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**Spectrum-Malaria: a projection tool for health impact assessment and   
strategic planning for malaria programs in sub-Saharan Africa**

**Model structure, methods and assumptions**

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**SUMMARY**

Background

Spectrum-Malaria is a model of health impact and cost of malaria intervention packages, intended to inform strategic planning at the national level. The model was developed by Avenir Health (Avenir) in collaboration with the Swiss Tropical and Public Health Institute (Swiss TPH), the Malaria Atlas Project (MAP), and the WHO. Spectrum-Malaria is implemented as part of the Spectrum suite of policy models and is freely available online.

Spectrum-Malaria projects the impact of changes in the coverage of five key interventions on case incidence and deaths in three age groups (0–4 years, 5–14 years, and 15+ years) and prevalence of *Plasmodium falciparum* infection (*Pf*PR) among children aged 2–9 years. The interventions insecticide-treated nets (ITNs), indoor residual spraying (IRS), seasonal malaria chemoprophylaxis (SMC), and effective management of uncomplicated cases (CMU) each reduce the *Pf*PR, case incidence and malaria mortality with both short-term immediate and longer-term population-level effects through indirect dynamic transmission reduction. In addition, effective management of severe malaria cases is modelled to reduce malaria mortality, as an immediate impact on beneficiaries receiving the intervention but without indirect transmission effects.

Methods/Approach

Spectrum-Malaria is intended to strike a balance between practical usability of a simple model and the accuracy and specificity of a state-of-the-art dynamical, but computationally intensive model. Spectrum-Malaria impact estimates are derived from the OpenMalaria model, developed by Swiss TPH, for the four interventions projected with long-term transmission effects. OpenMalaria simulates the dynamics of malaria transmission and epidemiology in mosquito and human populations, and effects of malaria control. It is far too complex to be easily used by policymakers for strategic planning, yet this complexity is necessary in order to realistically capture malaria dynamics. Rather than implement a simplified version of the full OpenMalaria model, Spectrum-Malaria impact estimates are based on statistical regression models fitted to a large set of OpenMalaria simulations, which collectively cover the realistic range of variation in and combinations of factors governing malaria endemicity parameters and intervention coverages.

The statistical impact functions are described in a companion report [[1](#_ENREF_1)]. The current report describes how statistical impact functions are combined with a database of malaria endemicity, epidemiology and control situations in countries and their provinces between 2000 and 2015, to project scenarios of future burdens and impacts over 2016–2030. Interaction of Spectrum-Malaria with the OneHealth Tool and Lives Saved Tool, for planning and costing of commodities to enable a projected program scale-up, is described in a forthcoming dedicated malaria costing report.

Spectrum-Malaria model outputs are summarized at country level, but impact is estimated at sub-national scales. Malaria epidemiology and intervention impact vary widely as a function of environmental factors such as seasonality, rainfall and geography, as well as dominant vector species and degree of anthropophagy. It is therefore necessary to model intervention impact at subnational spatial scales. The MAP provided data on malaria case incidence by age, parasite prevalence and ITN coverage at 5 km2 resolution. We aggregated this data to the district/province level, and model intervention impact at that scale. Estimates of country-level malaria mortality from GMP were allocated to districts, and between age groups, applying the MAP-estimated distribution of cases over districts and between 5–14 years versus 15+ years.

An additional health outcome modelled is the incidence of severe malaria cases, which (in the absence of official WHO country estimates) was modelled by applying to WHO MAP-based total case incidence within each of the three age groups, a ratio of severe-to-total malaria case incidence based on OpenMalaria simulations, summarized in statistical regressions using the same district-level endemicity predictor variables as for the intervention impact functions (*Plasmodium falciparum* parasite prevalence, seasonality, and baseline coverages)

For program scale-up projections, the user specifies intervention coverage at the national level, and this coverage is allocated to districts or provinces according to the distribution of coverage obtained at baseline. The impact of intervention is then calculated at the subnational level, and then aggregated back up to the national level.

Pilot applications

Spectrum-Malaria has been set-up and filled with baseline burden and intervention coverage data for 43 sub-Saharan African countries. It was piloted so far for Democratic Republic of the Congo (DRC), Zambia, Nigeria and Senegal. Data of epidemiological, control scale-up over 2000–2015 for these countries were obtained from WHO-GMP and MAP (latest estimates available as of October 2015). Scale-up scenarios were defined to reflect the national strategic plan for malaria control 2016–2021 of DRC, which was inspired by the WHO’s Global Technical Strategy for malaria control [[2](#_ENREF_2)].

In projections for all pilot countries, malaria control scale-up reduces health burdens in all age groups, with fairly similar proportional reductions across the three age groups modelled, and largest proportional burden reductions in lower-endemic settings, but larger absolute numbers of infections and deaths averted in the higher-endemic settings. The provisional results suggest that the ambitious global WHO, Roll Back Malaria and sustainable development goals (SDG) targets to reduce case incidence and mortality globally by 80% by 2025 may be feasible if scale-up to universal coverage of vector control combined with effective case management is achieved in the highest-burden countries, including at minimum Nigeria and DRC. An in-depth pilot is ongoing with the National Malaria Program in DRC, to explore the morbidity and mortality impacts expected from intervention scale-up as targeted in the national strategic plan 2016-2020.

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* *WHO Global Malaria Programme*: Richard Cibulskis, Edith Patouillard;
* *WHO* *Health Systems Governance and Financing* department: Jeremy Lauer;
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**BACKGROUND INFORMATION :**

<http://www.avenirhealth.org/software-spectrum.php>   
<https://github.com/SwissTPH/openmalaria>   
<http://www.who.int/choice/onehealthtool/en/>   
<http://www.map.ox.ac.uk/>

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**DESCRIPTION SOMMAIRE DE SPECTRUM-PALUDISME (Français)**

*Spectrum-Malaria* est un modèle pour l’étude des besoins en ressources et l'impact des programmes d'intervention contre le paludisme sur la santé. Il est destiné à éclairer la planification stratégique des programmes de lutte contre le paludisme et les ministères de la santé des pays d'Afrique sub-saharienne.

Ce modèle est développé par Avenir Health, en collaboration avec l'Institut Tropical et de Santé Publique Suisse (Swiss TPH), Malaria Atlas Project (MAP), et l’OMS (le Programme mondial de lutte anti-Paludique, et département du Financement des Systèmes de la Santé, et). *Spectrum-Malaria* est mis en œuvre dans le cadre d’une série de modèles de Spectrum, et sera disponible gratuitement en ligne.

Les impacts de l’intensification des interventions sur le fardeau du paludisme sont projetés à l'aide des fonctions statistiques qui décrivent l'efficacité selon les niveaux de couverture des interventions. Le modèle prend en compte l’endémicité, la saisonnalité et d’autres caractéristiques épidémiologiques et de santé. L’apprentissage statistique des fonctions d’efficacité s’est fait sur des simulations d’épidémies obtenues par le modèle dynamique de transmission du paludisme, OpenMalaria, développé et validé par Swiss TPH.

Les projections d’impact utilisent les estimations officielles passées de cas et de décès dus au paludisme. Elles se basent sur les caractéristiques d’endémicité, la couverture des MII, IRS et la gestion efficace des cas dans les trois groupes d'âge (0-4 ans, 5-14 ans et 15 ans), et sur la prévalence du *Plasmodium falciparum* chez les enfants âgés de 2 à 9 ans, tels qu’estimés par l’OMS au niveau national et au niveau provincial (pour certains indicateurs), jusqu’en 2014/2015. Les projections futures peuvent aller jusqu’en 2030 et sont faites en fonction de la présence ou non de l’intensification des interventions telles que les MII/MILDs, le PID, la prise en charge efficace des cas (cas simples et graves) et la chimio-prophylaxie du paludisme saisonnière.

Pour ce qui est des projections des ressources nécessaires pour atteindre les couvertures cibles spécifiées par l’utilisateur (sur 2016-2030), Spectrum-Malaria fait un lien avec le module OneHealth Tool inclus dans Spectrum et, si possible, utilise les indicateurs d’entrée et de sortie programmables recommandés par l’OMS (tels que le diagnostic et les volumes de traitement, et les taux de positivité des tests enregistrés dans les cliniques de santé publique) pour assurer la pertinence du Programme National de Planification et du suivi et d'évaluation du Paludisme.

Informations générales:  
<http://www.avenirhealth.org/software-spectrum.php>   
<https://github.com/SwissTPH/openmalaria>   
<http://www.who.int/choice/onehealthtool/en/>   
<http://www.map.ox.ac.uk/>

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Le développement et le pilotage de *Spectrum-Malaria* a été financé par le Fonds Mondial pour la lutte contre le sida, la tuberculose et le paludisme, avec le soutien de l'OMS Département du Financement des Systèmes de la Santé pour Swiss TPH et leur simulations dynamiques par OpenMalaria qui informaient la modélisation statistiques des impacts de Spectrum-Malaria.

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**INTRODUCTION AND RATIONALE**

This report describes the development of a malaria impact estimation module in the Spectrum suite of decision support tools [[3](#_ENREF_3)], to facilitate strategic national malaria program planning.

As of 2015, Spectrum included malaria modelling under the Lives Saved Tool (LiST), as part of a set of interventions selected for their effectiveness against under-5 mortality. LiST includes as interventions: insecticide-treated mosquito nets (ITNs) and/or Indoor Residual Spraying (IRS) combined into one overall protective coverage, effective case management with Artemisinin-based Combination Therapy (ACTs), and Intermittent Preventive Treatment for pregnant women (IPTp) [[4](#_ENREF_4)]. LiST models effectiveness as a fixed proportional reduction in malaria-attributed (direct) deaths, constant over time and across malaria endemicities, and linearly increasing with intervention coverage. Morbidity outcomes, and health outcomes in people over five years old (apart from pregnant women), and morbidity (apart from Low Birth Weight / Small-for-Gestational-Age (LBW/SGA) in children from pregnant women reached by malaria interventions) are not considered. Impact on under-5 mortality is applied to malaria-attributed deaths as estimated for each country by the United Nation’s Child Health Epidemiology Reference Group (CHERG)’s Multiple Causes-of-Death model [[5](#_ENREF_5)].

Requirements for the new Spectrum-Malaria module were:

* The model should be **evidence-based**, have a robust model structure, and assumptions that are **consistent with core, consensus insights from state-of-the-art dynamic transmission modelling;**
* It serves to examine alternative program/allocation packages, with varying intervention coverage and impact targets, to inform development of **national strategies and plans** that maximize impact or value for money, over a typical 3–5-year horizon;
* It should be pre-populated with country baseline epidemiology data, that are **consistent with official World Health Organization (WHO) national burden and coverage estimates** (notably, parasite prevalence, ITN coverage, malaria case incidence, malaria-attributable deaths and all-cause under-5 deaths, from WHO Global Malaria Programme (GMP)’s World Malaria Report, which for under-5 deaths aligns with LiST/CHERG), and ideally with WHO’s Choosing Interventions that are Cost-Effective (CHOICE) estimates;
* It should allow **application at province and/or district level**, as needed according to countries’ level of tailoring program packages and as possible given available dis-aggregated data on key parameters;
* It should be applicable to settings with **stable endemic malaria**, including (but not necessarily limited to) ***Plasmodium falciparum*** as the predominant species, in sub-Saharan Africa;
* It should **link** with the **OneHealth Tool**for detailed **costing in context of health sector planning**;
* It should have a **user-friendly interface**, allowing in-country staff to update input assumptions (on past and current intervention coverage, targeted coverage, epidemiology etc.) without hands-on support or long training workshops.

This report describes the conceptual approach, development process and resulting structure and initial results of Spectrum-Malaria.

**METHODS**

**Conceptual design & modelling approach**

The effect of intervention scale-up on health burden was based on statistical functions, fitted to intervention simulations done in the OpenMalaria dynamic transmission model [[6](#_ENREF_6)], as previously done to describe the impacts of case management [[7](#_ENREF_7)] and of future malaria vaccines [[8](#_ENREF_8)]. Simulations and statistical impact functions considered as endemicity-related determinants of impact, the annual Entomological Inoculation Rate (EIR) or parasite infection prevalence, and seasonality in malaria transmission. Impact is simulated for ITNs, IRS, SMC and effective management of uncomplicated episodes (CMU).

Statistical impact functions describe how a given coverage change leads to a given proportional reduction in case incidence, mortality and *Plasmodium falciparum* parasite infection prevalence (*Pf*PR), for a given setting with its endemicity characteristics, as described in [[1](#_ENREF_1)]. These functions are applied to all first administrative level (Admin1) units (i.e. states or provinces) in a country in turn, using Admin1-level endemicity, and baseline burden rates and baseline coverage values available from the Malaria Atlas Project (MAP) [[9-11](#_ENREF_9)], to determine OpenMalaria-predicted pre-intervention and post-intervention burden rates. The proportional burden reductions for all Admin1 units are then aggregated and produce a population-weighed national proportional burden rate reduction per country, separately for three time horizons of interest within a 10-year strategic planning horizon, for three age groups and for three burden indicators.

Next, projections of malaria burden over time for country populations are run in Spectrum, building on demographic projections in the *DemProj* module. Malaria burden trends over 2000–2015 are included as the WHO’s latest estimates of November 2015; the latest-year estimates of 2014 were taken to also apply in the projection baseline year 2015. Over 2016–2030, for the hypothetical scenario with constant coverage at 2015 levels, Spectrum projects constant *Pf*PR, case and death rates at 2015 levels as the counterfactual. Against this counterfactual, impacts of intervention coverage changes starting in 2016 are then projected, by applying the proportional reduction in each burden outcome and age group from the statistical model to that year’s counterfactual burden level.

The rationale to do intervention effectiveness calculations at Admin1 level, rather than at country level, is that malaria is highly spatially heterogeneous with impacts as well as current intervention coverages varying much by endemicity. Also, intervention coverages vary much by geography, notably for IRS, which is typically either implemented at high coverage (85–90% of households and people protected) or not at all.

**Figure 1. Design of Spectrum-Malaria module**

The numbers 1, 2 and 3 denote three project phases and report parts of Spectrum-Malaria development.



**Country and Admin1-level data for 2000–2015**

For all Admin1 units of all countries in sub-Saharan Africa, Spectrum is pre-populated with annual data over 2000–2015, described below and summarized in Table 1.

**Table 1. Country and sub-national data pre-loaded in Spectrum-Malaria**

| *Indicator* | *Age groups* | *Unit used in Spectrum* | *Data source & Comment* |
| --- | --- | --- | --- |
| ***Pf*PR** | 2–9y | % of children infected, as weighed median for the Admin1 population, *after excluding the population living at 0.0 PfPR* | *MAP.* The category with 0 *Pf*PR, and its exclusion from the Admin1’s weighted median *Pf*PR, are needed to convert burden and coverage rate between the population with >0 *Pf*PR in Spectrum (onto which OpenMalaria-based impact regressions are applied) and WHO official country estimates which includes populations with 0 *Pf*PR. |
| **Case incidence** | 0–4y, 5–14y, 15+y | Population-weighted average rate, *for population living at >0 PfPR\** | *WHO-GMP* national estimates, allocated across Admin1s, according to case incidence and population size distributions estimated by MAP for that year. 2014 rates applied in 2015. |
| **Malaria-attributable mortality** | <5y and >=5y | Population-weighted average rate, *for population living at >0 PfPR\** | *WHO-GMP* national estimates for 0–4 versus 5+ years, allocated by Avenir to Admin1s and the 5–14 versus 15+years sub-age groups, according to distribution in case incidence from MAP for that year. 2014 rates applied in 2015. |
| Seasonality index **CV\_ MAP\_EIR** | N/A | Population-weighted average, *for population living at >0 PfPR\** | *Swiss TPH and MAP.*  See Table 2. Time-constant |
| Population who **slept under an ITN** last night | All age total | Population-weighted average, in two variants:   * Actual (including *population living at 0 PfPR\*)* to inform ITN distributions for costing; * Effective coverage (limited to *population living at >0 PfPR\*),* used for impact calculation | *MAP and WHO-GMP* [[12](#_ENREF_12),[13](#_ENREF_13)].  N.B. Unlike Bhatt and colleagues’ national-level estimates, the MAP map and Spectrum do NOT assume that ‘all ITNs are distributed among households situated in malaria-endemic regions’. |
| **Households owning ≥1 ITN(s)** | All age total | Population-weighted average, *for population living at >0 PfPR\** | *MAP*. Not used within Spectrum-Malaria impact module, but to facilitate alignment with Spectrum-LiST, where the coverage indicator is household ITN possession. |
| **IRS** | All age total | Population-weighted average, in two variants:   * National (including *population living at 0 PfPR\*,* for whom 0 ITN usage is assumed)*;* * Effective coverage (limited to *population living at >0 PfPR\*)* | *WHO-GMP.* Allocated from WHO’s national total to Admin1s through the algorithm shown in Table 3.  For 2015, calculate coverage based on the WHO-reported number of people protected in 2014. |
| **Case management coverage, uncomplicated cases** | All age total | Population-weighted average, constant across all Admin1 units in a country, ad *irrespective of PfPR)* | *Swiss TPH* time-constant estimates of effective coverage cumulative over 14 days since onset of fever, adjusted for ACT access, non-ACT nationally recommended antimalarials, compliance, counterfeit drugs, dosaging, timeliness etc. [[14](#_ENREF_14),[15](#_ENREF_15)]. |
| **Population size** | 0–4y, 5–14y, 15+y | Total, *including people at >0 PfPR* | *MAP*, for both total population, and population at >0 *Pf*PR |

Notes: \* Spectrum impact projections are done using as driver/predictor, the *effective coverage in populations with PfPR>0,* because only populations with *Pf*PR>0 were simulated in OpenMalaria, and coverage-impact relationships derived from OpenMalaria thus apply to populations with malaria transmission (*Pf*PR>0, in most years) only.

* *Pf*PR at province level is calculated on all pixels in the province with *Pf*PR>0. It is the weighted median *Pf*PR over all these pixels, with pixels weighted by their population aged 2–9yrs. Avenir prepared but did not use an alternative method: the populations of all pixels at *Pf*PR>0 are pooled, with each “person” in the pool assigned their pixel’s *Pf*PR, and taking the median *Pf*PR of the pool. The difference is less than 1% for most provinces so we picked the more intuitive method.
* Case incidence rates are calculated using whole population (not population at *Pf*PR>0). MAP’s case incidence is always zero for pixels at *Pf*PR=0; same for Avenir’s interpolated malaria death rates, because where there are no malaria cases there can be no malaria deaths.
* ITN coverage is calculated for both whole population (‘ITN’ in database, ‘ITNactual’ in Spectrum code) and population at *Pf*PR>0 (‘ITNeff’).
* IRS coverage is being calculated with the whole population as denominator, rather than population at *Pf*PR>0. Exceptions are DRC, where IRS was allocated exclusively to Katanga region (personal communication by Christian Lengeler, Sept. 2015) and Senegal (based on data from National Malarial Programs (NMP), obtained via LSHTM in Dec. 2015).
* The number protected by IRS in 2015 is taken to be that reported by NMPs to WHO in 2014 or if 2014 not available, then 2013. If the values in both 2013 and 2014 are missing or zero, Spectrum assumes 0 IRS coverage in 2015 too.
* Allocation of national IRS numbers protected across provinces is inversely proportion to the past three years’ average of ‘ITNeff’.
* Seasonality values are calculated across all pixels (not as ‘effective Seasonality on pixels at *Pf*PR>0 only).
* Case management coverage, for South Africa and Swaziland which were not estimated in [[14](#_ENREF_14)], use 11.34% for South Africa and 0.95% for Swaziland, based on these countries’ MAP-estimated ACT access relative to the sub-Sahara Africa (SSA) regional average ACT access, multiplied with SSA regional average case management coverage from [[14](#_ENREF_14)].

*Case incidence*

Country estimates (as opposed to National Malaria Program (NMP) and Health Management Information System (HMIS) reports of cases and deaths, which in most countries considerably under-state the real population-level burdens) were obtained from WHO’s Global Malaria Program, for malaria case incidence (comprising uncomplicated and severe cases), direct malaria-attributable deaths as of October 2015 [[16](#_ENREF_16)].. For most sub-Saharan Africa countries with stable endemic *falciparum* malaria, the WHO’s case and death estimates were based on an epidemiological model that projects case incidence rates from parasite prevalence measured through household surveys [[11](#_ENREF_11)].

For case incidence in several lower-endemic countries, WHO instead used as basis the NMP-reported clinical cases, with adjustment for (public) clinic coverage and completeness of reporting. This resulted in case incidence trends over time that were occasionally not entirely consistent with the case incidence trend estimated by MAP, or with the mortality trend estimate (giving fluctuating or eccentric case fatality rates). To avoid inconsistencies within Spectrum’s country data, for these countries the Spectrum case incidence was set at WHO’s official estimate for 2014, and numbers and rates for 2000–2013 were derived by applying the historic trend in case incidence according to MAP onto WHO’s 2014 case incidence estimate. This scaling was implemented assuming the same fixed difference in number of cases for each year over 2000 to 2013 as for 2014 for Algeria, Eritrea, Ethiopia, Gambia, Madagascar, Mauritania, Namibia, Rwanda, Sao Tome & Principe, Senegal, and Zimbabwe. For South Africa, Swaziland and Botswana, a fixed case number difference would result in a negative number of cases in some years, so for these countries instead Spectrum took the NMP-reported time series, as adopted by WHO-GMP, without adjustment.

WHO provided case estimates for all age groups combined. We allocated WHO-estimated national case numbers across the three age groups and Admin1 units, using age- and Admin1-specific case incidence estimates in each year produced by MAP, who combined a spatial-temporal statistical description of *Pf*PR (see below) with a statistical model of the relationship of *Pf*PR to case incidence, that was fitted on simulations from OpenMalaria and two other dynamic transmission models and accounts for population’s history of exposure and treatment coverage [[9](#_ENREF_9)].

*Malaria-attributable deaths*

The WHO’s death estimates are available for 0–4 years versus older ages. Spectrum applies a 5–14 years versus 15+ years break-down as for case incidence in MAP’s Admin1 map for 2015, the latest available time point. These age allocations for cases and deaths result in case fatality rates that are consistent with epidemiological meta-analyses, with slightly higher case fatality in children 5–14 years and adults than in children 0–4 years [[17](#_ENREF_17)].

*Pf*PR

Admin1-level data concerning *P. falciparum* prevalence (standardized to the 2–9 year-old age range) and ensuing clinical incidence by three age groups (0–4, 5–14, 15+ year-olds) were derived from spatial high-resolution and time-dynamic maps for Africa, produced by the MAP in 5x5 km2 pixels. MAP generates these as spatial-temporal ‘cubes’ via statistical modelling for the community prevalence informed by a large archive of geo-positioned survey data concerning point prevalence, intervention coverage, and treatment seeking behavior, plus a bespoke suite of high resolution spatial and temporally dynamic predictor variables tracing environmental, as well as socio-demographic determinants. A statistical forecast of clinical incidence is then derived from the community level prevalence in each pixel using an ensemble of predictions from dynamic transmission models [[18](#_ENREF_18)]. Pixel data (only for pixels *within* the limits of stable transmission) were aggregated to Admin1 population-weighted totals and population-weighted averages using an Admin1 shape file of 2013 [[19](#_ENREF_19)]. Across 43 SSA countries, the average number of Admin1 units was 14, in a range of 6 (in Djibouti) to 37 (in Nigeria).

*Pf*PR in children 2–9 years is the core malaria indicator produced and used by MAP, and was hence selected as the key endemicity indicator in Spectrum. Statistical impact functions use OpenMalaria-simulated *Pf*PR averaged over 2000–2002, i.e. largely before intervention scale-up started to reduce *Pf*PR, as predictor variable.

*Seasonality*

MAP has produced a map for Africa depicting the extent of seasonality according to a mono-modal yearly pattern, based on rainfall and other environmental covariates (temperature, etc.) as done previously by MARA [[20](#_ENREF_20)] and by Cairns and colleagues [[21](#_ENREF_21)]; but not yet validated with EIR time series. The MAP seasonality index (MAPSI) is continuous (floating point). A value of 1 corresponds to an EIR time series that is, when log-transformed, a sinusoidal with a semi-amplitude of 2.5, while flat EIR series (no seasonality) have a MAPSI of 0. For the map of Africa, the index is capped at 1 (values higher than 1 could occur in "nature", but are set to 1); resulting pixels range from 0 to just below 1.

For impact projections in Spectrum, the MAPSI for a given Admin1 area was transformed into the index CV\_MAP\_EIR used in OpenMalaria simulations and statistical impact regressions. The Admin1-level population-weighted MAPSI was converted into CV\_MAP\_EIR with the formula:

CV\_MAP\_EIR = 2.3876 \* (1.879747\*MAPSI - 0.649789\*MAPSI^2),

The resulting CV\_MAP\_EIR was used to interpolate between simulation and regression outcomes for the OpenMalaria-simulated scenarios with CV\_MAP\_EIR= 0.1207213 (5% quantile of non-population weighted CV\_MAP\_EIR in malaria-endemic Africa; OpenMalaria parameter ‘a1’, describing the amplitude of the annual sinusoidal, of 0.171) and CV\_MAP\_EIR= 2.6614240 (95% quantile; OpenMalaria parameter ‘a1’ of 21.09).

**Table 2. Seasonality indices used in OpenMalaria simulations, in statistical impact models and Spectrum country and Admin1 database, and in the underlying 5x5km2 map by MAP**

|  |  |  |  |
| --- | --- | --- | --- |
| **Seasonality** | **OpenMalaria parameter ‘a1’ and value in statistical modelling** | **CV\_MAP\_EIR, in Spectrum** | **MAPSI, from MAP** |
| Low seasonal (5% of CV\_MAP\_EIR in Africa, according to MAPSI for endemic areas) | 0.171 | 0.121 | 0.0272 |
| Moderately seasonal (median of CV\_MAP\_EIR in endemic areas) | 2.813 | 1.310 | 0.329 |
| Highly seasonal (95% of CV\_MAP\_EIR in endemic areas | 21.09 | 2.662 | 0.833 |

*Coverage of Case Management, uncomplicated cases*

The best available estimates, that most closely resemble the definition of effective coverage as simulated in OpenMalaria, were those by Swiss TPH, which account for antimalarial access and use for antimalarials recommended in national policies, with adjustment for treatment (mis-)dosaging, counterfeit drugs, timeliness of treatment (within one day) etc. [[14](#_ENREF_14)]. These 2010–2013 estimates were taken as the 2014 estimate for each country and all its Admin1 units.

In future, these input data will be replaced by temporally varying effective coverage estimates of treatment with Artemisinin-based Combination Therapy (ACT) for parasite-confirmed child fevers, forthcoming from MAP with partners [[22](#_ENREF_22)], once these have been spatially mapped in conjunction with MAP’s maps of PfPR, case incidence and ITN coverage. In the farther future, further refined malaria treatment coverage estimates will account for treatment (mis-)dosaging, counterfeit drugs, and timeliness of treatment, as the existing time-constant estimates done by Swiss TPH and Tulane University [[14](#_ENREF_14),[15](#_ENREF_15)].

For Sudan and Swaziland, which lacked an effective coverage estimate from [[14](#_ENREF_14)], the Spectrum default data were based on an estimate by MAP of ‘ACT access’ [[11](#_ENREF_11)], produced by combining national household survey data on child fever treatments with national ACT distribution data. These ACT access are 1.4-1.8-fold higher than the Swiss TPH national effective coverage estimate for most endemic African countries -- whereas in settings where few child fevers are due to malaria (e.g. highland Ethiopia) low ACT usage may not mean that ACT coverage for the subset of malarial fevers is low, so ACT access likely underestimates effective treatment coverage. For Sudan and Swaziland, the ACT access estimates were adjusted downward by 1.4-fold to reflect the median difference between ACT access and effective treatment coverage, according to Swiss TPH’s estimates for 36 countries.

*Coverage of Case Management, severe cases*

For lack of country-specific data, this is put at a fixed 48% as estimated by Swiss TPH and also used in dynamic OpenMalaria simulations of *falciparum* malaria epidemiology [[23-26](#_ENREF_23)] at 2014-2015, for all countries and Admin1 units.

*ITN coverage*

MAP’s ITN estimates over space and time reflect ITN coverage (people sleeping under an ITN) estimated by a compartmental discrete-time stock-and-flow model, considering historical production and delivery from manufacturers, ITN distribution data reported by NMPs, and ITN retention, decay, loss, allocation patterns across and within households (including over-allocation to certain households) based on geographically dis-aggregated household survey data of ITN ownership and usage [[12](#_ENREF_12),[13](#_ENREF_13)] These MAP coverage estimates also underlie the WHO-GMP country-level ITN estimates.

*IRS coverage*

IRS coverage was taken from WHO-reported people protected by IRS per country, based on annual reports by NMPs. The latest available data (from 2013, or 2012 if not reported in 2013) were applied to give the coverage proportion for 2013, and the 2014 coverage was set at the same level. If a country reported no IRS since 2011 or before, coverage was set at 0 for all next years until 2014.

In the absence of standardized multi-country data of sub-national IRS allocations, Spectrum allocated national IRS coverage within countries, selecting Admin1 units with above 0 *Pf*PR as of 2015 (in the MAP map), and an IRS probability inversely proportional (as a complement from 100%) to the Admin1’s ITN coverage in 2014 (according to MAP’s ITN coverage estimates). For each ‘selected’ Admin1 unit the coverage is set at 90% (the maximum); only the last Admin1 unit that gets IRS allocated has a below 90% IRS coverage, to match the WHO-reported national number of people protected by IRS. If two Admin1 units have the same ITN coverage, IRS gets allocated to the one with lowest current IRS coverage; if this is equal between the two Admin1 units too, then IRS is allocated to the Admin1 unit with highest *Pf*PR at 2015. The resulting minimal overlap between IRS and ITNs reflects the recommendation of the WHO’s 2015 Global Technical Strategy for malaria [[2](#_ENREF_2)]. Each Admin1 unit allocated IRS was assumed to cover 90% of its resident population with IRS (even if part of its population has zero EIR and/or zero parasite infection prevalence). Table 3 illustrates the allocation for the four countries piloted. However, in countries where specific information is available about their locations of IRS, this can be entered manually and supersede the allocation algorithm. An example is DRC, where the algorithm allocated IRS to Kinshasa, but this was overridden by information from the NMP that IRS was exclusively done in Katanga province.

The IRS allocation algorithm may in future be replaced by a forthcoming spatial and temporal IRS coverage map from MAP, based on IRS coverage data from Demographic and Health Surveys (DHS), which is being prepared as input to MAP’s evaluation of progress on the Millennium Development Goals (MDG) targets for malaria in 2015.

*SMC coverage*

SMC coverage was set at 0% for all countries and Admin1s at 2014–2015. User-specified national-level SMC coverage targets are allocated uniformly across all Admin1s with *Pf*PR>0. To project more realistically SMC scale-up scenarios compliant with WHO recommendations, however, it may be preferable for Spectrum to limit the SMC allocation to areas with seasonality above a certain threshold (to be decided with the WHO Global Malaria Programme).

**Table 3. Allocation of national-level people protected by IRS, to Admin1 units: Senegal and Zambia 2014**



Notes to Table 3: The Spectrum algorithm first excludes any units with 0 *Pf*PR. Then IRS gets allocated by the highest complement of ITN coverage (= 100%-ITN coverage), at 90% (of the population living at *Pf*PR>) for each successive Admin1 unit, until the total people protected across selected Admin1 units saturates to the national total number of people protected. The last Admin1 unit allocated IRS gets a <90% total IRS coverage (in the example, unit D, with 63% instead of 90% IRS coverage), to exactly meet the national total people protected.

*Severe case incidence*

In contrast to the above health outcome measures, for severe case incidence there are no official WHO or MAP severe case burden estimates that Spectrum’s projections could be anchored to. Therefore, severe case burden estimates were generated within Spectrum, based on ratios of severe-to-total case incidence from the OpenMalaria simulations also used to inform Spectrum’s coverage-impact functions, in separate statistical models that used the same predictor variables considered for the coverage-impact regressions. Regressions of severe-to-total case incidence were done on logit-transformed ratios, since severe-to-total case incidence ratios are ≤1.0 by definition, separately for 0–4 years, 5–14 years and 15+ years.

OpenMalaria simulated severe case incidence based on parasite density (high density predisposing to severe disease) and by considering occurrences where an otherwise uncomplicated episode coincides with co-morbidity (modelled as an age-dependent risk), fitting to routine hospital, community-based surveillance, and demographic data from a range of SSA sites [[26-28](#_ENREF_26)]. The causal model accounted for distributions of parasite densities and comorbidities, as well as maternal immunity that partially protecting young infants from malaria.

In OpenMalaria simulations and Spectrum’s corresponding statistical models, the severe-to-total case incidence ratio is highest in children 0–4y, and lowest in adults 15+ years. The statistical fit (R2) of predicted relative to simulated ratios was better for older age groups (98% for 15+ years, 96% for 5–14 years and 80% for 0–4 years, each for the 2016–2018 horizon; Annex 1).

Based on these results, Spectrum calculates the severe-to-total case incidence ratio for each Admin1, and its three age groups separately, by applying the 2016–2018 regression functions to the Admin1’s endemicity and coverage situation as of 2015. The resulting Admin1-specific, age-group-specific ratios are then applied throughout the Spectrum projection, to derive a severe case incidence rate from the total case incidence rate, for each next year and scenario. In Spectrum, therefore, impact of interventions on severe cases is proportional to the impact on in total case incidence, and direct deaths.

**METHODS: Spectrum projection model**

Spectrum-Malaria was built as a module within the Spectrum suite of projection tools. It interacts with selected other Spectrum modules: *DemProj*’ and the *AIDS Incidence Model* (AIM). Demographic projections are done, at country level, in the *DemProj* module which interacts with the AIM module to add HIV/AIDS-related deaths. For the current first version of Spectrum-Malaria, projected mortality reductions caused by malaria control are not fed into *DemProj*, in other words, malaria mortality or control is assumed to not influence demography. For future versions, Avenir considers to possibly feedback dynamically changing malaria mortality rates into the *DemProj* population projection, as death rate reductions or as proportional changes in malaria death rates, for the three age groups

*Pre-2016 malaria burden trends*

Spectrum displays the WHO-GMP and MAP-based annual estimates for each malaria burden outcome over 2000–2015, at country-aggregate level. In principle, users cannot modify these.

*Post-2015 malaria burden trends, counterfactual*

For each burden outcome for each age group, a counterfactual trend for 2016–2030 is projected. The default counterfactual setting is that coverage of all interventions is frozen at 2015 levels, and case incidence, mortality and parasite prevalence are kept constant at 2015 rates. In the 2016 version of Spectrum, 2015 is defined to be the ‘base year’, i.e. the last year before user-specified intervention scale-up. A counterfactual of fixed constant burden rates for fixed constant coverage levels is also the default in Spectrum’s *Goals* module for HIV/AIDS strategic planning. Due to population growth, this counterfactual predicts gradually increases over next years in the absolute numbers of cases and deaths.

*National coverage targets, and allocation to Admin1 units*

Users are required to specify targets for effective coverage at national-level, up to a maximum imposed by Spectrum of 90%, judged to be the maximum feasible coverage. An option is to cap these effective coverages at 90% as the default, but include a ‘Configuration’ option for advanced users to de-activate the capping. However, prediction results for >90% (or even >80%) coverage are less certain since the OpenMalaria simulations and impact regression models used a coverage range of 0–80% only.

For interventions with baseline coverage varying sub-nationally (ITN and IRS), the user-specified (post-) 2016 coverage is allocated to Admin1 units, assuming a fixed proportional increase (or decrease) for each Admin1. For example, for a national-level increase from 20% to 40%, with half the population in unit A at 10% baseline coverage and half the population in unit B at 30% baseline coverage, after intervention coverage goes up to 20% and 60% in units A and B, respectively. This sub-national coverage allocation is implemented with the constraint, that coverage for each Admin1 unit is capped at 100%.

For ITNs, the user-specified national coverage target is applied to the Admin1s as a corresponding proportional increase (e.g. two-fold, for a national coverage scale-up from 20% to 40%), but capped at the maximum coverage of 90% for all Admin1s. If any Admin1 gets capped at 90% target coverage, in order to still reproduce the national-level target (e.g. 40%), the remaining ITNs i.e. persons protected that are missed by an Admin1’s capping are re-allocated to another Admin1, specifically the Admin1 with next-highest (but below 90%) ITN coverage, so that Spectrum adequately represents the user-specified national target coverage once all Admin1s are aggregated up to country-level.

*Impact projection*

In impact regression models (described in report Part 1), proportional health impacts of ITNs, IRS, CMU and SMC were generally smaller over the initial (2016–2018) horizon than the intermediate (2019–2021) and longest (2023–2025) time horizons, for scale-up of IRS, ITNs and CMU and their combinations – reflecting that the full health impact is realized only around 4 years after reaching high coverage. A translation step is needed in Spectrum to apply these time-varying impacts, from simulations and predictions of one-off immediate coverage changes (at year 2016 / year 1 across all interventions) to program scale-up packages, with multiple interventions scaled-up over different time periods, that users will specify in Spectrum. Specifically, the requirements for Spectrum’s use of the impact regression models were:

1. The equation allows for multiple interventions scaling-up over multiple years, concurrently but each in different coverage time pattern;
2. The projection results in burden trend over time including partial rebounds due to transmission dynamics and diminishing immunity, as in OpenMalaria and the 3 sets of regression models;
3. Final burden (at long-term) reflects final coverage values only, and is independent of whether scale-up was at-once, front-loaded, linear or back-loaded (as in OpenMalaria and the regression models).
4. So as to not over-estimate impact in the first and second year for a user-specified short-term coverage targets, the impact of a change in coverage applies with a one-year lag; that is, the effect of a change in coverage from year t to year t+1 is applied in year t+2 (e.g. for ITN scale-up at 2016, apply impact from 2017);
5. To avoid that the 2016 projected burdens are flat at 2015 level (since user-defined scale-up starts in 2016 only), the 2016 projection result reflects the coverage increase from 2014 to 2015 according to MAP & WHO data.

To meet these requirements, Spectrum uses the statistical models for the initial time horizon (1–3 years / 2016–2018 / 1st set) for the first 6 years of the projection (2016–2021), with a 1-year lag from coverage increase to health impact. From 2022 to 2030, Spectrum switches to the long-term (8–10 years / 2023–2025 / 2nd set) impact functions, so as to capture long-term dynamic impacts in full. This is operationalized as impact equation below, where denotes the quantity being projected (cases, deaths, or PfPR), and the function returns the result of evaluating the statistical model. The statistical model is a function of the change in IRS, ITN, and CMU coverages over a specified period between an initial year and a target year, as well as SMC coverage in the target year. The ratio of two impact functions gives the impact on *X* of one scale-up trend relative to the impact of another trend. We update relative to by the ratio of impact under ‘Coverage change over the scale up period’ (from to year , reflecting a one-year lag before impact in year ) to impact under ‘No coverage change’ (from to ).

The application of the statistical impact functions as *proportional* burden reductions, rather than absolute predicted post-scale-up burden levels, was chosen because OpenMalaria simulations and the corresponding statistical models were not calibrated on the WHO and MAP 2015 burden levels that form the Spectrum baseline database.

After the impact of IRS, ITN, CMU and SMC coverage trends have been projected, the trend in malaria mortality is adjusted to reflect the effect of Severe CM coverage, as below:

Finally, we disaggregate the overall malaria case incidence rate into severe and uncomplicated case rates by applying an estimated ratio of severe-to-all cases. This ratio is estimated statistically as a function of coverages in 2015, and each Admin1 unit’s PfPR (2-9 years, 2000-2002 average) and seasonality:

For simplicity, the ratio of severe-to-all cases is taken to be constant over the entire projection period.

This algorithm is applied for each Admin1 unit in a country, using Admin1-specific endemicity and baseline coverage values described in Table 1, for all from 2016 through the end of the projection period. Spectrum then aggregates across Admin1 units to produce national-level projected case and death rates and *Pf*PR, separately for each age group modelled. By running two projections, users can obtain the corresponding cases and deaths averted.

While impacts include a reduction in *Pf*PR among children aged 2–9 years, Spectrum assumes no change after 2015 in the proportion of population that lives at a *Pf*PR of 0 (i.e. no malaria risk). If in reality intervention scale-up considerably reduced the areas of ongoing malaria transmission, this simplification may cause Spectrum to under-estimate health impacts and over-estimate commodities and resources needed for malaria control in the medium (5–10 years) term.

*Impact projection: Malaria mortality*

Spectrum-Malaria aligns with Spectrum-LiST, CHERG, the WHO and the Global Burden of Disease in using a one-death-one-cause framework. Malaria mortality represents only deaths directly attributable to malaria, without additional indirect malaria-related deaths, to which malaria contributes when concurrent with or preceding another disease. However, especially in children under 5 years, indirect mortality is a considerable additional burden caused by malaria, estimated to be of similar magnitude as the direct mortality (so, doubling the overall mortality burden) as illustrated by cluster-randomized ITN trials in endemic Kenya and Ghana, where ITN scale-up reduced all-cause under-5 mortality almost as much as malaria-attributed mortality. In order to not under-state the mortality impact of malaria control, yet adhere to the one-death-one-cause framework, the lives-saved models used by CHERG/LiST, WHO and the Global Burden of Disease estimated a proportional malaria-related mortality reduction that they apply to the direct malaria-attributable deaths (e.g. in LiST: 55% reduction, at 90% ITN ownership and 60% child ITN usage [[4](#_ENREF_4),[29](#_ENREF_29)]), based on all-cause under-5 mortality reductions observed in the ITN trials (that averaged 17%) [[30](#_ENREF_30)].

Spectrum-Malaria also operates in a one-death-one-cause framework. In contrast, the dynamic OpenMalaria model that informed Spectrum’s statistical mortality impact reductions simulates direct malaria-attributable and indirect malaria-related mortality separately. Nevertheless, proportional reductions in OpenMalaria-simulated direct malaria-attributable deaths in 0–4 year-old children were generally in line with the CHERG estimated reductions for malaria-related mortality used in LiST; therefore Spectrum simply uses the OpenMalaria-based proportional reductions for direct malaria-attributable deaths, It results in a good fit of projected proportional malaria-related and all-cause mortality reductions compared to the ITN trials [[1](#_ENREF_1)], and compared to later empirical estimates of ITN effectiveness throughout African countries over the 2000s.

*Impact projection: Severe case management*

For severe case management, Spectrum projects an impact on malaria mortality rates in the age groups covered, without dynamically impact on any of the other burden indicators, or mortality in age groups and years beyond that of coverage shift concerned. Up to 2015, coverage of effective severe case management is assumed to be a fixed 48%, across age groups and Admin1 units – as in OpenMalaria [[26](#_ENREF_26)]. The effect of increasing the 48% to a user-specified target level (up to 90% maximum) is calculated based on a country’s relative rates of severe case incidence and direct malaria mortality, assuming a 0% case fatality rate for effectively treated severe cases, and case fatality among untreated severe cases fitted to match the MAP/WHO-estimated mortality rate. For example, for a country and age group with 2.5 (Spectrum-projected) severe cases and 0.10 malaria (direct) deaths per 100 person-years (in the population with  *Pf*PR>0), when increasing severe case management coverage from 48% to the maximum 90%, malaria mortality falls to 0.019 per 100 person-years (in the population with  *Pf*PR>0). Irrespective of the Admin1’s baseline case and death rates, the mortality rate reduction is always maximally 81% (for coverage scale-up from 48% to maximum 90%), and interpolated linearly for more moderate coverage scale-ups. In comparison, a meta-analysis performed to inform effectiveness assumptions in LiST had estimated that severe case management including intravenous quinine reduces malaria mortality in children 1–59 months by (range: 63–94%) compared to no treatment [[31](#_ENREF_31)].

This calculation is repeated for each age group and year in the country (since severe case management coverage and effectiveness assumptions do not differ among Admin1s within a country), starting from the severe case incidence rate and malaria mortality rate for that age group and year as estimated given the target coverage of all other interventions (ITN, IRS, CMU and SMC).

In contrast to the four other interventions for which impacts including onward dynamic long-term transmission effects (based on OpenMalaria dynamic simulations), projected impact is immediate for severe case management: the direct malaria mortality rate (for a given country and age group) gets adjusted in response to change in severe case management coverage in the same year.

**DESK-REVIEW PILOTS**

Spectrum-Malaria was desk-tested for four countries: Democratic Republic of the Congo (DRC), Zambia, Nigeria and Senegal. Data of epidemiological, control scale-up over 2000–2015 for these countries were obtained from WHO-GMP and MAP (latest estimates available as of October 2015). Scale-up scenarios were defined to reflect the national strategic plan for malaria control 2016–2020 of DRC [[32](#_ENREF_32)], which was in turn inspired by the WHO’s Global Technical Strategy for malaria control [[1](#_ENREF_1)].

In projections, for all four countries, malaria control scale-up reduces health burdens in all age groups, with fairly similar proportional reductions across the three age groups modelled, and largest proportional burden reductions in lower-endemic settings. The largest absolute numbers of infections and deaths averted in children under-5 years old and (within and across countries) in higher-endemic areas.

For DRC, given high ITN coverage but low effective case management coverage in 2015, case management is the intervention for which scale-up could have most additional impact by 2030 but programmatic inputs and resources to achieve this remain to be assessed by linking to the Spectrum costing module OneHealth Tool.

Impact projections for these countries suggest that the ambitious global WHO, Roll Back Malaria and SDG targets to reduce case incidence and mortality globally by 80% by 2025 may be feasible if scale-up to universal coverage of vector control combined with effective case management is achieved in the highest-burden countries, including at minimum Nigeria and DRC.

**PILOT APPLICATION in DR CONGO**

As of June 2016, a pilot is ongoing with DRC’s national malaria program (PNLP) and partners.

The pilot was launched with a workshop on 30-31st May 2016 in Kinshasa, with the following objectives:

* To review the approach, scope, methods and data used in Spectrum-Malaria, and the adequacy of its impact projections, and provide feedback to Avenir Health to refine these.
* To review, update and complete relevant malaria data from DR Congo informing the Spectrum projection;
* To conduct and review a Spectrum projection of program scale-up as foreseen in the 2016–2020 National Strategic Plan for Malaria (NSP) [[32](#_ENREF_32)], and its expected health impacts
* To discuss possible implications of the Spectrum projection of NSP scale-up according to DRC’s NSP for malaria control, for evaluation and implementation of the NSP, and for validating the Spectrum impact module.
* To review the adequacy of Spectrum-Malaria in terms of user friendliness, alignment of indicators, data and structure to the national Monitoring & Evaluation approach.

For DRC, the MAP estimates of baseline *Pf*PR, seasonality and case incidence over 2000-2015 had been informed by a national DHS that included parasite biomarkers undertaken in 2007 [[33](#_ENREF_33),[34](#_ENREF_34)].

Over 2016 to 2020, initial Spectrum projections suggest considerable reductions in case incidence and malaria death rate in all age groups. These were somewhat below the 40% reduction in malaria morbidity and mortality stipulated in the 2016–2020 NSP to result from its scale-up targets for vector control and effective case management (Table 4), but still in the same order of magnitude. Spectrum-projected burden reductions from 2015 baseline levels to 2020 are in part aided by a strong already ongoing burden decline, partially induced by the scale-up of ITN coverage over 2013–2015. This is also visible in the ‘counterfactual’ with constant coverage, where the long-term effect of ITN coverage increase from 2014 to 2015 is represented in a drop in burden rates at 2022 (when Spectrum switches to using the long-term, year 8–10 impact coefficients). In turn, due to long-term dynamic transmission effects, Spectrum projects that the scale-up to 2020 coverage targets will entail a further reduction in case and death rates from 2020 onwards.

The provisional projection results remain to be refined and validated, and they depend critically on:

* Baseline ITN coverage at 2015, for which existing estimates from PLNP, WHO and MAP differ somewhat. The lower the current ITN coverage, the higher the possible impact of the NSP-targeted ITN scale-up;
* Effective case management: The initial Spectrum projection conservatively assumed a more moderate scale-up to 50% effective coverage by 2020, a doubling of the effective coverage estimated up to 2015; but if DRC achieved the full 80% effective CMU coverage as stipulated in the NSP the possible impact could be larger (Figure);
* Projections assume that target coverages (80% ITN usage and 50% effective CMU) are reached in 2020 only; but if these are reached earlier, impact by 2020 would be larger.

**Table 4. Coverage and impact targets of DRC’s National Strategic Plan for malaria control 2016**–**2020, and (provisional) representation and projection in Spectrum-Malaria**

|  | **Spectrum 2015 coverage** | **NSP target for 2020** | **Representation of NSP target in Spectrum, for 2020** | **Comment** |
| --- | --- | --- | --- | --- |
| ITN utilization (all ages) | **55%** per MAP/WHO estimate, & given 56% usage by under-5s in DHS 2014 [[35](#_ENREF_35)] | 80% ‘protection’ for ITN/IRS combined | **80%** | Implemented in Spectrum as linear scale-up from 2015 baseline.  NSP does not specify of 80% protection is household ownership, and/or usage. |
| IRS coverage | **0.27%** (based on 2.2% in Katanga & 0% in all other provinces) | 0.27% constant |  |
| Effective case management coverage | Uncomplicated cases (estimated, population-level): 2014 20%; 2015 **26%**  Severe cases: 2014+2015 48% | 80-90% *sus-pected cases tested* & 100% *lab-confirmed* cases effect-ively treated; health care utilization\*\* | Uncomplicated cases: **47%;**  Severe cases: 48% | NSP Dec. 2015: 2014 baseline coverages were 19% for diagnosis (in the population, including patients not presenting as suspected case) and 6% for effective treatment, both based on EDS 2013–14. The Spectrum-projected target or 2020, a near-doubling of effective coverage, reflects PNLP’s strategic planning targets for increasing test coverage and care utilization \*\* |
| Reduction in malaria morbidity rate |  | **40%** (from 2015) | TBD | All ages combined, from 2015 baseline |
| Reduction in malaria mortality rate |  | **40%** (from 2015) | TBD | All ages combined, from 2015 baseline |

\*\*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Year | Fevers utilizing health care | *Pf*PR 2–9y | Test positivity rate\* | NSP target for lab diagnosis of cases attending public clinics | Population-in-Need getting treatment | Effective CMU coverage, inputted into Spectrum-Malaria |
| *2014* | 40% | 24% | 29% | 70% |  | 22% |
| *2015* | 41% | 21% | 25% | 80% | 33% | 26% |
| *2016* | 46% | 21% | 25% | 85% | 39% | 31% |
| *2020* | 66% | 21% | 25% | 90% | 59% | 47% |
| Source | PNLP’s GAP analysis | Spectrum-Malaria | Product of 2nd & 3rd columns | PNLP’s GAP analysis |  | Spectrum’s inference from trend in ACT need – anchored to 26% at 2015 [[14](#_ENREF_14)] |

\* Among fever patients after substracting the real malaria-attributable fevers. The proposed linear interpolation of all-age test positivity rate from *Pf*PR in children 2–9 years was justified based on a strong linear positive correlation between *Pf*PR in children and in pregnant women across sub-Sahara African countries [[36](#_ENREF_36)].



**USER GUIDE**

A detailed manual for users of Spectrum (demography, family planning and HIV/AIDS modules) is available at <http://avenirhealth.org/Download/Spectrum/Manuals/SpectrumManualE.pdf> [[37](#_ENREF_37)].

To install and launch Spectrum-Malaria (for Windows platforms, or through a Windows emulator on Mackintosh computers (<http://www.avenirhealth.org/download/spectrum/Mac%20instructions%20for%20Spectrum.pdf> )):

* Download the latest Spectrum beta version (5.45 Beta 4, 15 June 2016) from :

<http://spectrumbeta.futuresinstitute.org/>

* Save into C:/Program files x86
* Run the EXE .

Open and launch Spectrum-Malaria:

* Open the program
* Click on icon ‘Run Spectrum’
* *File – Options:*
  + Choose your preferred language (available as of May 2016: English and French – Annex 2)
  + *Cntrl+Shift+D*: To put Spectrum into ‘Developer Mode’ allowing to activate the malaria module.
* *File – New Projection*
* *Name of projection file*: Name your projection file, for example as *RDC CouvertureConstante\_30mai2016*
* *Base year*: Set at 2000 (= first year with default data loaded);
* *Final year*: Set at 2030, for the longest-possible projection.
* Activate the modules: Malaria, and AIDS (AIM), and Demography (DemProj)
* *Default data*: Select a country or region:
* Select the modules to use: Click/activitate DemProj, AIM, Malaria by clicking OK & OK.
* *File:* Save your projection file.

Project results for a counterfactual scenario with Constant coverage at 2015 levels:

* *Open* and *Save the projection file*, for example as *RDC CouvertureConstante\_30mai2016*
* Go to: *Module – Malaria*
* *Intervention coverage:* Verify that coverages (for all 5 intervention) over 2016–2030 are constant, at the same level as in 2015.
* Go to *Results;* select *‘Summary’*
* Copy the summary results from Spectrum into Excel, using ‘*Copy all’* function (right-click on mouse).
* *File* – Save the (newly projected) file again, for example as ‘*RDC CouvertureConstante\_30mai2016’.*

Project results for an NSP scale-up scenario:

* *Open* and *Save the projection file*, for example as ‘*RDC Cibles PSN\_30mai2016’.*
* *Intervention coverage:*
* ITNs: Put national coverage at 80%, at 2020
* Adjust coverages at 2016, 2017, 2018 & 2019 by:
  + Selecting the cells stating coverages in 2015, 2016, 2017, 2018, 2019 & 2020;
  + Use function *‘Interpolate’*, option *‘Linear’*, by right-clicking the mouse.
* Equalize coverage over 2021-2030 by:
  + Selecting the cells stating coverages in 2020 through 2030;
  + Use function ’Duplicate’ by right-clicking the mouse. *.*
* Go to *Results;* select *‘Summary’*
* Copy the summary results from Spectrum into Excel, using ‘*Copy all’* function (right-click on mouse).
* *File* – Save the (newly projected) file again, for example as ‘*RDC Cibles PSN\_30mai2016’.*

Analyze comparative results of the counterfactual and scale-up scenarios in a spreadsheet programme such as Microsoft Excel.

**COMMENTS AND LIMITATIONS**

Spectrum-Malaria presents a new, evidence- and consensus-based approach to predicting impact of malaria intervention scale-up to inform strategic national program planning in sub-Saharan African countries.

In projections for four desk-review pilot countries, malaria control scale-up reduces health burdens in all age groups, with fairly similar proportional reductions across the three age groups modelled, and largest absolute impact in under-5s, and a slight upward age shift. Very provisional impact projections for these four countries furthermore suggest that the ambitious global WHO, Roll Back Malaria and SDG targets to reduce case incidence & mortality by 80% by 2025 may be feasible if scale-up to universal coverage of vector control combined with effective CMU is achieved including in the highest-burden countries Nigeria and DRC.

In initial pilots, users appreciated the tool’s alignment with monitoring indicators also as used in performance frameworks for program target setting and impact evaluation, and its graphical interface embedded in Spectrum’s demographic platform for relatively quick comparison of policy scenarios. The synthesis of MAP spatial data about intervention scale-up, malaria endemicity and epidemiology, with WHO country estimates for malaria health burden trends, and with coverage-impact patterns as simulated in the dynamic transmission model OpenMalaria, ensures optimal internal coherence and accuracy in country-level burden and impact projections over time, as well as consistency with official indicators, data and estimates that are also used for progress evaluation in national plans, for MDGs and in donor grant performance frameworks, and consistency with state-of-the-art insights and evidence on malaria transmission dynamics. The resulting internal consistency and consistency with official, internationally agreed WHO and MDG estimates come at the price of limited user flexibility: users can essentially specify only intervention targets and scale-up scenarios. Spectrum-Malaria does not allow users to modify baseline burdens and coverage levels or their historic trends, or the expected future burden trend for the counterfactual scenario of constant coverage. If users would want to change any of the baseline Spectrum assumptions for their country, the process would be via the WHO Global Malaria Programme, through the country’s official update for the next year’s World Malaria Report and country profile – which would be reflected in Spectrum-Malaria the next year.

Besides data used for the impact projection, Spectrum includes a ‘Program data editor’ that displays routine programmatic (NMP-reported and HMIS-reported) indicator data (reported suspected and confirmed cases, RDT and slide test volumes and test positivity rates, ACT and non-ACT first-line drugs administered, etc.). These indicator data do not influence the impact projection – but they serve as context for commodity and cost projections through the OneHealth Tool module.

Anticipating users’ push-back on the limited user flexibility (as also encountered for the Spectrum TB-TIME module, which also anchors historic and baseline burden and coverage assumptions onto official WHO estimates), these limitations may be relaxed in future Spectrum versions.

Limitations:

* Applying OpenMalaria-based impact functions to MAP and WHO-estimated baseline burden trends is valid to the extent that OpenMalaria and MAP are consistent in their definitions of key indicators and corresponding data (e.g. coverage of CM) ⎯ notably in the relationships between *Pf*PR, and case incidence adjusted for intervention coverage. This is by and large the case, since MAP’s *Pf*PR-to-case incidence relationship was fitted onto (independent, earlier) OpenMalaria simulations (alongside results from two other dynamic transmission models). However, the respective indicators for coverage of CMU differ – with MAP’s ‘ACT access’ indicator an average 1.4– to 1.8–fold higher than the Swiss TPH’s effective coverage indicator that more closely reflects effective coverage as simulated in OpenMalaria and used in Spectrum’s statistical impact functions. The internal consistency of Spectrum-Malaria should therefore improve once it can adopt MAP’s 2016 new set of maps, including refined effective treatment coverage estimates and their effect on *Pf*PR-case incidence relationships.
* For CMU, the pre-2015 coverage estimates [[14](#_ENREF_14)] used were based on all child fevers (including non-malaria fevers) treated within a day of onset of symptoms with an antimalarial. For many settings this indicator may overestimate actual effective antimalarial treatment coverage, but in some lower-endemic settings it probably under-estimates effective coverage. For lack of data on older age groups, the resulting young-child treatment coverage estimates were assumed to apply to all age groups in the country. Nevertheless, this indicator should be valid to indicate shifts over time in the coverage and impact of effective treatment within a given setting.
* Intervention coverage indicators are all ‘effective coverage’, as opposed to reach by commodities or services (e.g. ITN usage as opposed to ITN ownership, and effective timely CMU instead of access to ACTs). The cascade of service delivery needed to achieve these effective coverages is not modelled within Spectrum-Malaria, but it will be modelled (as one of several options) in the OneHealth Tool part for commodity planning and costing. For example, effective timely CMU will require health care access, diagnosis and treatment; ITN usage will require ITN distribution and community-based education. When running Spectrum-Malaria without OHT there is a risk that users may over-state the feasible target coverage; notably for effective CMU, coverage at national level in African countries has never yet been observed to be higher than 71% (and median 31%), but as low as a 15% maximum when limited to timely treatment (within one day of the onset of the fever) [[14](#_ENREF_14)].
* For simplicity, no distinction was made in infections, disease episodes and deaths from *P. falciparum* versus other *Plasmodium* species. These simplifications, combined with the anchoring of impact projections on WHO’s population-level burden *estimates* instead of country-reported clinically diagnosed cases and deaths *data*, need proper explanation in the user manual.
* Projected severe case incidence is very uncertain, already for 2000–2015 where it was based on the ratio of severe-to-all (severe uncomplicated) cases as simulated in OpenMalaria [[26](#_ENREF_26)], and even more so for 2016–2030 where the same 2015 ratios continues to be applied for each province, and so severe case incidence changes proportionally with uncomplicated case incidence.
* Spectrum projects impacts to start from the year *after* the first year of the user-specified intervention coverage. This time lag may be conservative compared to other program planning models that assume impact immediately within the year that coverage increases (e.g. LiST). But this choice allows Spectrum to apply statistically estimated burden reductions averaged over years 1 to 3 after coverage increase, which are less biased by stochastic fluctuations and zero outcomes than if statistical models had been built on OpenMalaria simulation results for single years. Spectrum’s impact algorithm is also conservative in that it uses the 1–3 year and 8–10 year impact regression models, and not the 4–6 year impact model which produced the largest burden reductions (and would therefore likely project less meaningful fluctuations in impacts over time). These perhaps debatable choices will influence comparisons of Spectrum-projected malaria control with impacts of other disease programs (such as HIV/AIDS and TB and other child health interventions), especially for evaluations with a short time horizon. However, within the scope of evaluating and optimizing malaria control options for a given country and program, or of evaluating impacts over multi-year ongoing program scale-ups, it should not invalidate Spectrum-Malaria. Importantly, comparisons with LiST projections [[38](#_ENREF_38)] showed that, by applying the 1-year lag and the 1–3 year as well as 8–10 year impact regression models, Spectrum projects impact that are in fact well aligned with those in LiST over years 1–3 after coverage scale-up (for ITNs/IRS on child mortality), while for longer-term horizons Spectrum actually projects *larger* impacts than LiST, reflecting its capture of long-term transmission dynamic effects.
* In order to allow projecting impacts for packages of interventions scaled-up in parallel but with varying time patterns in their respective scale-ups, though based on the stylized OpenMalaria simulations where all coverage changes (for one or more interventions) happened at once, Spectrum applies the simulation-based impact regressions for years 1–3 following OpenMalaria-simulated scale-up for projecting through 2016–2021, and the impact regressions for years 8–10 following OpenMalaria-simulated scale-up for projecting through 2022–2030 − irrespective of the specific settings actual time pattern in intervention scale-up coverage. This is one of several alternative ways of operationalizing the impact projections over time. For scenarios where interventions are scaled-up gradually until a final coverage target no earlier than 2019, this application of the OpenMalaria-based regressions should be valid and in line with what dynamic (e.g. OpenMalaria) simulations would predict. But for scenarios with much earlier or later scale-up, the projected impacts may be less trustable and their match with OpenMalaria dynamic simulations for realistic actual national program scale-up scenarios over a typical 5-year strategic planning horizon will need to be confirmed.
* In general, the Admin1-level approach to impact modelling should provide a reasonable capture of spatial heterogeneity in malaria. For IRS in some lower-endemic countries such as in South Africa, however, implementation zones may be endemicity-based but crossing Admin1 boundaries, which necessitated simple interpolating between the 0% and 80% simulated and statistically modelled coverage scenarios to intermediate values.
* For counterfactual (non-scale-up) projections, Spectrum by default assumes that if coverage does not change, the burden rates will stay as in 2016. In contrast, MAP and WHO, based on statistical empirical models, estimate a secular trend of decline over 2000–2015, presumably reflecting changes in urbanicity, housing quality, land-use, nutrition, and similar socio-demographical factors, and MAP’s 2000–2015 counterfactual for a hypothetical 0 ITN, IRS and CMU coverage throughout 2000–2015 includes this gradual secular malaria decline. To the extent that we believe this secular trend is real and is continuing after 2015, Spectrum may thus over-estimate future malaria disease burden levels and numbers of cases and deaths preventable (though it would still be accurate for future proportional burden reductions). As alternative counterfactual could be considered to forward-project MAP-based secular declines e.g. from 2012–2015 [[11](#_ENREF_11)].
* Spectrum-Malaria is valid only for countries with stable endemic *falciparum* malaria, i.e. most of sub-Saharan Africa (and Haiti, if country data became available to add to the Spectrum database); but not for epidemic settings with exclusively non-*falciparum* malaria. Within sub-Saharan Africa the full range of low to high endemicities was simulated down to EIRs as low as 1 infectious bite per adult per year and *Pf*PR around 0.1%, and intervention scenarios simulated include several resulting in close to elimination. The low-endemicity sites and near-elimination scenarios which will become increasingly relevant for strategic planners over next years, as programs are successful in reducing malaria transmission.
* The age pattern in malaria mortality between 5-14 years and 15-years-and older is extrapolated in Spectrum-Malaria from the corresponding age pattern in case incidence (from MAP) – which implicitly assumes that the coverage and effectiveness of CM (uncomplicated and severe) are constant throughout the above-5-years age group. The latter is a common assumption (also used by MAP in their estimation of *Pf*PR and case incidence patterns and trends) driven by a lack of age-specific CM coverage data. But if in reality CM had better coverage in adults than in school-age children, then Spectrum may over-estimate mortality in adults compared to school-age children.
* Uncertainty ranges on projection outcomes are not yet modelled. These will in a next iteration be estimated by combining 95% confidence intervals on WHO- and MAP-estimated *Pf*PR, case, death and ITN coverage numbers (for MAP-based metrics, represented in the 100 samples presented from the Bayesian posterior distribution for each map) with the 95% confidence intervals on statistical impact predictions (Annex 3). A question is how to reflect additional non-measured uncertainties (such as in Avenir’s extrapolation of WHO’s all-age case and death rates into three age groups, according to MAP’s distribution of cases in these three age groups), and how to account for probable correlation in the uncertainties across parameters.

**Annex 3. Factors and quantifications of uncertainty in Spectrum-Malaria impact projections** – to include in uncertainty ranges on predictions.

| **Factor** | **Quantification of uncertainty** | **How to use?** |
| --- | --- | --- |
| Statistically predicted **% impacts** | 95% CIs from regressions, by age group, time horizon & health outcome [[1](#_ENREF_1)] | As such |
| **2015 case (**total uncomplicated + severe) **and death numbers & rates** | WHO-GMP: Lower and upper bounds on national death number (<5 years & >5 years) and case number (all-age aggregate) [[16](#_ENREF_16)] | Infer relative bounds (upper/point estimate & lower/point estimate) & apply that to Spectrum’s point estimates (for total and uncomplicated cases) |
| 2015 distribution of **5+ deaths** **between 5-14y and 15+ years**, and country-level deaths **into Admin1s** | NA; Avenir applied MAP’s distribution of cases between 5-14 years and +15+ years, and between Admin1 units [[9](#_ENREF_9)] |  |
| 2015 distribution of **cases by Admin1 & by age group** | MAP, percentiles (at pixel level) – separately for 0-4 years, 5-14 years, and 15+ years [[9](#_ENREF_9)] |
| **2015 PfPR** 2-9 years | MAP, percentiles (at pixel level) [[9](#_ENREF_9)] |
| **2000-2002 average** **PfPR** 2-9 years | MAP, percentiles (at pixel level) [[9](#_ENREF_9)] |
| **Seasonality** | MAP, percentiles (at pixel level) [[9](#_ENREF_9)] |
| **ITN coverage** (usage), by Admin1 | MAP: percentiles (at pixel level) [[11](#_ENREF_11)] &: country-level lower- & upper-bounds [[12](#_ENREF_12)] |  |
| **IRS coverage** | NA [[16](#_ENREF_16)] | Ignore, negligible effect |
| **Case management coverage** | NA [[14](#_ENREF_14)] | Assume a fixed, average uncertainty of +100% and -50% -- given the range of estimates (in varying definitions) in Galactionova et al. 2015 |
| 2015 **severe case** number & rate | * Ratios: 95% Confidence Intervals from regression/prediction. * Total cases ‘base’ 2015: See above | Add the two sources of uncertainty |
| **Impact of severe Case Management on mortality** | * Mortality 2015 ‘base’ numbers & rates: see above * % reduction: ? | Add:   * Uncertainty on mortality base numbers & rates, * A notional % uncertainty on the % reduction – the latter derived from % uncertainty in regression-predicted % reductions in mortality |
| Cases and deaths ***averted*** | } To combine all of the above, for case and death numbers or rates, in turn for scale-up & counterfactual scenarios | Standard statistics on the difference between 2 uncertain data points – considering that counterfactual and scale-up outcomes are likely highly collinear (so the uncertainty in their difference may be less). |

Abbreviations to Annex 3. NA = not available.

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