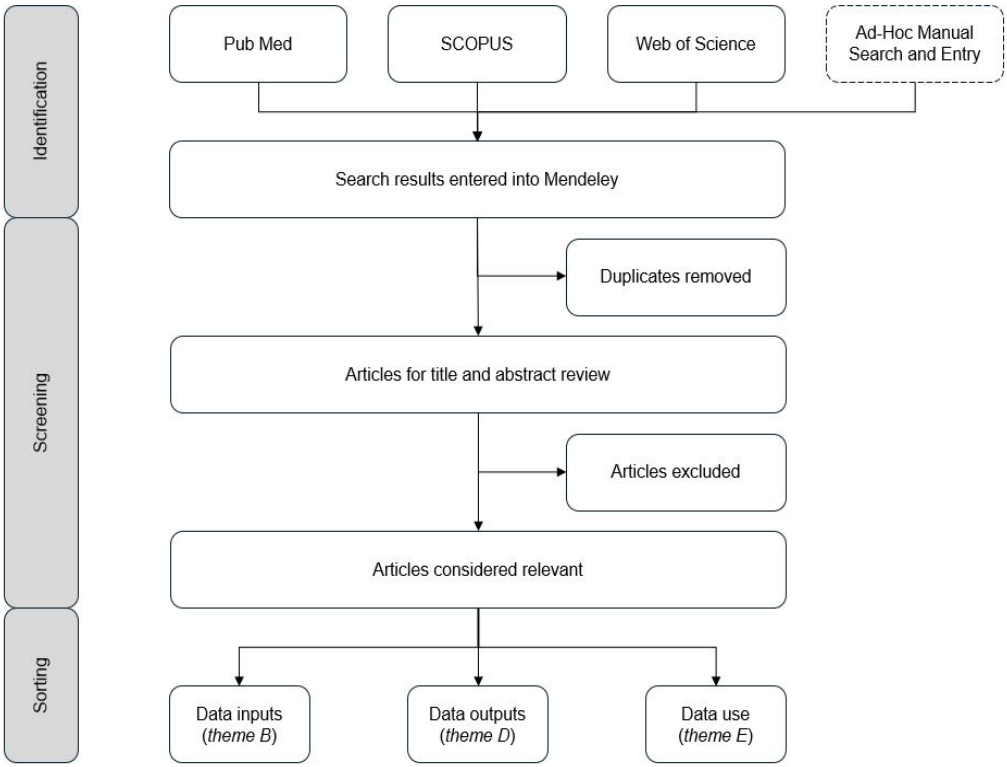
1.2.3 Out of scope

The malaria policy landscape is predominantly governed by the WHO and national MoHs, but is supported by a collection of international organisations, supranational non-profits, and financing authorities, including the BMGF, the U.S. Agency for International Development (USAID), the President's Malaria Initiative (PMI), the Global Fund to Fight AIDS, Tuberculosis and Malaria (GF), the Global Alliance for Vaccines and Immunization (Gavi), and academic/research groups affiliated with universities or foundations. While an exploration of the priorities and internal politics of these organisations and others actors (*theme F* in **Figure 1.2**) would be valuable for understanding the applications of and incentives for the use of malaria risk maps, these were outside the scope of this Chapter.

Also outside the scope of this Chapter were the specific analytical methods used in the production of the malaria risk maps (*theme C* in **Figure 1.2**), including, among others: variable selection techniques, model validation techniques, and spatio-temporal techniques (e.g., Bayesian conditional autoregressive (CAR) models, time series models, conventional Poisson, negative binomial regression).[41] Finally, this Chapter did not review the role of data collection in the production of malaria risk maps (*theme A* in **Figure 1.2**), including cross-sectional prevalence data and routine case data,

manipulated or collected by GIS, Global Positioning Systems (GPS), or remote sensing technologies.[42]

Figure 1.1: Schematic depicting narrative literature review methodology.



Note: Categories were additionally refined and new sources found since the creation of this schematic in 2018.

1.3 Results

Adapting the work of Clements *et al.* (2013) for the *Lancet Infectious Diseases*, one of this Chapter's results is a high-level framework for understanding how geospatial science is applied to the development of malaria risk maps in support of malaria control and elimination efforts.[42] This is depicted in **Figure 1.2**. The work of Odhiambo *et al.* (2020) was also consulted in this process.[41] The framework was also adapted into a table summarizing the major themes that emerged during the review – captured in **Table 1.1** – which serves as a guide for the structuring of the Chapter results and discussion below.

In addition, several exemplars of malaria risk maps are identified here. They can be found in **Figure 1.3**, **Figure 1.4**, and **Figure 1.5**.

Figure 1.2: Non-exhaustive and non-mutually exclusive summary of framework for the development of malaria risk maps, identified in the literature review.

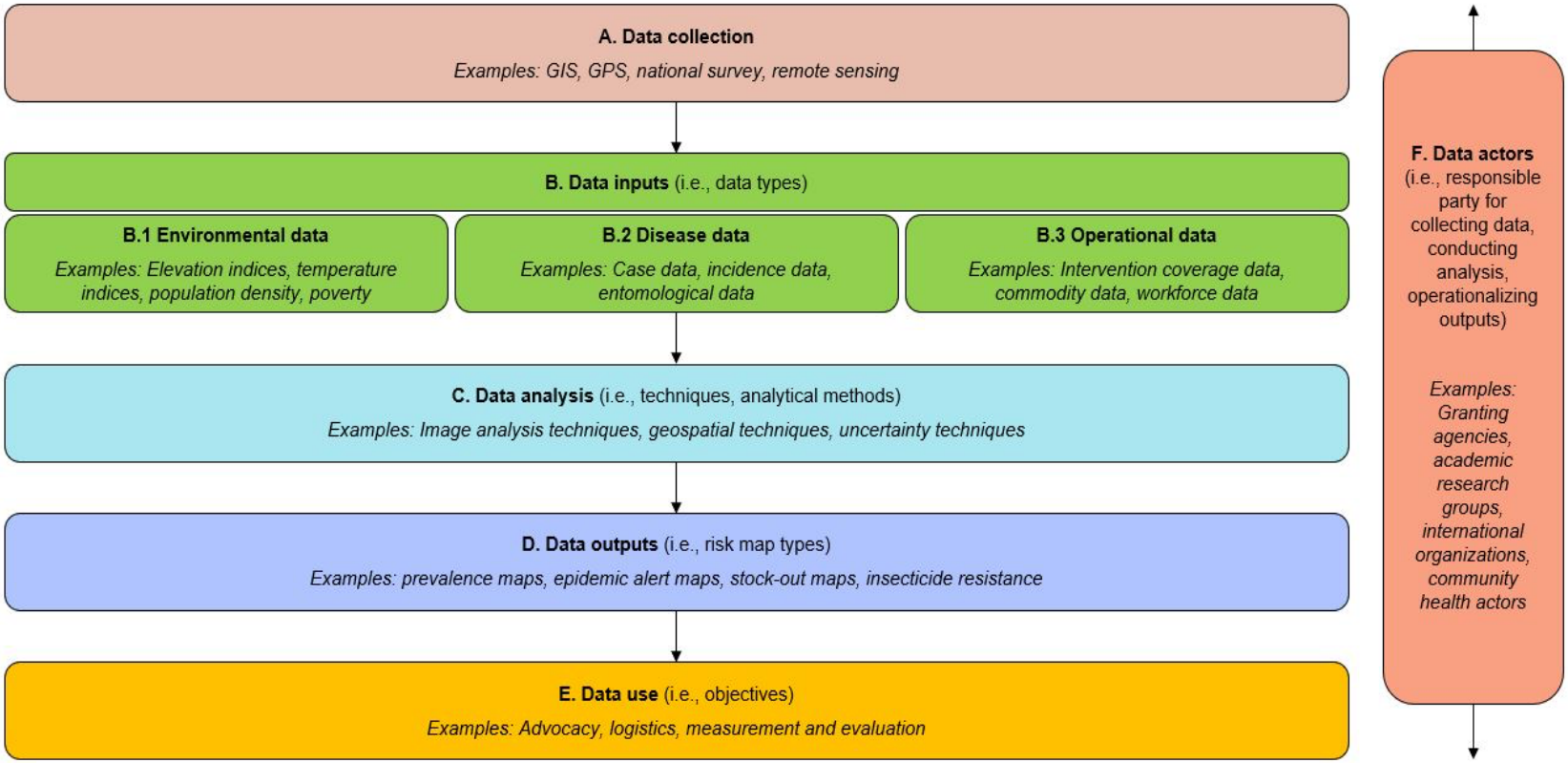


Table 1.1: Non-exhaustive and non-mutually exclusive summary of malaria risk map themes identified in the literature review.

Main themes and sub-themes
A. Data collection
A.1 Census or nationally-representative survey
A.2 Geographical information systems (GIS)
A.3 Global positioning systems (GPS)
A.4 Personal digital assistants, mobile telecommunication systems
A.5 Satellite remote sensing
B. Data inputs (i.e., data types)
B.1 Environmental data[41]
B.1.1 Climatic data
B.1.1.1 Digital elevation model derivatives
B.1.1.2 Elevation indices
B.1.1.3 GIS-derived indices (e.g., accessibility, distance)
B.1.1.4 Humidity indices
B.1.1.5 Rainfall indices
B.1.1.6 Reflectivity indices
B.1.1.7 Temperature indices
B.1.1.8 Vegetation indices
B.1.1.9 Wind indices
B.1.2 Socio-demographic data
B.1.2.1 Development
B.1.2.2 Gender
B.1.2.3 Livestock ownership
B.1.2.4 Population density
B.1.2.5 Urbanization
B.1.2.6 Wealth
B.2 Disease data
B.2.1 Burden data
B.2.2 Cases data
B.2.3 Entomological data
B.2.4 Importation data
B.2.5 Incidence data
B.2.6 Prevalence data
B.2.7 Transmission data
B.3 Operational data
B.3.1 Commodity, diagnostic, stock-out data
B.3.2 Cost data
B.3.3 Intervention coverage data
B.3.4 Quality of care provision data

B.3.5 Vector control data B.3.6 Workforce data
C. Data analysis (i.e., techniques, analytical methods)[41] C.1 Database management approaches C.2 Geospatial techniques C.3 Image analysis techniques C.4 Spatial statistical analysis techniques C.5 Uncertainty techniques C.6 Validation techniques C.7 Variable selection techniques C.8 Visualization techniques
D. Data outputs (i.e., risk map type) D.1 Accessibility, delivery time, and logistics maps D.2 Case maps D.3 Climatic and mosquitogenic condition maps D.4 Cost-efficacy maps D.5 Importation and population dynamics maps D.6 Incidence maps D.7 Insecticide resistance maps D.8 Intervention coverage maps (e.g., LLINs, IRS) D.9 Prevalence maps D.10 Spatial decision support systems (SDSSs) D.11 Stock-out maps D.12 Surveillance and epidemic alert maps D.13 Vector control maps
E. Data use (i.e., objectives) E.1 Advocacy E.2 Financing E.3 Logistics and planning E.4 Measurement and evaluation E.5 Research E.6 Training
F. Data actor (i.e., responsible party for collecting data, conducting analysis, operationalizing outputs) F.1 Granting agencies, financing authorities F.2 International organisations, supranational non-profits F.3 National authorities F.4 Research institutes, technical advisors F.5 Subnational and community health actors

Note: Unless otherwise stated, this table is the work of the author, but also informed by the methodology developed by Clements et al. *(2013).*[42] *Theme A (data collection), theme C (data analysis), and theme F (data actor) are outside the scope of this review Chapter.*

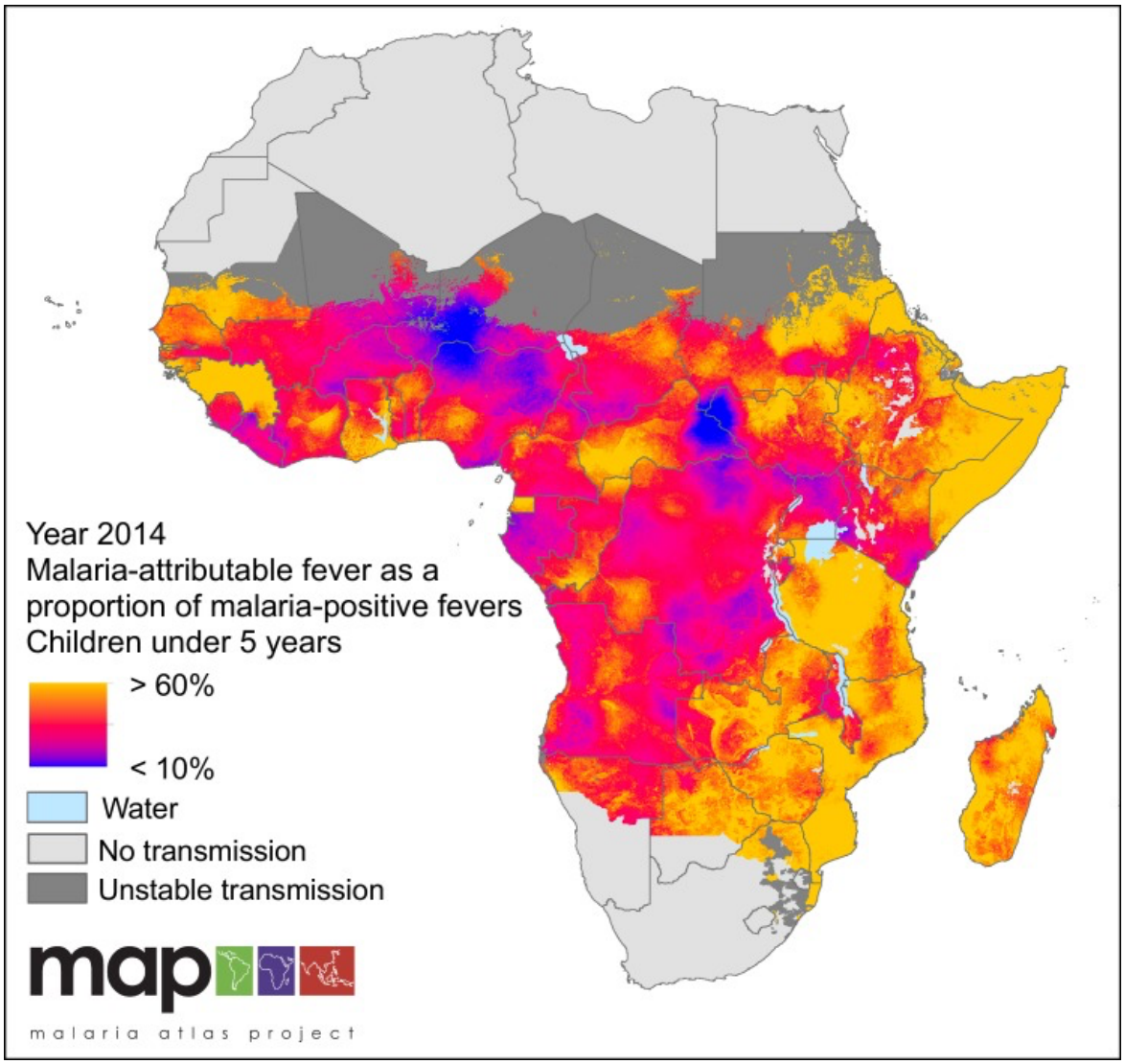
1.3.1 Disease indicators in malaria risk maps

Overall, the literature suggests that malaria risk maps can use several types of disease phenomena as data inputs (*theme B*) or as the ultimate subject of visualization (*theme D*).

Malaria risk maps have been used for understanding: clinical burdens;[43] describing populations at risk;[44,45] estimating mortality and morbidity;[46] visualizing incidence or visualizing prevalence (e.g., *Plasmodium falciparum* prevalence rate (*Pf*PR));[47] defining spatial distribution of transmission;[48] and integrating external co-variates into predictive analyses.[49] Less frequently, the products have also been used to depict: entomological inoculation rates (EIRs); the basic reproductive number (R_0); and the burden of morbidity due to malaria in pregnancy.[7] The various breakdowns of these disease indicators and their use cases will be reviewed in greater depth in **Chapter 2**.

An exemplar risk map use for depiction of disease indicators is taken from Dalrymple *et al.* (2017), showing 'predicted malaria-attributable fevers as a proportion of malaria-positive fevers in children under 5 years of age (2014)', and is provided in **Figure 1.3**.[50]

Figure 1.3: Predicted malaria-attributable fevers as a proportion of malaria-positive fevers in children under 5 years of age, year 2014, Dalrymple et al. *(2017).*[50]



1.3.2 Environmental indicators in malaria risk maps

Overall, the literature suggests that malaria risk maps can use several types of environmental phenomena as data inputs (*theme B*) or as the ultimate subject of visualization (*theme D*).

Several types of climatic data (*theme B.1.1*) were identified in the literature as being used as covariates in malaria risk mapping or independently visualized to assist policymakers. The thematic buckets for these indices included, among others: rainfall indices; temperature indices; vegetation indices; GIS-derived indices (e.g., accessibility, distance); elevation indices; humidity indices; digital elevation model derivatives; reflectivity indices; and wind indices.[41,51]

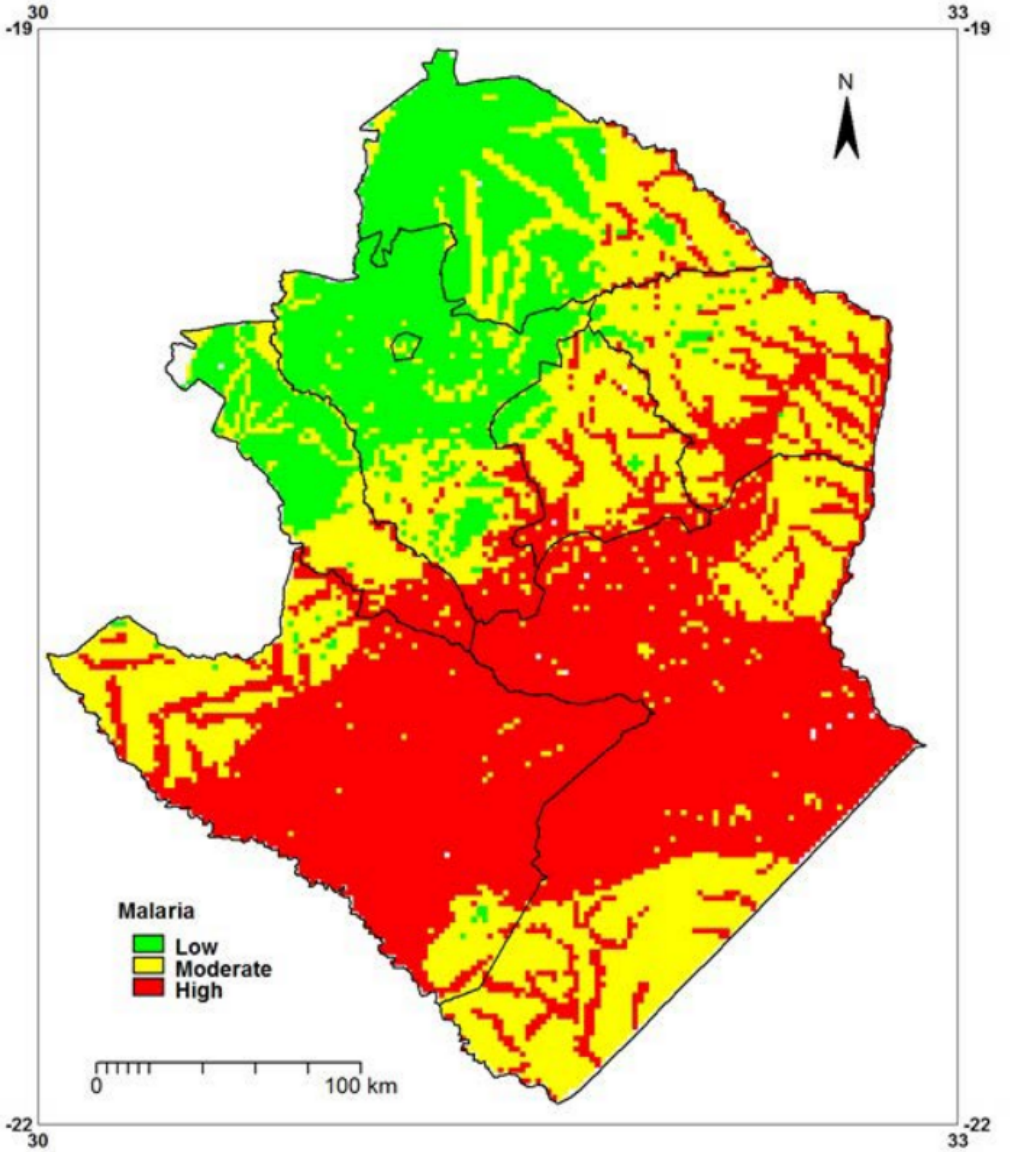
Some additional specific examples of climatic covariates were identified in a Kang *et al.* (2018) review of Madagascar's Malaria Indicator Survey (MIS) results, and included, among others: (1) 'accessibility', defined as distance to cities; (2) 'aridity index'; (3) GIS-derived 'distance to water' surface measurements; (4) 'elevation', as measured by the Shuttle Radar Topography Mission (SRTM); (5) 'potential evapotranspiration'; (6) GIS-derived 'slope'; (7) 'stable lights indices' that measure presence of light; (8) 'topographic wetness index'; (9) 'population size'; (10) 'enhanced vegetation index'; (11) 'daytime land surface temperature' and 'night-time land surface temperature'; (12) 'tasselled cap brightness' and 'tasselled cap wetness'; and (13) 'temperature suitability index'.[52]

Given the strong relationship between environmental changes and malaria prevalence, GIS and remote sensing technologies have all been used to examine mosquitogenic conditions in urban and rural centers, including

the prevalence of potential breeding surfaces and the relationships between land use and land cover.[53] In addition, several other variables were identified as of value to visualization to assist policymakers attempting to reduce proliferation of mosquito vectors: urban environmental sanitation; water supply; waste disposal; housing patterns; housing density; and urban land use, through the mapping of open wells, overhead tanks, pools, drainages, canals, and vector-breeding areas.[53]

An exemplar of this category of risk map is taken from Chikodzi (2013), depicting malaria risk in Masvingo province, Zimbabwe, using eight environmental malaria risk factors (rainfall, temperature, altitude, slope, land cover/land use (LCLU), distance to water bodies, potential evapo-transpiration, and distance from roads), and is provided in **Figure 1.4**.[54]

Figure 1.4: Spatial modelling of transmission risk in Masvingo province, Zimbabwe using eight environmental malaria risk factors (rainfall, temperature, altitude, slope, land cover/land use, distance to water bodies*, potential evapo-transpiration, distance from roads), Chikodzi (2013).*[54]



1.3.3 Operational indicators in malaria risk maps

Overall, the literature suggests that malaria risk maps can use several types of operational phenomena as data inputs (*theme B*) or as the ultimate subject of visualization (*theme D*). These include, among others: commodity, diagnostic, and stock-out data; intervention coverage data; vector control data; workforce data; and quality of care provision data.[55]

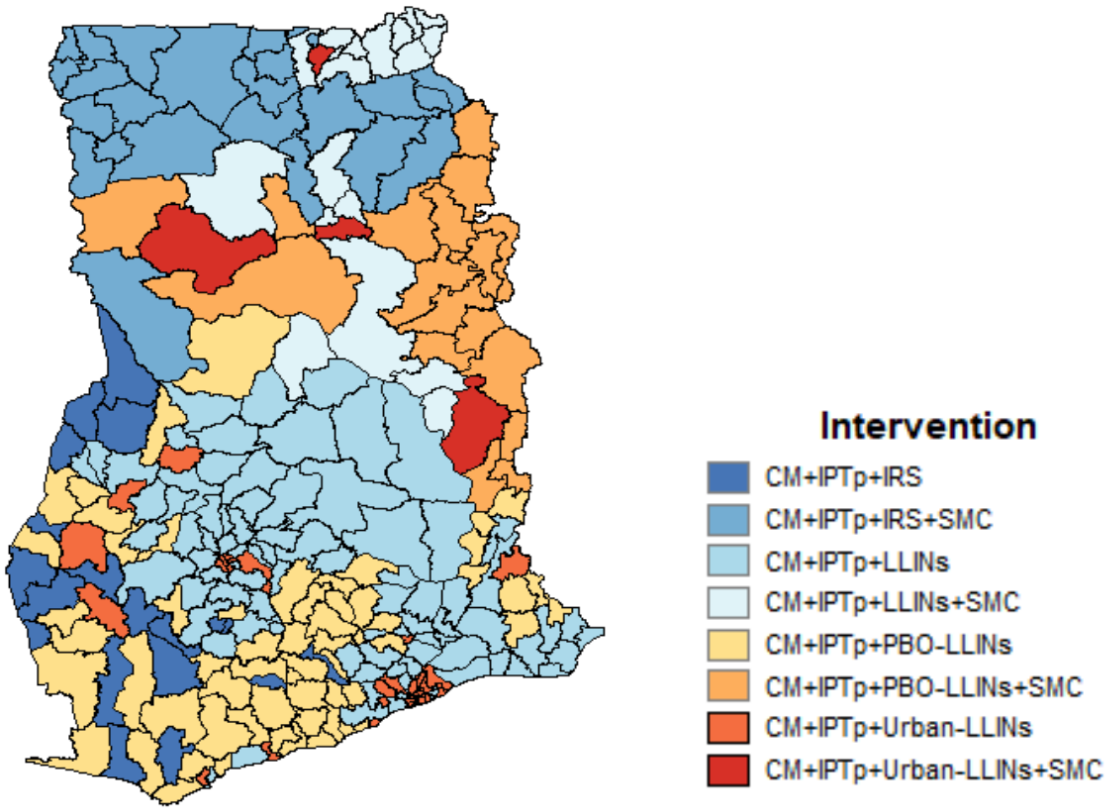
'Vector control' (*theme D.13*) was one of the most commonly mentioned use cases for malaria risk mapping. 'Vector control' is a major policy priority for NMCPs and MoHs, in part because of the existence of over 40 dominant malaria vector species, each bringing unique behaviours and challenges for control.[56] Vector control also remains among the highest-return public health investments in malaria, and is particularly well suited to well-characterized settings (i.e., through geographically- or spatially-informed representations).[57]

The WHO currently only recommends long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) as strategies for vector control (against adult mosquitoes), but also mentions larval source management (LSM) as a complementary approach.[16] One review of global NMSs (Africa (*n=18*); Asia–Pacific (*n=14*); and the Americas (*n=3*)) by Burkot *et al.* (2019) suggested that vector surveillance data was used to inform at least seven categories of decisions, from most- to least-cited: (1) stratification of control intervention for adult mosquitoes; (2) insecticide selection; (3) larval control strategy; (4) defining area 'receptivity'; (5) defining areas for focus studies; (6) identifying resting locations for IRS; and (7) identifying 'durability' for LLIN selection.[58] These are not necessarily mutually-exclusive use cases, and

certain mapping methodologies can contribute to multiple decision-making processes.[58]

An exemplar of this category of intervention map is taken from Ghana's GF malaria financing application (2020), depicting Ghana's 2019 intervention coverage and stratification across several interventions (uncomplicated malaria case management (CM), intermittent preventative treatment for pregnant women (IPTp), IRS, LLINs, and seasonal malaria chemoprophylaxis (SMC)), and is provided in **Figure 1.5**.[59]

Figure 1.5: Ghana intervention coverage malaria risk map, depicting 2019 intervention stratification (uncomplicated malaria case management (CM), intermittent preventative treatment for pregnant women (IPTp), indoor residual spraying (IRS), long-lasting insecticidal net (LLIN), and seasonal malaria chemoprophylaxis (SMC)), Ghana Global Fund malaria financing application (2020).[59]



1.3.4 Malaria risk map use cases

Data outputs (*theme D*) spanned descriptive, interpolative, and predictive risk map types, with several different use cases for each type. Overall, at least 15 interconnected use cases were identified for malaria risk maps: accessibility, delivery time, and logistics maps; case maps; climatic and mosquitogenic suitability maps; cost-efficiency maps; importation and population dynamics maps; incidence maps; insecticide resistance maps; intervention coverage maps (e.g., LLINs, IRS); prevalence maps; spatial decision support systems (SDSSs); stock-out maps; surveillance and epidemic alert maps; and vector control maps.

One of the most commonly-cited normative applications of malaria risk maps in evaluating and strengthening intervention coverage (*theme D.8*) focused on illustrating mismatches between control efforts in heterogenous transmission environments. The literature review identified that without appropriate targeting and stratification, control programmes could ultimately produce needlessly high coverage in low-risk settings and insufficient coverage in areas with the greatest need.[11] The smallpox and rinderpest eradication campaigns were occasionally cited as examples of where mismatched targeting had deleterious effects on intervention coverage.[11,60] The core tenet around this effort is 'optimization', that is, the ways an agent can alter the timing, location, and implementation of interventions to improve a particular deliverable and measurable target, such as coverage, cost-efficacy, speed, and vulnerable group access.[61]

Appearing several times in the narrative review was the use of malaria risk maps to depict predictive modelling of parasitic importation

and exportation (*theme D.5*). For instance, mobile phone and spatial malaria prevalence data has been used to predict areas of parasite importation and exportation, which can be helpful for targeting interventions and achieving national malaria control objectives.[62] For example, using a stochastic, non-linear, ordinary-differential equation model, researchers were able to show in Mpumalanga Province of South Africa that the impacts of scaling up of vector control and mass drug administration are limited without source reduction to stem importation from the Maputo Province.[63]

In addition, surveillance and epidemic alerts (*theme D.12*) were identified as a malaria map use case; 'surveillance' in these health contexts defined as 'the continuous and systematic collection, analysis and interpretation of disease-specific data, and the use of that data in the planning, implementation and evaluation of public health practice'.[64] The WHO Surveillance, Monitoring and Evaluation Technical Expert Group and the WHO GTS have identified surveillance as a 'core intervention' in malaria control.[65] This theme also included a reference for the use of GIS and remote sensing technologies in the development of a framework for integrated early warning systems.[66]

There has also been slow growth in the modelling and mapping of the cost-effectiveness of intervention allocations (*theme D.4*), with research studies calculating 'incremental cost-effectiveness ratios' across various intervention options to assist policymakers.[67] One such example is work by the MRC Centre for Outbreak Analysis and Modelling at Imperial College to identify the most efficient intervention packages based on malaria transmission dynamics and intervention coverage.[18]

Maps have also been used to define an accessibility parameter and map accessibility worldwide (*theme D.1*), with broader applications than just for malaria. This has strong links to the Sustainable Development Goals (SDGs) by allowing health ministries and malaria control programs in low-income settings to plan their delivery and implementation more effectively.[68] An exemplar methodology depicted by Weiss *et al.* (2018) used data from OpenStreetMap (OSM) and Google, combining human movement rates and ten global-scale surfaces to produce accessibility maps at a spatial resolution of approximately 1x1 km^2 – thereby taking into account new infrastructure developments and transportation networks.[69] These maps can also be used to help identify travel distance from urban centres and the correlation therein with socioeconomic status.[69]

Malaria risk maps were also used for more emergency-oriented programme objectives. These included data on drug stock-outs (*theme D.11*), which can be provided in an interactive and geographically-informed manner.[70] For instance, mobile phone short message services (SMS) have been used (in a pilot project) to assist in reporting antimalarial drug supplies in health facilities in Tanzania, with the transmitted data combined with facility tabular line lists and visualized on web-based map interfaces to understand real-time drug supply management and the rapid detection of stock-outs.[71] These efforts were distinct from the 'preventative' or predictive mapping for stock-outs, which were a further identified use case.

The narrative review identified SDSSs several times as malaria map case studies (*theme D.10*). SDSSs provide computerized decision-making support for decisions with strong geographic or spatial elements.[72] For

instance, SDSSs can be used to automatically generate maps to guide household IRS campaigns, as evidenced in a 2011 case study in Vanuatu.[73] A conceptual framework for SDSSs developed by Kelly *et al.* (2012) included four core elements: (1) geospatial data layer inputs informed by key stakeholders; (2) automated outputs pegged to operational decision-making needs; (3) decision and intervention outcome re-entry into SDSS for re-processing; and (4) the integration of expert knowledge throughout the entire process.[72]

Finally, within the logistics category (*theme D.1*), there was evidence of countries using mapping to: better understand the communities they served (including remote communities); plan the orders and supply cycles of their medicines based on predictions of need from previous data (significantly reducing the risk of costly stock-outs); and manage the allocation of human resources (to ensure effective staffing levels).[74]

1.3.5 Objectives and actors in the use of malaria risk maps

The literature review suggested that malaria risk maps can be used for a variety of objectives (*theme E*), falling within several non-exclusive categories: advocacy; financing; logistics and planning; measurement and evaluation; research; and training. This will be examined in greater depth in subsequent Chapters.

The literature review suggested that malaria risk maps can be used by (or produced by) a variety of actors (*theme F*), falling within several non-exclusive categories: international organisations, supranational non-profits; granting agencies, financing authorities; research institutes, technical

advisors; national authorities; subnational and community health actors. This will also be examined in greater depth in subsequent Chapters.

1.3.6 Upstream trends in development of malaria risk maps

While not explicitly the objective of the review, several studies suggested that one of the most salient explanatory factors for the growth in the development of malaria risk maps was the increased sophistication of geospatial instruments and methods and underlying technologies. In their review for *Lancet Infectious Diseases*, Clement *et al.* (2013) summarized the major categories of geospatial instruments and methods relevant to malaria elimination as being: satellite remote sensing; GIS; GPS; personal digital assistants; mobile telecommunications systems; spatial decision support systems; spatiotemporal cluster detection; geostatistics; generalized linear regression models; ecological niche models; Bayesian methods; and spatially explicit mathematical models.[42] In addition, this review found remote sensing, earth observations, and satellite technologies were repeatedly referenced as an emergent space.[75] Other identified factors contributing to the increased development of malaria risk maps were fairly synchronous with those explored in **Chapter 1.1.3**.

1.4 Discussion

Overall, the literature suggested that malaria risk mapping outputs are used across the national, regional, and local policymaking processes, including by domestic decision-makers, sub-national actors, and NMCPs across a variety of fora, while also being broadly adopted at the level of international regulatory and financing bodies as a means of assessing impact, setting best practices, and disbursing funding.

While historically, cartographic estimations of malaria endemicity have largely relied on routine health system data or specific published studies,[7] nationally-representative household surveys like The Demographic and Health Surveys (DHS) or the United Nations Children's Fund (UNICEF) Multiple Indicator Cluster Surveys (MICS) now provide standardized, geographically-salient data to assist geospatial techniques. Over the last two decades, the sophistication of model-based malaria risk maps has improved,[76,77] owing – according to Noor *et al.* (2012) – to increases in the availability of: the aforementioned 'national, geo-coded parasite prevalence data'; 'spatially-interpolated climate data derived from ground station observations'; and 'remotely sensed satellite surrogates of climate, urbanization, and topography'.[78] The result has been renewed focus on model-based malaria risk maps particularly as a versatile and multi-disciplinary public health tool.

The review suggested various different data inputs and covariate types used in risk map production that can be aligned with national and sub-national priorities. Specifically, the importance of mapping in elimination strategy emerged as a central theme, with a common view that as countries

move towards pre-elimination and elimination stages, universal coverage approaches become less impactful and cost-effective, resulting in greater value for surveillance and the linkage of mapping with surveillance data.[79,80]

Moreover, while not explicitly in the terms of the narrative review, agent-based models were also identified as an occasional contour of data analysis to inform mapping. An article by Smith *et al*. (2018) which systematically reviewed 90 articles published between 1998 and 2018 for all examples of agent-based models (ABMs) relevant to malaria transmission, which the authors defined as stochastic models of 'individual actions and responses' associated with 'stated variables and parameters'.[61] The concept of an agent in these models varied considerably, though most used a 'decision-tree' structure to model the decision-making behaviour of agents such as the host, the parasite, and the vector.

The factors influencing malaria transmission that have been successfully modelled in ABMs include: human factors (e.g., age, maternal immunity, co-morbidities, skin surface area, etc.); mosquito factors (e.g., biting rates, feeding patterns, species, mating competitiveness, etc.); disease process factors (e.g., pyrogenic threshold, episode severity, *dhfr* mutation, gametocyte sex, etc.); environmental factors (e.g., moisture, housing location, etc.); and intervention factors (e.g., IRS, vaccine costs, etc.).[61]

1.4.1 Limitations

There are a few identified study limitations. First, the chosen search terms were somewhat narrow. Upon review, it was identified that some known research papers in the field were not identifiable by the search term

Boolean logic outlined in **Chapter 1.2.2**. Known and seminal papers were manually updated to be included in the review, though this introduced elements of researcher bias.

This speaks to a second, deeper limitation with the search methodology: the difficulty of ascertaining operational utility of malaria risk maps from the narrow lanes of academic and programmatic research, without consulting planification documents and evaluation reporting where some of the most relevant insights are contained. These are, in part, the primary focuses of the subsequent Chapters of this thesis.

Thirdly, it would have been valuable to explore recurring challenges and barriers in malaria modelling, including: non-technical challenges (e.g., variable host dynamics, pathogen diversity, human contact network heterogeneity);[81] limited use cases in operational contexts;[72] and policymaker or public interest knowledge translation (e.g., approaches for public-facing or policymaker engagement with risk maps or visualization tools).

Finally, the narrative review could have spent time understanding participatory models in model-based geostatistics and its uses in malaria risk mapping. While mapping has largely been the domain of international technical partners or in-country analytics teams, participatory spatial data creation – sometimes referred to as volunteered geographic information (VGI)[82] – has found some cachet in mobilizing crowd-sourced mapping to identify and geolocate community assets in aid of development projects. VGI projects like YouthMappers regularly collaborate with programmatic and research teams at USAID and OSM, and have aided in mapping of building and road infrastructure in Mozambique assisting in insecticide spray

campaigns in Kenya.[83] Some research has focused particularly on the engagement of youth from the global south in participatory models of mapping malaria prevention and participatory GIS (PGIS).[83,84] These efforts rely on 'open mapping platforms' that crowdsource missing data in locations of need, and projects have received funding from groups like USAID and BMGF.[83]

Chapter 2

Auditing the inclusion of malaria risk maps in national malaria strategies and financing documents in sub-Saharan Africa

Research question

Over the last two decades, national agencies and international organisations have funded increases in the collection of geo-coded parasite prevalence data and spatially-interpolated climate data.[85,86] This has allowed for the use of model-based geostatistics to produce a variety of malaria risk maps across sub-Saharan Africa.[87] Given the importance of these maps in a host of fora, policymakers value systematic identification of the scale, scope, and uptake of their use by national malaria authorities. This chapter will conduct an audit of the malaria risk maps used in strategic documents and financing applications by National Malaria Control Programmes in forty-seven malaria endemic countries in Africa, to ascertain the resolution, function, and quality of data modelling that is informing national malaria eradication and control efforts.

2.1 Introduction

After a period in the late-1990s where international organisations and donors advocated for wide-spread, largely-undifferentiated coverage of malaria control interventions to be used in sub-Saharan Africa, recent years have seen renewed focus on the use of malaria risk maps to stratify geographies, target interventions, and evaluate programme efficacy.[76,88,89] These changes have been driven by several factors, including decreased malaria prevalence,[90] decreased malaria mortality,[47] and funding pressures[91] – all contributing to the perception of malaria risk mapping as a means to increasing the prioritization, targeting, and efficacy of malaria control and elimination efforts.[11]

To wit, the 'Global Technical Strategy (GTS) for Malaria (2016–2030)', calls for resources to be allocated and interventions to be delivered in evidence-based and targeted manners.[13,40] The GTS also designated 'malaria surveillance' (including 'entomological surveillance') a core intervention in malaria control and elimination efforts.[13,58] As such, key vector indicators for monitoring and visualization were detailed in an addendum document, 'Malaria Surveillance, Monitoring and Evaluation: A Reference Manual' (2018).[65] There, several objectives of vector surveillance were identified: (1) to 'characterize receptivity to guide stratification and selection of interventions'; (2) to 'track the relative density of malaria vector species to determine the seasonality of transmission and the optimal timing of interventions'; (3) to 'track insecticide resistance'; (4) to 'identify other threats to the effectiveness of vector control'; and (5) to 'monitor vector control intervention coverage and quality to identify gaps and

opportunities'.[58,65] How sub-Saharan African countries have both autonomously developed and taken up these calls for data monitoring, evaluation, and visualization is therefore an important area for exploration.

2.1.1 National malaria strategies

In 1998, the World Health Organization (WHO) and its partners founded the Roll Back Malaria (RBM) Partnership to End Malaria to help ensure synchronicity between national malaria control efforts[92] and to assess progress towards targets set in the 2000 Abuja Declaration.[93] Since the Declaration, the RBM has worked with the National Malaria Control Programmes (NMCPs) to develop National Malaria Strategies (NMSs) (sometimes known as Malaria Strategic Plans (MSPs)).[94] These national plans are updated with varying degrees of regularity, and have often depicted malaria risk maps, with or without modelled surfaces.[76] NMSs are the core documents guiding a country's approach to malaria control and elimination; they delineate objectives and targets, outline intervention strategies, and set metrics for evaluation.[94–96] The most up-to-date guidance on the development and structure of NMSs was issued by the WHO, as the 'Manual for developing national malaria strategic plans' (2019).[97]

2.1.2 National malaria programme performance reviews

Since 2009, the WHO's Regional Office for Africa (WHO-AFRO) has supported countries in conducting reviews of malaria control progress.[76,94] In 2011, the WHO recommended that NMCPs conduct evaluations of their progress towards goals delineated in their NMSs,[94] and published a resource

about these evaluations, termed national Malaria Programme Performance Reviews (MPRs).[98] The most up-to-date guidance on the development and structure of MPRs was issued by the WHO, as the 'Manual for malaria programme performance review (field trial)' (2010).[98] It does not appear to have been updated since. The updating of new national MPRs has become less frequent since 2013, though they are occasionally recommended for countries applying for international financing. MPRs often include: assessments of progress towards epidemiological and entomological impact; reviews of programme financing; and reviews of NMCP capacity to implement planned activities.

2.1.3 Global Fund financing applications

In addition to issuing these national guiding documents and working operationally to meet their objectives, NMCPs seek financing for control efforts from a variety of international and national actors. One of the core financing authorities is the Global Fund to Fight AIDS, Tuberculosis, and Malaria (hereafter, 'Global Fund' (GF)), which as of 2010, provided over 75% of Overseas Development Assistance (ODA) for malaria.[99] While GF financing was traditionally granted through a 'rounds-based' model (e.g., Round 2 held in 2002; Round 9 in 2009), the GF has since issued a new funding model, which emphasises early feedback through the application process, country-defined submission deadlines, and 'flexible grant-making', in the place of no pre-feedback, GF-defined submission deadlines, and 'rigid grant negotiations'.[100] Importantly for the use of malaria risk mapping, the GF has outlined in its 'Investing to End Epidemics' strategy (2017–2022) and

in its 'Strategic Framework for Data Use for Action and Improvement at Country Level' (2017–2022), objectives of using 'data at national, sub-national and community levels', which identify mapping as a specific component.[101,102] This has increased the requirement for countries to provide integrated cartographic depictions of malariometric data and indices in their submissions to the GF for financing.

GF financing applications are a package of documents submitted to the GF in order to receive funding support – a 'principal recipient' (e.g., an MoH) implements the grant through a 'country coordinating mechanism' (e.g., an NMCP), while the GF monitors implementation.[103] Applications often include: an epidemiological profile and profile of key and vulnerable populations; a report of salient details about existing malaria control strategies and progress; a funding landscape model; and a programmatic gap analysis document.[103,104] Applications can be 'multi-component' (e.g., supporting multiple disease control efforts) and/or can be with a 'partner' (e.g., submitted as part of a regional collaboration, like the West Africa International Treatment Preparedness Coalition (IPTC)).[103,104] The most up-to-date guidance on the development and structure of GF financing applications was issued by the GF, as the 'Applicant Handbook' (2020–2022)[103] and the 'Operational Policy Manual' (2021).[104]

2.1.4 Utility of national document review

This research study proposes to understand how malaria risk maps are used in sub-Saharan Africa by NMCPs to design and visualize malaria control efforts. It adapts the approach taken by Omumbo *et al.* (2013) in

auditing the use of malaria risk maps in sub-Saharan Africa, giving that study a needed update in the wake of the last decade's increased focus on geospatial techniques within the malaria policy community.[76]

Through examinations of core programmatic documents – NMSs, MPRs, and GF financing applications – the research study aims to evaluate which types of risk maps are relatively over- and under-utilised, and what conclusions can be derived about the types of maps countries use when setting epidemiologically-informed malaria strategies. In so doing, the research study hopes to help identify gaps that the malaria mapping community can address and areas of improvement in document guidelines for the future.

2.2 Methods

This chapter adapts the methodologies developed by Omumbo *et al.* (2013) and categorizes the usage of malaria risk mapping in NMSs, MPRs, and GF financing applications for forty-seven (*n=47*) sub-Saharan African countries.[76]

2.2.1 Scope

Sub-Saharan African countries were included based off the list from the WHO-AFRO and using the 2019 *World Malaria Report* (*WMR*).[37] Some additional malaria-endemic countries (e.g., Djibouti, Somalia, and Sudan) were included from the WHO's Regional Office for the Eastern Mediterranean (WHO-EMRO), while others that were not sub-Saharan African countries (e.g., Algeria, Egypt, Libya, Morocco, and Tunisia) were not.[37] Lesotho, Mauritius, and Seychelles were also not included because they had been certified as 'malaria-free' by the WHO.[105] Zanzibar is distinguished from Tanzania and South Sudan is recognized separately from Sudan, both per the *WMR* 2019.[37] The final result was a list of all sub-Saharan African countries with reported malaria transmission (*n=47*). The selected countries and the availability of their national documents for analysis is listed in **Table 2.1**.

Table 2.1: List of sub-Saharan African countries analysed in the study (n=47) and availability of national malaria documents and applications.

Country	**Malaria control category, *WMR* 2019**[37]	**National malaria strategy (NMS)**	**Malaria programme performance review (MPR)**	**Global Fund (GF) financing application**
Angola	Control	✓		✓
Benin	Control	✓		✓
Botswana	Elimination	✓	✓	✓
Burkina Faso	Control	✓		✓
Burundi	Control	✓	✓	✓
Cameroon	Control	✓		✓
Cabo Verde	Control	✓		✓
Central African Republic	Control	✓		✓
Chad	Control	✓		✓
Comoros	Elimination	✓		✓
Côte d'Ivoire	Control	✓		✓
Dem. Republic of Congo	Control	✓		✓
Djibouti	Control	✓	✓	✓
Equatorial Guinea	Control			✓
Eritrea	Control	✓		✓
Eswatini	Elimination	✓		✓
Ethiopia	Control	✓	✓	✓
Gabon	Control			✓
Gambia	Control	✓		✓
Ghana	Control	✓		✓
Guinea	Control	✓		✓
Guinea Bissau	Control	✓		✓
Kenya	Control	✓	✓	✓
Liberia	Control	✓		✓
Madagascar	Control	✓	✓	✓
Malawi	Control	✓	✓	✓
Mali	Control	✓		✓
Mauritania	Control	✓		✓
Mozambique	Control	✓	✓	✓

Namibia	Control	✓	✓	✓
Niger	Control	✓		✓
Nigeria	Control	✓		✓
Republic of Congo	Control			✓
Rwanda	Control		✓	✓
São Tomé and Príncipe	Control			✓
Senegal	Control	✓		✓
Sierra Leone	Control	✓		✓
Somalia	Control	✓		✓
South Africa	Elimination	✓	✓	
South Sudan	Control	✓		✓
Sudan	Control	✓		✓
Tanzania	Control	✓	✓	✓
Togo	Control	✓		✓
Uganda	Control	✓		✓
Zambia	Control	✓	✓	✓
Zanzibar	Control	✓		✓
Zimbabwe	Control	✓		✓

2.2.2 Types of malaria risk maps

The methodology for this analysis was modified from Omumbo *et al.*, which classified malaria risk maps into twelve (*n=12*) categories, based on variations in the sophistication of outputs, ranging from no map provision or low-quality, qualitative epidemiological categories to more advanced maps of climatic suitability or infection prevalence models generated by Bayesian model-based geostatistical (MBG) techniques.[*,76] These categories are fully summarized in **Table 2.2**.

While both original and valuable, the Omumbo *et al.* methodologies are also complex and somewhat arbitrary – aggregating certain functional subsets of malaria risk maps while distinguishing between others based on the research collaborations that produced them (e.g., prevalence maps are broken down into three non-mutually exclusive categories based on whether they were produced by the Malaria Atlas Project (MAP), the Mapping Malaria Risk in Africa / <<Atlas du Risque de la Malaria en Afrique>> (MARA/ARMA) collaboration, or generally 'using MBG methods').[76]

This present study proposes categorizations that group mapped outputs based on their mapped metrics and special scales more than their underlying methodologies, so as to reflect practical utility for health policymakers. It also includes several malaria risk map categories identified

[*] The malaria risk maps types identified included: no map provided in the report (*code 0*); qualitative definitions of epidemiological conditions (*code 1*); maps of eco-climatic determinants of malaria transmission such as temperature, altitude, or rainfall (*code 2*); maps of case numbers (*code 3*); maps of case incidence rates (*code 4*); maps of parasite prevalence (*code 5*); maps of climatic suitability (*code 6*); models of climatic suitability developed by MARA/ARMA (*code 7*); models of seasonality developed by MARA/ARMA (*code 8*); models of parasite prevalence developed by MARA/ARMA (*code 9*); models of parasite prevalence developed by MBG techniques generally (*code 10*); and models of parasite prevalence developed by MAP (*code 11*).

in the NMSs, MPRs, and GF financing applications that were not included in the Omumbo *et al.* study. Changes to the categorization methodologies included: *code 6*, *code 7*, and *code 8* were merged into 'modelled climatic maps' (*code 006*); *code 9*, *code 10*, and *code 11* were merged into 'modelled prevalence maps' (*code 007*); 'intervention coverage maps' (*code 008*) was added; 'insecticide resistance maps' (*code 009*) was added; and 'accessibility maps' (*code 010*) was added. The final list of malaria risk map categories (*n=11*) is summarized in **Table 2.3**.

Omumbo *et al.* also consulted national monitoring and evaluation (M&E) plans, where available (*n=11*).[76] These were not included in this study, given the low number of such reports available and their contemporariness.

Table 2.2: Malaria risk map types and associated coding used in Omumbo et al. *(2013) study (n=12).*[76]

Code	Description of malaria risk map type
0	No map provided in the report.
1	Qualitative definitions of epidemiological conditions used to describe areas as: malaria free; endemic, non-endemic; stable, unstable; low-moderate-high endemic or hypo-; meso-, hyper-, and holo-endemic. These maps are often based on expert opinion and may combine some empirical data in defining of levels of endemicity classes.
2	Maps based solely on eco-climatic determinants of malaria transmission such as temperature, altitude, or rainfall. Such maps may describe, for example, the duration of the transmission season or define altitudinal limits above which transmission may occur or altitudinal ranges within which epidemic outbreaks are frequent.
3	Maps of reported number of cases within administrative units (e.g., Region or District) based on observed routine health information systems data.
4	Maps of malaria case-incidence rates (usually per 1000 population per year) according to administrative units and developed using nationally reported cases and population census data as a denominator.
5	Maps of reported parasite prevalence according to administrative units usually derived from periodic cross-sectional national household sample surveys.
6	Models of the suitability of climatic conditions (rainfall, temperature, and humidity) to support transmission. The theoretical maps, developed by the MARA/ARMA collaboration, are based on 60-year climatology (estimates of standard means for the period 1920 to 1980) and threshold values for the climate variables. The first of these is presented as a continuous surface that defines the suitability of transmission ranging from 0 (unsuitable) to 1 (suitable).
7	MARA/ARMA climate suitability map categorized as endemic; marginal/epidemic; malaria-free
8	MARA/ARMA seasonality model showing the duration of the transmission season (classified as <3 months, 3-6 months, or >6 months), start month, and end month of malaria transmission season.
9	MARA/ARMA parasite prevalence model developed for West Africa. *Pf*PR data are used as training data in the development of this model.

10	Country-specific tailored models of parasite prevalence based on national prevalence survey data and developed using Bayesian model-based geo-statistical (MBG) methods.
11	Interpolated models of parasite prevalence presented as continuous surfaces or according to classes of unstable vs. stable endemic risk. These are developed on a global scale by the Malaria Atlas Project (MAP) and country-specific maps are available in the public domain.

Table 2.3: Malaria risk map types and associated coding used in present research study (n=11).

Code	Description of malaria risk map type	Mapping method and/or data source descriptions
000	No map provided in the report	No map provided in the report.
001	Descriptive epidemiological categorizations	Based on stakeholder-determined stratification; mapped onto given administrative unit.
002	Descriptive climatic maps	Based on climatic suitability data and/or seasonality transmission data; mapped onto given administrative unit.
003	Reported malaria case count maps	Based on national reported case data and/or routine surveillance data; mapped onto given administrative unit.
004	Reported malaria incidence maps	Based on national reported case data and population census; mapped onto given administrative unit; includes 'vulnerability maps' which combine incidence with additional factors to produce stratification categories.
005	Reported malaria prevalence maps	Based on national household survey data and/or parasitic prevalence survey data; aggregated and mapped onto given administrative unit.
006	Modelled climatic maps	Based on climatic suitability data and/or seasonality transmission data; developed using model-based geostatistical (MBG) methods.
007	Modelled malaria prevalence maps	Based on national household survey data and/or national prevalence survey data; developed using model-based geostatistical (MBG) methods.
008	Intervention coverage maps	Based on national household survey data and/or country-level data; depicts LLIN, IRS, IPTp, and other control intervention coverage; mapped onto given administrative unit.
009	Insecticide resistance maps	Based on country insecticide susceptibility data and/or insecticide resistance mechanism data; mapped onto given administrative unit.
010	Accessibility maps	Based on mean travel time data, mean distance data and/or logistical metrics data, with or without additional covariates; mapped onto given administrative unit.

2.2.3 Data collection

NMSs and MPRs were found using any combination of: web searches; the NMCP or MoH websites for the selected country; the RBM documents resource;[106] the MEASURE Evaluation documents resource;[107] WHO-AFRO documents resource;[108] the President's Malaria Initiative (PMI) documents resource;[109] and personal communications. The web-search strategy included keyword search for the country name, type of document, year, and/or control programme nomenclature.

GF financing applications were found using the Global Fund website's 'Data Explorer'.[110] The 'Funding Request Form' in the attached application package was reviewed for the most recent funding year that a selected country had applied to.

Searches were conducted in 2020 and updated again in 2021. The most recent documents (publication date 2005–2021 inclusive) were added to the database for each country.

2.2.4 Data analysis

Each NMS (*n=42*; 89%), MPR (*n=13*; 28%), and GF financing application (*n=46*; 98%) was analysed for its inclusion of malaria risk maps. Occurrences were counted and coded using the classification in **Table 2.3** to capture which types of risk maps appeared in each of the national documents. When multiple NMSs, MPRs, or GF financing applications were available for a single country, the most recent was selected for the analysis.

Documents were scanned visually and textually for evidence of malaria risk map publication. Unlike the Omumbo *et al*. methodology, this

research study allowed recording of multiple risk map types in a single NMS or MPR. For instance, the latest Kenya MPR (2018) displays: a map of malaria epidemiology by zone (*code 001*); a map of malaria incidence based on DHIS 2/Integrated Disease Surveillance and Response data (*code 004*); modelled *Pf*PR maps produced by MAP (*code 007*); and maps of sub-national distribution of insecticide resistance (*code 009*).[111,112]

In cases where risk mapping was explicitly alluded to having been done but not visually displayed, coding was still done on the assumption that such maps had been produced.

Any downstream analysis from the above (e.g., frequency assessments) was conducted using Excel 15.0 (Microsoft).

2.3 Results

The results of this research study are summarized at the country level in **Table 2.4** and aggregated by code in **Table 2.5**.

2.3.1 National malaria strategies

A total of 42 NMSs (representing 89% of the 47 countries) were analyzed. Of the available NMSs, approximately half (*n=23*; 49%) were operational within ±3 years of 2021 (i.e., concluding within 2018–2025).

The majority of the NMSs analysed had been updated since and different from those analysed in the Omumbo *et al*. study (*n=33*; 70% of the 47 countries analyzed by Omumbo *et al.*).[76]

The most common uses of malaria risk maps in the NMSs were ones which did not involve modelling methods: descriptive epidemiological categorizations (*code 001*; *n=15*; 23%[*]); and descriptive climatic maps (*code 002*; *n=10*; 15%[*]). The next most common uses of malaria risk maps in the NMSs were more directly related to depictions of disease burden: reported malaria incidence maps (*code 004*; *n=9*; 14%[*]) and reported malaria prevalence maps (*code 005*; *n=9*; 14%[*]). One modelled climatic map (*code 006*; 2%[*]) was used in an NMS (Senegal (2016–2020)), and no accessibility maps (*code 010*; 0%[*]) were present in any NMSs reviewed. Five NMSs (8%[*]) had no maps provided in the document (*code 000*).

[*] Of the 66 malaria risk maps found in NMSs.

Table 2.4: Summary of malaria risk map types in sub-Saharan African national malaria strategies (NMSs), malaria programme performance reviews (MPRs), and Global Fund (GF) financing applications.

Country	**National malaria strategies (NMSs)** Code (Strategic period)	**Malaria programme performance reviews (MPRs)** Code (Publication year)	**Global Fund (GF) financing applications** Code (Funding year)
Angola	**001** (2016–2020)	-	**001, 005** (2017)
Benin	**001** (2017–2021)	-	**003, 004, 009** (2021)
Botswana	**001** (2010–2015)	**003** (2009)	**001** (2018)
Burkina Faso	**001, 005** (2016–2020)	-	**007, 008** (2020)
Burundi	**001** (2008–2012)	**000** (2011)	**001, 004 (**2020)
Cameroon	**002** (2014–2018)	-	**004, 005** (2020)
Cabo Verde	**000** (2014–2017)	-	**001** (2014)
Central African Republic	**002** (2012–2016)	-	**004** (2020)
Chad	**002, 007** (2014–2018)	-	**001, 004, 005, 007** (2021)
Comoros	**000** (2012–2016)	-	**004** (2018)
Côte d'Ivoire	**002, 004** (2012–2015)	-	**004** (2017)
Dem. Republic of Congo	**001** (2013–2015)	-	**002, 004, 008, 010** (2020)
Djibouti	**007** (2013–2017)	**001** (2011)	**005** (2017)
Equatorial Guinea	-	-	**000** (2005)
Eritrea	**004** (2017–2020)	-	**004, 008** (2020)
Eswatini	**003** (2015–2020)	-	**000** (2020)
Ethiopia	**001** (2017–2020)	**002** (2011)	**001** (2021)

Gabon	-	-	**000** (2005)
Gambia	**004** (2014–2020)	-	**004** (2020)
Ghana	**002, 005** (2014–2018)	-	**001, 002, 004, 005, 008** (2020)
Guinea	**001** (2013–2017)	-	**004, 005** (2020)
Guinea Bissau	**000** (2013–2017)	-	**004** (2020)
Kenya	**007** (2009–2018)	**001, 004, 007, 009** (2018)	**001, 002, 007, 009** (2020)
Liberia	**005** (2010–2015)	-	**004, 005, 009** (2021)
Madagascar	**001, 004, 007** (2018–2022)	**002** (2011)	**004** (2020)
Malawi	**004, 007** (2011–2015)	**004, 007** (2010)	**004** (2020)
Mali	**001** (2013–2017)	-	**002, 004, 005, 008, 010** (2020)
Mauritania	**002, 003** (2014–2020)	-	**001** (2018)
Mozambique	**001, 004, 005, 009** (2017–2022)	**004** (2010)	**004, 008, 009** (2020)
Namibia	**004, 005** (2010–2016)	**007** (2011)	**004** (2017)
Niger	**009** (2017–2021)	-	**001, 003, 008, 009** (2020)
Nigeria	**007, 008** (2014–2020)	-	**005** (2017)
Republic of Congo	-	-	**004** (2020)
Rwanda	-	**005** (2011)	**004, 008, 009** (2020)
São Tomé and Príncipe	-	-	**003** (2007)
Senegal	**002, 004, 005, 006, 008** (2016–2020)	-	**002, 004, 005, 009** (2020)
Sierra Leone	**005, 007, 008** (2016–2020)	-	**000** (2017)
Somalia	**005** (2011–2015)	-	**001, 005** (2020)
South Africa	**001** (2012–2018)	**004** (2009)	-*

South Sudan	**002** (2006–2011)	-	**005** (2017)
Sudan	**000** (2014–2016)	-	**000** (2010)
Tanzania	**001, 002, 005, 008** (2014–2020)	**005** (2010)	**000** (2020)
Togo	**000** (2011–2015)	-	**001** (2020)
Uganda	**001, 007** (2014–2020)	-	**004, 008** (2020)
Zambia	**004** (2017–2021)	**001, 007** (2010)	**004** (2020)
Zanzibar	**003** (2014–2018)	-	**000** (2020)
Zimbabwe	**001, 002** (2008–2013)	-	**002, 004** (2020)

*Note: * = Not eligible for Global Fund financing.*

Table 2.5: Frequency of malaria risk map types appearing in sub-Saharan African national malaria documents and financing applications.

Code	Description of malaria risk map type	Frequency of appearance in national malaria strategies (NMSs)	Frequency of appearance in malaria programme performance reviews (MPRs)	Frequency of appearance in Global Fund (GF) financing applications
000	No map provided in the report	5 (8%)	1 (6%)	7 (8%)
001	Descriptive epidemiological categorizations	15 (23%)	3 (17%)	12 (14%)
002	Descriptive climatic maps	10 (15%)	2 (11%)	6 (7%)
003	Reported malaria case count maps	3 (5%)	1 (6%)	3 (4%)
004	Reported malaria incidence maps	9 (14%)	4 (22%)	25 (29%)
005	Reported malaria prevalence maps	9 (14%)	2 (11%)	12 (14%)
006	Modelled climatic maps	1 (2%)	0 (0%)	0 (0%)
007	Modelled malaria prevalence maps	8 (12%)	4 (22%)	3 (4%)
008	Intervention coverage maps	4 (6%)	0 (0%)	9 (11%)
009	Insecticide resistance maps	2 (3%)	1 (6%)	7 (8%)
010	Accessibility maps	0 (0%)	0 (0%)	2 (2%)
	Total appearances	**66 in 42 NMSs**	**18 in 13 MPRs**	**86 in 46 GF applications**

Note: Percentage in parentheses after the numerical value was calculated by dividing the number of appearances of a particular risk map by the total number of risk map appearances identified for the document type (not the number of actual maps, per se).

2.3.2 National malaria programme performance reviews

A total of 13 MPRs (representing 28% of the 47 countries) were analyzed. The most common uses of malaria risk maps in the MPRs were: modelled prevalence maps (*code 007*; *n=4*; 22%[**]); reported malaria incidence maps (*code 004*; *n=4*; 22%[**]); and descriptive epidemiological categorizations (*code 001*; *n=3*; 17%[**]).

One insecticide resistance map (*code 009*; 6%[**]) was present in an MPR (Kenya (2018)), and no modelled climatic maps (*code 006*; 0%[**]) were present in any MPRs reviewed. One MPR (6%[**]) had no maps provided in the document (*code 000*).

The use of malaria risk mapping in the MPRs did not vary substantially from when the Omumbo *et al.* research was conducted, and only three MPRs were available from the search methodology that were not in the 2013 review (Kenya (2018), Malawi (2010), and South Africa (2009)) – potentially because they were not available online at the time.

2.3.3 Global Fund financing applications

A total of 46 GF financing applications (representing 98% of the 47 countries) were analyzed, and all GF financing applications were updated since the Omumbo *et al.* review. The use of risk maps was higher in GF financing applications (86 incidences in 46 documents found; ratio of 1.87 per document) than in NMSs (66 incidences in 42 documents found; ratio of 1.57 per document) or MPRs (18 incidences in 13 documents found; ratio of 1.39 per document).

[**] Of the 18 malaria risk maps found in MPRs.

The most common uses of malaria risk maps in the GF financing applications were: reported malaria incidence maps (*code 004*; *n=25*; 29%[***]); reported malaria prevalence maps (*code 005*; *n=12*; 14%[***]); and descriptive epidemiological categorizations (*code 001*; *n=12*; 14%[***]).

No modelled climatic maps (*code 006*) were included in any of the GF financing applications reviewed. A minority of countries (*n=7*; 15% of the 47 countries) were coded as not having any malaria risk maps in their GF financing applications (*code 000*), though this is perhaps explainable in part by near-elimination status countries (e.g., Tanzania) not feeling obligated to submit their risk maps to the Global Fund.[37]

The most maps used in a GF financing application (*n=5*) was by Ghana (2020), which included maps of incidence (*code 004*) and prevalence (*code 005*) to create a composite stratified malaria burden then 'overlaid with information on access to health care, insecticide resistance, seasonality of malaria transmission [(also mapped; *code 002*)], and existing impactful interventions [(also mapped; *code 008*)]'.[59] This map is depicted in **Figure 1.5**.

[***] Of the 86 malaria risk maps found in GF financing applications.

2.4 Discussion

2.4.1 Increases in the use of malaria risk maps

More than 100 national malaria documents and applications were reviewed in this study. The publication of malaria risk maps increased across all three document types in the last decade.[76]

This is most clearly observed within the sub-category of GF financing applications – it is clear from the comparison of the more contemporary GF financing applications with those in Omumbo *et al.* that the publication of risk maps has increased in the decade since this national document audit was last conducted. While this does not necessarily imply programmatic use, it does suggest that access to tools and/or data necessary for producing these modelled products has increased. Given that in many cases the maps were not produced by the NMCPs themselves, but rather by international research or technical organisations, this should not be taken as an indication *per se* that sub-Saharan African countries are moving closer towards achieving the sub-goals related to capacities for surveillance, monitoring, and evaluation identified in pillar 3 of the WHO's GTS (2016–2030).[13]

Potential reasons for the increased development and publication of malaria risk maps of sub-Saharan African countries include: more robust surveillance systems; more effective data management systems;[42]
more successful national and sub-national advocacy for the value of malaria stratification; and greater emphasis on visualization or modelling in the expectations for receiving donor financing.[74]

It is worth noting that while modelled surfaces or maps using MBG techniques in particular have seen increased use since the last audit was published in 2013, reported incidence maps remain the most popular way to understand and visualize malaria risk, a phenomenon that is likely to persist as long as there remains pressure on countries to measure their success based on the political language of 'zero case and zero death' objectives.[113,114]

2.4.2 Donor priorities and national priorities

Several countries showed less stratification or granularity in their NMSs compared to their GF financing applications (e.g., Benin showed only descriptive epidemiological categorizations (*code 001*) in its NMS (2017–2021),[115] but displayed case count maps (*code 003*), incidence maps (*code 004*), and insecticide resistance maps (*code 005*) in its GF financing application (2021)).[116] This recurrent gap can be explained in some cases by the dates of documents assessed, or in others, by a difference in how countries tend to approach communication of malaria control and elimination objectives from a programmatic perspective compared to an advocacy perspective, particularly in light of the GF's view risk map inclusion in financing applications.

With regards to the latter, this has been explored in the literature and primarily revolves around the perceptions – not uniformly observed – that modelled surfaces towards malaria elimination are an international donor priority that must be accommodated, rather than endogenously-perceived programmatic benefit for NMCPs.[117] Deeper follow-up through stakeholder in-depth interviews could provide clarity as to why choices were made to

selectively display certain risk maps in certain national guidance documents or financing applications.

2.4.3 Additional risk map use cases

It was clear from the results that the three types of malaria risk maps added to the methodology for this research study – 'intervention coverage maps' (*code 008*); 'insecticide resistance maps' (*code 009*); and 'accessibility maps' (*code 010*) – had seen growth in their use since the last audit was published in 2013. While many of the documents consulted made it clear that these types of malaria risk maps are considered supplementary or additive to the operational goal of monitoring malaria incidence and/or malaria prevalence, their increased use is noteworthy and bears deeper examination.

Examples of the use of 'intervention coverage maps' (*code 008*) included: a map of IPTp3+ (i.e., three or more doses of IPTp) coverage and insecticide-treated net (ITN) coverage in Mali's GF financing application (2020);[118] a map of IRS coverage and coverage of preventative behaviours (usage of bed net and treatment seeking) in Sierra Leone's NMS (2016–2020);[119] and a map of integrated community case management (iCCM) coverage in Uganda's GF financing application (2020).[120]

Examples of the use of 'insecticide resistance maps' (*code 009*) included: maps of confirmed resistance for *An. gambiae* (2012–2019) and *An. funestus* (2012–2019) to deltamethrin, lamba-cyhalothrin, bendiocarb, DDT, and pirimiphos-methyl in Mozambique's GF financing application (2020), based on data from vectors collected at Mozambique's sentinel sites;[121] and a map of *An. gambiae* resistance to pyrethroids in Senegal's GF financing

application (2020) that helped to guide the NMCP in distributing piperonyl butoxide (PBO) long-lasting insecticidal nets (LLINs) funded by PMI to three priority regions (Tambacounda, Kolda, and Kédougou).[122]

Examples of the use of 'accessibility maps' (*code 010*) included: a map showing geographic accessibility by motorbike in less than an hour and by foot in less than an hour (produced by the Université de Genève) in Mali's GF financing application (2020);[118] and a map showing population-weighted average travel time and the proportion of children aged under 5 years seeking treatment for fever by walking to a public sector health care facility in the Democratic Republic of the Congo's GF financing application (2020).[123]

Finally, 'vulnerability' and/or 'susceptibility' were also mapped with increasing frequency (with at least three occurrences tracked). For example, Mali's GF financing application (2020) displayed a malaria map showing the spatial distribution of the country's community health workers as well as stratifying districts by 'vulnerability' (a composite of prevalence and climatic factors) in order to identify the highest priorities for strengthening community-based care.[118]

2.4.4 Limitations

There is some limitation in the timeliness of the NMS data in the research study. By referencing a 2019 review of the literature it is clear that a few (*n=6*; 13%) NMSs are known to exist in more updated form than what was collected in the present study, though they were not available using any of the search methods described in **Chapter 2.2.3** (e.g., the present study had

to analyze Mali's 2013–2017 NMS instead of Mali's 2016–2018 NMS, which is known to exist).[95]

Another limitation pertains to the inherent value of these national documents and financing applications as indicators of the use of malaria maps by NMCPs. The aforementioned 2019 review of NMSs (2000–2021) compared the stated NMS objectives to progress based on metrics across the durations of the NMS terms, finding that only 4 of the 135 verified targets identified by the NMSs were ultimately achieved.[95] The authors of that review argue that this indicates that NMSs and other national coordinating documents are ultimately projects tailored to international stakeholder and donor needs or demands, and do not represent realistic national objectives.[95]

A third limitation is related to this and focuses on the implications of display. While this study seeks to infer the use of malaria risk maps by sub-Saharan African countries, use is a complex term. At minimum, this research study audits the inclusion of malaria risk maps in a variety of national documents and implies their use in (1) advocacy and (2) planification. Researchers should be cautioned against inferring the use of malaria risk maps in (3) policy development or (4) monitoring and evaluation, simply on the basis of their inclusion in NMSs.

To more fully understand how and why malaria risk maps are used by national and sub-national authorities requires, at minimum, interviews with malaria stakeholders in each country. **Chapter 3** and **Chapter 4** attempt to shed light on this question for Madagascar.

Chapter 3

Stakeholder views on malaria risk maps in Madagascar

Research question

The perspectives of decision-makers and stakeholders are important in evaluating and understanding malaria control strategies in sub-Saharan Africa,[124,125] particularly given the historical prioritization of technical and evidentiary evaluations.[126] This chapter conducts semi-structured in-depth interviews with identified stakeholders engaged in Madagascar's malaria control efforts in order to evaluate the diversity of malaria maps that have been developed by and for Madagascar malaria control, as well as current-state use cases, perceived utility, perceived limitations, and future-state use cases of malaria risk mapping in the country.

3.1 Introduction

3.1.1 Madagascar malaria endemicity and transmission

Malaria is endemic to the island country of Madagascar, primarily as *Plasmodium falciparum* (*Pf*) infection.[127,128] Madagascar is in the 'malaria control' phase, per the World Health Organization (WHO) status definitions.[16,58] Madagascar's malaria control efforts are led by its Ministry of Health (MoH) (<<Ministère de la santé publique (MSNP)>>) through its National Malaria Control Programme (NMCP) (<<Direction de lutte contre le paludism (DLP)>>) (hereafter, 'DLP', unless referenced in the generic sense). Efforts are focused on vector control (e.g., insecticide-treated nets (ITNs) (<<Moustiquaire imprégnée d'insecticide (MID)>>), indoor residual spraying (IRS) (<<campagne d'aspersion intradomiciliare (CAID)>>), entomological monitoring, etc.), diagnosis and drug-based treatment and prevention (e.g., seasonal malaria chemoprophylaxis (SMC), intermittent preventative treatment for pregnant women (IPTp), case management, etc.), and others.[129,130]

While malaria incidence had been decreasing in Madagascar over the last decade due to more widespread intervention scale-up,[131] Madagascar has experienced several years of increases in reported malaria cases and deaths,[132] and Kang *et al.* (2018) have estimated that the proportion of Malagasy individuals residing in high transmission zones has increased significantly since 2011.[52] This is explainable by several potential factors including challenges in implementing prevention and control activities or

increased detection, in part due to improved community-based surveillance.[129]

Madagascar presents an important case study for the exploration of malaria risk-mapping for several reasons. It is a geographically-large, spatially-diverse, and low-income country,[133] with low malaria importation and heterogenous malaria endemicity (ranging from low to meso-endemic).[134,135] Malaria transmission in Madagascar is also highly complex, with the Island having several ecozones with differing transmission intensities; its East and West coastal regions have higher year-round transmission (the former perennial; the latter seasonal[135]), while its central Highlands and desert South experience less frequent outbreak events.[136] The operational feasibility of malaria elimination in Madagascar has been estimated at 'high' relative to others in the African region, while the mean technical feasibility of malaria elimination in Madagascar has been estimated at 'medium' relative to others in the African region, positing a technical or capability gap to which risk mapping can contribute.[14] Greater sophistication in intervention targeting has also been proposed as a means of improving cost-effectiveness of Madagascar's control programmes.[137]

Some researchers have attempted to model spatio-temporal trends in the prevalence of malaria infection in Madagascar using prevalence of infection using data from Malaria Indicator Surveys (MIS) and other sources.[52] While these forms of model-based geostatistics (MBG) risk mapping[138] have seen low to medium-low operational uptake in Madagascar thus far,[130] they have been described by Cohen *et al.* (2017) as one of multiple

components that are valuable to provide NMCPs with a holistic understanding of malaria risk in their country.[11]

3.1.2 Madagascar malaria control efforts

Across much of sub-Saharan Africa, the NMCPs work as a division within the MoH to coordinate malaria control efforts – and this is the case for Madagascar's DLP.[139] At a high level, Madagascar's malaria control strategies have included: several (usually triennual) mass LLIN distribution campaigns (2009–2018);[140] IPTp in endemic areas; IRS in lower-transmission areas, based on a District-level stratification of Madagascar; increased access to diagnostics and drug treatments; and information, education, and communication (IEC) programmes.[130,135] Various studies have attempted to adjudicate the comparative value of malaria control efforts in Madagascar, measuring the protective effectiveness of LLINs, IRS, IPTp, and IEC.[137,141] While integrated community case management (iCCM) is increasingly considered a best practice,[142] it has only recently been adopted at the national level in Madagascar. Madagascar's ITN coverage is considered low, relative to the rest of the African region, with the fourth-lowest percentage of households with 'enough ITNs for all occupants', per the 2019 *World Malaria Report*.[37]

An evaluation of the operational utility of reported routine case data for malaria control planning in Madagascar by Howes *et al.* (2016) has suggested that sub-national planning is a valuable and necessary component of addressing local control needs in Madagascar's heterogenous setting.[136] This subnational planning is occurring with greater frequency and is

managed across a variety of administrative levels in Madagascar, namely the Region (admin 1), District (admin 2), Commune (admin 3), and Fokontany (admin 4). **Table 3.1** summarizes these administrative levels used in Madagascar's malaria control efforts.

Table 3.1: Madagascar malaria control administrative levels.

Administrative Level	**Number** (as of 2017[130])
Country	1
Regions (<<régions>>)	22
Districts (<<districts sanitaires>>)	113
Communes (<<communes>>)	1,693
Fokontany (i.e., communities) (<<fokontany>>)	18,251

3.1.3 Production of malaria risk maps in Madagascar

The Madagascar DLP works with its government directorate counterparts and several research institutions to develop malaria risk maps for use by its malaria control officers and the responsible leaders at the District level, and using a variety of health, environmental, and ancillary data.[130]

Routine health data used in the production of the risk maps is reported monthly by primary and secondary health facilities acting in conjunction with community health workers (CHWs), aggregated to the health District level, and stored on a Health Management Information System (HMIS) system.[135,143] Madagascar's routine data is managed through its Système National d'Information Sanitaire (SNIS), with additional data collected from the MIS surveys (i.e., MIS 2013,[144] MIS 2016[145]). Primary health care delivery in Madagascar ranges from its district hospitals, over 3,000

basic health centres (<<Centres de Santé de Bases (CSBs)>>), a network of public and private health facilities (HFs), and its CHWs.[146]

Cartographic representations of malaria and related indices in the most recent (2018–2022) Madagascar National Malaria Strategy (NMS) (<<Plan strategique national de lutte contre le paludisme (PSN)>>) include: a District-level *Pf* incidence map using the WHO stratification levels (2013–2016); a District-level 'vulnerability' map that takes into account incidence, poverty, seasonality, and health centre attendance rate; a map of the modelled prevalence of *Plasmodium falciparum* infection across the 2–10 year old age range ($Pf\text{PR}_{2012–2015}$);[85] District-level parasitology maps showing *Plasmodium falciparum* contributing over 90% of the national burden; a map depicting entomologic surveillance sites (both nationally- and privately-managed); and a District-level epidemic alerts map (2013–2016).[130]

The only model-based malaria risk map in the NMS is the 2012–2015 *Pf*PR risk map – developed globally by the Malaria Atlas Project (MAP),[147] published by Bhatt *et al.* (2016),[85] and reproduced as a national cut-out for the Madagascar MoH by Howes *et al.* (2016)[136] – which takes into account digital elevation, total rainfall, temperature suitability index, and land cover.[136] **Table 3.2** highlights additional salient details about this risk map, adopting the summary columns from Ghilardi *et al.* (2020).[74]

Table 3.2: Model-based geostatistics (MBG) malaria risk maps in the Madagascar National Malaria Plan (NMS) 2018–2022.

Type of risk map	Data source	Resolution	Use of map in NMS	Use for prioritization or targeting
Modelled *Pf*PR map (using space-time geostatistical modeling)	Library of static and dynamic covariates (5x5 km pixel-level); clinical incidence data; *Pf*PR surveys data; household survey data of ACT and ITN coverage; programme data of ACT and ITN distribution; programme data on IRS coverage; seasonality data	5x5 km pixels from the original MAP methodology; aggregated to second-level administrative division of Madagascar (Districts)	To show District-level epidemiological variations in prevalence from 2012–2015	In conjunction with incidence maps to identify highly endemic Districts for targeting of control interventions[130]

Note: Unless otherwise cited, all evidence in **Table 3.2** *is adapted from the Malaria Atlas Project*[147] *and Bhatt* et al. *(2015),*[85] *and adapted by Howes* et al. *(2016)*[136] *for Madagascar specifically.*

Based on the literature, Madagascar has also produced malaria maps in a few of other ways that are unpublished in the NMS. For instance, in 2016, multi-criteria evaluation methodology that combined land cover information, temperature, and rainfall data to produce a risk map at the Commune level to help support IRS suitability targeting.[148] One research study used the monthly-reported routine data to produce several maps of malaria transmission, using crude incidence, standardized incidence, spatial cluster, temporal cluster, and space-time cluster analyses.[135]

In addition to its routine data systems, Madagascar also has an Integrated Diseases Surveillance and Response System (IDSRS), an epidemic monitoring system which functions by establishing bases and triggering alerts to the MoH, though in practice it is non-functioning or poorly functioning in most Districts.[136,149] In addition to its records of outbreaks and alerts, Madagascar has established a variety of evidence bases, including measures of accessibility to health centres and stock-outs of essential medicines,[70] with some represented cartographically on an ad-hoc basis.

3.1.4 Value of Madagascar malaria stakeholder perspectives

Despite significant growth in literature explorations of how routine health data and surveillance data are integrated into national and sub-national planning, studies that examine how spatially-defined maps are used in intervention planning are less common.[74]

It is increasingly important therefore to gather stakeholder perspectives on malaria mapping to better understand current-state use cases, perceived utility, perceived limitations, and future-state use cases.

Local knowledge and capacity can limit the usability of risk mapping, while of political contexts and transference can affect knowledge translation.[74] These insights could, therefore, with proper knowledge translation and communication, be used by Madagascar's DLP to improve programmatic delivery and evaluation.

Chapter 1 summarized academic, policy, and programme perspectives on risk-mapping in malaria control and elimination, while **Chapter 2** evaluated the use of malaria risk maps across sub-Saharan Africa. For **Chapter 3**, a mixed-methods examination of stakeholder perspectives of malaria risk mapping in the selected country of Madagascar is proposed.

3.2 Methodology

3.2.1 Introduction and settings

A total of 17 semi-structured in-depth interviews (IDIs) were conducted with malaria policymakers to ascertain views on key research questions surrounding the use of malaria maps in Madagascar.[150] The study was conducted between July and August 2018 in Madagascar. The study sites included the headquarters of the DLP and the offices of the MoH in Antananarivo. Health policy decision-making structures in Madagascar at the time of interviews are summarized in organograms of the DLP (**Appendix B.1**) and MoH (**Appendix B.2**).

Access to this research was facilitated through the Madagascar Roll Back Malaria (RBM) Partnership. The list of potential interviewees was communicated to the MoH and DLP.

3.2.2 Mixed-methods interview design

Prior to study design, the researchers conducted inquiries into the most appropriate mixed-methods interview design practices for qualitative and quantitative malaria policy research. Within the literature on 'mixed-methods' research, design methodologies have been proposed for areas where one data modality (e.g., qualitative or quantitative) is not sufficient on its own.[151–153] Some mixed-methods design methodologies include: 'parallel design', wherein quantitative and qualitative data are collected separately in phases such that one source is able to improve or complement data from the other; 'explanatory sequential design', wherein quantitative data is collected

first and emphasized, with qualitative data helping to explain aberrant or unexpected results; and 'exploratory sequential design', wherein qualitative data is collected before quantitative data to help elucidate more understudied phenomenon.[151] This research study uses an 'embedded design', which collects quantitative and qualitative data simultaneously or sequentially, with one – in this case the post-interview questionnaire data – playing a supporting role to the other – in this case, the IDI data.[151]

Two mixed-methods qualitative research methods were used for constructing this Chapter's study design: (1) semi-structured IDIs with the selected stakeholder interviewees; and (2) a post-interview questionnaire.

3.2.3 Stakeholder landscape

In preparation for fieldwork, the research team conducted a landscaping of key Madagascar stakeholders and reviewed documents and research pertaining to Madagascar. In order to identify relevant stakeholders for interviews, KH adapted methodologies delineated by Schmeer (1999) for the Partnerships for Health Reform[154] and republished in the Global Health Workforce Alliance's 'Stakeholder Analysis Policy Toolkit'.[155] This provided a lens for identifying major players in the research, planning, financing, implementation, impact assessment, and norm-setting necessary in malaria elimination and control – and sets out an approach for identifying their relative power and impact on the policy process.[155] An audit was also conducted of the MoH directorates with mandates relevant to data collection and analysis for public health response.

Selection of stakeholders was done through a combination of sampling techniques, predominantly purposive sampling, but also convenience sampling.[156,157]

To assist with selection of stakeholder interviewees, thematic stakeholder 'classes' were identified, which included: (1) 'international organisations/supranational non-profits'; (2) 'granting agencies/financing authorities'; (3) 'research institutes/technical advisors'; (4) 'national authorities'; (5) 'sub-national actors/community health actors'. The stakeholder classes are summarized in **Table 3.3**.

In addition, categories were identified for stakeholder scope of responsibilities. These categories were adapted from PATH documents[158–160] and the Bill & Melinda Gates Foundation (BMGF) – using the latter's framework of 'building blocks' necessary for mobilizing malaria policy ('policy', 'governance', 'financing', 'planning and operations', 'tool development', and 'evidence base').[160] Changes in this methodology included: (1) 'policy' and 'governance' merged into 'policy and programme management' responsibilities given the relative lack of distinction at the national and sub-national level in Madagascar; (2) 'evidence base' broadened to include 'monitoring and evaluation' responsibilities; and (3) 'tool development' replaced with 'technical assistance', given the make-up of stakeholders being engaged through the RBM and DLP. The stakeholder scope of responsibilities are summarized in **Table 3.3**.

Stakeholders could hold multiple responsibilities. For instance, *Interviewee 002* was a senior DLP official with some responsibilities for vector control programming. Given their role oversaw other colleagues, they were

categorized as having 'policy or programme management' (*category 1*) responsibilities, in addition to their 'vector control' (*category 3*) responsibilities.

Table 3.3: Mapping of classes and scope of responsibilities of malaria stakeholders.

Stakeholder classes	**Stakeholder scope of responsibilities**
International organisations, supranational non-profits	Policy or programme management
Granting agencies, financing authorities	Data, surveillance, or evaluation
Research institutes, technical advisors	Implementation of interventions or vector control
National authorities	Financing
Subnational and community health actors	Research or technical support

Ultimately, at least one stakeholder from the institutions identified in the stakeholder landscaping participated in the research study. The final list of interviewees comprised a broad collection of stakeholders from organisations operating in Madagascar that included (in alphabetical order): the U.S. Centers for Disease Control (CDC); The Demographic and Health Surveys Program (DHS), a subunit of USAID which commits resources towards the development of quantitative approaches for assessing[161] and strengthening[162] global capacity for the elimination and eradication of malaria; the DLP; the Institut Pasteur de Madagascar (IPM), a Malagasy research institution in Antananarivo; MEASURE Evaluation, a U.S.-funded non-profit organisation that aims to provide technical support to improve Health Information Systems; the MoH; USAID; and WHO.

3.2.4 Data collection

Stakeholders received an invitation letter to participate in the research interview process, with a participant information sheet attached (**Appendix B.3**). If they were interested, prior to enrolling in the study, stakeholders signed a consent form (**Appendix B.4**). Ethical approvals were received from Oxford University (*Reference R58102/RE001*) prior to data collection (**Appendix B.5**).

Interviews were conducted over the course of two weeks, in July and August 2018. Stakeholders were provided with a range of dates and times to choose from prior to interviewer arrival to Madagascar. Prior-day confirmations and same-day reconfirmations were done. In some occasions due to scheduling constraints, interviewees requested ad-hoc scheduling

which the interviewers accommodated. All IDIs were conducted by KH in collaboration with their co-investigator RH. All IDIs were conducted on the basis of an interview guide (**Appendix B.6**) (for more information, please refer to **Chapter 3.2.5**). The IDIs were conducted in either French or English, depending on the preferences of the subject and the comfort level of the interviewer.

Prior to the initiation of interview guide questions, stakeholders were read the full consent form provided and signed digitally before the interview, which included a review of research purpose and data protection. Participants were given a copy of the information sheet and consent form to keep. The interviewer explained that the interviews were intended to be recorded and transcribed in a de-identified fashion. Stakeholders were offered the opportunity to reconfirm or withdraw consent to be audio-recorded during the interview process. The majority of the interviewees (*n=13*; 77%) agreed to have their interviews audio-recorded.

All scheduled interviews exceeded 45 minutes in length and took place as planned with the exception of the interview scheduled with the DLP official responsible for IRS, who was ultimately away from the capital for the duration of the researchers' time in Madagascar.

Regardless of audio-recording, detailed field notes were taken. In the case of interviewees who withheld consent to be recorded, field notes were used for the data analysis portion of the study.

After the IDI was concluded, the stakeholder was provided the option of filling out a post-interview questionnaire (**Appendix B.7**). All interviewees (*n=17*; 100%) completed the post-interview questionnaire. The

post-interview questionnaire was designed to allow direct comparison of stakeholder perceptions across several phenomena. Questions focused on three core themes: (1) the perceived utility of malaria risk-mapping in policy-making, research, grantmaking, and intervention-targeting; (2) the perceived limitations of malaria risk-mapping; and (3) the perceived utility of specific types of malaria risk-mapping outputs, including IRS coverage maps, RDT positivity maps, and ITN coverage maps.

3.2.5 Interview guide

A semi-structured interview guide was developed by KH based on observational data, research group expertise, and a review of the literature. All interviews were conducted on the basis of this themed interview guide.

A core priority of the interview guide was to emphasize simplicity, in order to facilitate broad conversation that could be narrowed to the programmatic specifics through follow-up questions. These probes and follow-ups were a necessary complement to the open-ended question construction. The semi-structured interview style meant that some interviews were allowed to divert from strict adherence to the interview guide, but ultimately, all questions were asked of all interviewees

Questions were chosen to represent a broad measure of the status of malaria mapping in the Madagascar context. The interview guide questions focused on six core themes: (1) the participant backgrounds and responsibilities; (2) the current-state applications of malaria maps in national and sub-national control; (3) the perceived functional utility of malaria maps in national and sub-national control; (4) the perceived limitations of malaria

maps in national and sub-national control; (5) the use of malaria maps in intervention targeting and prioritisation; and (6) the future-state utility of malaria maps in national and sub-national control. These themes are summarized in **Table 3.4**. The full interview guide is provided in **Appendix D.6**.

Table 3.4: Interview guide themes and sub-themes for follow-up used in Madagascar malaria stakeholder IDIs.

Main themes and sub-themes
A. Participant background and responsibilities A.1 Duration A.2 Evolution
B. Current-state applications of malaria maps in national and sub-national control B.1 Descriptive B.1.1 Typology B.1.2 Data source B.1.3 Resolution B.2 Function B.2.1 Malaria control interventions B.2.2 Surveillance and alerts B.2.3 Incidence B.2.4 Prevalence B.2.5 Measurement and evaluation B.2.6 Stock-outs and supplies B.2.7 Logistics and planning B.2.8 Training B.2.9 Research B.2.10 Financing B.3 Administrative level B.3.1 Region B.3.2 District B.3.3 Commune B.3.4 Fokontany B.4 Colleague approaches B.5 International approaches
C. Perceived functional utility of malaria maps in national and sub-national control C.1 Environmental and climatic C.2 Parasitic and entomologic C.3 Malaria control interventions C.4 Measurement and evaluation C.5 Maternal, child, and newborn health C.6 Surveillance and alerts C.7 Stock-outs and supplies C.8 Logistics and planning C.8 Training C.9 Research

C.10 Financing
D. Perceived limitations of malaria maps in national and sub-national control D.1 Time and efficiency D.2 Usability and knowledge D.3 Methodological uncertainty D.4 Trust D.5 Accuracy and data quality D.6 Conflicting priorities D.7 Human resources D.8 Tools and technology D.9 Level of detail D.10 Systematic vs. non-systematic D.11 Cultural or sociological factors D.12 Time requirements D.13 International standardization D.14 Political will or buy-in D.15 Clarity about 'uncertainty' metrics D.16 Level of granularity D.17 Link to actionable decisions D.18 Donor or international priorities
E. Use of malaria maps in intervention targeting and prioritisation E.1 Intervention(s) E.1.1 LLINs E.1.2 IPTp E.1.3 IRS E.1.4 ACTs E.1.5 RDTs E.2 Setting(s) E.2.1 Schools E.2.2 Mines E.2.3 Cities E.2.4 Villages E.2.5 District health centres E.2.6 Basic health centres (CSBs) E.3 Scale and decision-making E.4 Strategic variations E.5 Proposals E.6 Campaigns and census
F. Future-state utility of malaria maps in national and sub-national control F.1 Proposed metrics F.1.1 Modelled or geospatial prevalence F.1.2 Epidemic susceptibility and alert prediction

F.1.3 Environmental and climatic
F.1.4 Parasitic and entomologic
F.1.5 Predictive ITN need
F.1.6 Predictive IRS need
F.1.7 Delivery times and logistics
F.1.8 Insecticide coverage
F.1.9 Predictive stock-outs and commodity shortages
F.1.10 Antimalarial resistance
F.2 Linkages to observed limitations

3.2.5.1 Limiting bias

The research team reviewed the interview guide and post-interview questionnaire with two experts on qualitative interview practices, within the Oxford University Nuffield Department of Medicine (NDM). Efforts were taken to eliminate bias from the interview questions. Overviews of social research methods were consulted, including Bryman's *Social Research Methods* (2016)[163] and Gilbert & Stoneman's *Researching Social Life* (2016).[164]

3.2.6 Data analysis

Interviews were transcribed by-hand and/or through the use of Trint (Trint International) automated transcription software. Interviews were translated into English by-hand and/or through the use Trint (Trint International) automated translation software. Textual data were then imported into and analysed using NVivo 1.5 (QSR International), a digital qualitative data analysis software.

Braun & Clarke (2006) describe several phases of thematic analysis, including familiarisation with data, initial code generation, theme research, theme review, definition of themes, and report production.[165] Several data analysis approaches were explored (e.g., content analysis, narrative analysis, grounded theory), and ultimately framework analysis of interviews was conducted – a methodology which emphasizes examining thematic connection both within interviewee transcripts ('cases') and between them.[166]

Transcripts were reviewed and coded in NVivo. Both deductive and inductive approaches were used. The deductive approach used questions and thematic codes developed in advance to match with transcript themes.

The inductive approach observed emergent trends, frequencies, and patterns and developed themes from there.[167] The deductive and inductive themes were collapsed and the thematic structure of the analysis was refined, in order to settle on clear parameters with minimal overlap and explicable definitions. This process included pre-reviewing interview transcripts to ensure themes were broadly functional in each case and would generate insight. This finalized thematic NVivo structure was then re-run on all interviews for completion. The final 'thematic map' is described in fuller detail in **Table 3.5**.

Table 3.5: NVivo thematic coding used in analysing Madagascar malaria stakeholder IDIs.

Main themes and sub-themes
Perceived utility
Value of prioritization - Increase efficacy
Value of prioritization - Limited resources, value for money
Value of prioritization - Efficiency, time
Value of targeting - Increase efficacy
Value of targeting - Limited resources, value for money
Value of targeting - Efficiency, time
Treatment vs. prevention tradeoffs
Visualization
Advocacy
Decision-making
Perceived functions
Case management - ACTs
Case management - RDTs
Prevention - LLINs
Prevention - IPTp
Prevention - IRS
Prevalence
Incidence
Surveillance and alerts
Training
Operational interventions
Stock-outs and supplies
Resource mobilization and advocacy
Intra-national policy communication
Logistics and planning
Environmental and climatic
Parasitic and entomologic
Measurement and evaluation
Joint use cases
Inverted use cases
Other
Predictive use cases
Modelled or geospatial prevalence
Epidemic susceptibility and alert prediction
Environmental and climatic
Parasitic and entomologic
Predictive ITN need
Predictive IRS need
Delivery times and logistics

Insecticide coverage Predictive stock-outs and commodity shortages Antimalarial resistance
Perceived limitations Time and efficiency Usability and knowledge Methodological uncertainty Trust Accuracy and data quality Conflicting priorities Human resources Tools and technology Level of detail Systematic vs. non-systematic Cultural or sociological factors Time requirements International standardization Political will or buy-in Clarity about 'uncertainty' metrics Level of granularity Link to actionable decisions Donor or international priorities
Incentives for use Perception of need Understanding of quality Understanding of relevance Understanding of inputs Understanding of 'uncertainty' Ownership Trust in data Political Accuracy
Scale World Country Region District Commune Fokontany
Class of stakeholder International organisations, supranational non-profits Granting agencies, financing authorities Research institutes, technical advisors

National authorities Subnational and community health actors
Scope of responsibilities Policy or programme management Data, surveillance, or evaluation Implementation of interventions or vector control Financing Research or technical support
Setting Schools Mines Cities Villages District health centres Basic health centres (CSBs) Other
Concepts Campaigns and census Elections Security Colonialism HIV/AIDS TB Sexism, racism, classism
Stakeholders PMI/USAID/CDC WHO BMGF GF Gavi DHS TPI MEASURE Evaluation MoH DLP CHWs FBOs Hospitals and health centres Other

3.2.7 Data protection

No patients or individuals in clinical care settings were interviewed. Total confidentiality of stakeholder responses was ensured among researchers besides KH and RH, using an interviewee code system.[74] All interviewees were provided an appropriate consent form outlining digital storage practices. In analysing and presenting results, individual responses are highlighted for insights with the affiliation of the stakeholder (e.g., DLP stakeholder, international stakeholder, etc.), but no names or other personal identifying information is made available.[159] Data was stored locally, password-encrypted, and backed-up. Once the interviews had been analyzed, recordings were erased.

3.2.8 Additional national planning meetings

The research study's methodology also included attendance at two RBM meetings and one MoH meeting. RBM meetings in Madagascar typically occur on a biweekly schedule, though can also be scheduled on an ad-hoc basis. The researchers KH and RH were permitted to attend two RBM meetings in Madagascar, on 24 July 2018 and 31 July 2018. With attendees' consent, KH took observational notes at the meetings. With attendees' consent, an audio recording of the 24 July 2018 meeting was made. Discussions of malaria mapping were assessed for descriptive, qualitative insights and post-meeting minutes circulated to all attendees were reviewed to corroborate findings. Finally, both meetings (the transcript of the first; the notes of the second) were analyzed for insights using the NVivo-coded themes in **Chapter 3.2.6**.

In addition to the two meetings mentioned above, KH and RH also had the opportunity attend one of the MoH cartography meetings, held on 27 July 2018. The purpose of the meeting was to provide an update on DLP mapping efforts to senior MoH officials. With attendees' consent, KH took observational notes at the meeting. The meeting was analyzed for insights, using the NVivo-coded themes in **Chapter 3.2.6**.

Outside the scope of this chapter is the DHS workshop held from 26 July 2018 to 30 July 2018. Of the stakeholder interviewees, more than a third (*n=6*; 36%) were also participants in the workshop, though the workshop occurred after the IDIs had been conducted and so did not affect the results. Specific workshop-related analyses are covered in **Chapter 4**.

3.2.9 Synthesis and presentation of results

The mixed-methods portion of the results depicted in **Chapter 3.3** adopts an approach similar to other semi-structured malaria policy interview studies in the literature: Ghilardi *et al*. (2020), who conducted a study of decision-maker perceptions of malaria maps in Kenya, Malawi, and the Democratic Republic of the Congo, as part of the London School of Hygiene and Tropical Medicine's 'Data for malaria decision-making' project[74]; and PATH's Malaria Control and Elimination Partnership in Africa (MACEPA), which conducted landmark *Accelerating Towards Malaria Elimination* stakeholder intereviews[159,168] aimed at identifying operational and technical challenges and opportunities to scaling and developing national malaria policies. As such, the interviewee observations are summarized in an aggregated analytical form or using pull quotes.

3.3 Results

In total, 17 IDIs were conducted with malaria stakeholders in Madagascar. The interviewed stakeholders are anonymized and classified in **Table 3.6**. The strategic and operational applications of malaria risk maps in Madagascar were assessed through current-state use cases (*interview guide question 2*) and intervention targeting use cases (*interview guide question 5*). Drivers of the adoption and use of malaria risk maps were assessed through perceptions of malaria risk map utility (*interview guide question 3*) and perceptions of malaria risk map limitations (*interview guide question 4*). Finally, future-state use cases for malaria risk maps in Madagascar were assessed (*interview guide question 6*).

Table 3.6: Madagascar malaria stakeholder interviewees (n=17).

Code	Class of stakeholder	Scope of responsibilities	Gender	Nationality	Educational status	Post-interview questionnaire	Audio recording
001	National authorities	Data, surveillance, or evaluation	F	Malagasy	Postgraduate	Y	Y
002	National authorities	Policy or programme management; Implementation of interventions or vector control	F	Malagasy	Postgraduate	Y	Y
003	National authorities	Implementation of interventions or vector control	M	Malagasy	Postgraduate	Y	Y
004	National authorities	Data, surveillance, or evaluation	F	Malagasy	Postgraduate	Y	Y
005	Research institutes, technical advisors	Research or technical support	M	Non-Malagasy	Postgraduate	Y	Y
006	National authorities	Policy or programme management; Financing	M	Malagasy	Undergraduate	Y	Y
007	National authorities	Policy or programme management; Implementation of interventions or vector control	F	Malagasy	Postgraduate	Y	Y

008	Granting agencies, financing authorities	Financing; Research or technical support	M	Malagasy	Postgraduate	Y	N
009	International organisations, supranational non-profits	Policy or programme management	F	Malagasy	Postgraduate	Y	N
010	National authorities	Policy or programme management; Implementation of interventions or vector control; Research or technical support	F	Malagasy	Postgraduate	Y	Y
011	National authorities	Policy or programme management; Implementation of interventions or vector control; Research or technical support	M	Malagasy	Postgraduate	Y	Y
012	Research institutes, technical advisors	Research or technical support	F	Malagasy	Postgraduate	Y	Y
013	International organisations, supranational non-profits	Policy or programme management; Research or technical support	F	Non-Malagasy	Undergraduate	Y	Y
014	National authorities	Policy or programme management	M	Malagasy	Postgraduate	Y	Y

015	Granting agencies, financing authorities	Financing; Research or technical support	M	Non-Malagasy	Postgraduate	Y	N
016	National authorities	Policy or programme management; Data, surveillance, or evaluation	F	Malagasy	Postgraduate	Y	Y
017	International organisations, supranational non-profits	Research or technical support	F	Non-Malagasy	Undergraduate	Y	N

3.3.1 Interviewee demographics

Stakeholder interviewee demographics were assessed on the basis of educational status, nationality, and gender. The majority (*n=14*; 82%) of interviewed stakeholders were medical doctors or in possession of post-graduate degrees. The majority (*n=10*; 59%) of interviewed stakeholders were women. The majority (*n=13*; 76%) of interviewed stakeholders were nationally Malagasy. (The 'Malagasy' designation in this case references all stakeholder interviewees who belong to the Malagasy ethno-linguistic group or who are part of the communities of Indians, Arabs, and Somalis of Madagascar.) These demographic results are summarized in **Table 3.7**.

Table 3.7: Demographics of Madagascar malaria stakeholder interviewees (n=17).

Category	**n**	%
Educational status		
Graduate and/or medical degree	14	82%
Undergraduate degree only	3	18%
Gender		
Female	10	59%
Male	7	41%
Nationality		
Malagasy	13	76%
Non-Malagasy	4	24%

3.3.2 Interviewee class and scope of responsibilities

The majority (*n=10*; 59%) of interviewed stakeholders fell into the category of 'national authorities', with a minority being categorized as 'granting agencies/financing authorities' (*n=2*; 12%), 'international organisations/supranational non-profits' (*n=3*; 18%), and 'research institutes/technical advisors' (*n=2*; 12%). No 'subnational or community health actors' were interviewed.

53% of interviewed stakeholders (*n=9*) held some form of responsibility for 'policy or programme management', followed in frequency by 'research or technical support' (*n=7*; 41%), 'implementation of interventions or vector control' (*n=5*; 29%), 'data, surveillance, or evaluation' (*n=3*; 18%), and 'financing' (*n=3*; 18%).

The interviewee class and scope of responsibility results are summarized in **Table 3.8**. For the scope of responsibilities category, note that some stakeholders have responsibilities which are cross-cutting in nature and can therefore be counted multiple times.

Table 3.8: Stakeholder class and scope of responsibilities of Madagascar malaria stakeholder interviewees (n=17).

Category	**n**	%
Class of Stakeholder		
International organisations, supranational non-profits	3	18%
Granting agencies, financing authorities	2	12%
Research institutes, technical advisors	2	12%
National authorities	10	59%
Subnational and community health actors	0	0%
Scope of Responsibilities		
Policy or programme management	9	53%
Data, surveillance, or evaluation	3	18%
Implementation of interventions or vector control	5	29%
Financing	3	18%
Research or technical support	7	41%

Note: Absolute value in the 'scope of responsibilities' category will exceed the total number of interviewees, given the multiple roles played by each stakeholder; percentage value in the 'scope of responsibilities category' represents the number of interviewees who held that responsibility out of the total

3.3.3 Use of malaria risk maps in current responsibilities

Ultimately, all interviewees (*n=17*; 100%) described having used malaria maps in their current responsibilities or having observed others use malaria maps in their current responsibilities. All interviewees (*n=17*; 100%) described malaria maps as being useful for malaria control in Madagascar. Most interviewees (*n=16*; 94%) believed there were problems or limitations with malaria maps. All interviewees (*n=17*; 100%) described some form of map-based stratification, targeting, or prioritization in the delivery of interventions.

In particular, incidence maps were described as being used for decision-making at DLP meetings, at MoH meetings, and at RBM meetings with international actors from WHO and PMI, among others (*007; DLP stakeholder*). Most maps identified by interviewees were descriptive maps that did not use modelled surfaces.

The depiction of and stratification by incidence levels was the most commonly-cited use of malaria risk maps (*n=14*; 82%). This was described as having direct impact on policy making; interviewees suggested that in areas of lower transmission the DLP chose to 'harmonize' with the WHO Global Malaria Programme (GMP) guidelines on intervention approaches (*006; DLP stakeholder*). Alerts and surveillance mapping was the second most-commonly identified use case (*n=10*; 59%). Finally, 'ecological mapping' that discretely depicted phenomena like vegetation, climate, and rainfall was identified as being used on an ad hoc basis (*010; MoH stakeholder*).

3.3.4 Spatial scale of malaria risk mapping in Madagascar

Many interviewees described the use of malaria maps at the Regional (*n=13*; 77%) or District (*n=15*; 88%) level, while fewer described their use at the Commune (*n=3*; 18%) or Fokontany (*n=3*; 18%) levels.

One interviewee (*006; DLP stakeholder*) suggested that while the NMS had communicated a hope for mapping at the Commune level, the reality was that the maps were being used operationally at the District level. This is explained further by another interviewee:

> 'It always comes back to the data access problem, and it is quite difficult to get data for anything more granular than the District for a map. We already have great difficulty in gaining access to this data, at the Regional level, which is the level above the Districts. And when you go into detail, completeness is a big problem; 75% of Districts fail to send us full data'.
>
> *—Interviewee 011; MoH stakeholder*

Interviewees showed knowledge of the value of increased incidence granularity (e.g., how aggregated District-level data could conceal Commune-level outbreaks), and identified this finer resolution cartography as a valuable addition to the work of the DLP (*007; DLP stakeholder*).

Several interviewees (*n=4* ; 24%) referenced the use of maps to inform the Malagasy local strategic distribution plan (<<micro plan de positionnement>>). An output from the microplan was provided to the interviewers. For each District, a summary page highlights the total population, the total number of Communes, the total number of Fokontany,

the total number of distribution sites, and the adjusted malaria burden (*003; DLP stakeholder*). After the demographic and epidemiological phenomena, a line list of each Fokontany is produced, with the following data: region, community, population, related distribution site, distance, the relevant health locality (<<formation sanitaire>>), the adjusted malaria burden values, whether or not the sites comprise a difficult to access zone (<<zones difficiles d'accès>>), and additional operational observations, notably the types of vehicles required for distribution (*003; DLP stakeholder*).

Some interviewees suggested that in a limited-resource setting, devolution of data responsibilities to lower administrative scales may be increasingly attractive to the DLP, and increase the value of adopting malaria risk mapping at finer resolution.

> 'So, if you're cash-strapped but also want this finer-level data, what do you do? They probably want to rely on their facility-level or hospital data because it will allow for a more granular perspective. But they probably don't think their HMIS data is reliable enough'.
>
> *—Interviewee 017; international stakeholder*

3.3.5 Use of malaria risk maps in prioritization and targeting of interventions

The most commonly cited function of malaria risk maps in Madagascar was the selection of interventions ('prioritization') and the selection of geographic areas ('targeting'). Comparing and contrasting these concepts is challenging because they are inter-dependent and are 'difficult to disentangle in fact and in practice'.[74] The literature tends to view

'prioritization' as the determination of which intervention or delivery method is most appropriate for a specific geographic area and 'targeting' as the determination of which populations or areas the interventions should be used for.[74,169,170]

The prioritization or targeting of three types of preventative interventions – ITNs, IRS, IPTp – was identified as being partially informed by malaria risk maps by several interviewees. ITN distribution was described as being organised and planned at the District level, and distributed at the Fokontany level, based on census data and some cartography (*003; DLP stakeholder*). Madagascar was described as having implemented mass ITN campaigns approximately every three years, and these efforts were described as requiring establishment of distribution sites serving multiple Fokontany. Pre-elimination areas identified by the NMS using modelled epidemiological surfaces were described as being selectively excluded from some interventions by the DLP.

> 'The use of [ITNs] changes according to the place, for example, we have 113 Districts and we do the mass distribution in 106 Districts. So that means there are other strategies for certain places. For the zones in pre-elimination, we often choose not to use the nets, which is different from the strategy for those in the control phase'.
>
> *—Interviewee 002; DLP stakeholder*

IRS was described as being planned at the national level, and implemented at the Commune level in conjunction with municipal-level maps. IRS decision-making was described as being based on incidence and test

positivity rates (*009; international stakeholder*). IRS policy is affected in part by malaria risk maps; one interviewee (*002; DLP stakeholder*) suggested that a mass IRS campaign was considered before it was ultimately limited to the Central East coast, with more granular decision making deputized to the District leader responsible for malaria control (<<Responsable paludisme de district (RPD)>>).

Control intervention efforts were described as relying primarily on incidence maps that did not take into account entomology or climate, for instance, according to one interviewee (*002; DLP stakeholder*). Another added:

> 'While we can see the number of cases in the districts or in the communes, we do not really have the surveillance data relating to the entomological or geographical situations. These are not always combined with the cartography currently used, which I know is important for us'.
>
> *—Interviewee 007; DLP stakeholder*

Maps were described as being less commonly used for commodity quantification (e.g., of RDTs, ITNs, or artemisinin-based combination therapies (ACTs)) or logistical decision-making. One DLP official who interfaces primarily with the Global Fund (GF) for funding applications said that in the realm of control intervention prioritization and targeting, the DLP had a major priority focused on budget financing for commodities (*006; DLP stakeholder*), while another confirmed that at the moment, use and supplies of commodities were depicted through tables, not cartographically (*009; international stakeholder*). Given timeline constraints, several stakeholders

suggested that the DLP tended to prioritize high-burden malaria areas for control interventions, using the additional time this provided to search for funding for more targeted interventions.

3.3.6 Additional uses of malaria risk maps in Madagascar

While malaria risk maps were described as predominantly being used for intervention prioritization and targeting functions, several other use cases emerged as examples in the IDIs.

Firstly, malaria risk maps were also identified as being used for epidemic surveillance and response. The Madagascar DLP was described as using a 'hybrid model', whereby continuous surveillance is done at the District level, but in the event of outbreaks, more granular data is leveraged to understand community-based outcomes (*001; DLP stakeholder*). One interviewee described this alert mapping process in fuller detail:

> 'We receive a warning that malaria is spreading very quickly in some communities and then we choose to visualize this through the maps. When an alert is triggered, we contact the Regional and District officials and we investigate to understand the cause of the epidemic, to see if the people are using the prevention tools, which zone is the most affected, and whether that zone is accessible to the MoH. We also ask ourselves whether or not the medications available are sufficient. We ask the people in charge to go to the affected region if possible, but if they do not have the resources to make the trip themselves, the central department can organise a trip to the affected zone to provide a report'.

—Interviewee 001; DLP stakeholder

Interviewees also suggested that maps were used to support training for control intervention teams, with maps existing at the Commune level indicating which trainings had been done and how many people had been trained (*003; DLP stakeholder*).

Malaria risk maps were also described as being used for planning in specific settings that required tailored interventions and strategies (*n=4*; 24%). For example, mining sites were described as an important area of focus for the DLP, as a high transmission locale with migrant worker populations.

> 'In 2017 in the Sakaraha region, there are mining sites where they extract sapphires. We used maps at the Fokontany level to target the use of ITNs and IRS for the populations there'.
>
> *—Interviewee 006; DLP stakeholder*

This is not without its challenges, according to another interviewee:

> 'We have the maps on the mining areas but often they lack precise information on the evolution of climatic conditions favorable to the spread of malaria […] These people, they move a lot, their numbers increase and decrease seasonally at certain times of the year'.
>
> *—Interviewee 006; DLP stakeholder*

Finally, justification of policy decisions was also mentioned as a use case for malaria maps, even if the ultimate underlying cause was not epidemiological or public health–related.

> 'So, they can be used to bring technical justifications to those who question the use of funds on epidemic posts. Sometimes our choices to allocate to specific districts also relate to how they might generate jobs and all that'.
>
> *—Interviewee 006; DLP stakeholder*

3.3.7 Perceptions of malaria risk map utility

At the highest level, interviewees described a DLP and MoH that was increasingly integrating malaria maps into national malaria control efforts, as they moved from simple representations of epidemiological indicators (e.g., tables, line charts) to cartographic representations and some limited modelled surfaces.

> 'Normally, our work depends mostly on the epidemiologic data. However, now when we create campaigns, we try to use cartography in order to highlight the indicators that may allow us to know the number of mosquito nets per district and other activities in each district'.
>
> *—Interviewee 003; DLP stakeholder*

The utility of malaria risk maps was often described as being based on the accuracy of mapped outputs and their alignment with decision-maker positions and donor priorities. Donor priorities were sometimes described as 'rigid' (*n=3*; 18%) and their 'over-emphasis' on linking funding to metrics and outcomes was identified as potentially having an adverse effect on DLP planning. One interviewee identified that in certain parts of the county (e.g.,

the central Highlands), the decreases in cases meant that funding had become less available for control interventions, despite the persistent and perceived need at the national level to provide for those communities (*007; DLP stakeholder*). Other interviewees suggested that international donor-supported terminologies like 'pre-elimination' were unpopular in the DLP (*002; DLP stakeholder*) and that mapping products occasionally used designations that did not concord with Madagascar's operational stratification. As such, risk maps were sometimes described by interviewees (*n=3*; 18%) as being intended more to assist advocacy with international donors or organisations.

Several other examples of the perceived utility of malaria risk maps were identified, including as a tool for advocacy (*n=10*; 59%) and as a means of improving cost efficiencies across governments (*n=8*; 47%) related to not mis-allocating interventions where they were 'not needed'.

Despite mostly positive assessments of risk map utility, a minority of interviewees were less optimistic, and suggested that risk maps were primarily used for descriptive purposes and infrequently for decision-making.

> 'People tend to use them to contextualize malaria epidemiology. As prevalence is dropping in certain countries, more people are using maps to look at different interventions to see how they differ across a country, but I don't think people are using them for decision-making. Mainly people use them for illustrative purposes or in a report to give context'.
>
> —*Interviewee 017; international stakeholder*

3.3.8 Data reliability and comprehensiveness

A cross-cutting theme for answers to all questions asked in the IDIs was data reliability and comprehensiveness.

Routine health data was described as being collected from the primary and secondary health facilities and sent to the District level on a monthly basis, with the DLP monitoring for 'promptness, completeness, and data quality' through the use of the HMIS (*004; DLP stakeholder*). At the national level, data was described as being managed by the MoH across three directorates.

> 'There are three directorates within the Ministry responsible for data. There is the Directorate of Studies and Planning, the Health and Epidemiological Surveillance, and the Directorate of Information Systems'.
>
> *—Interviewee 011; MoH stakeholder*

Two core data limitations were identified. First, data completion was cited as a recurring challenge (*n=12*; 71%), with data collection described as putting too much pressure on CSBs – which were estimated at a 35% data completion rate by one interviewee (*006; DLP stakeholder*). Second, data accuracy was identified as a challenge (*n=9*; 53%), with 'fuzziness' (e.g., being unable to distinguish which Fokontany within a District data is coming from) contributing to a lack of confidence in mapped outputs which are based on this data (*004; DLP stakeholder*).

3.3.9 Perceptions of malaria risk map limitations

The above-mentioned challenges with data completeness and data accuracy were the most commonly identified limitations of malaria mapping in Madagascar and the primary limiting factor in the use of maps at any level more granular than the District. While these are mostly described as upstream limitations related to the inputs for mapped products, they were commonly mentioned in conjunction with critiques of the modelled *output* accuracy. One interviewee went so far to say that, 'generally speaking, the data does not really correspond with reality' (*004; DLP stakeholder*).

Interviewees also suggested that risk maps could not adequately represent trade-offs and local contexts. For example, shorter malaria transmission periods and smaller houses in some areas of the country reduce population willingness to use ITNs, which was described as not being easily representable by a mapping output (*008; international stakeholder*). Accordingly, methodological uncertainty was identified as a major barrier to the utility of malaria mapping.

> 'People don't know what is in the modelled surfaces and the spatial covariates that go into it. We use the analogy in Madagascar of a smoothie. There are all these different ingredients going into it and when you blend it up, you can no longer see all the different pieces anymore. People just look at the map and they don't know all the things that went into it. So, it is divorced of context'.
>
> *—Interviewee 017; international stakeholder*

'Methodological uncertainty' was often referenced in conjunction with the thematic of 'trust'. One perceived contributor for interviewees who described a lack of trust of malaria risk map outputs was the limited amount of human resources available for interpretation and training (*004; DLP stakeholder*). Another trust-related challenge pertained to the identified methodological uncertainty, which some interviewees identified as being used to ultimately cater to decision-makers' priorities, rather than present a rigorous, evidence-based conclusion.

> 'Sometimes I did not agree with how a map was used to justify a decision'.
>
> *—Interviewee 006; DLP stakeholder*

Or, put another way by an interviewee:

> 'You can lie with maps. Change gradients and cut-off points. But with a modelled surface you can do even more! So much can be fiddled with. With a standard model, you would normally be able to see all the variables that went into it and question the assumptions. Whereas with these modelled surfaces, people don't understand the outputs as well, so people are just trusting that this is good and is the truth. There is a lot of uncertainty around it'.
>
> *—Interviewee 017; international stakeholder*

3.3.10 Identified future malaria risk map outputs in Madagascar

One interviewee summarized a vision for the various malaria risk maps that could be produced in Madagascar:

> 'Maps of the epidemiological situation; test positivity rate; prevalence; incidence; morbidity; a central reference map of which interventions are in which areas; integrative mapping of geographic, environmental, and climatic metrics; geographic accessibility to and from CSBs, potentially linked with mortality; IRS coverage by commune for focal districts with low endemicity; surveillance, case management, point of care – all are worthwhile metrics for evaluation'.
>
> *—Interviewee 009; international stakeholder*

Not in the above-mentioned list but commonly cited (*n=7*; 41%) was early epidemic alert mapping – maps that take into account historic alert or incidence data to support warning systems, as has been done in research studies conducted for Eritrea[171] and Mozambique.[172]

Another commonly-cited malaria risk mapping output identified as being valuable to the DLP was climatic mapping (*n=6*; 35%). For instance, stakeholders identified value in linking routine surveillance data in conjunction with climatic and environmental covariates, and acknowledged that the modelled *Pf*PR maps in the NMS did already include these covariates.

> 'We do programmatic surveillance systematically, every year in different sentinel sites, for example for entomology. But there is a need for us to integrate the temperature, the altitude, the transmission season – which when overlaid with the use of the map can develop into the makings of an overall epidemiological strategy'.

—Interviewee 014; MoH stakeholder

Another commonly-cited mapping output identified as being valuable to the DLP was accessibility or logistics mapping (*n=5*; 29%). DLP and MoH stakeholders identified the value of integrating maps exploring the distance between District health centres and CSBs, as well as the population coverage in a particular area by a CSB to assist with deployment planning (*011; MoH stakeholder*). It was suggested that these maps could be linked to stock-outs or supply metrics as well (*011; MoH stakeholder*).

Several other use cases were mentioned by stakeholders, including mapping to identify residual malaria transmission (*009; international stakeholder*), maternal-child and newborn health (*010; MoH stakeholder*), and entomology (*010; MoH stakeholder*), though more substantive description of methods, inputs, or metrics were not provided.

Despite falling outside the scope of their responsibilities, a stakeholder with a vector control remit suggested that resistance maps could be valuable to the work of the DLP, given increases in resistance to front-line anti-malarial artesunate–amodiaquine (ASAQ) (<<Combinaison artésunate amodiaquine>>) (*002; DLP stakeholder*).[173]

One interviewee (*006; DLP stakeholder*) suggested that maps could be used to support more integrated monitoring and evaluation.

> 'We could have a project to quantify the use of interventions and to create incentives. If a District received 500 mosquito nets in 2017, for example we would review the change to the incidence rate in 2018

and then analyze it. This could be overlaid with another map of drug distribution and these investigations should inform us'.

—Interviewee 006; DLP stakeholder

Finally, from a process perspective, some interviewees (*002; DLP stakeholder*) suggested that planning for risk mapping should be more deeply integrated into the organisation of the national census so as to ensure better data availability.

3.3.11 Findings from the post-interview questionnaire

The first set of questions asked in the post-interview questionnaire related to the perceived utility of malaria risk maps, and allowed for direct comparison of several commonly-cited examples of risk map utility. Interviewees identified 'improving the targeting and stratification of interventions', as having the highest perceived utility (out of 4) for malaria risk maps (*3.88*), which corroborates the qualitative findings in **Chapter 4.3.5**. This was then followed by 'informing ministry officials of highest-need areas' (*3.47*), 'helping government to attain international grants and financing' (*3.24*), 'increasing cost efficiency of malaria control efforts' (*3.06*), and 'assisting academics and researchers in their work' (*3.06*).

The second set of questions asked in the post-interview questionnaire related to the perceived obstacles to the use of malaria risk maps. Interviewees most commonly agreed (out of 5) with the statement 'people do not know what types of maps exist' (*3.82*), followed by 'malaria maps are an inaccurate reflection of actual conditions' (*2.63*) and 'it is hard to act

effectively on malaria map recommendations' (*2.59*). The remaining statements were perceived as not a significant obstacle to the use of malaria risk maps, most notably, participants did not believe there was a low cost-effectiveness of intervention targeting based on maps (*1.12*).

The third set of questions asked in the post-interview questionnaire related to highest perceived value (out of 4) of metrics to visualize with malaria risk maps. All metrics were described by interviewees as being valuable to visualize, with the most important identified as 'case incidence maps' (*3.88*).

The results of the post-interview questionnaire are summarized in **Table 3.9**.

Table 3.9: Aggregated post-interview questionnaire results from Madagascar malaria stakeholder interviewees (n=17).

Question	Theme	Result	Range available
1.1	Perceived utility – Improving the targeting and stratification of interventions	3.88	1 (not useful) – 4 (very useful)
1.2	Perceived utility – Increasing cost efficiency of malaria control efforts	3.06	
1.3	Perceived utility – Informing ministry officials of highest-need areas	3.47	
1.4	Perceived utility – Helping government to attain international grants and financing	3.24	
1.5	Perceived utility – Assisting academics and researchers in their work	3.06	
2.1	Perceived obstacle to use – Malaria maps are an inaccurate reflection of actual conditions	2.65	1 (disagree) – 5 (strongly agree)
2.2	Perceived obstacle to use – We do not trust the institutions that produce malaria risk maps	2.29	
2.3	Perceived obstacle to use – We find it hard to use and understand malaria maps	2.53	
2.4	Perceived obstacle to use – Malaria maps are not useful to achieving health targets	1.65	
2.5	Perceived obstacle to use – It is hard to act effectively on malaria map recommendations	2.59	
2.6	Perceived obstacle to use – It is not cost-effective to apply interventions based on maps	1.12	
2.7	Perceived obstacle to use – People do not know what types of maps exist	3.82	
3.1	Indicator priority for mapping – Infection prevalence maps	3.82	1 (not useful) – 4 (very useful)
3.2	Indicator priority for mapping – Case incidence maps	3.88	
3.3	Indicator priority for mapping – Test positivity rate	3.47	
3.4	Indicator priority for mapping – ITN coverage maps	3.47	
3.5	Indicator priority for mapping – IRS coverage maps	3.47	
3.6	Indicator priority for mapping – Combination of intervention coverage and incidence	3.47	

3.3.12 Additional national planning meetings

The 24 July 2018 RBM meeting had 25 attendees while the 31 July 2018 RBM meeting had 20 attendees, based on the RBM's attendance sheets (<<fiche de présence>>). Attendees represented a range of responsibilities (e.g., research, control, advisory, and preventative) and affiliations (e.g., international organisations, the DLP, and non-governmental organisations (NGOs)). KH and RH were solely there in an observational and research capacity, with KH presenting the contours of the research study at one of the meetings.

The subjects covered in the RBM meetings included: logistics for the launch of an ITN campaign; budgeting processes for the ITN campaign; reports on civil society engagement in ITN campaign; validation of the list of operational partners; review of insecticide redeployment efforts; review of District-level epidemiological data; and a review of monitoring and evaluation processes for incidence rates.

Two structured quantitative outputs were presented by the DLP during those meetings, though neither were malaria risk maps or modelled malaria surfaces.[174] The first were strategic priority tables, which described the District, health locality, and strategic actions to take (e.g., whether emergency IRS distribution was warranted or some other intervention instead). These tables were predominantly used to deliberate on 'prioritization' of interventions.[174] The second were line graphs of outbreak alerts, displaying case numbers. These depicted the Region, District, and CSB where the alert was recorded. These did not translate into a geographically-

overlaid map of outbreaks at either the national or sub-national levels. These were predominantly used to deliberate on 'targeting' of interventions.[174]

3.4 Discussion

3.4.1 Current-state uses of malaria risk maps

At the operational level, the interviews suggest at least two distinct malaria risk-mapping outputs are used in Madagascar: District-level aggregated malaria incidence maps using routine health system data; and District- and facility-level surveillance maps for epidemic alerts. At the descriptive level, an additional malaria risk-mapping output was used in the NMS: modelled *Pf*PR malaria prevalence maps.

Within the scope of intervention delivery and its upstream considerations, the aforementioned malaria risk maps were identified as having been used by Madagascar's national decision-makers to assist with the targeting of preventative interventions like ITNs or IPTp, the targeting of IRS, operational planning, 'financial justification',[74] and advocacy – even though the mapped outputs did not necessarily depict the control interventions being implemented.

3.4.2 Drivers of the use of malaria risk maps

The use of malaria risk maps in Madagascar was driven by perceptions of utility and perceptions of limitations. With regards to the former, many factors have been identified from previous research that influence the perception of risk map utility, including: (1) their availability; (2) their technical features; and (3) their alignment with decision-maker priorities.[74]

'Trust' and 'understanding' were consistently mentioned as drivers of the adoption of malaria risk maps. Several studies have depicted the challenges of cartographic or visual representations of disease on decision-makers, with a focus placed on cognitive overload and misinterpretation.[175,176] Human-centred design (HCD) is commonly proposed as means of both assessing the usability of maps, and improving on these limitations,[177] though was not mentioned by any of the interviewees or interviewers.

Malaria risk map 'understanding' can range from understanding the quality of risk maps, understanding the relevance of risk maps, understanding the underlying data used by risk maps,[74] and understanding 'uncertainty' in the context of risk maps.[178] On the topic of 'understanding relevance', interviewees suggested that while it was clear that decision-makers understood how modelled surfaces could provide estimates of technical feasibility, their political implications were less widely understood.

It was also clear that stakeholders identified concerns about the ability of malaria risk mapping to take into account family, social, and cultural determinants of health, which play an important role in LLIN adherence in Madagascar,[179] as well as the adoption of other preventative interventions.[180] A qualitative study on Malagasy perceptions of malaria across four contrasting epidemiological areas, published by Mattern *et al.* (2016), suggested these social determinants of health affected care-seeking behaviors.[131]

Data quality was another consistently-reported barrier to the use of malaria risk maps. Concerns around data tended to be focused on accuracy

and timeliness. With regards to 'accuracy', mobile technology-based and 'participatory risk mapping' approaches have been proposed in the literature as means of addressing challenges with perception of and trust in risk maps.[181,182] With regards to 'timeliness', several interviewees identified that while prevalence modeling (e.g., *Pf*PR risk maps) could be useful for long-term planning, it had less clear value for daily or weekly programmatic decision making, unless appropriate tools were in place to streamline data reporting and analysis. Other interviewees suggested that routine health data would remain preferable to national survey data collected every few years.

While data was consistently referenced as a challenge, stakeholders were clear that an integrated whole-of-government data approach was preferred to direct technical reforms, given two separate directorates were responsible for routine and outbreaks reporting, and given the current MoH surveillance systems were responsible for linking across more than a dozen disease types in Madagascar.[130]

Moreover, interviewees suggested that policymakers tended to see malaria risk maps more as a visualization tool than as a decision-support tool. Accordingly, knowledge translation was another important barrier identified in Madagascar; for instance, several decision-makers were not aware IPM's use of a multi-criteria evaluation decision-support tool to identify priority zones for IRS intervention in the central Highlands,[183] and those who were largely perceived it as being intended for a 'research' domain rather than having programmatic utility.

3.4.3 Future-state use cases of malaria risk maps

Despite these critiques, the perspective of the majority of interviewees was positive about the utility of malaria risk maps and the function they have played and will play in Madagascar's malaria control efforts. Future-state use cases identified by interviewees can be categorized as serving one of three functions: (1) 'needs identification', to understand where to allocate resources or interventions and which types; (2) 'impact evaluation', to assess the impacts of actions taken; and (3) 'cost-benefit analysis' to better model trade-offs and decision-points.

A variety of malaria risk mapping outputs were described as potentially useful or desirable, including: (1) insecticide coverage and resistance maps (e.g., pyrethroid resistance to LLINs, carbamate resistance to IRS, etc.); (2) predictive epidemic alert maps; and (3) logistical or accessibility maps. These can be interrelated. Others are described in greater depth in **Chapter 3.3.10**.

With regards to accessibility mapping, some interviewees showed knowledge of the 'access' covariate (e.g., travel time via all transport methods) in the 2016 DHS Spatial Annual Report (SAR 14).[184] Moreover, interviewees identified that the DLP already uses 'microplanning' tables for each District that identify the distances between Fokontany and distributions sites within specific health localities, the number of ITNs adjusted for each, and a notation for whether the zones are difficult to access.[185] Both of these metrics could be mapped more effectively.

One of the most consistently articulated desires was for trend-informed and predictive epidemic alert maps that could be integrated into

planning for ITN or IRS campaigns, or for more reactive emergency efforts. Stakeholders referenced the routine data collected by Madagascar's sentinel surveillance system (<<Postes sentinelles de surveillance epidémiologique (PSSE)>>), and suggested the value of a malaria early warning system (MEWS), which can be used detect or predict malaria epidemics in order to trigger public health interventions. IPM and PMI have piloted a web-based MEWS tool that used routine surveillance data in Madagascar and demonstrated its ability to detect outbreaks in 2014.[143]

Repeatedly, interviewees identified the need to make difficult trade-offs when international donors or supplies did not provide sufficient funding or commodities for control interventions, creating decision-points for community stratification. Malaria risk maps have been used to visualize the outputs of a multi-criteria decision analysis (MCDA) – whereby the relative value and trade-offs of specific phenomena are weighed to assist decision-makers[186,187] – as well as being integrated alongside more descriptive decision analysis programmes, like the Malaria Decision Analysis Support Tool (MDAST), used in Kenya, Tanzania, and Uganda.[188,189] While decision-support was identified as a potential value-add, it was unclear from the interviewees that the link between cartographic representations and decision-making tools had been clearly communicated.

Overall, interviewed stakeholders were proud of and felt ownership over their government's use of malaria risk maps. Stakeholder interviewees remained optimistic about the impacts that malaria risk maps would have in the future, and believed maps would see increased use in Madagascar in the years to come. Trends supporting future-state use included: (1) increased

devolution of responsibilities and decision-making; (2) decreased prevalence increasing the need for stratification; and (3) better data reporting and management systems.

3.4.4 Limitations

This research study has a few limitations. First, the PATH *Accelerating Towards Malaria Elimination* research suggests a qualitative interview methodology focused on: 'decision-makers', which it defines as individuals with the 'ability to directly or indirectly impact the design of the NMS'; 'implementers', which it defines as individuals 'who play the crucial role of operationalizing the NMS'; and 'adopters', which it defines as individuals who 'manage the implementation and realization of the NMS at the district and facility levels'.[190] This research study had adequate representation from the first two categories of Madagascar stakeholders, but did not interview 'adopters'. Their perspectives would have been valuable in ascertaining use cases for and limitations of malaria risk-mapping at the community level and in 'last-mile' logistics.

This limitation is replicated at the category of 'class of stakeholder' adapted for this research study, in which there were no 'subnational or community-based actors' interviewed. While Madagascar's malaria programme delivery occurs inter-dependently across a variety of administrative units (i.e., Region, District, Commune, Fokontany), stakeholder interviews were limited to decision-makers who primarily engaged at the Region and District levels.

Another limitation is that the most highly-represented 'scope of responsibilities' of the interviewed stakeholders fell into the 'policy and programme management' category and the 'research and technical assistance' category. This means there was less representation of on-the-ground intervention delivery and vector control expertise. This is perhaps to be expected given the interviews were arranged through the DLP and MOH – which are national coordinating bodies – and also because of the specific contours of how malaria risk mapping is used under the status quo in Madagascar.

Faith based organisations (FBOs) and other cultural groups are also important national and sub-national partners in malaria control,[191] and have been successfully leveraged to scale-up IPTp programmes in Madagascar,[192] but were outside of the scope of this stakeholder mapping.

Finally, it is clear that many of the factors regarding the adoption of malaria risk maps were outside the control of the stakeholders most involved in their use. At an operational level, the geospatial components of malaria elimination require high-resolution surveillance, targeted prevention interventions, targeted response interventions, effective service delivery, and coverage level optimization.[72] In the absence of these things – or at least while they are being strengthened – sometimes the less-stratified approaches are easier, both politically and from the perspective of implementation.

Chapter 4

Findings from a stakeholder workshop by The Demographic and Health Surveys Program about modelled maps of identified key malaria indicators in Madagascar

Research question

The Demographic and Health Surveys Program supports Madagascar in conducting Malaria Indicator Surveys to collect valuable malariometric data that can be used to produce modelled surfaces for use by the National Malaria Control Programme. In 2018, a workshop was held to strengthen capacity among malaria stakeholders to understand, build, and integrate malaria risk maps using the indicators produced by the national surveys. This Chapter summarizes the results of that workshop, participant learnings and outputs, as well as programmatic recommendations for Madagascar malaria control that emerged from the sessions.

Note on contribution

This chapter is developed from the research conducted as part of USAID's The Demographic and Health Surveys Program (DHS) 2018 Madagascar Modeled Surfaces Workshop (hereafter, 'DHS workshop') held in Antananarivo, Madagascar in July 2018. The DHS workshop was designed by CT and facilitated by CT and RH, not KH. KH led the evaluation discussions at the end of the workshop, coordinated a workshop participant survey, took notes for post-workshop analysis, and contributed to the writing of the manuscript that was eventually published in *Malaria Journal* in 2019 (with RH and KH sharing co-first authorship).[*] While unpublished in the 2019 article, KH also conducted analysis of participant perspectives on malaria control policy and programming based on the notes, which is presented in this Chapter.

While this Chapter summarizes findings that were directly facilitated, analyzed, or written by KH, due contribution of CT and RH must be acknowledged in the upstream development of the ideas and planning of the DHS workshop that made these results possible.

Funding for this workshop was provided by the President's Malaria Initiative (PMI) and the Global Fund to Fight AIDS, Tuberculosis, and Malaria (GF). KH's travel costs were covered by a Bill & Melinda Gates Foundation (BMGF) grant to the Malaria Atlas Project (MAP), as well as The Rhodes Trust.

[*] The statement of contributions from the article is as follows: 'CT designed and facilitated the workshop with RH. KH led the evaluation discussions at the end of the workshop. PWG developed the geostatistical methods and maps. All authors (except PWG) participated in the workshop discussions. RH, KH and CT wrote the first draft of the manuscript, based on original ideas from the workshop participants. All authors read and approved the final manuscript'.

4.1 Introduction

4.1.1 DHS Madagascar workshop

With decreases in malaria prevalence and international funding available for malaria control, malaria risk maps have been proposed as a means to ensure the most effective targeting of limited resources.[67] The gaps in the collection of national routine health data have also strengthened the case for spatial interpolation of malariometric data, which often requires advanced modelling tools or statistical methods.[11] In addition, these epidemiological and financial pressures have increased the importance of monitoring and evaluation of how health information systems (HIS) are used by Ministries of Health (MoHs) and assessments of their capacity to visualize the data they collect (e.g., through tools like MEASURE Evaluation's Monitoring and Evaluation Capacity Assessment Toolkit (MECAT)).[193]

One such initiative to improve access to data and visualization tools available to MoHs is the DHS Spatial Data Repository Program (SDR), which offers insights into the various layers of information that can be mapped to assist national disease control programmes.[194,195] The DHS has worked with the Madagascar National Malaria Control Programme (<<Direction de lutte contre le paludisme (DLP)>>) to roll-out three (2011[196], 2013[144], 2016[145]) household Malaria Indicator Surveys (MIS) (<<Enquête sur les indicateurs du paludisme (EIPM)>>), whose data have been used to produce modelled surfaces using model-based geostatistical (MBG) techniques. The DHS SDR stores and displays maps produced from the specific MIS indicators (*n=13*)

that were selected as appropriate targets for mapping,[195] which in the case of Madagascar are summarized in **Table 4.1**.

The goal of the DHS workshop was to develop and strengthen the skills of DLP and other malaria control stakeholders in Madagascar related to the understanding and creation of malaria risk maps using MIS indicator data.[197] The workshop used a variety of adult learning techniques and culminated in the presentation of participant-developed malaria risk maps (District-level aggregations of MIS indicator data related to three malaria control subject areas).[197]

This Chapter summarizes core learnings from the DHS workshop related to malaria control efforts in Madagascar, and provides support for the utility of future collaborative, capacity-strengthening workshops. It specifically seeks to understand the perceived value of the modelled surfaces reviewed in the workshop for Madagascar's technical malaria stakeholders, and possible roles modelled surfaces and malaria risk maps can play for control programme efforts.

Table 4.1: Selected key Madagascar Malaria Indicator Survey (MIS) indicators for mapping (n=13) and evidence of use by Madagascar stakeholders during The Demographic and Health Surveys Program (DHS) workshop, Howes et al. *(2019).*[197]

Malaria Indicator Survey (MIS) indicator	**Malaria Indicator Survey (MIS) indicator description**	**Evidence of use by Madagascar stakeholders during DHS workshop**
MLFEVTCACT	Among children under age five with fever in the 2 weeks preceding the survey, the percentage who took a drug combination with artemisinin	
MLFEVTCADV	Among children under age five with fever in the 2 weeks preceding the survey, the percentage for whom advice or treatment was sought	✓
MLFEVTCBLD	Among children under age five with fever in the 2 weeks preceding the survey, the percentage who had blood taken from a finger or heel for testing	
MLHEMOCHL8	Percentage of children aged 6–59 months with haemoglobin lower than 8.0 g/dl	
MLIPTPW2SA	Percentage of women aged 15–49 with a live birth in the 2 years preceding the survey who during the pregnancy took two or more doses of SP/Fansidar, with at least one dose during an antenatal care visit [intermittent preventive treatment for pregnant women (IPTp2+)]	✓
MLIRSMHIRS	Percentage of households with indoor residual spraying (IRS) in the 12 months preceding the survey	
MLITNAPACC	Percentage of the de facto household population who could sleep under an ITN if each ITN in the household were used by up to two people	✓
MLNETCCITN	Percentage of children under age five who slept under an ITN the night before the survey	

MLNETPHITN	Percentage of households with at least one ITN	✓
MLNETUPITN	Percentage of the de facto household population who slept under an insecticide treated net the night before the survey	✓
MLNETWWITN	Percentage of pregnant women who slept under an ITN the night before the survey	
MLPMALCMSY	Percentage of children aged 6–59 months tested using microscopy who are positive for malaria	
MLPMALCRDT	Percentage of children aged 6–59 months tested using a rapid diagnostic test (RDT) who are positive for malaria	

Note: Unless otherwise indicated, the sources for **Table 4.1** *are the Madagascar Malaria Indicator Survey (2013),*[144] *Madagascar Malaria Indicator Survey (2016),*[145] *and the Howes* et al. *(2019) workshop review paper.*[197] *This list is not the exhaustive list of indicators, but rather the indicators (n=13) chosen for visualization in tbe DHS workshop. The third column depicts whether the MIS indicator in question was manipulated or mapped by participants during the course of the DHS workshop.*

4.2 Methods

The DHS workshop held a variety of sessions related to interpreting household MIS indicators and modelled surfaces, as well as strategies for using maps to answer important programmatic questions.[197] The workshop agenda is available in **Appendix C.1**. Guiding documents for understanding the work of the DHS in malaria risk mapping include: the DHS's 'Global Capacity Strengthening Strategy',[162] 'Demographic and Health Survey Capacity Assessment Tool',[161] the 'DHS Program's Modeled Surfaces Spatial Datasets' data paper (published in *Studies in Family Planning*),[198] and 'Guidance for Use of The DHS Program Modeled Map Surfaces: Spatial Analysis Reports 14 (SAR14)'.[184]

CT and RH contacted officials from the Madagascar Ministry of Health (MoH) (<<Ministère de la Santé Publique>>), DLP, Directorate of Studies and Planning (<<Direction des Etudes et de la Planification (DEP)>>), Directorate of Information Systems (<<Direction du Système d'Information (DSI)>>), The Pasteur Institute research organization (<<Institut Pasteur de Madagascar (IPM)>>), and the technical organisation MEASURE Evaluation to develop a list of workshop attendees.[197] The attendees were selected on the basis of their existing use of MBG techqniues, Geographic Information System (GIS) software, or other cartographic methods in their current responsibilities.[197] Ultimately, attendees at the DHS workshop included representatives with responsibilities for vector control, implementation of malaria control interventions, surveillance, monitoring, and policy from the DLP, DEP, DSI, and MoH, among others.[197] These participants vary considerably from those interviewed in **Chapter 3**,

primarily due to their more technical backgrounds and responsibilities. An anonymized list of the final attendees (*n=15*; 8 men, 7 women) and affiliations is provided in **Table 4.2**.

Methods for the qualitative activities presented in this chapter comprised three distinct efforts. First, attendees were provided a workshop questionnaire to assess knowledge of geospatial techniques and MIS indicators both pre- and post-workshop, which was analysed in Excel 15.0 (Microsoft) by KH, and the results published in the Howes *et al.* (2019) study in *Malaria Journal*.[197] Due to data connectivity issues with the Madagascar-partner Dropbox account, the questions could not be retrieved and are unfortunately not included in the Appendices.

Second, notes taken by KH throughout the workshop were transcribed by-hand and/or through the use of Trint (Trint International) automated transcription software. Textual data were then analyzed in NVivo 1.5 (QSR International) using the thematic coding developed in **Chapter 3.2.6**. This was then used to produce a table of Madagascar stakeholder perspectives and recommendations on improving the efforts of the DLP that emerged from the participant conversations: the success of their insecticide-treated net (ITN) distribution campaigns, their work to improve access to intermittent preventative treatment for pregnant women (IPTp) in Madagascar, their work in treatment seeking, and their integration of malaria risk mapping into malaria control efforts. This is a qualitative, policy-level analysis conducted using the knowledge attained by the researchers as part of the DHS workshop.

Finally, attendees were provided a workshop feedback questionnaire (**Appendix C.2**), which was analysed in Excel 15.0 (Microsoft) by KH, and the results published in the Howes *et al.* (2019) study in *Malaria Journal*.[197]

Table 4.2: Attendee affiliations and demographics at The Demographic and Health Surveys Program (DHS) 2018 Madagascar malaria workshop (n=15).

Participant ID	Sex	Stakeholder scope of responsibility	Organisation
001	Male	Data, surveillance, or evaluation	Direction de Lutte contre le Paludisme
002	Female	Data, surveillance, or evaluation	Direction de Lutte contre le Paludisme
003	Female	Data, surveillance, or evaluation	Direction de Lutte contre le Paludisme
004	Male	Research or technical support	Direction de Lutte contre le Paludisme
005	Female	Policy or programme management	Ministère de la Santé Publique
006	Male	Policy or programme management	Ministère de la Santé Publique
007	Female	Data, surveillance, or evaluation; Research or technical support	Institut Pasteur de Madagascar
008	Male	Data, surveillance, or evaluation; Policy or programme management	Ministère de la Santé Publique
009	Female	Implementation of interventions or vector control	Direction de Lutte contre le Paludisme
010	Male	Data, surveillance, or evaluation; Implementation of interventions or vector control	Direction des Etudes et de la Planification
011	Male	Data, surveillance, or evaluation	Direction du Système d'Information
012	Male	Research or technical support	Direction des Etudes et de la Planification
013	Female	Data, surveillance, or evaluation	Direction de Lutte contre le Paludisme
014	Female	Research or technical support	Institut Pasteur de Madagascar
015	Male	Research or technical support	MEASURE Evaluation

Note: Methodology for determining stakeholder 'scope of responsibility' is based off of **Table 3.4**.

4.3 Results

4.3.1 DHS workshop knowledge questionnaire

The DHS workshop questionnaire featured a variety of questions (*n=13*), covering topics including: knowledge of modelled surfaces; knowledge of MIS indicators; and knowledge of conceptual uncertainty in risk mapping. The mean participant score at the outset of the workshop was 54% (range 29%–86%), while the mean participant score at the conclusion of the workshop was 87% (range 57%–100%). All but one participant (who stayed constant at 86%) improved their performance between the first and second knowledge questionnaires. Two participants (*n=2*; 13%) did not complete the post-workshop questionnaire because they were unable to join the final day of the workshop. The results of the questionnaire are summarized in **Table 4.3**.

Table 4.3: Results of The Demographic and Health Surveys Program (DHS) 2018 Madagascar malaria workshop knowledge questionnaire (n=15; questions=13).

Participant ID	**Pre-workshop questionnaire**	**Post-workshop questionnaire**
001	71%	79%
002	43%	86%
003	64%	93%
004	64%	86%
005	57%	100%
006	50%	-
007	64%	86%
008	86%	86%
009	43%	86%
010	50%	93%
011	36%	57%
012	43%	93%
013	50%	93%
014	29%	93%
015	64%	-
Average	**54**% (*n=15*)	**87**% (*n=13*)

Note: Participants 006 and 015 had to leave before the final session and did not complete the post-workshop questionnaire, and their results were excluded from the calculation of the mean for the post-workshop questionnaire.

4.3.2 DHS workshop policy analysis

The DHS workshop worked on three case studies for the modelled MIS surfaces and malaria mapping, based off of participant interests and areas of work: (1) IPTp access; (2) ITN access; and (3) treatment seeking for febrile infants.[197] The visualization of modelled IPTp access generated by the workshop attendees displayed a map of District-level mean coverage of IPTp2+ rates (MIS 2016), as well as a map of modelled pixel-level uncertainty.[197] The visualization of modelled ITN access generated by the workshop attendees displayed spatially-continuous maps of household-level presence, coverage, and usage at the District level (MIS 2013; MIS 2016), as well as maps of relative uncertainty based on crude means of the pixel-level uncertainty metrics.[197] Finally, the visualization of modelled treatment seeking generated by the workshop attendees displayed maps of treatment seeking rates (MIS 2013; MIS 2016) by mothers for febrile infants under 5 years old.[197]

Top of mind for participants was the planning for the then-upcoming 2018 ITN campaign. One of the workshop participants was the responsible lead at DLP for the campaign, and several other participants had direct operational responsibilities related to its success. As such, participants were particularly interested in exploring the utility of the MIS modelled surfaces and mapping products in supporting this programmatic effort. Participants indicated that these products had both perceived utility and limitations. The results of the stakeholder perspective analysis – summarizing identified challenges, identified strategies, and identified possible roles for modelled surfaces – are displayed in **Table 4.4**.

Table 4.4: Result of policy analysis of stakeholder perspectives from The Demographic and Health Surveys Program (DHS) 2018 Madagascar malaria workshop.

Malaria control programme category	Identified challenges	Identified strategies and/or possible role for modelled surfaces
Insecticide-treated nets (ITN)	• Low ITN coverage with high logistical challenges related to access of remote areas; • Access falls short of national objectives, particularly in coastal East; • Data is unreliable and not continuously monitored; • Under- and/or mis-allocated external donor financing; • Utilisation challenges related to cultural variables.	• Macro-quantification and macro-planification followed by identification of key populations for 2018 ITN campaign; • Responsible parties for logistics and data management during 2018 ITN campaign to be integrated; • Community mobilization around value of ITN in key Districts can be mapped; • An SMS-based data collection system integrated across Central, Region, District, and Fokontany levels; • Micro-planification to be assisted by map outputs on ITN coverage; • Intra-government funding advocacy to reduce external donor dependency; • Increased focus on monitoring and surveillance.
Intermittent preventative treatment for pregnant women (IPTp)	• Increases in number of pregnant women combined with lower proportional ITN use in several key Districts; • Relatively low antenatal consultation rates; significant reporting of	• Visualization and/or mapping of SP and other related stock-outs for IPTp efforts; • Increased coordination between DLP and the National Family Health programme;

	sulfadoxine–pyrimethamine (SP) stock-outs.	• Higher sampling in high modelled uncertainty coastal districts in future Malaria Indicator Surveys (MIS); • Strengthening monitoring and evaluation systems to understand the use of commodities; better training and coordination.
Treatment seeking	• Increased but low treatment seeking rates for febrile infants; • Drug efficacy limitations and stock-outs; • Care guidelines are not uniformly applied; • Weak data management systems; delays in treatment seeking due to access.	• Increase MIS datapoints for treatment seeking rates by mothers for febrile infants under 5 years old in the 2 weeks preceding the interview (MLFEVTCADV) indicator to augment spatial heterogeneity; • Allow for more robust mapping of febrile treatment seeking to coordinate policy solutions; • Strengthen DHIS2 and community monitoring systems.

Note: Evidence for this policy analysis compiled by KH using resources from DHS Madagascar workshop, Howes et al. *(2019) review,*[197] *and DLP national ITN campaign planning documents.*

4.3.3 DHS workshop feedback questionnaire

At the conclusion of the DHS workshop, an evaluation form was offered to participants as part of DHS standard practices for post-workshop assessment. This DHS workshop questionnaire featured a variety of questions (*n=18*), covering topics including: clarity of objectives; mastery of skills; risk map interpretation; and understanding of programmatic applications of maps. Feedback was positive overall. Strengths and critiques were provided qualitatively in the latter set of questions (Q15–Q18). In this qualitative section, participants identified several valuable aspects of the workshop training they received, including: developing an understanding of foundation techniques in cartography; analysing and manipulating modelled surfaces and translating their insights into recommendations for malaria control; and aggregating data to the District level to help with decision-making. Some limitations were identified including: time provided to participants; clarity of instruction; and, most importantly, the communication of the underlying metrics being depicted by the modelled surfaces. This will be explored in further depth in **Chapter 4.4**. The raw data results of the questionnaire are presented in **Appendix C.3**.

4.4 Discussion

This was the DHS's first-ever country-specific 'modelled surfaces workshop' run globally.[197] As such, it was a significant pilot for rolling out further DHS capacity strengthening activities, while also underscoring the role DHS could play in supporting expanded use and analytical skills-building for malaria risk mapping in sub-Saharan Africa. More importantly, the DHS workshop helped key Madagascar malaria control stakeholders to develop a portfolio of modelled surfaces and malaria risk maps to assist their efforts.[197]

The workshop results showed that individuals involved in data analysis and decision-making in malaria control already possessed significant reservoirs of knowledge and expertise related to malaria risk mapping, and that modelled surfaces workshops can be valuable tools for connecting policy to practice in the space of data visualization. Participants in particular suggested that it was valuable to be provided space and time to discuss in a focused setting which metrics were available and needed in Madagascar, their strengths and limitations, and the ways they might be integrated into national and sub-national planning.

Limitations of this study include the low attendance of stakeholders with 'policy and programming' responsibilities ($n=3$; 20%) and 'implementation of interventions or vector control' responsibilities ($n=2$; 13%) – though they were not the intended target audience for the workshop.

Moreover, the DHS workshop emerges as a potential avenue for addressing a key limitation to the use of malaria risk maps identified in **Chapter 3** – that being *communication* (i.e., a lack of understanding or

awareness of the underlying malariometrics being depicted by modelled surfaces and their attendant programmatic value). This suggests that the development of mapped outputs and policy recommendations via a modelled surfaces workshop is a form of capacity strengthening and knowledge co-production, it is also arguably a form of 'community-based participatory research' (CBPR), a collaborative research approach that attempts to equitably include those affected by a research process in the design and implementation of that research.[199] CBPR has ethical risks related to study design and data collection; in this case, the DHS and MAP mitigated these by working closely with the Madagascar DLP and MoH to design the workshop in a way that aligned well with Malagasy needs, and to provide support for additional trainings for interested stakeholders (e.g., sponsoring four DLP officials to attend the Regional Malaria Indicator Trends Workshop in Dakar, Senegal in April 2018). Nevertheless, to be more effectively aligned as a CBPR project, future modelled surfaces workshops should consider including participants from the directly-affected Malagasy communities.

This alludes to a final limitation of the study – a lack of workshop-specific follow-on knowledge co-production between the researchers and workshop attendees. This latter concern is perhaps mitigated by the post-workshop questionnaire (6 months later) that was conducted by DHS, though the results were not reviewed as part of this Chapter. More importantly, it is clear that there is concerted, ongoing programmatic relationship between MAP, DHS, and the Madagascar malaria control teams – which like all relationships based on trust, requires maintenance and care.

Chapter 5

Recommendations for future research

This short Chapter summarizes – in brief – three possible extensions which have been identified for the further research building upon this thesis: (1) implications for future Madagascar <<Direction de lutte contre le paludisme>> (DLP) malaria control efforts; (2) implications for malaria control decision-making frameworks; and (3) implications for global health pandemic policymaking.

5.1 Implications for future Madagascar DLP malaria control efforts

Firstly, researchers could use the insights generated from the in-depth interviews in **Chapter 3** and **Chapter 4** to generate programmatically-valuable maps (e.g., accessibility maps, predictive stock-out maps, etc.) to assist the Madagascar DLP with their future insecticide-treated bed net (ITN) campaigns or other malaria control efforts.

For instance, researchers could follow-up to collaborate with The Pasteur Institute and DLP officials to model and map stockouts, accessibility, and epidemic outbreaks to show the relationships between where they are occurring, with the goal of assisting with predictive supple management to provide for the areas most likely to be in need soonest and with the greatest difficulty of having those needs met.

5.2 Implications for malaria control decision-making frameworks

Secondly, an investigation could be conducted into how malaria risk maps can contribute to existing or novel decision-making frameworks and tools for malaria control in Madagascar. The research suggested that with a range and complexity of trade-offs existing in malaria control, significant

investment has been made into producing tools and schematics for guiding policymakers in crafting their responses. A review in *Health Policy* identified malaria elimination and control as a particularly important candidate for decision making analysis,[200] and outlined five unique challenges that exist in vector-borne disease control policy that make decision analysis particularly salient: (1) a high-stakes environment; (2) multiple actors at multiple scales; (3) complex trade-offs; (4) dynamics, inter-dependencies, and uncertainties; and (5) complex human-environment interactions.[201]

A potential research extension for this thesis would therefore focus on building out theoretical approaches for malaria decision-analysis. The work could provide insight on factors such as: the optimum geographic scales for a particular control intervention;[202] integrating 'uncertainty' at the appropriate level of geographical detail needed to support intervention allocation decisions; quantification of asymmetric decision cost functions to account for trade-offs in cost and efficiency;[203] and approaches to structural inclusion of participatory co-design principles into policy development.[204]

Moreover, the findings from the mapping and stakeholder interviews could be usefully integrated into existing outputs like the Malaria Decision Analysis Support Tool (MDAST)[188] – going beyond the malaria and disease control literature and investigating relevant transdisciplinary theoretical approaches[205] in a potentially broad range of fields, especially normative decision theory literature concerning the optimum allocation and targeting of resources under uncertainty.

5.3 Implications for global health pandemic policymaking

Finally, it is worth exploring how malaria risk map tools, methodologies, and outputs could inform or be retrofitted to assist global health pandemic policymaking. The World Health Organization's Global Malaria Program (GMP) and Health Emergencies Program (HEP), in collaboration with its Regional Offices, has been investigating how the surveillance work of the Africa Taskforce for Coronavirus Preparedness and Response (AFTCOR) can be aided by the malaria community. It is worth examining how malaria policy and malaria mapping can assist with: integrating COVID-19 syndromic surveillance into existing malaria surveillance systems; using modeling of malaria logistics (e.g., travel time, accessibility) to assist operational and technical questions for COVID-19 vaccination programmes; understanding shortages of health workers and commodities that may be salient for COVID-19 response efforts; and examining disruptions to control intervention campaigns (e.g., long-lasting insecticidal bed net (LLIN) distribution campaigns) under new COVID-19 conditions.

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Appendices

Appendix A.1: Research presentations and meetings

The following comprises a non-exhaustive list of meetings, conferences, and presentations attended and contributed by this author, since matriculating Oxford University.

Malaria Modelling Consortium
8th Malaria Modelling Conference (Participant)
London, United Kingdom | 27-28 March 2017

School of Geography and the Environment, Oxford University
4th Oxford Desert Conference (Oral presentation)
Oxford, United Kingdom | 8-9 June 2017

American Society of Tropical Medicine and Hygiene
66th Annual ASTMH Meeting (Participant)
Baltimore, U.S.A. | 5-9 November 2017

Rhodes Trust
2nd Rhodes Healthcare Forum (Oral presentation)
Oxford, United Kingdom | 3-5 November 2017

Appendix A.2: Publications

Malaria Journal

MEETING REPORT

Open Access

A stakeholder workshop about modelled maps of key malaria indicator survey indicators in Madagascar

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Abstract

The Demographic and Health Surveys (DHS) Program has supported three household Malaria Indicator Surveys (MIS) in Madagascar. The results of 13 key malaria indicators from these surveys have been mapped as continuous surfaces using model-based geostatistical methods. The opportunities and limitations of these mapped outputs were discussed during a workshop in Antananarivo, Madagascar in July 2018, attended by 15 representatives from various implementation, policy and research stakeholder institutions in Madagascar. Participants evaluated the findings from the maps, using these to develop figures and narratives to support their work in the control of malaria in Madagascar.

Keywords: Madagascar, The DHS Program, Malaria Indicator Surveys, Malaria indicator maps, Geostatistical modelling, Workshop

Background

The Demographic and Health Surveys (DHS) Program in Rockville, Maryland USA, funded by USAID, has provided technical assistance to more than 300 household surveys in over 90 countries, advancing global knowledge of health and population trends in developing countries [1]. The most recent nationally-representative surveys conducted in Madagascar are the 2011, 2013 and 2016 Malaria Indicator Surveys (MIS) [2–4]. Following the 2016 MIS, there was a request to further examine the outputs from these surveys and aid in the capacity strengthening of the participants to use the data for programmatic decision-making. Given the diverse epidemiology of malaria in Madagascar and issues of accessibility across the country [5–7], it was proposed to collaborate with the Malaria Atlas Project (MAP) to create a series of modelled surface maps showcasing the results of 13 key malaria indicators from both the 2013 and 2016 MIS surveys [8]. The MAP research group is a World Health Organization (WHO) Collaborating Centre in Geospatial Disease Modelling that uses an evidence-based cartographic approach to model continuous spatial maps and quantify metrics including population estimates of malaria infection prevalence and clinical burden [9–11]. At the time of writing, modelled indicator maps for 32 different country surveys globally are freely available from the DHS Spatial Data Repository website.

The spatially modelled surfaces of the DHS malariometric data are produced using a combination of publicly available DHS data and global environmental datasets,

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and use standardized geostatistical methods to promote comparability across countries and facilitate policy and programme decision-making. Although the creation of these surfaces is not new, their incorporation as part of formal decision-making processes is not yet routine.

To help contribute to informed decision-making about future malaria policies and intervention programmes in Madagascar, The DHS Program and MAP collaborated to create a workshop curriculum exploring the spatially modelled surfaces of the 2013 and 2016 MIS surveys. The workshop goals were to convey the added value of spatial modelling in deriving more robust indicator metrics, and to help support the integration of maps into monitoring and evaluation of malaria indicators across Madagascar.

Why map the MIS indicators?

Improved understanding of geographic variation and inequity in health status, wealth, and access to resources within countries is increasingly recognized as central to meeting malaria control targets [12]. Malaria indicators assessed at national levels may conceal important inequities in smaller administrative/geographic areas, often with the rural poor the least well represented. As malaria prevalence drops and international funding for malaria comes under pressure, the ability to target limited resources to underserved groups becomes more crucial [13, 14]. At the same time, gaps exist in progress towards achieving targets for key malaria indicators [15]. Monitoring inequalities for targeting control interventions and measuring progress towards health and development goals requires a reliable, detailed, and disaggregated evidence base.

Different approaches currently allow for estimating malaria indicator metrics for small geographic units. These include (i) increasing the sample sizes of national household surveys to ensure representative sampling of lower administrative areas, (ii) using data from routine health information systems from health facilities or communities, and (iii) small area estimation including spatially interpolated maps that use statistical modelling techniques to predict values for small geographic units. Increasing sample sizes incurs additional costs and time, which are often not feasible in an increasingly resource-constrained environment. Next, the quality and national representativeness of routine health information system data is not always reliable, nor are the data always easily accessible. It is, therefore, the third approach with spatial interpolation that has attracted increased interest in recent years [12, 16, 17].

Malaria is highly diverse across Madagascar, requiring different combinations of interventions across the country's epidemiological ecozones [5, 18]. These areas are stratified based on the duration and intensity of transmission, and the preceding years' diagnostic positivity rates. The Madagascar MIS sampling design was powered to generate summary indicator metrics at these epidemiological and programmatic scales (n = 5), as well as at the national level. Programme implementation, however, is managed at the health district level (n = 114), and the raw MIS results cannot determine indicator progress at this scale. Geostatistical approaches are able to use the available cluster-level MIS results coupled with environmental covariates to predict indicator values for all areas of the country. This greatly empowered dataset allows indicators to be aggregated to programmatically useful scales [8].

Workshop structure and objectives

The purpose of the Madagascar Modelled Surfaces Workshop was to assist the National Malaria Control Programme (NMCP, or "Direction de Lutte contre le Paludisme") and other malaria data partners in the interpretation and application of modelled maps that showcase the geographic variation of malaria indicators across Madagascar. The workshop's specific objectives included training on (i) understanding and correctly interpreting the core household MIS indicators, (ii) understanding the creation of the modelled surfaces, their limitations and inherent assumptions, (iii) accurately interpreting the modelled surfaces, and (iv) identifying narratives in the maps to answer key programmatic questions.

In advance of the workshop, key members of the NMCP, the Ministry of Health (MoH), the Direction des Etudes et de la Planification, the Direction du Système d'Information, and the research organization Institut Pasteur de Madagascar were contacted to nominate members of their staff to attend the workshop. Participants were required to have some experience with geographic information system (GIS) software and needed to analyse malaria data as part of their job. In total, 15 people participated in the workshop, which took place over 4 days in July 2018 in Antananarivo, Madagascar.

Activities throughout the workshop were designed to encompass a range of adult learning techniques. Interactive PowerPoints, blended learning, guided demonstrations, hands-on exercises and small group activities were all used. The workshop culminated in final presentations from each indicator topic team (broadly categorized as: vector, case management, and morbidity) including a programmatic question they wanted to address, the audience for their presentation, an introduction to the problem in Madagascar, the indicators selected for analysis, appropriate maps, and interpretation/recommendations emerging from the modelled surfaces.

Mapping methodology

The field of spatial statistics is continually developing ever more complex and refined models [12, 16]. Highly bespoke approaches, however, limit the comparability of model outputs, both through time and between locations. Instead, the methodological approach for mapping The DHS Program indicators was deliberately designed to generate standardized outputs informed by globally available input datasets, thereby allowing full comparability across countries and survey years [8]. From the Madagascar MIS results, a subset of 13 malaria indicators was identified as suitable for spatial analysis [19], and were modelled in advance of the workshop (Table 1). These surfaces (including both mean predictions and the associated 95% credible interval uncertainty maps) are all freely available from The DHS Spatial Repository website, together with detailed reports about the mapping methods employed [17, 19–22]: http://spatialdata.dhsprogram.com/modeled-surfaces/. Globally, modelled maps of selected indicators from 32 MIS/DHS surveys from 31 countries are currently available.

As previously described, a model-based geostatistics (MBG) approach was found most appropriate for generating standardized spatial outputs from the raw MIS cluster results [8, 20]. The foundation of MBG is spatial interpolation, where estimates for each grid cell are driven by nearby survey observations coupled with the geographic patterns of biologically pertinent spatially-continuous covariate surfaces (Table 2). The modelling process characterizes the patterns observed in the survey data into four components: sampling variance is represented by a binomial sampling model; non-sampling error is explained through fixed effects (by a multivariate regression relationship defined by linking the indicator variables to the covariates) and random effects (Gaussian Process parameterized by a Matern spatial covariance function); and finally, a simple Gaussian noise term represents residual variation. All model parameters are jointly estimated in a Bayesian framework [8, 20] which generates pixel-level predictions for each indicator across the country, informed by the patterns in the relevant environmental covariates selected by the model for their spatial correlation with the raw indicator data.

These overarching methodological concepts were introduced during the workshop, together with a discussion of exploratory spatial data descriptive statistics (including variograms and histograms plotting the structure of the indicator values) and model validation statistics. The workshop objective was to provide conceptual insight into the mapping methods and allow appropriate critical evaluation of the modelled outputs. As such, strong emphasis was also placed on the output limitations (e.g. weakness of modelling urban areas and difficulties of temporality in the indicator measures [17]) and the importance of assessing relative confidence in the predictions between areas. Examples of GIS-based manipulations of the modelled surfaces were then presented and trialed by the participants.

Table 1 MIS indicators from the 2013 and 2016 Madagascar surveys selected for spatial modelling

Indicator	Definition
MLFEVTCACT	Among children under age five with fever in the 2 weeks preceding the survey, the percentage who took a drug combination with artemisinin
MLFEVTCADV	Among children under age five with fever in the 2 weeks preceding the survey, the percentage for whom advice or treatment was sought
MLFEVTCBLD	Among children under age five with fever in the 2 weeks preceding the survey, the percentage who had blood taken from a finger or heel for testing
MLHEMOCHL8	Percentage of children aged 6–59 months with haemoglobin lower than 8.0 g/dl
MLIPTPW2SA	Percentage of women aged 15–49 with a live birth in the 2 years preceding the survey who during the pregnancy took two or more doses of SP/Fansidar, with at least one dose during an antenatal care visit [intermittent preventive treatment for pregnant women (IPTp2+)]
MLIRSMHIRS	Percentage of households with indoor residual spraying (IRS) in the 12 months preceding the survey
MLITNAPACC	Percentage of the de facto household population who could sleep under an ITN if each ITN in the household were used by up to two people
MLNETCCITN	Percentage of children under age five who slept under an ITN the night before the survey
MLNETPHITN	Percentage of households with at least one ITN
MLNETUPITN	Percentage of the de facto household population who slept under an insecticide treated net the night before the survey
MLNETWWITN	Percentage of pregnant women who slept under an ITN the night before the survey
MLPMALCMSY	Percentage of children aged 6–59 months tested using microscopy who are positive for malaria
MLPMALCRDT	Percentage of children aged 6–59 months tested using a rapid diagnostic test (RDT) who are positive for malaria

The modelled continuous surfaces together with 95% credible interval maps are available for both survey years as .png images and .tif raster files from the DHS Program Spatial Data Repository [21, 22]

Table 2 Mapping covariates used in the modelling [17]

Short name	Description	Original data source	Temporal	Date
Population				
Access	Travel time to cities with greater than 50,000 population via all transport methods	http://forobs.jrc.ec.europa.eu	Static	2000
NTL	VIIRS nighttime lights	http://ngdc.noaa.gov/eog/	Static	2012
GPW	Gridded population of the world (GPW) population density	http://sedac.ciesin.columbia.edu/	Static	2010
Physical earth				
Elevation	Shuttle radar topography mission (SRTM) near—global digital elevation models (DEMs)	http://webmap.ornl.gov/	Static	2000
Environment				
Aridity	Mean annual aridity	http://csi.cgiar.org/Aridity/	Synoptic	1950–2000
PRECIP	Average monthly rainfall	http://www.worldclim.org/	Synoptic	1950–2000
EVI	Enhanced vegetation index	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014
LST.day	Land surface temperature in the daytime	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014
LST.delta	Land surface temperature daily fluctuation range	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014
LST.night	Land surface temperature in the nighttime	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014
PET	Mean annual potential evapotranspiration	http://csi.cgiar.org/Aridity/	Synoptic	1950–2000
TCB	Tasseled—cap brightness	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014
TCW	Tasseled—cap wetness	http://modis.gsfc.nasa.gov/	Multitemporal	2001–2014

Putting maps into practice: exploratory case studies of programmatic applications of the modelled MIS indicator maps

The final two days of the workshop were largely dedicated to allowing the participants to explore the modelled maps to derive programmatically-pertinent recommendations that could plausibly be applied in the context of their current positions. Outcomes of these group discussions are summarized here, illustrating different ways in which The DHS Program modelled surfaces may be easily and rapidly applied by NMCPs and fellow stakeholders. While more formal analyses were encouraged, these were outside the timeframe of the workshop.

Example 1 Strengthening access to intermittent preventative treatment in pregnancy.

Intermittent preventative treatment in pregnancy (IPTp) with sulfadoxine–pyrimethamine (SP) was brought into policy in Madagascar in 2004, and a progressive scale-up has led to this now being implemented in all control-phase districts. The WHO recommendation to increase the minimum number of doses from two (IPTp2+) to three (IPTp3+) was initiated in Madagascar in 2015. Given this, the IPTp3+ coverage indicator was not appropriate to examine given the temporality of its definition (having as denominator the "total number of women surveyed who delivered a live baby in the 2 years preceding the survey" [23], i.e. extending to before the IPTp3+ policy was locally implemented). Instead, IPTp2+ was evaluated. District-level aggregation of the modelled surface indicated that coverage in 2016 remained below 20% in 40% of target districts (Fig. 1a). This was consistent with relatively weak coverage of antenatal consultations with an estimated one third of pregnant women never attending an antenatal consultation (source: MoH, 2017), and health facilities regularly notifying SP stock-outs (43% did during 2016; source: NMCP, 2017).

The modelled surfaces made apparent a degree of spatial heterogeneity in the coverage of IPTp2+ (Fig. 1a), with high predictive uncertainty (> 20%) also widespread (Fig. 1b) likely associated with the relatively small sample sizes inherent to this indicator (N = 2786, relative to 10,816 respondents for other indicators in 2016).

Recommendations were made for increased sampling effort in high uncertainty coastal districts during future MIS, as well as strengthening the reporting of IPTp during antenatal consultations at health facilities. Reinforced collaboration between the NMCP and the National Family Health programme was also recommended, alongside renewed awareness campaigns targeted to areas of weakest coverage (Fig. 1a).

Example 2 Spatio-temporal trends in access to insecticide-treated nets and implications for future mass distribution campaigns.

Madagascar aims for universal coverage of insecticide-treated nets (ITN) across all control-phase districts. This

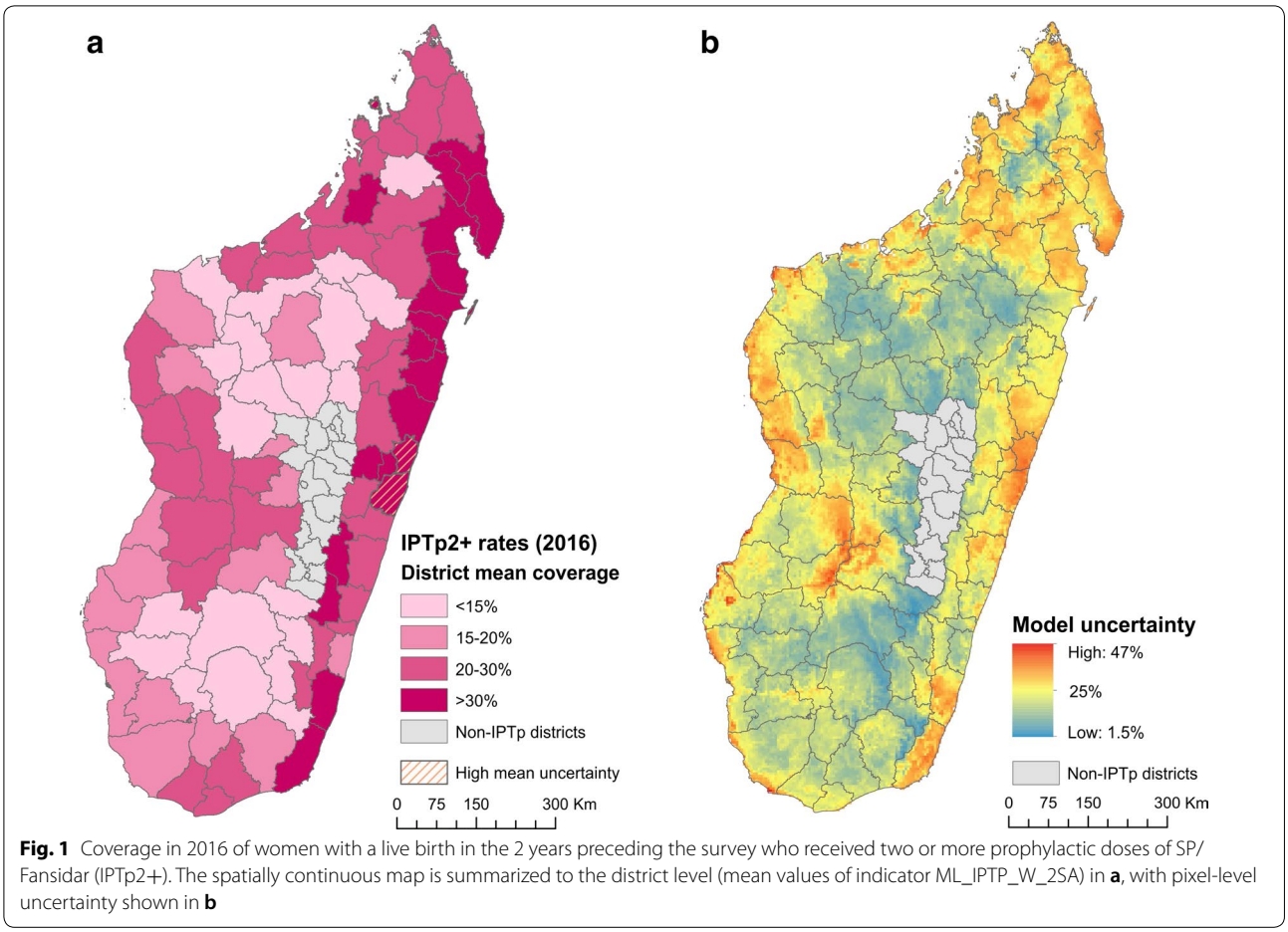

Fig. 1 Coverage in 2016 of women with a live birth in the 2 years preceding the survey who received two or more prophylactic doses of SP/Fansidar (IPTp2+). The spatially continuous map is summarized to the district level (mean values of indicator ML_IPTP_W_2SA) in **a**, with pixel-level uncertainty shown in **b**

is achieved primarily through mass distribution campaigns, the last having been in 2012–2013, 2015 and 2018 [18, 24]. The current objective is that at least 90% of households in the target districts should have at least one ITN per two residents. Several channels of continuous distribution supplement the mass campaigns, including antenatal consultations, community-health worker distributions, and subsidized sales in peri-urban communities. The MIS in 2013 and 2016 therefore assessed the overall impact of these activities, allowing changes in coverage during that time period to be quantified.

Interpretation of the survey outcomes must account for timings relative to mass distribution campaigns. The 2013 MIS took place part way through a distribution campaign, with 31 districts covered in the 6 months before the MIS, and 61 districts after the MIS. In contrast, all target districts were included in the mass ITN distribution during the 6 months preceding the 2016 MIS.

Several ITN coverage indicators based on different denominators (households vs. residents) were included in the spatial analyses, each representing different aspects of the programme's impact (Table 1). Here, participants selected three of these indicators to assess ITN coverage across Madagascar in 2016 (Fig. 2a–c) and relative changes in these indicator levels since 2013 (Fig. 2d–f), with the aim of exploring what lessons could be derived from the modelled surfaces for future distribution campaigns. These included the spatial reach of the distribution campaigns using the indicator of presence of any ITNs in the household (Fig. 2a, d), the adequacy of coverage when accounting for the number of household residents (the target is for one net per two individuals; Fig. 2b, e), and finally usage of available nets (Fig. 2c, f). The mapped surfaces were aggregated to district units to reflect the level at which decision-making and logistics are coordinated during ITN campaigns.

The modelled surfaces revealed that while the reach of the ITNs was quite high, with 52 of 92 target districts predicted to have > 90% of households with at least one bed net, this coverage dropped dramatically when considering the adequacy of ITN availability according to the objective of one ITN per two people by household. No district met the national objective of 90% in 2016, though 39 (42%) had levels > 75%. Nevertheless, reported

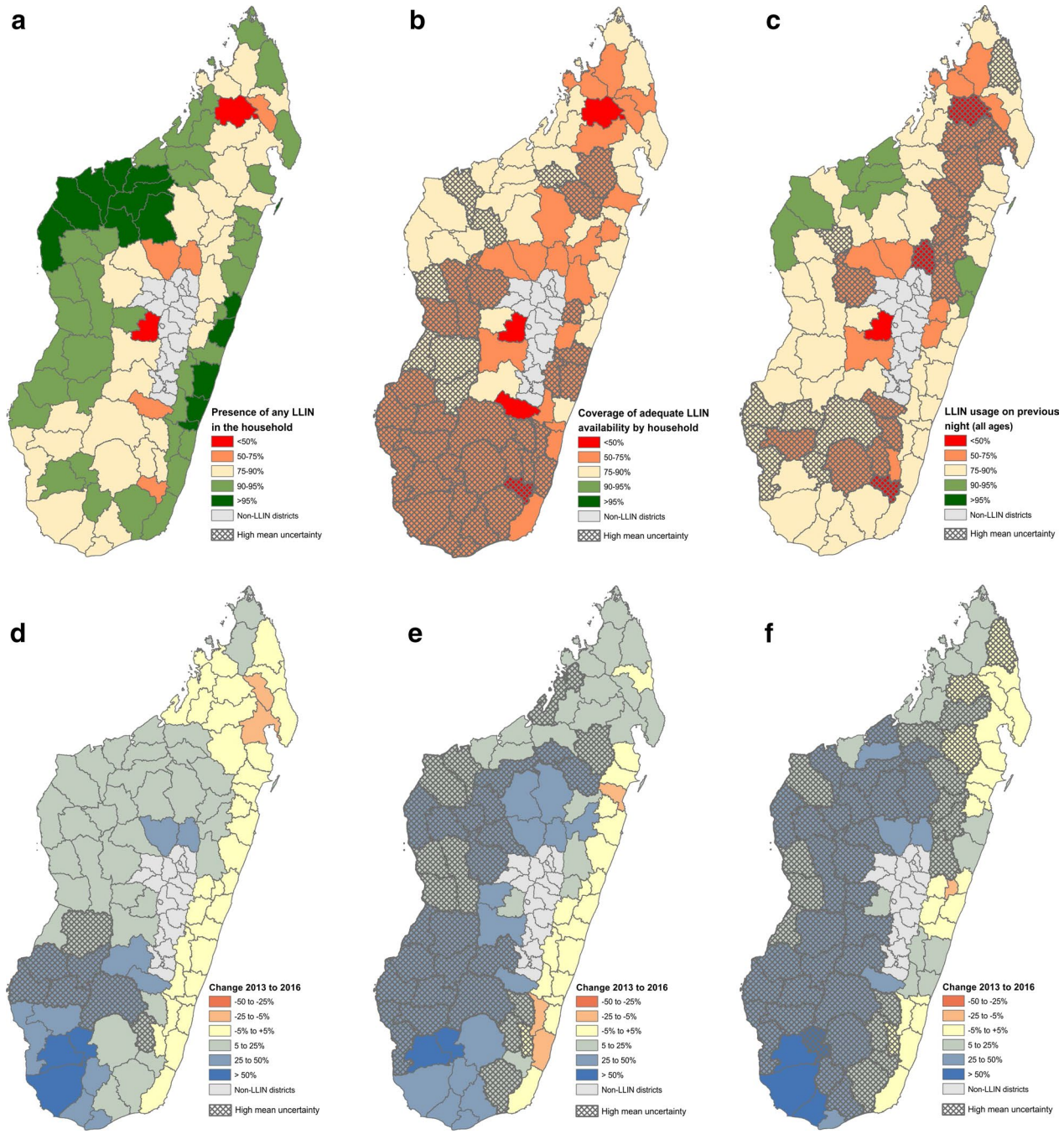

Fig. 2 Characteristics of ITN coverage and usage at the district level for 2016 (**a**–**c**) and relative change from 2013 (**d**–**f**). **a**, **d** Correspond to the percentage of households with at least one ITN (indicator ML_NETP_H_ITN). **b**, **e** Quantify the proportion of the population with access to an ITN within their household when shared by at most two people (ML_ITNA_P_ACC). **c**, **f** Map the percentage of household residents reported to have slept under an ITN the night preceding the interview (ML_NETU_P_ITN). The spatially continuous maps are aggregated to the district level and presented as mean values, with relative uncertainty based on crude means of the pixel-level uncertainty metrics

indicators of usage by household residents indicated that ITNs were being used at rates suggesting that even where ITN numbers were insufficient within households, residents were sleeping under the nets which were available. Coverage of these ITN indicators was generally better in coastal areas where transmission was higher [6], particularly along the northern districts of the west and east coasts. Coverage dropped into the highland areas where

transmission was less intense. The maps suggested generally sustained or positive changes in coverage between 2013 and 2016, with greatest improvements in southern districts even though coverage remained among the lowest nationally in these same districts. In the east coast districts, where transmission is highest and ITN coverage still falls short of national targets, there was little reported change from 2013. However, there were extensive areas of high uncertainty in the model predictions, notably in the maps of ITN accessibility and usage where the map estimates need to be interpreted with caution (Fig. 2b, c, e, f). Spatial heterogeneity in the cluster-level results may explain uncertainty in these areas.

Recommendations for future campaigns that emerged from these modelled maps were to focus on increasing the numbers of nets distributed, with reinforced efforts particularly in east coast areas where coverage was low despite relatively high transmission. Results on usage were encouraging but still inadequate, indicating that further behaviour communication interventions would be important alongside the distributions, as per the NMCP's guidelines.

Example 3 Treatment-seeking for febrile infants.

Seeking treatment during a febrile episode is the critical first step towards effective case management and reductions in malaria morbidity, as well as towards ensuring reliable reporting of malaria episodes for surveillance. Low treatment-seeking rates across much of Africa are a main reason for the WHO using data sources independent of routine surveillance in their estimations of clinical case burdens [15, 25]. The MIS indicator quantifying this is rates of treatment seeking by mothers for any children younger than 5 years having suffered a febrile episode in the 2 weeks preceding the survey.

The national-level MIS results from Madagascar suggest an increased, but nevertheless low, treatment-seeking rate from any type of health provider for febrile children from 38% in 2013 to 46% in 2016. Only 29% and 36%, respectively, sought treatment from the public health facilities likely to provide appropriate free case management and to report monthly case estimates to the centralized MoH database. These low rates of contact with recommended healthcare providers are a target of Madagascar's current National Strategic Plan through behaviour-change communication activities. Better insight into this indicator's tendencies would help focus future efforts based on current gaps and local infection risk levels.

The MIS treatment-seeking indicator was therefore evaluated to see what spatio-temporal trends could be derived beyond the national summary figures. Descriptive statistics are presented for 2013 (Fig. 3a–c) and 2016

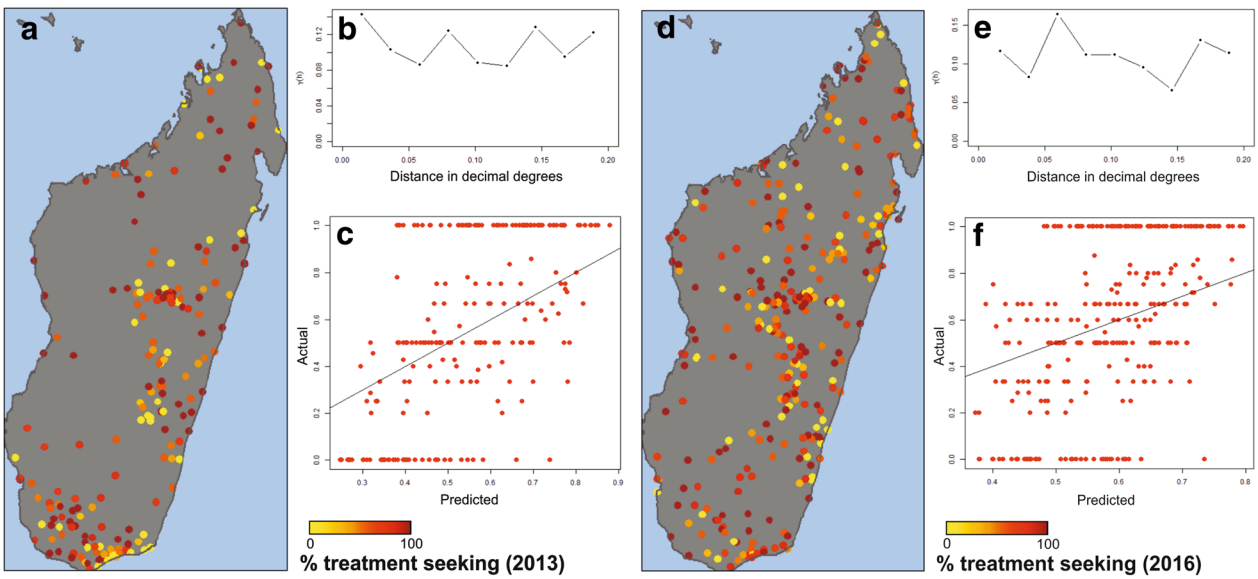

Fig. 3 Descriptive statistics of the spatial characteristics of treatment seeking rates by mothers for febrile infants under 5 years old in the 2 weeks preceding the interview (indicator ML_FEVT_C_ADV). **a**–**c** Represent the 2013 MIS data, and **d**–**f** are for 2016. The maps in **a**, **d** illustrate the cluster-level raw treatment-seeking rates, while **b**, **e** are variograms (a tight spatial structure would show an increasing lag—or dissimilarity between points—with increasing spatial distance). **c**, **f** Plot the model validation of observed cluster-level raw values (y-axis) against predicted values in those locations. In the model validation, a random 25% of the dataset is withheld and the model run with the remaining 75%; this process is repeated four times without replacement, thus giving validation-predictions for all cluster locations (**c**, **f**). Tight scatterplot correlation suggests greater precision in the model's predictive performance

(Fig. 3d–f). The cluster-level raw numbers showed a high level of spatial heterogeneity (Fig. 3a, d), likely associated with the variable and sometimes small samples sizes (overall $n_{2013} = 633$ and $n_{2016} = 1096$ eligible mothers across the country whose children had suffered a febrile episode in the 2 weeks preceding the survey, which become very small when considered at the cluster-level). The raw datapoint values (Fig. 3a, d) and the variograms (Fig. 3b, e) revealed that the dataset had limited spatial structure, also reflected by high relative uncertainty in the predicted maps. Consistent with these characteristics, the model predictions revealed low correlation with the raw cluster-level observed data (Fig. 3c, f). These warnings in the data suggest that the spatial predictions from this current dataset and model may not be appropriate to rely on.

These insights indicate to stakeholders interested in improving rates of appropriate malaria case management that the data and models examined here are insufficient to allow meaningful assessments of current treatment-seeking levels. Additional efforts will be necessary to strengthen the evidence base and allow this indicator's subnational trends to be understood. The low sample sizes associated with this specific MIS indicator—owing to its opportunistic nature—limit the statistical power required for high-resolution analyses.

Alternative approaches, such as active case detection, or simply larger sample sizes could provide more robust insight into this important indicator. A strong message, therefore, emerges to advocate for reinforcement of this indicator, to allow important questions about variability in behaviour across the island and the impact of NMCP initiatives on behaviour change over time to be answered. This remains essential to improving treatment-seeking rates and appropriate case management: cornerstones of any control programme.

Participant evaluations

Qualitative interviews conducted ahead of the workshop with NMCP staff suggested that knowledge and use of maps by the Programme were commonly limited to descriptive mapping of aggregated reported incidence rates and summaries of epidemic clusters. Modelled malaria risk maps were not used programmatically, nor was there significant knowledge of what they represent.

Participants were issued a 13-question test to evaluate their knowledge of MIS indicators, modelled surfaces, and statistical uncertainty both before and after the workshop. The mean participant score increased from 54 to 87%, with all but one participant improving in their performance (that participant's score remained constant at 86%). Anonymous evaluation forms were also filled out on the last day of the workshop, giving participants the opportunity to assess the relevance, pace and content of the workshop content, and to give comments or suggestions. Feedback was positive. Participants indicated that they learned a great deal from the lectures and exercises. They appreciated the knowledge and skills acquired during the workshop and planned to use the modelled surfaces as part of programmatic decision-making in the future.

Throughout the workshop, participants identified examples of how the modelled maps could be applied in their specific domains of work. These included, for example, allowing more precise decision-making in the absence of complete datasets; tailoring intervention responses appropriately during epidemics using regionally-specific indicator information; providing more information in resource-constrained contexts where additional data is difficult to request; and use as advocacy tools when communicating with non-expert audiences or for synthesizing information in grant applications. The imminent launch of the 2018 bed net distribution campaign provided a very explicit case study for how the modelled surface maps could support refinements to future planning activities, with the maps highlighting areas at greatest need for reinforced resources.

The most consistent critique was that the workshop was not long enough. In particular, the majority of participants thought that they would have benefitted from more time to practice manipulating the maps in ArcGIS, as well as training in R coding. The workshop allowed participants the opportunity to discuss data-informed decision making in Madagascar, and many commented that the workshop helped further their understanding of malaria indicators which they deemed essential for programme level decisions. Discussions around the context, strengths and weaknesses of the indicators, as well as MIS study designs, proved to be a very valuable asset to the workshop.

Conclusions

This was the first country-specific Modelled Surfaces Workshop to be implemented by The DHS Program. While this type of workshop may not be recommended for every country, it was highly beneficial for Madagascar, where multiple MIS surveys have been implemented and the malaria epidemiology is variable across the country. Developing the portfolio of modelled indicator maps and training the workshop participants to critically evaluate and analyse them, increases the capacity of the country's malaria control stakeholders to make data-driven decisions. The Madagascar maps are freely accessible from the DHS Spatial Data Repository website [21, 22], alongside maps of selected indicators from MIS/DHS surveys in 30 other countries. All participants recommended the

workshop to other NMCPs, and some requested additional training to be conducted in Madagascar.

Abbreviations

DHS: Demographic and Health Surveys; GIS: geographic information system; IPTp: intermittent preventative treatment in pregnancy; ITN: insecticide-treated net; MAP: Malaria Atlas Project; MBG: model-based geostatistics; MIS: Malaria Indicator Survey; MoH: Ministry of Health; NMCP: National Malaria Control Programme; SP: sulfadoxine–pyrimethamine; WHO: World Health Organization.

Authors' contributions

CT designed and facilitated the workshop with REH. KH led the evaluation discussions at the end of the workshop. PWG developed the geostatistical methods and maps. All authors (except PWG) participated in the workshop discussions. REH, KH and CT wrote the first draft of the manuscript, based on original ideas from the workshop participants. All authors read and approved the final manuscript.

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Competing interests

REH and PWG were consultants to The DHS Program for different aspects of the work described here, and CAT is an employee of The DHS Program.

Availability of data and materials

All maps developed for this workshop are freely available from the DHS Program Spatial Data Repository: http://spatialdata.dhsprogram.com/home/.

Ethics approval and consent to participate

Not applicable.

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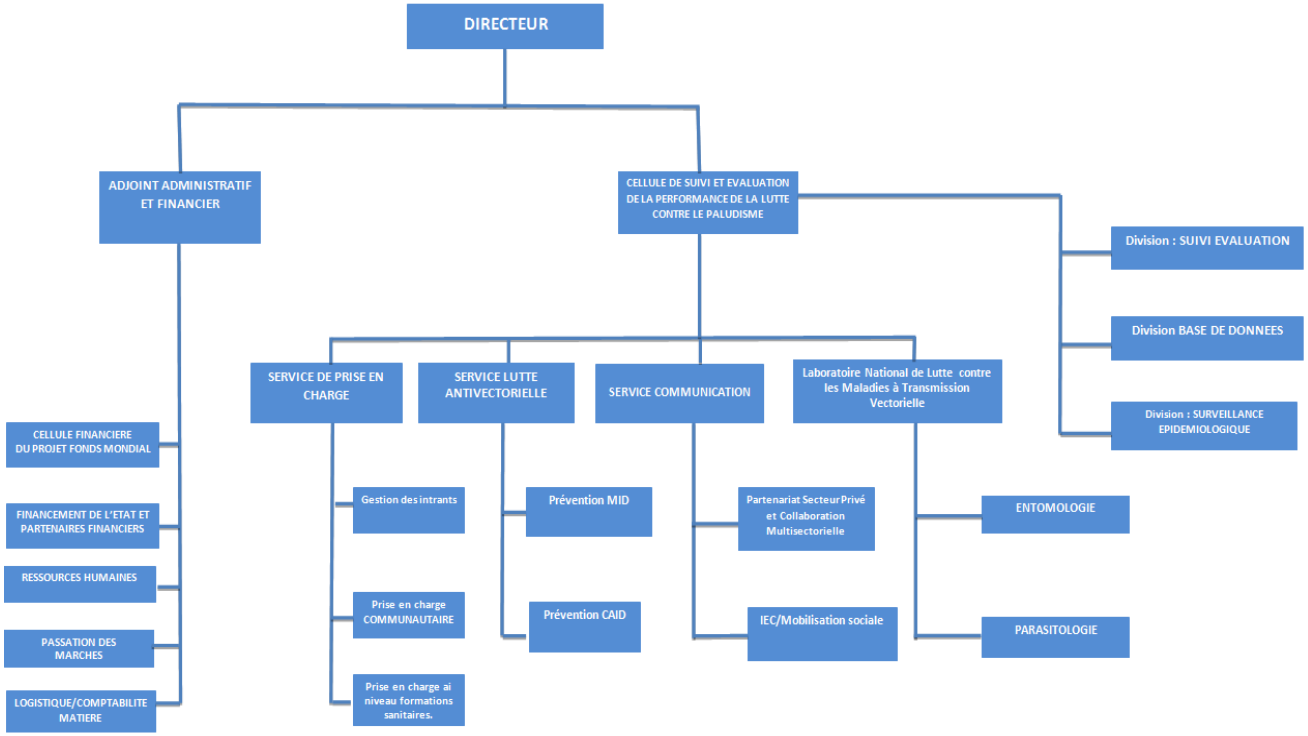
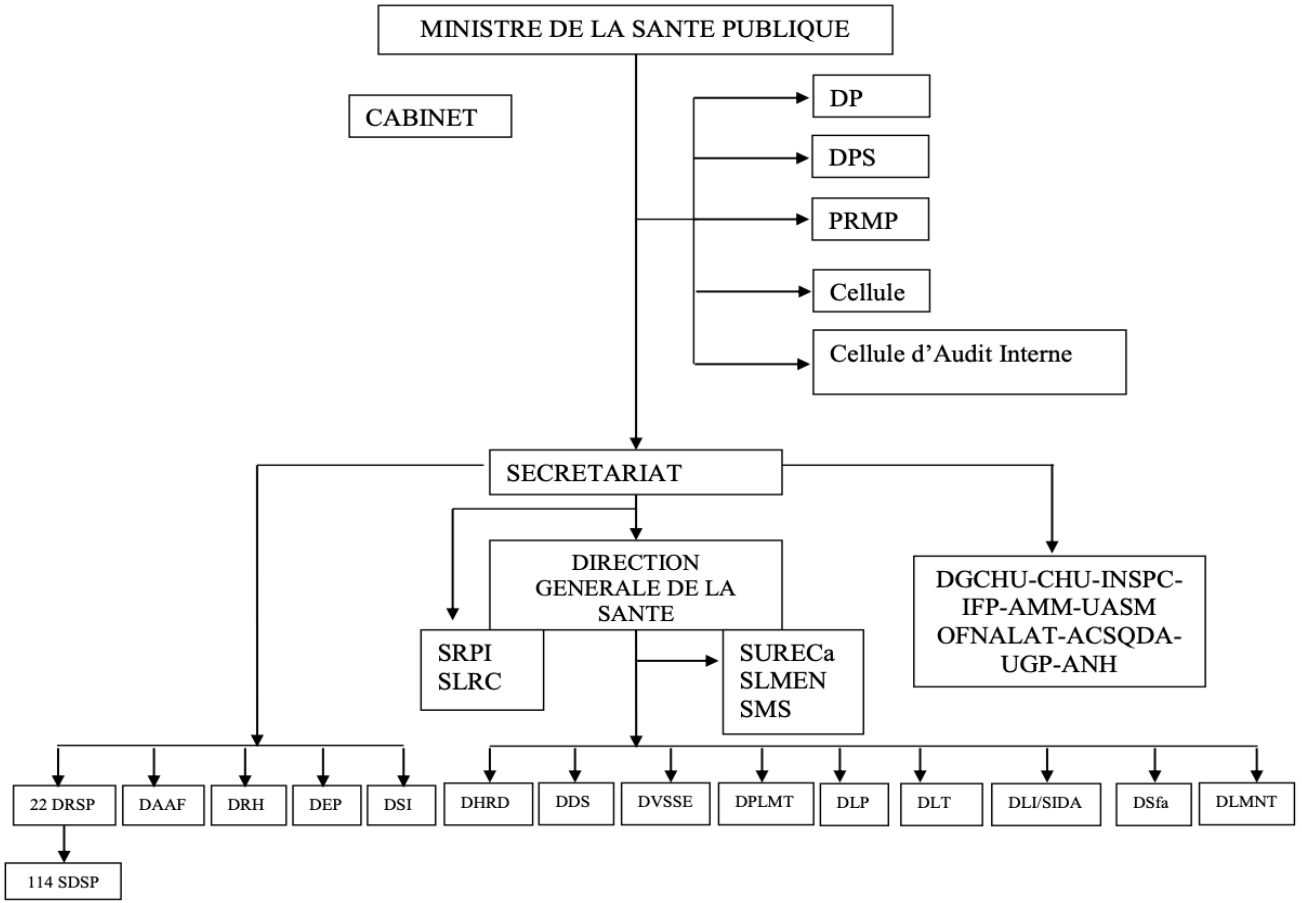
Appendix B.1: Madagascar DLP organogram



Appendix B.2: Madagascar MoH organogram



Appendix B.3: Madagascar stakeholder in-depth interview participant information sheet

Oxford Big Data Institute

Mr. Kaleem Hawa
Kaleem.hawa@bdi.ox.ac.uk

Understanding and improving the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa

PARTICIPANT INFORMATION SHEET

1. ***What is the purpose of this research?***

   To better understand and improve the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa, in order to assist policymakers in control efforts.

2. ***Why have I been invited to take part?***

   As a malaria policymaker, you have been selected to provide insights into the use of geospatial disease mapping in malaria risk stratification. Your role at an organization involved in health decision-making positions you well to contribute to this research.

3. ***Do I have to take part?***

   No. You can ask questions about the research before deciding whether or not to participate. If you do agree to participate, you may withdraw yourself from the study at any time, without giving a reason, by advising the researchers of this decision.

4. ***What will happen to me if I take part in the research?***

   If you are happy to take part in the research, you will be asked to sit down with our researcher for a single interview at a location of your choosing. You will be told about the research, provided a consent form to sign, and then the interview will begin. This should take approximately 30 minutes. This research will involve audio-recording of answers for anonymized transcription. You will be asked question about malaria control efforts and how they might be improved by the use of geospatial disease mapping.

5. ***Are there any potential risks in taking part? Are there any benefits in taking part?***

   There are no potential risks to taking part, and we anticipate that the insights you provide will help future decision-making about malaria control.

6. ***What happens to the data provided?***

   The information you provide as part of the study is the **research data**. Any research data from which you can be identified (eg. your name, audio recording), is known as **personal data**.

   We will minimise our use of personal data in the study to your name, taking care to pseudo-anonymize and encrypt all files. The **research data** will also be encrypted and stored confidentially, and transferred onto an

encrypted departmental server. Only the researcher and their supervisors will have access to the research data.

All research data, pseudo-anonymised data, and link code list files and records will be stored for at least 3 years after publication or public release of the work of the research. They will then be destroyed/deleted. We may retain and store your personal data for an additional period of time as necessary for the purposes of the study, and for further research, but only with your consent.

Consent forms will be stored securely until research is completed and will be destroyed within a year of publication at latest.

7. *Will the research be published?*

The University of Oxford is committed to the dissemination of its research for the benefit of society and the economy and, in support of this commitment, has established an online archive of research materials. Therefore, this research may be published in relevant academic journals. The research will also be written up as a thesis. On successful submission of the thesis, it will be deposited both in print and online in the University archives, to facilitate its use in future research. The thesis will be openly accessible.

8. *Who is organising and funding the research?*

The Oxford University Big Data Institute is funding and organizing this research, to be conducted by Rosalind Howes and Kaleem Hawa, researchers within the Malaria Atlas Project.

9. *Who has reviewed this study?*

This study has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee. Ref: R58102/RE001.

10. *Who do I contact if I have a concern about the study or I wish to complain?*

If you have a concern about any aspect of this study, please speak to Kaleem Hawa [kaleem.hawa@bdi.ox.ac.uk], who will do their best to answer your query. The researcher should acknowledge your concern within 10 working days and give you an indication of how they intend to deal with it. If you remain unhappy or wish to make a formal complaint, please contact the relevant chair of the Research Ethics Committee at the University of Oxford who will seek to resolve the matter in a reasonably expeditious manner:

Chair, **Medical Sciences Inter-Divisional Research Ethics Committee**; Email: ethics@medsci.ox.ac.uk; Address: Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD, UK.

11. *Data Protection*

The University of Oxford is the data controller with respect to your personal data, and as such will determine how your personal data is used in the study.

The University will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest.

Further information about your rights with respect to your personal data is available from http://www.admin.ox.ac.uk/councilsec/compliance/gdpr/individualrights/.

12. Further Information and Contact Details

If you would like to discuss the research with someone beforehand (or if you have questions afterwards), please contact:

Dr. Rosalind Howes (Senior Postdoctoral Researcher)
Big Data Institute, Oxford University
rosalind.howes@bdi.ox.ac.uk

Mr. Kaleem Hawa
Big Data Institute, Oxford University
kaleem.hawa@bdi.ox.ac.uk

Appendix B.4: Madagascar stakeholder in-depth interview consent form

Oxford Big Data Institute

Mr. Kaleem Hawa
Kaleem.hawa@bdi.ox.ac.uk

Understanding and improving the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa

PARTICIPANT CONSENT FORM

		Please initial each box
1	I confirm that I have read and understand the information letter for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, and without any adverse consequences or academic penalty.	☐
3	I understand that research data collected during the study may be looked at by designated individuals from the University of Oxford where it is relevant to my taking part in this study. I give permission for these individuals to access my data.	☐
4	I understand that this project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.	☐
5	I understand who will have access to personal data provided, how the data will be stored and what will happen to the data at the end of the project.	☐
6	I understand how this research will be written up and published.	☐
7	I understand how to raise a concern or make a complaint.	☐
8	I consent to being audio recorded	☐
9	I understand how audio recordings will be used in research outputs	☐
10	I give permission to be quoted directly in the research publication	☐
11	I agree to take part in the study	☐

Name of Participant	Date	Signature
Name of person taking consent	Date	Signature

Appendix B.5: Madagascar stakeholder project research ethics approval

MEDICAL SCIENCES INTERDIVISIONAL RESEARCH ETHICS COMMITTEE

Research Services, University of Oxford, Wellington Square, Oxford, OX1 2JD
Tel: +44(0)1865 616577 Fax: +44(0)1865 280467
ethics@medsci.ox.ac.uk

CONFIDENTIAL

Ref: R58102/RE001

Mr Kaleem Hawa
52 Abingdon Road
Oxford
OX1 4PE

6th July 2018

Dear Kaleem

Research Ethics Approval - CUREC 1

Study title: Understanding and improving the use of geospatial disease mapping in malaria risk stratification and intervention targeting across sub-Saharan Africa

The above application has been considered on behalf of the Medical Sciences Interdivisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for Ethical Approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and approval has been granted for a period of **18 months**, commencing on **6th July 2018**. The reference number for this study is **R58102/RE001**.

This is **subject to:**

a) **it is your responsibility to comply with the requirements for administering any tests or questionnaires and, if in doubt, to contact the publisher of those tests or questionnaires.**

b) **if new research staff are engaged, the PI is responsible for ensuring they are suitably qualified by training and/or experience.**

I would like to remind you that your study may be selected for review by the MS IDREC during an annual audit.

Amendments

Should there be any subsequent changes to the study, you should submit details to the MS IDREC for consideration and approval. Details of changes must be listed on an amendment form. If your study received University Sponsorship through CTRG, then the amendment will first need to be submitted to CTRG for approval of continued Sponsorship.

Please do not hesitate to contact me if you have any queries.

Yours Sincerely

H. Barnby-Porritt

Dr. Helen Barnby-Porritt
Research Ethics Manager, Medical Sciences

Appendix B.6: Semi-structured in-depth interview guide

Guidance to interviewer: Probe deeper, as necessary, for questions that elicit meaningful engagement. Provide interviewee with visual (sample modelled-surface map and/or malaria risk map from the National Strategic Plan) to ground interview questions.

1. What is your background, and what is your current position?
2. Do you personally use malaria maps in your work?
    - If so:
        i. What types of maps do you use? (e.g., data source/resolution)
        ii. What purpose do maps serve in your work?
    - If not:
        i. Why not?
        ii. Have you seen others use maps?
            - If so, what types of maps do you see others using, and how?
3. Do you believe malaria maps can be/are useful in malaria control efforts?
    - If so, how?
    - If not, why not?
4. Do you think there are any problems with malaria maps?
    - If so, what do you think these are?
        i. How can you generate political or cultural support for the use of malaria maps?

- If not, why not?

5. When deciding how to use malaria interventions (e.g., ITN/IRS. depending on interviewee), is the strategy the same everywhere or does it change based on the area?
    - Is so, at what scale? How is this decided? To what extent is this informed by maps like the ones you saw?
    - If not, should it be? Why or why not?
6. If mapped like this, are there measures of malaria (e.g., metrics) that would be useful to you and your work?
    - If so, what would these be?
    - If not, why not?
    - Would maps of any of these other metrics better address the limitations you identified? How and why?

Appendix B.7: Madagascar stakeholder post-IDI questionnaire

Participant ID Number	

Q1. From your perspective, rate the usefulness of high-resolution malaria maps to the following applications:				
	Very Useful	Useful	Somewhat Useful	Not Useful
Improving the targeting and stratification of interventions				
Increasing cost efficiency of malaria control efforts				
Informing ministry officials of highest-need areas				
Helping government to attain international grants and financing				
Assisting academics and researchers in their work				

Q2. To what extent are any of the following an obstacle to the use of malaria maps in malaria control:					
	Strongly Agree	Agree	Somewhat Agree	Neutral	Disagree
Malaria maps are an inaccurate reflection of actual conditions					
We do not trust the institutions that produce malaria risk maps					
We find it hard to use and understand malaria maps					
Malaria maps are not useful to achieving health targets					
It is hard to act effectively on malaria map recommendations					
It is not cost-effective to apply interventions based on maps					
People do not know what types of maps exist					

Q3. Do you believe that maps of the following malaria metrics would be useful for malaria control?				
	Very Useful	Useful	Somewhat Useful	Not Useful
Infection prevalence maps				
Case incidence maps				
Test positivity rate				
ITN coverage maps				
IRS coverage maps				
Combination of intervention coverage and incidence				

Appendix C.1: DHS workshop agenda

* = *data collected during this session*

Agenda	
DAY 1 (Thursday 26 July 2018):	
8:30am-1:00pm	Welcome, Introductions, and Workshop Overview
	Overview of Madagascar MIS 2013 and 2016 surveys
	Overview of Household-Survey Malaria Indicators
	Malaria Indicator Stations
1:00pm-2:00pm	Lunch
2:00pm-5:30pm	Overview of the DHS Program Modeled Surfaces
	Creation of modeled surfaces*
DAY 2 (Friday 27 July 2018):	
8:30am-1:00pm	Limitations and Assumptions of modeled surfaces*
	Use of modeled surfaces*
1:00pm-2:00pm	Lunch
2:00pm-5:30pm	Finding the story in the maps*
	Group Work*
DAY 3 (Saturday 28 July 2018):	
8:30am-1:00pm	Group Work*
1:00pm-2:00pm	Lunch
2:00pm-5:30pm	Group Work*
	Presentation of key findings*

DAY 4 (Monday 30 July 2018):	
8:30am-1:00pm	Discussion of overall key findings* Discussion on further analysis* Manuscript writing*
1:00pm-2:00pm	Lunch
2:00pm-5:30pm	Finalization of map key findings* Review and Next Steps* ▪ Discuss next steps ▪ Evaluation and suggestions Closing (end of workshop)

Appendix C.2: DHS workshop feedback questionnaire

Data Collection Form (to be completed by participants anonymously)

Your answers are very important. Please take a few minutes to complete the form below.

Check the box that corresponds to the best answer for each statement.

Question	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**
1. The objectives of the workshop were clear.				
2. The teaching materials used during the workshop were relevant and useful.				
3. The pace of the workshop was appropriate.				
4. The workshop environment was conducive to learning.				
5. The workshop provided me with enough practical experience and opportunities to receive feedback.				
6. The facilitators were able to answer questions.				
7. I have mastered the skills taught during this workshop.				
8. The facilitators were well prepared.				
9. The facilitators were positive and uplifting.				
10. I feel that I have a better understanding of methodological concepts and the limitations of modelled maps.				
11. I feel able to interpret modelled maps correctly.				
12. I feel that I have a better understanding of the utility and programmatic application of maps.				
13. I plan to integrate modelled maps into my work.				
14. If yes, give a specific example: If no, explain why not :				

Appendix C.3: DHS workshop feedback questionnaire results

Questionnaire number	Questions												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
001	4	4	3	4	4	3	4	4	4	4	3	4	4
002	4	4	3	3	3	3	3	4	-	4	4	3	4
003	3	4	4	4	3	3	3	4	4	3	3	3	3
004	4	3	4	4	3	4	4	4	4	4	4	4	4
005	4	3	3	3	3	4	3	4	4	3	3	3	4
006	3	4	3	4	4	4	3	4	4	2	3	3	2
007	3	4	3	3	4	4	3	4	4	3	3	4	3
008	4	3	3	3	3	3	4	3	3	4	4	4	4
009	4	4	4	4	3	3	4	4	4	4	3	3	4
010	3	3	2	3	3	3	3	3	3	3	3	3	3
011	3	3	3	3	4	4	3	4	4	3	3	3	4
012	4	3	3	3	3	3	3	4	4	3	4	4	3
013	4	4	4	4	4	4	3	4	4	3	3	3	3
Average	**3.62**	**3.54**	**3.23**	**3.46**	**3.38**	**3.46**	**3.31**	**3.85**	**3.83**	**3.31**	**3.31**	**3.38**	**3.46**

15. What are two things you learned during this workshop?

16. How can we improve this workshop?

17. What did you find least useful in this workshop ?

18. What did you find most useful in this workshop ?