A description of the epidemiology of malaria to guide the planning of control in Nigeria

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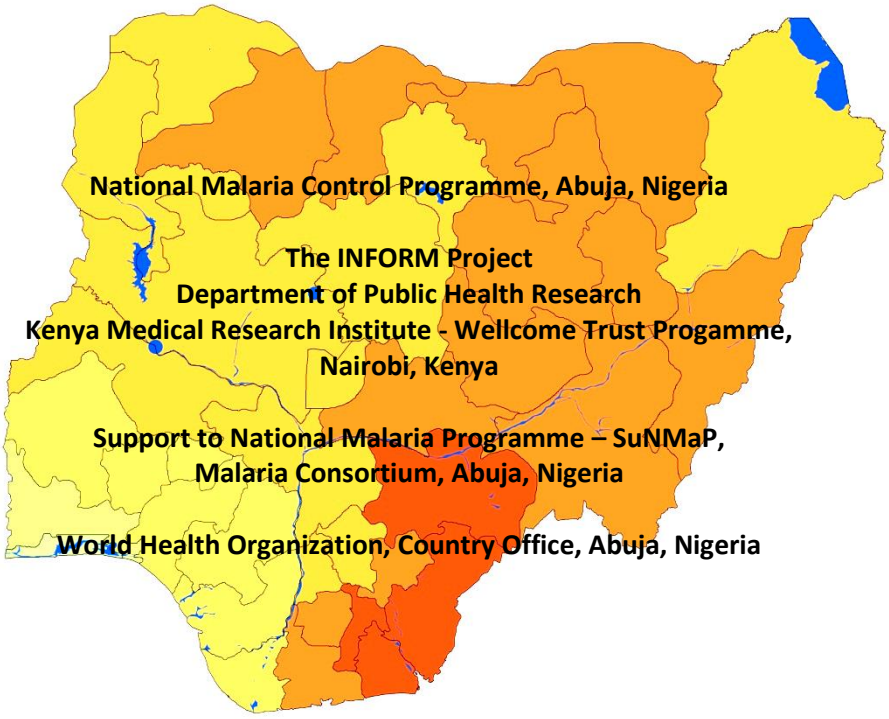

National Malaria Control Programme, Abuja, Nigeria

The INFORM Project
Department of Public Health Research
Kenya Medical Research Institute - Wellcome Trust Progamme, Nairobi, Kenya

Support to National Malaria Programme – SuNMaP, Malaria Consortium, Abuja, Nigeria

World Health Organization, Country Office, Abuja, Nigeria

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Author details

Audu B Mohammed, Ibrahim Maikore, Nnena Ezeigwe

National Malaria Control Programme,
Department of Public Health, Federal Ministry of Health
Abia house, First Avenue, FCT Abuja, Nigeria
Email: drninaezeigwe@gmail.com; drbalazfa2004@yahoo.com

Ebenezer S Baba, Emmanuel Adegbe

Support to National Malaria Programme (SunMaP)
3rd Floor Abia House, Central Area, FCT Abuja, Nigeria
Email: e.baba@malariaconsortium.org

Lynda Ozor

World health Organization, Country Office Nigeria
FCT Abuja, Nigeria
Email: ozorl@ng.afro.who.int

Abdisalan M Noor, Bernard Mitto, Catherine Linard, Clara W Mundia, Damaris Kinyoki, Caroline W Kabaria, Punam Amratia & Robert W Snow

INFORM Project
Department of Public Health Research, KEMRI-Wellcome Trust Programme
P.O.Box 43640 00100 Nairobi, Kenya
Emails: rsnow@kemri-wellcome.org; anoor@kemri-wellcome.org

Abbreviations

ACTs	Artemisinin-based combinations
AFRO	WHO Regional Office for Africa
AIRS	Africa-wide Indoor Residual Spraying project
AJOL	African Journal Online
AL	Artemether-lumefantrine
AMFm	Affordable Medicines for Malaria
ANC	Antenatal care
AU	African Union
AVHRR	Advanced Very High Resolution Radiometer
BEONC	Basic Essential Obstetric and Neonatal Care
BHC	Benzene-hexachloride
BHSS	Basic Health Service Scheme
BIC	Bayesian Information Criteria
BS	*Bacillus sphaericus*
BTI	*Bacillus thurigiensisvarisraelensis*
CPC	Climate Prediction Centre
CQ	Chloroquine
DDT	dichlorodiphenyltrichloroethanein
DEM	Digital Elevation Models
DFID	Department for International Development
DHIS	District Health Information Systems
DHS	Demographic and Health Survey
DIC	Deviance Information Criterion
EIR	Entomological inoculation rate
FAO	Food and Agricultural Organization
FCT	Federal Capital Territory
FEWS	Famine Early Systems Network
FHI	Family Health International
FMoH	Federal Ministry of Health
GAUL	Global Administrative Unit Layers
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GIST	Geographic Information Support Team
GLWD	The Global Lakes and Wetlands
GMEP	Global Malaria Eradication Programme
GMRF	Gaussian Markov Random Field
GPS	Global Positioning Systems
GRUMP	Global Rural-Urban Mapping
IGME	Inter-Agency Group for Child Mortality Estimation
IMF	International Monetary Fund
IMR	Infant Mortality Rate
INFORM	Information for Malaria Project
INLA	Integrated Nested Laplace Approximations
IPR	Infant parasite rate

IPT	Intermittent preventive treatment
IPTp	Intermittent preventive treatment in pregnancy
IRS	Indoor residual house-spraying
ITCZ	Inter-Tropical Convergence Zone
ITN	Insecticide treated nets
IVM	Integrated vector management
JICA	Japan International Cooperation Agency
KEMRI	Kenya Medical Research Institute
LGA	Local Government Authorities
LCCS	Land Cover Classification System
LiST	Lives Saved Tool
LLIN	Long-lasting insecticide treated nets
M&E	Monitoring and Evaluation
MABA	The Malaria and Anthropometric Baseline Assessment
MAPE	Mean Absolute Prediction Error
MAP	Malaria Atlas Project
MARA/ARMA	Mapping Malaria Risk in Africa
MBG	Model Based Geo-Statistics
MCMC	Markov Chain Monte Carlo
MDA	Mass drug administration
MDG-F	Millennium Development Goals Achievement Fund
MERIS	Medium Resolution Imaging Spectrometer
MeSH	Medical Subject Headings
MICS	Multiple Indicator Cluster Survey
MIS	Malaria Indicator Survey
MPE	Mean prediction error
MPR	Malaria Programme Performance Review
MRF	Markov Random Field
NDHS	National Demographic and Health Survey
NBS	Nigeria National Bureau of Statistics
NDVI	Normalized Difference Vegetation Index
NDHS	National Demographic and Health Survey
NDP	National Development Plan
NEPAD	New Partnership for African Development
NGO	Non-governmental organization
NHIS	National Health Insurance Scheme
NHMIS	National Health Management Information System
NMCC	National Malaria Control Committee
NMCP	National Malaria Control Programme
NMIS	National Malaria Indicator Survey
NMS	National Malaria Strategic
NSHDP	National Strategic Health Development Plan
NOAA	National Oceanic and Atmospheric Administration
NPC	National Population Commission
NPopC	National Population Commission
NPHCDA	National Primary Health Care Development Agency

NWS	National Weather Service
OA	Open Access
ODA	Overseas development assistance
PA*Pf*PR$_{2-10}$	Population adjusted *Pf*PR$_{2-10}$
*Pf*PR$_{2-10}$	Age-corrected *Plasmodium falciparum* parasite rate
PHC	Primary Health Care
PMI	US President's Malaria Initiative
PPS	Probability-Proportional-to-Size
RBM	Roll Back Malaria
RDTs	Rapid Diagnostic Test
RFE	African Rainfall Estimate
RTI	Research Triangle International
SAE	Small Area Estimations
SD	Standard Deviations
SIM	Sudan Interior Mission
SMC	Seasonal Malaria Control
SMOH	State Ministry of Health
SP	Sulphadoxine-Pyrimethamine
SPDE	Stochastic Partial Differential Equations
SPOT	System for Earth Observation
SRTM	Shuttle Radar Topographic Mission
SUM	Sudan United Mission
SuNMaP	Support to National Malaria Programme
TSHIP	Target State High Impact Project
TSI	Temperature Suitability Index
U5M	Under-five Mortality Rate
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
USAID	Agency for International Development
WAM	West African Monsoon
WHO	World Health Organization
WOCBA	Women of Child Bearing Age

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Executive Summary

Nigeria has historically experienced intense *Plasmodium falciparum* transmission with only a few localized pilot investigations aimed at aggressive transmission and disease control.

The dominant vectors include *Anopheles gambiae* s.s, *An. arabiensis* and *An. funestus*. All share similar ecological niches across the country and evidence exists that *An. arabiensis* has expanded its range in recent times.

Plasmodium falciparum accounts for between 85-90% of infections; *P. malariae* previously accounted for almost 15% of infections but since 2006 now accounts for only 6% of all infections. *Plasmodium ovale* is a rarer infection, accounting for approximately 1.5% of all infections before 2006 but its contribution to all human malaria's may have increased in recent years.

Climatic conditions vary considerably across the country and notable are the semi-arid areas of the north bordering Niger. Acute seasonal transmission, as defined by ≥ 60% of rainfall falling within 3 continuous months, affects an estimated 46 million people and 9 million children below the age of five years living in 13 States. These communities are likely to benefit from new pulsed drug-based prevention initiatives referred to as Seasonal Malaria Control.

There has been only one previous attempt to map the intensity of malaria transmission across Nigeria, based on a climate model developed by MARA using empirical data from only 22 survey locations in Nigeria. This map has been used routinely by the federal NMCP for over 10 years.

The principle aim of the present work was to improve the precision of malaria risk mapping in Nigeria and examine changes in risk since the launch of RBM in 2000 to support the Federal NMCP and State level control agencies in planning and monitoring control.

921 parasite prevalence survey location data were identified, assembled and geo-coded from a variety of published, unpublished and personal contact sources. These data covered the examination of 155,343 individuals of whom 64,768 were *P. falciparum* positive between 1960 and 2010; 61% of the data were after 1990 and there was little variation in overall parasite prevalence between 1960 and 2000.

Bayesian model-based geostatistcial methods were used to interpolate in space and time the age-corrected point prevalence data ($Pf R_{2-10}$) to provide a prediction of expected prevalence at un-sampled 1x1 km grids across Nigeria for the years 2000, 2005 and 2010 based on intrinsic priors of the effects of temperature, rainfall, distance to major rivers and urbanization. Linear correlations of model predicted and observed hold-out data were over 0.79.

In 2000, at the launch of RBM, 85% of Nigerians were exposed to hyper-holoendemic transmission (at least 50% of children aged 2-10 years harbouring *P. falciparum* infection).

By 2005, 45% of Nigerians were exposed to hyper-holoendemic transmission conditions and by 2010 this proportion reduced to only 15%.

Nigeria is probably the only country in Africa that has set parasite prevalence as an evaluation milestone, aiming to reduce prevalence by 50% by the year 2013. Between 2000 and 2005 all states witnessed a decline in mean population adjusted *Pf*PR_{2-10}. A 25% or higher reduction in the modelled predicted mean prevalence probably occurred in 21 States.

Between 2005 and 2010, the model predictions of population weighted *Pf*PR_{2-10} suggest that further declines were witnessed in 29 states, however, in the states of Kwara, Kogi, Osun, Ekiti, Ondo, Anambra, Edo and Delta the population adjusted mean *Pf*PR_{2-10} rose during this interval.

Over the entire period 2000 to 2010 all states may have witnessed a reduction in transmission intensity. The modelled predicted percentage change 2000-2010 exceeded 50% in 19 states. Despite significant changes in infection risks these States and those without a 50% decline all have risks of infection that exceed 20% in 2010 but are all dramatically different from levels of infection risk in 2000.

We have used spatial techniques and cluster-level data on ITN reported use to make state level coverage predictions between 2000 and 2011. In 2000, almost all States had a predicted mean ITN coverage below 5.0% among all age groups. By 2008, the predicted coverage among all age groups had not improved substantially.

By 2010/11 the modelled data from household surveys suggested a very different pattern of coverage: 17 States had predicted coverage estimates in excess of 20% of their population protected; 13 of these States had over 30% of the population protected. Conversely, 10 States still had overall predicted coverage below 5% with Osun State having less than 1% predicted ITN coverage.

It is not clear what the dominant divers of changing intensity of parasite transmission were between 2000 and 2005. Nevertheless there is strong evidence of the beginnings of an epidemiological transition before scaled ITN coverage nationwide in 2009. This transition continued from 2005 through to 2010 and it would seem reasonable to assume that the significant increase in financial and commodity resources contributed to this change during this second period.

It would be prudent to improve the model with more empirical data in time and in space, triangulate these data with other information on disease burden transitions and build a plausibility model of drivers of change with time by state including better climate, intervention coverage/use and service accessibility data. We have initiated an exercise in geo-coding Nigeria's health services and presented in Chapter 8.

New maps now exist, based on empirical data that should be used in preference to the older MARA maps in future descriptions of the cartography of malaria risk in Nigeria.

Parasite prevalence, as shown here, is a valuable monitoring and evaluation indicator of change with far greater precision and less ambiguity than malaria morbidity and mortality. Federal and State malaria control agencies might consider a more formal enhancement of parasitological surveillance over the next 5-10 years.

Chapter 1

Introduction

The clinical epidemiology [Snow & Marsh, 2002], disease reduction impact-size of vector control [Killeen *et al.*, 2007; Smith *et al.*, 2009; Griffin *et al.*, 2010], cost-effectiveness of treatment and prevention interventions [Okell *et al.*, 2012] and timelines to malaria elimination [Cohen *et al*., 2010] are all critically dependent on pre-control parasite transmission intensity. Effective planning of malaria control depends on a reliable understanding of the temporal and spatial determinants of parasite transmission, its seasonal patterns and the dominant vectors implicated in transmission. Epidemiological profiling should form the cornerstone of any effective national malaria strategy planning cycle.

At the launch of the Roll Back Malaria (RBM) initiative, calls for universal coverage of all available interventions was probably an appropriate response to the epidemic that affected most of sub-Saharan Africa during the mid-late 1990s [WHO, 2000; Snow *et al.*, 2012]. At a time when the international donor community is constrained by the global financial crisis, accessing overseas development assistance (ODA) and using limited national domestic funding for malaria control will require a much stronger evidence-based business case. These future business cases must be grounded in the best possible epidemiological evidence to predict the likely impact of future intervention, assess the impact of current investment and, equally important, demonstrate what might happen should funding and intervention coverage decline.

In 2011, the WHO Office for the Africa Region (AFRO) developed a manual to assist countries in developing their National Malaria Strategic (NMS) plans including, as a prelude, the undertaking of a National Malaria Programme Performance Review (MPR) [WHO-AFRO, 2012]. It is recommended that the MPR should include a detailed review of the malaria epidemiology and stratification including the geographical distribution of malaria burden, parasite prevalence and parasite species.

The use of survey data, maps and epidemiological intelligence was routinely undertaken across many African countries during the Global Malaria Eradication Programme (GMEP) era from the mid 1950s. The art and skills necessary to design malaria control based on an understanding of the spatial epidemiology was lost during the 1970s when the agenda for malaria control fell under a less specialized, integrated primary care mandate focused on managing fevers. In 1996, there was a renewed plea for better malaria cartography to guide malaria control in Africa [Snow *et al.*, 1996] and over the last decade there has been a growth in spatial data on malaria and populations not available to malariologists or programme control managers 60 years ago. In addition, it is now possible to model and map risk and intervention access in space and in time using innovations in Model Based Geo-Statistics (MBG) [Diggle & Ribeiro, 2007].

In 2009, a revised Federal National Malaria Strategy was launched in Nigeria which has as a long-term vision that malaria will no longer be a major national public health problem following a significant reduction in illness and death from malaria as a result of families having universal access to malaria prevention and treatment. Coverage targets were set to include 80% coverage of vector control interventions, Long-lasting insecticide treated nets (LLIN) and/or indoor residual house-spraying (IRS), and clinical case-management strategies

by 2013 and sustained through to 2017 to meet the targets of a two-third reduction in the 2007/8 levels of the malaria burden [NMCP, 2009a].

Here we present an overview of the epidemiology of malaria in Nigeria, to support a mid-term review of progress around the NMS 2009-2013. The report is a combination of narrative descriptions of context (Chapter 2); a review of previous malaria control efforts necessary to understand the evolution of today's control ambitions and proposed intervention combinations (Chapter 3); descriptions of dominant vectors, seasonality and climate/ecological determinants of malaria transmission (Chapter 4); a detailed modelling exercise to provide a series of malaria maps to understand the impact of recent control investment and chart the future requirements necessary to accelerate impact (Chapter 5); and finally linking the basic spatial epidemiology of risk, population data against control ambitions (Chapter 6). Chapter 9 discusses the combined evidence and suggests new work which might be completed in Nigeria to improve the evidence-based profiling to assist control over the next 5, 10 and 15 years. The preliminary work was completed in January 2013, where it was highlighted that two additional pieces of spatial mapping work were necessary to assist the planning of control in Nigeria. These have been included in this revised report and cover the evolution and mapping of ITN and IRS coverage (Chapter 7) and an attempt to assemble and describe the spatial distribution of Nigeria's public health service (Chapter 8).

The work is a collaborative effort between the Federal National Malaria Control Programme, the WHO-country office, SunMAP programme of the Malaria Consortium and The INFORM Project of the KEMRI-Wellcome Trust Programme in Nairobi, Kenya. Funding has been provided by the Department for International Development - UK through the Roll Back Malaria programme, Geneva and The Wellcome Trust, UK.

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Chapter 2

Country context

2.1. Political and administrative evolution

Nigeria shares land borders with the Republic of Benin in the west, Chad and Cameroon in the east, Niger in the north and an Atlantic coastline along the Gulf of Guinea in the south. The nation has a rich cultural heritage including the early Nok and Benin civilizations, the Hausa Kingdoms at Kanu and Katsina from the 900s, the 10th Century Kingdom of Nri in the South Eastern region, the Yoruba Kingdoms at Ife and Oyo during the 12th and 14th Centuries and the Fulani empire during the early 19th Century, all having an important sub-regional influence. In 1901, Nigeria became a British protectorate marking a time of ongoing wars against subjugation. In 1914, the Niger area was formally united as the Colony and Protectorate of Nigeria and was administered as the Northern provinces, Southern provinces and Lagos Colony.

Nigeria gained independence on 1st October 1960 and declared a Federal Republic in 1963. From 1966 through to the early 1970s coups and civil war plagued the newly formed Republic including the bloody failed attempts to establish the Republic of Biafra in the oil rich Igbo region. Instability characterized the country through the Second Republic (1979) with coup attempts in 1983 and 1985. In 1985 a military government was established which maintained rule until 1993 when international pressure led to civilian democratic elections and the formation of the Third Republic. In May 1999, Chief Olusegun Obasanjo was elected President, heralding in the Fourth Republic and a period aimed at building better international relations, transforming economic growth and reducing corruption. Nigeria has a strong regional leadership role, influential in the New Partnership for African Development (NEPAD) and the African Union (AU). The Roll Back Malaria (RBM) initiative was launched at Abuja, the Federal capital in April 2000 [WHO, 2000]. The current President, Goodluck Jonathon, elected in 2011, remains committed to the regional efforts to RBM.

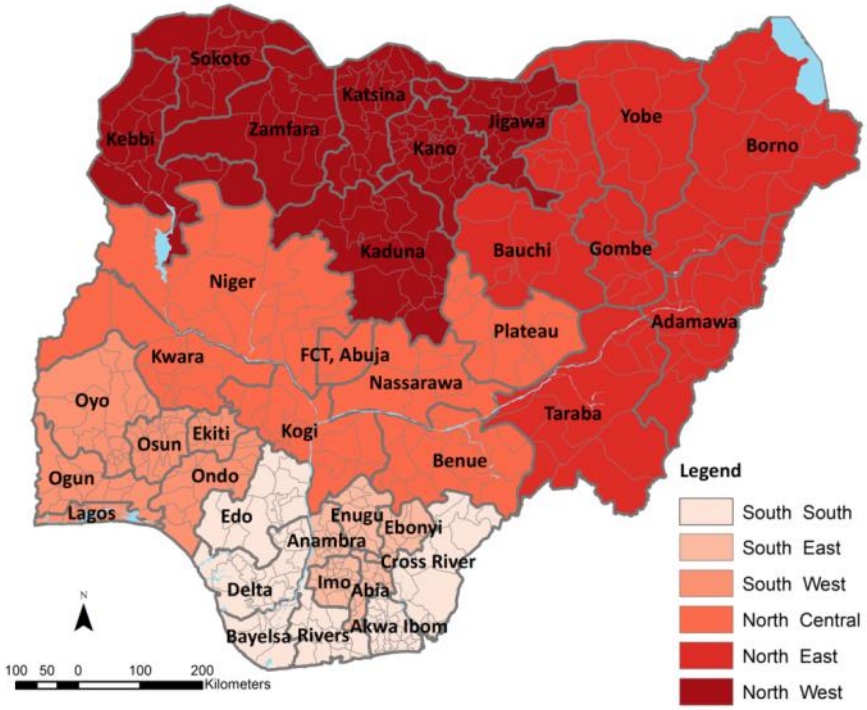
The country is divided along six broad, geo-political regions representing the cultural and linguistic diversity of the country: North Central, North Eastern, North Western, South Eastern, South-South and South Western (Figure 2.1). These regional boundaries are often used to examine equity of government spending and development progress. The Federal Government provides policy guidance, financing and pooled procurement in the health sector, to the 36 regional States (Abuja constitutes the Federal Capital Territory and can be seen as the 37th State). As part of the decentralized Federal system, each State has a Ministry of Health directed by a State Commissioner for Health responsible for administration and federal policy interpretation, priority setting and expenditure across the Local Government Authorities (LGAs) within a State (totaling 774 nationwide) (Figure 2.1).

2.2 Demography

Nigeria is the most densely populated country in Africa, home to a sixth of all Africans and the seventh most populous country in the world. While exact figures remain in dispute [Onuah, 2006], the December 2006 national household census estimated that there were over 140 million people with an estimated projected annual growth rate of 2.8% [NPC, 2006]. During the first national census in 1931 Nigeria's population was 20 million [Bruce-Chwatt, 1951]. According to United Nations projections, Nigeria is one of eight countries expected to account collectively for half of the world's total population increase from 2005–

2050 [UNDP, 2011]. By 2100, the UN estimates that the Nigerian population will be approximately 730 million [UNDP, 2011]. Nigeria has eight cities with a population of over 1 million people (Lagos, Kano, Ibadan, Kaduna, Port Harcourt, Benin City, Maiduguri and Zaria). Lagos is the largest city in sub-Saharan Africa, with a population of over 8 million in its urban area alone.

Figure 2.1: Map of regions, States (dark boundary) and LGAs (light boundary and unlabelled) derived from Global Administrative Unit Layers (GAUL) [FAO, 2008]



2.3 Economy and poverty

Successive economic reforms to the agricultural, telecommunications and manufacturing sectors have resulted in an improved Gross Domestic Product (GDP) growth; 6.7% in 2009 [UNDP, 2009] and 8% in 2010 [IMF, 2012], where only China and India out-performed Nigeria in the same years. Oil and natural gas continue to account for 95% of foreign exchange and contribute to 80% of government expenditure. Nigeria is the 12th largest producer of petroleum, the 8th largest exporter, and has the 10th largest proven reserves worldwide. The equitable distribution of government revenues remains a constant challenge [Maier, 2002]: 20% of Nigerians own 60% of national assets, there are an estimated 20 Nigerian billionaires, three of whom make the Forbes list of most richest people in the world [Anon, 2012]. In stark contrast, 60% of Nigerians receive an income of less than $1.25 per day (the World Bank's benchmark of extreme poverty). The incidence of poverty has increased since 1980 (Figure 2.2) [NBS, 2012] and poverty is higher in some regions than others; more northern regions have lower household incomes compared to southern regions (Figure 2.3) [Bello & Roslan, 2010; NBS, 2012]. All regions have witnessed a general trend toward increasing depths of poverty despite a growing GDP.

Figure 2.2: National poverty incidence 1980-2011: calculated as the proportion of the population, for whom consumption falls below poverty line (defined as 2/3^{rds} of the weighted mean per capita household expenditure for food and non-food derived from national, sample household welfare monitoring surveys) [NBS, 2012].

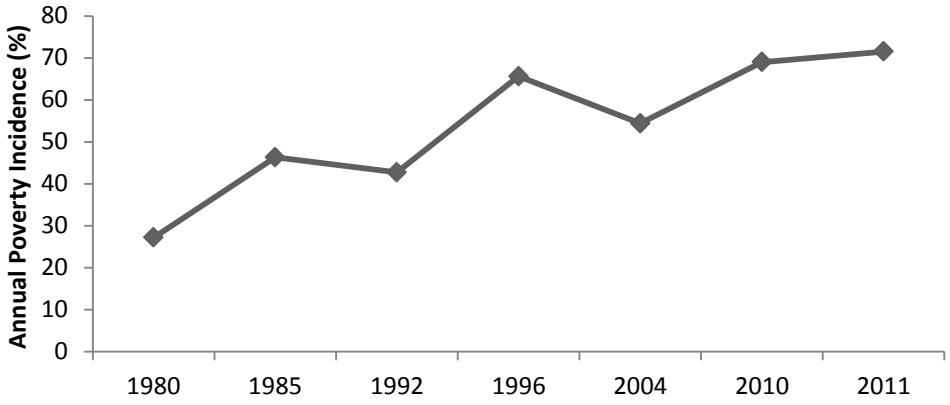
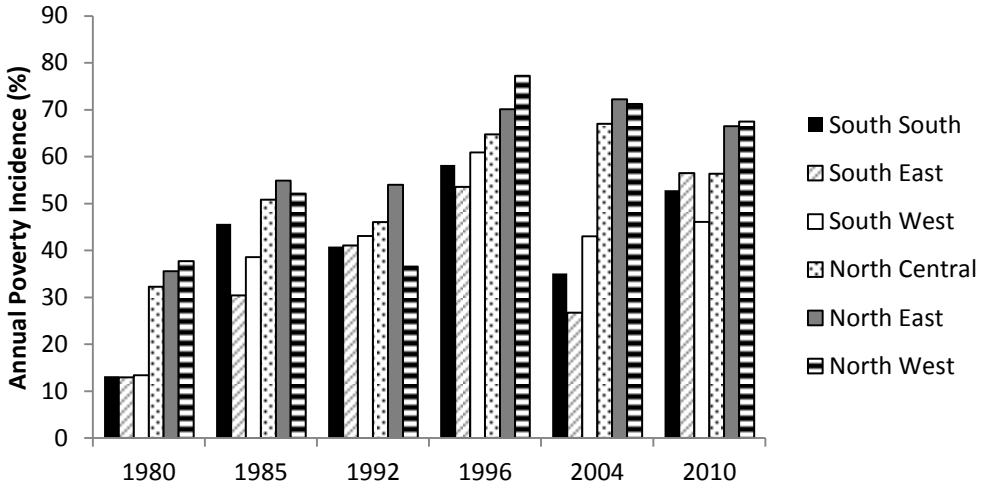


Figure 2.3: Regional poverty incidence: data derived from Bello & Roslan (2010) and augmented with recent estimates from the Nigeria National Bureau of Statistics [NBS, 2012].

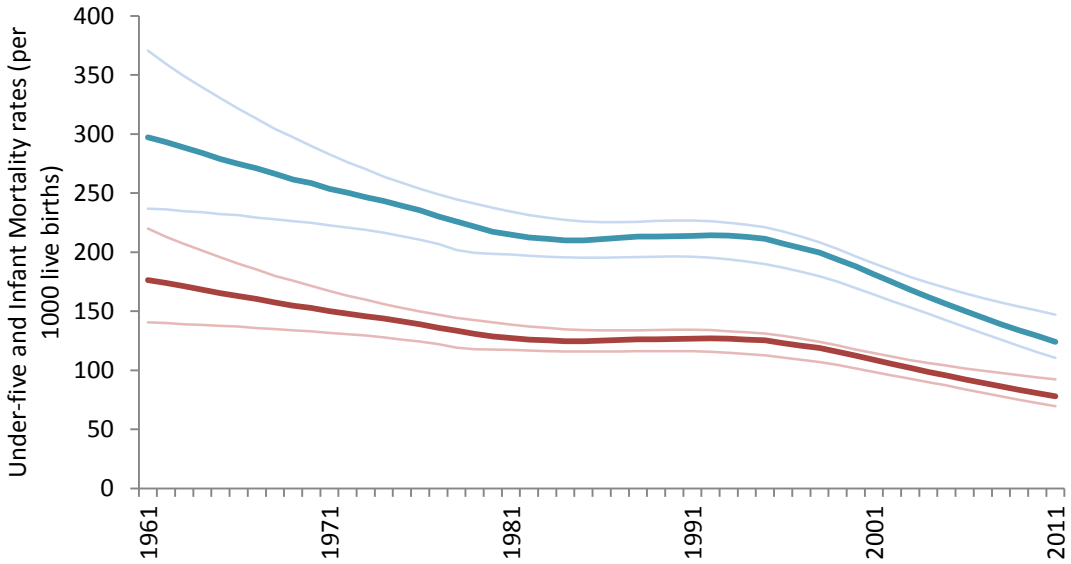


2.4 Child survival

The absence of reliable civil and vital registration of childhood deaths has meant that changes in child survival are defined using indirect methods of estimating under-five mortality rates from birth histories reported by mothers. These histories include information on the residence and survival of their live births and computed within a life-table of probabilities of dying between exact ages [Hill & David, 1988; Bicego & Ahmad, 1996]. The birth history data are most often collected through national household sample surveys and cover mortality experiences of varying periods prior to the survey date depending on the age of the mother. Data have been compiled by the Inter-Agency Group for Child Mortality Estimation (IGME) using combinations of weighted LOESS regression techniques to fit smoothed mortality trends to estimate mortality between survey periods using combinations of sample survey data (Demographic and Health Surveys, Multiple

Indicator Cluster Surveys and World Fertility Surveys) and census data [UNICEF-IGME, 2011]. The IGME estimates of under-five mortality (the probability of dying between birth and the fifth birthday) and infant mortality (number deaths in the first year of life per 1000 pregnancies) for Nigeria between 1961 and 2011 are shown in Figure 2.4 [UNICEF-IGME, 2011].

Figure 2.4: Under-five mortality rates (red) and Infant mortality rates (blue) per 1000 live births for Nigeria, 1961 to 2011 [UNICEF-IGME, 2011]



Footnotes: For IMR and U5MR, a country-specific local log-linear regression model is fitted to observations to be used within a model life table. Projections have been adjusted for projected mother-to-child HIV infection risks [You *et al*., 2009; Hill *et al.*, 2012; UNICEF-IGME, 2011]. A LOESS line is fitted with an uncertainty range (shown as boundaries to dark line in Figure).

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Chapter 3

A brief history of malaria control

3.1 Malaria and its control in Nigeria 1900 to the Second World War

Malaria was ranked the number one infectious disease in almost every annual return of the medical department through the first forty years of colonial administration. Malaria accounted for 7.9% of all treated diseases in southern Nigeria in 1907, of which, over 90% were from the "non-European" population [Colony of Southern Nigeria, 1913]. In 1926, the annual medical report states that "*malaria is still the most prevalent of the tropical infections* [and] *is responsible for a considerable number of infant and child deaths amongst Africans*" [Colony & Protectorate of Nigeria, 1926]. However, as stated in the annual report for the period 1919-1921 "*…..it must be remembered that the diagnosis in the majority of cases is based upon clinical rather than upon microscopical evidence, and whilst our present shortage of staff continues, and in the absence of pathologists....., I am afraid this is a disability that cannot be remedied.."* and that "*the incidence of malaria will be found to correspond with a curve representing the number of its medical officers*" [Colony & Protectorate of Nigeria, 1922]. This was later emphasized by Bruce-Chwatt in the 1950s, who states that "*The data referring to the morbidity and mortality caused by malaria in the indigenous African population are incomplete and not reliable*" [Bruce-Chwatt, 1951] - a characteristic of today's attempts to estimate disease burdens across Nigeria [MPR, 2012]. Pathologists in Lagos undertook 100 autopsies among children aged less than three years in 1937 and found direct evidence of malaria as a cause of death among 26 (26%), eleven of which were associated with cerebral malaria [Colony & Protectorate of Nigeria, 1937]. Bruce-Chwatt reviewed 3,085 post-mortems among children aged 0-15 years in Lagos hospitals between 1933 and 1948 and found direct attribution of malaria as a primary cause of death for 8% [Bruce-Chwatt, 1951]. Between 1944 and 1948, malaria (including blackwater fever) mortality rates among non-African populations was approximately 1 per 1000 residents per year [Bruce-Chwatt, 1951], supporting the widely held view of the West African coast as the "White Man's Grave" [Lethbridge-Banbury, 1889].

Between 1910 and 1948 malaria prevention focused largely on environmental sanitation, following Sir Ronald Ross's recommendations for "mosquito brigades" [Ross, 1902] and prophylaxis using quinine. In the 1917 annual Medical & Sanitary report, Dr W.B Johnson notes that "*Quinine as a prophylactic still holds its important position amongst the necessary measures that have to be adopted for personal prophylaxis. To depend on small doses of quinine alone to combat heavy malaria infection which is gaining access to the body constantly would be futile but its utility is great as an adjuvant to other means that are essential such as the use of the mosquito net and mosquito boots, when combined with the many other factors of personal hygiene...*". Table 3.1 shows the extent to which quinine was used as a prophylactic across Nigeria, often recommended as 5 grains daily.

Table 3.1: Reported distribution of grains of quinine for use as prophylaxis 1910-1916 [Colony & Protectorate of Nigeria, 1917]

	1910	**1911**	**1912**	**1913**	**1914**	**1915**	**1916**
Total	1,747,203	2,416,447	2,000,734	1,948,330	2,165,732	1,475,363	1,597,304

Vector control measures were promoted in the urban areas of the Colony and Protectorate and focused primarily on protecting colonial administration employees. Government employed sanitary staff were responsible for the detection of vector breeding sites, drainage and the use of oil to prevent the establishment of mosquito larvae in swampy areas. An ordinance for the destruction of mosquitoes was enacted in August 1910 and later replaced with the Public Health Ordinance in 1917 which provided penalties aimed at preventing the proliferation of mosquito breeding sites [Colony & Protectorate of Nigeria, 1922]. Mosquito brigades had reclaimed over 12 acres of swamps at Oke Suna and Alakoro in Lagos by 1914 [Colony of Nigeria, 1915]. Most vector control was centred around the rapidly expanding city of Lagos and organized around sectors managed by different teams (Figure 3.1) [Gauchi & Evans, 1929]. This work continued through to the 1930s, in 1932 the annual medical report states that over 12,185 gallons of fuel oil, 18 hundredweight (*circa* 900 kg) of Paris Green and 1,012 wells stocked with larviforous fish to control breeding sites on Lagos Island and surrounding areas of Ikoyi and Victoria Beach [Colony & Protectorate of Nigeria, 1933].

Figure 3.1: Map of Lagos in 1911 showing historical centers of Lagos metropolis around Lagos Island, Ikoyi, Apapa, Iddo, Ebute Metta and Yaba [Gauchi & Evans, 1929].

3.2 Malaria control from the Second World War to 1999

During the Second World War, swamp drainage was intensified and tidal flooding control was introduced. The Lagos mosquito control scheme was established in 1942 and handed over to the Lagos town council public health department in April 1948. The scheme covered an area of approximately 4,200 acres of coastal swamp and mainly focused in controlling *An. melas* breeding near the Royal Air Force airport at Apapa and was later extended to cover other parts of Lagos metropolis [Gilroy & Bruce-Chwatt, 1945; Bruce-Chwatt, 1951]. By 1945, 1677 acres of swamp had been reclaimed at Apapa mainland, Tin Can and Magazine Islands, Middle point and Meridian point, all financed by the Royal Air Force and the Nigerian government [Gilroy & Bruce-Chwatt, 1945].

An ordinance providing for the destruction of mosquitoes was re-enacted in April 1945 and the Malaria Service established in 1948 under the Colonial Development and Welfare Act [Bruce-Chwatt, 1951]. The service had the responsibility of carrying out field surveys, malaria research and organizing control schemes [Bruce-Chwatt, 1951]. Unlike other malaria control departments of neighbouring Franco-phone West African states (Cameroun: Languillon, 1957; Niger: Ochrymowicz *et al*., 1968; Togo: Cano, 1971), the malaria service of Nigeria never undertook any nationwide epidemiological pre-eradication reconnaissance surveys or any national or sub-national large scale eradication projects. The Malaria Service was however active in establishing small projects across the country beginning with the Ilaro Scheme in 1949.

Ilaro Project: This project began in February 1949 in a small community in south-western Nigeria (Figure 3.2) to establish the feasibility of eliminating an "island" of transmission in a small population of 12,000 people living in an area 31 km^2. IRS was undertaken using Benzene-hexachloride (BHC) against the major vectors *An. gambiae* and *An. funestus* between March 1950 and 1952 four times a year [WHO, 1955; Bruce-Chwatt, 1950; Bruce-Chwatt *et al*., 1955]. Parasite rates among children aged 2-9 years dropped from 75% in 1949 to 53% in 1952 and cases of malaria among the population declined from 600 to 64 over the same period. Despite a significant decline in disease burden, transmission was not interrupted and when IRS stopped in 1952 malaria prevalence and disease incidence rose the following year [Bruce-Chwatt *et al*., 1955].

Across Nigeria during the mid-1950s, few reports of large-scale control were documented. The annual medical report of the Department of Medical Services for the Northern Region for 1954/1955 [NRN, 1955] states that "*Although malaria continues to take its annual heavy toll of infant life, the immensity of the problem and the heavy cost of preventative measures limits control with one important exception to urban areas with organized sanitary staff... Even in urban areas the limited funds available make one question the value of usual control measures adopted*". As an example the report goes on to describe a survey at the urban area of Lokoja in November 1954 which showed an average resting density of 113 and 19.5 per hut per night for *An. gambiae* and *An. funestus* respectively, spleen and parasite rates in children in excess of 60% and where malaria accounted for 8.7% of all out-patient attendances. So surprised by this state of urban malaria at the town of Lokoja that a proposal for urban control was made estimating to cost over £3,000 annually [NRN, 1955], however no details exist of whether this project was initiated.

Western Sokoto project*:* The next major project to be undertaken by the Malaria Service, in collaboration with UNICEF and the WHO, began in 1954 in the North-West of Nigeria covering a population of approximately 130,000 people across 1554 km^2 at Sokoto (Figure 3.2) [Bruce-Chwatt & Archibald, 1958]. This project continued to examine the role of IRS and compared across three zones and a control zone the impact of dieldrin, dichlorodiphenyltrichloroethanein (DDT) and BHC. The first spray round began in April 1954 and repeated every 6 months in the pilot area until October 1957. Follow-up surveys of infant parasite rates (IPR) showed a marginal decline of 9.2% in IPR from 65.4% recorded in 1954 prior to spraying. In 1955, DDT zones recorded a significant drop in IPR from 65.4% to 34%. Dieldrin was seen to be the least effective; between 1955 and 1956 IPR increased from 44.1% to 54.1%. The pilot project was later extended to cover 250,000 people in April 1956

and 500,000 people in April 1957; the new areas used BHC residual spraying. DDT replaced all Dieldrin zones in April 1957 and by September 1957 replaced all zones; in April 1958 IPR was 7.9% in infants [Bruce-Chwatt & Archibald, 1958].

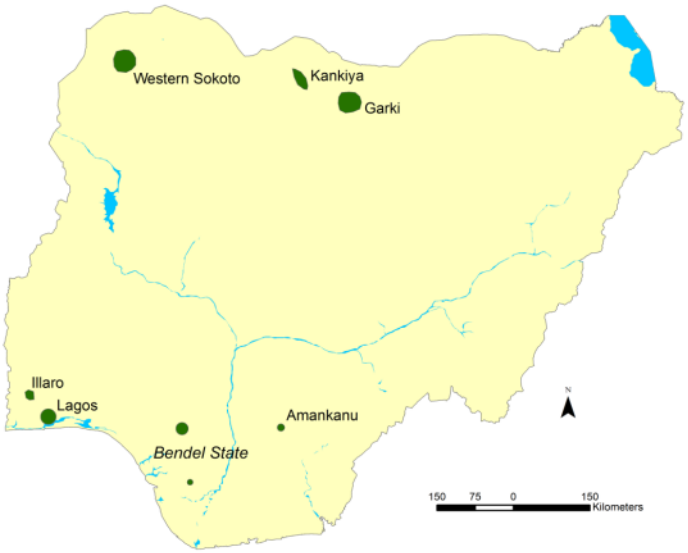
Kankiya/Katsina Province Project: In 1963, a WHO team implemented a large-scale field trial of dichlorvos in Kankiya district (Figure 3.2) exploring the possibilities of interrupting transmission in the holoendemic Guinea-savannah [Foll & Pant, 1964]. The project began in March 1963 and continued on into 1964 covering 25,000 people living in an area of 466 km^2. IPR was used as the primary indicator of impact. Among infants located in the intervention zones IPR dropped from 34.5% in the pre-intervention dry season to 3% post-dry season 1964; however, transmission was not interrupted and changes in IPR were not significantly different in the control zones [Foll & Pant, 1965]. In 1967, it was decided to explore the added value of combining Mass Drug Administration (MDA) with IRS. MDA was provided every 2 months at an estimated 80% coverage to 52,000 people using a combination of chloroquine and pyrimethamine during a period when DDT was used over three rounds a year. IPR declined from 24.2% before MDA in 1966 to less than 1% in 1967 after three rounds of IRS and seven rounds of MDA [Foll & Cuellar, 1967].

The results of the Katsina study were dramatic but never implemented at scale across Nigeria and thus remained an isolated project. The use of drugs to target infections in the host had a long legacy in Nigeria through quinine prophylaxis. Prophylaxis was seen to have a preventative role in eastern Nigeria in the early 1960s. In 1961, the Ministries of Health and Education in eastern Nigeria established an antimalarial campaign for primary school children using Daraprim. Children aged between 6 and 14 years were given weekly doses of Daraprim for three consecutive years covering almost 75,000 children across Enugu, Port Harcourt and Onitsha [Arthur, 1965]. At Onitsha parasite rates of 7.3% were observed in school children under treatment compared to 21.8% in children not treated [Arthur, 1965]. The extent to which school based prophylaxis was promoted in other areas of Nigeria during the 1960s is not clear.

Garki project: The "failures" of the pilot projects did however lead to an important experimental project at Garki (912 km^2) in the Savannah region of northern Nigeria to better understand the epidemiology of transmission and control [Molineaux & Gramicca, 1980]. This collaborative project between the WHO and the Government of Nigeria began with preliminary entomological and parasitological surveys from September 1969 to September 1970 to provide a basis for a sequence of multiple interventions mounted from April 1972 to October 1973. These included Propoxur spraying every 2 months plus twice extra during each transmission season; Propoxur spraying and MDA (sufalene–pyrimethamine) given every 10 weeks; and Propoxur spraying and MDA every two weeks in wet seasons and 10 weeks in dry seasons. The project ended in February 1976. In summary IRS alone had no significant effect on the high Entomological Inoculation Rate (EIR), circa 145 sporozoite-positive bites/year, and the only significant reduction was produced using high frequency drug administration and residual spraying where parasite rates among children aged 1 to 4 years were reduced from 59% at baseline to 1% during dry seasons and 5% in the wet seasons. Here again transmission was not interrupted and there was a rapid resurgence of *P. falciparum* exposure in the post-intervention period [Molineaux & Gramicca, 1980].

Enugu project: The Arbovirus Vector Research Unit of the WHO at Enugu started a trial of Ultra Low Volume application of Malathion as indoor and outdoor spraying against *Aedes* and *Anopheles* at Amankanu (Figure 3.2) in Anambra State in 1978 covering 1,700 people across 2 km^2 [Bown *et al.*, 1981]. Three spray teams from the States Malaria Control Department applied indoor and outdoor spraying in June 1978 followed by weekly entomological surveillance. Indoor and outdoor adult *Anopheles* landing catches were 5.4 and 4.2 per man respectively before intervention and declined to zero for indoors and outdoors one week post-intervention and remained to below 0.3 per man per night 20 weeks post-intervention and were 10 times lower compared to a control village [Bown *et al.*, 1981].

Figure 3.2: Location of specialized pilot projects on malaria control and elimination 1940s-1980s: size of dot relative to surface area of project



Despite the demonstrable impacts of the pilot projects, experimental IRS and MDA projects in reducing transmission, which today would be seen as huge successes, at the time were viewed as failures to interrupt transmission and therefore not promoted at scale as part of national control within Nigeria or regionally for decades. There is little documentation to suggest that IRS was rolled out anywhere from the late 1970s (with the exception of an extended pilot project following Gharki in Edo and Delta states, previously Bendel, in late 1970s) until the mid-2000s when Nigeria began to implement IRS in target states.

In 1975, the National Malaria Control Committee (NMCC) was established. The aim of the NMCC was to reduce the malaria burden by 25% by 1980. The emphasis of the five year plan, as with much of sub-Saharan Africa, was on building the capacity of Primary Health Care to deliver clinical services and the provision of presumptive malaria treatment. In 1985 the NMCC launched a more ambitious five year plan of reducing malaria morbidity and mortality by 50%, again based primarily on chloroquine (CQ) treatment. In 1987 a National Malaria Technical Committee was constituted to assist Federal planning of priority malaria control activities, including the establishment of sentinel drug sensitivity testing sites to monitor the growing threats posed by CQ resistance and the preparation of the National Guidelines on Malaria Control in 1989 [FMoH, 1989].

Reports from as early as 1959 suggest that antimalarials purchased from retailers were widely available in the home, including mepacrine, quinine and paludrine [Onuigbo, 1961]. By the mid-1990s retail sector antimalarials were a large part of urban private sector sales, it was estimated from a sample of 330 shops in Lagos that the selling of anti-malarials generated over US$ 4,000 per week [Brieger *et al.*, 2001]. Despite widespread use of CQ there was no evidence of reduced sensitivity at Ibadan by 1980 [Aderounmu *et al.*, 1980]. However, the first case of CQ-resistant falciparum malaria was notified in 1985 and confirmed reduced CQ sensitivity in 1987 [Salako & Aderounmu, 1987]. Field investigations of CQ in 1987 showed complete day 14 parasitological clearance at Igbo Ora, in Oyo State [Ekanem *et al.*, 1990], complete parasite clearance by day 7 in Sokoto [Elueze *et al.*, 1990] but significant day 7 failures to CQ at Oban, in Cross River State [Ekanem *et al*., 1990]. By 1989 CQ resistance was confirmed in Zaria accompanied by a reduced sensitivity to Sulphadoxine-Pyrimethamine (SP) [Lege-Oguntoye *et al.*, 1989]; both CQ and SP resistance had reached the RI stage by 1995 at Zaria [Adagu *et al.*, 1995].

3.3. Strategies for malaria control in Nigeria from 2000

The first summit of African leaders on malaria was held in Abuja in April 2000. This provided a much needed national and regional political support to the objectives outlined in the Abuja declaration to essentially ensure that over the next five years at least 60% of at-risk populations would receive prompt efficacious treatment, sleep under an ITN or if pregnant receive at least two doses of IPTp with SP.

In 2001, Nigeria launched a five year strategic plan focusing on these RBM targets [NMCP, 2001] under the policy stewardship of the Federal National Malaria Control Programme (NMCP) and with the aim of reducing the malaria burden by 25% by 2005. An ITN strategy was developed to ensure 60% coverage among children by 2005 and promoted the creation of an enabling private sector market combined with social marketing initiatives. Those partners engaged with the FMoH at State levels for ITN distribution included UNICEF (Ogun, Bauchi, Enugu and FCT-Abuja); the Futures Group/DFID (Ekiti, Jigawa, Benue and Enugu); USAID/BASICS (Lagos, Kano and Abia); and USAID/NetMark (Edo, Rivers, Lagos, Kano, FCT and Abia). Despite these initiatives, by 2005 ITN use by children aged less than five years was only 1.7% [NMCP, 2005a; Oresanya *et al.*, 2008]. During much of the 2001-2005 national policy, CQ and SP were the recommended 1st and 2nd line anti-malaria regimens, respectively. However, sensitivity tests undertaken across the country in 2002 revealed unacceptably high CQ treatment failures (*circa* 39%) and SP (*circa* 43%) [NMCP, 2001]. In 2004, the efficacy of two candidate artemisinin-based combinations (ACTs) were evaluated and using these results artemether-lumefantrine (AL) was selected as first line treatment in 2005 [NMCP, 2005b; Meremikwu *et al*., 2006].

The second, post-Abuja strategic plan was launched in 2006, revising targets to 80% coverage of key interventions, re-invigorating the role of selected IRS and environmental management [NMCP, 2005b] with a combined aim to reduce the malaria mortality and morbidity burden by 50% by 2010. In 2006, the optimistic vision of a "Malaria free Nigeria" was first declared. However, coverage of ITN across the country by 2008 was extremely poor, only 5.5% of children below the age of five years were sleeping under a treated net

[NPC, 2009]. Of all unprotected children in sub-Saharan Africa not sleeping under a net in 2007, 25% were Nigerian [Noor *et al.*, 2009].

Between 2004 and 2006, ODA for malaria control was between US$ 15 and 23 million per year. Between 2007 and 2010, US$ 117 million was disbursed by the World Bank to support delivery of interventions in seven states (Akwa Ibom, Anambra, Bauchi, Gombe, Jigawa, Kano, and Rivers). Nigeria made successful applications to the Global Fund during Round 2 (US$ 20 million), Round 4 (US$ 64 million), and Round 8 (US$ 220 million); Round 8 funding was largely used for mass LLIN campaigns in seven additional states, not covered by the World Bank Booster program (Adamawa, Ekiti, Kaduna, Kebbi, Niger, Ogun, and Sokoto). Since 2007 other donors have included USAID, DFID-UK, UNICEF, US President's Malaria Initiative and JICA.

It is estimated that between 2008 and 2010, US$ 3.5 million was spent on malaria control out of the Government of Nigeria budget and US$ 78 million was disbursed through the Debt Relief Millennium Development Goals Achievement Fund (MDG-F) [RBM, 2012]. Nearly US$ 600 million of external funds was provided for Nigeria's national malaria control efforts between 2004 and 2010. In 2009, donor disbursements reached a peak of around US$ 325 million, a staggering amount of ODA but nevertheless this remains less than US$ 2 per person at risk for malaria less than the minimum recommended requirement [Snow *et al.*, 2010].

The most recent National Malaria Strategic Plan covers the period 2009-2013, the *Road Map for Malaria Control in Nigeria* [NMCP, 2009a] and highlights its ambitious goals for the rapid national scale-up of a package of core interventions to achieve impact as a pathway toward a malaria free Nigeria. As one of its primary objectives it aims to reduce malaria mortality and morbidity by 50% by 2013 and minimize the social impact of the disease. Consequently, the current strategic plan aims for universal ITN coverage, combined ITN and IRS approaches in areas intractable to reductions in transmission with ITN alone and a more prominent coordinated role of integrated vector management (IVM) that considers larval control following pilot studies using *Bacillus thurigiensisvarisraelensis* (BTI) and *Bacillus sphaericus* (BS). In 2009 and 2012 mass ITN distribution campaigns were launched and 50 million long-lasting insecticide treated nets (LLIN) had been distributed by April 2012. The impact on coverage of these campaigns were reflected in the national household survey data in 2010 which showed an improvement in coverage of under-fives to a national average of 29% sleeping under an ITN the night before the survey [NPC *et al.*, 2012]. States without LLIN campaigns at the time of the national survey included: Abia, Bayelsa, Benue, Bono, Cross Rivers, Delta, Ebonyi, Edo, Enugu, FCT, Imo, Katsina, Kogi, Kwara, Lagos, Nasarawa, Ondo, Osun, Oyo, Plateau, Taraba, Yobe and Zamfara. The current strategy to distribute LLIN includes continued free distribution of LLINs through routine health services, antenatal clinics, during national campaigns and routine immunization and a smaller role played by the commercial sector. IRS was implemented in three LGAs in 2008 in seven states supported by the World Bank Malaria Booster Program (Bauchi, Jigawa, Gombe, Kano, Anambra, Akwa-Ibom and River State) and one state supported by the US President's Malaria Initiative (PMI) (Nassarawa) using alphacypermethrin, lambdacyhalothrin and deltamethrin. Between 2009 and 2011, Lagos State started a campaign of IRS covering 246,803 households [MPR, 2012].

Providing prompt efficacious treatment under evolving guidelines related to the WHO recommendations to Test, Treat and Track [WHO, 2012a] continue to pose challenges to the national strategy [MPR, 2012]. From the national malaria indicator survey in 2010, 44% of women reported that malaria in children should be treated with aspirin, panadol or paracetamol, while 37% reported that CQ should be the drug of choice; only 12% were aware that ACTs are the drug of choice [NMCP, FMoH, 2009a]. Many Nigerians use the private sector for treatment and strengthening this sector has been a focus of the NMCP through support from the Affordable Medicines for Malaria (AMFm) initiative launched in Nigeria in 2010 [Tougher *et al.*, 2012].

The specific targets for malaria control during the five-year period (2009-2013) are:

- To reduce malaria-related mortality by 50% by 2013
- To reduce malaria parasite prevalence in children under age 5 by 50% by the year 2013
- To increase net ownership to at least 80% of households by 2010 and to sustain this level until 2013
- To expand and sustain net usage to at least 80% of children under the age of 5 and to pregnant women by 2010 and to sustain the coverage until 2013
- To introduce and scale up indoor residual spraying (IRS) to national household coverage of 8% in selected areas by 2010 and to 20% by 2013
- To increase diagnostic malaria testing by 2013 to at least 80% of patients age 5 and older who come to health facilities to seek treatment for fever or malaria
- To increase appropriate and timely treatment of all patients who seek treatment for fever or malaria in health facilities to at least 80% by 2013
- To increase the coverage of pregnant women who receive at least two doses of intermittent preventive treatment (IPT) to 100% of pregnant women attending antenatal care (ANC) by 2013

In measuring the projected 50% disease impact of the strategic plan 2009-2013 [NMCP, FMoH, 2009a] it is proposed that death rates associated with malaria, all-cause under-5 mortality rates, hospital based case fatality rates and the incidence of confirmed malaria cases in 14 sentinel demographic surveillance sites will be used as primary evaluation end-points [NMCP, FMoH, 2009b]. However, only two sites co-supported by sunMAP in Kano and Anambara states have begun to develop systematic information as proposed within the strategic plan. The monitoring and evaluation (M&E) plan highlights that the current HMIS reporting rate is too low for effective monitoring of impact but efforts will be made to harness better, more complete data from sentinel sites. The M&E plan also raises the importance of tracking parasite prevalence in children under five years of age and assumes

that there will be a 25% reduction of prevalence by Year 2 and 50% reduction in Year 5 (2013) [NMCP, FMoH, 2009b]. This is an important and unique M&E milestone, one that will form the basis of review in Chapter 5.

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Chapter 4

Dominant vectors, climate & seasonality of transmission

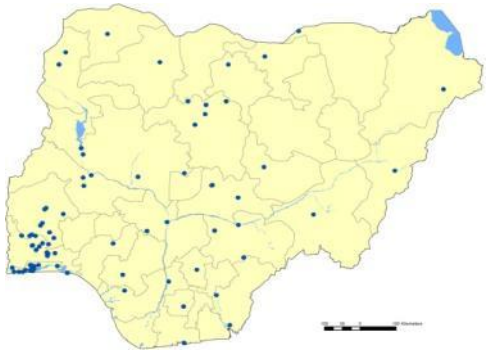
4.1 Dominant malaria vectors

A systematic search of published reports on the presence of major malaria vectors in Nigeria over the period 1900 to 2010 has recently been completed [Okorie *et al.*, 2011]. This review is by far the most comprehensive undertaken but supplemented here from additional pan-African vector data assemblies by Sinka *et al.* (2010) and the MARA/ARMA collaboration [http://www.mara.org.za/]. The 320 location-specific descriptions of vector species of the *An. gambiae* and *An. funestus* complexes show a sympatric co-existence at most locations (Figure 4.1). It has been traditionally thought that within the *An. gambiae* complex, *An. gambiae* s.s. (Figure 4.1a) is the dominant species with *An. arabiensis* being found more often in the arid North [Ramsdale & Leport, 1967; Coluzzi *et al.*, 1979; Okwa *et al.*, 2009], although *An. arabiensis* may have extended its range and contribution to transmission over the last 20 years [Onyabe & Conn, 2001], inhabiting more areas in the southern reaches of Nigeria (Figure 4.1b).

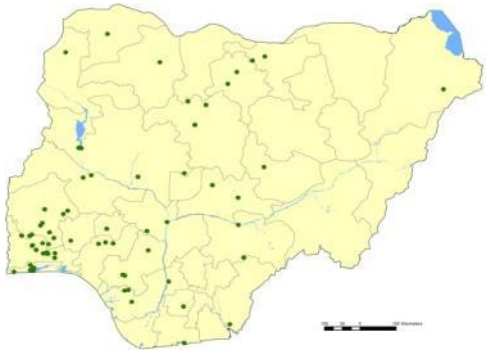
Broadly *An. gambaie* s.s, *An. arabiensis* and *An. funestus* are the dominant vectors identified across Nigeria with a co-existent, sympatric relationship where found. *An. melas*, a salt tolerant vector of the gambiae complex, however is confined entirely to the mangrove coastal zone. Other less frequently reported species include *An. nili*, *An. coustani*, *An. hancocki*, *An. leesoni*, *An. moucheti*, *An. rivulorum* and *An. wellcomei* and their role as major vectors of malaria is less clear.

The review by Okorie and colleagues provides an audit of the dates and locations of published studies on the presence of insecticide resistance: at 70 locations different preparations of DDT, Dieldrin, Permethrin and Deltamethrin have been tested for sensitivity against the complexes and sub-species of *An. gambiae* and *An. funestus*. The distribution of reported resistance shows a concentration of kdr mutations in the south west of Nigeria [Awolola *et al.*, 2005; Awolola *et al.*, 2007] compared to the northern regions. Equally important is that there is a complete absence of sensitivity testing in the south-eastern and north-eastern regions [Okorie *et al*., 2011].

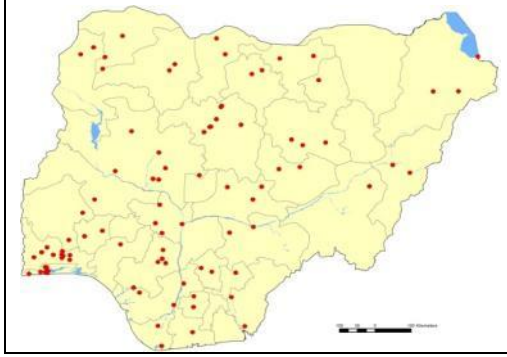
Figure 4.1: Maps of *An. gambiae s.s.*, *An. arabiensis* and *An. funestus* sampled across Nigeria between 1901 and 2012 and their bionomics



a. Anopheles gambiae *s.s*: *Anopheles gambiae* larvae typically inhabit sunlit, shallow, temporary bodies of fresh water such as round depressions, puddles, pools and hoof prints. This aspect of their bionomics may allow members of the *An. gambiae* complex to avoid most predators, and the larvae are able to develop very quickly (circa 6 days from egg to adult under optimal conditions). *An. gambiae* has been reported from habitats containing floating and submerged algae, emergent grass, rice, or 'short plants' in roadside ditches and from sites devoid of any vegetation. *Anopheles gambiae* is considered to be highly anthropophilic, with many studies finding a marked preference for human hosts, typically feed late at night and often described as an endophagic and endophilic species, i.e biting and resting indoors. *Anopheles gambiae* is considered to be one of the most efficient vectors of malaria in the world. From their review of the published evidence Okorie *et al*. (2012) highlight important differences in the distributions of the molecular S and M forms of *An. gambaie* s.s. across 120 sites: pure S forms were located predominantly in the northern Guinea and Sudan Savannah regions, pure M forms were predominantly in the southern mangrove, forested areas. The significance in different chromosomal forms of *An. gambiae* s.s. have been suggested being important in the design of combined lymphatic filariasis and malaria control [Bayoh *et al.*, 2001; Onyabe *et al.*, 2003].



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

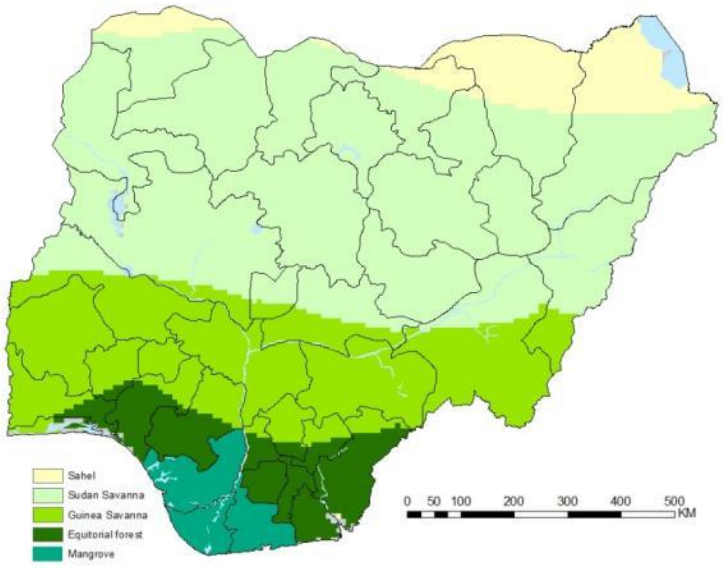


c. Anopheles funestus: A typical *Anopheles funestus* larval habitat is a large, permanent or semi-permanent body of fresh water with emergent vegetation, such as swamps, large ponds and lake edges. *An. funestus* is a highly adaptable species, allowing it to occupy and maintain its wide distribution and utilise and conform to the many habitats and climatic conditions. *Anopheles funestus* is considered to be highly anthropophilic with a late-night biting pattern (after 22.00 hours). Endophilic resting behaviour is also commonly reported, and these characteristics are responsible for rapid disappearance of this vector following expanded indoor residual spraying and insecticide-treated nets. Compared to other dominant vector species in Africa, *An. funestus* shows fairly consistent behaviour (generally anthropophilic and endophilic) throughout its range. In the absence of insecticide use, the endophilic resting behaviour of *An. funestus* combined with a relatively high longevity, makes it as good a vector, or better in some areas, as *An. gambiae s.s*.

4.2 Climate

Nigeria occupies 924,000 km^2 and covers a diverse ecology and climatic profile. The country is effectively divided into three by the Niger and Benue rivers creating a "Y" from the centre of the territory meeting at the capital Abuja, where they flow into then oil rich Niger Delta before reaching the Atlantic Ocean. Tropical forests are found in the southern humid regions, mangrove swamps in the Niger Delta spanning 36,000 km^2 along the coast, temperate higher latitude areas including the Mambilla and Obudu Plateaus and Savannah landscapes give way to Sahelian deserts in the North. The deforestation rate in the country is about 3.5% per year, translating to a loss of 350,000–400,000 ha of forest land per year. Rainfall varies from 500 mm per year in the north (the driest areas in the north-east corner of the country bordering Lake Chad) to between 1500 and 2000 mm a year in the most southerly regions. This diversity in climate conditions across the country affects the spatial epidemiology of malaria transmission, human settlement and human vulnerability. Malaria has traditionally been described according to the eco-climatic variations across the country [Bruce-Chwatt, 1951; Kleinschmidt *et al.*, 2001]. The dominant ecozones used to describe composite climate conditions for agricultural potential are shown in Figure 4.2.

Figure 4.2: Ecozonation based on modified FAO stratifications



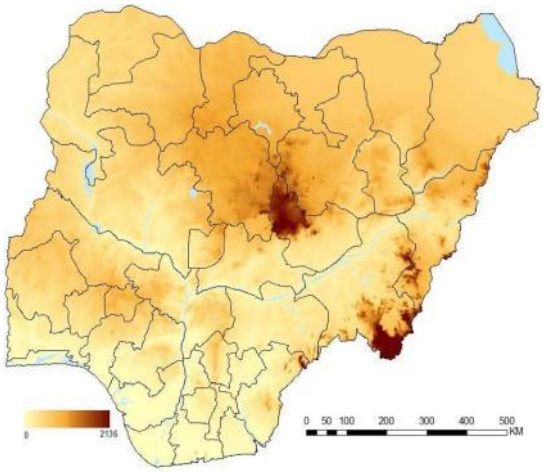
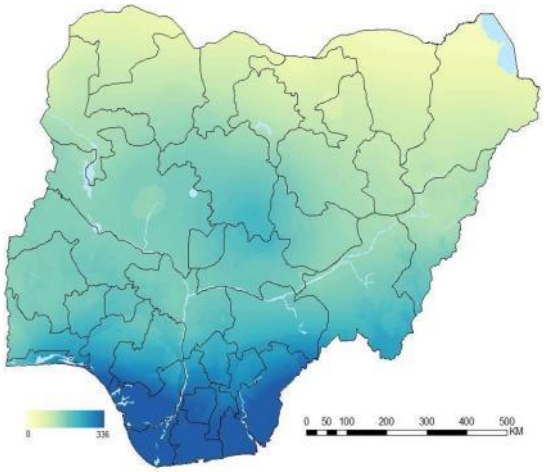
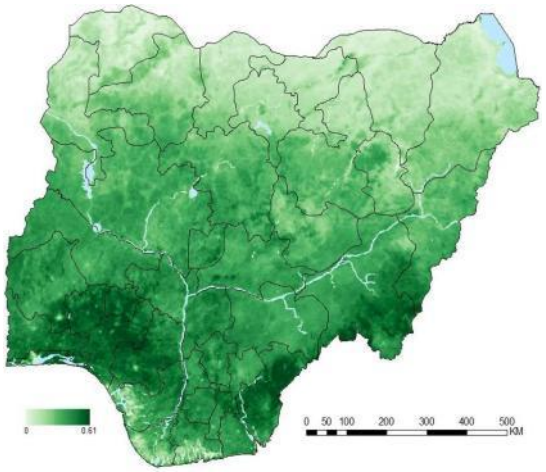
Footnote: Kleinschmidt *et al*. (2001) used ecological zones as a stratum to delineate malaria risk models in West Africa [see section 5.1]. Here we show a modified ecological zonation based on agro-ecological zones developed by FAO. The ecological zones are defined by the length (in days) of the growing season and are developed based on quantified information on soil moisture, rainfall and temperature [FAO 1978; Fischer *et al.,* 2006]. These zones were further modified in ArcGIS 10.1 (ESRI, USA) to incorporate mangrove vegetation along the coastline and in Rivers State based on GlobCover land classification classes 160 – 180 that define Aquatic vegetation [Bontemps *et al.,* 2010]. As such this descriptive encompasses many discrete climate variables into a single parameter used for agricultural mapping and adapted by others for malaria mapping.

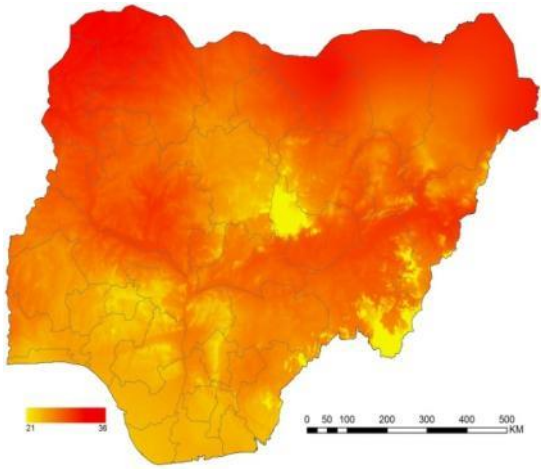
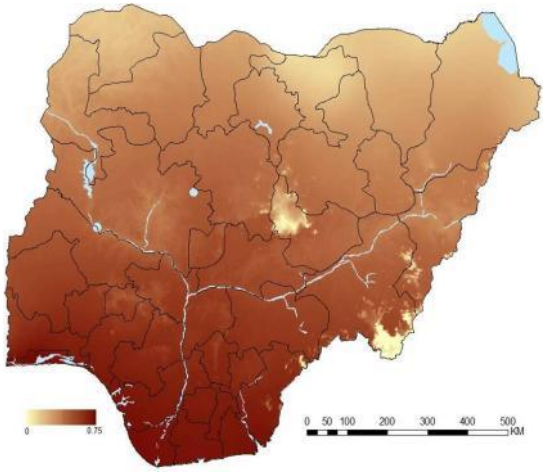
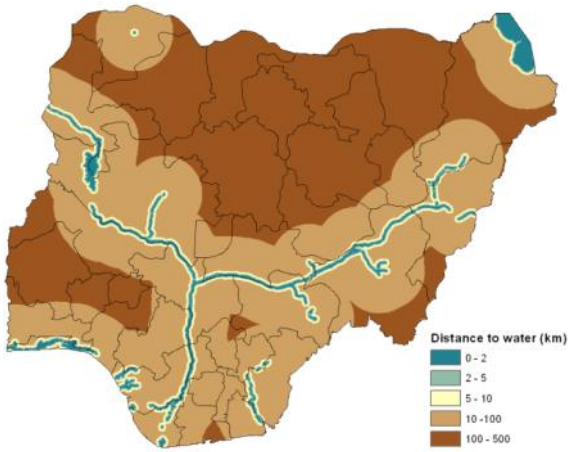
Amongst the ecological strata, the Sahel is of particular recent significance. The Sahel region represents a transition zone between the Saharan desert and the wet climate of tropical Africa. The dominant feature of the climate of this region is the West African Monsoon

(WAM) system. The WAM system develops from April to October, bringing the Inter-Tropical Convergence Zone (ITCZ) and associated rainfall maxima to the northernmost location in August. Rainfall distribution is associated with the dipole structure that associates dry conditions in the Sahel and wet conditions along the Guinean coast with the presence of warm Gulf of sea surface temperature anomalies. An increase in precipitation over the Sahel is usually associated with a decrease in precipitation along the coast and *vice-versa* [Hadley Centre for Climate Change, 2010]. Over the last decade, the Sahel region has experienced one of the most severe and dramatic droughts of the last hundred years. In 2011, sporadic rainfall, insufficient local harvests, high food prices and the consequences of the armed crises across the region had a serious impact on already vulnerable communities in the Sahel. For the northern states of Nigeria located within the Sahel the growing threats posed by terrorist groups such as Boko Haram has added to the vulnerability imposed by drought on the communities in this area.

We have assembled a number of important climatic drivers of malaria transmission that are traditionally used in malaria risk mapping. These are shown and described in the panels a-f of Figure 4.3 and we return to these climatic and ecological drivers of malaria risk in Chapter 5.

Figure 4.3: Climatic drivers of malaria transmission in Nigeria

		
a) Altitude in metres derived from digital elevations provided at http://asterweb.jpl.nasa.gov/gdem.asp derived from NASA Shuttle Radar Topographic Mission (SRTM) digital elevation models (DEM) originally provided at a 1x1 km resolution is re-sampled to a resolution of 90 m at the Equator [Jarvis *et al*., 2008]	b) Rainfall is a major determinant of vector abundance. Monthly rainfall surfaces are produced from global weather station records gathered from a variety of sources for the period 1950-2000 and interpolated using a thin-plate smoothing spline algorithm to produce a continuous global surface [Hijmans *et al.*, 2005] and monthly average rainfall raster surfaces at 1×1 km resolution available from the WorldClim website (http://www.worldclim.org/download.html). Data shown here are mean maximal monthly rainfall in mm	c) The normalized difference vegetation index (NDVI) is a measure of the intensity of photosynthetic activity downloaded from the earth orbiting Advanced Very High Resolution Radiometer (AVHRR) satellite dataset. Data have been pre-processed to capture seasonality using Temporal Fourier analysis between 2001 and 2005 [Scharlemann *et al*., 2008]. NDVI values range from 0-1 and available at 1x1 km resolutions.

		
d) Temperature plays a key role in determining the transmission of human malaria based on its relationship with the duration of sporogony and is particularly relevant to *P. falciparum*. Temperature surfaces are produced from global weather station temperature records gathered from a variety of sources for the period 1950-2000 and interpolated using a thin-plate smoothing spline algorithm, with altitude as a covariate, to produce a continuous global surface [Hijmans *et al.*, 2005] and monthly average temperature raster surfaces at 1×1 km resolution available from the WorldClim website. Data shown here are mean annual temperatures ^{o}C	e) As a metric for the effect of temperature on malaria transmission, a temperature suitability index (TSI) has been developed at a spatial resolution of 1×1 km [Gething *et al*., 2011]. The TSI model uses a biological framework based on survival of vectors and the fluctuating monthly ambient temperature effects on the duration of sporogony that must be completed within the lifetime of a single generation of Anophelines and constructed using monthly temperature time series [Hijmans *et al.*, 2005]. On a scale of increasing transmission suitability, TSI ranges from 0 (unsuitable) to 1 (most suitable)	f) A map of water bodies for Nigeria was created from a combination of two sources: a rivers layer digitized from 1:50,000 topographic maps and provided by the International Livestock Research Institute, and a map of water bodies developed by the Africover project [www.africover.org]. Major perennial and seasonal water bodies were identified from the combined map by first excluding small and highly seasonal streams and tributaries and confirmed using Google Earth [www.google.com/earth].

4.3. Malaria seasonality

A dominant epidemiological characteristic of malaria across much of Africa is its seasonal profile ranging from single, acute proliferation of vectors followed by a lagged short disease incidence profile, to predictable seasonal transmission with between year variability and areas that support perennial transmission due to constant rainfall or seasonal rainfall in areas adapted for permanent breeding (inland river courses or irrigated areas). Relationships between climate, seasonal parasite transmission and disease outcomes are complex and have been poorly defined for many years [Gill, 1938]. There is a suggestion that areas with acute transmission represent settings that are more adapted to synchronized infections leading to higher host parasite densities [Mckenzie *et al*., 2001]. Acutely seasonal malaria exposure areas may lead to poorly "designed" immunization for new-born children, resulting in different disease-severity profiles compared to settings with equivalent annual parasite exposure more evenly distributed throughout a year (spaced immunization) [Caniero *et al.*, 2010; Greenwood *et al.*, 1991].

The description of seasonality represents an important operational information platform to target the timing of vector control, most notably IRS and larval control operations, and the renewed interest in pulsed mass drug administration or restricted chemoprophylaxis in the Sahel, known as Seasonal Malaria Control (SMC) [Cairns *et al*., 2012; Meremikwu *et al.*, 2012; WHO, 2012b]. The map of malaria seasons in Africa most widely used today was developed by the MARA/ARMA collaboration over ten years ago and continues to be used in Nigerian reports, policy documents and applications for funding.

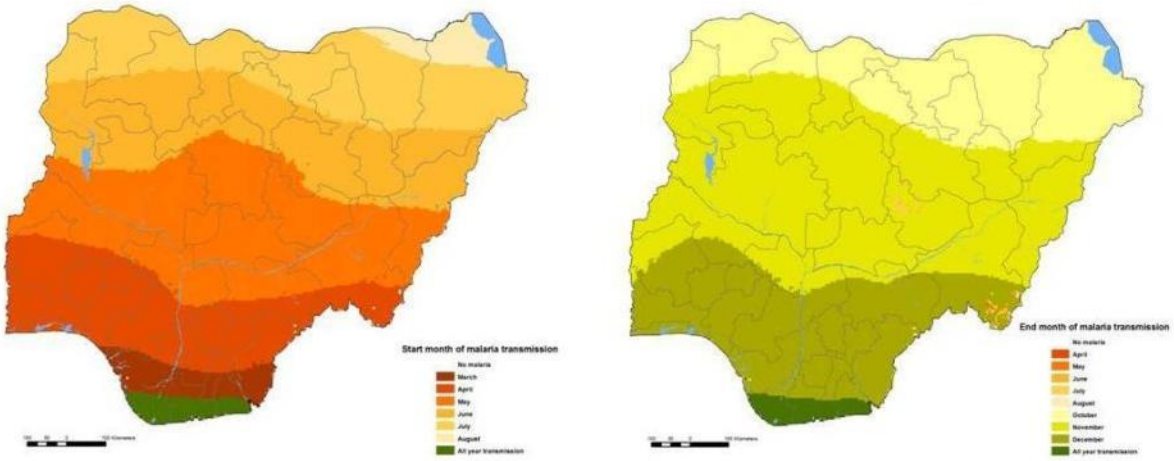
The climate suitability maps developed by the MARA collaboration are based on the likelihood of stable transmission using a rules-based approach [Craig *et al.*, 1999]. These theoretical maps are not trained on empirical data but reflect an approximation of local climate conditions to support stable transmission on an average year in the absence of control. The models are based on fuzzy logic and use long-term rainfall and temperature data [Hutchinson *et al.*, 1995] to model the effects on transmission from dominant vectors to human hosts of climatic conditions. The fuzzy logic model of suitability uses monthly temperature ranges between 22-32^{o}C for optimized parasite sporogny within the mosquito and consecutive months of rainfall above 80 mm to support adequate vector abundance. The models assigns fuzzy values between 0 (unsuitable) and 1 (suitable). These models were then extended to be able to predict the start and end month of transmission and the duration of the transmission season [Tanser *et al*., 2003; http://www.mara.org.za/].

The MARA models of seasonality are defined using the combination of temperature and rainfall thresholds and a catalyst month. Areas where mean annual temperatures were <5^{o}C were considered not to have a malaria transmission season. A pixel was considered "seasonal" if the temperature range varied considerably or if annual rainfall was <720 mm. Seasonal zones were then classified according to the numbers of average months in which temperature was > 22^{0}C and rainfall > 60 mm within a 3-month moving window and at least one month of highly suitable conditions (> 22^{0}C, > 80 mm) occurred as a catalyst month. For areas considered "stable" the equivalent values were 19.5^{0}C and 80 mm with no requirement for a catalyst month. From these values the duration and start/end of the transmission season were predicted and the gridded surface of Africa was classified at

5x5km grids into 1-3 months of transmission (highly seasonal/epidemic), 4-6 months of transmission (representing seasonal endemic conditions) and 7-12 months reflecting perennial endemic transmission (Figure 4.4) and by start and end transmission months in Figures 4.5a and 4.5b.

Figure 4.4: Seasonality of malaria transmission developed by MARA; perennial 7-12 months transmission (dark green), 4-6 months seasonal endemic malaria (light green); acutely seasonal, potentially epidemic 1-3 months transmission (brown) [http://www.mara.org.za]

Figure 4.5: b) Start and b) end months of malaria transmission in Nigeria based on MARA seasonality model [http://www.mara.org.za]

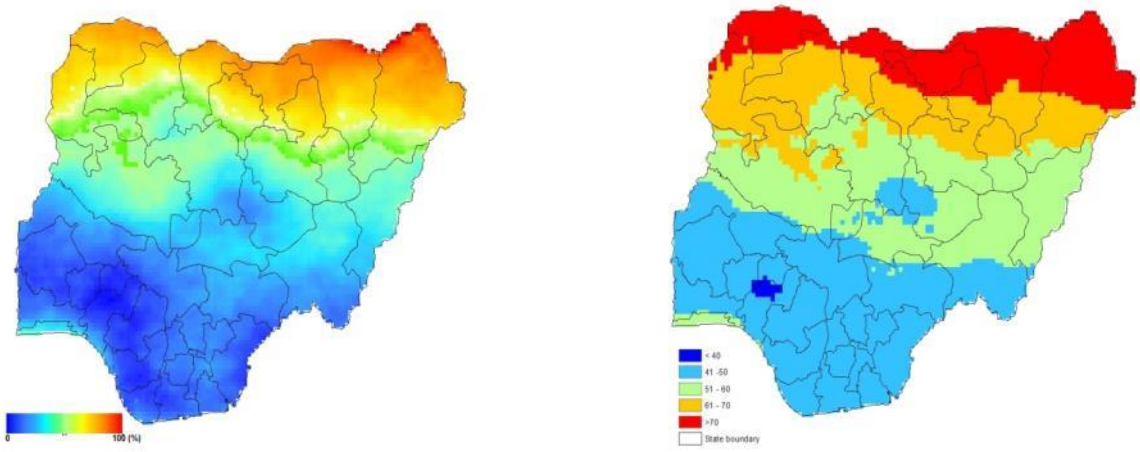


The MARA model was an important development over ten years ago, however its fidelity requires further validation using a wider range of time-series data on the clinical presentation of malaria to hospitals and clinics across Africa. New models of "malaria seasons" could be developed using alterative long-term climatology data [Hijmans *et al.*, 2005; Scharleman *et al*., 2008], higher temporal and spatial resolution data since 1999 from SPOT imagery at 1x1km resolution every 10 days [http://www.inra.fr] and use other seasonality concentration metrics [Ermert *et al.*, 2011; Mabaso *et al.*, 2007; Mitchell &

Jones, 2005]. An early and provisional attempt at using empirical data to define extremes of seasonality for SMC have recently been published by Cairns and colleagues using Fourier processed daily rainfall data [http://www.cpc.noaa.gov/products/fews/rfe.shtml] since 2000 and tested against monthly clinical incidence data from 55 sites across sub-Saharan Africa. The optimal model was one where 60% of annual rainfall occurred within 3 months and best fitted the seasonal clinical profiles of >60% of cumulative cases occurring in 4 consecutive months [Cairns *et al.*, 2012]. Using this rainfall, profile areas with incidence patterns suitable for SMC were identified, with a sensitivity of 95.0% and a specificity of 73.5% [Cairns *et al.*, 2012].

Here we have used daily rainfall estimates from the African Rainfall Estimates version 2 (RFE 2.0) dataset developed as a collaborative programme between NOAA's Climate Prediction centre (CPC), USAID/Famine Early Systems Network (FEWS). The RFE 2 gridded dataset combines gauge and satellite information on a near-real time basis to provide daily rainfall estimates over the African continent and is archived from January 2000 at 10 km spatial resolution [NOAA CPC, 2001; Novella & Thiaw, 2012]. To match work done by Cairns and colleagues we have selected daily-accumulated rainfall data between 2002 to 2009 per 10km pixel to define the maximum percentage of the total annual rainfall occurring in a period of consecutive months (Figures 4.6 a and 4.6b). These predictions are more tangibly rooted in current models of disease risk and are used here in preference to MARA models described above and subsequently used in Chapter 6 to create populations-at-risk of acutely seasonal malaria.

Figure 4.6: a) NOAA rainfall/seasonality concentration index in continuous form and b) binned to show red and orange priority SMC areas where >= 60% of rainfall falls within 3 continuous months



Footnotes: The gridded daily rainfall estimates at 0.1 degree resolution from the RFE 2.0 dataset between January 2002 and December 2009 was acquired from the NOAA CPC/FEWS archive [NWS, 2012; ftp://ftp.cpc.ncep.noaa.gov/fews/newalgo_est/]. The daily rainfall estimates were then aggregated to calculate total monthly and annual rainfall. For each pixel, the maximum percentage of the total annual rainfall occurring in three month-iterations was then calculated for each year using spatial analyst tool in ArcGIS 10.1 (ESRI, USA). The average pixel value between 2002 and 2009 was then calculated and the resulting image reclassified to give a binary output of areas where rainfall in three consecutive months was < 60% or > 60%.

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Chapter 5

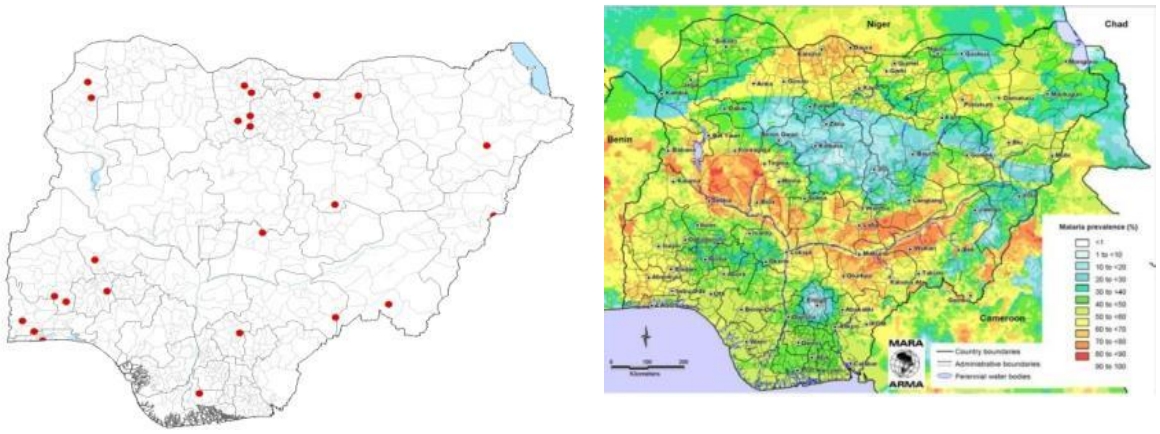
Malaria risk mapping

5.1. Previous efforts at mapping malaria risk in Nigeria

There are no early maps of malaria risk developed during the pre-independence period. Bruce-Chwatt, however, provides a narrative description of the epidemiology of malaria in the country in 1951, stating that the whole of Nigeria is malarious and that hyperendemic malaria extends from the coast to the 254-mm dry season (November-April) isohyet, with varying degrees of endemicity throughout the rest of the country [Bruce-Chwatt, 1951]. To emphasize the uneven distribution he highlights that in the traditionally hyperendemic southern region there are islands of low endemicity (Ijebu Ode) and in the northern arid areas there are numerous hyperendemic foci (Katsina) and that even on the Bauchi plateau malaria is endemic malaria [Bruce-Chwatt, 1951]. Spleen rates among children aged 1-10 years in the 1950s were between 65% and 80% with relatively little seasonal variation in the southern provinces and between 50% and 60% in the northern provinces with extreme seasonal variation [Bruce-Chwatt, 1951]. The global assembly of medical intelligence, parasite rates and climate data by Russian malariologists in the 1960s classified all of Nigeria as hyperendemic (parasite rates in children 50-74%) with small pockets of holoendemicity (parasite rates in infants above 75%) in the North West of the country and around Lagos [Lysenko & Semashko, 1968]. Not until 2000 was an attempt made to formally quantify malaria endemicity in Nigeria.

In 2001, the MARA collaboration used 450 parasite prevalence surveys from across West Africa among children aged below 10 years from studies undertaken between 1960 and 1999 as the basis of a predictive model of *P. falciparum* prevalence across the region [Kleinschmidt *et al.*, 2001; http://www.mara.org.za]. The input data to the model included only 22 survey locations in Nigeria (Figure 5.1.a). The model used a series of climatic and ecological covariates to train the predictions of prevalence from sparse data including long-term monthly average rainfall, minimum and maximum temperature, remotely sensed satellite imagery of vegetation indices, soil drainage capacity and population density. The data were partitioned according to ecological zones used by the Food & Agricultural Organization (FAO) for crop potential: Equatorial Forest, (> 270 days of rainfall), Guinea Savannah zone (165-270 days of rainfall), and a combined Sudan and Sahel Savannah zone (less than 165 days of rainfall) [FAO, 1978]). The models were developed for each ecological zone using regression techniques (Generalized Linear models with logit functions) with the parasite prevalence as the dependent variable. The optimized model was then used to predict malaria prevalence among children aged less than 10 years at un-sampled 5x5 km grid squares and smoothed using a process of krigging. The resultant combination of modelling prevalence where data are sparse and krigging available data is shown in Figure 5.1.b. This map has served as the only map of the intensity of malaria transmission used by the Nigerian NMCP since the launch of RBM and with MARA maps of seasonality (Figure 4.3) appears in the Roll Back Malaria Focus series on Nigeria [RBM, 2012], the National Malaria Strategy 2009-2013 [NMCP, 2009a], the 2012 operational plan of action for national control [NMCP, 2012] and applications to the Global Fund Rounds 4 and 8. Ten years ago this was a revolutionary product but the field of Model Based Geostatistics (MBG) has evolved, Bayesian approaches are now preferred for infectious disease mapping and there has been a growth in available data to model the risks of malaria in time and space.

Figure 5.1: a) Nigerian survey data used in the regional malaria prevalence modelling/krigging exercise in 2001; and b) the results of the regional model shown as categories of *Pf*PR_{0-10} for Nigeria [Kleinshmidt *et al.*, 2001; http://www.mara.org.za]



The principle objective of this report is to provide the NMCP with an improved map of modelled *P. falciparum* transmission intensity at the time of the launch of RBM in 2000 to represent the pre-scaled intervention pattern of transmission intensity and a corresponding modelled predictive map based on more recent survey data to present the patterns of risk in 2010. In addition we use this output against high spatial resolution population settlement and density models to provide a relative proportion of state level populations-at-risk of the ranges of transmission intensity likely to affect decisions on appropriate combinations of intervention, timelines to sustained endemic control and denominators for the future estimation of disease burden.

5.2 Developing new malaria risk maps for Nigeria 2000, 2005 and 2010

5.2.1 Malaria parasite prevalence

There are a variety of measures of the intensity of malaria transmission derived from field investigations of human populations or malaria vectors. The most widely used measure, for over 100 years, is the parasite rate - the proportion of individuals on a single cross-sectional survey among an entire or sampled community who have evidence of a peripheral blood stage malaria infection. These data are often expressed as infection prevalence among children aged 2-10 years (*Pf*PR_{2-10}) and used since the 1950s to define categories of endemic risk designed to guide progress toward malaria elimination targets [Boyd, 1949; Metselaar & van Thiel, 1959; Macdonald & Göeckel, 1964; Lysenko & Semashko, 1968]. The ubiquity and modeling value of *Pf*PR has led to a renaissance in malaria risk cartography using modern spatial statistical methods not available to those who promoted malaria risk mapping in the 1950s [Snow *et al*., 1996; Omumbo *et al*., 2013].

The *Pf*PR_{2-10}, has a predictable relationship to other far less frequently measured parameters of transmission intensity, notably the Entomological Inoculation Rate (EIR) and the Basic Reproduction Rate of Infection (R_o). As such values of *Pf*PR_{2-10} can be used to model control timelines to transmission reduction and the appropriate combinations of available interventions [Hay *et al.*, 2008; Smith *et al.*, 2009; Griffith *et al.*, 2010] and a factor in the decision pathway to predict the likelihood of elimination [Cohen *et al.*, 2010].

5.2.2 Parasite prevalence data search strategies

5.2.2.1 Electronic data searches: Online electronic databases were used as the main means for identifying peer reviewed published data on malaria infection prevalence. Due to its wide coverage of the biomedical literature, PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez) was used as the basis for all the initial online searches of published sources as it covers all references compiled by the National Library of Medicine's MEDLINE database, *circa* 13 million references to biomedical journals, plus references not indexed in MEDLINE. In addition, we used the Armed Forces Pest Management Board – Literature Retrieval System (http://www.afpmb.org/publications.htm) that holds more than 100,000 articles on vector borne diseases available in full-text; The World Health Organization Library Database (http://www.who.int/library); and the Institute de Recherché pour le Development on-line digital library service (http://www.ird.fr) for the few articles published on malaria in Nigeria in French (largely early studies on the borders with Cameroun or studies on haemoglobinopathies). Regional journals, most notably the large number of Nigerian medical, public health and parasitological journals were not accessible routinely through the above sources but titles and abstracts were available on African Journals Online (AJOL) (http://www.ajol.info), the world's largest online collection of African-published, peer-reviewed scholarly journals. AJOL proved an invaluable resource for malaria parasite surveys conducted locally and published in Nigerian journals or by Nigerian scientists in other national public health journals across the region. In all digital electronic database searches for published work the free text keywords "*malaria*" and "*Nigeria*" were used. We avoided using specialised MeSH terms in digital archive searches to ensure as wide as possible search inclusion. Major database searches were undertaken three times in the last 12 months and supplemented between searches with weekly notifications from Malaria World (http://www.malaria-world.com), the Roll Back Malaria news alert service (http://www.rollbackmalaria.org) and the Environmental Health at USAID malaria bulletins (http://www.ehproject.org).

Titles and abstracts from digital searches were used to identify possible cross-sectional survey data undertaken in a variety of forms: either as community surveys, school surveys, intervention trials (where pre-intervention, baseline and control groups could be identified). We paid special attention to the identification of studies investigating the prevalence of conditions associated with malaria directly or indirectly (e.g. anaemia, haemoglobinopathies and other erythrocytic polymorphisms, hepatitis B and human immunodeficiency viral infections or nutritional status) where concomitant malaria parasite prevalence were presented. In addition, it was common practice during early anti-malarial sensitivity protocols to screen community members or school attendees to recruit infected individuals into post-treatment follow-up surveys, often data from the survey sites selected present the numbers screened and positive. Reports showing possible data were either downloaded from journal archives where these have been made Open Access (OA) or sourced from HINARI (http://www.who.int/hinari/), a programme set up by WHO together with major publishers, to enable developing country scientists to access biomedical and health literature free of charge. If publications were not available OA from HINARI we obtained copies from the libraries of the London School of Hygiene and Tropical Medicine, the Liverpool School of Tropical Medicine and the Bodleian library at the University of Oxford. With the help of Philip Agomo of the National Institute of Medical Research, Lagos and

Grace Adeoye of the University of Lagos we were able to source Nigerian Journal references not accessible through UK library services. References not found following these searches were requested using world catalogue searches through the Oxford libraries at a per-page cost. All publications from which data were extracted were cross referenced using the bibliographies for additional sources that may have been missed or that may correspond to unpublished or 'grey' literature (i.e. not controlled by commercial publishers).

5.2.2.2 Historical archive data searches: A wealth of data, both published and unpublished, is available from a variety of archives related to malaria in Nigeria. We identified the Malaria Service, Department of Medical Services, Federation of Nigeria quarterly and annual reports of the 1940s and 1950s and other unpublished reports by Drs Bruce-Chwatt and Archibald at the Wellcome Library in London (http://library.wellcome.ac.uk). Colonial annual medical reports, that included laboratory, clinical and survey data, (1914-1959/60) were copied at the British Library/National Archives at Kew, London (http://www.nationalarchives.gov.uk) or a manual search of the many box files dating back over 100 years at the Wellcome Library (now Ministry of Health Library) at the National Public Health Laboratories in Nairobi, Kenya. Of significance for data from 1970-71 collected as part of the Gharki project [Molineaux & Gramiccia, 1980], data used by mathematical modellers over the last 10 years, have been reconstructed in a public domain accessible from by the Swiss Tropical Institute and available online (http://www.swisstph.ch/fr/ressources/epidemiological-databases.html). Finally we performed a manual search of every volume of the *West African Medical Journal* between its first issue published in 1927 to 1966 when the journal changed and captured on PubMed. We have stored the results of these historical searches are as PDFs on CD, whether they contained information related to malaria parasite prevalence or not, for future use and reference by the Federal NMCP.

5.2.2.3 Unpublished community survey data post-2005: We have been fortunate to have access to community-based survey data undertaken as part of national or state level surveys supported by bi-lateral partners through survey agencies or NGO partners. Data have been generously provided by The Carter Center as part of their work between 2007 and 2008 integrating control of malaria with lymphatic filariasis in Benue, Ebonyi and Imo States [Graves *et al*., 2009]; the SuNMaP project in Anambra and Kano States between 2009 and 2011 [Kilian *et al*., 2010]; The Malaria and Anthropometric Baseline Assessment (MABA) Survey undertaken in 2011 as a collaboration between the MDG offices and the NMCP across 14 States; and the data from the national Malaria Indicator Survey (MIS) undertaken nationwide in 2010 [NPC *et al*., 2012] supported by USAID, Global Fund and UKAID through their Implementing Partners. This combined rich data set would not have been accessible from traditional data search approaches and has significantly improved our ability to undertake the work described below and the precision of the malaria risks across Nigeria in 2010.

5.2.3 Data abstraction

The minimum required data fields for each record were: description of the study area (name, administrative divisions and geographical coordinates, if available), the dates of start and end of the survey (month and year) and information about blood examination (number of individuals tested, number positive for *Plasmodium* infections by species), the methods

used to detect infection (microscopy, Rapid Diagnostic Tests (RDTs), Polymerase Chain Reaction or combinations) and the lowest and highest age in the surveyed population. Given its ubiquity as a means for malaria diagnosis, the preferred parasite detection method was microscopy. No differentiation was made between light and fluorescent microscopy nor is it possible to classify the skill and precision of individual studies microscopists. In only one series were RDTs (Azog MFV 124R) included as no alternative data from blood smears were available. For data derived from randomized controlled intervention trials, data were only selected when described for baseline, pre-intervention and subsequent follow-up cross-sectional surveys among control populations. When communities were surveyed repeatedly in time we endeavoured to include only the first survey and subsequent surveys if these were separated by at least five months from the initial survey to avoid a dependence between observations based on treatment of preceding infected individuals. If it was not possible to disaggregate repeat surveys these were finally excluded from the analysis. Where age was not specified in the report for each survey but stated that the entire village or primary school children examined we assumed age ranges to be 0-99 years or 5-14 years respectively. Occasionally reports presented the total numbers of people examined across a number of villages and only the percentage positive per village; here we assumed the denominator per village to be equivalent to the total examined divided by the total number of villages. In addition, some reports presented no information on the denominator, here we have elected to presume a minimum sample size of 50 individuals examined per site unless other information from other sources indicated the sample size might have been smaller (where we presumed 15) or much larger (where we presumed 100) and included a record of this assumption. Where we were not confident on the necessary detail we excluded the record. It was possible to establish the year of every included survey, however, the month of survey was occasionally not possible to define from the survey report. Here we used descriptions of "wet" and "dry" season, first or second school term or other information to make an approximation of the month of survey and included a record of this assumption. Some survey results were reported as an aggregate in space (e.g. a single *Pf*PR for a group of villages) or time (e.g. a mean *Pf*PR estimated from four different surveys conducted over time). In such cases we either sought additional reports of the same surveys with higher spatial or temporal resolution. Where this was not possible and where clusters of villages exceeded 25 km^2 we excluded the record from the analysis (see below). Where additional information to provide unique time, village, and complete data was necessary and it was possible to contact authors by email we entered correspondence to provide any missing information. The many individuals who have assisted in the process of identifying survey data, providing additional information and cascading our enquiries are acknowledged at the begging of this report.

5.2.4 Data geo-coding

Data geo-coding, defining a decimal longitude and latitude for each survey location, was a particularly demanding task. According to their spatial representation, data were classified as individual villages, communities or schools or a collection of communities within a definable area, corresponding to an area ≤ 25 km^2 or 5x5km pixel grid squares. Wherever possible we aimed to retain disaggregated village, "point" level data rather than data across a "wide-area". Where data were reported across communities that exceeded 50 km^2 we regarded these as too low a spatial resolution, with significant possible variation within the

polygon of information to be excluded. Data were therefore labeled as points, wide-areas or polygons. To position each survey location in space we used a variety of digital resources, amongst which the most useful were Microsoft Encarta Encyclopedia (Microsoft, 2004) and Google Earth (Google, 2009). Other sources of digital place name archives routinely used included GEOnet Names Server of the National Geospatial-Intelligence Agency, USA (http://www.earth-info.nga.mil/gns/html/cntry_files.html); Falling Rain Genomics' Global Gazetteer (http://www.fallingrain.com); and Alexandria Digital Library prepared by University of California, USA (http://www.alexandria.ucsb.edu). Although standard nomenclatures and unique naming strategies are attempted in digital gazetteers [Hill, 2000], these are difficult to achieve at national levels where spellings change between authors, overtime and where unique place names are replicated across a country. As such, during the data extraction, each data point was recorded with as much geographic information from the source as possible and this was used during the geo-positioning, for example checking the geo-coding placed the survey location in the administrative units described in the report or corresponded to other details in the report on distance to rivers or towns when displayed on Google Earth. More latterly, with the unpublished data sets, Global Positioning Systems (GPS) have been used to record the longitude and latitude. While in theory GPS coordinates should represent an unambiguous spatial location, these required careful re-checking to ensure that the survey location and LGA names matched the GPS coordinates. For the MABA surveys the coordinates were not as precise as they may have been and likely subject to either reading errors or transcription errors as several GPS coordinates were either in the Atlantic Ocean or neighbouring Cameroun. As routine we therefore rechecked all GPS noted data from all sources using place names and/or Google Earth to ensure coordinates were located on communities. All coordinates were subject to a final check using second level administrative boundary GAUL spatial database developed and revised in 2008 by Food and Agriculture Organization (FAO) of the United Nations [FAO, 2008]. The spatial selection tool in ArcGIS 10.1 (ESRI, USA) was used to verify points along the coastline were within land area as defined by GAUL 2008. The Global Lakes and Wetlands (GLWD) database developed by the World Wildlife Fund [Lehner & Doll, 2004] was used to ensure inland points were within defined land area. Here we aimed to identify survey coordinates that fell slightly off the coastline, located on the river or in incorrect administrative units, every anomaly was re-checked and re-positioned using small shifts in combination with Google Earth.

5.2.5 Database fidelity checks, exclusions and pre-processing

5.2.5.1 Data checks: The entire database was first checked with a series of simple range-check constraint queries to identify potential errors that could have occurred during data entry. These queries assessed all data fields relevant to modelling for missing or inconsistent information. The final objective was to check for any duplicates introduced during the iterative data assembly process. Pairs of survey sites found within 1 km or within five months at the same location were identified using R-script. These may have entered erroneously into the data assembly where multiple reports reviewed describing similar data. These were listed, checked and duplicates removed.

5.2.5.2 Data exclusions: The data search identified a total of 1106 site and time specific survey reports of malaria infection prevalence between 1929 and 2011. Following rigorous and multiple attempts at geo-coding the assembled data we were unable to provide any

coordinates with confidence for one survey location, Ugugu Camp, from a 1970s report on nomadic health by the WHO; this survey point was excluded. One survey report reported information at a spatial resolution that exceeded 25 km^2 across the Jos Plateau and this were also excluded. Data identified from surveys undertaken between 1929 and 1959 (n=69) were over-distributed, largely from descriptions of infection prevalence around Lagos and the projects at Ilaro and Kebbi (see Chapter 3). To simplify the modelling of temporal risks we have excluded the survey data 1929-1959 leaving 1,035 unique space-time survey data points.

Sample size is inversely related to prevalence where, at low sample sizes, biases in prevalence estimates are introduced, dependent on the true prevalence of the population and translates into large standard errors [Gregory & Blackburn, 1991]. There is a critical threshold of between 10 and 20 individuals sampled below which the standard error increases exponentially in most surveys of parasitic infections and the curve starts to flatten at a sample size of about 50 and reaches an asymptote at about 100 [Jovani & Tella, 2006]. The sample size of individual survey samples is also important in the derivation of correlations with covariates of endemicity, in testing plausible associations between say rainfall and prevalence during covariate selection small, imprecise samples introduce bias. We aimed to combine communities in close proximity where any village had less than 15 people sampled and where communities were within 25 km of each other, sampled at exactly the same time by the same investigators. Communities where less than 15 people were sampled and not close to other communities sampled at the same time were excluded. Among the 1,035 post-1960 survey samples identified 114 were among communities where less than 15 individuals were examined, >95% of these samples were from the MIS 2010, MABA or Carter Centre surveys. To retain precision in our point estimates of risk we have excluded these leaving a total spatial sample of data of 921 space-time survey locations.

5.2.5.3 Age standardization: There was a large diversity in the age ranges of sampled populations between studies. To make any meaningful comparisons in time and space a single standardized age range is required. Correction to a standard age for *Plasmodium falciparum* is possible based on the observation and theory of infectious diseases where immunity is acquired following repeated exposure from birth. We have retained the classical age range of 2-10 years as this best describes the exposure to infection among semi-immune hosts at any given location and conforms to classifications established in the 1950s [Metselaar & Van Thiel, 1959]. We have adapted catalytic conversion Muench models, first used in malaria by Pull & Grab (1974), into static equations in R-script that uses the lower and upper range of the sample and the overall prevalence to transform into a predicted estimate in children aged 2-10 years, $Pf\mathrm{PR}_{2\text{-}10}$ [Smith *et al.,* 2007].

5.3 Data summaries

Of the 921 unique time-space survey locations identified through the data search strategy described above, 415 (45%) were sourced from unpublished WHO or project reports or on-line databases, 312 (34%) were indentified from unpublished sources provided by research, NGO and survey groups in Nigeria, 146 (16%) were sourced from peer-reviewed journals, 23 (2.5%) from survey reports published in books, 17 (2%) from Ministry of Health reports and

eight (0.5%) from conference abstracts. The data cover the years 1960 to 2011 but, as would be expected, unevenly distributed through time and in space. To explore the temporal (not spatial) variance in the age-standardized estimates of parasite prevalence we used a LOESS regression method that fits a best fitting curve using moving temporal windows on the data using information before and after the reference year in STATA (version 12). The results suggest that there has been little temporal change in the available estimates of *Pf*PR_{2-10} over the first 45 years of the data series (Figure 5.2). Data are sparse for the mid-1970s, 1980s and 1990s. There is some evidence of a declining mean *Pf*PR_{2-10} over the period 2006 to 2011, beginning with the launch of the second national malaria strategic plan in 2006. Figures 5.3a and 5.3b show the locations of *Pf*PR_{2-10} estimates for the periods 1960-2005 and 2006-2011 respectively.

Figure 5.2: LOESS regression fit to *Pf*PR_{2-10} standardized data between 1960 and 2011.

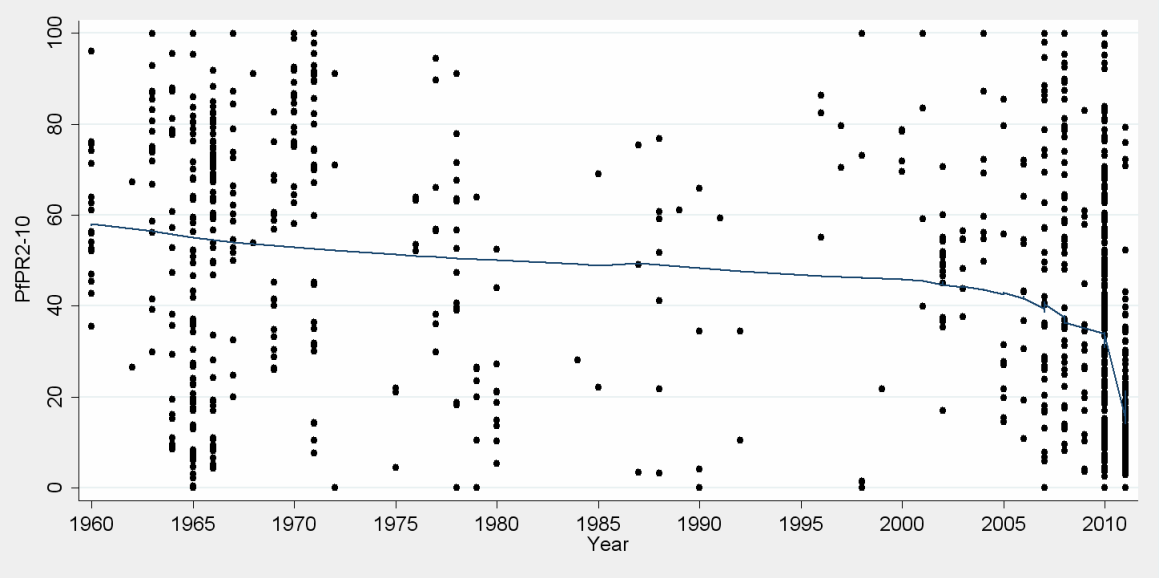
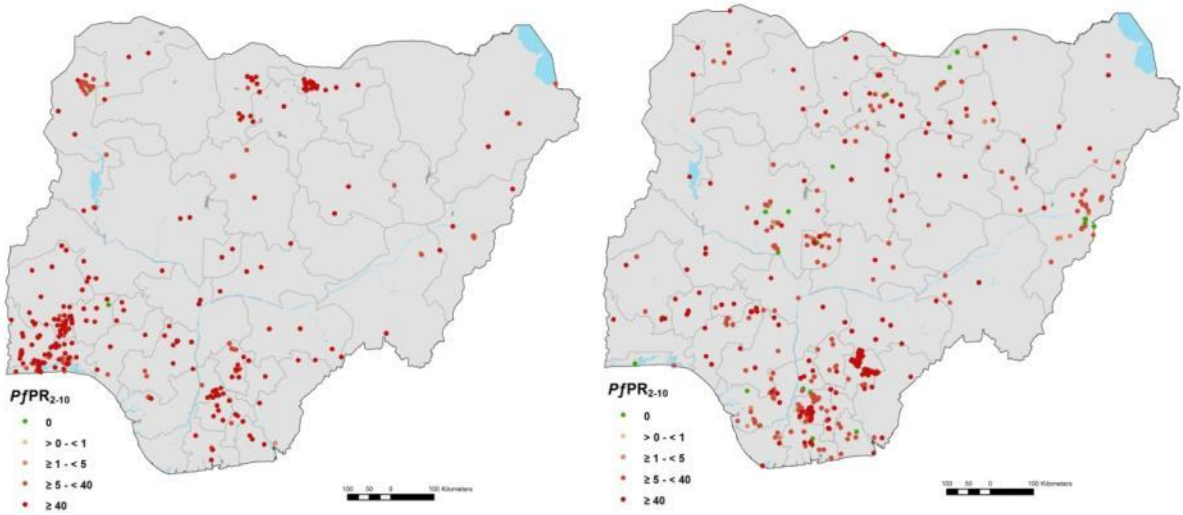


Figure 5.3 a) Distribution of *Pf*PR_{2-10} survey data 1960-2005 (n=433) and b) 2006-2011 (n=488)



5.4 Assembling and testing the ecological and climate predictors of *Pf*PR$_{2-10}$

Ecological and climatic heterogeneity affect the development and survival of the Plasmodium parasite and the malaria-transmitting Anopheles vectors. Environmental covariates are therefore commonly used to improve the precision of malaria risk modelling and traditionally include measures of aridity, vegetation, rainfall, temperature, proximity to water bodies and urbanization. These are derived from meteorological, topographical and remotely sensed satellite sources or census data. Climatic and ecological covariates are shown and described in Chapter 4 and urbanization is defined in Chapter 6 and Annex C. For each survey location we extracted covariates using ArcGIS 10 (ESRI Inc., USA). These were first analyzed using a univariate analysis with *Pf*PR$_{2-10}$ as the dependent variable (Table 5.1). To select the combination of covariates that best predicted *Pf*PR$_{2-10}$ we conducted a total-sets analysis based on a generalized linear regression model and implemented in *bestglm* package in R [Miller, 2002; Lumley, 2010]. The best combination of covariates, those with the lowest value of the Bayesian Information Criteria (BIC) statistic [Schwarz, 1978], was selected for the predictive models of malaria risk and included precipitation, TSI, distance to main water bodies and urbanisation (Table 5.2). NDVI and ecozones were not included as their contribution to the variance in *Pf*PR$_{2-10}$ was superseded by long-term measures of precipitation.

Table 5.1: Coefficients: Univariate Analysis

Variable	Level	Estimate	Std. Error	t value	P value
NDVI[1]		3.47	9.57	0.36	0.72
TSI[2]		-1.64	8.16	-0.20	0.84
Precipitation[3]		-0.06	0.02	-3.32	0.00
Urban[4]		-4.13	2.14	-1.93	0.05
Distance to water (Km)[5]		0.08	0.02	4.10	0.00
Altitude (m)[6]		0.01	0.00	2.23	0.03
FAO ecozone[7]	FAO ecozone 2	2.64	2.45	1.08	0.28
	FAO ecozone 3	0.09	2.68	0.03	0.97
	FAO ecozone 4	-10.38	8.86	-1.17	0.24
	FAO ecozone 5	-19.14	4.09	-4.69	0.00

Footnotes: 1) see Figure and footnotes 4.3c; 2) see Figure 4.3e and footnotes; 3) see Figure 4.3b and footnotes; 4) see Figure 6.1 Annex C; 5) see Figure 4.3f and footnotes; 6) see figure 4.3a and footnotes; 7) see Figure 4.2; 1= Equatorial Forest; 2= Guinea Savannah; 3 Sudan Savannah; 4 = Sahel; 5= Mangrove)

Table 5.2: Best fitting predictive Model using total sets analysis

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
TSI	1	34	34	0.043	0.836	
Precipitation	1	31218	31218	39.347	5.46e-10	***
Urban	1	8642	8642	10.893	0.001	**
Distance to water	1	12137	12137	15.298	9.86e-05	***

5.5 Model Based Geo-statistic (MBG) mapping of *P. falciparum* risk in Nigeria

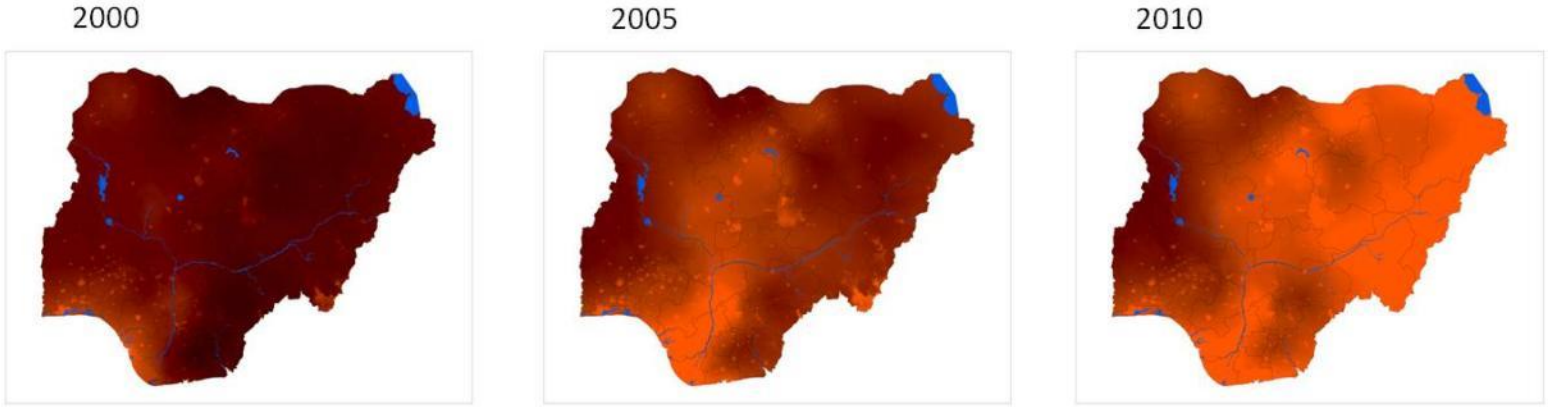
Model Based Geostatistics (MBG) were developed to interpolate from sparse information of known locations in space and time to provide predictions of quantities at locations and times where data do not exist. All MBG methods operate under geographer's principles that things that are closer in space and time are more similar than those more spatially and temporally distal to surveyed locations – Tobler's First Law of Geography. As these methods have evolved over the last 25 years they have been approached using Bayesian statistical methods which are most suited to testing hypotheses with noisy, sparse and uncertain data allowing the application of prior constraints on the data forms and predictions.

A Bayesian hierarchical spatial-temporal model was implemented through the Stochastic Partial Differential Equations (SPDE) approach using Integrated Nested Laplace Approximations (INLA) to produce continuous maps of *Pf*PR_{2-10} at 1×1 km spatial resolution using data from 1960-2011. Technical details of model specifications are presented in Annex A.

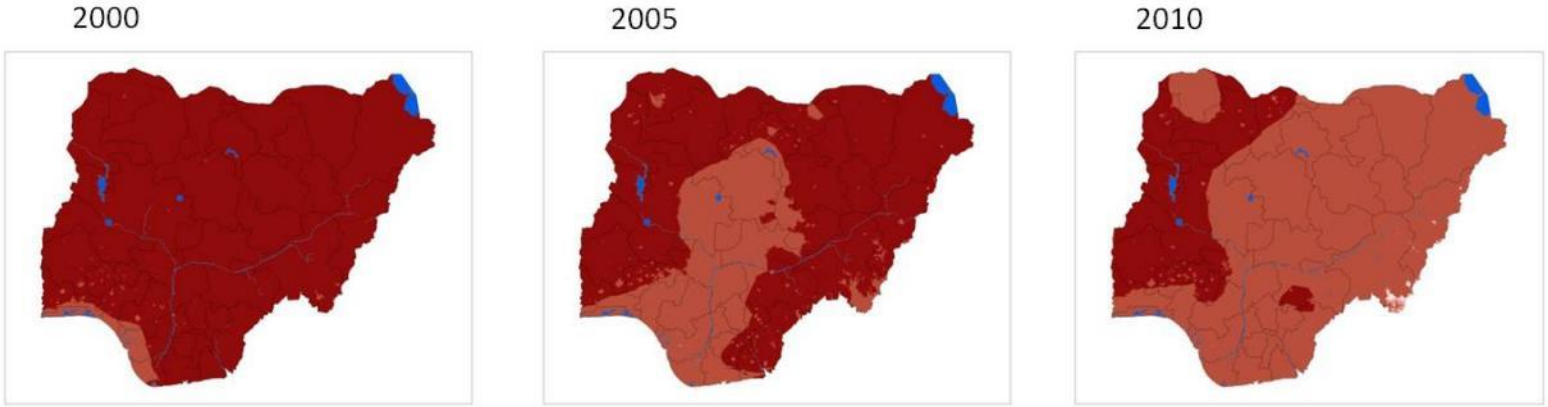
In the SPDE approach, the overall hierarchical space-time binomial model of the prevalence to malaria parasite was represented as the realization of a spatial-temporal process of the *Pf*PR_{2-10} at the community location and time, the covariates (TSI, urbanisation and distance to water) vector for the given location and time, the coefficient vector and the measurement error defined by the Gaussian white noise process. The realization of state process or the unobserved level of *Pf*PR_{2-10} is defined by a spatial-temporal Gaussian field that changes temporally as a first-order autoregressive function.

Data were used from 1960-2011 with covariates to provide at each 1x1 km grid location estimates of the full posterior distribution and the annual mean *Pf*PR_{2-10} for the predictions during the years 2000, 2005 and 2010 (Figure 5.4a, 5.4b and 5.4c). The continuous *Pf*PR_{2-10} maps were then classified into the endemicity classes of *Pf*PR_{2-10} <5%; *Pf*PR_{2-10} 5% - <10%; *Pf*PR_{2-10} 10%-49% (mesoendemic); and *Pf*PR_{2-10} ≥50% (a combined hyper- and holoendemic class). These binned classifications of *P. falciaprum* endemicity are shown for the three reference years 2000, 2005 and 2010 in Figures 5.5a-5.5c.

Figures 5.4 a-c Continuous mapped posterior predictions of mean *Pf*PR$_{2-10}$ 2000, 2005 and 2010



Figures 5.5. a-c Binned forms of endemicity class 2000, 2005 and 2010 (light brown <10%, mid-brown 10-49% and dark brown >=50%)



5.6 Model accuracy

Model accuracy was estimated by computing the linear correlation, the mean prediction error (MPE) and mean absolute prediction error (MAPE) of the observations and predictions of a 10% hold-out dataset. The hold-out set was selected using a spatially and temporally declustered algorithm [Isaacs & Svritsava 1989] which defined Thiessen polygons around each survey location. Each data point had a probability of selection proportional to the area of its Thiessen polygon so that data located in densely surveyed regions had a lower probability of selection than those in sparsely surveyed regions setting a high threshold for model performance. The Bayesian spatio-temporal geostatistical model was then implemented in full using the remaining 90% of data and predictions were made to the 10% hold-out.

The linear correlation of the observed and predicted *Pf*PR_{2-10} was 0.79 showing a very high agreement between the two measures. The MPE and MAPE of the 1960-2010 full space-time *Pf*PR_{2-10} model were 0.3% and 15.2% respectively indicating a very low under-prediction and overall moderate average prediction error respectively. Maps of uncertainty of predictions at 1 x 1 km grids are shown in Annex A; Figure A.2. The lowest uncertainty were predictions to 2000 and the highest uncertainty in predictions were the northern borders with Niger for 2000 and 2005 and some areas located in the South East; more historical data from these regions would reduce uncertainty.

5.7 Interpretation of *P. falciparum* risk maps

As suggested by Figure 5.2 predicted malaria endemicity across Nigeria was ubiquitously high, hyper-holendemic (above 50% *Pf*PR_{2-10}) in 2000, despite a few pockets of mesoendemicity in the South (Figures 5.4a and 5.5a). This nationwide intense transmission pattern prevailed at the launch of the RBM initiative and should be seen as the "receptive" risk at the beginning of the last decade. By 2005, however, the pattern of intense transmission had begun to change. In the south and centre of the country the modelled prediction of mesoendemic (*Pf*PR_{2-10} between 10-49%) transmission had begun to expand. By 2010 the transition was dramatic; the country by this time is best described as predominantly mesoendemic; areas in the southeast bordering Cameroun and coastal areas in the south had transitioned to a predicted endemicity below 10%. This dramatic decline coincided with a number of plausible contributing events a) the rapid scale-up of LLIN distribution through mass campaigns, b) the transition from CQ to AL as a first-line treatment regimen, and c) droughts in the most northern states. We return to the plausibility of drivers of change in the discussion (Chapter 9).

5.8 Other parasite species

The current focus of control in Africa is justifiably *P. falciparum*, by far the most pathogenic of the five human malarias and contributes to over 95% of the world's mortality from malaria. However, it is not the only malaria parasite to affect man. *Plasmodium knowlesi,* the most recently discovered human malaria, has not been described in Africa. *Plasmodium vivax* is thought to have a restricted distribution in Africa owing to the refractory nature of duffy-negative red cells that lack a necessary receptor (Fy(a-b-)) for invasion but may be

transmitted between a small minority of individuals with receptive antigens [Culleton *et al.*, 2008] or incomplete refractoriness of the duffy-negative phenotype [Ryan *et al.*, 2007; Rosenberg, 2007]. *Plasmodium ovale* and *P. malariae* have been reported in most regions of the world, however both parasites seem to be largely confined to sub-Saharan Africa and a few islands in the Western Pacific [Lysenko & Beljaev, 1969; Collins & Jeffery, 2005; Mueller *et al*., 2007]. There appears to be no duffy blood group restriction to infection for either of these parasites [Collins & Jeffery, 2005]. Recent genetic studies of parasite populations in Africa suggest that there may be more than one genetically distinct form of *P. ovale; Plasmodium ovale curtisi* (classic type) and *Plasmodium ovale wallikeri* (variant type) [Sutherland *et al.*, 2010].

The non-falciparum human malarias are often susceptible to most antimalarial drugs including those that currently fail to treat *P. falciparum* [White, 2008], however most evade drug action as they are more often benign and/or relapse. The disease burdens of the rarer human malaria parasites in Africa have been poorly defined. *Plasmodium ovale* is a relatively benign parasite [Collins & Jeffery, 2005]. Most *P. malariae* infections are rarely uniquely associated with clinical events but persist for decades at very low parasite densities and have been associated nephritic syndromes [Hendrickse, 1980; Collins & Jeffery, 2005]. It is likely that we have underestimated the range and incidence of *P. ovale* and *P. malariae* in Africa because both parasites have a relatively short erythrocytic life cycle and thus prevalence may be low but incidence may be considerably higher and are often missed during routine microscopy [Mueller *et al.*, 2007]. Our current knowledge of the distribution on non-falciparum parasites in Nigeria is patchy, however, the data assembled from multiple sources described in section 5.3 provides an opportunity to look at the relative distributions and contributions of both *P. malariae* and *P. ovale* where both have been described in surveys of *P. falciparum* since 1960 (Table 5.3).

Table 5.3: Distribution of *P. malariae* and *P. ovale* infections 1960-1989; 1990-2005 and 2006-2001 by region. Percentage infection [number of sites included] percentage of all infections.

	P. malariae **Prevalence [# study sites] % of all infections**		***P. ovale*** **Prevalence [# study sites] % of all infections**	
Region	**1960-2005**	**2006-2011**	**1960-2005**	**2006-2011**
North Central	17.2% [13]; 20.3%	2.7% [68]; 8.0%	1.2% [14]; 1.4%	3.0% [68]; 9.0%
North East	7.1% [10]; 25.7%	1.3% [56]; 5.8%	0.31% [10]; 1.1%	0.3% [56]; 1.2%
North West	6.5% [92]; 16.6%	3.0% [46]; 7.0%	1.1% [92]; 2.7%	2.2% [46]; 5.0%
South East	4.2% [24]; 8.0%	1.0% [42]; 2.6%	0.2% [24]; 0.4%	0.2% [42]; 0.6%
South South	6.6% [31]; 14.4%	2.2% [64]; 8.6%	0.7% [31]; 1.5%	1.4% [64]; 5.5%
South West	7.3% [116]; 15.5%	3.5% [43]; 9.1%	1.1% [116]; 2.4%	2.0% [43]; 5.1%

There were no reports of *P. vivax* infection in any of the survey reports. *Plasmodium malariae* infection prevalence has declined by over 50% between the two intervals 1960-2005 and 2006-2011 and the contribution to all Plasmodium infections has also declined to approximately 8%. *Plasmodium ovale* however, although a much rarer infection but with a dormant liver stage, seems to have remained at a similar prevalence between time intervals, or some evidence of a rise in some regions, and its contribution to all infections has increased in the second, more recent interval.

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Chapter 6

Population-at-risk 2000, 2005 & 2010

6.1 Background

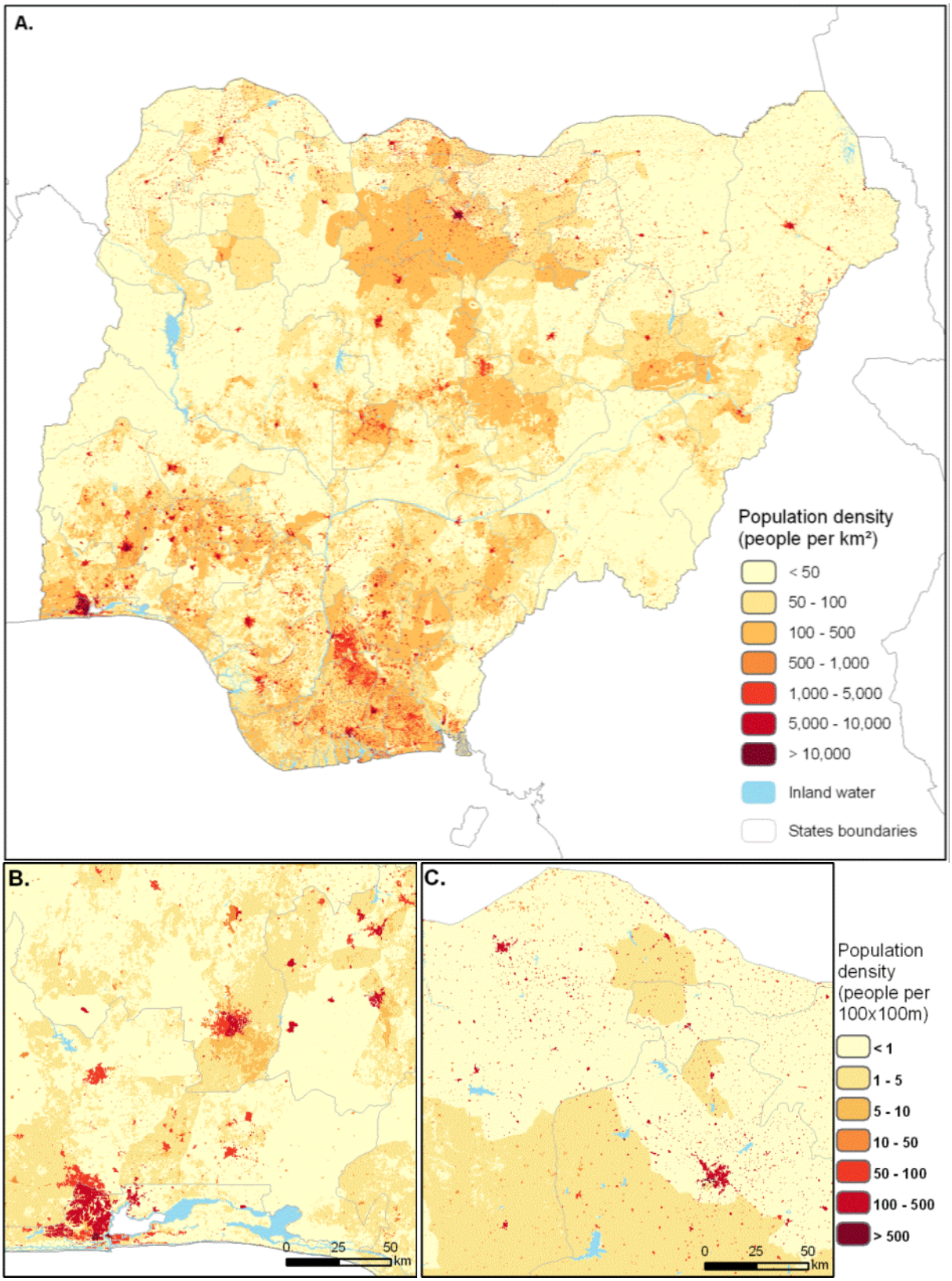
Where disease risks are heterogeneous in space, population distributions and counts should ideally be resolved to higher levels of spatial detail than large regional estimates. Accurate and detailed information on population size, distribution and attributes are of significant importance for deriving populations at risk estimates in spatial epidemiological studies. For many low-income countries of the World, where disease burden is greatest, however, spatially detailed, contemporary census data and spatial information on age and sex composition are lacking.

Modelling techniques for the spatial reallocation of populations within census units have been developed in an attempt to overcome the difficulties caused by input census data of varying resolutions and produce continuous gridded population distribution (or count) datasets. In producing maps of gridded population distribution, the principal factor affecting accuracy has been shown to be the administrative boundary level, or spatial resolution, of the input census data. Where contemporary census data collected at high administrative unit levels exist, it can facilitate accurate, realistic-looking population mapping. Ancillary data such as land cover and settlement locations can be incorporated to improve mapping accuracies where data are available at lower spatial resolutions [Linard *et al.*, 2012].

6.2 Methods

Here we use population mapping approaches developed by Linard *et al.* (2012) to produce detailed population distribution maps for Nigeria for different dates and different categories of people. These population distribution datasets are then combined with modelled malaria endemicity distributions described in Chapter 5 to extract estimates of populations at risk of *P. falciparum* malaria by Nigerian State in 2000, 2005, 2010 and a projection to 2015. Given that the risk of malaria and targets for control vary with age and sex, we have also produced population distribution datasets of the most vulnerable categories of people (i.e. pregnant women and children under 5 years) in addition to total population maps. Precise methods are provided in Annex B. In brief, we have used land cover data sets derived from satellite imagery [Arino *et al.*, 2008], urban extents produced by the Global Rural-Urban Mapping Project (GRUMP) [Balk *et al.*, 2006], 2006 census data for the 774 LGAs and State level inter-censal growth rates between 1991 and 2006. Dasymetric modelling techniques were used to produce a gridded dataset of population distribution at 100 m resolution based on land cover classification, using weights developed from four African countries to apportion population to pixels within an area. This modelled prediction was then overlaid on detailed urban versus rural settlement extents to refine population distribution. The final modelled surface of population density distribution for the year 2010 is shown in Figure 6.1 with highlighted areas around Lagos and the northern region.

Figure 6.1: The spatial distribution of population in Nigeria in 2010. (A) Whole Nigeria at 1km spatial resolution (B) Close-up for the Lagos area. (C) Close-up for a region in the North (region of Kano and Katsina).



The 2006 population map was projected backwards to 2000 and 2005 using State-level intercensal growth rates, and projected forward to 2010 and 2015 using extrapolated State-level growth rates. Sub-national growth rates follow the same decreasing trend as the national growth rates estimated by the UN [UNPD, 2011] and were adjusted such that the total population in 2010 and 2015 matches UN estimates. Population counts were projected forward, using the following equation:

$$P_y = P_d e^{rt}$$

where P_y is the population for year *y* within a pixel, P_d is the population within the same pixel at the year of the input population data, *t* is the number of years between the input data and year *y*, and *r* is the average annual growth rate.

Age and sex structure of the population at each pixel were derived from combinations of state level 2006 census data, Demographic and Health Surveys 2003 and 2008, Multiple Indicator Cluster Survey 2007, Malaria Indicator Survey 2010 and the 2010 MABA survey data on household composition. Growth rates and age/sex distributions were then used to enumerate populations aged 0-11 months, 0-4 years, 5-14 years, 15+ years and Women of Child Bearing Age (WOCBA) for each State in Nigeria for the years 2000, 2005, 2010 and 2015.

6.3 Populations at varied malaria risk classes 2000, 2005 and 2010

In the following tables we combine estimates of seasonality, malaria endemicity and population to provide a sequence of metrics useful for state level planning and tracking of intervention progress. The first table provides information on the projected numbers of people and under-fives likely to be exposed in 2010 to acute seasonal malaria, more than 60% of average rainfall within 3 consecutive months as defined in section 4.3, (Table 6.1).

A useful metric is risk associated with population densities, i.e. within a state people are unevenly distributed and risk is heterogeneous. To account for this we developed a population weighted mean *Pf*PR_{2-10} estimate for each State for the years 2000, 2005 and 2010. The 2000, 2005 and 2010 population surface was used to extract population counts by *Pf*PR_{2-10} and compute population adjusted *Pf*PR_{2-10} (PA*Pf*PR_{2-10}) by state for the modelled predicted malaria risks distributions for each of the respective years. PA*Pf*PR_{2-10} for each State was computed by first multiplying the *Pf*PR_{2-10} (in proportions) by the population count for each re-sampled 5 x 5 km grid were *Pf*PR_{2-10} predictions were made to compute the number of people likely to be positive at each 5 x 5 grid location. The estimated positive cases and the total population counts were then summarised for each state as PA*Pf*PR_{2-10} (Table 6.2a). These summary indices are shown in Figure 6.2. We then computed the changes in PA*Pf*PR_{2-10} between the intervals 2000-2005, 2005-2010 and 2000-2010 (Table 6.2b; Figure 6.3) [(PA*Pf*PR_{2-10} of comparison year (e.g. 2005) - PA*Pf*PR_{2-10} of reference year (e.g. 2000))/ PA*Pf*PR_{2-10} of reference year (e.g. 2000)]* 100]

For the purposes of defining control commodity needs and burden estimation we have computed the total population, children below the age of five years and women of child bearing age in 2010 under transmission conditions that prevail in 2010 (Table 6.3); using the following endemicity classes: *Pf*PR_{2-10} <10% (hypo-endemic), 10-49% (mesoendemic) and ≥ 50% (Hyper-/holoendemic). During each extraction we used the population surfaces developed as described in sections 6.2-6.3.

Table 6.1: Numbers and percentage of state population and under-fives exposed to criteria for Seasonal Malaria Control (SMC) in 2010 (See Figure 4.5a & b). Note none of States in South West, South East and South South experience SMC appropriate conditions. Seasonality maps re-sampled to 1x1km grid squares to match population surfaces described in Figure 6.1 and population counts extracted for 2010 using ArcGIS 10.1 (ESRI, USA)

Region	**State**	**Total population living in areas with 3 consecutive months having 60% or more of annual rainfall (% of total population in State)**	**Total under-five population living in areas with 3 consecutive months having 60% or more of annual rainfall**
North West	Sokoto	3,927,240 (100%)	793,822
	Kebbi	3,580,706 (97.5%)	722,606
	Zamfara	3,518,458 (87.6%)	711,318
	Katsina	5,402,915 (81.8%)	1,122,348
	Kano	10,472,779 (97.9%)	2,027,032
	Kaduna	1,548,398 (22.7%)	297,033
	Jigawa	4,870,985 (100%)	980,515
North East	Yobe	2,669,427 (98.8%)	505,566
	Borno	4,145,189 (85.8%)	790,021
	Gombe	902,022 (33.8%)	175,700
	Bauchi	3,363,926 (65.5%)	673,581
	Adamawa	127,699 (3.8%)	22,518
	Taraba	0	0
North Central	Niger	1,046,737 (22.6%)	208,039
	Kwara	0	0
	Kogi	0	0
	FCT,Abuja	0	0
	Nassarawa	0	0
	Plateau	0	0
	Benue	0	0

Table 6.2a: Estimated population-weighted mean *Pf*PR_{2-10} in 2000, 2005 and 2010. See text for methods

Region	State	Population-weighted mean *Pf*PR_{2-10} in 2000	Population-weighted mean *Pf*PR_{2-10} in 2005	Population-weighted mean *Pf*PR_{2-10} in 2010
North West	Sokoto	60.24	49.97	43.52
	Kebbi	62.89	56.67	56.19
	Zamfara	71.65	58.86	52.25
	Katsina	76.23	60.25	48.13
	Kano	67.89	48.20	33.04
	Kaduna	66.65	42.01	31.26
	Jigawa	71.30	53.43	33.08
North East	Yobe	74.49	58.93	32.26
	Borno	69.83	56.41	24.52
	Gombe	76.32	60.18	29.94
	Bauchi	77.13	58.30	37.35
	Adamawa	71.98	56.86	19.52
	Taraba	73.10	52.13	25.01
North Central	Niger	63.76	46.50	43.42
	Kwara	62.66	55.83	57.53
	Kogi	64.02	39.08	41.87
	FCT,Abuja	68.83	40.77	33.98
	Nassarawa	75.12	46.78	36.17
	Plateau	70.79	46.06	28.17
	Benue	80.88	53.22	43.80
South West	Oyo	55.23	52.32	49.84
	Osun	56.19	50.02	50.15
	Ogun	46.40	43.62	38.90
	Lagos	32.44	29.10	23.73
	Ekiti	58.56	46.91	49.61
	Ondo	54.07	41.30	44.34
South East	Enugu	66.32	33.30	32.81
	Ebonyi	79.81	50.25	43.93
	Abia	81.66	50.22	38.97
	Imo	75.33	44.65	38.00
	Anambra	60.19	28.23	28.33
South South	Edo	51.85	30.37	36.42
	Delta	50.03	25.17	27.59
	Bayelsa	51.54	25.87	21.20
	Rivers	71.57	41.83	28.25
	Akwa Ibom	80.43	51.74	35.17
	Cross River	80.73	52.83	40.20

Figure 6.2: Population adjusted mean *Pf*PR$_{2-10}$

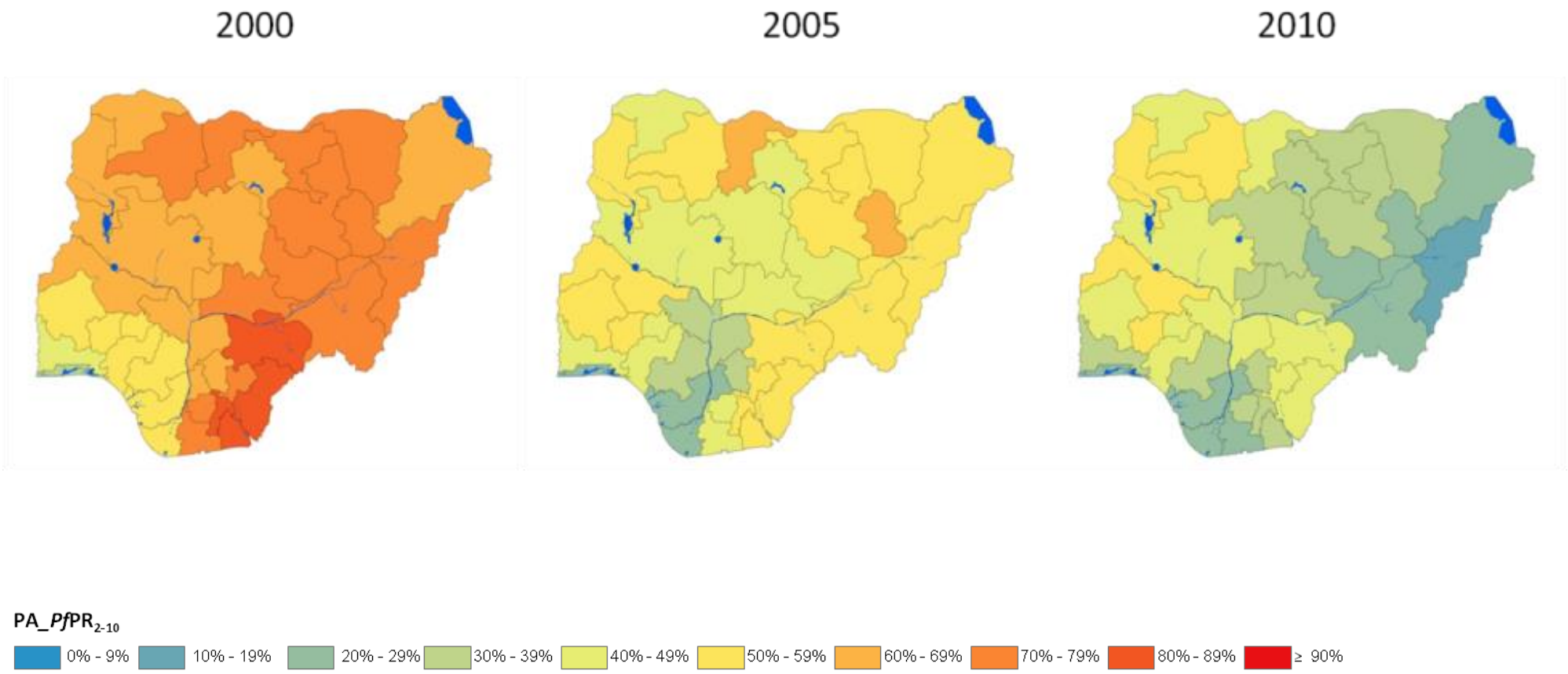


Table 6.2b: Estimated percentage change of population-weighted mean *Pf*PR_{2-10} between 2000-2005, 2005-2010 and 2000-2010. See text for methods

Region	State	Percentage change population-weighted mean *Pf*PR_{2-10} 2000-2005	Percentage change population-weighted mean *Pf*PR_{2-10} 2005-2010	Percentage change population-weighted mean *Pf*PR_{2-10} 2000-2010
North West	Sokoto	-17.06	-12.92	-27.77
	Kebbi	-9.90	-0.85	-10.66
	Zamfara	-17.85	-11.24	-27.09
	Katsina	-20.96	-20.13	-36.87
	Kano	-29.01	-31.46	-51.34
	Kaduna	-36.98	-25.58	-53.10
	Jigawa	-25.07	-38.09	-53.61
North East	Yobe	-20.90	-45.25	-56.69
	Borno	-19.23	-56.53	-64.89
	Gombe	-21.15	-50.25	-60.77
	Bauchi	-24.43	-35.94	-51.58
	Adamawa	-21.01	-65.67	-72.88
	Taraba	-28.69	-52.03	-65.79
North Central	Niger	-27.08	-6.63	-31.91
	Kwara	-10.91	+3.05	-8.19
	Kogi	-38.97	+7.16	-34.60
	FCT,Abuja	-40.76	-16.66	-50.63
	Nassarawa	-37.73	-22.68	-51.85
	Plateau	-34.94	-38.85	-60.22
	Benue	-34.20	-17.71	-45.85
South West	Oyo	-5.26	-4.75	-9.76
	Osun	-10.98	+0.27	-10.75
	Ogun	-6.01	-10.81	-16.17
	Lagos	-10.31	-18.47	-26.87
	Ekiti	-19.90	+5.77	-15.28
	Ondo	-23.62	+7.37	-17.99
South East	Enugu	-49.80	-1.48	-50.54
	Ebonyi	-37.04	-12.59	-44.97
	Abia	-38.50	-22.41	-52.28
	Imo	-40.74	-14.89	-49.56
	Anambra	-53.11	+0.37	-52.94
South South	Edo	-41.44	+19.93	-29.77
	Delta	-49.70	+9.60	-44.87
	Bayelsa	-49.80	-18.05	-58.86
	Rivers	-41.56	-32.46	-60.53
	Akwa Ibom	-35.68	-32.02	-56.28
	Cross River	-34.57	-23.91	-50.21

Figure 6.3: Percentage change in population weighted mean *Pf*PR$_{2-10}$ between 2000-2005, 2005-2010 and 2000-2010

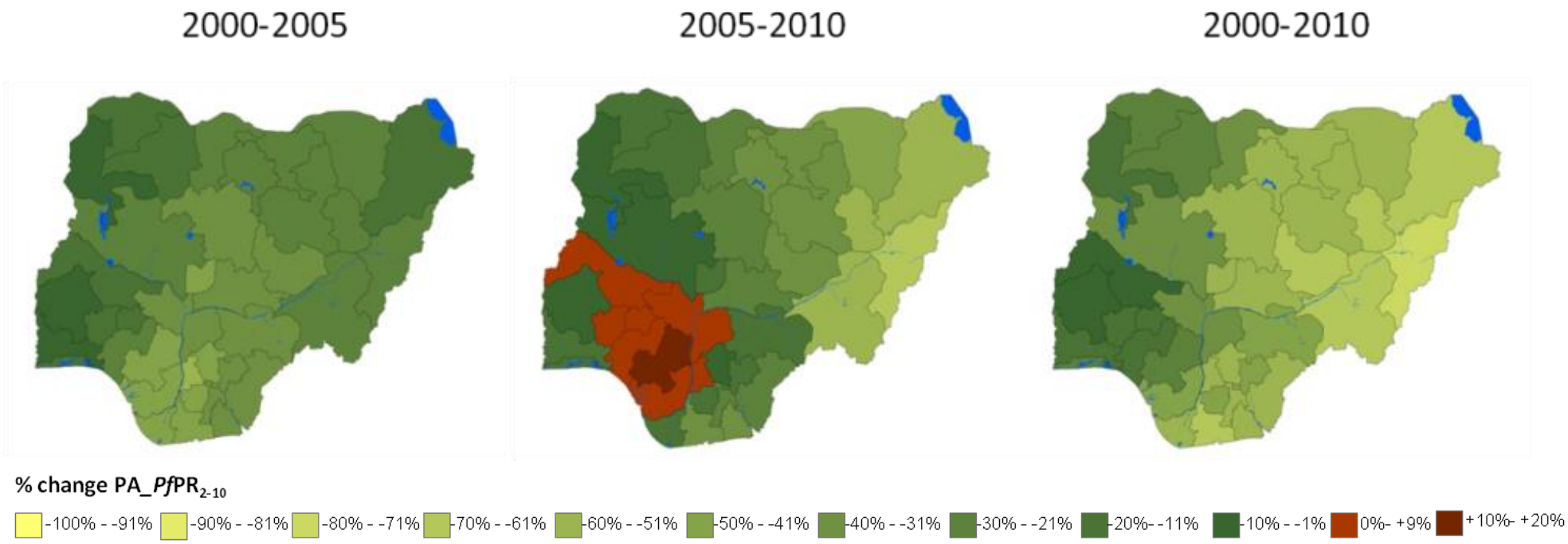


Table 6.3: Populations (in 1000's) exposed to three endemicity classes (hypoendemic, *Pf*PR_{2-10} <10%); mesoendemic (*Pf*PR_{2-10} 10-49%; and hyper-holoendemic *Pf*PR_{2-10} >= 50%) in 2010. See text for methods

State	Hypoendemic class	Mesoendemic class	Hyper-holoendemic class
	Total, U5 and WOCB	Total, U5 and WOCB	Total, U5 and WOCB
Sokoto	0, 0, 0	3280, 663, 710	617, 125, 134
Kebbi	0, 0, 0	671, 136, 145	3002, 606, 649
Zamfara	0, 0, 0	797, 161, 174	3222, 652, 701
Katsina	0, 0, 0	3909, 811, 836	2700, 563, 577
Kano	0, 0, 0	10694, 2070, 2264	0, 0, 0
Kaduna	0, 0, 0	6837, 1308, 1554	0, 0, 0
Jigawa	0, 0, 0	4842, 975, 1050	16, 4, 4
Yobe	0, 0, 0	2703, 513, 584	0, 0, 0
Borno	1606, 307, 348	4670, 890, 1013	0, 0, 0
Gombe	0, 0, 0	2672, 520, 568	0, 0, 0
Bauchi	0, 0, 0	5140, 1028, 1113	0, 0, 0
Adamawa	2747, 485, 627	3133, 553, 714	0, 0, 0
Taraba	2401, 449, 545	2190, 409, 497	0, 0, 0
Niger	0, 0, 0	3254, 640, 735	1386, 275, 310
Kwara	0, 0, 0	790, 138, 185	1907, 328, 447
Kogi	0, 0, 0	2853, 534, 654	762, 143, 175
FCT,Abuja	0, 0, 0	1770, 279, 475	0, 0, 0
Nassarawa	0, 0, 0	2091, 399, 482	0, 0, 0
Plateau	0, 0, 0	3554, 612, 841	0, 0, 0
Benue	0, 0, 0	4125, 752, 930	804, 146, 182
Oyo	0, 0, 0	2957, 379, 754	3346, 429, 853
Osun	0, 0, 0	1703, 204, 434	2238, 268, 571
Ogun	0, 0, 0	3423, 481, 883	431, 61, 111
Lagos	0, 0, 0	10570, 1341, 3013	0, 0, 0
Ekiti	0, 0, 0	788, 91, 203	1822, 210, 468
Ondo	0, 0, 0	2736, 348, 692	1151, 147, 291
Enugu	0, 0, 0	3601, 428, 949	20, 3, 6
Ebonyi	0, 0, 0	2286, 338, 564	25, 4, 6
Abia	0, 0, 0	3033, 348, 789	4, 1, 1
Imo	0, 0, 0	4528, 534, 1165	0, 0, 0
Anambra	0, 0, 0	4684, 532, 1221	0, 0, 0
Edo	0, 0, 0	3431, 439, 884	311, 41, 80
Delta	0, 0, 0	4506, 575, 1148	0, 0, 0
Bayelsa	0, 0, 0	1792, 224, 451	0, 0, 0
Rivers	0, 0, 0	5748, 685, 1501	0, 0, 0
Akwa Ibom	0, 0, 0	4445, 544, 1135	0, 0, 0
Cross River	0, 0, 0	3132, 407, 796	160, 21, 41

6.5 References

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Chapter 7

ITN & IRS coverage 2000-2011

7.1 Background to insecticide treated net (ITN) distribution 2000-2011

The first project to test the use of ITN in Nigeria was undertaken at Nsukka in 1992 [RBM, 2012]. By the end of the 1990s there was overwhelming evidence of the clinical and child survival advantages of insecticide-treated nets (ITN) in Africa [Lengeler, 2004]. In October 2000, the US funded NetMark agency conducted a survey of 1000 households in the urban and peri-urban peripheries of five Nigerian cities: Kano, Maiduguri, Nsukka, Ibadan and Lagos. 12% of households reported owning a mosquito net, with the highest ownership in the highest socio-economic status households. Few households (7%) had heard of treating mosquito nets with insecticides. All nets were purchased in an open-air market. Only one household reported owning a net that had been pretreated with insecticide before purchase. Of all women aged 15-44 in the sampled households 68% cited disadvantages for a child sleeping under a mosquito net, including "it is hot sleeping under a net" (27%) and "there is not enough air under the net" (10%) or "child may suffocate" (8%) [NetMark, 2001]. An analysis of 1908 household expenditure budgets and willingness to pay enquiries in Enugu State in the late 1990s suggested that an average annual household expenditure per capita on basic items was US$ 716.1 and an average retail family-size ITN available at the time would have consumed 0.44% of this and ITN re-impregnation 0.03% [Onwujekwe, 1999]. More detailed studies on willingness to pay using a bidding game were undertaken in Enugu and showed that generally households (71%-91%) were willing to pay for net re-treatments at an average of US$ 0.21 [Onwujekwe *et al.*, 2000].

In 2001, an ITN strategy was developed to ensure 60% coverage among children by 2005 and promoted the creation of an enabling private sector market combined with social marketing initiatives. However, two years after the ITN strategy was launched, the March-August 2003 national household survey showed that only 12% of households reported owning at least one net and only 2% of households owned an ITN. Household ownership ranged from 1% in the South West to 22% in the North East. Only 6% of children under five slept under a mosquito net the night before the survey and 1% slept under an ITN [NPC, 2004].

From 2004, the Federal Government's nation-wide IMPAC Program supported the distribution of nets with support from UNICEF, WHO, JICA and the Chinese government resulting in a reported one million free nets to women attending antenatal care and immunization clinics across Nigeria. NetMark worked to establish a commercial market for ITNs in Lagos, Kano, Abia, Edo, Jigawa, Kaduna, Bauchi, Adamawa, Niger, Plateau, Benue, Nasarawa, Kwara, Oyo, Ekiti, Osun, Ondo, Ogun, Enugu, Anambra, Cross River, Delta, Akwa Ibom, Rivers states and FCT Abuja. UNICEF also worked in Bauchi, FCT Abuja, Ogun and Enugu states supporting the commercial sector. In Enugu state, UNICEF provided free nets for sale through community-based organizations, and DFID and the Futures Group were active from 2002 to 2004 in the promotion and distribution of ITNs in Benue, FCT Abuja, Enugu, Jigawa, Kano, Lagos and Ondo states. Maiduguri (Bornu State) had a large international market (Monday Market) for untreated nets.

Surveys were repeated in 2004 in the five cities investigated by NetMark in 2000. These surveys did show an increase in net ownership over the four year interval: 12% in 2000 to 27% in 2004 but varied widely depending on the site - 2% at Ibadan, 19% at Nsukka and 51% at Maiduguri. Most nets (74%) were obtained from commercial market sources. Reasons given for not using a bed net were lack of money, no access and lack of need or used something else. Among all households, use of ITNs increased among children under five from 1% in 2000 to 3.3% in 2004 (range 1.2% in Maiduguri to 9.6% in Nsukka) [NetMark, 2005].

The early phases of the ITN distribution in Nigeria adopted a "Total Market Approach", based on social marketing models to create profit-driven interest and kick-start activities in the retail market, slowly increasing accessibility and affordability to the target population [RBM, 2012]. Despite attempts to create this enabling environment, a survey of 7,200 households, from 12 randomly selected states from the six geopolitical zones in October 2005 showed that household ownership of any net was 23.9% and only 10.1% for ITNs. Utilization of any net by children under-five was 11.5% and 1.7% for an ITN [NMCP, 2005a; Oresanya *et al*., 2008]. Household funds to purchase nets continued to pose significant problems. A study in 2004 in Oji-river Local Government Area (LGA), Enugu State, using focus group discussions found that the average monthly expenditure on malaria prevention per household was US$ 0.4, however over 80% of the respondents had never purchased any form of mosquito net [Onwujekwe *et al.*, 2005].

The second, post-Abuja strategic plan was launched in 2006, revising targets to 80% coverage of key interventions and the optimistic vision of a "Malaria free Nigeria" [NMCP, 2006]. ITN scale up activities began in earnest in 2007 and 2008. About 706,186 Long-lasting, insecticide-treated nets (LLINs) were allocated for distribution in 34 LGAs in 18 States during the January round 2007 of the immunization campaign in Nigeria. These LLINS were procured through support from UNICEF, Exxon Mobil and the Global Fund [Int. Federation, 2009].

However, coverage of ITN across the country by 2008 remained extremely poor, only 5.5% of children below the age of five years were sleeping under a treated net [NPC, 2009]. Of all unprotected children in sub-Saharan Africa not sleeping under a net in 2007, 25% were Nigerian [Noor *et al*., 2009]. By 2009, donor disbursements to Nigeria for malaria prevention and control reached a peak of around US$ 325 million [Snow *et al*., 2010], and it was this year that marked a turning point in ITN distribution nationwide and coincided with the launch of the current National Malaria Strategic Plan (2009-2013), the *Road Map for Malaria Control in Nigeria* [NMCP, 2009].

The current national strategy highlights the urgent need for the rapid national scale-up of a package of core interventions to achieve impact as a pathway toward a "malaria free Nigeria". The current strategy includes an aim for universal ITN coverage, combined ITN and IRS approaches in areas intractable to reductions in transmission with ITN alone and a more prominent coordinated role of integrated vector management (IVM) that considers larval control following pilot studies using *Bacillus thurigiensis israelensis* and *Bacillus sphaericus*. The

national malaria control strategy calls for the distribution of 63 million new LLINs by the end of 2010 and that at least 80% of these nets will be appropriately used.

Mass distribution of long-lasting insecticidal nets (LLINs) started in Kano State in 2009 and involved several partners, including the U.S. Agency for International Development (USAID), the World Bank, Malaria Consortium, and Support to the Nigeria Malaria Programme (SuNMaP). The campaign in Kano was undertaken in two stages in May and July 2009 and finally distributed more than four million nets. A post-campaign survey was undertaken in November 2009 in 987 households randomly selected from 60 clusters that showed that equity in ITN coverage and ITN ownership coverage increased from 10% before the campaigns to 70% and that the campaigns reduced the ownership coverage gap, reaching parity among wealth quintiles. ITN use (individuals reporting having slept under an ITN the night before the survey visit) among individuals from households owning at least one ITN, was 53.1% with no statistically significant difference between the lowest, second, third and fourth wealth quintiles and the highest wealth quintile [Yé *et al*., 2012]

The mass campaigns continued after Kano State's initial launch and were conducted by a variety of different partner organizations, in collaboration with the state Ministries of Health, using a standard implementation guide and toolkit, and with oversight by the NMCP. Mass campaigns were conducted in nine states in 2009, an additional seven states in 2010, and 12 states plus Abuja FCT in 2011. Smaller projects continued to operate including for example 150,000 LLINs from the Japan International Cooperation Agency to the Lere community in Kaduna State in June 2010 [Njoku, 2010]. The major objective of the “universal coverage” campaigns to ensure distribution of two LLINs to every household by 2010 was however slow to materialize as a national ambition. 29 million LLINs were distributed in 2010, representing 46% of the target of 63 million by December 2010. About 700,000 LLINs had been distributed by June 2011 in states where population-wide campaigns had not taken place. By the end of June 2011, 24 States had benefited from these "catch-up" campaigns [RBM, 2012]. The impact on coverage of these campaigns were reflected in the national household survey data in 2010 which showed an improvement in coverage of under-fives to a national average of 29% sleeping under an ITN the night before the survey [NPC *et al*., 2011].

In 2011, NMCP activities focused primarily on the continuation of the nationwide scale-up of LLIN distribution. However, the NMCP encountered problems mobilizing sufficient financial contributions from the states to fill distribution budget gaps for operational expenses and the management of waste generated during the campaign (discarded plastic bags). During the distribution itself, there were problems related to the production of appropriate numbers of net distribution cards (vouchers) in a timely fashion, and confusion regarding the definition of a household. It was recognized that there must be a more pro-active engagement of LGA administration, the development of materials designed to create demand and improved health education, and increased involvement of the media. In some settings per-capita distribution was very different from ownership and use. A survey of 170 households that received free nets during mass campaigns at Ishiodu - Emohua, Rivers State: 72% had hanged the nets as at the time of the survey (84% over a bed, while 10.7% used the nets as window curtain). Of the 102

ITNs that were properly deployed, only 27.5% were occupied the night before the survey, by an average of 2.5 persons, mainly under-five children (37.7%) [Ordinioha, 2012]. Furthermore, some communities were not reached despite mass campaigns. A study conducted in Yakurr LGA in Cross River State showed that increasing distance from mass campaign distribution centres led to reductions in household access/ownership of an ITN [Eni *et al*., 2012].

As of February 2012, campaigns had been conducted in 28 of the 36 states, plus Abuja FCT involving the distribution of 45.7 million LLINs, 71% of the target initially set for December 2010. 13.9 million LLINs remained to be distributed because of challenges associated with funding, coordination and the mobilization and engagement of the federal governments in the following states: Abia, Delta, Edo, Imo, Kogi, Ondo, Osun, and Oyo. At the end of February 2012 over one million nets were eventually successfully distributed to Ondo State. By June 2012, 46.9 million LLINs had been distributed, representing 73% of the total number of LLINs planned for universal coverage distribution. Of these, almost 18 million were distributed in 2011 and early 2012 [PMI, 2012].

A notable feature of success in reaching so many households is the partnerships with various agencies working at State level in Nigeria. Since 2009, PMI has supported the LLIN distribution campaign in eight states through support for the LLIN Campaign State Support Teams. By 2011, PMI had supported distribution in following states through universal coverage campaigns: Bauchi, Cross River, Ebonyi, Nasarawa, Sokoto, Zamfara, Benue and Oyo [PMI, 2013]. The Carter Center's Malaria Control Program works in Abia, Plateau, Ebonyi, Enugu, Edo, Delta, Nasarawa, Imo and Anambra states and helps not only distribute nets but develops tools and strategies around Behavioural Change and Communication to ensure nets are used properly. Between 2004 and 2011, the Carter Centre helped distribute nearly 4.3 million nets, 90% of these in 2010 and 2011. 2.3 million nets were distributed in partnership with the Carter Centre in Enugu and Ebonyi in 2011 who reported that while 74.3% of household owned at least one net but that only 84% of nets were hanging at baseline. After six months of intervention, 100% of households owned at least one net and 95% of LLINs were observed to be hanging [Carter Centre, 2012].

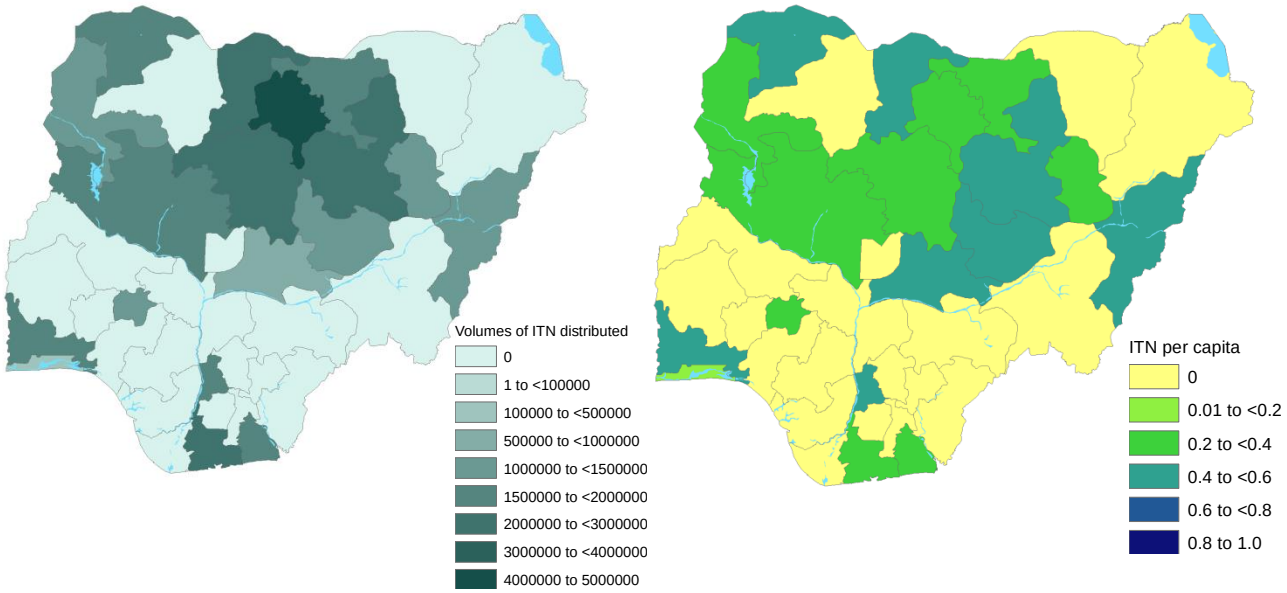
Malaria Action Program for States (MAPS) is a comprehensive five-year (2010- 2015) USAID funded program to improve malaria control in Nigeria (US$ 65 million) aimed at using the model of USAID's Target State High Impact Project, their flagship Health, Population, and Nutrition project started in Bauchi and Sokoto States in 2009 and focuses on integrated maternal neonatal and child health initiatives that use high impact and low cost interventions. The MAPS initiative began in three target states, Cross River, Nassarawa and Zamfara States in 2010 but is expected to expand to four additional states before 2015 and implemented by the US based Non-Government Organization FHI 360 in partnership with Health Partners International, GRID Consulting Nigeria and the Malaria Consortium [Health Partners International, 2012].

This division of support did however leave some states without assistance. This is a continued problem facing decisions to allocate resources by the NMCP. This is most evident when examining State-level distribution data (Section 7.2) and the analysis of ITN coverage by State though household surveys in 2010 (Section 7.3). States without LLIN campaigns at the time of the national 2010 surveys included: Abia, Bayelsa, Benue, Bono, Cross Rivers, Delta, Ebonyi, Edo, Enugu, FCT, Imo, Katsina, Kogi, Kwara, Lagos, Nasarawa, Ondo, Osun, Oyo, Plateau, Taraba, Yobe and Zamfara.

7.2 Enumerating ITN distribution

ITN distribution data by State were assembled from databases provided by the sunMAP and the NMCP. Data were provided by year and were re-assembled to match each of the 37 States up to, and including, December 2010. 75% of all LLINs were distributed in 2010. We focus here on distribution data to 2010 as this corresponds to previous predictions of malaria risk to this year and the last national household survey of ITN use. Distribution data have been expressed as nets delivered and per capita projected populations for each State for the interval 2008 - 2010 (Figure 7.1).

Figure 7.1 Annual total distributions of ITNs from 2008-2010 by state (left) and per capita (right)



7.3 Assembling ITN coverage data

Since 2003, four large scale, sample national household surveys, with information on the proportion of persons sleeping under an ITN the night before survey, have been undertaken in Nigeria (Table 7.1). The details of the survey sampling procedures and sample sizes are provided in Annex C.1. Data on ITN coverage were aggregated for each survey cluster and

information on the State, year of survey, the number of persons interviewed and the number who slept under an ITN the night before survey (coverage) and the total ITNs in the household were summarised. Each cluster and State was assigned unique identifiers.

Table 7.1 Summary of large scale household survey data with information on persons sleeping under an ITN the night before survey

Survey	Clusters	Households	Persons	Age group for ITN coverage information	Source
DHS 2003	362	7,225	35,820	all ages	NPC (2004)
DHS 2008	886	34,070	156,809	all ages	NPC (2009)
MIS 2010	239	5,895	30,537	all ages	NPC (2012)
MABA 2011	755	6,818	31,763	all ages	NMCP & NPHCDA (2011)

7.4 Modelling spatial aggregates of ITN coverage using Small Area Estimation

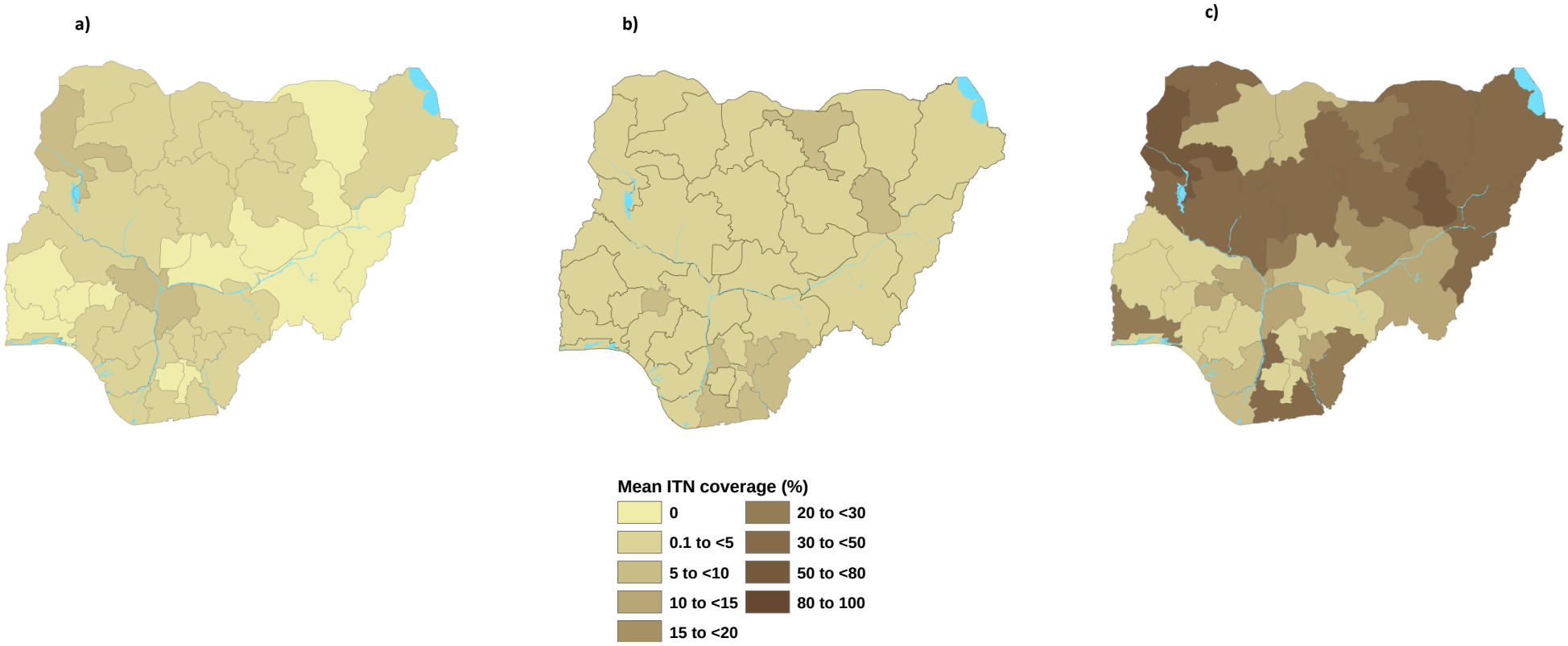
Typically, national household surveys are designed to be precise at national and regional levels and rarely at lower levels such as districts. Therefore, simply aggregating survey data to provide district level estimates of an outcome of interest will lead to values of low precision. District level estimates, however, are more important to planners in order to accelerate policy interventions, optimise inputs and improve coverage of health interventions. Small Area Estimation (SAE) methods handle the problem of making reliable estimates of a variable at these areal units under conditions where the information available for the variable, on its own, is not sufficient to make valid estimates [Rao *et al*., 2003; BIAS, 2007]. We have used hierarchical Bayesian spatial and temporal SAE techniques using a geo-additive regression approach [Banerjee *et al*., 2004; Best *et al*., 2005; Fahrmeir & Lang 2001; Kamman & Wand 2003] to estimate the ITN coverage by district for the years 2000/03, 2008 and 2010 (combining MIS 2010 and MABA 2011). The prediction quantities cover all age groups, as this represents an important indicator for universal coverage and necessary when computing likely impacts on malaria transmission [Smith *et al*., 2009; Griffin *et al*. 2010]. Details of model procedures and accuracy metrics are presented in the Annex. The results are shown in Figure 1.2 with sensitivity of district level predictions shown in Annex Figure C.1 as standard deviations of predicted means.

In 2000, almost all States had a predicted mean ITN coverage below 5.0% among all age groups. Only two States Kogi (5.9%) and Kebbi (6%) had ITN coverage among its population more than 5% (Figure 7.2a). By 2008, the predicted coverage among all age groups had not improved substantially with only eight States having a coverage in excess of 5.0% (Jigawa, Rivers, Akwa Ibom, Cross River, Anambra, Gombe, Ebonyi and Ekiti) and no district exceeded 10% coverage (Figure 7.2b). By 2010/11 the modelled data from household surveys suggested a very different

pattern of coverage (Figure 7.2c): 17 States had predicted coverage estimates in excess of 20% of their population protected; 13 of these States had over 30% of the population protected. Two States, Gombe and Kebbi had over 50% of the population protected; Gombe had the highest percentage of the population protected, 56% and Kebbi had 53.3% of population protected. Conversely, 10 States still had overall predicted coverage below 5% with Osun State having less than 1% predicted ITN coverage.

While the coverage data are based on reported use the night before the survey, there remains the issue of actual versus reported use. In the MIS of 2010, 18% of households had at least one net that was not slept under the previous night. Among households with a net that was not slept under the previous night, the most common reason cited for non-usage was that it was too hot to sleep under the net (18%), especially in North West region (31%) and 16% reported that the net was not used because the net was too difficult to hang [NPC *et al.*, 2011].

Figure 7.2: The mean ITN coverage predictions in Nigeria (using neighbouring information: MRF prior) for: a) 2000-03; b) 2008; c) 2010/11



7.5 Indoor Residual House-spraying coverage

IRS was implemented in Nigeria from as early as 1949 through to 1970s as part of pilot projects to examine the feasibility of elimination [Bruce-Chwatt, 1950; 1984; Bruce-Chwatt *et al.*, 1955; Bruce-Chwatt & Archibald, 1958; Foll & Pant, 1965; Molineaux & Gramicca, 1980]. It was not for another 40 years that IRS began to be rolled out again in Nigeria.

In 2006-2007, IRS trials were undertaken using four pyrethroids and a carbamate (bendiocarb) in collaboration with insecticide manufacturing companies. In 2006, IRS was carried out in Epe LGA, Lagos State, Barkin-Ladi in Plateau State and Damboa in Borno State using three different synthetic pyrethroids (Lambdacyhalothrin, Alpha Cypermethrin and Bifenthrin). A further IRS pilot trial using Deltamethrin and Bendiocarb was carried out in Remo North LGA in Ogun State, Barkin-Ladi in Plateau State and Madagali LGA in Adamawa State [Okwa, 2013]. IRS activities began to expand in 2008 in three selected LGAs in seven States supported by the World Bank Malaria Booster Program covering over 65,000 houses (Bauchi, Jigawa, Gombe, Kano, Anambra, Akwa-Ibom and River State) and one State supported by PMI (Nassarawa) using alphacypermethrin, lambdacyhalothrin and deltamethrin. Between 2009 and 2011, Lagos State started a campaign of IRS covering 246,803 households [RBM, 2012; PMI, 2012].

The Nigerian National Malaria Strategic Plan 2009-2013 calls for scale-up of IRS in a) areas with a short transmission season where the addition of IRS might make local elimination feasible; b) in areas where ITN implementation is difficult and use is low; and c) in areas where IRS may have a greater impact, such as in and around more densely populated municipalities. The objective of the IRS Strategic Plan is to increasingly scale up IRS to cover seven million households by 2013, or reaching 20% of households nationwide.

At present, the World Bank, in collaboration with insecticide manufacturing companies, RBM, and PMI, are the only donors supporting IRS. Nigeria became a PMI focus country in 2011 and contracted Research Triangle International (RTI) to undertake spray site selection, establishing an entomological base-line, procuring commodities, and conducting training in entomological monitoring for IRS in preparation for an eventual spray round [RTI, 2013]. In August 2011, Abt Associates was awarded a three-year Africa-wide Indoor Residual Spraying project (AIRS), IRS 2 Task Order 4, funded under PMI [AIRS, 2013]. The key objectives of the program in Nigeria were initially to reduce malaria-associated morbidity and mortality in two selected LGAs, Doma and Nassarawa Eggon, in Nasarawa State, as well as to establish a model IRS program that will set national performance standards. In 2012, alpha-cypermethrin was used to spray 58,704 dwellings protecting 346,115 people [PMI, 2012; ABT, 2012].

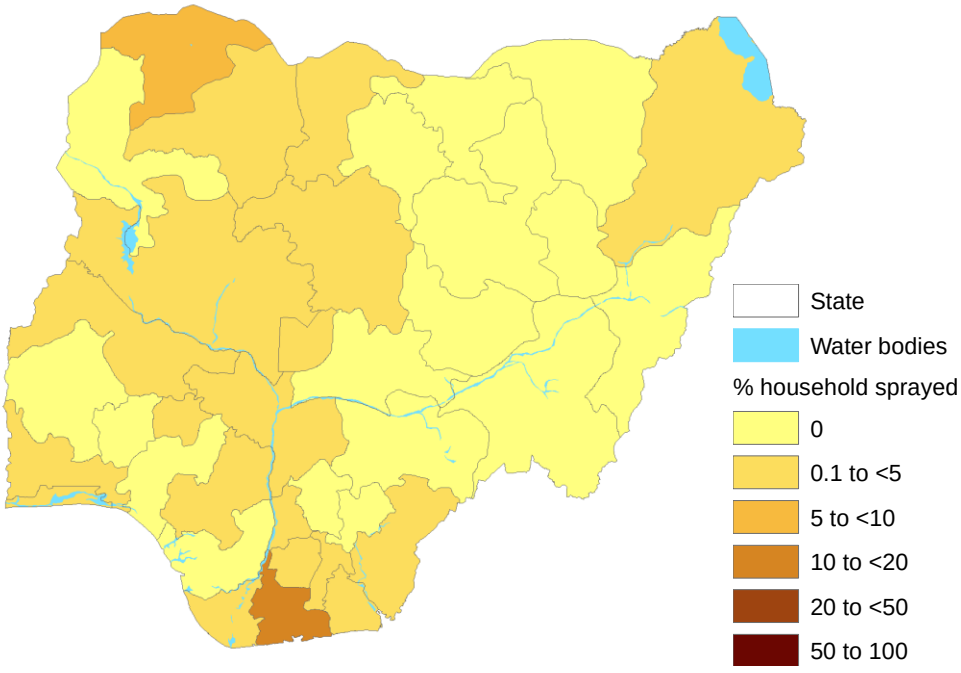
In 2011, the Carter Centre under its Malaria Control Program sprayed 63,000 households in 13 states. IRS was implemented on a pilot basis in Plateau, Borno, Lagos, Adamawa, and Ogun states, and scaled up in one LGA in each of the seven states supported by the World Bank (Akwa Ibom, Anambra, Bauchi, Gombe, Jigawa, Kano, and Rivers). Lagos state has scaled-up IRS

in a total of eight LGAs [Carter Cente, 2012]. Select villages in Ondo state have also received IRS with support from the United Nations Development Project.

The World Bank will support IRS in two LGAs in each of six states in 2013 and 2014. A draft implementation plan for IRS has been developed and is awaiting finalization. The NMCP is now seeking comprehensive technical and financial support to help them scale up IRS in line with their national strategic plan [PMI, 2012]. Larviciding activities have been piloted in four states: Rivers, Lagos, Jigawa, and Nasarawa. A strategic plan to guide the scale-up of larviciding nationwide has been prepared.

We have selected as the indicator the proportion of households reporting or documented as sprayed (at least once) in the last 12 months. Data from household surveys only using DHS data, without SAE methods described above for ITN coverage interpolation, is shown in Figure 7.3 for the 2010.

Figure 7.3: Proportion of households sprayed in last 12 months using from household survey data (2010)



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Chapter 8

Health Facility Mapping

8.1. Development of Nigeria's medical services from 1800 to independence

Western medicine was formally introduced in coastal Nigeria in the 16th Century by Roman Catholic missionaries who established St. Thomas Island Hospital (1504). By 1859, two ex-slaves (Dr. Horton and Dr. Davis) returned from England after training as physicians to advance western medicine. In 1871, the colonial government began providing formal medical services with the construction of the first 42-bed capacity hospital in Lagos. In 1879, an infectious disease hospital was built in Lagos, by early the 1880s the colonial government had built several clinics and hospitals in Lagos, Calabar, and other coastal trading centres to cater largely for the health of Europeans [Schram, 1971; Ityavyar, 1987]. After integration of British Army Medical Services with the colonial government, medical care was progressively extended to the local civil servants and their relatives and eventually to the local population, especially those living close to government stations [Adeyemo, 2005; Ityavyar, 1987].

World War I had a devastating effect on the provision of basic medical services because of the large number of medical personnel, both European and African, who were engaged in the war in Europe. The construction of new hospitals was halted and existing hospitals lacked supplies of drugs and medical equipment. Ilesha, Opobo, and Badagry hospitals were closed since there were no medical personnel to attend to patients [Ityavyar, 1987]. The war years and the immediate aftermath witnessed various epidemics (plague, the global influenza pandemic, relapsing fever, gonorrhea and syphilis) [Schram, 1971]. Several developments took place after the war including the rapid expansion of medical facilities in Enugu, Jos, Mubi, Aba, Ijebu-Ode and Lagos and the establishment of government-sponsored schools for the training of Nigerian medical assistants including the Dispensary Attendant School in 1920 and the Yaba medical school.

After World War II, the colonial government tried to extend modern health and education facilities to much of the Nigerian population. A ten-year health development plan (1946-1956) was announced in 1946 [Mongabay, 1991; Osain, 2011]. The 1946 health plan established the Ministry of Health to coordinate health services throughout the country, including those provided by the government, private companies and for the first time missions. The plan also budgeted funds for hospitals and clinics, most of which were concentrated in the main cities with little funding for rural health centres and preventive care. The nationalist movement lobbied hard for a university for Nigeria and in 1948 after a long struggle the University of Ibadan was founded with the first faculty of medicine and university teaching hospital (known today as University College Hospital). By 1960, training and clinical services (Table 1) had expanded across the country: nursing schools (32), midwifery training centers (33), and pharmacy schools at Zaria and Yaba [Mongabay, 1991; Schram, 1971; Ityavyar, 1987].

The mission sector, largely driven by the Roman Catholic missionaries, dominated medical work from the 1860s with the establishment of the Sacred Heart Hospital (1865) in Abeokuta, through to the 1960s when they ran 38 hospitals and leprosarium, concentrated in mid-western and eastern regions [Ityavyar, 1987]. In 1960 there were a total of 118 mission hospitals compared to 101 government run hospitals [Mongabay, 1991]. The Sudan United Mission and

Sudan Interior Mission concentrated provision of medical services in the Muslim middle and northern regions providing 93 doctors operating in 25 hospitals during the 1960s [Mongabay, 1991; Schram, 1971]. Other missionary-run medical services were operated by the Basel Mission, Church of Brethren Mission, Church of Scotland, Church Missionary Society, Lutheran Mission, Methodist Missionary Society, Nigerian Baptist Mission, Qua Ibo Mission, Seventh Day Adventist and the United Mission Society [Schram, 1971]. The growth of missionary and government medical services accelerated the acceptance of modern medicine in Nigeria [Mongabay, 1991; Ityavyar, 1987].

Table 8.1: The distribution of hospitals by region in 1960 [Schram, 1971]

Ownership	North	East	West	Lagos	Total
Government	39	26	24	12	101
Mission	31	16	1	70	118
Unknown*	14	11	5	1	31
Total	84	53	30	83	250

Unknown* includes leprosarium facilities and nursing homes owned by either the government or missions.

8.2. Evolution of current health services

Changes were made to the first ten-year National Development Plan (NDP), developed at independence, to create the five-year health development plan (1970–74). This plan focused on correcting some of the deficiencies in the health delivery services. There was a deliberate attempt to draw up a comprehensive national health policy dealing with such issues as health man-power development, provision of comprehensive health care based on basic health care service scheme, disease control, efficient utilization of health resources, medical research and health planning and management [Adeyemo, 2005; Asuzu, 2005]. In the subsequent years, the third and fourth NDPs were developed in 1975 and 1981 respectively. The third NDP (1975–80) incorporated Basic Health Services Scheme (BHSS) policy that aimed at increasing the proportion of the population receiving health care from 25% to 60% sand increasing preventive services, communicable disease control, family health, environmental health and nutrition [Adeyemo, 2005]. The Fourth NDP (1981–1985) also made BHSS the core of its orientation in the health sector, though the Federal government neglected BHSS in favour of teaching and specialist hospitals.

During the early 1980s, currency devaluation and structural adjustment led to crises in the government and public health care facilities. At the same time privately owned health care services began to fill a void and rapidly expanded. One unfortunate consequence was that the limited medical personnel, drugs, and equipment were increasingly diverted to the private sector [Baba & Omotara, 2012; Osain, 2011]. The deterioration of the public health sector became an issue of policy debate and public contention during the late 1980s and was prominent in the Constituent Assembly held in 1989 to draft a proposed constitution. The original draft reported by the assembly included a clause specifying that free and adequate

health care was to be available as a matter of right to all vulnerable groups such as children below eighteen years old, every sixty five year olds and above, and all the physically disabled or handicapped. This provision was, however, deleted by the president and the governing council when they reviewed the draft constitution [Mongabay, 1991].

In 1987, the federal government launched a primary healthcare (PHC) plan under President Babangida with the aim of: a) improving health data collection and monitoring, promoting health services such as treatment of endemic and epidemic disease; b) improving immunization against infectious disease; c) providing material and child care, including family planning; d) educating people on best health practices in preventing and controlling health problems; e) promoting proper nutrition; and f) providing essential drugs and supplies [Osain, 2011; Adeyemo, 2005].

The 1999 Constitution mentions health only with regard to the responsibilities of local governments, implying that the responsibility for health services is shared between the State and local levels. The diffusion of responsibility is particularly evident at the primary level, where services are managed by Local Governments, under the supervision of the States, and involving Federal Ministry of Health (FMOH) Departments and Federal parastatals concerned with particular programs and diseases [FMOH, 2010].

The federal government established the National Health Insurance Scheme (NHIS) in 2005 as a means of financing healthcare [WHO, 2001]. Out of pocket payments at service delivery points have proved to be a challenge to the poor thus limiting their access to care. In response to this, a National Health Bill was drafted to address financing at the PHC level while the NHIS supports secondary and tertiary health payment systems. To date, the bill has not been signed into law despite being passed at the National Assembly [Akinloye, 2013; Osain, 2011].

In 2010, the Federal Ministry of Health embarked on reforming the national healthcare delivery system leading to the formation of the National Strategic Health Development Plan (NSHDP) (2010 – 2015) that was endorsed in 2010 by the National Council of Health. The current NSHDP took a more inclusive approach where key stakeholders at all levels in the health sector participated. Public health experts from the Government and academia took the lead in preparing evidence-based background studies for the work of drafting a framework for the plan's focus areas and objectives. The Department of Health Planning, Research & Statistics at the FMOH in conjunction with the NSHDP Reference Group managed the process to make it consistent with vision 2020 and Millennium Development Goals [FMOH, 2010].

8.3 Current structure of the health care in Nigeria

Nigeria's health care system reflects the federal to 36 States (and a Federal Capital Territory) system of government and further sub-divided into 774 local government areas [Umokoro, 2011]. The national health system is decentralized into a three-tier system with responsibilities at the federal (tertiary health care), state (secondary health care), and local government (primary health care) levels [Khemani, 2006]. Private health care institutions also exist to

complement the role of the government. Health facilities in the private sector are not generally accessible to the poor, and private hospitals mainly cater for higher income households [Umokoro, 2011]. The levels of recognized care form a pyramid as defined below:

Primary Health Care (PHC): This level provides the first point of contact with patients and the national health system and is largely the responsibility of local governments with the support of state ministries of health and within the overall national health policy. Facilities in this level include comprehensive health centres, primary health centres, health clinics and health posts. A comprehensive health centre should have at least three doctors and offer both PHC services and a limited number of secondary clinical services. The constitution requires that there should be at least one comprehensive health centre per local government area serving a population of 20,000 persons. Within each ward, there should at least be one basic essential obstetric and neonatal care centre (BEONC) staffed by medical officers, two midwives, two community health workers, senior community health extension workers, laboratory and pharmacy technicians offering basic preventive care and curative services [Adeyemo, 2005]. At the community level, health clinics or health posts are served by junior community health extension workers who work 80% in the community and 20% in the facility. Health clinics and posts serve a population of 2,000 persons [WHO, 2001].

Secondary Health Care: This level of health care provides specialized services to patients referred from the primary health care level through out-patient and in-patient services of hospitals for general medical, surgical, paediatric patients and community health services. Secondary health care is available at the district, divisional and zonal levels of the states. Adequate supportive services such as laboratory, diagnostic, blood bank, rehabilitation and physiotherapy are also provided. It includes district and general hospitals.

Tertiary Health Care: This level consists of highly specialized services provided by teaching hospitals and other specialist hospitals which provide care for specific diseases such as orthopaedic, eye, psychiatric, maternity and paediatric cases. The tertiary health facilities provide extensive primary and first referral care to patients mainly in urban settlements [Akande, 2004].

At the federal level, the FMOH is responsible for policy making and providing technical and financial support to the national health system, international relations on health matters, national health management information systems and the provision of health services through tertiary hospitals, teaching hospitals, federal medical centres, and national laboratories [WHO, 2001]. At the state level, the State Ministry of Health (SMOH) is responsible for regulating and providing financial support to secondary healthcare such as general hospitals and primary health care services [WHO, 2001]. At the local government level, the local government areas (equivalent of districts in other countries) are responsible for primary health care (dispensaries) facilities that are regulated by the federal government through the National Primary Health Care Development Agency (NPHCDA). Each local government is subdivided into 7–15 wards which are managed by ward development committees. Below the wards is the community level which provides the most important link to in healthcare delivery. The community level forms

the support structure for the implementation of primary health care services and is managed by community/village development committees [WHO, 2001].

In 1999, the National Demographic Health Survey (NDHS) indicated that 71% of households in Nigeria were within 5 km of a PHC facility. The distribution of PHC facilities was biased towards urban areas (80%) than rural areas (65%) in the survey findings. In 2000, there were an estimated 13,000 public PHC facilities and 7000 private PHC facilities [WHO, 2001]. In 2005 FMOH estimated a total of 23,640 health facilities in Nigeria of which 85.5% are primary health care facilities, 14% secondary and 0.2% tertiary. 38% of these facilities are owned by the private sector [FMOH, 2010].

8.4 Health facility mapping

8.4.1 Background

Accurate health information is the cornerstone of effective decision-making and reliable assessment of disease burden and resource needs [Detmer, 2003; WHO, 2007]. Efforts to tackle the enormous burden of ill-health in low-income countries are hampered by the lack of functioning health information structures to provide reliable health statistics [Osisobe, 1989; Boerma & Stansfield, 2007; WHO, 2008]. Central to a fully operational Health Information Systems (HIS) is a basic inventory of all functioning health facilities and the services they provide. Such an inventory requires a spatial dimension, allowing facilities to be linked to the populations they serve by level of care to other proximate determinants of health such as environment, poverty and education. This spatial linkage can be provided by geographic information systems (GIS). The use of GIS for health services planning is widespread in developed countries [Bullen *et al*., 1996; Gatrell & Markku, 1998] but there are few examples of their development and operational use in resource poor settings in Africa [Noor *et al*., 2004; 2009; Kazembe *et al*., 2007; Lozano-Fuentes *et al*., 2008].

8.4.2 Previous health facility mapping in Nigeria

As far back as the late 1920s, health facility maps were thought an important Ministry of Health & Sanitation tool. Health facility maps for Nigeria were developed in 1927, 1928, 1934, and 1953 [Nigerian Surveys, 1927; 1928; 1934; 1953]. We have obtained copies of these maps from the archives at WHO Geneva, The Wellcome Library, UK and the Ministry of Health Archives in Nairobi, Kenya. The maps were scanned and imported into *ArcGIS* [ArcMap 10.1, Esri systems, Redlands, CA, USA] for geo-referencing and on-screen digitization; while none of the facilities had distinctive names except those of 1934, the location of facilities by State have been represented in Figures 8.1-8.3.

The 1926-27 map showed the location of 69 facilities: dispensaries (18), Leprosy centres owned by missionaries (6), hospitals run by native administration (9), government facilities (30) and 6 nursing homes. Of these, four government hospitals and two missionary dispensaries were under British Cameroon protectorate and thus not shown in Figure 8.1b. The distribution of 35

hospitals and 16 dispensaries excluding leprosy clinics and nursing homes is shown in Figure 8.1b against the original map in Figure 8.1a.

Figure 8.1a: 1926-27 original image of Health Facility Map

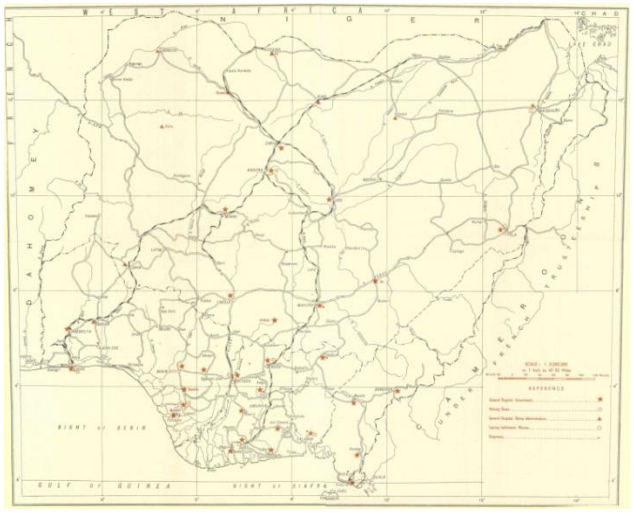


Figure 8.1b: 1926-27 digitized Public Health Facility map

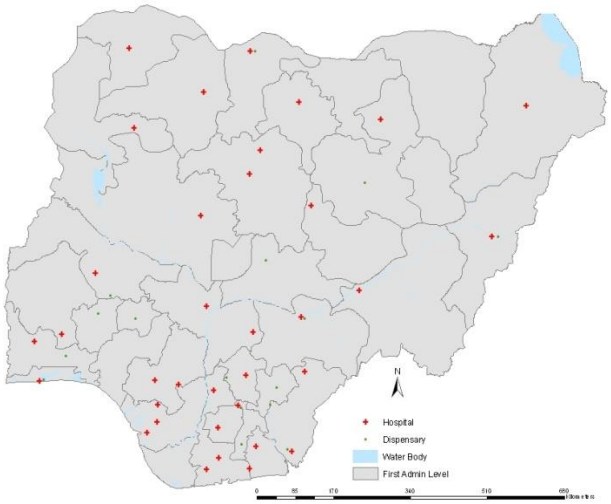


Figure 8.2a: 1934 original image of Health Facility Map

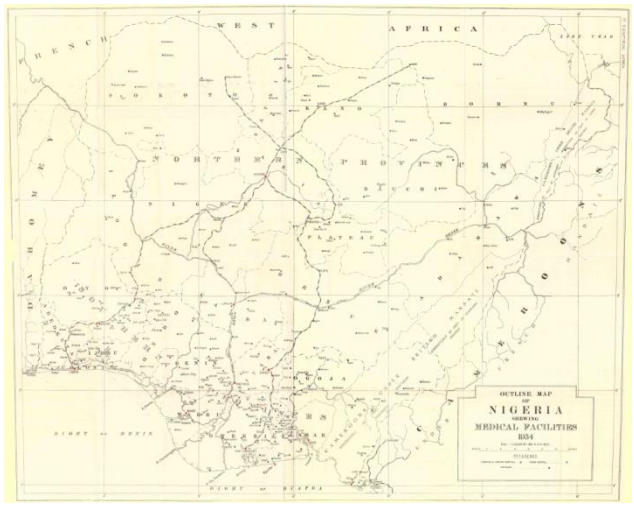
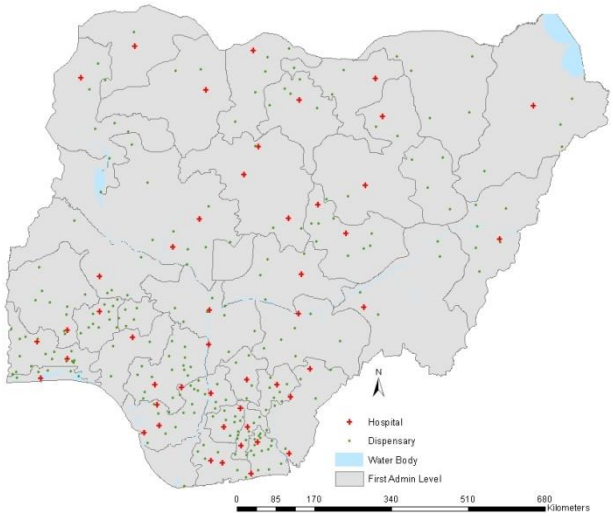


Figure 8.2b: 1934 digitized Public Health Facility Map



The 1934 health facility map showed European and African Hospitals (12), African Hospitals (41), and dispensaries (239) shown in Figure 2a. Of these, eight dispensaries, one European and African Hospital, and four African Hospitals were under British Cameroon protectorate hence not shown in Figure 8.2b. The remaining 279 public facilities were re-coded into 48 Hospitals (European and African Hospitals), and 231 dispensaries (Figure 8.2b).

The 1952-53 health facility map (Figure 8.3a) showed hospitals maintained by government (51), native administration (8), mission (38), and private/industry (13); government nursing homes

(13), leprosy centres maintained by government (4) and missions (21); government rural health centres (5); dental care centres (3); Medical Field Unit Headquarters (10); and a mixture of 997 facilities designated as dispensaries, maternity centres, leprosy villages, health centres managed by government, missionary, and private institutions. Of these, 70 facilities under the British Cameroon protectorates were not digitized. 61 structures comprising of dental centres, health office headquarters, leprosy settlements, nursing homes and hospitals managed by private institutions were excluded under the digitization process of public clinical service provision (Figure 8.3b). Figure 8.3b shows the location of 1043 facilities: 92 hospitals (47 managed by government, 37 by missions, and 8 by native administration), five health centres managed by government and 946 dispensaries. The dispensaries could not be differentiated since they all had similar symbols (small red dots).

Figure 8.3a: 1952 - 53 original image Health Facility Map

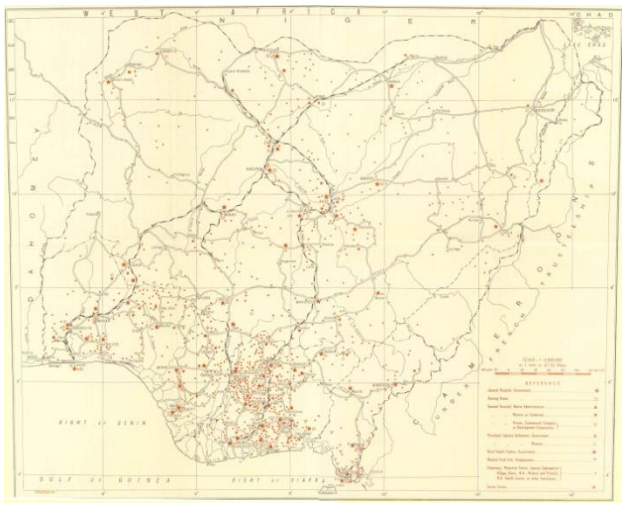
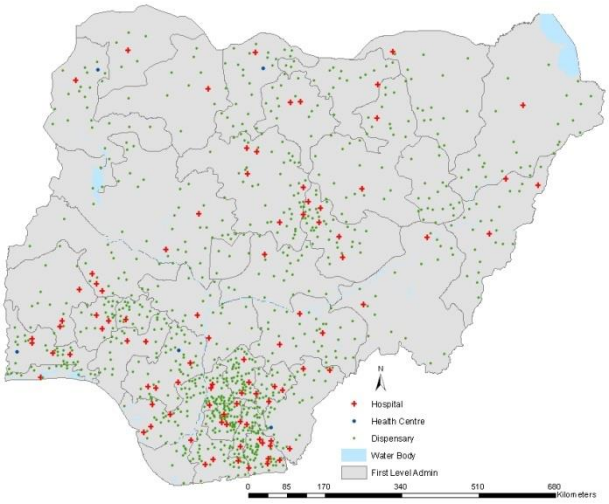


Figure 8.3b: 1952 - 53 digitized Health Facility Map



In recent years there have been several partial mapping activities within the health sector using Geographic Information Systems (GIS) dealing on specific areas of interests. First, in 2006-07 a service availability mapping exercise was undertaken in 11 states. The exercise aimed at capturing the locations of district health offices, general characteristics of health facilities, types of equipment available, human resource, drugs and interventions available and was sponsored by WHO. The data is available at the FMOH, though it has not been made public [FMOH & FGN, 2009]. Second, in 2007-08 a service utilization mapping of health facilities accredited to National Health Insurance Scheme (NHIS) was conducted in which some 1,265 facilities were covered. Attributes collected in questionnaires included location, ownership, type, services offered, accreditation status and human resource. WHO provided Global Positioning Systems (GPS) devices and training of NHIS staff; NHIS provided logistics. Though 1,265 facilities were covered, not all of these had GPS coordinates, instead such facilities were located using enumeration area centroids. The data is available, but has not been released to the public [Indabawa, 2011]. Third, in 2010 the National Health Management Information System (NHMIS) unit of FMOH mapped all service delivery points in selected LGAs using African Development Bank funds and NPC provided technical support. Data captured on public and registered private

facilities included health infrastructure, human resources, and MDG services. The facilities were assigned a unique code for purposes of identification. The data on facilities is available on request from FMOH [Adeleke, 2011]. Fourth, in 2010-11 an HIV/AIDS service provision mapping exercise was undertaken by the Federal Ministry of Health. The study initially started in 2006 covering only HCT but was later expanded in 2010 to cover all aspects of HIV/AIDS and provide the much needed information on HIV/AIDS service delivery across all levels of care in Nigeria. The exercise captured the location of health facilities, ownership of the facilities, infrastructure type and status, services offered, human resource available, amongst others in 32 states. This database is available and was provided to us by FMOH, but it has not been made public [Azeez, 2010; Healthsystems2020.org, 2012]. Finally, in 2011 a Primary Health Care (PHC) facility mapping effort was undertaken by National Primary Health Care Development Agency (NPHCDA) at ward levels. The initiative was to provide information on the existing PHC facilities, and their coverage to enhance local level planning for vaccination programmes. Data collected included services available, location, health personnel, and travel times to health clinics [NPHCDA, 2012; Hanoviamedical.com, 2003; Emmanuel, 2011].

8.4.3 Current health facility geo-coding exercise

Health facility lists were provided through an agreement between NMCP, sunMAP and the FMOH in separate MS Excel files for each of the 36 states and FCT of Nigeria [FMOH, 2012]. Information on facility code, name, location (state, local government authority, ward), service level (primary, secondary, tertiary), management (public, private, others) was abstracted into a single excel sheet containing 33,142 records. The resultant file had several anomalies. To begin with, some wards were missing names in Kano, Ondo and Yobe States. Labeling of service provider was incorrect in several instances (five "primary", two "secondary" and one "closed"), these we relabeled as per the name provided of the facility. Several facilities originally coded as public state managed services (Army, National Police Force etc) we relabeled to "other" public institution. 55 Mission and five community-care providers were incorrectly labeled and we relabeled as "public" facilities. Several facilities only had facility type instead of name, we changed the latter by appending ward names to the facility type and removed the blank named and ward records (7). We identified 440 facilities that had duplicated codes despite having different names, and location. We were able to correct 346 facility code duplicates that occurred between states by changing state prefix code. Gombe and Imo States shared a state code of 16, we changed state code for Gombe to 15 which was missing in the entire database. The remaining 94 state code duplicates occurred within states and we could not correct for these until another file is availed to reconcile the duplicates, we noted these alongside the facilities. Facilities that were duplicated in names but had different facility codes were retained. We excluded facilities that were labelled dental clinics, laboratories, drug stores, X-ray clinics, eye clinics, maternity homes, mental clinics, youth centres or other specialist and teaching facilities that were unlikely to be providing routine curative services or “closed” (1854); and facilities labelled as private (10,464). The latter are significant providers of curative services but as with previous audits of master health facility lists in Kenya, Somalia and Uganda these are often under-represented in FMoH registries, located in urban centers, accessible only to those

able to afford services, unregulated and do not often feature in anti-malarial and net distribution supply management systems.

The final public sector facility list contained 20,816 facilities. We developed a new field with facility types extracted from names and used this to recode facility types with 19,705 offering primary health care, 1,043 offering secondary health care and 68 offering tertiary health care. We have retained were possible two columns representing facility codes. The first facility code accompanied the original FMOH database (10 digit number: first 2 digits were state code, the second two digits represented LGA code, followed by a one digit facility type code, one digit facility owner code, and finally four digits representing the facility) and the second coding column was used to record the seven digit code used in the FMOH HIV/AIDS service provision database (not available for 83% of facilities).

Geo-coding was a particularly laborious task and involved using multiple sources of information and triangulation of sources. Geo-location gazetteers were available from sources shown in Table 8.2. We carefully matched names of facilities to digital databases of facilities available starting with the FMOH database and used in descending order the other resources shown in Table 8.2.

Table 8.2: Databases, gazetteers and sources to assist with geo-coding

Database	Fidelity	Source/URL	Number of place names	Notes
FMOH health facility database	GPS – gold standard	FMOH HIV Service Provision Mapping Exercise (2011-2012)	24,473	Several anomalies noted including duplicates in coordinates, some coordinates were plotting in the wrong State while others were outside the country boundary shapefile. Each corrected using Google Earth and ARCGIS admin boundary shape files
Google Earth	Trusted	https://maps.google.com/		
Geonames	Trusted	http://www.geonames.org/		
Encarta	Trusted	Encarta Maps		
Fallingrain	Trusted	http://www.fallingrain.com		Global gazetteer version 2.2
Chikun LGA	GPS	Abbas et al. (2012)	41	Contained GPS collected points for 41 facilities in Chikun LGA
OpenStreetMap (OSM)	Unverified	http://www.openstreetmap.org/	47,180	Several anomalies noted including points were outside country boundary
Geographic Information Support Team (GIST)	Unverified	https://gistdata.itos.uga.edu Geographic Information Support Team (GIST) is maintained by USAID	37,599	Downloaded from GIST website. Several anomalies similar to OSM. Generally this DB had fewer points than OSM after eliminating points that were outside Nigeria boundary. Several duplicates in coordinates suspected though not checked.
DIVA-GIS (digital gazetteers)	Unverified	http://www.diva-gis.org/datadown. DIVA-GIS maintain digital gazetteers for several countries.	43,041	Downloaded from DIVA-GIS website. Several points falling outside Nigeria were eliminated. Several duplicates in coordinates suspected though not checked.
ArcGIS Online Resources	Unverified	http://www.arcgis.com/home/search.html?q=chinedu&t=content&focus=layers	311	Map layer containing 311 health facilities in Jigawa and Kano States

Of the 20,816 public facilities, we were able to geo-locate 5905 using FMOH database, 2565 using Google Earth, 835 using Geonames, three using Encarta, 22 using Fallingrain, 4826 using OSM database, 837 using GIST database, 354 using GIS-DIVA database, 43 using other sources and 2229 using combinations of listed sources in cases where facilities were differentiated by type within same wards, these will however require further investigation and improvement using the HIV/AIDS service mapping database. Summary by state of un-positioned facilities is given in Table 8.3

Hospitals have been relatively easy to distinguish within the originator database. However, the nomenclature of all other facilities is confusing and not easy to reconcile against levels of care. For example the database contains descriptions as follows: Comprehensive Health Centre/clinic, Health/medical Centre, Model Health Centre/clinic, Model Primary Health Centre/clinic, Primary/basic Health Centre/clinic, Clinic, Community Dispensary, Community Health Centre/clinic/Post, Dispensary, Government House Clinic, Health Post/Clinic/Facility, Mission Clinic, Out Post and Primary Health Clinic. This requires additional work to reconcile and improve to make the database of value.

Figure 8.4: Distribution of 17619 (84.6 %) geo-coded health facilities managed as public sector in circa 2011

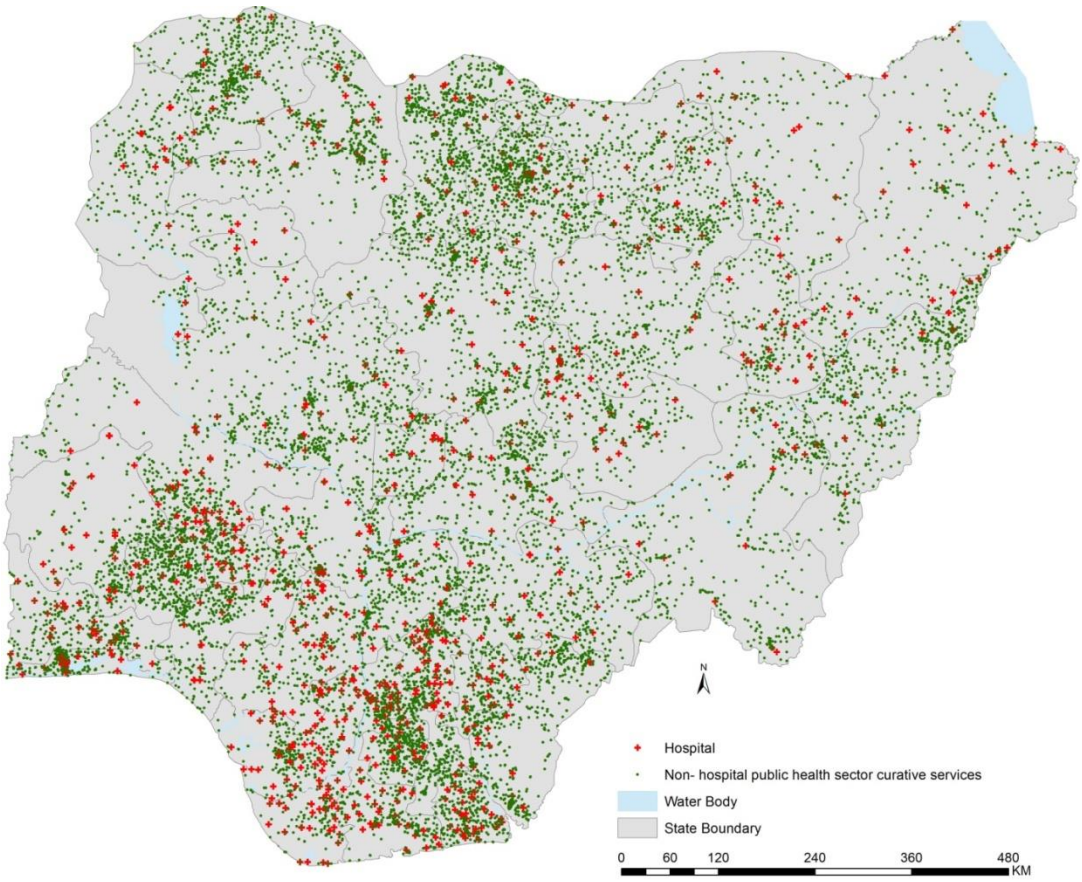


Table 8.3: Un-positioned facilities

State	Un-positioned	%
Abia	7	3.5
Adamawa	17	2.1
Akwa Ibom	14	3.6
Anambra	1	0.3
Bauchi	21	2.7
Bayelsa	18	8.7
Benue	52	6.9
Borno	34	8.5
Cross River	7	1.2
Delta	22	4.5
Ebonyi	79	20.8
Edo	15	4.3
Ekiti	80	25.3
Enugu	136	28.7
Federal Capital Territory	52	28.9
Gombe	60	18.9
Imo	24	6.1
Jigawa	184	30.8
Kaduna	147	15.9
Kano	12	1.2
Katsina	322	25.3
Kebbi	84	22.3
Kogi	124	15.7
Kwara	67	13.8
Lagos	12	4.7
Nasarawa	93	15.2
Niger	326	26.4
Ogun	96	19.9
Ondo	55	11.9
Osun	88	12.9
Oyo	159	26.2
Plateau	166	22.8
River	102	25.9
Sokoto	55	8.2
Taraba	219	29.5
Yobe	107	23.9
Zamfara	140	21.4

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Chapter 9

Discussion and recommendations

This report focuses on the basic epidemiological features of malaria transmission, assembling the data and interpolating information in space and time. This follows recommendations by WHO-AFRO to provide the evidence platform for MPR's through a malaria stratification that includes the geographical distribution of malaria burden, parasite prevalence and parasite species. We have assembled as much epidemiological data and control context as possible from a wide variety of sources to support the description of malaria in Nigeria. Central to the report has been the assembly of parasite prevalence data and modelling the spatial and temporal properties of this metric of transmission intensity.

9.1 Measuring change in *P. falciparum* transmission intensity 2000-2010

In 2000, at the launch of RBM, 85% of Nigerians were exposed to hyper-holoendemic transmission, i.e. living in areas where at least 50% of children aged 2-10 years would be harbouring *P. falciparum* infection. These conditions were ubiquitous across almost all states with restricted areas of mesoendemicity (*Pf*PR_{2-10} 10-49%) located predominantly in the South West coastal area (Figure 5.5). From available survey data it is likely that these conditions had prevailed for several decades prior to the launch of RBM (Figure 5.2) and while small scale heterogeneity will have existed conforms to a pattern of transmission described by LJ Bruce-Chwatt in the 1950s. It is notable from Chapter 3 that despite successful pilot control projects using IRS and MDA, there is little reported evidence of a nationwide malaria prevention campaign before the launch of RBM.

By 2005, the pattern of transmission across much of Nigeria had begun to change. The predicted mean parasite prevalence in 2005 (Figure 5.4 & 5.5) suggests that 45% of the population were exposed to hyper-holoendemic conditions and 55% of the population were exposed to mesoendemic conditions. By 2005 no one was exposed to hyper-holoendemic transmission in FCT Abuja, Lagos, Anambra, Edo, Delta and Bayelsa States.

By 2010, 85% of Nigerians lived in areas supporting mesoendemic transmission, 15% lived under conditions of hyper-holoendemicity and areas within FCT Abuja, Adamwa and Borno States supported hypoendemicity (Figures 5.4 & 5.5). Almost all of the central and south-eastern regions of Nigeria had, by 2010, transitioned to mesoendemic conditions.

Importantly, Nigeria is probably the only country in Africa that has set parasite prevalence as an M&E Milestone, aiming to reduce prevalence by 50% by the year 2013. To examine this metric in more detail we have re-sampled the posterior predicted mean *Pf*PR_{2-10} across each state and weighted for the population density within each 1x1 km pixel. This provides a population-adjusted mean *Pf*PR_{2-10} by state allowing us an opportunity to look at proportional change between 2000 and 2005, 2005 and 2010 and across the entire decade (Figures 6.2 & 6.3; Tables 6.2a & 6.2b).

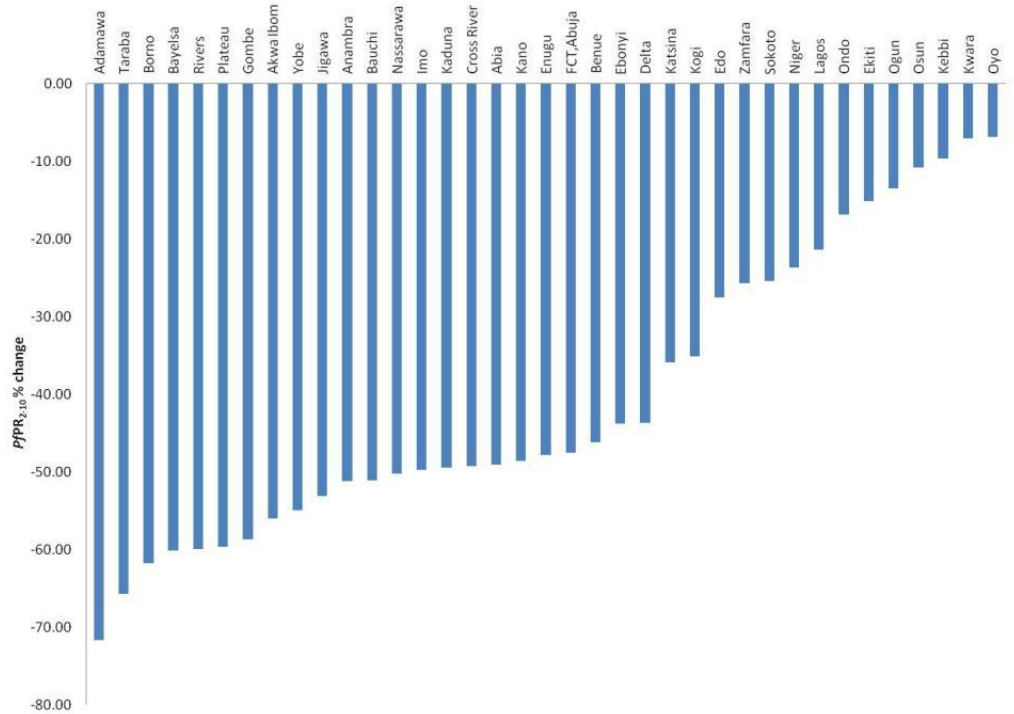
The pattern of population adjusted mean transmission intensity in 2000 (Figure 6.2) conforms largely with the continuous spatial risk patterns (Figure 5.4) and highlights the fact that the most intense transmission was located in the northern and eastern States. Between 2000 and

2005 all states witnessed a decline in mean population weighted *Pf*PR_{2-10}. A 25% or higher reduction in the modelled predicted mean prevalence may have occurred in Kano, Kaduna, Jigawa, Taraba, Niger, Kogi, FCT Abuja, Nassarawa, Plateau, Benue, Enugu, Ebonyi, Abia, Imo, Anambra, Edo, Delta, Baylesa, Rivers, Akwa Ibom and Cross River States. This transition in transmission intensity transformed the pattern of parasite exposure across Nigeria before any significant scaled intervention began.

Between 2005 and 2010, 29 states might have experienced a further decline in transmission based on 2005 transmission extents. The percentage change 2005 to 2010 in population weighted *Pf*PR_{2-10} exceeded 25% in Kano, Kaduna, Jigawa, Yobo, Borno, Gombe, Bauchi, Adamawa, Taraba, Plateau, Akwa Ibom and Rivers States. However, in the states of Kwara, Kogi, Osun, Ekiti, Ondo, Anambra, Edo and Delta the population adjusted mean *Pf*PR_{2-10} rose during this interval.

An examination of the percentage change in population corrected transmission intensity over the decade since the launch of RBM (2000-2010) suggests that all states may have witnessed a reduction in transmission intensity (Table 6.2b; Figure 9.1). The modelled predicted percentage change 2000-2010 exceeded 50% in 19 states: Kano, Kaduna, Jigawa, Yobe, Borno, Gombe, Bauchi, Adamawa, Taraba, FCT, Abuja, Nassassawa, Plateau, Enugu, Abia, Anambra, Bayelsa, Rivers, Akwa Ibom and Cross River. Despite significant changes in infection risks these states and those without a 50% decline all have risks of infection that exceed 20% but are all dramatically different from levels of infection risk in 2000.

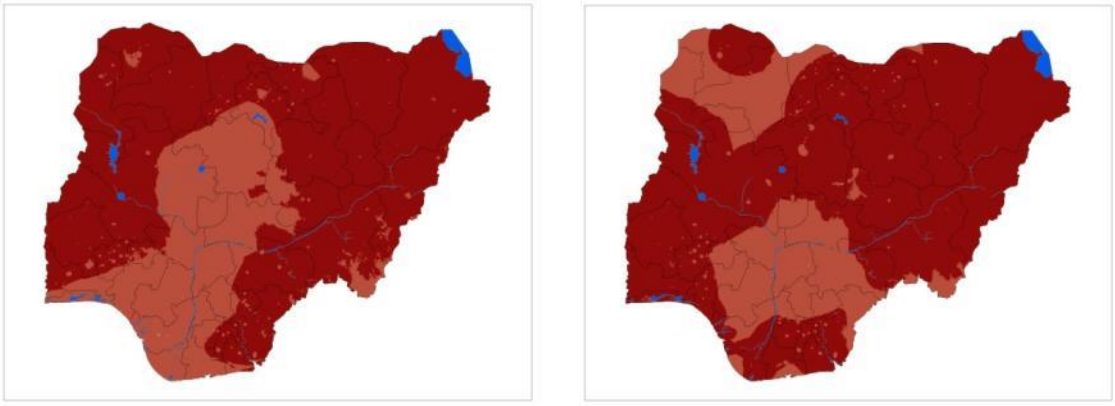
Figure 9.1: Percentage change in population weighted mean *Pf*PR_{2-10} between 2000 and 2010 by State



Because the model is constructed in time and space it is possible that the large amount of 2010 data influence the shape of the decline between 2000 and 2005. To examine the possible influence of the time-space data sampled in 2010 on the predictions of parasite prevalence in 2005 we partitioned the data and re-ran the INLA models. Here only data pre-2006 were included in the model to predict to 2005 (Figure 9.2b). Because the data cube is less spatially rich there are differences between a partitioned data assembly and the full time-space cube (Figure 9.2a), however, both data driven models suggest that there was an expansion of mesoendemic transmission and a decline in hyper-holoendemic conditions between 2000 and 2005. The full time-space data cube provides more information and reduced standard errors of predicted mean parasite prevalence and is a preferred reference model.

Figure 9.2: a) Full spatial and temporal data (1960-2010) used to predict endemicity classes in 2005; b) partitioned data cube including only data 1960-2005 to predict to the year 2005.

a) b)



9.2 Provisional interpretation of changing transmission intensity

It is hard to make recommendations about the future of control in Nigeria without understanding the drivers of the epidemiological transition across the country over the last decade. Clearly the transition is more complex than might have been anticipated. Declines in mean *Pf*PR_{2-10} were observed from raw data (Figure 5.2) and modelled spatial predictions between 2000 and 2005 (Figures 5.4 & 6.2). ITN coverage across all states during this period was exceptionally low, less than 2%; chloroquine was still widely used but SP had begun to replace CQ as a drug of first-line treatment choice and generally there were insufficient funds to implement the 2001 national malaria strategy. There are several possible explanations that require further investigation: a) this period coincided with pervasive droughts across the Sahel which would have affected transmission potential across the northern, but not southern, states; b) the increasing use of SP as a treatment in the formal and informal sectors may have had a suppressive effect of a long half-life drug on subsequent new infections, serving as a "prophylactic"; c) there may have been a systematic change in dominant vector composition as suggested in Section 4.1 from authors reporting increasing extents and dominance of *An. arabiensis*; and d) some general change in health status or proximal effect on health that would

have mediated to the likelihood of being infected by dominant vectors. There has been a decline in under-five mortality in Nigeria that began in 2000 (Figure 2.4).

The period 2005-2010 witnessed further changes in transmission intensity but this was less ubiquitous than the period 2000 to 2005. Eight states witnessed either no change or a rise in infection prevalence between 2005 and 2010. Several of these states were congruent with states that had not benefited from mass-campaign distributions of ITN in 2009 (Figure 7.2c).

9.3 Assembling more prevalence data past, present and future

As with all data dependent models uncertainty in the 2000, 2005 and 2010 predictions would be reduced with more empirical data. These data may well exist and it would be valuable to invest time in re-assembling these data from libraries and archives across Nigeria.

Our data searches have not been systematic, traditional evidence review strategies. These would have missed many unpublished sources of information. Rather our strategy has used a cascaded, opportunistic approach. Authors of peer-reviewed papers were often asked about additional information within their paper and directions to other possible unpublished work in their geographic area or from their institution. A mass email circular was sent to known and active malaria researchers across Nigeria, identified from the peer review search as active in malaria epidemiology. The intention was to identify any other sources of parasite prevalence data that may have been undertaken as surveys that had not been published. This failed to solicit much response and consequently no further leads on whether new or historical data might exist. This might be a more successful strategy if initiated by the Federal and State Ministries of Health highlighting the significance of a complete national archived record of parasite prevalence. Our search will have missed several important sources of data and it is worth highlighting some additional requirements to ensure completeness of a national archive of parasite prevalence in its next iteration:

a) We have not established whether the Malaria Service record archives, established in the 1950s, still exist at Yaba in Lagos and this may yield additional historical information not captured by us using remote library and archive sources. It is possible for example that the Malaria Service undertook routine community and school-based parasite surveys and records remain of these surveys.

b) We have not been able to access the community level data published as an aggregate in the *Nigerian Journal of Nutritional Sciences* volume 31 (10) in 2010 by CA Agbon and colleagues [Agbon *et al*., 2010]. Only the abstract could be obtained and no information exists on location of survey of malaria parasitology among pre-school children in 9 villages.

c) Similarly, and more significantly, a survey reported by OC Ani (2004) in Ebonyi State in the abstract from *Animal Research International* suggests a 1,300 primary school

children aged 5-16 years where malaria infection was recorded; however we have not been able to identify the full text paper, nor the disaggregated data.

d) Data were presented at the American Society of Tropical Medicine and Hygiene annual meeting in Atlanta, November 2012 from the Carter Centre where comprehensive State wide surveys of infection prevalence were reported for Abia and Plateau States [Patterson *et al*., 2012] a request to Drs Norman, Graves and Richards has been made in January 2013 to make these data available for the Nigeria modelling but they have declined sharing these data until published and are not available at the time of this revised report (October 2013).

e) There is no online digital archive of masters, MD, MPH and doctoral theses undertaken by students of the faculties of parasitology, public health and medicine at the many Nigerian universities nationwide. It is very likely that parasite surveys have formed part of research theses of many students over the years and this assembly has not been captured here and might constitute further investment to house all possible survey data into a single archive.

f) We have been unable to locate all information signalled as potentially relevant from the published and unpublished literature searches this includes for example surveys possibly undertaken by NGO agencies working in the Sahel region or among the nomadic pastoralists in the north of the country.

During a similar modelling exercise of parasite prevalence in Kenya [Noor *et al*., 2009] it was recognized that spatial predictions in some areas of the country were highly uncertain. To redress this uncertainty rapid, school-based surveys were undertaken covering approximately 100 children aged 5-14 years attending schools in areas were little previous parasitological data had been done. This approach improved predictive accuracies in these spatial areas. Because of the comparative ease and cost-efficiency of sampling school children this has become an integral part of parasite surveillance in Kenya [Gitonga *et al*., 2010]. Given the significance of parasite prevalence within the Nigerian M&E plan, school-based surveillance might be seen as a valuable adjunct to household sample surveys nationwide. Household surveys and school surveys must increasingly be designed to provide precision at State levels.

9.4 The need for a more detailed understanding of change

Each State has had a particular recent history of malaria investment and control. Funding, partners and intervention coverage have varied significantly between states since 2000. The effects of the Sahelian drought will have impacted on some but not all states. It is not possible here to examine in detail the combined impact of intervention coverage, drug use, climate and other factors. The headline message is that transmission risks have declined dramatically in Nigeria since the launch of RBM but cannot be explained by scaled malaria control activities alone. The transition in some but not all states since 2005 requires a careful, more detailed analysis and should be made a priority.

To understand and explain changes in transmission across Nigeria would require the assembly of additional data at state levels with higher temporal resolutions. These data would include a) interpolated small area estimation (SAE) approaches [Rao, 2003] to household survey data on ITN coverage combined with distribution data; b) mapped extents of IRS and larval control to estimate populations protected and volumes of insecticides used by year; c) SAE approaches to estimating the likely use of SP and ACTs from household sample survey data in combination with mapped locations of formal health service providers; and d) detailed ground-station meteorological data from NIMET, the Nigerian Meteorological Service.

State level change in predicted transmission intensity should be assessed against the range of possible explanatory variables both quantitatively using a variety of techniques including Oaxaca-Blinder decomposition methods [Demombynes & Trommlerová, 2012] and Multinomial logistic regression [Fegan *et al*., 2007]. This would be accompanied by a semi-quantitative, causal pathway plausibility framework [Habicht *et al*., 1999; Rowe *et al*., 2007]. Finally it would be valuable to use the combined data on change in transmission metrics and change in intervention coverage to explore the observed and predicted impact size from currently available mathematical models [Griffin *et al*., 2010; Smith *et al*., 2009]

9.5 Triangulation of information

Recognizing the possibility of a dramatic epidemiological transition over the last decade in Nigeria demands an assembly of other supporting data to triangulate with the evidence based on parasite prevalence. To a large extent most of the empirical evidence of a declining malaria burden across Africa has been generated through an examination of hospital admissions since 2000 [Barnes *et al*., 2005; Ceesay *et al*., 2008; Chizema-Kawesha *et al*., 2010; Karema *et al*., 2011; O'Meara *et al*., 2008; Okiro *et al.*, 2009; Okiro *et al*., 2011; Otten *et al*., 2009; Sievers *et al*., 2008]; in several reports variations in the rate and magnitude of changing hospitalization have been linked to differences in endemicity, for example Kenya [Okiro *et al*., 2009], Uganda [Okiro *et al*., 2011] and Malawi [Okiro *et al*., submitted]. Hospital data are not without their limitations [Rowe *et al*., 2009] notably they may be incomplete, malaria may not be universally parasitologically diagnosed, other temporal factors may influence admission rates (abolition or increases in user fees) etc. However they are often more precise data than the temporal examination of out-patient department records.

It would be valuable to try a retrospectively assemble monthly paediatric admission data (malaria versus non-malaria diagnosed) from several teaching hospitals across Nigeria likely to have maintained reasonable laboratory services for as complete a period as possible between 1999-2012. If enough data could be assembled from enough hospital sites these data would help interpret the rate, slope and magnitude of changing risks across the changing climate and intervention conditions in different regions of Nigeria since 2000.

9.6 Measuring impact on mortality burdens

For over 50 years it has been widely accepted that establishing the precise malaria mortality burden in Nigeria has been impossible (Chapter 3). Malaria shares many symptoms with other competing causes of death, most deaths occur outside of the formal health system and are neither registered nor diagnosed. Recent attempts have been made by the WHO to use the Lives Saved Tool (LiST). LiST estimates the numbers of deaths averted as a direct result of increasing coverage of preventative measures, ITN and IPT, that have a proven mortality efficacy from community randomized trials; the model makes various assumptions about the impact size on a fraction of under-five mortality presumed to be malaria from verbal autopsy studies [Eisele *et al*., 2010a; 2010b; Komatsu *et al*., 2010]. Applying this model to intervention coverage data in Nigeria it was estimated that approximately 166,000 (range: 121 000–264 000) deaths among children under five were averted in Nigeria between 2001 and 2010 [RBM, 2012]. However, this model does not account for variations in either intervention effect size or patterns of malaria mortality by parasite transmission intensity nor the combined effects of intervention access that include the effective treatment of clinical attacks. There is a non-linear relationship between the risks of severe, life-threatening malaria and deaths directly attributed to malaria infection and the intensity of transmission [Snow & Marsh, 2002] and partially used in disease burden estimations by the WHO [Cibulskis *et al*., 2007] and others [Snow *et al*., 1999; Snow *et al*.,2003; Murray *et al*., 2012].

Combining state level information on changing malaria exposure, changing intervention coverage, all-cause and estimated malaria-attributable mortality, and combined intervention impact efficacy provides a unique opportunity to re-examine the changing malaria burden in Nigeria.

9.7 Health facility mapping

There is a growing emphasis across Africa on improving geo-coded master health facility lists. Non-spatial facility lists must evolve into geo-coded platforms to support better commodity planning and supply, and targeted facility-based interventions. This will become increasingly important as data on malaria diagnosis improves in the public sector through evolving national malaria case-management policies as part of WHO recommendations for Test Treat and Track. Diagnostic commodity supply, adherence to test results, accuracy and data reporting all remain imperfect. Incomplete data with known precision/coverage properties are well suited to MBG methods and these have recently been applied to examine the time-space incidence of HMIS malaria data in Namibia [Alegana *et al*., 2012]. More broadly, with the sustained emphasis on District Health Information Systems v2. (DHIS 2.0) since 2008 in more than 14 African countries there is an increasing need to provide a spatial, mapped element to visualizing data. This is a broader health sector initiative, beyond the immediate scope of the current project. However, this data layer is central to NMCP effective planning. Our provisional efforts at mapping out the Nigerian Master Facility list have taken four months with five full time staff. What is now required is for this to be continued within each State using existing data as an entry point to finalize the geo-coded lists and improve the level descriptions.

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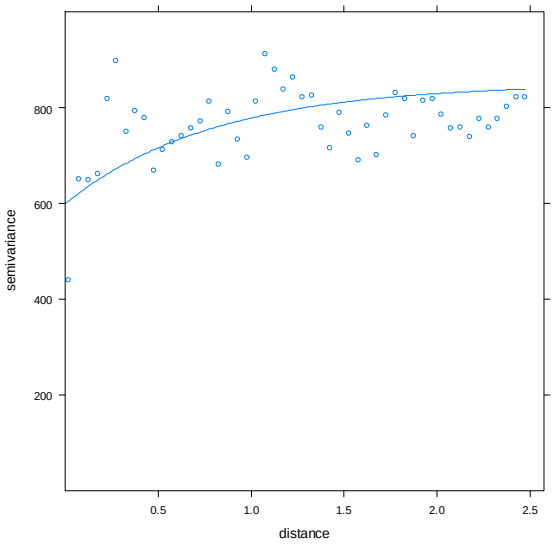
Annexes

Annex A: Mapping *Pf*PR$_{2-10}$ using SPDE in INLA

A fundamental concept behind analyzing geographic data is determining the presence of spatial dependence [Tobler, 1970]. Spatial dependence simply means co-variation of properties within a geographic space driven by the principle that observations at proximal locations are more correlated (positively or negatively) than those at locations further away. There are a number of reasons for spatial dependence and but all generally relate to factors that lead to spatial correlation, causality or interaction (e.g. people who live in same neighbourhood are more likely to be similar than those who live in communities further away). Spatial dependence in data leads to the statistical problem of spatial autocorrelation which negates the conventional regression wisdom that observations at one location are independent of observations at a neighbouring location often yielding unstable parameter estimates and unreliable significance results [Tobler, 1970; Isaacs & Srivastava, 1989]. Geo-statistical techniques overcome this challenge by incorporating the spatial effects in the data analysis. However, not all data from different locations exhibit spatial dependence and before geo-statistical techniques are used the data need to be explored for the presence of spatial structure or autocorrelation. To explore any data for spatial autocorrelation, the variogram, also commonly referred to as the semi-variogram, is used [Isaacs & Srivastava, 1989]. The variogram is a graphical summary (Figure B.1) of spatial autocorrelation structure and has three parameters: the *nugget* (n) which is the height of the jump of the variogram at the Y-axis and is considered to represent the measurement error; the *sill* (s) which is limit of the variogram tending to infinity lag distances; and the *range* (r) which is the distance in which the difference of the variogram from the sill becomes negligible. The *semi-variance* (half the variance of data pairs) is shown on the Y-axis and increases with increasing separation distances or lag between data pairs shown on the X-axis. For data to be used to construct the variogram, their location must be defined explicitly i.e. they are provided with latitude and longitude coordinates. The variogram of the Nigeria *Pf*PR$_{2-10}$ data (Figure A.1) shows the presence of spatial autocorrelation with a range of up to about 1.5 decimal degree or around 167 km at the equator.

Figure A.1 Variogram and model fit for distribution of *Pf*PR$_{2-10}$ data (n=921 clusters) from 1960 to 2011 in Nigeria. The X-axis shows distance in degrees latitude and longitude while the Y-axis shows the semivariance



After the presence of spatial structure has been established, a suitable MBG model is then developed to fit the data where the spatial (and temporal) covariance is used to generate samples of the predicted posterior distribution from which point estimates and the uncertainty around these estimates are computed simultaneously [Chilés & Delfiner, 1999; Diggle *et al*., 2002; Noor *et al.*, 2009]. These models can include covariates of the outcome measure and account for non-stationarity, a condition where the statistical parameters (mean and standard deviation) of the data-generating process change over space and/or time [Isaacs & Srivastava, 1989; Atkinson & Tate, 2000]. Normally, Bayesian inference is done using Markov Chain Monte Carlo (MCMC) algorithms [Gilks & Spiegelhalter, 1996]. MCMC approaches, although used widely, suffer from problems of convergence and dense covariance matrices which increase the computational time and cost significantly, especially where there are large data points spatially and temporally [Rue *et al*., 2009]. Recently, Integrated Nested Laplace Approximations (INLA) has been identified as an alternative algorithm for Bayesian inference [Rue *et al*., 2009]. The advantage of INLA-based approaches is mainly computational speed and can be undertaken in open source, easily adaptable R packages [R-INLA project]. Spatial and temporal analysis in INLA can be undertaken through the Stochastic Partial Differential Equations (SPDE) approach [Cameletti *et al*., 2012] and the covariance functions are represented as Gaussian Markov Random Field (GMRF) [Rue *et al*., 2009; Cameletti *et al*., 2012].

A Bayesian hierarchical spatial-temporal model was implemented through the SPDE approach using R-INLA library [R-INLA] to produce continuous maps of *Pf*PR$_{2-10}$ at 1 × 1 km spatial resolution using data from 1970-2011. Technical equations can be provided on request. In brief, the *Pf*PR$_{2-10}$ survey data were modelled as realizations of a continuously indexed spatial process (random field) changing in time. These realizations were used to make inference about the process and predict it at desired locations and at a specified time. In this report, the Gaussian Field (GF) with Matern covariance function was represented as a GMRF through the SPDE

approach to carry out space-time predictions [Rue & Held, 2005; Lindgren *et al*., 2011; Cameletti *et al*., 2012]. By using the GMRF approach the covariance function and the dense covariance matrix of a GF are replaced by a neighbourhood structure and sparse precision matrix respectively which allow for faster computation. The sparsity of the precision matrix offers the computational advantage when making inference with GMRF. This is because the linear algebra operation is performed using numerical methods for the sparse matrices which results in a considerable computational gain and this can be further enhanced by using the INLA algorithm for Bayesian inference [Rue & Held, 2005]. The GF Matern field with a Matern covariance function that is used in this report is a second-order stationary isotropic. A finite element representation is used to outline the Matern field as a linear combination of basic functions defined on a triangulation of the prediction surface, the domain. This is achieved by subdividing the domain into non-intersecting triangles meeting in at most common edge or corner, or a *mesh*.

In the SPDE approach, the overall hierarchical space-time binomial model of the prevalence to malaria parasite was represented using the following measurement equation $y(s_i,t) = z(s_i,t)\beta + \xi(s_i,t) + \varepsilon(s_i,t)$. Where $y(s_i,t)$ was the realization of a spatial-temporal process representing the *Pf*PR$_{2\text{-}10}$ at the community location s_i, where $i = 1.....n$, and year t. The function $z(s_i,t) = (z_1(s_i,t)...z_p(s_t,t))$ is the covariates (EVI, TSI, urbanisation and precipitation) vector for the cluster s_i at time t, $\beta = (\beta_1.....,\beta_p)'$ is the coefficient vector, $\varepsilon(s_i,t) \square N(0,\sigma_\varepsilon^2)$ is the measurement error defined by the Gaussian white noise process, and $\xi(s_i,t)$ is the true state or prevalence of the plasmodium parasite in that cluster. In the model formulation the large scale component that depends on the covariates is defined as $Z(s_i,t)\beta$ while the measurement error variance or the nugget effect is σ_e^2. The realization of state process or the unobserved level of *Pf*PR$_{2\text{-}10}$ in this case is defined by $\varepsilon(s_i,t)$ as a spatial-temporal Gaussian field that changes with temporally as a first-order autoregressive function.

Figure A2: Maps of model prediction uncertainty based on one Standard Deviation of mean posterior prediction – yellow through green good predictions, blue through dark blue poorer predictions.

a) 2000

b) 2005

c) 2010

A 1 References

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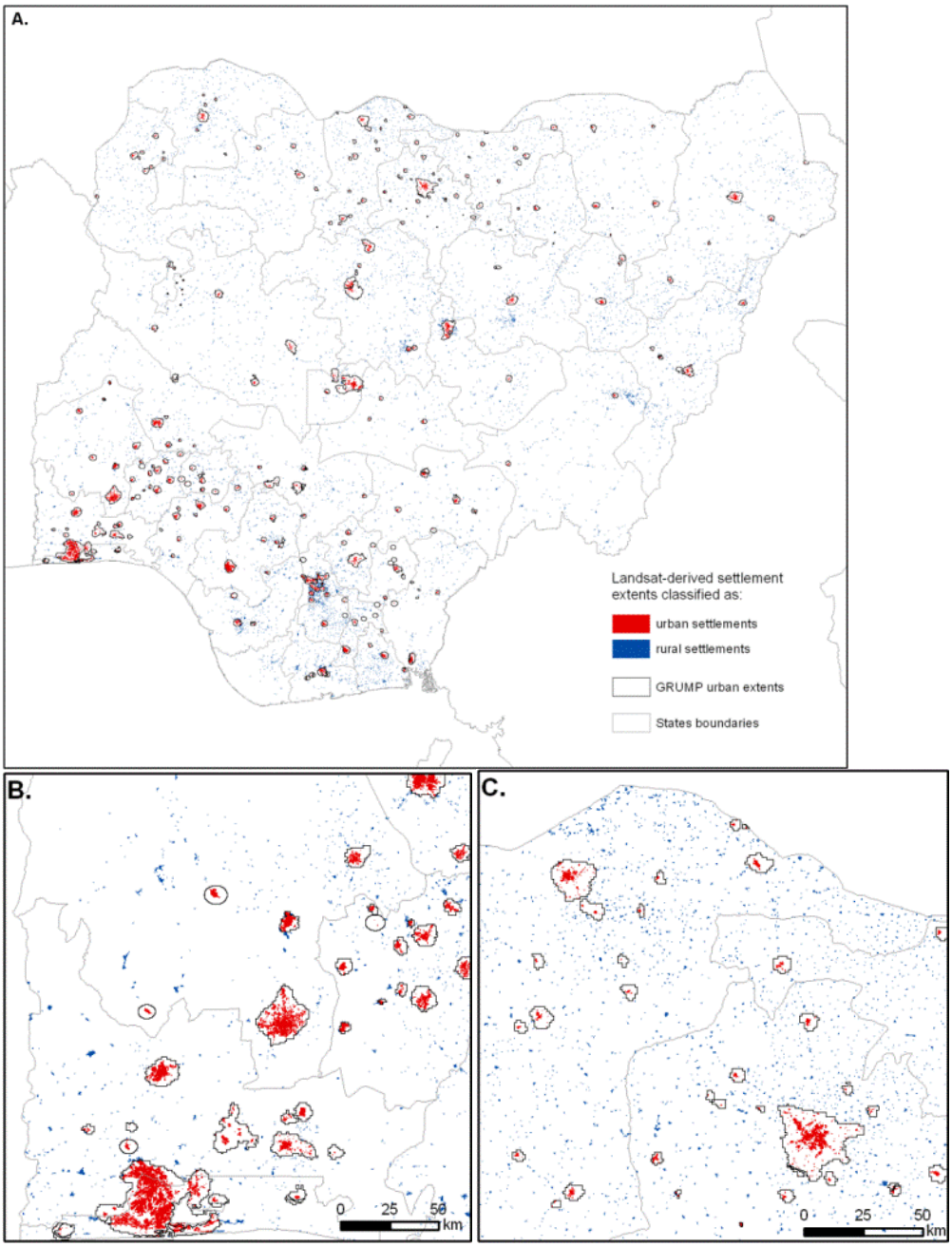
Annex B: Population modeling approaches

B.1 Land cover data

Recent work showed that GlobCover – derived from a time-series of Medium Resolution Imaging Spectrometer (MERIS) images acquired from December 2004 to June 2006 [Arino *et al.*, 2008] – was the global land cover dataset that, combined with detailed settlement extents, produced the most accurate population distribution data in an African context [Linard *et al.*, 2010]. The dataset has a spatial resolution of 300 meters and is compatible with the UN Land Cover Classification System (LCCS). Linard *et al*. (2010) showed that aggregating GlobCover land cover classes from 47 to 10 generic classes did not reduce the accuracies of output population distribution datasets. The GlobCover dataset was acquired from [http://ionia1.esrin.esa.int], and the 10 generic GlobCover land cover classes were used as a basis for the redistribution of rural populations across Nigeria. The GlobCover land cover data were 'refined' to accommodate finer spatial resolution and more accurate information on settlement extents. A dataset depicting expert-opinion derived settlement extent outlines derived from Landsat imagery was acquired from the GeoTerraImage Consultancy [www.geoterraimage.com] (Figure C.1). This dataset was principally derived from 2005 Landsat imagery, through a combination of conventional expert opinion on-screen interpretation and hierarchical clustering techniques, often involving the use of area-specific geographic masks. The accuracy of the satellite-derived settlement maps was assessed elsewhere [Linard *et al.*, 2012]. The GlobCover dataset was modified to accommodate these more detailed settlement extents obtained from satellite imagery. The GlobCover dataset was first re-sampled to 100 m spatial resolution, and the urban class – which typically overestimates settlement extent size [Tatem *et al.*, 2007; Linard *et al.*, 2010] – was removed and the surrounding classes expanded equally to fill the remaining space. The more detailed settlement extents were then overlaid onto the 'urban class deprived' land cover map and land covers beneath were replaced to produce a refined land cover map focussed on detailed and precise mapping of human settlements. The detailed settlement extents include both urban areas and smaller and more rural settlements - the critical size of villages to be detected and included in the detailed settlement extent database was estimated to 30 ha [Linard *et al*., 2012]. We distinguished "urban areas" from "rural settlements" using GRUMP (Global Rural-Urban Mapping Project) urban extents [Balk *et al*., 2006] (Figure B.1). GRUMP urban extents beta version was acquired from [http://sedac.ciesin.columbia.edu/gpw/index.jsp]. This global dataset was produced using night-time lights [Elvidge *et al*., 2007] as a baseline, then polygons identified by other ground-based or remote sensing sources (such as the Digital Chart of the World) not intersecting with the lights were added [Balk *et al.*, 2005]. It has been showed that the GRUMP dataset overestimates urban areas due to the use of un-threshold night-time lights data, incorporating the blooming effect associated with this imagery [Potere *et al.*, 2009]. However, GRUMP urban extents were only used here to distinguish between urban and rural settlements, and not to delineate urban areas. Settlements located within GRUMP urban extents were classified as "urban"; whereas settlements located outside were classified as "rural settlements" (Figure B.1).

Figure B.1: Landsat-derived settlement extents used in the construction of the population dataset outlined here. These settlement extents were classified as "urban" (in red) or "rural" (in blue) settlements according to GRUMP urban extents (black lines). (A) Nigeria (B) Close-up for the Lagos area. (C) Close-up for a region in the North (region of Kano and Katsina).



B.2 Population data

Human population census data and corresponding administrative unit boundaries at the highest level available from the most recent available censuses were acquired. For Nigeria, 2006 census data were acquired for the 774 Local Government Areas (LGAs) (administrative unit level 2) and 1991 census data were acquired for 37 States (administrative unit level 1) from the National Bureau of Statistics. Annual inter-censal growth rates were calculated at the State level using 1991 and 2006 census data. Age and sex structure of the population was also available at the State level from the 2006 census. Other demographic data were available from different national household surveys for different years: Demographic and Health Surveys 2003 and 2008, Multiple Indicator Cluster Survey 2007, Malaria Indicator Survey 2010 and MABA 2010. Sub-national demographic and growth rates data were matched to corresponding GIS datasets showing the boundaries of each unit. Population counts for 103 major settlements of more than 60,000 inhabitants were also assembled by combining data from GRUMP and the Atlas of Urban Expansion [Angel *et al.*, accessed 2012] for the year 2000. These population counts were projected forward to 2006 using the UN urban growth rate [UN, 2011].

B.3 Population distribution modelling

The modelling method distinguishes urban and rural populations in the redistribution of populations. Major settlements have population numbers already derived and validated (as described above) and this makes up 33% of the total Nigerian population. The remaining 67% rural population was redistributed using a dasymetric method, i.e. based on land cover weightings. The refined land cover data and fine resolution population data from Ghana, Kenya and Namibia were used to define per land cover class population densities (i.e. the average number of people per 100 x 100 m pixel. According to the Köppen-Geiger classification, Nigeria is covered by two climate zones: a large part is equatorial except the North, which is arid. Different land cover specific population densities were thus calculated for the two climate zones and used as weights to redistribute the rural populations within administrative units in Nigeria (Table C.1).

Table C.1: Average population density per land cover class (from the 10 aggregated GlobCover classes) for the two main Köppen-Geiger climates covering Nigeria. These population densities were calculated based on detailed census data from Ghana, Kenya and Namibia.

GlobCover aggregated land cover classes	Equatorial	Arid
Cultivated Terrestrial Areas and Managed Lands	108.69	2.22
Natural and Semi-natural Terrestrial Vegetation – Woody / Trees	22.19	2.91
Natural and Seminatural Terrestrial Vegetation – Shrubs	39.67	1.98
Natural and Seminatural Terrestrial Vegetation – Herbaceous	5.85	2.08
Natural and Semi-natural Sparse Terrestrial Vegetation	5.07	1.75
Natural and Seminatural Aquatic Vegetation	78.10	11.25
Bare areas	5.30	1.52
Urban settlements	3327.65	1153.89
Rural settlements	2376.54	332.63
Waterbodies	0	0
Industrial area	0	0

B.4 Projections and adjustments

The 2006 population map was projected backwards to 2000 and 2005 using State-level intercensal growth rates, and projected forward to 2010 and 2015 using extrapolated State-level growth rates. Subnational growth rates follow the same decreasing trend as the national growth rates estimated by the UN and were adjusted such that the total population in 2010 and 2015 matches UN estimates. Population counts were projected forward, using the following equation:

$$P_y = P_d e^{rt}$$

where P_y is the population for year *y* within a pixel, P_d is the population within the same pixel at the year of the input population data, *t* is the number of years between the input data and year *y*, and *r* is the average annual growth rate. The datasets were adjusted to ensure that national population totals matched those reported by the UN.

B.5 Demographic datasets & output

The proportion of women of childbearing age (WOCBA) and the proportion of children under 5 years old were extracted for each State from the 2006 census (administrative unit level 1). WOCBAs are defined as the number of women aged between 15 and 49 years (18). Estimated proportions of infants (i.e. age < 1) by State were calculated for each target year using national household surveys, either using one survey when only one was close in date (e.g. for the year 2000, proportions of infants estimated using DHS 2003 data were used), or preferably several surveys when several were available, in order to increase the sample size (e.g. estimated proportions of infants in 2005 were calculated as the average proportions of infants based on DHS 2003 and 2007 data, and estimated proportions of infants in 2010 and 2015 were calculated based on MICS 2008, MIS 2010 and MABA 2010 data, by taking the average of the proportions derived from each survey). The GIS unit-linked proportions of WOCBAs, infants and children under 5 were used to adjust the spatial total population datasets, to produce estimates of the distributions of populations by category across Nigeria in 2000, 2005, 2010 and 2015.

The outputs datasets are raster grid surfaces at ~100 x 100 m spatial resolution (0.0008333 decimal degrees) of resident human population of Nigeria for different dates (2000, 2005, 2010, 2015) and different categories of people (total population, WOCBAs, infants, children under 5 years). These surfaces were also aggregated to ~1 x 1 km (0.008333 dd) and ~5 x 5 km grids (0.04166 dd). Raster grid surfaces are provided in TIFF format (32 bit floating point).

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Annex C: Survey data with information on ITN utilisation and Bayesian mapping procedures

C1 ITN coverage data for Nigeria

The national household sample surveys where data are available on household and individual net ownership and use are described here.

Demographic and Health Survey (DHS) 2003: The data collection was carried over a five-month period, from March to August 2003. The sample was selected in two stages. In the first stage, 365 clusters were selected from a list of enumeration areas developed from the 1991 population census. In the second stage, a complete listing of households was carried out in each selected cluster. Households were then systematically selected for participation in the survey. Of the 7,327 existing households, 7,225 were successfully interviewed [NPC, 2004].

Demographic and Health Survey (DHS) 2008: Data collection took place over a period of 5 months from June to October 2008. The 2008 NDHS sample was selected using a stratified two-stage cluster design consisting of 888 clusters, 286 in the urban and 602 in the rural areas. However, the final sample included 886 clusters instead of the 888 clusters as access to two clusters was hindered by floods and inter-communal disturbances respectively. A representative sample of 36,800 households was selected for the 2008. In the second stage of selection, an average of 41 households was selected in each cluster, by equal probability systematic sampling. Of the 34,644 households found, 34,070 were successfully interviewed [NPC, 2009].

Malaria Indicator Survey (2010): Data collection took place over a period of 3 months between October and December 2010. The 2010 NMIS sample was selected using a stratified, two-stage cluster design consisting of 240 clusters, 83 in the urban areas and 157 in the rural areas. However, the final sample included 239 clusters since access to one cluster was prevented by inter-communal disturbance. Within each state, the number of households was distributed proportionately among urban and rural areas. A total of 6,197 households were selected, and of these 5,986 were occupied. Of the occupied households, 5,895 had occupants who were successfully interviewed [NPC et al., 2012].

Malaria Anthropometric Baseline Assessments (MABA) 2011: Data collection took place over a one-month period, from July to August 2011. The survey was conducted in the first group of seven LGAs out of the 113 LGAs that are targeted for scale-up implementation. These LGAs were among LGAs considered to have significant challenge in meeting some or all of the MDGs. These seven selected LGAs, namely: Ukwuani, Song, Nwangele, Kuje, Miga, Wushishi and Akoko-North East represent different geographical areas of the country. An additional seven LGAs outside of the intervention area were selected to serve as comparison areas for future impact assessment. Potential LGAs to serve as comparison LGAs to the seven selected LGAs were identified from each of the seven states where the first group of LGAs were selected for intervention. The selection criteria were as follows: 1) LGAs with higher socioeconomic status,

higher population size, and LGAs that have common border with either of the 113 LGAs were excluded from the potential control LGAs; 2) matching of the potential control and intervention LGAs using state, socio-economic status, and malaria prevalence (from MARA map). The seven comparison LGAs include Fufore, Bomadi, Gwagwalada, Orlu, Birniwa, Katcha and Akure North. Sampling was conducted in two stages, one at the LGA level, and another at the household level. During the first stage sampling, Enumeration Areas were selected randomly with Probability-Proportional-to-Size (PPS) from each of the 14 study LGAs. A total of 20 EAs (clusters) were selected randomly with probability-proportional-to-size of the EAs. In the second stage sampling, households were selected randomly from the selected EAs. Twenty-four (24) households were selected randomly from each cluster. A total of 6,818 households were surveyed in the 14 LGAs sampled from seven states. 3,148 households were sampled from the intervention LGAs and 3,400 households from the control LGAs [NMCP & NPHCDA, 2011].

C. 2. Bayesian geo-additive regression models

The presentation of ITN coverage data is often limited only to the lowest sampling precision estimates of national surveys, states in the case of Nigeria. Here, we use the properties of intervention coverage at geo-coded cluster levels combined data within a regression framework using a geo-additive semi-parametric mixed model constructed within a Bayesian framework [Kammann & Wand, 2003]. Here, we use a fully Bayesian approach based on Markov priors that uses MCMC techniques for inference and model checking [Fahrmeir & Lang, 2001; Lang & Brezger, 2004] where the classical linear regression model is formulated as follows

$$y_i = w_i'\gamma + \varepsilon_i, \qquad \varepsilon_i \sim N(0, \sigma^2), \qquad \text{(Equation C.1)}$$

for observations $(y_i, w_i), i = 1, ..., n,$ on a response variable *y* and a vector *w* of covariates assume that the mean $E(y_i | w_i)$ can be modeled through a *linear predictor* $w_i'\gamma$. In our application to ITN coverage no covariate was used. The geographical small-area information was given in form of a location variable *s*, indicating the areal unit to which predictions of ITN coverage are to be made. In our study, this geographical information is given by state of Nigeria. Attempts to include such small-area information using district-specific dummy-variables would in our case entail more than 100 dummy-variables and using this approach we would not assess spatial inter-dependence. The latter problem cannot also be resolved through conventional multilevel modeling using uncorrelated random effects [Goldstein, 1999]. It is reasonable to assume that areas close to each other are more similar than areas far apart, so that spatially correlated random effects are required.

To overcome these difficulties, we replace the strictly linear predictor through a *geo-additive predictor*, leading to the *geo-additive regression model*

$y_i = f_{spat}(s_i) + \varepsilon_i$ (Equation C.2)

here, f_{spat} is the effect of the spatial covariate $s_i \in \{1,...,S\}$ labelling the state in Nigeria. Regression models with predictors as in (A.2) are sometimes referred to as geo-additive models. The observation model (A.2) may be extended by adding $f_1,...,f_p$, which are non-linear smooth effects of the metrical covariates or including interaction $f(x)w$ between a continuous covariate x and a binary component of w, say leading to so called varying coefficient models, or by adding a nonlinear interaction $f_{1,2}(x_1, x_2)$ of two continuous covariates.

In a Bayesian approach unknown functions f_j and parameters γ as well as the variance parameter σ^2 are considered as random variables and have to be supplemented with appropriate prior assumptions. In the absence of any prior knowledge we assume independent diffuse priors $\gamma_j \propto const, j=1,...,r$ for the parameters of fixed effects. Another common choice is highly dispersed Gaussian priors.

Several alternatives are available as smoothness priors for the unknown functions $f_j(x_j)$ [Fahrmeir & Lang, 2001; Fahrmeir et al., 2004]. We use Bayesian (Penalized) – Splines, introduced by Eilers and Marx in a frequentist setting. It is assumed that an unknown smooth function $f_j(x_j)$ can be approximated by a polynomial spline of low degree. The usual choices are cubic splines, which are twice continuously differentiable piecewise cubic polynomials defined for a grid of k equally spaced knot p on the relevant interval $[a,b]$ of the x-axis; written in terms of a linear combination B-spline basis functions $B_m(x)$,

$$f(x) = \sum_{m=1}^{l} \beta_m B_m(x) \qquad \text{(Equation C.3)}$$

These basis functions have finite support on four neighbouring intervals of the grid, and are zero elsewhere. A comparably small number of knots (usually between 10 and 40) is chosen to ensure enough flexibility in combination with a roughness penalty based on second order difference of adjacent B-spline coefficients to guarantee sufficient smoothness of the fitted curves. In our Bayesian approach this corresponds to second order random walks

$$\beta_m = 2\beta_{m-1} - \beta_{m-2} + u_m, \qquad \text{(Equation C.4)}$$

with Gaussian errors $u_m \sim N(0,\tau^2)$. The variance parameter τ^2 controls the amount of smoothness, and is also estimated from the data. More details on Bayesian P-Splines can be found in Lang and Brezger (2004). Note that random walks are the special case of B-Splines of degree zero.

For the spatially correlated effect f_{str} (s), s = 1, … S, we have chosen Markov random field priors common in spatial statistics [Besag et al., 1991]. These priors reflect spatial neighbourhood relationships. For geographical data one usually assumes that two sites or regions s and r are neighbours if they share a common boundary. Then a spatial extension of random walk models leads to the conditional, spatially autoregressive specification

$$f_{str}(s) \mid f_{str}(r), r \neq s \sim N(\sum_{r \in \partial_s} f_{str}(r) / N_s, \tau^2 / N_s) \quad \text{(Equation C.5)}$$

where N_s is the number of adjacent regions (states), and $r \in \partial_s$ denotes that region r is a neighbour of region s. Thus the (conditional) mean of $f_{str}(s)$ is an average of function evaluations $f_{str}(s)$ of neighbouring regions. Again the variance τ^2_{str} controls the degree of smoothness. For a spatially uncorrelated (unstructured) effect f_{unstr} a common assumption is that the parameters $f_{unstr}(s)$ are i.i.d. Gaussian

$$f_{unstr}(s) \mid \tau^2_{unstr} \sim N(0, \tau^2_{unstr}) \quad \text{(Equation C.6)}$$

Variance or smoothness parameters τ^2_j, $j=1,...,p, str, unstr,$ are also considered as unknown and estimated simultaneously with corresponding unknown functions f_j. Therefore, hyper-priors are assigned to them in a second stage of the hierarchy by highly dispersed inverse gamma distributions $p(\tau^2_j) \sim IG(a_j, b_j)$ with known hyper-parameters a_j and b_j. For model choice, we routinely used the Deviance Information Criterion (DIC) as a measure of fit and model complexity [Spiegelhalter et al., 2002].

C.3 Model selection

The spatial effects were modelled through the Markov random field prior (MRF) with penalized splines (P-spline) with second-order random walk penalty. With MRF prior, it was possible to predict ITN coverage in states with no coverage data based on information of neighbouring states. Two model formulations were explored: a spatial model with state as random effect and with MRF priors (Model A); and geo-spline model with weights applied as inverse proportional to the distance of the centroids of neighbouring states (Model B). Table C.1. summarises the comparison of the DIC and prior sensitivities for the two models.

Table C.1 Summary of the DIC & sensitivity analysis of the choice of spatial priors for model selection

Hyper-parameters	Year	Diagnostics	Spatial (A) With MRF	Spatial (B) With geo-spline
a=1, b=0.005	2000	Deviance	1014.6	1017.3
		pD	10.1	9.8
		DIC	1034.8	3563.1
a=1, b=0.005	2010	Deviance	357.8	360.9
		pD	49.2	44.8
		DIC	456.2	450.5

Models with asterisks (*) is the best.

The results indicate for the year 2000 Model A (albeit without ITN per capita) was most accurate and for 2010 and 2012 the geo-spline provided the best fit (Model B). In addition to

the sensitivity analysis (Table A.2.1), the standard deviations (SD) of the mean ITN coverage predictions per district were computed for each year with higher values of the SD indicating greater uncertainty (Figure C. 1).

C.4 References

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Figure C.1: standards deviations of mean ITN coverage predictions in Nigeria for the years: a) 2000; b) 2008; c) 2010/11