Epidemiology and control profile of malaria in

Senegal

PNLP

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Abbreviations

ACT	Artemisinin Combination Therapy
ADB	African Development Bank
AJOL	African Journals Online
AL	Artemether-Lumefantrine
AQ	Amodiaquine
AS-AQ	Artesunate-Amodiaquine
BIC	Bayesian Inference Criteria
CAP	Center of Poison Control (Centre Anti-poison)
CCPLP	Consultation Framework of Partners against Malaria (Cadre de Concertation des Partenaires de la Lutte contre le Paludisme)
CDC	Centers for Disease Control and Prevention
CDMO	Chief District Medical Officer (Médecin Chef de District, MCD)
CHW	Community Health Worker (Agent de Santé Communautaire, ASC)
CME	Medical Commission of the Health facility (Commission Médicale de l'Etablissement)
CQ	Chloroquine
CRDT	Constrained Refined Delaunay Triangulation
CRMO	Chief Regional Medical Officer (Médecin Chef de Région, MCR)
CS	Health Centre (Centre de Santé)
CSR	Referral Health Centre (Centre de Santé de Référence)
CTE	Technical Committee of the Facility (Comité Technique de l'Etablissement)
DCW	Digital Chart of the World's Populated Places
DDT	Dichloro Diphenyltrichloroethane
DFID	Department for International Development (UK)
DHA-PQ	Dihydroartemisinine- Piperaquine
DHS	Demographic and Health Surveys
DPM	Directorate of Pharmacy and Drugs (Direction de la Pharmacie et des
DRC	Democratic Republic of Congo
DSISS	Division of Social and Health Information System (Division Système d'Informations Sanitaires et Sociales)
DSDOM	In-house malaria treatment provider (Dispensateur de Soins à Domicile)
DVS	Dominant Vector Species
ESIA	Environmental and Social Impact Assessment
ETM+	Enhanced Thematic Mapper
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FDA	Focal drug administration (Traitement focalisé de médicaments)
FEM	Fine Element Method
FIND	Foundation for Innovative New Diagnostics
GAUL	Global Administrative Unit Layers
GDP	Gross Domestic Product
GF	Gaussian Field
GFATM	Global Fund to fight AIDS, Tuberculosis and Malaria
GIS	Geographic Information Systems
GLWD	Global Lakes and Wetlands Database

GMP	Global Malaria Programme, WHO Geneva
GMRF	Gaussian Markov Random Field
GPS	Global Positioning Systems
GRF	Gaussian Random Field
GRUMP	Global Rural Urban Mapping Project
HDI	Human Development Indicators
HFDB	Health facility database
INFORM	Information for Malaria Project
INLA	Integrated Nested Laplace Approximations
IPT	Intermittent Presumptive Treatment
IPTp	Intermittent Presumptive Treatment in pregnancy
IRS	Indoor Residual Spraying
ITN	Insecticide Treated Nets
LEVP	Laboratory of Vectorial Ecology and Parasitic (Laboratoire d'Ecologie Vectorielle et Parasitaire)
LLINs	Long Lasting Insecticidal Nets
LNCM	National Laboratory for Drugs Control (Laboratoire Nationale de Contrôle des Médicaments)
MAPE	Mean Absolute Prediction Error
MARA/ARMA	Mapping Malaria Risk in Africa
mASL	Metres Above Sea Level
MBG	Model Based Geo-Statistics
MDG	Millennium Development Goals
MeSH	Medical Subject Headings
MICS	Malaria Indicator Cluster Survey
MIS	Malaria Indicator Survey (Enquête Nationale sur le Paludisme)
MODIS	MODerate-resolution Imaging Spectroradiometer
MPAC	Malaria Policy Advisory Committee
MPE	Mean Prediction Error
MPR	Malaria Programme Review
MSAS	Ministry of Health and Social Welfare (Ministère de la Santé et de l'Action Sociale)
NHDP-II	National Health Development Plan-II (Plan National de Développement Sanitaire -
NMCP	National Malaria Control Programme
NMSP	National Malaria Strategic Plan
OA	Open Access
ODA	Overseas Development Assistance
PA*Pf*PR$_{2-10}$	Population adjusted *Pf*PR$_{2-10}$
PCR	Polymerase Chain Reaction
PDP	Product Development Partnership
PECADOM	Prise En Charge A Domicile
*Pf*PR2-10	Age-corrected *Plasmodium falciparum* parasite rate
PMI	President's Malaria Initiative
PNA	National Supply Pharmacy (Pharmacie Nationale d'Approvisionnement)
PPP	Purchasing Power Parities
PRA	Regional Supply Pharmacy (Pharmacie Régionale d'Approvisionnement)
PS	Health post (Poste de Santé)
PSI	Population Services International

QAMSA	Quality of antimalarials in selected African countries
R&D	Research and Development
RBM	Roll Back Malaria
RDTs	Rapid Diagnostic Tests
SD	Standard Deviations
SMC	Seasonal Malaria Chemoprevention
SNAME	Système d'Approvisionnement en Médicaments Essentiels
SP	Sulphadoxine-Pyrimethamine
SPDE	Stochastic Partial Differential Equations
SRTM	Shuttle Radar Topography Mission
TSI	Temperature Suitability Index
UCAD	University Cheikh Anta Diop of Dakar
UN	United Nations
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development
WHO	World Health Organization

1. Introduction

The use of malariometric data, maps and epidemiological intelligence was a routine feature of control planning across most African countries during the Global Malaria Eradication Programme (GMEP) era from the mid-1950s. Data included epidemiological descriptions of transmission, vectors, topography and climate. More than 50 years ago the infection prevalence among children aged 2-10 years (P*f*PR2-10) was recognised as one important source of planning data and used to define categories of endemic risk designed. These were used to guide and monitor progress toward malaria elimination targets.

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 specialised, integrated primary care mandate focused on managing fevers. In 1996, a plea was made for better malaria cartography to guide malaria control in Africa[1,2] and over the last decade there has been enormous growth in spatial data on malaria and populations which was not available to malariologists or programme control managers 60 years ago. The growth in data has been accompanied by the development of statistical approaches to model and map risk and intervention access in space and in time using Model Based Geostatistics (MBG).[3]

At the launch of the Roll Back Malaria (RBM) partnership, 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.[4,5] A decade on, the international donor community is constrained by the global financial crisis; accessing overseas development assistance (ODA) and using limited national domestic funding for malaria control now requires a much stronger evidence-based business case. These future business cases must be grounded in the best possible epidemiological evidence to predict the likely impact of future intervention, assess the impact of current investment and, equally important, demonstrate what might happen should funding and intervention coverage decline.

This epidemiological profile of malaria in Senegal attempts to assemble a brief history of malaria control in Senegal and the epidemiological evidence base for a more targeted approach to malaria control. It draws together data on parasite transmission risk from household surveys, malaria cases from routine systems, the distribution of dominant vector species and coverage of insecticide-treated mosquito nets (ITN). This information is described by health district, and could inform the planning of targeted sub-national control efforts to accelerate progress towards the targets specified in the national malaria strategic plan.

1 Snow RW, Marsh K, le Sueur D (1996). The need for maps of transmission intensity to guide malaria control in Africa. *Parasitology Today*, **12**: 455–457.
2 Snow RW and Noor AM (2015). Malaria risk mapping in Africa: The historical context to the Information for Malaria (INFORM) project. Working Paper in support of the INFORM Project funded by the Department for International Development and the Wellcome Trust, Nairobi, Kenya June. http://www.inform-malaria.org/wp-content/uploads/2015/07/History-of-Malaria-Risk- Mapping-Version-1.pdf Accessed 30 March, 2017.
3 Diggle PJ and Ribeiro PJ (2007). *Model-Based Geostatistics*. New York: Springer.
4 World Health Organization (2000). The Abuja Declaration and the Plan of Action. An extract from the African Summit on Roll Back Malaria, Abuja, 25 April 2000 (WHO/CDS/RBM/2000.17).
5 Snow RW, Amratia P, Kabaria CW, Noor AM, Marsh K (2012). The changing limits and incidence of malaria in Africa: 1939- 2009. *Advances in Parasitology*, **78**: 169–262.

2. Country context

2.1 Geography and population

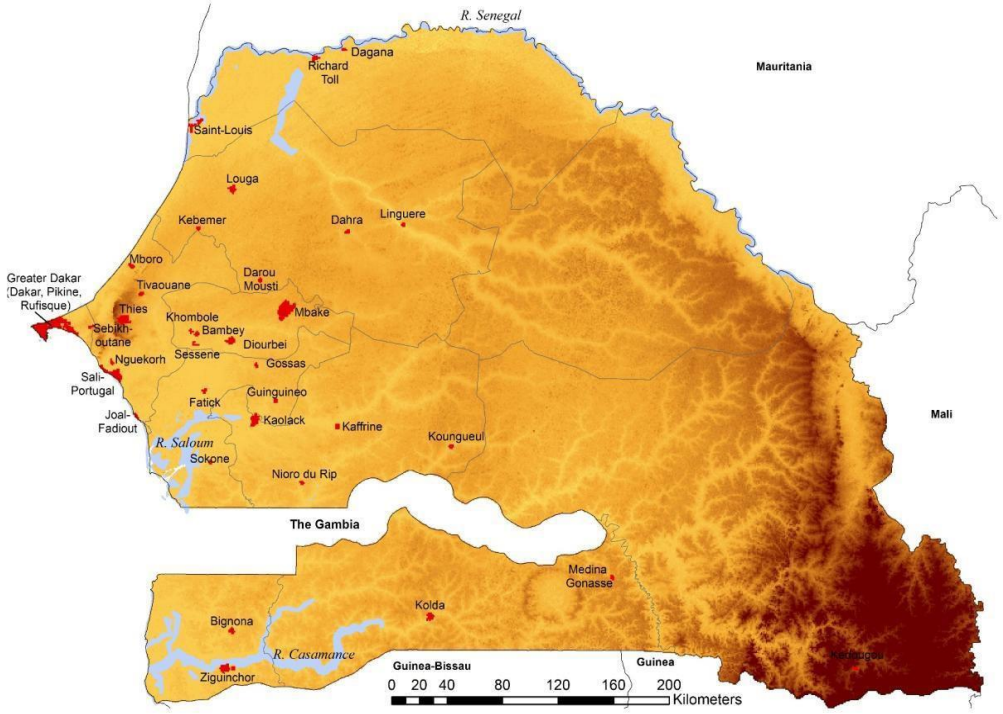
Senegal is the western-most country in sub-Saharan Africa, situated in the northern hemisphere (between 12° 30 and 16° 30 North, 1° 30 and 17° 30 West), with a land mass of 196,772 square kilometres and a population of approximately 13 million. Senegal shares land borders with Mauritania in the north, Mali in the east, Guinea and Guinea Bissau in the south, and is bounded to the west by its 700 km coast along the Atlantic Ocean. Senegal almost completely envelops The Gambia, between the regions of Kaolack, Kaffrine and Tambacounda on the north, and Ziguinchor, Sedhiou and Kolda in the south, along the lower course of the River Gambia.

Senegal is a flat country, its altitude rarely over 100 m (Figure 2.1). The Assiriki Hill, in the south-east, has a height of 381 m. The country is crossed from east to west by four rivers – Senegal, Gambia, Casamance and Saloum. This network is complemented by temporary streams and Lake Guiers in the north. The development of dams such as the Diama,Affiniam and Anambé dams, as well as the micro-dams of the southern regions, support irrigation and prevent saltwater intrusion. However, they also provide an ecological setting that encourages the year-round emergence of malaria vectors.

From three million inhabitants in 1960, the population grew to 13.9 million in 2014. The total population is growing by more than 260,000 people per year, (2.7%), although recent decades have seen a net migratory flow of 20,000 departures per year. According to 2014 estimates, 55% of the population lives in rural settings and nearly two-thirds are under the age of 25.

The overall population density is 70 inhabitants per square kilometre, with lower densities in the east and higher densities towards the coast (Figure 2.1). The highest populations are found in the regions of Dakar, Thiès and Diourbel with, respectively 3,139,325 (23.2 % of the total population), 1,789,923 (13.3 %) and 1,499,867 (11.1 %) inhabitants. Kedougou region has the lowest population size with 151,715 inhabitants (1.1%). Tambacounda, which represents the largest region (21.5% of the country's land mass), accounts for only 5% of the population. The country is divided into three climatic zones of high, medium and low rainfall, corresponding to the forest in the south, the tree savannah in the centre and the desert area in the north, respectively. The central region has a dry season from November to June and a rainy season from July to October.

Figure 2.1 Extents of major Senegalese rivers, cities and towns, and their elevation



Population distribution predictions for the year 2010 were derived from the population products shown in Figure 6.3 (see Section 6). The population distribution provided at 100 m spatial resolution was resampled in ArcGIS (ver10.1 ESRI, USA) to obtain population density per km^2. A population density threshold of greater than 1000 persons per km^2 was used to identify urban settlements, a threshold found to significantly influence malaria prevalence (C Kabaria, personal communication). Polygons covering an area greater than 5 km^2 with population density across the polygon of >= 1000 people per km^2 were selected. These were then matched to a place name gazetteer of Senegal (www.geonames.nga.mil/gns/) to identify 34 major urban settlements shown in the figure. These include Bambey, Diourbel, Khombole, Mbacke, Sessene (Diourbel region), Fatick, Gossas, Guinguineo, Sokone (Fatick region), Kaffrine, Kaolack, Koungheul, Nioro du Rip (Kaolack region), Kolda and Medina Gounass (Kolda region), Dahra, Darou Mousty, Kebemer, Linguere, Louga (Louga region), Dagana, Saint-Louis, Richard Toll (Saint-Louis region), Kedougou (Tambacounda region), Joal-Fadiout, Mboro, Nguekokh, Thies, Saly-Portudal, Thies, Tivaouane (Thies region), Bignona and Ziguinchor (Ziguinchor region), Greater Dakar (Dakar, Pikine, Rufisque) and Sebikhoutane (Dakar region).

Digital elevation from sea level (light brown) to maximal elevation of 564 m above sea level (dark brown).

Goree island is one of the 19 *communes d'arrondissement* of the city of Dakar located 2 km from the main harbour of Dakar; its official population in 2005 was 1,056 inhabitants; Morfil (Ivory Island) lies between the River Senegal and the Doué River in northern Senegal and has two main towns, Podor and Salde.

References

30m ASTER DEM: www.asterweb.jpl.nasa.gov/gdem

Rivers from Global Lakes and Wetlands Database: GLWD; www.worldwildlife.org/ GLWD

2.2 Administration and policies

Senegal is a democratic country ruled by a president. The president appoints the prime minister who is responsible for conducting the government's action plan. The National Assembly comprises 150 deputies elected for five year periods and is mandated to make laws and ensure their enforcement.

In order to bring public services closer to the population, and to accelerate development processes, the country adopted policies of decentralisation in the 1990s which increase political and management authority in sub-national administrative levels such as regions, cities and towns. Cities and towns are led by elected mayors who, together with their executive boards, are able to generate and manage resources for the benefit of their territory.

The adoption of the Millennium Development Goals (MDGs) in 2000 catalysed serial reforms by the government of Senegal. This led to radical shifts in policy vis-à-vis the social sectors. Policies were developed in the context of the poverty reduction strategy to reduce the deleterious effects of internal and external shocks on the economy, in particular for vulnerable groups. Policies aimed to eradicate extreme poverty and hunger, promote universal access to basic education, enhance the quality of primary care to reduce infant and maternal mortality, promote gender equality, empower women, and improve access to safe drinking water.[6]

Monetary poverty – defined as the proportion of the population living on less than $1 (PPP) per day[7] – decreased from 55.2% to 48.7% between 2001-2002 and 2005-2006, and was 46.7% in 2011. Rural populations, where 57.1% live in monetary poverty, are generally worse off than populations in Dakar (26.1% in poverty) and other cities (42.1%).

The government's social and economic development model is articulated in its Emerging Plan for Senegal (*Plan Sénégal Emergeant* - PSE) which sets targets for 2035. The emphasis is on jobs and welfare creation, the strengthening of governance, the development of strategic sectors which will improve population wellbeing, especially through the protection of vulnerable groups and by ensuring access to essential services.[8]

2.3 The health system

2.3.1 Health system structure

The Ministry of Health is responsible for health policy and prioritisation. It develops national health guidance and policies and is responsible for their implementation and for monitoring their progress. It is also responsible for providing the necessary materials, equipment and training for health staff to fulfil their responsibilities.

The public health system is arranged as a three tiered structure: hospital level; health centre (*Centre de Santé*) level and health post (*Poste de Santé*) level. Although the rural health

6 Diagne A, Cabral FJ, Cisse F (2011) Assessing Development Strategies to Achieve the MDGs in Senegal. UN Department of Economics and Social Affairs. March
7 International Development; Monetary Approach; http://internationaldevelopment.wikia.com/wiki/Monetary_Approach Accessed 30 March, 2017.
8 Ministry of Health (2014). National Strategic Framework for 2014–2018: 8

points/huts (*Case de Santé*) are not generally considered part of the formal heath system they are nevertheless supported by it.

The central level is made up of two important directions of the MSAS: the General Directorate of Health and the Directorate of Social Welfare. The National Malaria Control Programme (NMCP) is under the General Directorate of Health, which in turn is under the direction of Disease Control. There are 14 health regions, corresponding to the administrative regions. Each health region is headed by a Chief Regional Medical Officer (CRMO or *Médecin-Chef de Région*, MCR) who manages the regional health team made up of the supervisors of the various programs. The health regions oversee implementation of the health programmes and the management of public and private facilities in the region. Hospitals report to the regional authorities. In 2012, the country had 35 hospitals, each with a board of trustees, a director and two advisory bodies: the Medical Commission of the Facility (*Commission Médicale de l'Etablissement - CME*) and the Technical Committee of the Facility (*Comité Technique de l'Etablissement – CTE*)[9] The country has two university hospitals (CHNUs) offering teaching facilities for doctors and referral facilities for regional hospitals (CHRs).

Under the health regions are the 76 health districts, which may or may not match the administrative districts. These are managed by a Chief District Medical Officer (CDMO, known locally as *Médecin Chef de Distric*t, MCD) and practice medicine in its four dimensions: treatment, prevention, social and educative. Each health district has at least one health centre (89 in total). Health centres are the highest level of the rural healthcare system, staffed by one or two medical doctors, and 15-20 health staff. District health centres provide first-level referrals and limited hospitalisation services with between 10 to 20 beds.

Below the health centres is a network of health posts (1,247 in total). These typically have four or five health workers with no medical doctor and provide both preventive and primary curative services, such as care for chronic patients (tuberculosis patients), prenatal care, family planning, and health promotion/education activities. Health posts supervise the health huts (2,162 in total) and rural maternity homes (129). The provision of health care at the community level has been developed during the last three decades and consolidated through the National Strategic Plan for Community Health.[10] Rural health huts are managed by local communities and usually staffed by one or two trained *Agent de Sante Communautaire* or community health workers (CHWs), matrons (trained birth attendants) and *relais*, who are health educators and communicators. Malaria prevention activities, case management and other interventions for child survival are delivered through the health huts.

In villages where there is no health hut or other health facility, the NMCP has trained home-based health care providers (DSDOM) who are responsible for home-based malaria case management. There were 1,992 DSDOM in 2015, of whom 515 were trained not only in malaria case management but also to deal with Acute Respiratory Infections and diarrhoea in children under 5 years old. Referral and counter- referral mechanisms have been established to facilitate case management and to ensure the transfer of health information between the peripheral level (including health centres and health posts) and hospitals and other facilities.

Health care provision is mainly carried out by the public sector but complemented by the private sector, which is loosely integrated into the implementation of the national health programmes'

9 Government of Senegal Decree No. 98-701.
10 Senegal: Ministere de la Sante et de l'Action Sociale (2014). Direction Generale de la Sante. Plan Strategique de Sante Communautaire 2014–2018

policies. In 2001, 58% of the population was estimated to live at less than 30 minutes away from a health facility (health post or higher), but these figures vary across the country – 80% in urban areas, 42% in rural settings. Approximately one-third of the population was living less than 5 km away from a health post or higher facility.

2.3.2 Health context and priorities

The priority objectives of the second National Health Development Plan (NHDP-II, 2009-2018) and the operational plan for 2014-2018 include the reduction of maternal and child mortality, the control of fertility and increased access to basic services for the poor.[11] These are being achieved by work to:

- guarantee access to quality health care for the whole population, regardless of socio- economic status
- deepen decentralisation and local health governance
- promote health insurance coverage
- ensure the protection of vulnerable groups
- strengthen private-public partnership
- promote multi-sectorality in health
- align external assistance and support to national health priorities
- grow the results-based management mechanism

In 2011 the all-cause mortality rate in children under five years was 72 deaths per 1000 live-births, and maternal mortality was 392 deaths per 100,000 live-births.[12] The major causes of morbidity in Senegal are infectious diseases. In 2011, malaria was estimated to account for 6.1% of all morbidity and 11% of all mortality.[13]

The DHS-MICs 2010-2011 drew attention to other important causes of morbidity. In the week before the surveys 5% of children under five were estimated to have suffered an Acute Respiratory Infection (ARI), 21% a diarrheal disease and 18% were found to be underweight. In 2011, HIV prevalence in the general population was 0.7% and the incidence of tuberculosis was 85.7 new cases per 100,000 inhabitants.

2.3.3 Progress with malaria control in Senegal

Malaria transmission occurs during the rainy season and the first month of the dry season, when densities of the vector populations are high. Malaria is unequally distributed across the country and according to socio-demographic as well as ecological determinants.

Overall malaria risk has declined in Senegal between 2008 and 2014. Large-scale household surveys (e.g. Demographic and Health Surveys [DHS][14] Malaria Indicator Surveys [MIS]) found 5.9% of children under five years infected with *P falciparum* in 2008, falling to 1.2% in 2014. The prevalence of infection varies across the regions, with higher figures (up to 5.9%) in southern regions (Ziguinchor, Tamba, Sédhiou, Kolda, Kédougou), intermediate figures (0.3%)

11 Continuous Demographic and Health Survey (2012). http://dhsprogram.com/what-we-do/survey/survey-display-423.cfm Accessed 30 March, 2017.
12 Senegal: 2013 Annual Health Statistics. https://www.measureevaluation.org/his-strengthening-resource-center/resources/national-health-statistics-report-annual Accessed 30 March, 2017.
13 Senegal: Special NMCP Statistics Report for 2010-2013: 3–4
14 Demographic and Health Surveys. http://www.dhsprogram.com/data/available-datasets.cfm Accessed 15 March, 2017.

in central regions (Diourbel, Kaolack, Fatick, Kaffrine) and the lowest values in western (Dakar, Thiès at 0.2%) and northern regions (0.1% in Louga, Saint Louis and Matam).

Progress with control is not expected to be homogeneous and it will become increasingly important to understand variations in malaria epidemiology with greater spatial resolution. The DHS and other nationally representative household surveys are designed to be representative at the regional level. However, the operational unit for malaria control is the district and ensuring the availability of key information on malaria risk at this level will become increasingly important.

As disease risk falls the efficiency and utility of household surveys to monitor progress with transmission reduction will also fall. At some levels of transmission, it will become important to monitor case incidence, and then absolute case numbers. This will depend on the reliable capture and forwarding of data on parasitologically confirmed malaria cases presenting to health facilities.

3. Structure and function of the National Malaria Control Programme (NMCP)

The National Malaria Control Programme (NMCP) coordinates malaria control and ensures the development and implementation of annual work plans. It ensures information sharing with stakeholders and develops and disseminates reports on activities carried out in collaboration with partners. The NMCP is responsible for resource mobilisation and advocacy.[15] The NMCP is made up of the programme manager and the deputy programme manager, assisted by a secretariat and supported by a number of officers heading units set up to deal with each type of intervention and critical activity.

The NMCP performs its mission in collaboration with financial and technical partners, as well as representatives from collaborating units in the Ministry of Health and Social Welfare (MSAS) and other ministries, research and training institutes, regional and medical district personnel and other stakeholders. The medical regions coordinate implementation and follow-up activities and oversee health districts' performance. The health district plans and implements specific malaria control activities and supervises front-line staff.

To better involve and coordinate partners in the national fight against malaria, a consultation framework for the partners' fight against malaria (CCPLP) has been established[16] Its mission is to participate in progress monitoring through data analysis in order to identify bottlenecks and suggest solutions; make suggestions on strategic directions, taking into account the new changes occurring in the fight against malaria in the country; participate in the mobilisation of resources for the implementation of activities; and participate in partners' information updates relevant to malaria control. The CCPLP also provides a decision making framework.

3.1 Financing malaria control

The share of the government budget allocated to health has steadily increased in recent years, from XOF 36 billion (US$ 72 million) in 1998 to XOF 90.5 billion (US$ 181 million) in 2008, and XOF 105.9 billion (US$ 212 million) in 2011 to XOF 110.5 billion (US$ 220 million) in 2012. This figure represents 10.4% of the government's operating budget.[17]

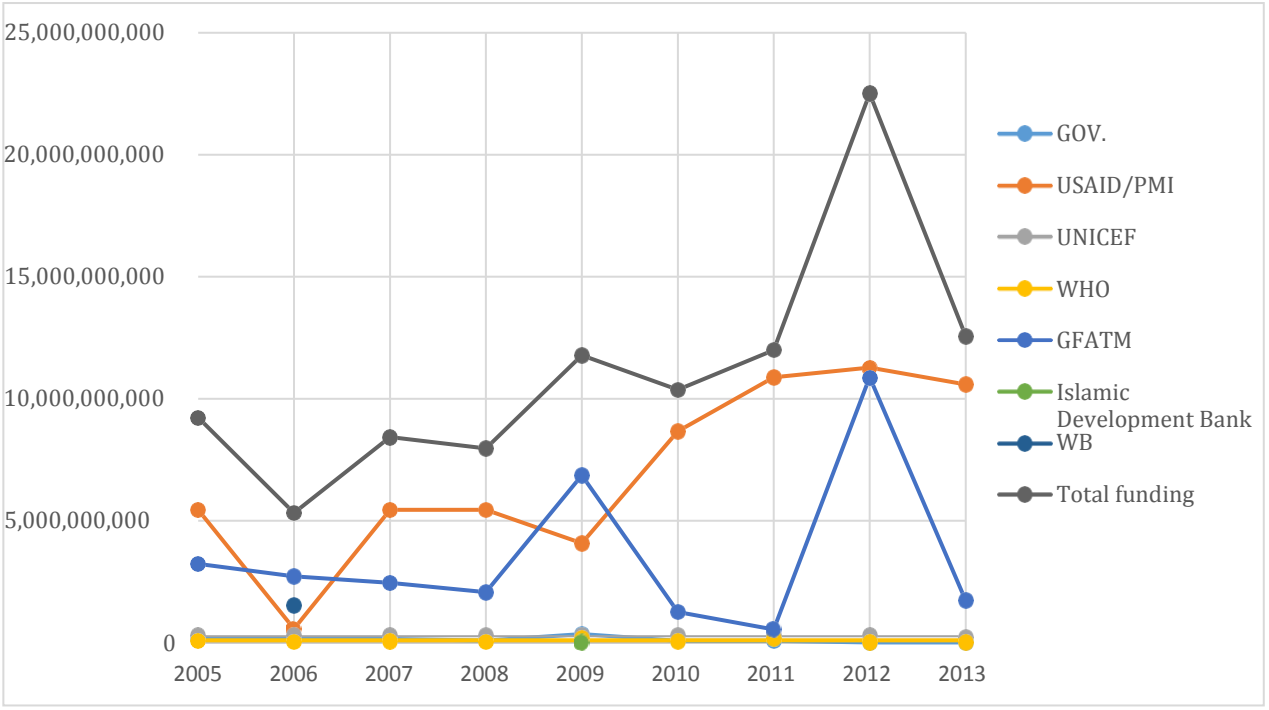
Domestic investment in malaria control averaged XOF 120.9 million per year between 2005 and 2013, equivalent to 0.12% of the total health budget. Absolute investments ranged from a low of XOF 13.7 million in 2012 to XOF 357 million in 2009, an almost 30-fold variation. These figures should be treated with caution: there is a need for greater clarity over investments in malaria and, in particular, agreement on how the costs of the personnel and infrastructure required for the supply and prescription of malaria - but also other, non-malaria conditions - at all levels of the health system, should be apportioned to malaria control.

Total funding to Senegal's NMCP rose from XOF 9.22 billion in 2005, through a high of XOF 22.51 billion in 2012 to XOF 12.57 billion in 2013[18] (Figure 3.1). The main external contributors

15 Making Malaria History. Lutte contre le paludisme au Sénégal: Histoire d'un partenariat réussi. http://www.makingmalariahistory.org/educate-and-advocate/senegal-media-gallery/french-introla-lutte-pour-des-communautes-sans-paludisme-au-senegal/ Accessed 12 March, 2017
16 Ibid.
17 Demographic and Health Survey (2012): p18
18 Average conversion rate used: USD/XOF = 500

have been President's Malaria Initiative (PMI)/USAID and the Global Fund, with steady support from UNICEF and contributions from WHO, the World Bank and the Islamic Development Bank.

Figure 3.1 Financial contributions to malaria control in Senegal 2005-2013 (Data source: Senegal's National Strategic Framework for Malaria 2014–2018)



The enhanced funding has enabled the NMCP to step up the implementation of the activities outlined in the two strategic plans and to intensify its activities to expand the coverage of key malaria interventions. Significant progress has been achieved in intervention coverage and access to malaria case management and prevention between 2005 and 2015 countrywide. Activities are described in detail in Section 5 but some key accomplishments include:

- The roll out of RDTs and ACTs across the country, and down to the community level through PECADOM. This home-based malaria management scheme initially provided RDTs and ACTs to 20 villages affected by a high parasite prevalence but with poor access to health facilities; the programme has been expanded to 1,962 villages in 61 health districts; Artemisinin-based monotherapies have been prohibited in an effort to retard the development and spread of artemisinin resistance (2010)[19]
- Subsidised ITNs were introduced in 2006 free LLIN distributions were subsequently introduced (in 2008) for under-five year olds in six regions before the first national mass free distribution campaign of LLINs for children aged six to 59 months in 2009. Universal coverage distribution began in 2010, initially covering the southeast and, progressively, the entire country by 2013.

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19 Making Malaria History. Lutte contre le paludisme au Sénégal: Histoire d'un partenariat réussi. http://www.makingmalariahistory.org/educate-and-advocate/senegal-media-gallery/french-introla-lutte-pour-des-communautes-sans-paludisme-au-senegal/ Accessed 12 March, 2017

- IRS has been implemented in a total of seven health districts.
- Sentinel sites were established to monitor progress with malaria control.

However, the strong dependency on external partner contributions represents a risk to sustainability.

3.2 Supply chain overview

A major reform of the national supply chain management was initiated in 2010. The national supply system for drugs and health products depends primarily on the National Supply Pharmacy (PNA), which is responsible for the procurement of drugs and other health products for the public sector. It is a non-clinical, parastatal public health establishment under the supervision of the MSAS but with management autonomy. It is governed by the public contracts code and uses international competitive tenders for drugs and supplies procurement.

The PNA distributes commodities through its regional warehouses – Regional Supply Pharmacy (PRA) – and has recently set up mobile supply warehouses for regions without a PRA. The central warehouse of the PNA distributes supplies to PRAs, which in turn supply peripheral structures (health districts, regional hospital and other health structures). District warehouses resupply from PRAs, and supply health posts, health huts and PECADOM sites. The PNA is responsible for distribution of commodities from the national to regional level warehouses. Health structures at the peripheral levels in the system, such as health posts, submit stock requisitions to district health/stock personnel to express their commodity needs. Districts aggregate health facility data and send those to the PRA. The PRA prepares supplies which, when ready, are collected by the district. Each service delivery point is responsible for collecting their respective supplies from the district stockists.

The NMCP has a memorandum of understanding with the PNA through which the storage and distribution of malaria commodities (ACTs and RDTs) is managed. Due to the logistics of managing very large quantities of LLINs, private transporters, and occasionally the army, assists with storage and transport of nets. LLINs are distributed to the population through two main approaches: (i) mass campaigns for their free distribution and (ii) routine distribution, based on the demand of clients, through multiples channels. This includes free distribution for pregnant women and with subsidised costs for the rest of the population, free distribution in schools, and subsidised distribution through community based organisations, private pharmacies and grocery stores. Private pharmacies also supply malaria drugs. In mid-2013, 963 private pharmacies were recorded in Senegal but more than 62% of these were in the Dakar region. Private outlets play a limited role in the supply of malaria commodities to the target population.

Since the reform of the PNA, the availability of ACTs has increased (pre-reform 14%, post reform >90%).[20] In 2014, Rapid Diagnostic Tests (RDTs) were estimated to be available in more than 90% of health structures (excluding health huts), 98% of public sector facilities and 75% of private sector facilities. First-line ACTs for children, adolescents and adults were available in 86%, 61% and 70% of public health facilities above health hut level. The ACTs for children were available in just over half (53%) of the health huts. Availability of ACT in the private sector was lower than for the public sector with ACTs available for child, adolescent and adults in 47%,

20 Service Provision Assessment, Senegal (2014) http://dhsprogram.com/pubs/pdf/OF25/OF25.pdf Accessed 15 March, 2017.

35% and 41% of facilities, respectively. Mosquito nets for continuous distribution were available in nearly half of all facilities (47%).[21]

Quality assurance of products is the responsibility of the Directorate of Pharmacy and Drugs (DPM), the National Laboratory for Drugs Control (LNCM), and the national commission in charge of pesticides and chemical products management, located in the Ministry of Environment and Wildlife Protection. These institutions collect samples of procured commodities, including drugs, for quality assessments. While there is limited published research as to the quality of antimalarials in Senegal, WHO/QAMSA reported that 43% of antimalarial samples from Senegal did not meet requirements for visual inspection, identification, drug content or disintegration, with sulphadoxine-pyrimethamine (SP) beingthe most likely antimalarial to fail (2009).[22]

3.3 Drug and insecticide safety and efficacy monitoring

Malaria drug safety is monitored through national pharmacovigilance plan in collaboration with the DPM, started under a 2006 NMCP initiative. The safety of insecticides and LLINs is the responsibility of the Centre of Poison Control (CAP) which works to strengthen clinical toxicology.

A wide range of drug efficacy, tolerability and safety studies are carried out by the University Cheikh Anta Diop of Dakar (UCAD), and other research institutions. Since 2008, insecticide sensitivity testing has been undertaken by UCAD's Laboratory of Vector and Parasitic Ecology (LEVP)[23], with financial support from PMI/USAID. Surveillance includes sites in 23 districts across Senegal. Evaluations of the following insecticides have been carried out so far: deltaméthrine 0.05%, lambdacyhalothrine 0.05%, perméthrine 0,75%, DDT 4%, bendiocarb 0,1%, fenitrothion 1% (2008-14); alphacypermethrin (2013-14); cyfluthrin (2011-14); dieldrin, malathion 5% (2011-13) and primiphos-methyl (2012-13). While no resistance was recorded to primiphos-methyl - 100% sensitive across all 23 districts where it was tested in 2013 and 2014 - malathion 5%, and fenitrothion 1%, were respectively found sensitive in 13 out of 15, and in 13 out of 19 sites where they were tested between 2008 and 2014[24]

3.4 Data relevant for malaria control

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

The analyses presented here are based largely on data from cross-sectional household surveys and are described in detail in Section 4, overview of technical methods. Here we briefly describe the routine health information system and sentinel sites, and give examples of data generated through operational research.

21 Service Provision Assessment, Senegal (2014) http://dhsprogram.com/pubs/pdf/OF25/OF25.pdf Accessed 15 March, 2017.
22 WHO-USP (2009) Survey of the Quality of Selected Antimalarial Medicines Circulating in Madagascar, Senegal, and Uganda.
23 Laboratoire d'Ecologie Vectorielle et Parasitaire.
24 Insecticide resistance monitoring from 2008 to 2014. Excel sheet from PNLP.

3.4.1 Routine health information system

Data are routinely reported from public health facilities on a monthly basis. These include all health information – including that relevant to malaria – as well as information on human resources and equipment allocated by the government to health facilities. Data from health districts' datasets are aggregated and collated in a national database. Malaria data are collected from patients of all ages but analyses emphasise the most vulnerable groups: children under-five years and pregnant women.

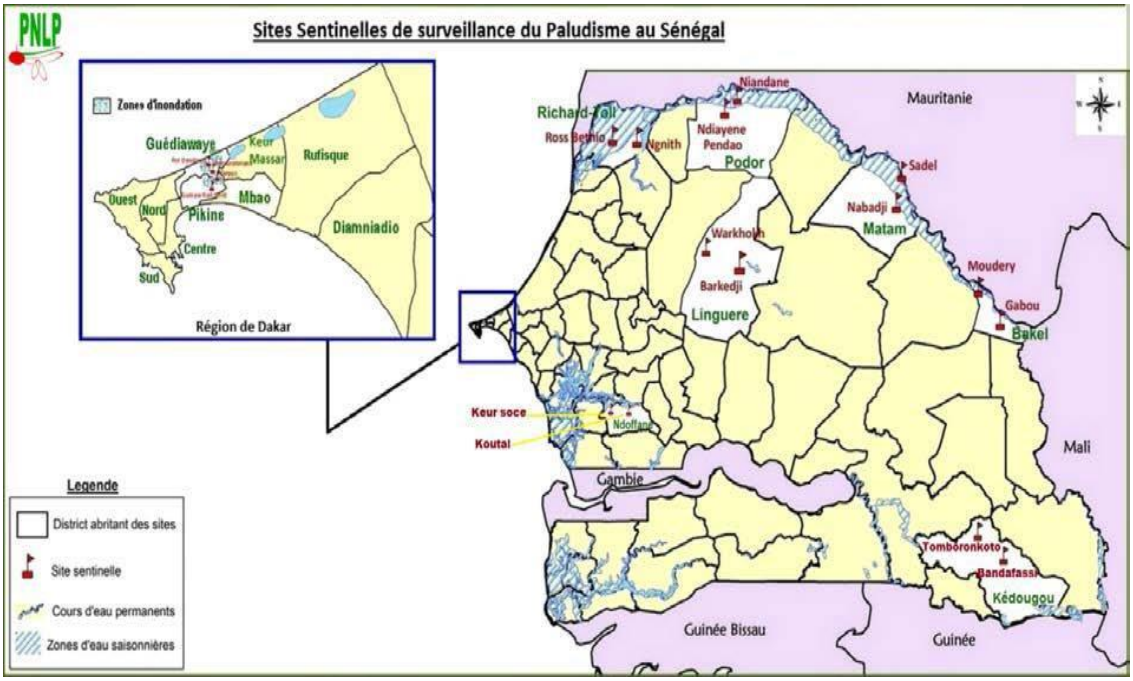
Malaria-relevant information reported through the health information system (HIS) includes data on mortality, morbidity, intermittent preventive treatment in pregnancy (IPTp), ACT and RDT stock management, and LLIN distribution. Though routine data are the most accessible, their quality, completeness, timeliness and reliability are variable. The NMCP has a parallel system that captures information on hospital mortality among children under five years and on malaria morbidity. This is through a database updated regularly using data sent quarterly by health officers from districts and hospitals. Members of district health management teams gather quarterly with NMCP members to submit, review, and validate routine data. During the quarterly reviews, data are submitted from all levels of the health system. On-site data consistency checks are performed to identify discrepancies among information in the records of health facilities and information in reports submitted to the intermediate and central levels.

In recent years, the MSAS and partners have made huge efforts to improve the availability and quality of routine data through the adoption and deployment of DHIS2. Roll-out is complete but work continues to ensure the quality of the information collected and the timeliness of data reporting. The NMCP is working with the DSISS tomerge the parallel systems and support the roll-out of the DHIS2 for weekly malaria case reporting. Ten districts currently report data weekly.

Sentinel sites

Sentinel sites for malaria surveillance started in 2008 with 10 sites in the north of the country. After 2010, due to heavy flooding in the Dakar region, six sites were added in Dakar, bringing the number of sites to 16 and then to 20 in October 2012 (Figure 3.2). The surveillance is undertaken in 10 health districts spanning seven regions, corresponding to the various malaria risk strata in the country. The sentinel sites generate data required for the assessment of malaria trends, including parasitological, entomological and environmental parameters, drug and insecticide resistance

Figure 3.2 Malaria surveillance sentinel sites in Senegal



On a weekly basis all sentinel districts convey their data to the NMCP using a template provided by the programme. Data are then aggregated and analysed to identify where action may be necessary to tackle emerging epidemics, inconsistent data or unacceptable indicators. In 2014, the completeness and timeliness of data reporting were 100% (Table 3.3).

Table 3.3 Routine data assembled through the system of sentinel surveillance sites

DISTRICTS	SITES	Total number of consultations (C)	*Total suspected cases of malaria (A)	Total RDTs performed (B)	Total cases of malaria confirmed (P)	Total suspected cases of malaria /Total consultations (A) / (C)	RDT performance rate (B) / (A)	Positivity Rate (P) / (B)
RICHARD TOLL	GNINTH	5 906	148	148	8	3%	100%	5%
	ROSS BETHIO	6 051	171	171	24	3%	100%	14%
PODOR	NDIAYENE PENDAO	4 307	95	95	3	2%	100%	3%
	NIANDANE	4 764	117	117	10	2%	100%	9%
MATAM	NABADJI	8 073	104	104	24	1%	100%	23%
	SADEL	3 572	8	8	7	0%	100%	88%
LINGUERE	BARKEDJI	8 481	328	328	78	4%	100%	24%
	WARKHOKH	4 230	292	292	5	7%	100%	2%
NDOFFANE	KOUTAL	4 534	522	522	204	12%	100%	39%
	KEUR SOCE	5 184	1 030	1 030	389	20%	100%	38%
PIKINE	GUINAW RAIL NORD	8 536	181	181	35	2%	100%	19%
	DEGGO	19 624	2 480	2 480	1 197	13%	100%	48%
GUEDIAWAYE	DAROURAKHMANE	11 952	817	817	511	7%	100%	63%
	HAMO 5	11 100	128	128	26	1%	100%	20%
MBAO	THIAROYE GARE	9 201	471	471	120	5%	100%	25%
	THIAROYE SUR MER	10 775	164	164	45	2%	100%	27%
BAKEL	GABOU	11 726	951	951	542	8%	100%	57%
	MOUDERY	5 605	199	199	18	4%	100%	9%
KEDOUGOU	BANDAFASSI	4064	2010	2010	1331	49%	100%	66%
	TOMBORONKOTO	5992	2173	2173	1398	36%	100%	64%
Total		153677	12389	12389	5975	8%	100%	48%

The epidemiology of malaria in Senegal includes areas in the pre-elimination and control phases. The surveillance system has been adapted to the level of endemicity. In the northern sentinel sites, where transmission is low, all recorded cases are systematically documented in line with the national surveillance guidelines. Surveillance aims to help interrupt local malaria transmission through the identification and investigation of malaria cases. In these areas, passive detection of confirmed malaria cases from health care providers (health centres, DSDOM, health posts, health huts and hospital) is combined with reactive active detection of cases in communities and households.

Since 2012, reactive active case detection was piloted in Richard Toll district for elimination feasibility by PATH-MACEPA. Reactive case investigation is triggered when a patient has malaria; this is called an index case. Following the identification of such an index case, the investigation begins as soon as possible, but not later than seven days after becoming aware of the case. Information about the index case (birth date, sex, single number TDR identification (barcode), symptoms, history of fever, use a mosquito net, date of onset of symptoms etc.) is entered into questionnaires using electronic touch phones. Treatment (Focal Drug Administration, or FDA) with dihydroartémisinine (DHA)-pipéraquine (DHA-PQ) is given to all household members of the index case, and they are also tested to document the rate of infection. Households located within 100 m, or the five closest households if there are more than five, are also visited and all members tested. In neighbouring households where there is at least one positive TDR, an FDA is conducted and all members receive DHA-PQ**.**

In moderate and high transmission areas, passive detection of malaria cases at health facilities (health centre, DSDOM, health post, health huts and hospital) provides important information for programme managers to track progress and enable them to target actions to control malaria morbidity and mortality.

In order to assure the quality of data and to prevent biases in analyses, the NMCP has set up a system to ensure close supervision of sentinel sites. Every month, a district data supervision team is convened which includes representatives from the NMCP, the health region and the District Chief Medical Officer. A biannual review is conducted with a central supervision team, comprising representatives of the NMCP. supervision teams include specialists in malaria case management, monitoring and evaluation and biological diagnosis.

After a year of surveillance, the steady decrease in malaria indicators in northern Senegal (Richard Toll, Podor, Matam and Linguère) confirmed the disease was in decline in that part of the country, with only 3% of all consultations being suspected malaria cases, and a test positivity rate of 21%. These figures contrast with the situation in southeastern Senegal where suspected cases amounted to 43% of the total consultations in Tomboronkoto and Bandafassi, where the average test positivity rate was 65%. At the centre of the country and in Dakar the average positivity rate of RDTs was 35%. Since 2013, the NMCP has been releasing a web-based malaria surveillance bulletin, available at www.pnlp.sn and also shared through the e-mailing to more than 500 people.

3.5 Local operational and implementation research

Over the last decade, the NMCP and partners have increased operational research efforts to maximise the impact of diagnostics, prevention and therapeutic strategies. Studies have covered

a number of areas including: the monitoring of malaria drug efficacy[25,26] and safety[27 28 29 30 31]; monitoring the quality of diagnostics; approaches to prevent malaria (seasonal malaria chemoprevention [SMC][32], IPTp[33]); vector control (indoor residual spraying[34 35]); drug and insecticide resistance assessments; knowledge for performance enhancement; and intervention coverage assessment. The evidence has contributed nationally and regionally to changes in policy.

A special example relates to SMC. Following the first study of SMC, carried out in Niakhar, Senegal, a series of studies involving seven additional West African countries, confirmed the efficacy and safety of SMC. This led to its adoption in 2012 as a regional malaria prevention strategy in children.[36] Countries generally target children aged three to 59 months living in areas with intensely seasonal malaria transmission. In Senegal the age range has been extended from 60 to 120 months on account of age pattern of malaria disease. Pilot implementation in 2014 achieved very high coverage, with 98.7% of the 624,139 targeted children from 16 districts of four eastern Senegal regions receiving the three rounds of SMC.[37] Pilot implementation has been supported by UNICEF, USAID/PMI, World Vision, Child Fund, Africare, Plan and the Peace Corps. While formal evaluation of the strategy is pending, reports from the field suggest a marked drop in malaria cases and deaths associated with SMC.[38]

25 Faye B, Ndiaye JL, Tine R, Sylla K, Gueye A, Lô AC, Gaye O (2010). A randomized trial of artesunate mefloquine versus artemether lumefantrine for the treatment of uncomplicated Plasmodium falciparum malaria in Senegalese children. *Am. J. Trop. Med. Hyg*. 82 (1): 140–144.
26 Tine RC, Faye B, Sylla K, Ndiaye JL, Ndiaye M, Sow D, Lo AC, Abiola A, Ba MC, Gaye O. Efficacy and tolerability of a new formulation of artesunate-mefloquine for the treatment of uncomplicated malaria in adult in Senegal: open randomized trial. *Malar. J,* **11**: 416.
27 Thiam S, Ndiaye JL, Diallo I, Gatonga P, Fall FB, Diallo NE, Faye B, Diouf ML, Ndiop M, Diouf MB, Gaye O, Thior M (2013). Safety monitoring of artemisinin combination therapy through a national pharmacovigilance system in an endemic malaria setting. *Malar J.* **12**(1): 54.
28 de Sousa A, Rabarijaona LP, Tenkorang O, Inkoom E, Ravelomanantena HV, Njarasoa S, Whang JN, Ndiaye JL, Ndiaye Y, Ndiaye M, Sow D, Akadiri G, Hassan J, Dicko A, Sagara I, Kubalalika P, Mathanga D, Bizuneh K, Randriasamimanana JR, Recht J, Bjelic I, Dodoo A (2012) Pharmacovigilance of malaria intermittent preventive treatment in infants coupled with routine immunizations in 6 African countries. *J. Infect Dis.*, **205** Suppl 1:S82-90. doi: 10.1093/infdis/jir799.
29 Ndiaye JL, Faye B, Gueye A, Tine R, Ndiaye D, Tchania C, Ndiaye I, Barry A, Cissé B, Lameyre V, Gaye O (2011). Repeated treatment of recurrent uncomplicated Plasmodium falciparum malaria in Senegal with fixed-dose artesunate plus amodiaquine versus fixed-dose artemether plus lumefantrine: a randomized, open-label trial. *Malar J.,* **10**: 237.
30 Ndiaye JL, Randrianarivelojosia M, Sagara I, Brasseur P, Ndiaye I, Faye B, Randrianasolo L, Ratsimbasoa A, Forlemu D, Moor VA, Traore A, Dicko Y, Dara N, Lameyre V, Diallo M, Djimde A, Same-Ekobo A, Gaye O (2009). Randomized, multicentre assessment of the efficacy and safety of ASAQ--a fixed-dose artesunate-amodiaquine combination therapy in the treatment of uncomplicated Plasmodium falciparum malaria.. *Malar J.*, **8**: 125.
31 Randomized, comparative study of the efficacy and safety of artesunate plus amodiaquine, administered as a single daily intake versus two daily intakes in the treatment of uncomplicated falciparum malaria. Ndiaye JL, Faye B, Diouf AM, Kuete T, Cisse M, Seck PA, Brasseur P, Same-Ekobo A, Lameyre V and Gaye O (2008). *Malar J.,* **7**:16.
32 Cisse et al (2006). Niakhar, Senegal
33 Newman RD, Moran AC, Kayentao K, Benga-De E, Yameogo M, Gaye O, Faye O, Lo Y, Moreira PM, Duombo O, Parise ME, Steketee RW (2006). Prevention of malaria during pregnancy in West Africa: policy change and the power of subregional action. *Trop Med Int Health*, **11**(4): 462–469.
34 President's Malaria Initiative (PMI) (2013). Senegal, End of Spray Report 2013. 1 November. Executive Summary
35 Evaluation de l'efficacite entomologique de l'aspersion intradomiciliaired'insecticide (aid) au senegal: campagne 2014 (an 8).
36 Report of the technical consultation on seasonal malaria chemoprevention (SMC); Geneva 4-6 May 2011: 1–2
37 The Seasonal Malaria Chemoprevention: Implementation Report for 2014 and 2015 Outlook: 3
38 Cairns M, Roca-Feltrer Arantxa, Garske T, Wilson AL, Diallo D, Milligan PJ, Ghani Azra C, Greenwood Brian M (2012). Estimating the potential public health impact of seasonal malaria chemoprevention in African children: 4–6.

Indoor residual spraying (IRS) has been accompanied by intensive entomological monitoring. In 2007, with the financial support of PMI, IRS was piloted in three health districts (Nioro, Richard-Toll, and Vélingara). The districts of Guinguineo, Malem Hodar, and Koumpentoum were added three years later, using the carbamate insecticide. Many partners[39] were involved in the strategy implementation through a framework named the IRS Steering Committee. Due to the low malaria prevalence in Richard Toll district, the steering committee decided to stop spraying there in 2011.

During the 2014 IRS campaign, the total number of structures spayed was 204,159 out of 209,603 (97.4%), and the population protected was 708,999.[40] Monitoring of the effectiveness of IRS in the carbamate-sprayed districts showed that although wall treatments recorded mortality rates of 100% and 79.2% during the first month after spraying in the districts of Koungheul and Malem Hodar, respectively, very low efficiency was observed with the local *An. Gambiae sl* by two months after spraying. However, the districts using pyrimiphos methyl (Actellic CS 300) reported that walls remained effective throughout the winter monitoring period, five months post-spraying, with a mortality rate above 78% in Koumpentoum as well as Vélingara.[41]

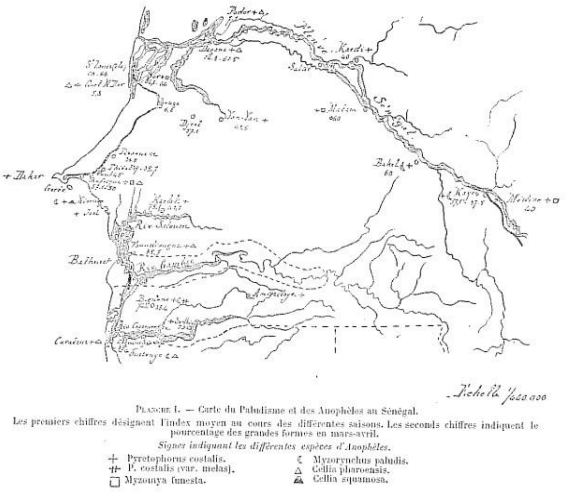
The NMCP and its key partners involved in research (UCAD, PMI/USAID, PATH MACEPA, IRD, Pasteur Institute, etc.) have developed an ambitious research agenda in order to generate more evidence for planning and decision making. Topics include: the assessment of G6PD prevalence in the north, centre, east and south epidemiological zones; factors associated with SMC acceptability; impact assessment of SMC in high transmission areas; primaquine efficacy and tolerability in children, adults and pregnant women; dosage, supply, the political and sociological factors influencing the roll-out of primaquine.

39 National Malaria Control Program (NMCP), the Ministry of Health and Social Action (central and districts levels), University Cheikh Anta Diop (UCAD), Ministry of Agriculture (Directorate for Plant Protection), and Ministry of Environment (Directorate for the Environment and Classified Factories, or DEEC), Abt Associates.
40 President's Malaria Initiative (PMI) (2014). Senegal End of Spray Report 2014. 17 October. 201:34.
41 Ndiaye JL, Faye B, Gueye A, Tine R, Ndiaye D, Tchania C, Ndiaye I, Barry A, Cissé B, Lameyre V, Gaye O (2011). Repeated treatment of recurrent uncomplicated *Plasmodium falciparum* malaria in Senegal with fixed-dose artesunate plus amodiaquine versus fixed-dose artemether plus lumefantrine: a randomized, open-label trial. *Malar J.* **10**:237.

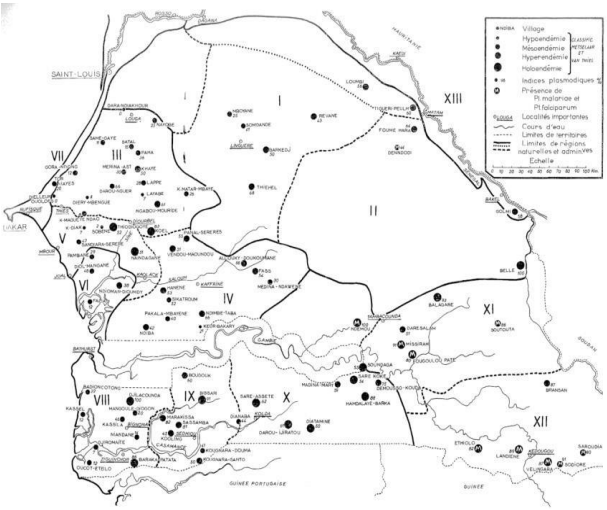
4. Mapping malaria risk

Mapping of malaria risk in Senegal has a long history (Figure 4.1). The first evidence of malaria cartography based on vectors dates from 1908, when Thiroux and D'Anfreville mapped information on the distribution of the *Anopheles* vectors.[42] In 1961 Lariviere and colleagues used estimates of infection prevalence in a sample of the population to map malaria risk across the country.[43] Ten years later, empirical data on endemicity, resolved to the district level, were used to provide operational guidance for malaria control[44] (Figure 4.2). More recently, Senegal's PNLP has used maps of ecozones, district level crude incidence and regional estimates of *P. falciparum* prevalence to support planning for malaria control (Figure 4.3) and to design suites of interventions on the control-elimination pathway (Figure 4.4).

Figure 4.1 Historical malaria risk mapping in Senegal



Source: Thiroux & D'Afreville (1908)



Source: Lariviere et al (1961)

42 Thiroux DA & D'Anfreville L (1908). Le paludisme au Senegal pendant les annees 1905-1906. Gouvernement general de l'Afrique Occidentale Francaise.
43 Lariviere M, Hocquet P, Abonnenc E (1961). Resultats d'une enquete palustre dans la republique du Senegal. Indices plasmodiques chez les enfants en milieu rural. *Bulletin de al Societe Medicale d'Afrique Noire de Langue Francaise*, **6**: 386–403.
44 Carpentier JC (1971). Developement des services de santé de base, Senegal-4001. World Health Organization, AFR/MAL/111

Figure 4.2 Senegal: Carpentier (1971) maps based on district estimates of P*f*PR$_{2-10}$ years and an operational plan of action based on risk

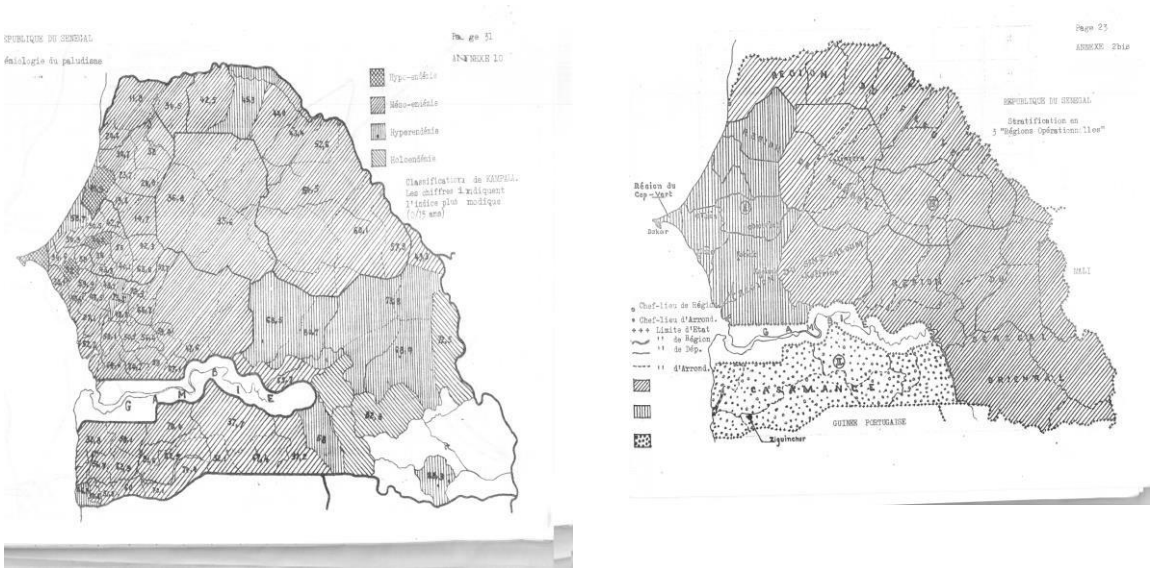
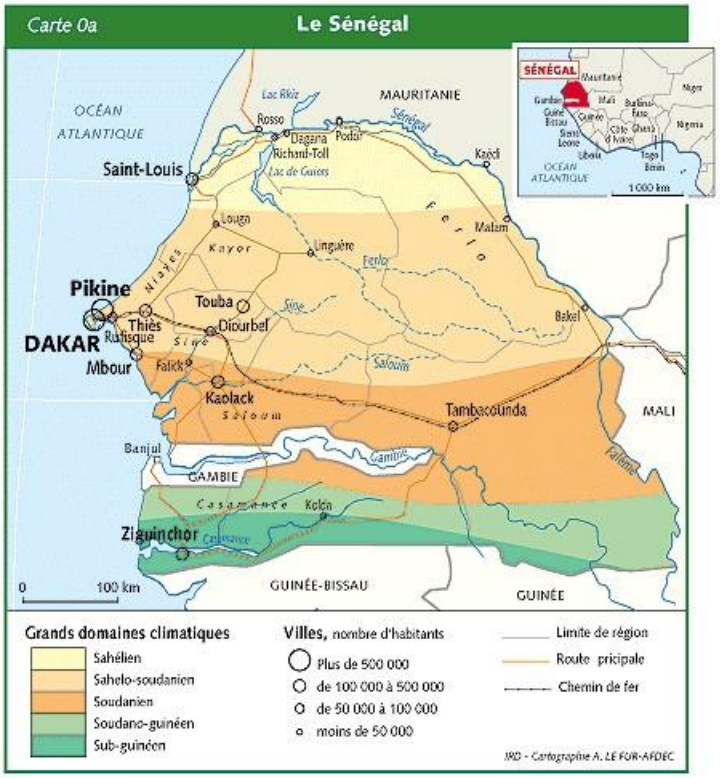
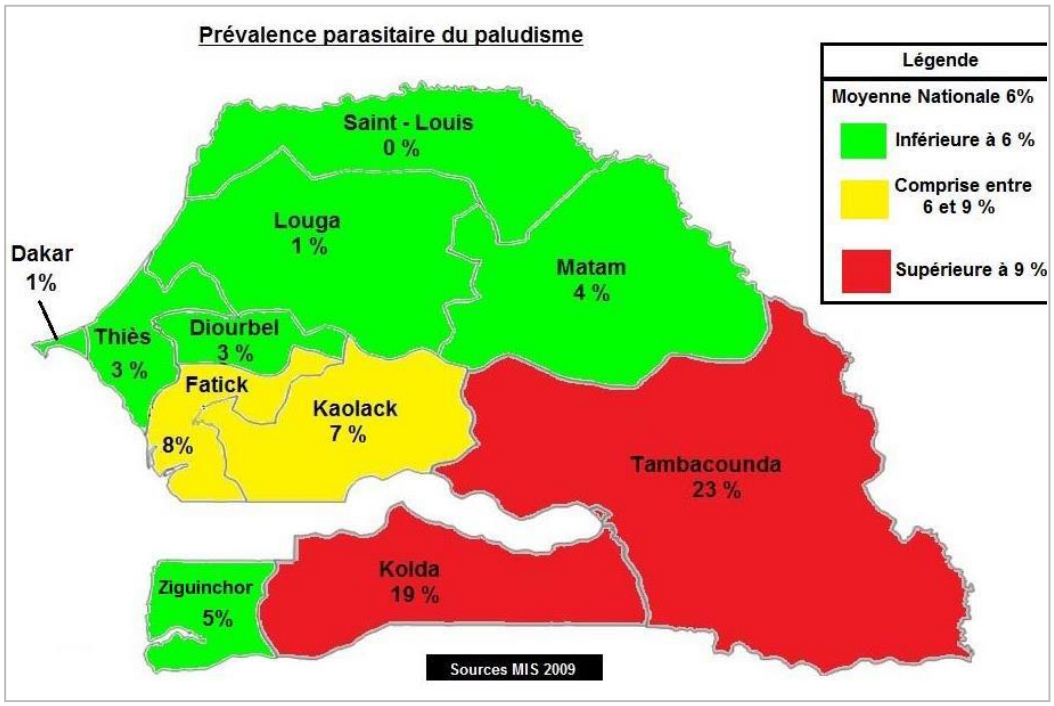


Figure 4.3 Recent use of malaria risk maps in Senegal (Source: MPR 2011: ecofaciae)



MIS parasite prevalence 2008-2009 (Source: Global Fund Rd 10-2012)



2009 HMIS district incidence (Source: Global Fund Rd 10 2012)

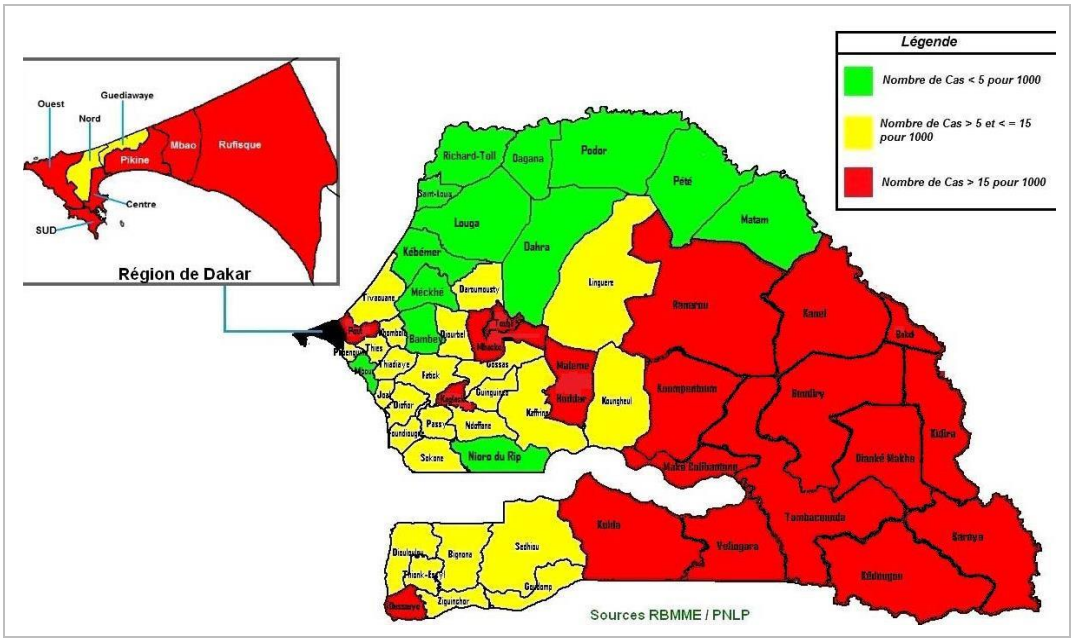
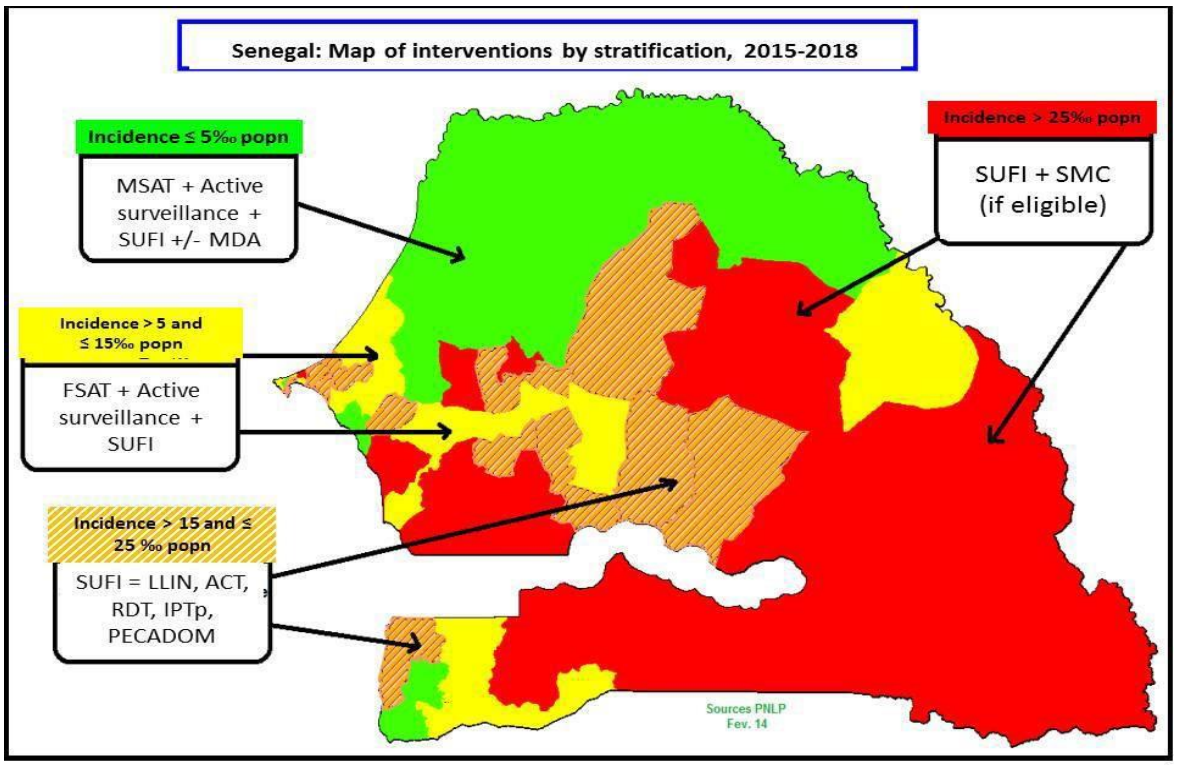


Figure 4.4 Use of malaria risk maps to guide operational activities in Senegal in 2015 (Source: PMI report 2015)



5. Malaria control in Senegal - Milestones

Important and decisive steps have been taken by the government of Senegal to control malaria over the last 60 years. Efforts have intensified over the past 10 years as the government, its internal and external partners, worked to achieve the MDGs. This section attempts to capture the key initiatives across the main areas of intervention.

In 1953, the French colonial administration recognised the threat presented by malaria and, in partnership with WHO and FISE (now UNICEF), established the Anti-Parasite Office, (*Service de lutte anti-parasitaire* – SLAP). This was based in Thies, where many French, including military personnel, were based. This programme dealt mostly with vector and larval control, including the destruction of mosquitoes' breeding sites.

The fight against malaria was set as a national agenda priority at the time of independence in 1960, with the goal of pre-eradication. WHO launched the malaria pre-eradication project called WHO Senegal-13, which promoted weekly chloroquine prophylaxis during transmission seasons (similar to the more recently recommended SMC) for children 0-14 years and for pregnant women in Dakar and Thies, and later countrywide. The initiative lasted until 1969. Indoor residual spraying was used sporadically, with a shift to fenitrothion and malathion in the late 1980s following the identification of resistance to the first-generation insecticides (DDT, HCH). Around the same time (1988) resistance was reported to chloroquine.

The situation was bleak until the government established the NMCP in 1995. Up to that point the malaria fight had been led by the Office of Endemic Diseases of the Ministry of Health. However, malaria was becoming increasingly complex – case management, diagnosis, surveillance, vector control, chloroquine resistance, insecticide (DDT) resistance, training, funding and changes in malaria epidemiology in parts of the country. The formation of the NMCP reflected the political will to improve the malaria control. The NMCP was mandated to coordinate all the interventions undertaken nationally to deal with the disease, to provide the necessary guidance and strategies, as well as the appropriate means, to fight the disease. The NMCP encouraged studies to generate evidence for new policies and strategy development. For instance, a number of chemo-sensitivity tests to chloroquine and studies on sensitivity to permethrin, were undertaken. Tests of impregnated mosquito nets were performed across the country and regionally to generate evidence to guide action.

In 1996, with evidence of the progressive loss of chloroquine to resistance, the chloroquine campaigns treating mainly children under-five years during the transmission season, were given up in favour of presumptive malaria treatment. The use of insecticide treated nets (ITNs) was also promoted as part of the implementation of the Malaria Accelerated Plan, established in 1999 with the support of WHO. Though these interventions proved useful, over time the issues of drug and insecticide resistance would emerge again.

With the advent of the Roll Back Malaria (RBM) partnership in 1999, African heads of state indicated their commitment to fight malaria, and its effects on the workforce and economies, and to dedicate an appropriate share of their national budgets to health, and therefore to malaria. In 2000, with support from WHO, UNICEF, World Bank and JICA, Senegal developed its 2001-2005 strategic plan. This was fully funded by the Global Fund (GFATM) in 2003 and enabled implementation of the first subsidised ITN distribution in 2004, the introduction of IPTp using two doses of sulfadoxine pyrimethamine (SP) and the adoption of the interim

first-line treatment policy of amodiaquine (AQ)+SP in 2005. The Demographic and Health Survey (DHS) carried out in 2005 found that just 7.1% of children under five years old slept under an ITN the night before the survey.

Evidence for the efficacy of ACTs was generated through studies carried out in Senegal – and beyond – between 2000 and 2005. This led in 2006 to the introduction of ACTs, the combination artesunate-amodiaquine (AS-AQ), in health facilities. This was followed soon after by the introduction of RDTs to strengthen malaria diagnosis.

The 2006-2011 strategic plan built on lessons learned and envisioned the achievement of both the sixth MDG and Senegal's poverty reduction strategy (DSRP 2006-2010). Finance from the Global Fund in 2006 and the newly formed US President's Malaria Initiative (PMI) in 2007 enabled the implementation of the strategic plan and led to unprecedented accomplishments. These included the shift in malaria diagnosis away from presumptive diagnosis to parasitological confirmation using rapid diagnostic tests (RDTs), and treatment based on artemisinin-combination treatment (ACTs). The RDTs and ACTs were rolled out countrywide in 2006 and 2007, respectively. Improvement in access to malaria treatment was initiated by the pilot testing of home-based malaria management (PECADOM), which began in 20 villages in 2008. The first nation-wide campaign to distribute LLINs targeting children under five years of age was conducted in 2009, with the distribution of 2.2 million LLINs. In 2010, LLIN distribution aimed to achieve universal coverage – targeting each sleeping place. This began in the four most heavily burdened regions in the southeast and progressively covered the whole country. Indoor residual spraying (IRS) was implemented in target districts from 2007. The sentinel site surveillance system was launched in 2007. In 2010 the DHS Survey confirmed a marked improvement in ITN coverage with 34.5% of under 5 year olds sleeping under an ITN the night before the survey.

The Global Fund's Round 7 grant in 2009 and building PMI financial and technical support played a massive part in the implementation of this plan. A welcome diversification of funding also began to emerge. For example, PGIRE was a World Bank project in the Senegal River Basin, and the Islamic Development Bank provided support in 2009.

The 2011-2015 strategic plan was developed in the same spirit, with the intention of pursuing strategies to deliver proven interventions, including free net distributions, IRS, malaria case management with the use of ACTs and RDTs and surveillance. The plan also included malaria pre-elimination activities in some locations. In 2012, USAID/PMI began directly funding some of the NMCP's activities. The ongoing financial and political support of the government was also key to the implementation of this strategic plan and allowed the implementation of a number of interventions. For example, PECADOM has been rolled out, integrating diarrhoea and pneumonia management in children under 5 years and, importantly, introducing RDTs at this level in 1,962 villages across 32 districts. Indoor residual spraying protected about 690,000 people in 2013 in six target districts; universal coverage net distribution campaigns delivered more than 14.7 million nets across the country from 2010 to 2014, and SMC was implemented in 2013 and 2014 among children of three to 120 months old in four regions.

These efforts have been associated with tangible improvements in disease burden and survival. For example, the total number of deaths attributed to malaria dropped from 12.93 per 100,000 people in 2000 to 8.26 in 2013 and 4.0 in 2014.[45,46]

1904-1935
Breeding site reduction and legislation (1905) in Dakar

Reports of QN prophylaxis among young children in Dakar and St Louis

1945
School-based prophylaxis using rotations of quinacrine and rodoprequine in Dakar

1953
Service de lutte anti-parasitaire (SLAP) established by WHO, UNICEF and French government

1953-1957
Pilot eradication project initiated using DDT IRS in Thies Region protecting about 500,000 people

1960
Independence from France

1960s
Periodic IRS and larval control in Dakar region

1963-1969
Pre-eradication project (WHO-Senegal 13), CQ prophylaxis weekly during transmission seasons (SMC) for children 0-14 years and pregnant women in Dakar and Thies

1970
Start of prolonged drought that effectively removed *An. funestus* from northern provinces along Senegal River; severe drought 1972

1971-1973
CQ prophylaxis among children 0-5 years in 65 villages near Niakhar

Early 1980s
Evidence of CQ prophylaxis among general population in some areas, notably Mlomp, Zinginchor

1983
Severe drought in northern region

45 WHO (2014) World Malaria Report 2014. 9 Dec. http://www.who.int/malaria/publications/world_malaria_report_2014/report/en/ Accessed 23 March, 2017.
46 National Malaria Control Program (2014). Annual Report.

1987
Construction of Diama dam on Senegal River and artificial Lake Guiers alters epidemiology of transmission

At four sites across country vectors sensitive to fenitrothion and malathion, but resistance detected to DDT at Dakar and Kolda

1988
CQ resistance detected at Pikine, Dakar

The health region of Podor, through the regional office of major endemic based in Podor, introduced nets treatment in its malaria programme, using deltamethrine and K-Othrine insecticide

1988-1990
Trial of IRS using Fenitrothion at Pout, Thies region

1991-1992
Severe droughts

1995
Development of the first Antimalarial Plan, leading to the establishment of the National Malaria Control Programme (NMCP)

Trial of permethrin treated bed nets at Wassadou, Tambacounda region NMCP established

1997
Development of the Accelerated Malaria Control Plan (PALP), covering 12 districts[47] with the support of WHO

An. funestus re-appears along Senegal River Basin

The first pan-African conference on malaria research, Multi-lateral Initiative on Malaria (MIM), hosted in Dakar

2000
Situation analysis in Senegal and development of the first Roll Back Malaria Strategic Plan for the period 2001 to 2005, with the financial support of the World Bank, UNICEF and Japan government (JICA). The plan implementation was fully funded by the Global Fund in 2003

MICS survey carried out

2002
Trial of SP+AS SMC among children aged 2-59 months at Niakhar

47 Mbao, Dagana, Podor, Kébémer, Linguère, Goudiry, Nioro, Bignona, Guinguinéo, Popenguine, Dioffior, et Thiadiaye

2004
Interim first line treatment policy of AQ+SP
IPTp using two doses of SP after quickening policy introduced

2005
7.1% of children < 5 years old slept under an ITN

2006
First post-RBM launch National Malaria Strategy launched through to 2010 Round 4 Global Fund financing awarded

MIS survey carried out

ACT first line treatment policy introduced

ITN free mass distribution

16.4% of children slept under an ITN

Beginning of decentralisation of malaria interventions with the advent of community-based pilot initiatives e.g. malaria case management, using RDTs and ACTS; free distribution of LLINs and the involvement of community health workers in malaria diagnostic and treatment with RDTs and ACTs

2007
RDTs introduced nationwide to support malaria diagnosis PMI funding starts

2007-2009
IRS using lambda-cyhalothrin started in Richard-Toll, Nioro du Rip and Velingara Districts protecting about 650,000 people per annum

2008
Catch-up mass ITN distribution campaigns, targeting children < 5: 1,057,835 nets in 58 districts spanning the regions of Diourbel, Fatick, Kaolack, Thiès, Zinguinchor, St. Louis, Matam, Tambacounda andLouga

ACTs and RDTs introduced nationwide in health huts (CHW)

Ivermectin MDA for onchocerchiasis shown to interrupt malaria transmission in Kédougou region

IRS using alpha-cypermethrin started at mining concerns in Saraya district MIS 2008-09 survey carried out

29.2% of < 5 years old children slept under an ITN

System of village malaria workers introduced to provide testing with RDTs and treatment with ACTs through the Home-based Malaria management program - prise en charge à domicile (PECADOM)- piloted in three districts in Kolda and Sedhiou regions (Mékhé, Ranérou et Dioffior)

2009

Round 7 Global Fund financing awarded

Nationwide mass ITN distribution campaign as part of integrated vitamin A and deworming activities distributing 2.2 million nets

ITN sleeping space census and universal coverage distribution schemes piloted in two districts (117,060 nets)

DDT and pyrethriod resistance reported across all IRS districts

The World Bank funded OMVS/PGIRE Health project in Senegal River basin established and first malaria indicators survey (baseline) carried out in Senegal, as well as in the rest of member states (Guinea, Mauritania and Mali)

UCAD tasked with insecticide sensitivity studies

2010

ITN sleeping space census and universal coverage distribution in 16 districts (621,481 nets)

PEDACOM expanded to Fatick, Kaolack, Kaffrine, Kédougou, Matam; IRS expanded to three new districts (Guinguinéo, Malem Hoddar, Koumpentoum) bringing the total IRS districts to six, including the previous three districts: Richard Toll, Velingara, and Nioro, with a switch toward using deltamethrin, protecting about 1 million people

34.5% of children slept under an ITN; IRS coverage in last 12 months >73% in all target districts

Third situation analysis: Malaria review programme and development of the third Malaria Strategic Plan for the period 2011-2015

2010-2011

Trials of SMC (AQ+SP) for children aged < 10 years in Saraya district and combined with home-based management in Velingara district

DHS-MICS survey carried out

2011

Richard Toll district dropped as IRS district and Koungheul added; switch to Bendiocarb (Carbamate): Total: 6 districts

Trial of IPTc in school children in Kédougou Region

National Strategic Plan launched with goal of reaching pre-elimination (less than one case per 1,000 population) in 9 districts (5 in the region of Saint Louis and 4 in the region of Matam) by 2015 and nationwide pre-elimination by 2018

ITN universal campaign of 2,465,770 nets in 27 districts

2012

Continuous DHS-SPA, Year 1 2012-13 46% of children slept under an ITN

Reactive case-detection piloted in Richard Toll District for elimination feasibility

ITN universal campaign of 983,696 nets in 13 districts

2013

SMC (AQ+SP) for children aged 3 months – 10 year policy introduced for Kédougou, Tambacounda, Sédhiou and Kolda regions

IPTp 3 adopted

SMC (AQ+SP treatment for children in 3 months -10 years in 4 districts (Kédougou, Salemata, Saraya and Dianké Makhan) spanning Kédougou and Tambacounda regions
IRS stopped in Guinguinéo and Nioro districts

IRS decreased to 4 districts (Malem Hoddar, Koungheul, Koumpentoum, and Velingara), Bendiocarb used

DSDOM (home-based management - PECADOM) use RDTs and ACTs, scaled up to 841 villages by 2010 and 1,962 in 61 districts by 2012, in 13 out of the 14 regions

ITN universal campaign of 3,285,254 nets in 25 districts – 19 Round 1, six for Round 2 initial covered 2010)

2014

National Malaria Strategic Plan (the updated 2010 version) launched through to 2018 with stratified suites of interventions based on current district malaria incidence and aiming for pre-elimination by 2018

Continuous DHS-SPA, Year 2 2014 43% of children slept under an ITN

SMC (AQ+SP treatment for children in 3 months-10 years in 16 districts protecting 708,999 children

PEDACOM Plus, including diagnosis started in SE regions and 149 villages

ITN universal campaign (Round 2 distribution of 3,349,204 nets in 29 districts originally covered in 2010-2011)

Resistance to all forms of pyrethroids insecticide, DDT and dieldrin recorded across 30 sentinel sites nationwide; bendocarb resistance at 10/21 sites tested; fentithrion, malathion and primiphos-methyl largely sensitive at sites tested

The World Bank funded project OMVS/ PGIRE purchased and distributed 775,000 LLINs during the two phases of the health project in 23 health districts in five regions in the northern Senegal (St. Louis, Louga, Matm, Tambacounda, Kedougou)

IRS (Bendiocarb) continued in Malem Hoddar and Koungheul, while Koumpentoum and Velingara switch to organophosphate (pyrimiphos- methyl) protecting circa 650,000 people

2015

Global Fund financing awarded (New Funding Mechanism) Focal IRS adopted using pyrimiphos-methy in four districts[48]

School-based distribution of LLIN targeted in Louga, Ziguinchor, Saint-Louis and Matam regions

Focal spraying in Malem Hoddar, Koungheul, Koumpentoum, and Nioro, using pyrimiphos-methyl

Co-ordinators of the Senegalese National Malaria Control Programme

- Dr Elisabeth SELLER DANSOKHO ; January 1995 to January 1997
- Médecin Commandant Bakary SAMBOU ; January 1997 to August 2000
- Dr Papa Amadou DIACK ; August 2000 to September 2004
- Médecin Commandant Papa Moussa THIOR ; September 2004 to November 2011
- Dr Cheikh Tacko DIOP ; November 2011 to June 2012
- Médecin Commandant Mady BA ; June 2012 to date

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6 Overview of technical methods

The analyses presented here draw on a series of datasets which have been assembled to house information on administrative boundaries, health facility location, population, parasite prevalence, clinical case data and entomological data.

6.1 Mapping administrative divisions

Senegal is divided into 14 regions (first level), 46 *départements* (second level), 103 *arrondissements* (third level) and 332 *communes* (fourth level). However, health administration operates at the level of the district sanitaire, of which there were 76 in 2015. These are presented in (Figure 6.1) and listed in (Table 6.1).

Figure 6.1 Health administration units in Senegal

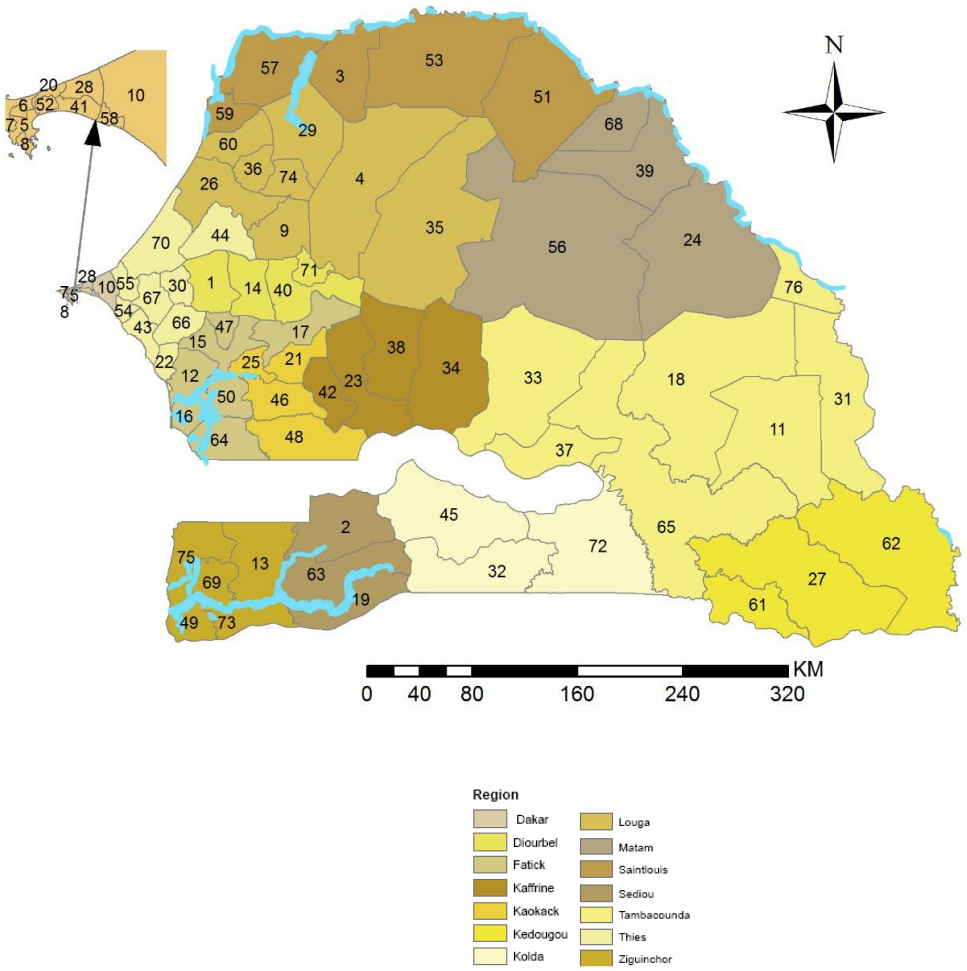

Table 6.1 Health administration units in Senegal

Map code	District	Map code	District	Map code	District
	Dakar Region		Kaffrine Region		Matam Region
5	Dakar Centre	23	Kaffrine	24	Kanel
6	Dakar Nord	34	Koungheul	39	Matam
7	Dakar Ouest	38	Maleme Hoddar	56	Ranerou
8	Dakar Sud	42	Mbirkilane	68	Thilogne
10	Diamniadio		Kaokack Region		Saint-Louis Region
20	Guediawaye	21	Guinguinéo	3	Dagana
28	Keur Massar	25	Kaolack	51	Pete
41	Mbao	46	Ndoffane	53	Podor
52	Pikine	48	Nioro	57	Richard Toll
58	Rufisque		Kedougou Region	59	Saint-Louis
	Diourbel Region	27	Kedougou		Sedhiou Region
1	Bambey	61	Salemata	2	Bounkiling
14	Diourbel	62	Saraya	19	Goudomp
40	Mbacke		Kolda Region	63	Sedhiou
71	Touba	32	Kolda		Tambacounda Region
	Fatick Region	45	Medina Yoro Foulah	76	Bakel
12	Dioffior	72	Velingara	11	Diankhe Makhan
15	Fatick		Louga Region	18	Goudiry
16	Foundiougne	74	Coki	31	Kidira
17	Gossas	4	Dahara	33	Koumpentoum
47	Niakhar	9	Darou-Mousty	37	Makacolibantang
50	Passy	26	Kebemer	65	Tamba
64	Sokone	29	Keur Momar Sar		
	Thies Region	35	Linguere		
22	Joal	36	Louga		
30	Khombole	60	Sakal		
43	Mbour		Ziguinchor Region		
44	Meckhe	13	Bignona		
54	Popenguine	75	Diouloulou		
55	Pout	49	Oussouye		
66	Thiadaye	69	Thionckessyl		
67	Thies	73	Zigiunchor		
70	Tivaouane				

We used Global Administrative Unit Layers (GAUL) shapefiles and produced maps of new health districts to reconcile one shapefile in ARCGIS (Version 10). Notably the revised district sanitaire in Kedougou region (from Tambacounda region), Sedhiou region (from Kolda region) and Kaffrine (from Kaolack region) and the following districts sanitaire: Diamniadio, Keur Massar, Mbacke, Niakhar, Medina Yoro Foulah, Coki, Keur Momar Sarr, Sakal and Thilogne. Notto was renamed as Thies and Thienaba to Khombole as per the region maps. Thilogne did not exist before 2011 and was part of Matam.

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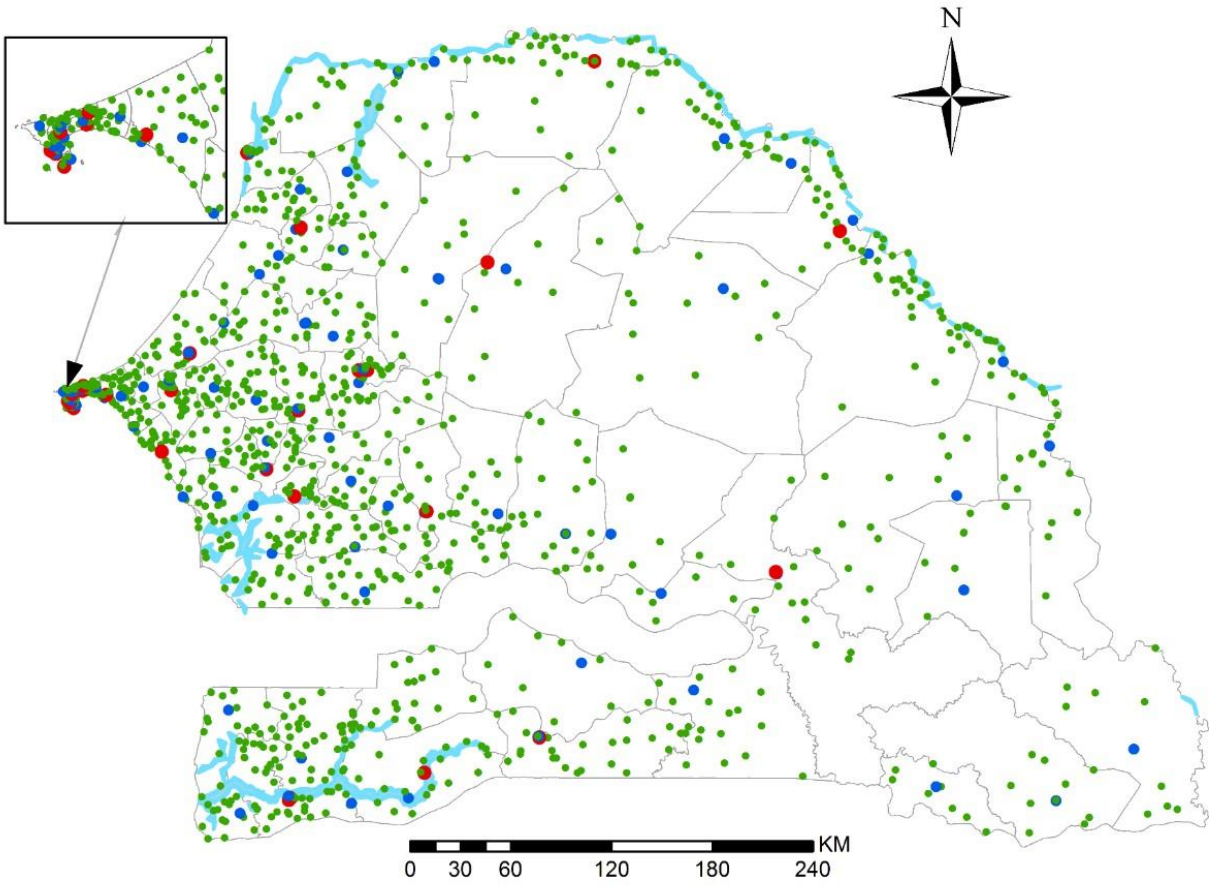
6.2 Database of geolocated health facilities

Defining district level incidence has been an important part of malaria risk mapping in Senegal of recent years, and will form the basis of defining control-to-elimination endpoints and suites of intervention packages. HMIS data provided by health facilities will be incomplete. In addition, to understand how the incidence of disease presenting to health facilities relates to malaria risk in the community will demand a modelled approach to facility access. To this end a geocoded database of health service providers is key.

Figure 6.2 Distribution of 1,269 public health facilities in Senegal hospitals (red), health centres (blue) and health posts (green)



The Senegal health facility database prepared by USAID and the Ministry of Health (2012) did not contain a comprehensive list of the health huts and therefore these are not included in the final health facility database (HFDB). None of the facilities had longitude and latitude coordinates. Several variables were included in the original file. We retained: region (14), district (76), facility name (1570), facility type (10), and owner (7). We created the following additional fields: Latitude, Longitude, Gaul Admin 1 and 2, Health Admin 1 and 2, and recoded facility type.

There were 10 unique facility types for both private and public facilities namely: Cabinet (101); Private Clinics (45); CMS - Centre Medico Social (22); CS – Health Centre (89); CSG (40); DPC (1); EPS 1 (9); EPS 2 (18); EPS 3 (8); and PS – Health Post (1,237). Toachieve a three-tier system, the facilities were re-coded into Hospitals (EPS 1, 2 and 3), Health Centres (CS), and Health Post (PS).

There were seven unique owners namely: Prive (4); Prive Militaire (55); Prive Non Lucrative (1); Privee Confessionnelle (83); Prive Lucrative (166); Publique (1207); and; Publique Confessionnelle (1). These were largely categorised into two namely Public (Publique and Publique Confessionnelle) and Private (Prive, Prive Militaire, Privee Confessionnelle, Prive Lucrative and Non lucrative).

Summary of data cleaning

There were 1,570 facilities in the original health facility list. Of these, 362 were private facilities which were excluded. Another 38 facilities comprising of military, police and prison clinics, youth centres, mental clinics, university and college clinics, municipal health offices, nursing and maternity centres, and other specialist facilities that were unlikely to be providing routine curative services were also excluded.

The remaining 1,169 public facilities were geo-located using WHO GPS assembled database of Senegal villages that contained 13,181 villages. Other sources used in geo- location included ENCARTA, Google Earth, Geonames (http://www.geonames.org/) and Falling rain. Coordinates were checked with the health administrative boundary to locate those facilities that were in the wrong administrative boundary and attempt re-positioning. In addition, points along the coastline were checked using the GAUL 2008 coastline shape file. The Global Lakes and Wetlands (GLWD) database developed by the World Wildlife Fund was used to ensure facilities were within defined land areas. We used the spatial join tool in *ArcGIS* (ArcMap 10.1, Esri systems, CA, Redlands) to identify facility coordinates that fell slightly off the coastline, located on a river/lake, or slightly outside their correct administrative units and every anomaly was re-positioned using small shifts in combination with Google Earth. Of the 1,169 facilities we were unable to geolocate 175 (15%).

On 2 June 2015 we obtained a health facility database from INTRAHEALTH Senegal via Cesaire Ahanhanzo. This contained 1,668 public and private health facilities of which 698 health facilities were geocoded. The primary source of coordinates for this database was not indicated but it was accompanied by a list of 13,321 villages in Senegal, of which 12,463 were geocoded. Comparisons of the health facilities coordinates with villages of the same name showed that the health facility coordinates were derived from the village list Comparisons of public health facilities between the INTRAHEALTH and our database were made. This resulted in an additional 186 health facilities. The final assembled database contained 1355 public health facilities. Of this 1269 (94%) were geocoded and are shown on the map (Figure 10).

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Heyen-Perschon J (2005). Report on current situation in the health sector of Senegal and possible roles for non-motorised transport interventions. Institution for Transport and Development Policy.

Bioforce Development Institute (2011). Survey on Human Resource Capacity in Public Health Supply Chain Management in Senegal. http://www.peoplethatdeliver.org/ Accessed 23 March, 2017.

CAFSP (Cellule dAppui ai Financement de la Santé et au Partenariat) (2005). Protocole d'élaboration des Comptes Nationaux de la Santé du Sénégal. Dakar: Ministère de la Santé et da la Prévention

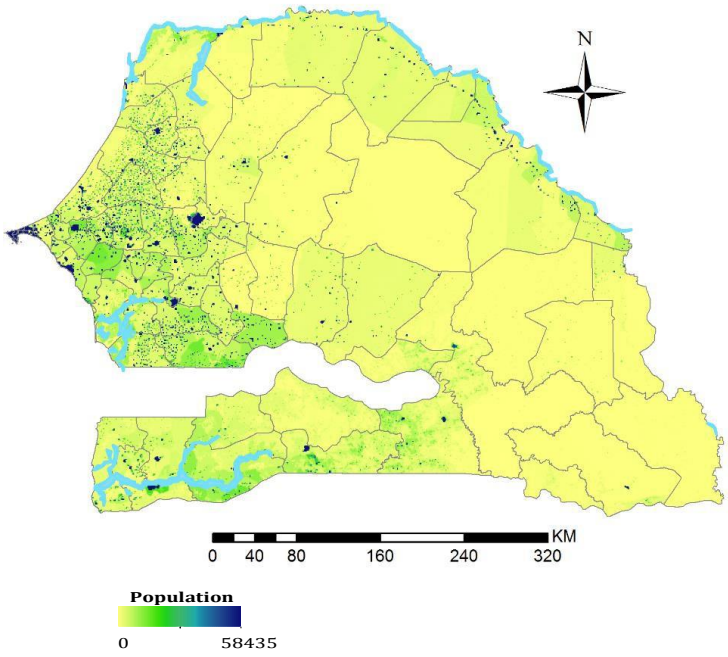
Ji-Elle, Badmood, Kostia, et al. (2013). "Santé au Sénégal" Wikipedia, The Free Encyclopedia, accessed from http://en.wikipedia.org/wiki/Healthcare_in_Senegal#cite_note-sante-5 Accesed 11 July 2013.

PMI (2011). Malaria Operational Plans. https://www.pmi.gov/resource-library/mops/archive/fy-2011 Accessed 23 March, 2017.

6.3 Mapping the population of Senegal

A basic requirement for mapping malaria risk across a country is an understanding of the distribution of its population. We have built on standard approaches to distribute Senegal's population across its geographic extent (Figure 6.3).

Figure 6.3 Population density and distribution across Senegal



Modelling techniques for the spatial reallocation of populations within census units have been developed in an attempt to (i) disaggregate population count data to a finer spatial detail and (ii) convert population count data from irregular administrative units to regular raster layers[49, 50] Population census size estimates, corresponding census enumeration unit boundaries at the

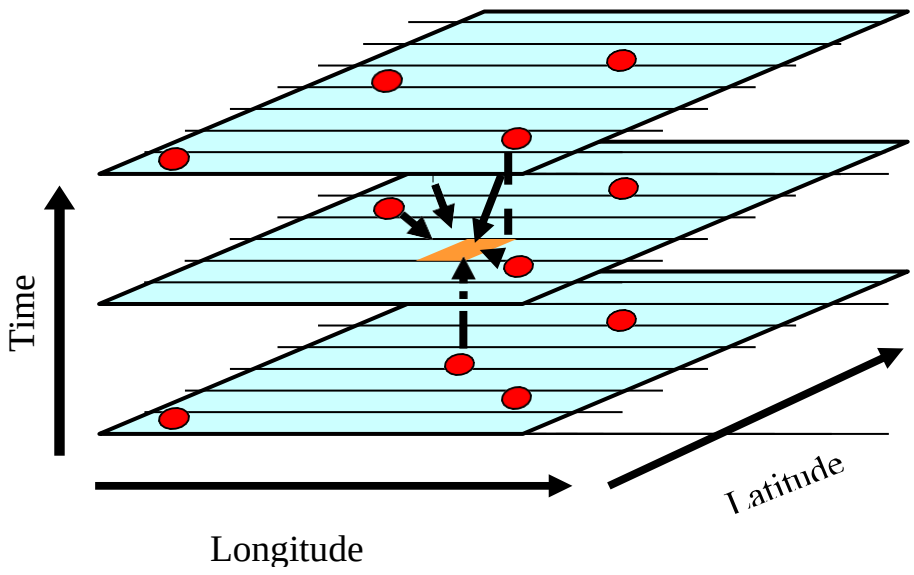
49 Linard C, Gilbert M, Tatem AJ (2011). Assessing the use of global land cover data for guiding large area population distribution modelling. *GeoJournal*, **76** (5): 525–538.
50 Linard C Gilbert M, Snow RW, Noor AM, Tatem AJ (2012). Population distribution settlement patterns and accessibility across Africa in 2010. *PLoS One*, **7**: e31743.

highest spatial resolution (332 communes) from the most recently publically available census (2012) were acquired for Senegal. Typical regional per-land cover class population densities were estimated from African countries for which very fine resolution population data were available, following approaches outlined by Linard et al. These typical population densities were then applied as weightings to redistribute census counts according to the land cover and to map human population distributions at a finer spatial resolution using dasymetric modelling techniques[51] The modelling method distinguishes urban and rural populations in the redistribution of populations.

6.3.1 Space-time geostatistical modelling

Geostatistical methods were developed to interpolate from data at sampled locations in space and time to provide predictions of quantities at locations and times where data do not exist. All model-based geostatistical (MBG) methods operate under Tobler's First Law of Geography (Figure 6.4), which states that things which are closer in space and time are more similar than those more spatially and temporally distal.[52] When applied with a Bayesian inference framework, these methods are referred to as model-based geostatistical (MBG) methods. Bayesian inference allows for better use of sparse data and through the application of prior knowledge of an outcome in an iterative process. MBG allows for robust estimation of uncertainties around the estimates of the outcome.

Figure 6.4 Space-time geostatistical models of *P. Falciparum* transmission intensity



Each blue grid represents a geographic space at one of three time points. The red dots represent positions and time for which *P falciparum* parasite prevalence data are available. The small orange square represents a position and time of interest, but for which no data exists. The black arrows indicate that the data points surrounding (in time and space) the square of interest are used to predict the likely parasite prevalence in the orange square.

51 Mennis J (2009). Dasymetric mapping for estimating population in small areas. Geography Compass, 3(2):727–745.
52 Tobler W (1970). A computer movie simulating urban growth in the Detroit region. Economic Geography, 46: 234–240.

The procedures used to assemble, geocode, archive, model and validate the transformation of empirical *P. falciparum* parasite prevalence data to continuous predictions of age-corrected mean prevalence in children aged 2-10 years (*Pf*PR_{2-10}) are provided by Noor[53] and Snow.[54,55] In brief, we used information from available age-corrected survey data (sample size and numbers positive) at known locations (longitude and latitude) and times (year) with a minimal set of conservative, long-term covariates traditionally used in vector- borne disease mapping. These were brought together in a Bayesian hierarchical space-time model, implemented through an adapted stochastic partial differential equations (SPDE) approach using integrated nested laplace approximations (INLA) for inference[56,57] to produce continuous maps of *Pf*PR_{2-10} at 1 km x 1 km spatial resolutions.

Estimating precision

A spatially and temporally de-clustered 10% of the *Pf*PR_{2-10} data was held out for model validation. Model accuracy was estimated by computing three variables based on the observations and predictions of the holdout dataset: (i) the linear correlation, which quantifies the strength of the linear relationship between the observed and predicted values for the 10% validation data; (ii) the mean prediction error (MPE), a measure of the bias of predictions (the overall tendency to over or under predict); and (iii) the mean absolute prediction error (MAPE), a measure of overall precision (the average magnitude of error in individual predictions. Covariates were not used in mapping *Pf*PR_{2-10} in Senegal.

The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean.[58] It has no measurement units and is an indicator of the magnitude of variability in relation to the mean or dispersion in data or estimates of a variable. One disadvantage of the CV is that where the mean is equal to zero, it approaches infinity and is therefore sensitive to small changes in the mean. In such a case, the standard deviation should be used to describe the uncertainty of the model predictions

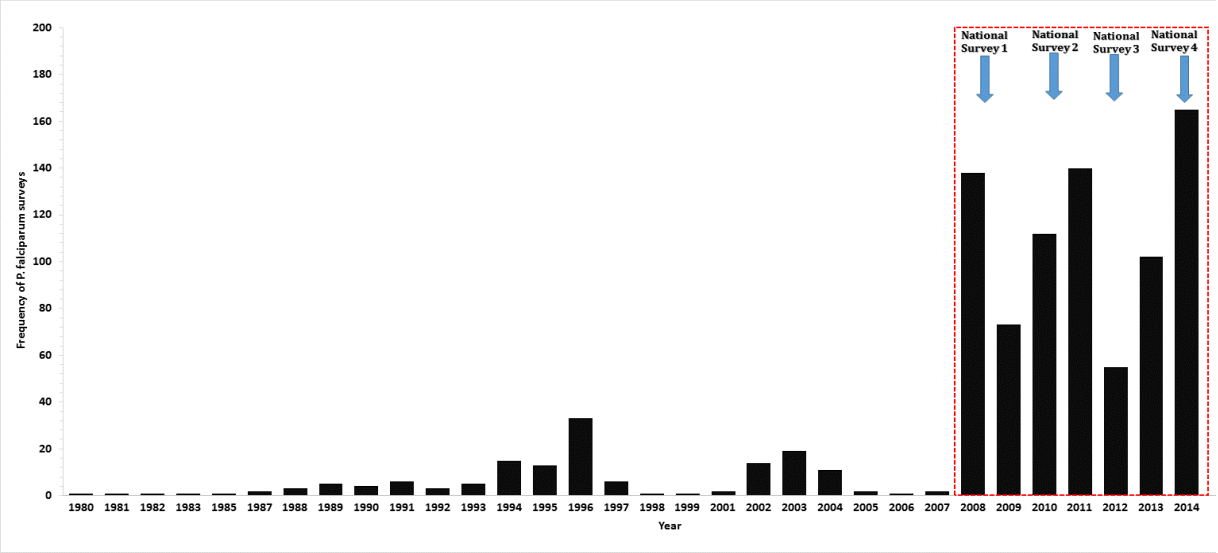
53 Noor AM, Kinyoki DK, Mundia CW, Kabaria CW, Wambua JM, Alegana VA, Fall IS, Snow RW (2014). The changing risk of Plasmodium falciparum malaria infection in Africa: 2000 to 2010. **Lancet**, **383**: 1739-1747.
54 Snow RW, Amratia P, Mundia CW, Alegana VA, Kirui VC, Kabaria CW, Noor AM (2015). Assembling a geo-coded repository of malaria infection prevalence survey data in Africa 1900-2014. INFORM Working Paper, developed with support from the Department of International Development and Wellcome Trust, UK, June 2015; http://www.inform-malaria.org/wp- content/uploads/2015/07/Assembly-of-Parasite-Rate-Data-Version-1.pdf Accessed 1 March, 2017.
55 Snow RW & Noor AM (2015). Malaria risk mapping in Africa: The historical context to the Information for Malaria (INFORM) project. Working Paper in support of the INFORM Project funded by the Department for International Development and the Wellcome Trust, Nairobi, Kenya June 2015; http://www.inform-malaria.org/wp-content/uploads/2015/07/History-of-Malaria-Risk- Mapping-Version-1.pdf Accessed 1 March, 2017.
56 R-INLA project. http://www.r-inla.org/. Accessed 10 April 2012.
57 Rue H, Martino S, Chopin N (2009). Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the Royal Statistical Society Series B*, **71**: 319–392.
58 Kirkwood BL (1979). Geometric means and measures of dispersion. *Biometrics*, **35**: 908–909.

6.3.2 Malaria prevalence survey data in Senegal

We assembled community-based surveys of malaria parasite prevalence from a variety of sources. These included peer-reviewed journals, international and national ministry of health and academic archives, personal correspondence and recent national household survey samples. The detailed methods used to identify, extract and geocode survey reports are presented elsewhere.

A total of 785 geolocated surveys were undertaken between 2008 and 2014 (Figure 6.5) and form the basis for the analyses presented here. All surveys used microscopy for parasite detection between 2008 and 2014, the 35 surveys undertaken in Dakar in 2010 were additionally confirmed using PCR.

Figure 6.5 Malaria parasite prevalence surveys (n=938) in Senegal, by year 1980-2014



A total of 971 time-space surveys undertaken since 1980 were identified through the data search process. The earliest survey was undertaken in 1980 and the most recent survey undertaken in 2014. Six surveys were excluded because after repeated efforts it was not possible to identify the longitude and latitude of the survey site; two surveys were excluded because it was not possible to disaggregate repeated surveys in time and 25 surveys were excluded because their sample sizes were less than 10 individuals.

The data volumes to make reliable spatial predictions are temporally sparse between 1980 and 2007. We have therefore elected to use only data from the most data-rich period 2008-2014 (n = 785) in further analyses. These data include the national household surveys of 2008/09, 2010/11, 2012/13 and 2014.[59,60,61] In addition, survey data from Dakar in 2008,[62] Kolda in 2010[63] and Fatick in 2010[64] have been included.

59 Ndiaye S and Ayad M (2009). Enquête Nationale sur le Paludisme au Sénégal 2008-2009. Centre de Recherche pour le Développement Humain (Sénégal) et ICF Macro Calverton, Maryland, USA.
60 Agence Nationale de la Statistique et de la Démographie (ANSD) (Sénégal) et ICF International (2012). Enquête Démographique et de Santé à Indicateurs Multiples au Sénégal (EDS-MICS) 2010-2011. Calverton, Maryland, USA: ANSD et ICF International.
61 Agence Nationale de la Statistique et de la Démographie (ANSD) (Sénégal) et ICF International (2014). Enquête Démographique et de Santé Continue (EDS-Continue 2012-2013). Calverton, Maryland, USA: ANSD et ICF International.

6.3.3 Malaria vector data in Senegal

We used historical archives and published sources, and sourced more recent unpublished data from scientists and control agencies working in Senegal, to assemble a database of malaria vectors in Senegal. Full details of the data assembly, geocoding methods and classifications of species according to their role in malaria transmission are provided elsewhere.[65] The database has been arranged as a site-specific, referenced inventory to capture details of species identified since the earliest surveys in 1902 through to the latest records in 2014.The full digital PDF library, database and bibliography accompany this report.

From each identified report, data extraction included whether a species was identified at a given site, methods used to capture adults or larvae and the methods used to speciate each *anopheline* collection. "Y" was recorded if species was identified and "N" was only recorded when the absence of the species was reported. The database is therefore one of species presence, not absence or proportional presence of the different vectors.

6.4.4 ITN/LLIN coverage mapping

Typically, national household surveys are designed to be precise at national and regional levels and rarely at lower levels such as districts. Simply aggregating survey data to provide district level estimates of an outcome of interest will lead to values of low precision. Small area estimation (SAE) methods handle the problem of making reliable estimates of a variable at these units under conditions where the information available for the variable, on its own, is not sufficient to make valid estimates.[66,67] We have used hierarchical Bayesian spatial and temporal SAE techniques using a geo-additive regression approach[68,69] to estimate the proportion of the population in each health district sleeping under an insecticide treated net (ITN) the night before the survey. This has been done by health district for the years 2005, 2008-2009 and 2010-20011 and 2012-2013. This method uses survey data from a health district and neighbourhood information from adjacent districts to smooth values at the health district level.

Covariates were not used in this approach. However, if information on the month and year that distributions of ITNs was available for each health district, this could improve the precision of the estimates.

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62 Diallo A et al. (2012). Asymptomatic carriage of Plasmodium in urban Dakar: the risk of malaria should not be under-estimated. *PLoS One*, **7**: e31100.
63 Tine RC et al. (2011). Impact of combining intermittent preventive treatment with home management of malaria in children less than 10 years in a rural area of Senegal: a cluster randomized trial. *Malar. J,* **10**: 358.
64 Roucher C et al. (2012). Changing malaria epidemiology and diagnostic criteria for Plasmodium falciparum clinical malaria. *PLoS One*, **7**: e46188; JF Trape, personal communication. 13 October, 2012.
65 Snow RW, Kyalo D, Amratia P, Kabaria CW, Noor AM (2015). Developing a geo-coded repository of malaria vector species occurrence for Africa: methods and data summaries 1900-2014. Working Paper 2: Report prepared in support of the INFORM Project funded by the Department for International Development and the Wellcome Trust, April; http://www.inform-malaria.org/wp- content/uploads/2015/07/Assembly-of-Vector-Data-Version-1.pdf Accessed 1 March, 2017.

66 Rao JNK (2003). *Small Area Estimation*. John Wiley & Sons, Inc., Hoboken, New Jersey.
67 BIAS (2007). Introduction to Bayesian Small Area Estimation, January 2007. http://www.bias-project.org.uk/software/SAE.pdf Accessed 3 February, 2016.
68 Banerjee S, Carlin BP, Gelfand AE (2004). *Hierarchical Modeling and Analysis for Spatial Data*. New York: Chapman & Hall.
69 Best N, Richardson S, Thomson A (2005). A comparison of Bayesian spatial models for disease mapping. *Statistical Methods in Medical Research*, **14**: 35–59.

7. Mapping malaria risk

Figure 7.1 shows the locations of the 785 *P falciparum* parasite prevalence (P*f*PR) survey data points reported between 2008 and 2014. The data were age-corrected to reflect the prevalence in 2-10 year olds (P*f*PR$_{2-10}$). These data points are split into their respective time periods in Figure 7.2

Figure 7.1 Senegal: location of 785 age-corrected parasite prevalence data (P*f*PR$_{2-10}$), 2008 2014 (Green=zero: light orange >0 - <5%: dark orange >= 5%)

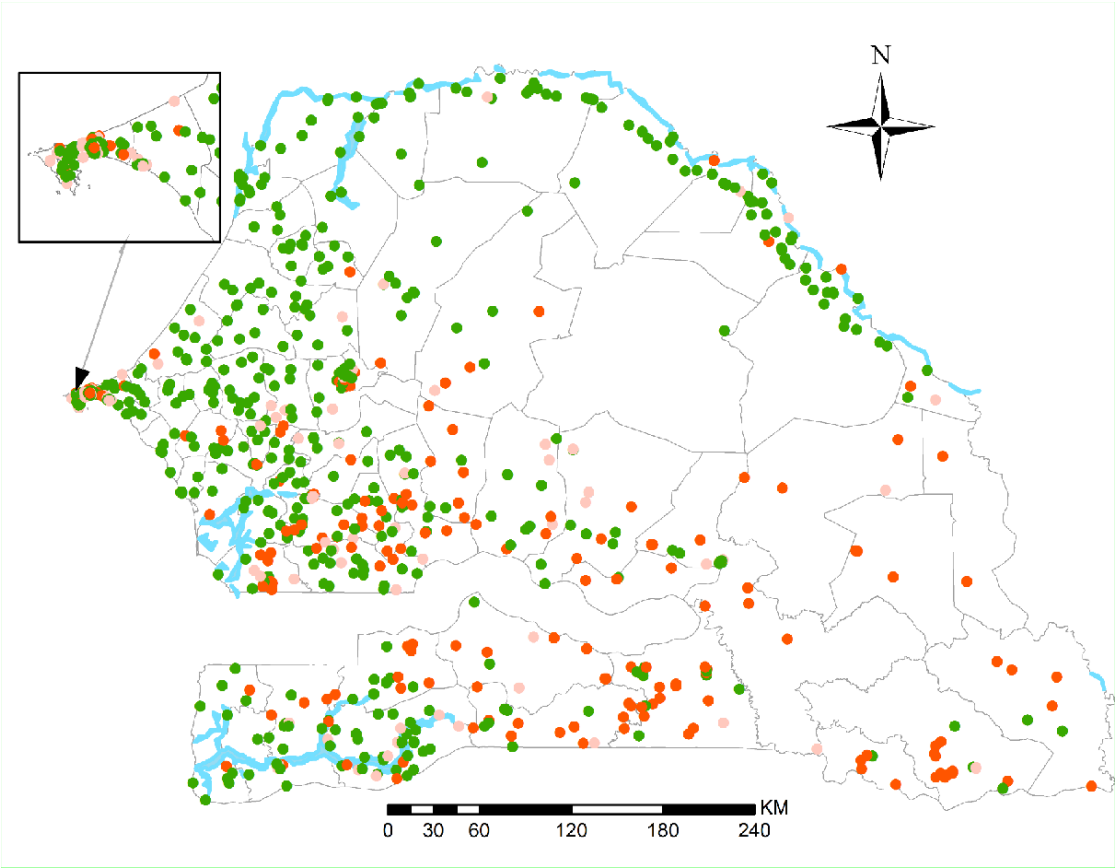
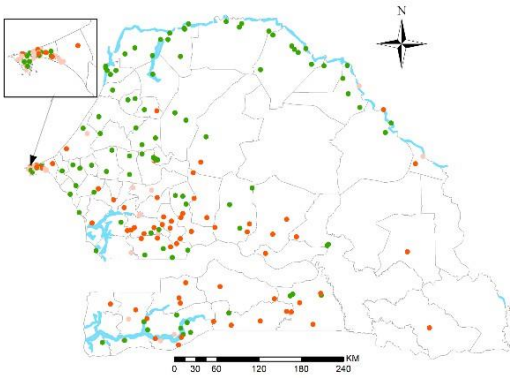
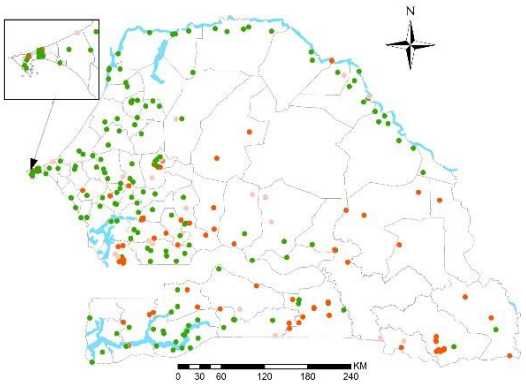


Figure 7.2 Location of age-corrected parasite prevalence data (P*f*PR2-10) (Green=zero: light orange >0 - <5%: dark orange >=5%)

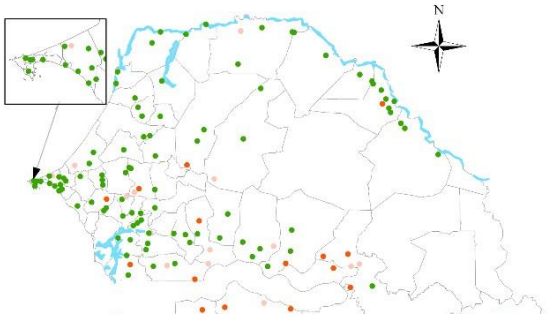
Location of 211 age-corrected parasite prevalence data (*Pf*PR2-10): 2008-2009



Location of 252 age-corrected parasite prevalence data (*Pf*PR2-10): 2010-2011



Location of 157 age-corrected parasite prevalence data (*Pf*PR2-10): 2012-2013



Location of 165 age-corrected parasite prevalence data (*Pf*PR2-10): 2014

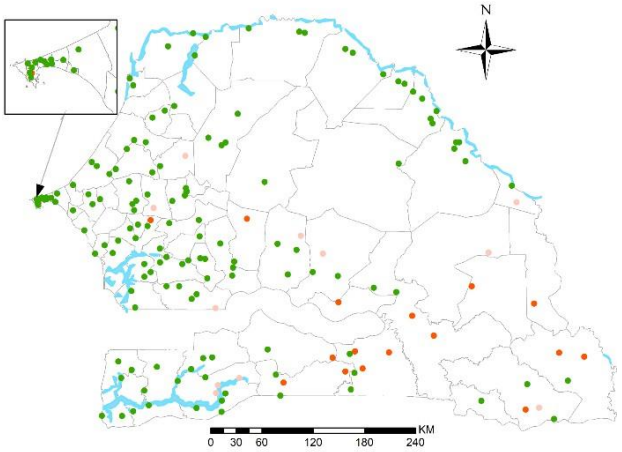


Figure 7.3 shows the evolution of malaria risk, reflected by the P*f*PR2-10, between 2008 and 2014. The accompanying pie chart represents the proportion of the population living at different levels of malaria risk. It is clear that the proportion of the population living at low risk of malaria (P*f*PR2-10 1-5%) has increased from 56% in 2008 to 67% in 2014, with a corresponding decrease in the population living at higher (especially P*f*PR2-10 5-10%) levels ofrisk.

Figure 7.3 Population adjusted P*f*PR 2-10 prediction by health district

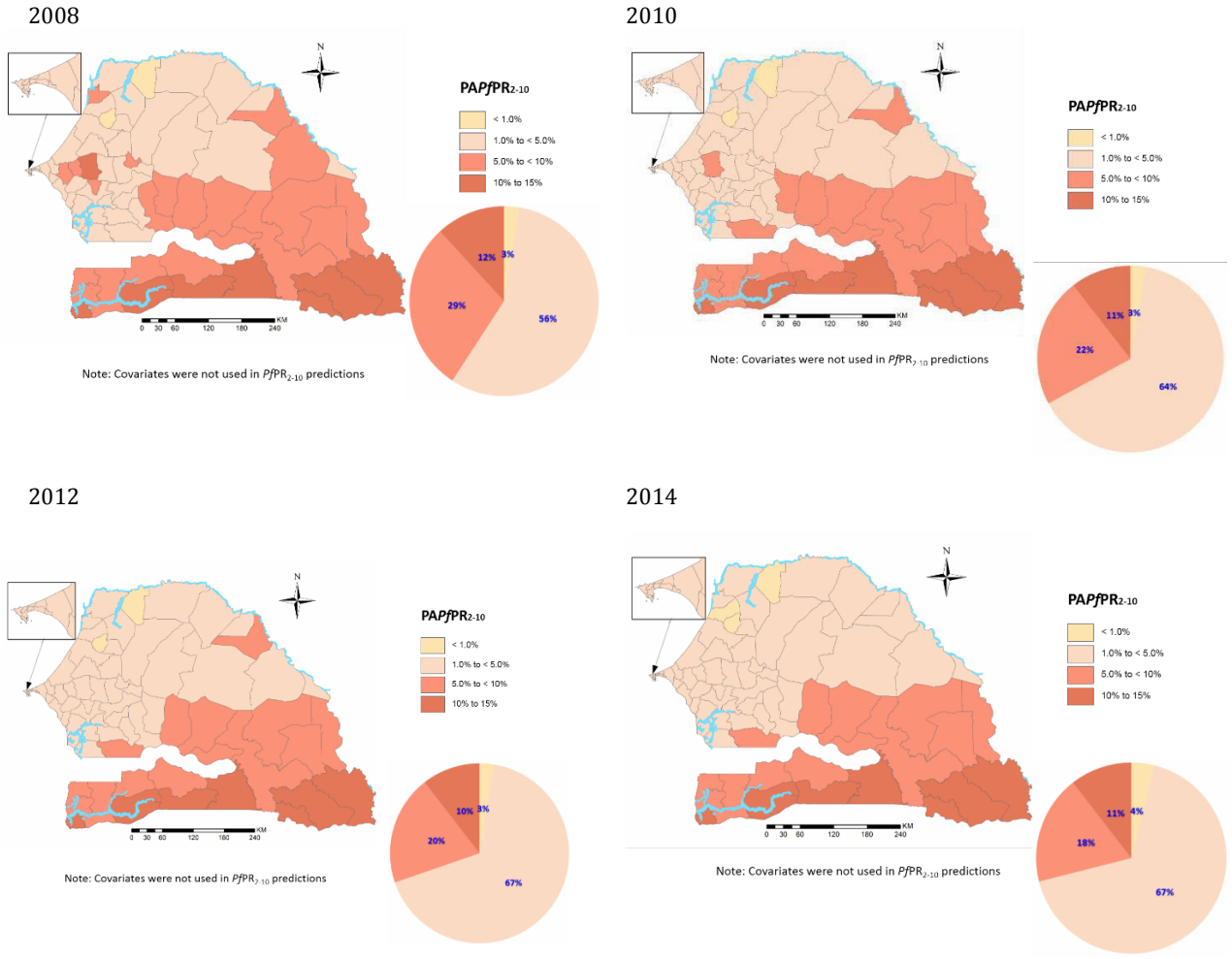
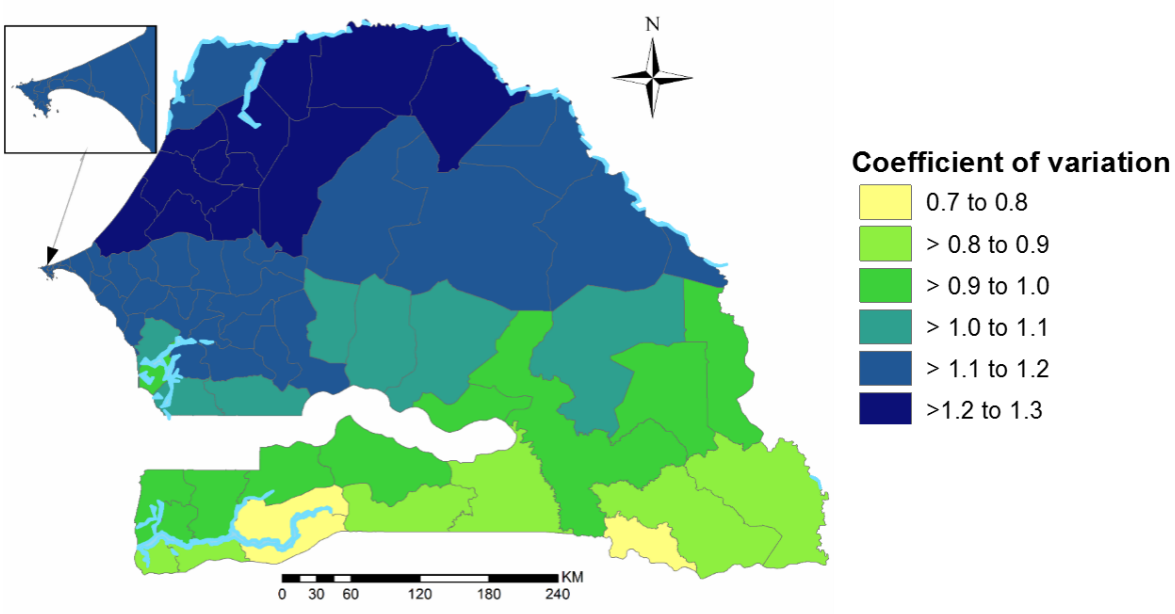


Figure 7.4 Senegal: P*f*PR 2-10 model precision. The coefficient of variation (ratio of standard deviation to mean) is used as a measure of uncertainty



The population adjusted 2014 P*f*PR$_{2-10}$ model was validated as described earlier (Estimating Precision in Section 6.3.1: Space-time geostatistical modelling).

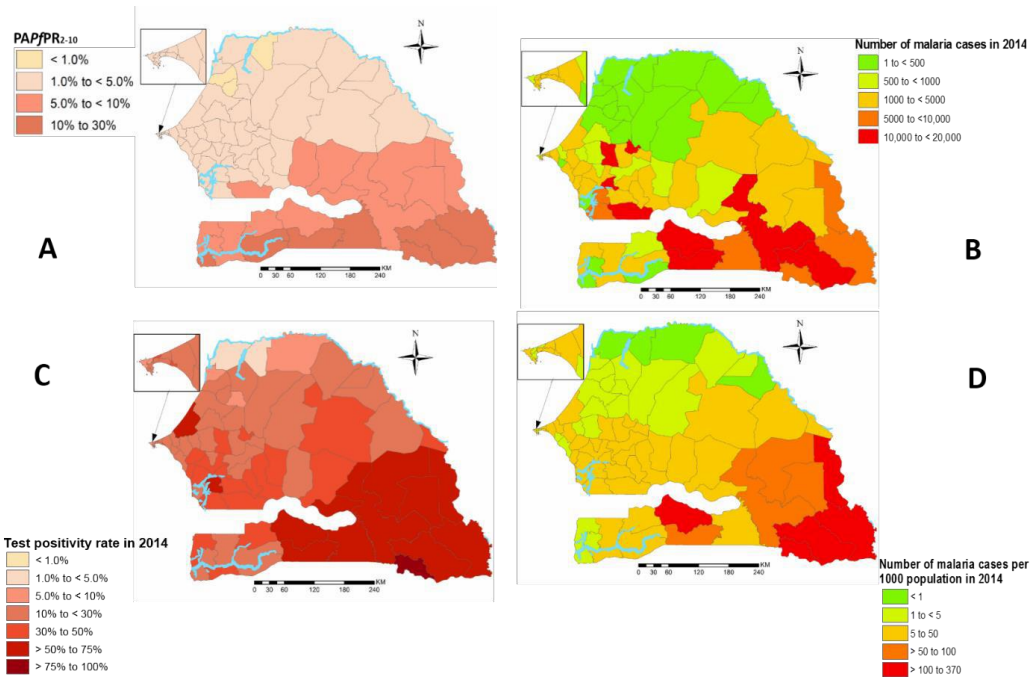
Estimates were computed from a comparison of the predictions and observations for a 10% "hold out" dataset. The precision parameter estimates were a linear correlation of 0.72, a mean percentage error (MPE) of 1.4%; and a mean absolute percentage error (MAPE) of 4.7%. These statistics suggest satisfactory model accuracy.

Generally, low coefficient of variation (CV) values suggest that the standard deviations around the mean are relatively small, whereas high values may indicate increasing model uncertainty.[70] In Senegal the upper limit of the CV values is around 1 (Figure 7.4) indicating that in most districts predictions of PA*Pf*PR$_{2-10}$ are of good precision. The highest CV values appear to be in the lower transmission but sparsely populated districts of the north. To improve the precision of estimates for these districts, future surveys could consider over-sampling in these districts. Alternatively, household surveys could be supplemented with bespoke school parasiteamia surveys.

7.1 Malaria case and case incidence mapping

Routine malaria case data for January to December 2014 were available to the NMCP and included 1,210 public health facilities and 153 private health facilities. These data were summarised by district to compute total case numbers (Figure 7.5b) slide positivity rate (Figure 7.5c) and case incidence (Figure 7.5d), per district.

Figure 7.5 Senegal: comparison of PA*Pf*PR$_{2-10}$, cases, test positivity rate and case incidence in 2014 by health district



70 Noor AM, Alegana VA, Patil AP, Moloney G, Borle M, Ahmed F, Yousef F, Amran J, Snow RW (2012). Mapping the receptivity of malaria risk to plan the future of control in Somalia. *British Medical Journal Open Access*, **2**: e001160.

Comparisons of PA*Pf*PR$_{2-10}$, test positivity rate (TPR) and case incidence for 2014 present a mixed and in some cases conflicting epidemiological profile. Some areas with low PA*Pf*PR$_{2-10}$ seem to have high TPR. Some districts with very low cases numbers and case incidences also show high TPR. Geolocations were available for 1,116 (92%) of the public health facilities that reported malaria cases in 2014. The reported case numbers and test positivity rates are presented for each health facility, by region and health district in Figures 7.6-7.9.

The utility of these analyses could be enhanced by the following:

1. Establish an authenticated master list of health facilities to determine accurately the proportion that report data (reporting rate).
2. Define health facility catchments areas to determine the actual catchment population so that utilisation rate can be estimated when computing case incidence. Undertake quality assurance of malaria case data in selected districts where the different metrics do not reconcile.
3. It is important to assure the quality of reported data, the proportion of cases that are likely to be imported and the prevalence of infection in the communities from which the cases are drawn.
4. Agree on the metrics to track progress for each district.

Figure 7.6 Senegal: malaria cases and test positivity rate in 2014 by region and district

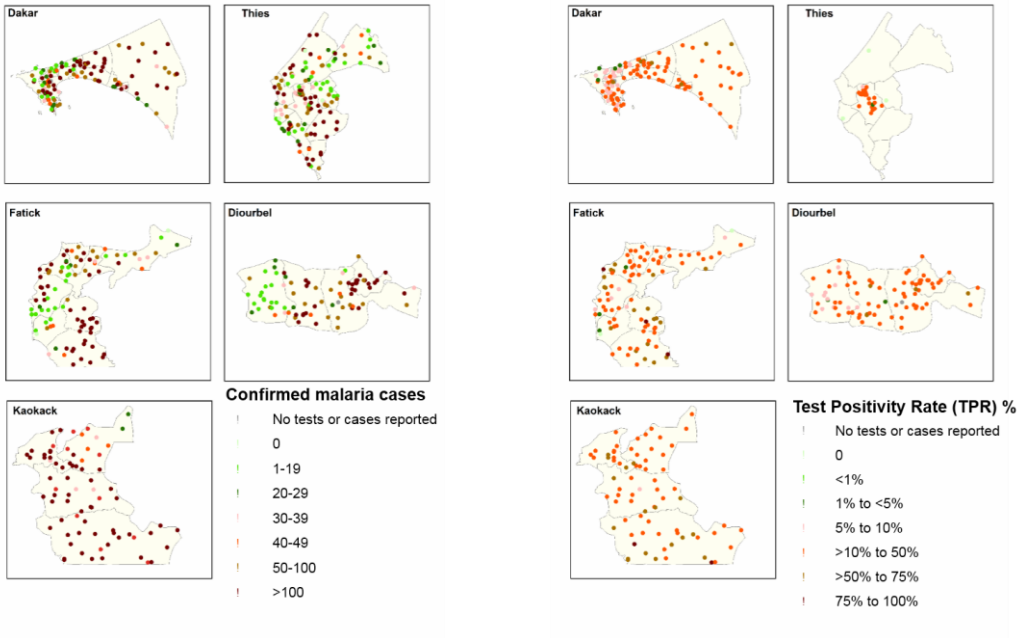
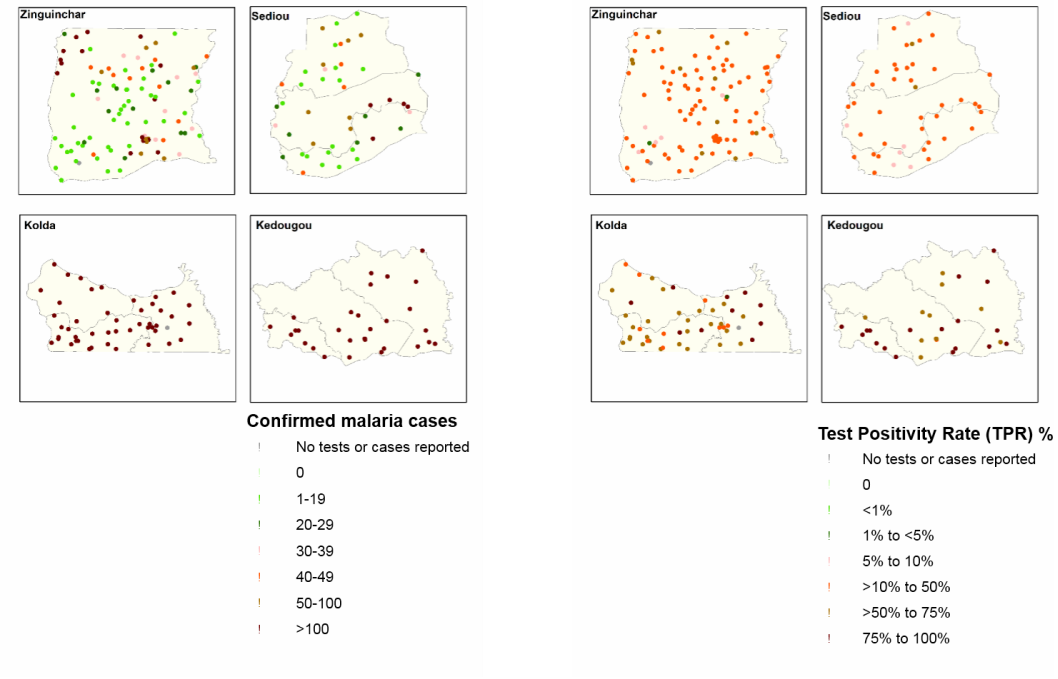


Figure 7.7 Senegal: malaria cases and test positivity rate in 2014 by region and district

Figure 7.8 Senegal Malaria cases and test positivity rate in 2014 by region and district



8. Entomological profile

The final entomological database contained 500 site/time-specific reports of *anopheline* vectors in Senegal, reported between 1902 and 2014 and for which we were able to geolocate the survey site (Figure 8.1).

Figure 8.1 Mosquito sampling sites in Senegal. Location of 500 surveys undertaken between 1902 and 2014

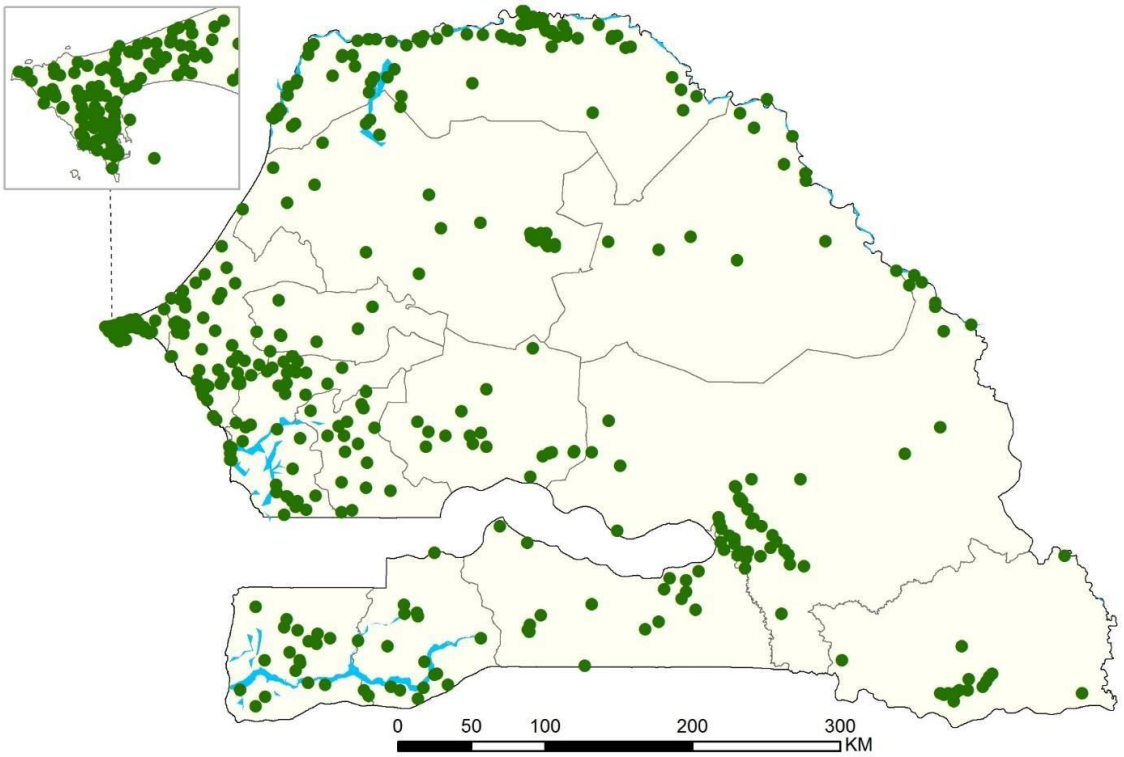


Figure 8.2 shows the subset of data generated between 2005 and 2014. We were unable to geolocate 18 (3.5%) of the survey sites.

The database includes site specific data-rich West African Map of the Office of Scientific and Technical Research Overseas, compiled in 1955,[71] sub-national surveys undertaken in different regions of Senegal during the 1930s[72] and 1950s;[73] national surveys of vector species compositions during the 1990s;[74] data, cross-referenced, from a malaria vectors profile developed in 2011;[75] and recent data from national sentinel sites (NMCP and partners, unpublished data).

71 Hamon J, Adam JP, Grjebine A (1956). Observations sur la répartition et le comportement des anophèles de l'Afrique- Equatoriale Française, du Cameroun et de l'Afrique Occidentale. *Bulletin of World Health Organization*, **15**: 549–591.
72 Cazanove F (1932). Les moustiques à Dakar en 1931. Bulletin de la Société de Pathologie Exotique, 7: 797–817.
73 Hamon J, Devemy P, Rickenbach A, Causse G (1956). Contribution à l'étude des moustiques de la Casamance. Annales de Parasitologie Humaine et Comparée, 31: 607–618.
74 Konaté L, Faye O, Gaye O, Sy N, Diop A, Diouf M, Trape JF, Molez JF (1999). Zoophagie et hôtes alternatifs des vecteurs du paludisme au Sénégal. Parasite, 6: 259–267.
75 République du Sénégal, Ministère de la Sante et de la Prévention (2011). Programme National de Lutte contre le Paludisme. Profil entomologique du paludisme au Sénégal. June.

We have not assembled geocoded information related to vector resistance; these data have been carefully curated, validated and mapped by the IRBase initiative[76,77]

Figure 8.2 Mosquito sampling sites in Senegal. Location of 280 surveys undertaken between 2005 and 2014

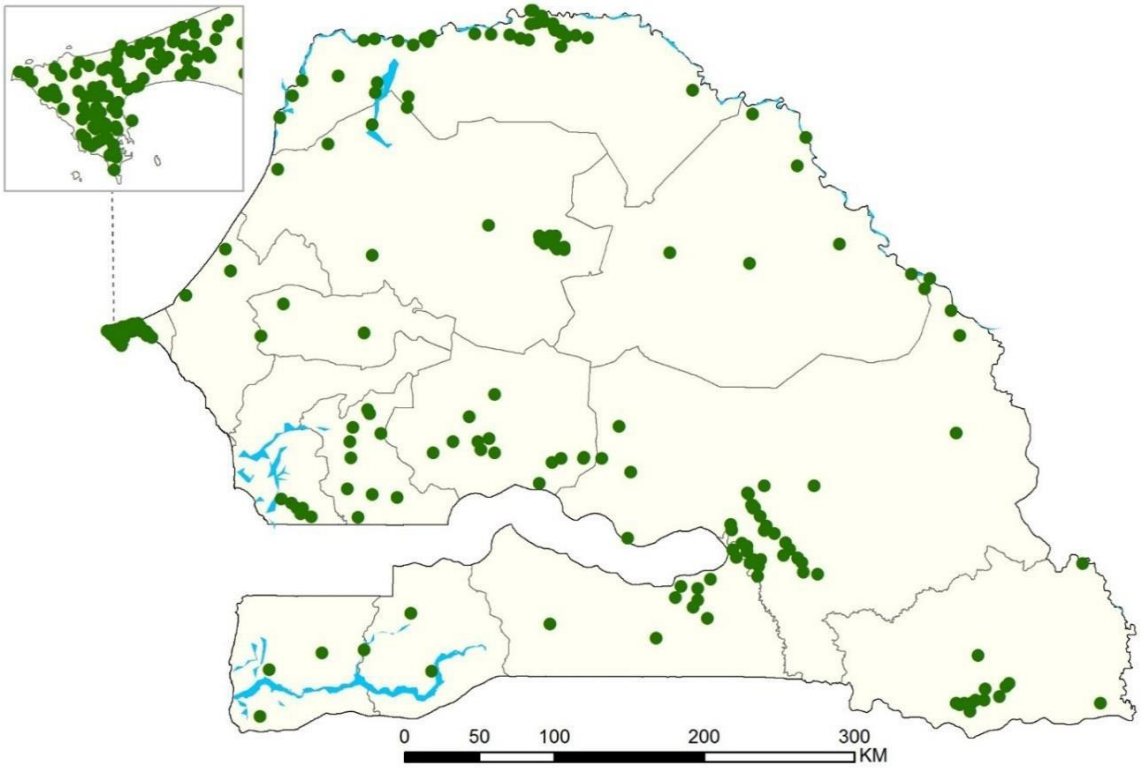


Figure 8.3 summarises the available information on reported mosquito species in Senegal. The presence of the *An. gambiae* complex and the *An. funestus* group are sympatric across the entire county. However there is a predominance of *An. funestus* in the south and southeastern regions of the country[78]

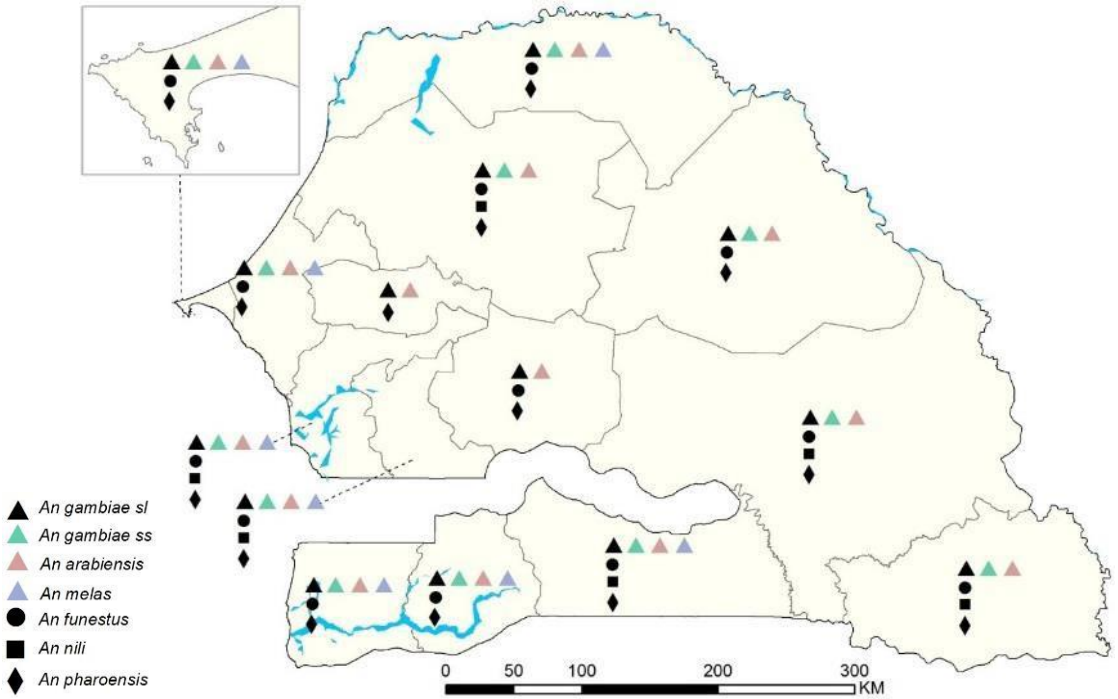
Among the *An. gambiae* complex, *An. gambiae ss* (both M [*An. Colluzzi*] and S forms) and *An. arabiensis* have been recorded in almost all the regions of Senegal. Salt water breeding members of the *An. gambiae* complex have been identified along the coastal regions, further inland along the Casamance River[79] and inland at Ndoffane (Kaolack region) and Kandiadiou and Senoba (Sedhiou region)[80].

76 Knox TB, Juma EO, Ochomo EO, Pates Jamet H, Ndungo L, Chege P, Bayoh NM, N'Guessan R, Christian RN, Hunt RH, Coetzee M (2014). An online tool for mapping insecticide resistance in major Anopheles vectors of human malaria parasites and review of resistance status for the Afrotropical region. *Parasites & Vectors*, **7**: 76.
77 www.irmapper.com
78 Hamon J, Devemy P, Rickenbach A, Causse G (1956). Contribution à l'étude des moustiques de la Casamance. *Annales de Parasitologie Humaine et Comparée*, **31**: 607–618.
79 Davidson G (1966). Distribution records of member species of the *Anopheles gambiae* Complex (identifications up to May 1966). WHO/Mal/66.570; World Health Organization Archive, Geneva
80 Bryan JH, Di Deco MA, Petrarca V, Coluzzi M (1982). Inversion polymorphism and incipient speciation in *Anopheles gambiae s.str*. in The Gambia, West Africa. *Genetica*, **59**: 167–176.

An. nili[81] and *An. pharoensis*[82] are considered secondary vectors of malaria in Senegal. *An. hancocki* has been described in Senegal in only three areas: Barkédji and Ngari (Louga) and Kédougou (Kedougou region). It is not clear, however, whether *An. hancocki* plays any role in transmission of malaria in Senegal. *An rivulorum*, a member of *An. funestus* group, and *An. moucheti* have not been described in Senegal.

Reports of other *anopheline* species, either non-vectors or considered incidental vectors of malaria, since 1939 include *An. brohieri, An. brunnipes, An. coustani, An. domicolus, An. flavicosta, An. freetownensis, An. ingrami, An. maculipalpis, An. paludis, An. pretoriensis, An. rufipes, An. squamosus, An. wellcomei and An. ziemanni*.

Figure 8.3 Mosquito species recorded in Senegal. All surveys, by region



81 Dia I, Diop T, Rakotoarivony I, Kengne P, Fontenille D (2003). Bionomics of *Anopheles gambiae* Giles, *An. arabiensis* Patton, *An. funestus* Giles and *An. nili* (Theobald) (Diptera: Culicidae) and transmission of *Plasmodium falciparum* in a Sudano-Guinean zone (Ngari, Senegal). *Journal of Medical Entomology*, **40**: 279–283.
82 Carrara GC, Petrarca V, Niang M, Coluzzi M (1990). *Anopheles pharoensis* and transmission of *Plasmodium falciparum* in the Senegal River delta, West Africa. *Medical & Veterinary Entomology*, **4**: 421–424.

9. Intervention coverage

9.1 Insecticide treated mosquito nets (ITN) and long lasting ITN (LLIN)

Manufacturers' distribution data for ITN (up to 2006) and LLIN (2006 onwards) were provided by the ALMA-RBM harmonisation working group, which maintains data on the numbers of nets delivered to each country each year (Melanie Renshaw, personal communication, 2015). These data are assembled by the Alliance for Malaria Prevention (http://allianceformalariaprevention.com/working-groups-view.php?id=19). Data do not always reflect actual in-country distributions by NMCP and partners. Procurements may include those made by private entities and sold through the commercial sector.

Data have been arranged as follows: nets delivered in 2004 and 2005 (assumed to be ITN only) would have lasted for one year in the absence of re-treatment. We have assumed that LLIN would remain effective in the year they are delivered and for three years afterwards, by which time they would have lost efficacy. Figure 9.1 shows therefore a cumulative in-country availability of mosquito nets. This is not usage or coverage, which are modelled from household surveys below.

Figure 9.1 Cumulative national importation of ITN/LLIN to Senegal: 2004–2014

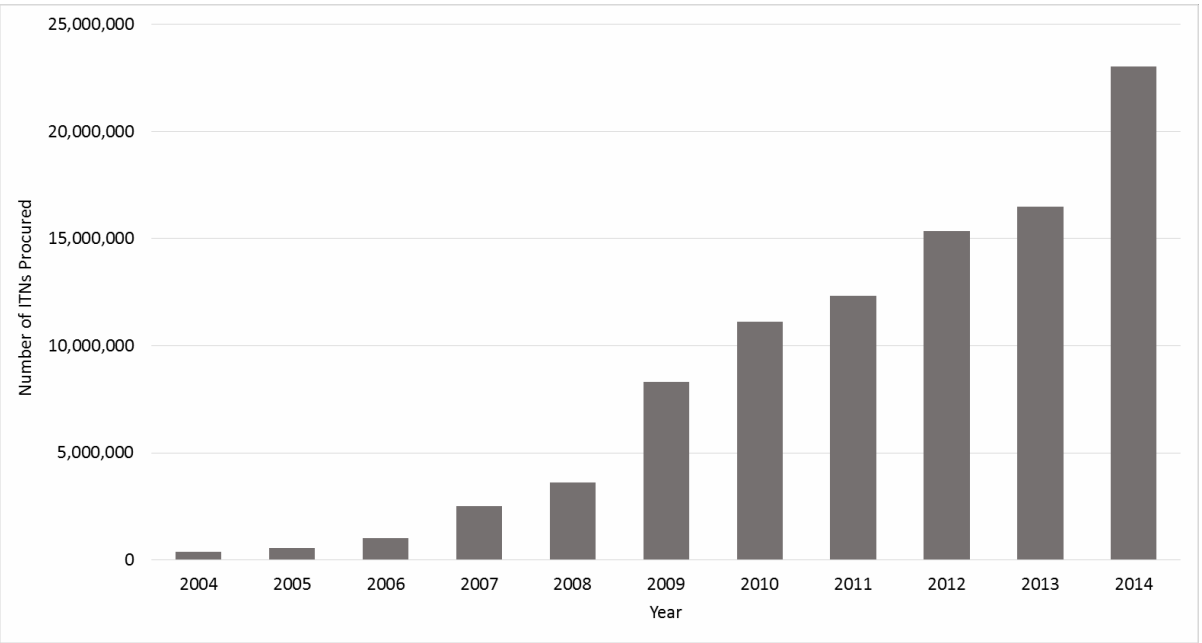
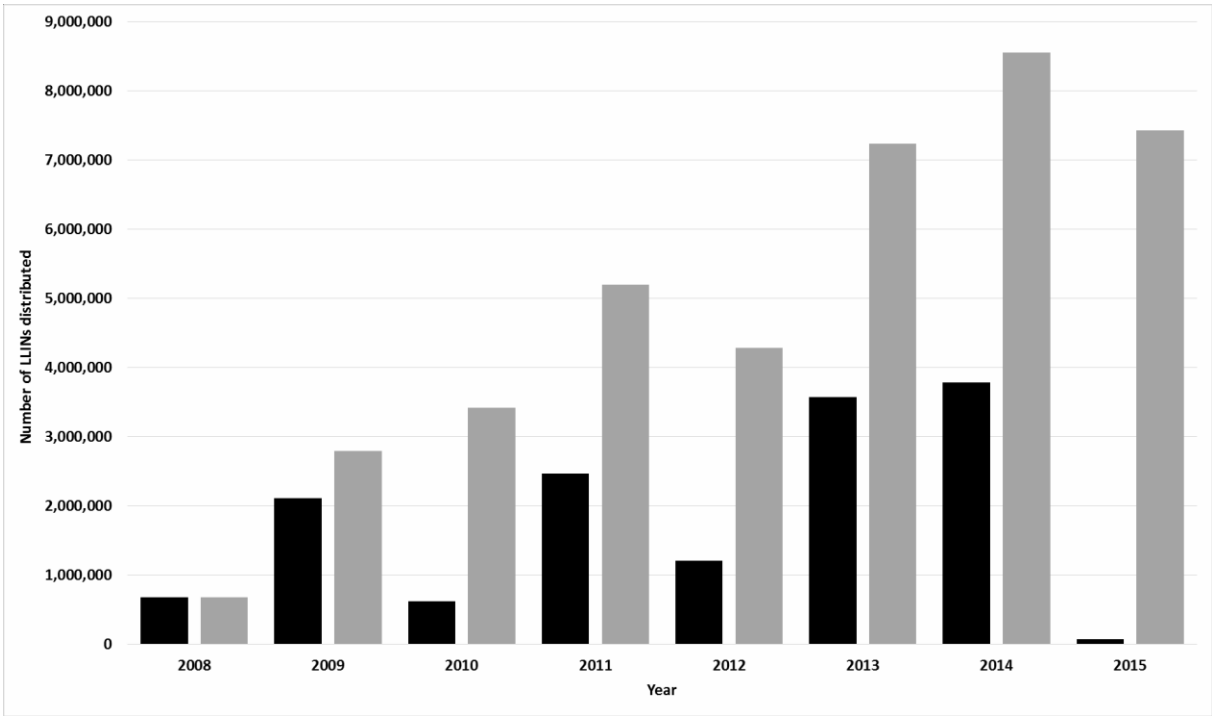


Figure 9.2 presents data on ITN distribution by the NMCP and partners from 2008 to 2015. Cumulative effective ITN distribution was computed by assuming that LLINs remain effective for three years from the year of distribution; LLIN distribution more than three years previously was therefore excluded from the cumulative figure. Estimates may vary if the actual month of distribution was used to compute the lifespan of the LLINs. Data shown include distribution through free mass campaigns and the routine system.

Figure 9.2 National and cumulative effective distribution of ITN/LLIN in Senegal: 2008-2015



The number of LLIN distributed per district between 2008 and 2015 are presented in Figure 9.3. In 2009, 274,603 LLINs were distributed through the routine system and 2.2 million LLINs during mass campaigns. The map for 2009, however, shows only the mass campaign distribution as district level routine systems data were not available.

Data from nationally representative household surveys were complemented by ITN/LLIN distribution data, where available, to estimate key ITN/LLIN coverage indicators (Figure 9.4). The proportion of the population sleeping under ITNs/LLIN, and the proportion of households with at least one ITN for every two persons, are presented for a number of years between 2005 and 2014. The marked increase in coverage is clearly portrayed.

Figure 9.3 Senegal: number of LLINS distributed to households through mass distribution campaigns and routine programmes

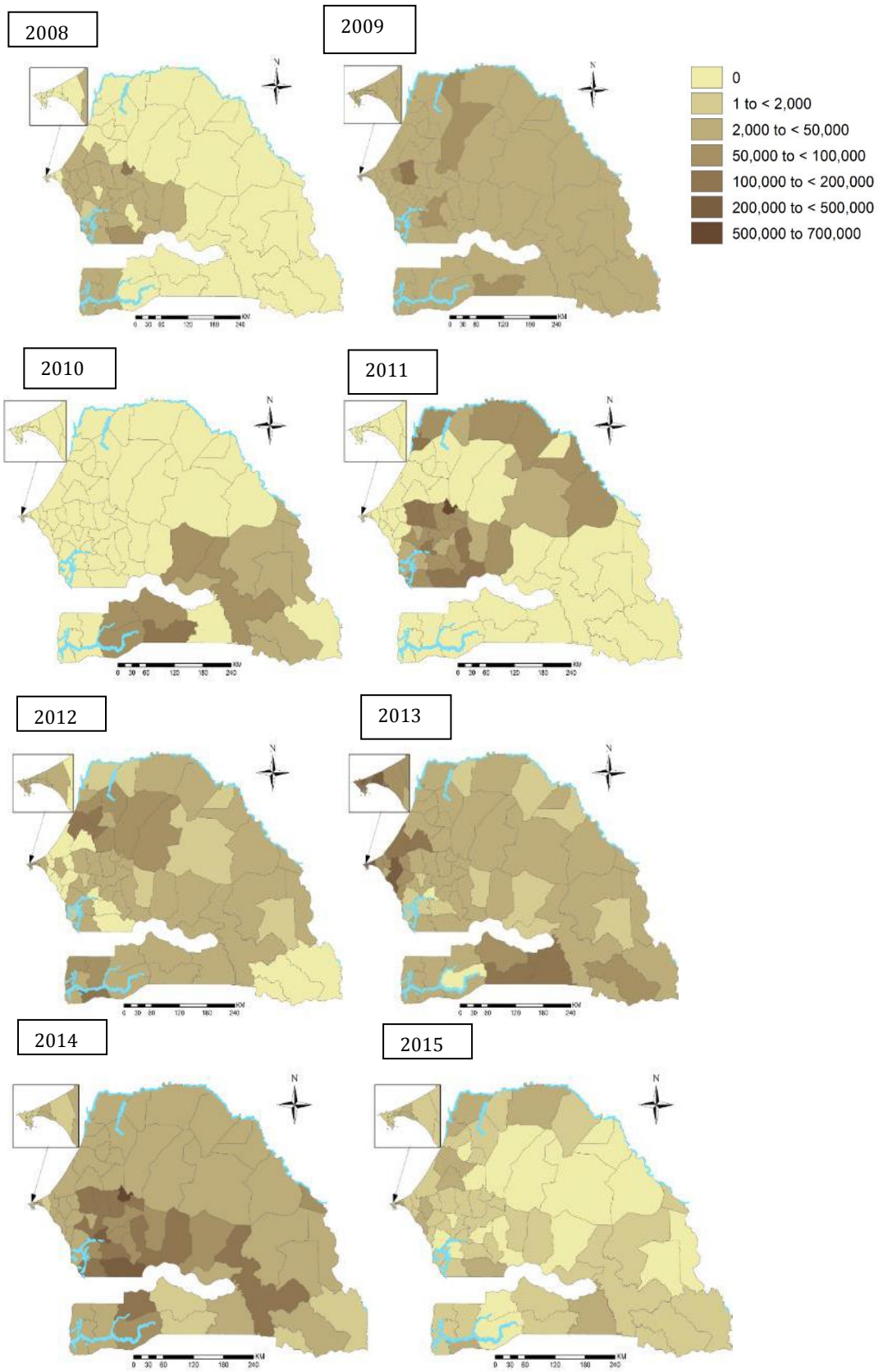
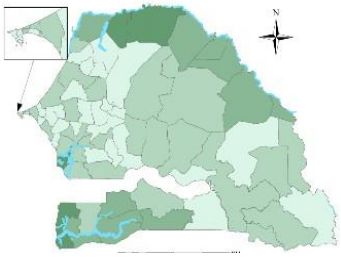


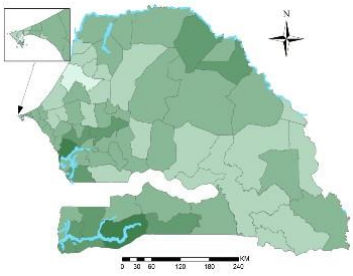
Figure 9.4 Proportion of population sleeping under ITN/ households with at least one ITN

Proportion of population sleeping under ITN

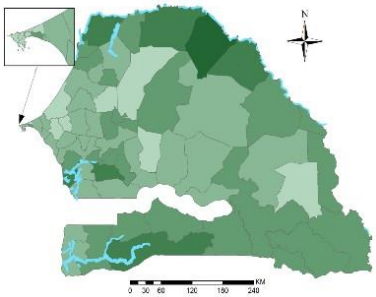
2005



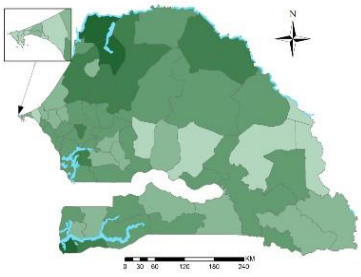
2008



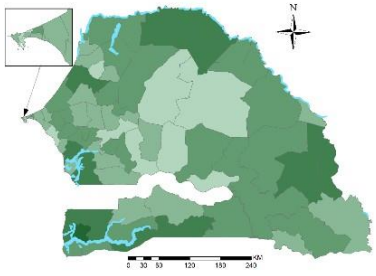
2010



2012



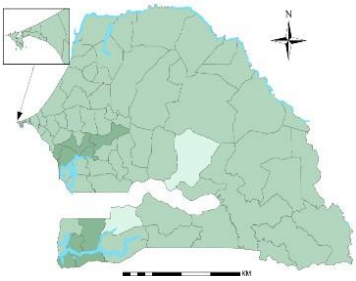
2014



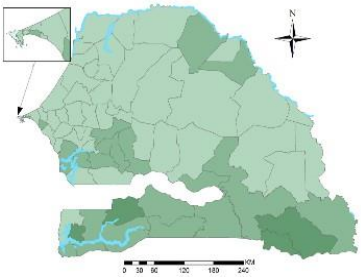
Households with at least one ITN for every two persons

2005

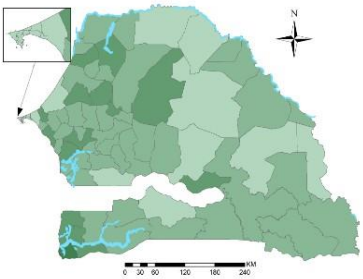
2008



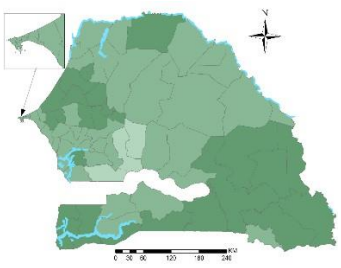
2010

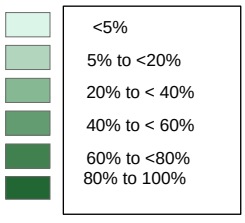


2012



2014

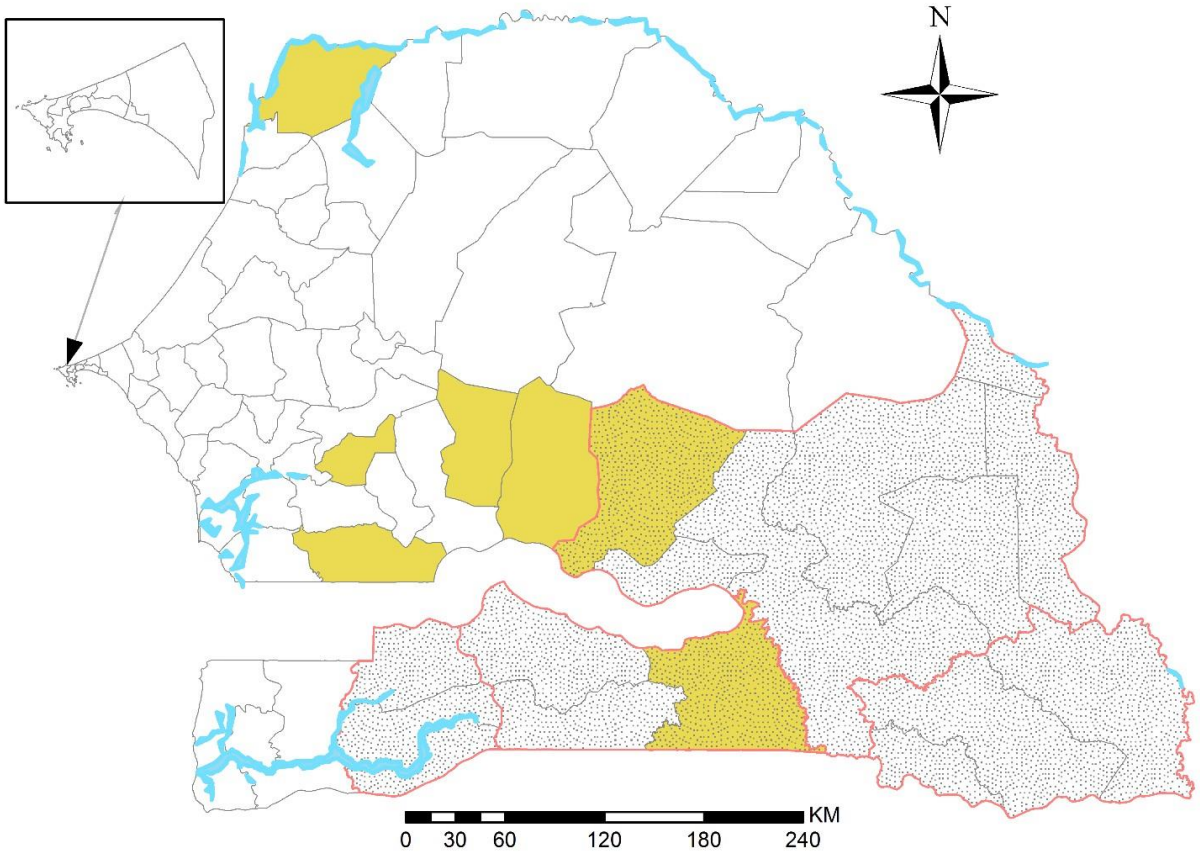




9.2 Indoor residual spraying

Figure 9.5 shows the districts targeted for Indoor Residual Spraying (IRS) since 2007. These were Velingara (2007-2014), Guinguineo (2010-2012), Matam Hodaar (2010-2015), Koumpentoum (2010-2015), Nioro (2007-2012; 2015), Richard Toll (2007-2010) and Koungheul (2011-2015). Indoor residual spraying was conducted on a limited basis by mining concerns in Saraya (2008).

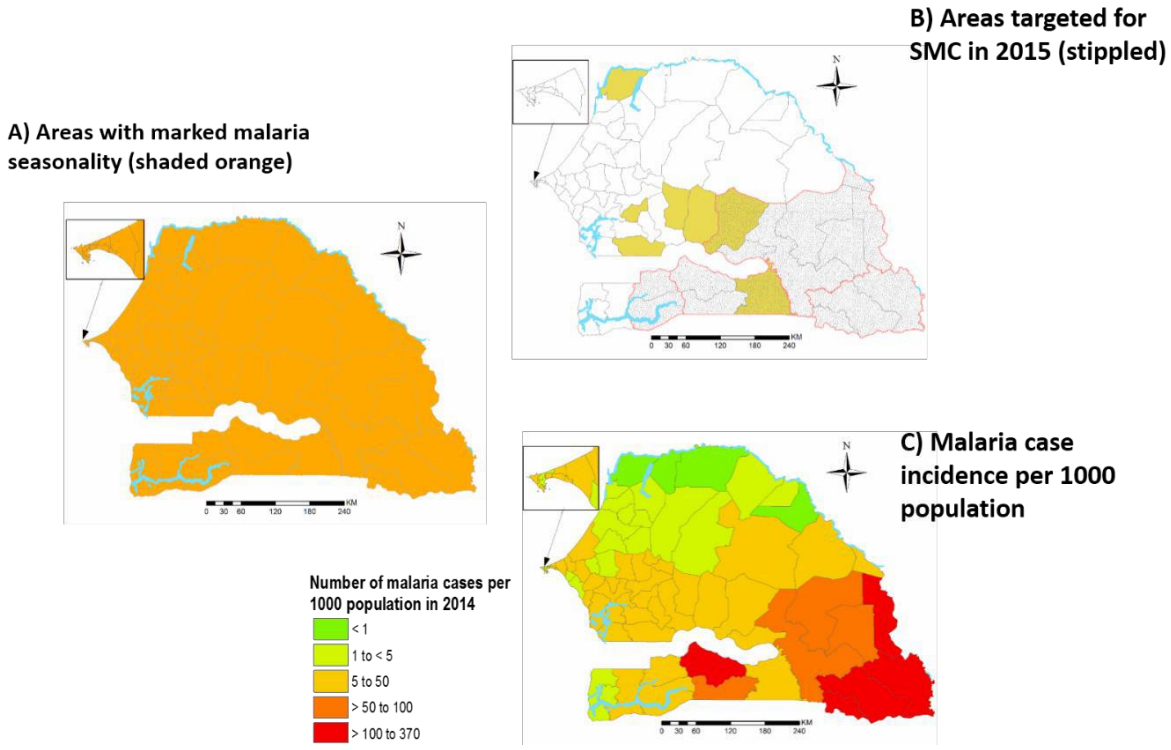
Figure 9.5 Senegal: districts (yellow) targeted for irs using alpha-cypermethrin or deltamethrin since 2008; and areas now targeted for SMC (stippled) (IRS: indoor residual spraying. SMC: seasonal malaria chemoprevention



10. Special considerations

Seasonal malaria chemoprevention (SMC) is recommended by WHO for areas where: (i) malaria transmission is intensely seasonal, with at least 60% of clinical malaria cases occurring within a maximum of four months; (ii) the clinical attack rate of malaria is greater than 0.1 per transmission season in the target age group, and (iii) AQ+SP remains efficacious (>90% efficacy). Figure 10.1 shows the districts targeted for SMC in Kedougou, Tambacounda, Sedhiou and Kolda regions.

Figure 10.1 SMC in Senegal



The approach developed by Cairns et al[83] was used to define areas of acute seasonal transmission suitable for SMC, on the basis that 60% or more of the annual rainfall occurs in three consecutive months. To reproduce this metric we used daily rainfall estimates from the Africa Rainfall Estimates version 2 (RFE 2.0) from 2002-2009 at 10 km × 10 km spatial resolution[84,85] as synoptic monthly average rainfall surfaces re-sampled to 1 km x 1 km using ArcGIS (Version 10.1. ESRI Inc., USA). The analysis shows that all of Senegal experiences marked rainfall seasonality. According to the data from routine information systems, all districts targeted for SMC had crude population malaria case incidence rates of ≥5 cases per 1,000 population in 2014.

83 Cairns M, Roca-Feltrer A, Garske T, Wilson AL, Diallo D, Milligan PJ, Ghani AC, Greenwood BM (2012). Estimating the potential public health impact of seasonal malaria chemoprevention in African children. *Nature Communications*, **3**: 881

84 Novella N and Thiawa W (2012). Africa rainfall climatology version2. NOAA/Climate Prediction Centre. www.cpc.ncep.noaa.gov/products/fews/AFR_CLIM/afr_clim Accessed 12 March, 2017.

85 NWS (2012) ftp://ftp.cpc.ncep.noaa.gov/fews/newalgo_est/

Epidemiology and control profile of malaria in

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