Cost of Malaria Elimination in Kenya by Means of IVM Implementation.

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1. INTRODUCTION

Malaria is one of the world's most deadly diseases, and it is especially dangerous for pregnant women and children under 5 years of age. Apart of the consequences in mortality and the subsequent reduction in life expectancy, malaria affects people's physical conditions, making them more vulnerable to other diseases.

As a result malaria leads to anemia, malnutrition and many other health problems that also affect the amount of hours worked by the labor force in a country, and have a relevant impact on their productivity, thus reducing a country's economic growth prospects. In addition, malaria reduces students' attendance at school, affecting their education and productivity in the long run. Malaria prevention and treatment also absorb a large amount of funds that could otherwise be used for investment in productive activities.

Kenya is one of the sub-Saharan countries where malaria is still endemic in some of its regions. In collaboration with partners, the government of Kenya (GoK) has made substantial efforts to control malaria transmission in the whole country, reaching significant reductions in malaria prevalence, especially along the coast.

Malaria interventions focus on both, case management and prevention. The first type of intervention deals with diagnosis and treatment of the disease. Case management is especially effective to control malaria in low prevalence areas, although is a necessary measure in any malaria risk area. The second type of intervention – prevention – includes very diverse methods, all of them aiming at reducing bites from Anopheles mosquitoes (main vector of malaria transmission) to humans. During the last years, prevention in Kenya has been basically based on two main methods: bed net distribution and insecticide indoor spraying operations.

As no intervention in isolation is able to control malaria transmission and as mosquitoes adapt to some interventions, integration and coordination of various prevention methods is essential to reach malaria elimination. The Government of Kenya (GoK) is advocating for the use of Integrated Vector Management (IVM), which is a rational decision-making tool designed to provide intelligent and optimal management of resources meant for malaria prevention and vector control. [http:] In addition to achieving optimal use of existing resources to fight malaria, IVM also aims at increasing social mobilization and capacity building[1].

In this context, during the last years the GoK has significantly reduced malaria transmissions in the country through IVM implementation, achieving states of pre-elimination or even elimination in places where twenty years ago malaria was endemic.

The present study evaluates the potential impact of different IVM strategies for the future, in order to obtain optimal results in malaria reduction. The analysis has been performed using as

1 Beier J, Keating J, Githure J, Macdonald M, Impoinvil D, et al. (2008), Integrated vector management for malaria control. Malaria Journal 7: doi:10.1186/1475-2875-1187-S1181-S1184.

point of departure a model inspired in the Threshold 21 (T21) – Kenya model developed by the Millennium Institute. The T21 – Kenya is a simulation-based decision support tool to facilitate the design of effective policies for the most relevant national development issues such as broad-based economic growth, poverty reduction, climate change, etc.

The model inspired in the T21 has been expanded to include a malaria sector, which is based on the Malaria Management Model (MMM) [http:]. The malaria sector is dynamically integrated into the model, capturing the major dynamics of malaria and its effects on economy, society, and environment.

The resulting model can simulate and evaluate different IVM interventions under different scenarios of development prospects, climate change or effectiveness of anti-malaria methods. Such scenarios can help to identify adequate interventions to maximize reduction in malaria transmission while observing their repercussions, for example, on population development, health, education, or economic production.

Finally, the model allows estimating the possible cost of eliminating malaria in Kenya on a mid-term horizon under different scenarios and considering different combinations of IVM interventions.

2. SITUATION OF MALARIA IN KENYA

2.1 Malaria landscape

The National Malaria Strategy (KNMS) has been developed in line with the Government's first Medium-Term Plan of Kenya Vision 2030 and the Millennium Development Goals (MDGs), as well as Roll Back Malaria partnership goals and targets for malaria control. KNMS has been designed to cover the period 2009 – 2017, and the plan envisions achieving a malaria-free Kenya by 2017.

Actually, since the National Malaria Control Program started to be autonomous in 2000, malaria prevalence has been significantly reduced in most of the regions thanks to the increased support during the last decade. The average malaria prevalence in Kenya was more than 20% in 2000, and nowadays is about 12%.

The situation however is still complicated: Kenya had an estimated 11 million malaria cases in 2011, and about 30 million out of the 42 million inhabitants still live in malaria risk areas. The west for instance, is a very densely populated region where malaria prevalence is more than 40%.

In order to have a general vision of malaria in Kenya, Figure 1 provides an overview of malaria prevalence in 2009.

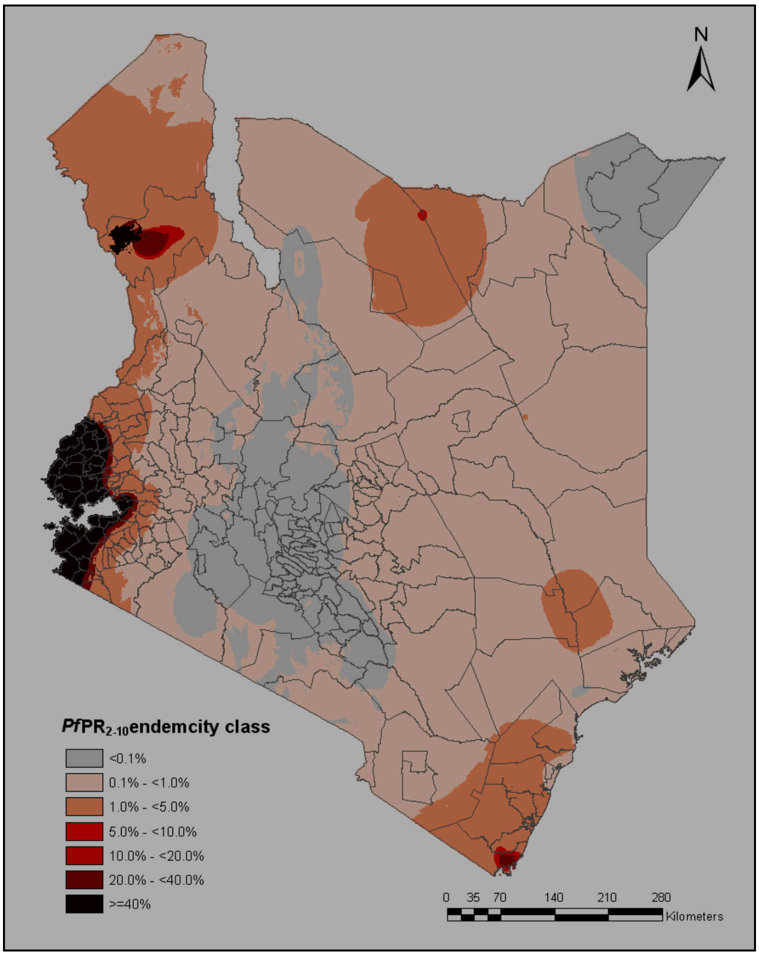

Figure 1: Malaria prevalence (Kenya Malaria Monitoring and Evaluation Plan 2009-2017) [http:]

As it appears from the map, malaria prevalence is lower than 5% in most of the country. Currently, it is estimated that 60-70% of the Kenyan land has a parasite prevalence of less than 5% where 78% of the population lives. [http:] If compared with the situation ten years ago, endemicity has been significantly reduced along the country. However some regions with yet high endemicity are also high densely populated, implying many people living at risk of malaria transmission. It is important to note that malaria reduction is resulting from continuous years of malaria interventions. Any decrease in efforts will mean the return of endemic malaria in the regions where the pre-elimination state has been achieved.

2.2 Malaria Interventions

As mentioned above, Malaria interventions include treatment and prevention. Successful treatments are based on prompt disease recognition and the use of adequate and high-quality therapies for eradication of the parasite causing malaria. Methods for prevention are very diverse, and components within the IVM framework include [http]:

- The use of personal protective measures: Bed nets, wearing of protective clothing or repellents which appear in various forms.
- Chemical control: Indoor Residual Spraying (IRS), outdoor spraying.
- Environmental Management (EM): Environmental control measures for vector control.
- Biological Control Measures: Larviciding

Nevertheless, despite a big variety of possible preventive strategies, during the last years the most relevant preventive methods implemented in Kenya have been the distribution of bed nets to population at risk and insecticide spraying operations in targeted areas.

On the side of bed nets distribution, the targeted population for such interventions mostly consists of the people living in endemic regions, and during 2011, 12 million bed nets were distributed. Approximately 60% of the population has a bed net and estimations are that following with the current program, almost all the population at risk will be soon covered under the assumption of one LLIN per every second person.

The bed nets distributed were treated with insecticide in order to repel mosquito (such nets are commonly called “Insecticide treated Nets” (ITNs)). Conventional ITNs need to be retreated every 6 months, but since 2007 GoK is mostly delivering long lasting insecticide nets (LLIN), an improved version of ITN which does require retreatment or substitution after about 3 years...

The approximate costs of LLIN per person are $6, where about $5 is the cost of the net itself, and the rest is transportation/distribution cost.

On the side of insecticide spraying, indoor residual spraying (IRS) have been the most popular type of intervention. IRS interventions are implemented in targeted areas based on two fundamental criteria:

- Burden reduction
- Response or prevention of epidemics (it’s known when an epidemic could occur)

IRS interventions are made once per year, and the most common compounds used in Kenya are pyrethroids. Also organophosphate is used, but this product is more expensive since it needs to be sprayed twice per year. The approximate cost of IRS interventions per person is 6$, where the chemical is 2$, and the rest is around 4$: Transport, spraying operations, local labor, etc.

Both LLITNs distribution and IRS need sensitization and social mobilization in order to achieve the desired efficacy. Similarly, the level of education among Kenyan population is also a key aspect affecting interventions’ efficacy. Reports indicate that general knowledge in Kenya about malaria transmission is currently at 95%; nevertheless still many people do not use or misuse the nets that have been given. It is estimated that the cost of sensitization for LLITNs interventions is about $1 per person, which adds to the cost of the net and transport/distribution.

2.3 Geographical Distribution of Interventions

When it comes to IVM, the decisions are basically prevalence based made. For instance, in Kenya IRS is not implemented in low prevalence regions. IRS starts being considered worthy when prevalence is 10% or higher. As for LLITNs, in the provinces of Western, Rift valley, Coast and Nyanza LLINs are delivered to the entire population. In the rest of the country LLINs are only delivered to people in the highest risk categories: pregnant women and children of less than one year old. The delivery policy is such that in regions of malaria prevalence the net distribution aims for placing one LLIN per two persons.

In order to have a more comprehensive view of the interventions carried out in the different regions Kenya can be divided into four malaria epidemiological zones [http]:

-A: Endemic: Areas of stable malaria have altitudes ranging from 0 to 1300 meters around Lake Victoria in western Kenya and in the coastal regions. Rainfall, temperature and humidity are the determinants of the perennial transmission of malaria. The vector life cycle is usually short with high survival rate due to the suitable climatic conditions.

-B: Malaria epidemic prone areas of western highlands of Kenya: Malaria transmission in the western highlands of Kenya is seasonal, with considerable year-to-year variation. The epidemic phenomenon is experienced when climatic conditions favors sustainability of minimum temperatures around 18ºC. This increase in minimum temperatures during the long rains period favors and sustains vector breeding resulting in increased intensity of malaria transmission. The whole population is vulnerable and case fatality rates during an epidemic can be up to ten times greater than what is experienced in regions where malaria occurs regularly.

-C: Seasonal malaria transmission: This epidemiological zone in arid and semi-arid areas of northern and south-eastern parts of the country experiences short periods of intense malaria transmission during the rainfall seasons. Temperatures are usually high and water pools created during the rainy season provide the malaria vectors breeding sites. Extreme climatic conditions like El Niño Southern Oscillation lead to flooding in these areas leading to epidemic outbreaks with high morbidity rates due to low immune status of the population.

-D: Low risk malaria areas: This zone covers the central highlands of Kenya including Nairobi. The temperatures are usually too low to allow completion of the sporogonic cycle of the malaria parasite in the vector. However, increasing temperatures and changes in the hydrological cycle associated with climate change are likely to increase the areas suitable for malaria vector breeding with introduction of malaria transmission in areas it never existed.

The next diagram shows the population distribution for the four malaria epidemiological zones:

Epidemiologic strata	Total projected population 2009	% of total projected population	Cumulative % of total projected population
Lake stable endemic & Coast seasonal stable Endemic	11,452,028	29.0%	29.0%
Highland epidemic Prone	8,007,718	20.3%	49.3%
Seasonal low transmission including arid and Semi arid	8,029,683	20.4%	69.7%
Low Risk	11,933,834	30.3%	100.0%
Total	**39,423,263**	**100%**	

Table 1: Population distribution by malaria epidemiology [http:]

Although the endemic zones do not represent a big area in the malaria endemicity map, these regions contain almost one third of the total population in Kenya.

Table 2[2] represents the policies for malaria interventions depending on the malaria epidemiological zone:

Epidemiology	Case Management	LLIN	IRS	Health Education/BCC	IPTp	EPR	Surveillance
Lake stable endemic & Coast seasonal stable Endemic	X	X	X	X	X		X
Highland epidemic prone	X	X	X	X		X	X
Seasonal low transmission including arid and Semi arid	X			X		X	X
Low risk	X			X			X

Table 2: Stratification of districts by malaria risk and appropriate intervention [http:]

[2] Note that the table includes IPTp and EPR, which are not discussed in the paper. IPTp consist of intermittent preventive treatment of malaria for pregnant women, only delivered in endemic areas. Epidemic Preparedness and Response (EPR) is an approach intended to improve epidemic preparedness and response by establishment of malaria early warning systems and carrying out preventive measures such as IRS campaigns in order to avoid epidemics [http]. EPR is useless in endemic areas since malaria transmission is present during the whole year.

In summary, LLINs are delivered only in the two zones with higher risk. This is almost half of the population with access to LLINs to attain universal coverage defined as one LLIN for every two persons at risk of malaria. IRS is only implemented in endemic areas for disease burden reduction, and also IRS campaigns for malaria prevention where epidemics can occur. Case management and surveillance are implemented in all the zones: Case Management is the combination of diagnosis and treatment, and surveillance basically consists of the monitoring of malaria incidence: Surveillance is the continual and systematic collection, analysis and interpretation of malaria data essential to the planning, implementation and evaluation of interventions. It is also a tool for measuring the health status of a population [http:]

Health education includes sensitization activities that promote public awareness of malaria transmission. Communication programs embrace basic strategies to increase demand for and acceptance of malaria interventions and services, including information, education and communication (IEC) and behavior change communication (BCC) methodologies. [http:]

Beyond LLINs and IRS interventions, in Kenya very little EM and biological control has been done, a part from some environmental modifications introduced through infrastructures or agricultural projects, providing some EM indirectly. An exception is the coastal region, were IRS was rarely used, but thanks to implementation of ITN, EM and larviciding, the region experienced prevalence reductions from 60% in the 90's to current values of around 5%.

3. THE MODEL

This section presents in more detail the malaria sectors of the model, to provide a better understanding of the key factors and mechanisms that drive our malaria projections. Just as the rest of the model, the malaria sector is developed by way of the System Dynamics method. The malaria sector builds on the Malaria Management Model (MMM) developed by BiM, although with some important structural differences. The malaria sector is dynamically linked two-way with the rest of the model: in one direction, the malaria sector uses various inputs generated from the rest of the sectors, such as population figures, or figures for expenditure in the health sector; in the other direction, malaria prevalence and deaths are used to affect productivity and demographics in the rest of the model. The malaria sector can be divided into four sub-sectors:

1. IVM Interventions
2. Case Management
3. Malaria Transmission
4. Malaria Costs Accounting

The sectors above indicated all dynamically interact, endogenously generating the major trends of development for malaria and highlighting the impact of malaria interventions. The next diagram provides a simplified representation of the four malaria subsectors, with the main indicators and the links connecting each other:

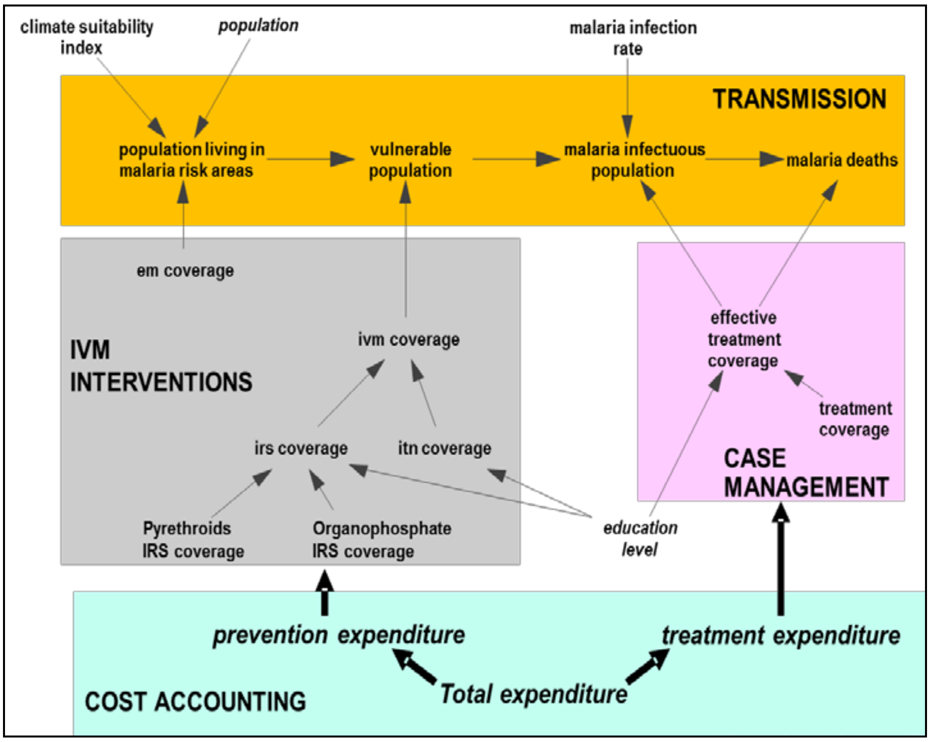

Figure 2: Malaria subsectors in the model

Further details on the structure of the malaria sub-sectors and their function are provided below.

3.1 IVM Interventions

This sector represents the implementation mechanisms and related costs of selected representative IVM interventions. These interventions are basically the combination of the most relevant protective measures: Bed-net distribution, IRS, and EM. Possible future achievements regarding vaccination are not considered, as the time required for developing such vaccination, its potential effectiveness, and the resources involved remain highly uncertain.

3.2 Case Management

This sector keeps track of the diagnosis and treatment coverage, and expenditures for malaria infected population. Per capita health expenditure is used, together with the contribution of malaria treatment expenditure, to determine the theoretical treatment coverage.

The actual coverage is based on the theoretical coverage, but also the percentage of people who attend formal health services, and the average efficacy of the malaria treatments in terms of drug resistance of the parasite that causes malaria. Such treatment coverage strongly affects malaria mortality.

3.3 Malaria Transmission

This sector provides a representation of the mechanisms underlying long-term dynamics of malaria infections and deaths.

Climatic conditions play an important role for malaria transmission: the density and level of activity of the vector depend on climatic conditions such as temperature, rainfalls and humidity. Consequently, more suitable climate conditions may turn low risk areas into high risk areas. Vulnerable population is determined based on the estimated proportion of population living in risk areas, and on the actual coverage of the malaria preventive methods (IVM). Actual coverage of IVM depends on the intensity of IVM interventions, as well as on the education level and per capita income of local population.

Malaria infections are determined based on the interaction between vulnerable population and malaria infectious population. Considering the short life-span of a mosquito (a few weeks) with respect to the long-term time horizon of the model, the mosquito life-cycle is not explicitly represented in the model. On the contrary, the ability of the mosquito population to function as vector for the malaria parasite is implicitly represented as part of the rate of transmission of the malaria parasite (infectivity).

The deaths caused by malaria are calculated based on the malaria infected population and the malaria mortality, which depends on the efficacy and coverage of malaria treatments, as described above.

3.4 Malaria Cost Accounting

This sector summarizes all economic costs of the epidemic and of implemented interventions, as well as long-term impacts on human life expectancy and productivity.

The indicators calculated in this sector will allow deriving broad assessment of the desirability of alternative strategies to fight malaria.

4. BASE RUN RESULTS FOR KEY INDICATORS

As a mean of model validation, the model was subjected to a number of validity tests[3], including both structural and behavioral tests. Regarding the former type of tests, the model underwent reiterative cycles of revision from local malaria experts, who reviewed the model structure and parameters. Regarding behavioral validation, a base run simulation was generated for the period 1980-2012, with the aim of assessing model's ability to replicate the

[3] Barlas, 1996, Formal aspects of model validity and validation in system dynamics, System Dynamics Review Vol. 12, no. 3, (Fall 1996): 183-210

historical trends for key malaria-related indicators. Because of the incompleteness and at times inconsistency of the available data, such activity has been especially challenging for some indicators.

More precisely, we observed an important disparity between simulated malaria cases and malaria cases from data collection. According to WHO reports and local data surveys such as the Kenya National Bureau of Statistics 2011 (KNBS), the number of suspected cases has been increasing during the last decade. Data collection in different sources showed values from around 4 million cases in 2002, and almost uninterrupted growth over time until reaching approximately 11 million cases in 2011. Figure 3 displays the trend in the data collected from WHO and KNBS.

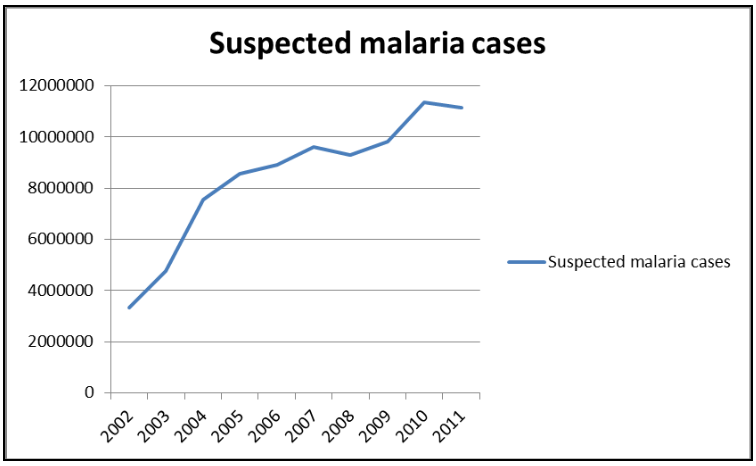

Figure 3: Suspected malaria cases (source: WHO and KNBS)

This growth indicates that the number of cases in 2011 is almost triple than in 2002. Even considering the important population growth rate of Kenya, the suspected cases in 2011 per thousand people is double than in 2002.

The increase in malaria incidence that seem to emerge from collected data is not consistent with the growing intensity of anti-malarial interventions in the country. Actually the efforts made in Kenya over the last decade have led to a situation where the population has more access to antimalarial resources than never before.

Figure 4 (from WHO) illustrates the evolution of coverage of ITN and IRS: the increase in the percentage of households with access to ITNs during the last years is substantial.

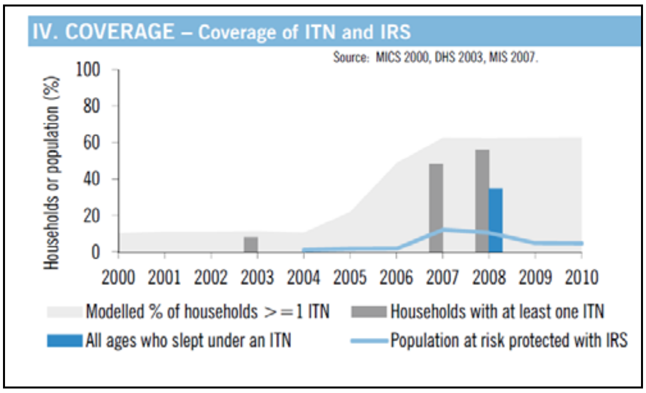

Figure 4: Coverage of ITNs and IRS (source: WHO)

Such substantial increase in coverage of anti-malaria interventions lead us to consider the possibility that the apparent increase in malaria cases is artificial, probably due to some problem at the survey level. In this case it is essential to interpret the data in a right way in order to understand the system, or one may conclude that the increase in the level of interventions experienced over the last decade only led to more cases of malaria over time.

Many other factors were analyzed with the purpose of finding what could be the reason to this apparent increase in the number of cases:

One of the factors that could have been responsible is climate change, but that does not seem to be the case based on the analysis of key main climatic indicators: actually the average temperature in Kenya has been relatively constant, the same with the humidity, and if we attend to the rainfall, its behavior does not provide any pattern that could explain the increase of malaria cases. Figure 5 shows trends for historical temperature and rainfall.

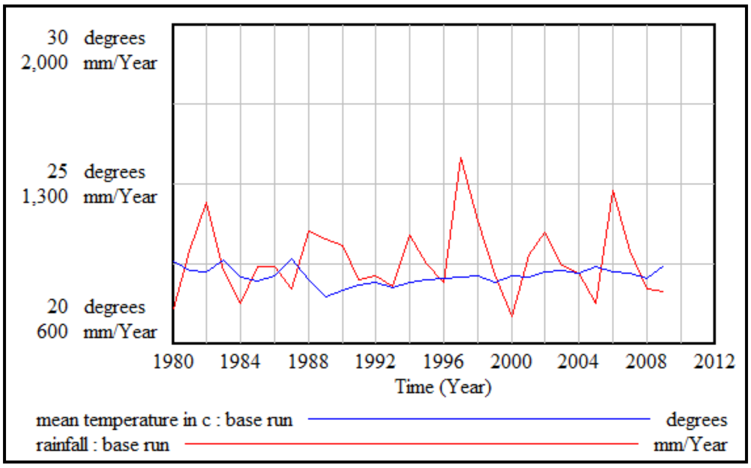

Figure 5: Mean temperature and rainfall

Other factors were also considered, but we found no possible driver for such increase in the number of malaria cases: No decrease of education level , no increase in poverty, or no increase in malnutrition level were observed in this period that could explain the increase of malaria cases.

The local T21-Kenya team illustrated such discrepancy to malaria experts during the T21-Kenya Malaria Workshop 2012 in Nairobi, and the discussion led to a possible explanation of the increase in suspected malaria cases over time. According to the experts, there was actually no increase in real number of cases during last years. The improvement in the Kenyan health system has resulted in a higher access to health centers, increasing the attendance rate. Also the collection of data for malaria cases has certainly improved by achieving better monitoring and diagnosis of malaria cases, and by improving the quality of the data collection. Then the surveillance system provides now numbers of reported cases which are closer to the reality than ever before. This improvement in surveillance and reporting has thus created an artificial increase in the number of cases while the real number of malaria cases was in fact decreasing.

Figure 6 shows a comparison between the model results from the base run simulation and the suspected malaria cases from the data collection.

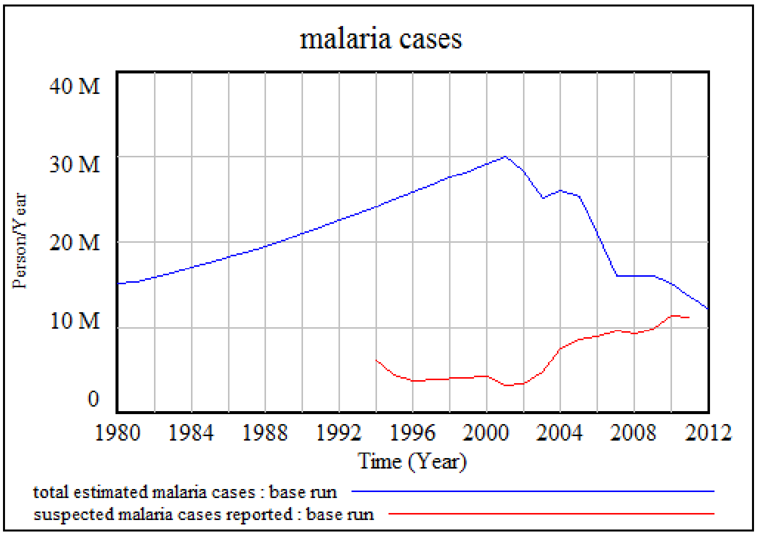

Figure 6: Model simulation vs. historical data for suspected malaria cases (source: WHO and T21)

As it can be observed from the graph, the simulation displays a very different behavior of total estimated malaria cases with respect to the suspected malaria cases from WHO and KNBS reports for most of the period. Only for the most recent years, when the surveillance and reporting system in health centers have improved, the number of cases simulated by the model is close to the suspected malaria cases.

The model simulation thus provides a tentative picture of the actual development of malaria cases over the last 30 years. Given the increasing implementation of IVM in Kenya during the last decade, the expected trend in malaria cases over time is a decreasing curve. Before that, the number of cases was increasing at the same rate as the population growth.

Such simulation is based on the assumption that the proportion of population living in malaria risk areas has been constant and around 75% of the total population (WHO 2009 and 2010), and on the existing figures regarding access to protective measures.

The results of the model simulation are to be intended inclusive also of cases that were not reported, as well as cases that were treated at home and also asymptomatic cases.

Figure 7 shows the simulated malaria prevalence in Kenya, i.e. the population fraction having malaria at any given point in time.

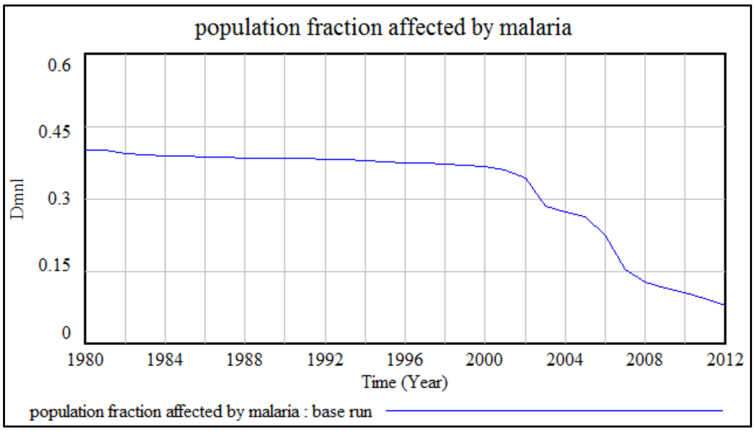

Figure 7: Simulated results for malaria prevalence (source: T21)

When it comes to analyze malaria deaths, the historical data also differs from the simulation and the explanation follows the same arguments as those discussed above for malaria cases. Figure 8 shows simulated number of deaths versus reported malaria deaths.

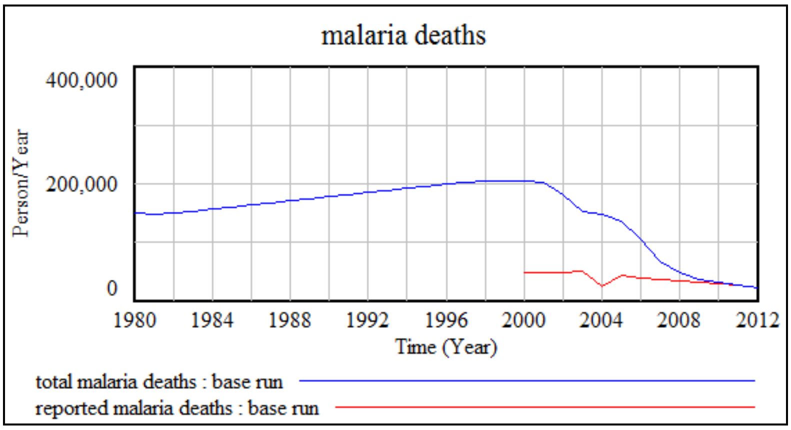

Figure 8: Model simulation vs. historical data for malaria deaths (source: WHO and T21)

In this case, although the number of deaths is generally better reported (deaths are to be reported by law), the number of deaths has also been under reported, especially because without a proper diagnosis it is difficult to assess whether malaria was the real cause of the death or not. The model provides the estimated number of deaths and the simulated deaths match with the deaths reported only for the very last years, when an improved monitory system is in place.

A final challenge with historical data is related to the level of funding of malaria interventions. The implementation of antimalarial campaigns over the last decade has been very costly. During the last years the GoK in collaboration with partners has deployed large amounts of LLINs and IRS interventions, together with an increased access to treatments, especially Artemisinin-based Combination Therapy (ACT). However there is also certain disparity between the calculated budgets to deploy such interventions and the reported funding by the GoK.

Figure 9 displays together the funding reported by Kenya, and the necessary budget to cover the reported most relevant intervention, in this case the sum of ITNs, IRS and ACT.

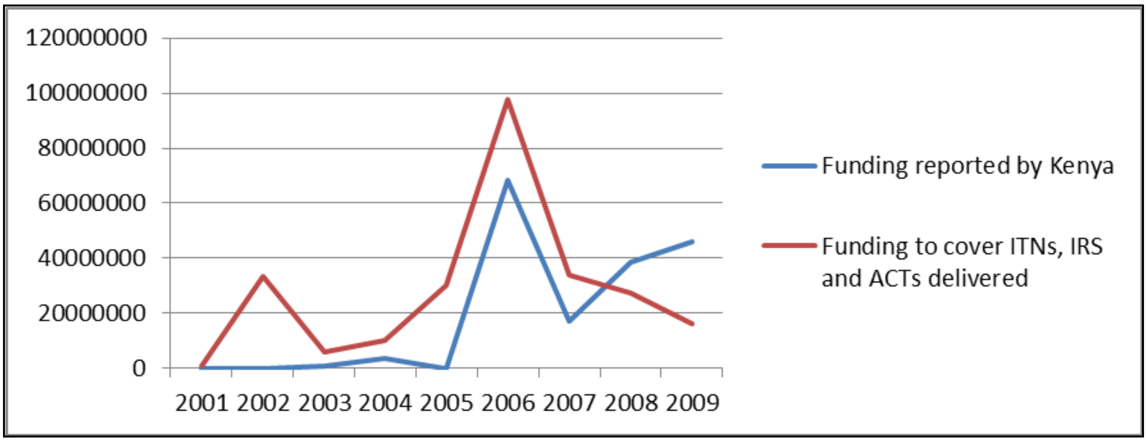

Figure 9: Funding reported and estimated resources needed for implemented interventions.

Lack of reporting is again the reason why both graphs do not square, although in this case both lines follow qualitatively similar paths.

In summary, model validation has focused mostly on structural validity tests, especially direct confirmation of model's structure and parameters by local malaria experts. In terms of behavioral validation, results from the model cannot be directly compared with the available historical data for validation purposes. However, considering all available information the simulation results provide a more realistic representation of malaria trends than official data alone would provide. While clearly the availability of more complete and reliable data would improve model accuracy, we believe that the approximation provided by the current model can facilitate the design of effective location-specific IVM strategies.

5. POLICY ANALYSIS

The current expenditure in Kenya to fight malaria differs from year to year, but during last years it is around 100 Million (constant 2000 US$). When divided by a total population of around 40 million, the approximate per capita expenditure in real terms is on average about 2.5$ per person per year.

However, intensity of malaria interventions is not the same across the country. The anti-malaria interventions in Kenya are made at regional level depending on the malaria prevalence and the conditions at the targeted area; in consequence before deploying any intervention it is necessary to know the malaria local situation. Based on the malaria risk map and the epidemiology of malaria in Kenya, the 4 districts can be stratified as follows:

A. Lake stable endemic and Coast seasonal stable endemic: Risk > 20%

B. Highland epidemic-prone districts: Risk 5% - 20%

C. Seasonal low transmission including arid and semiarid districts: Risk < 5%

D. Low risk districts: Risk < 0.1%

A 2007 malaria indicator survey showed that there are variations in malaria parasite prevalence across the epidemiological zones of the country among children under 5 years of age [http:]:

- 17% in endemic areas
- 1% in epidemic prone areas
- 1.4% in areas of seasonal malaria transmission (arid and semi-arid lowlands)
- 0.4% in low risk transmission areas

Based on the values above for prevalence corresponding to the weakest population group (together with pregnant woman), we assume that the biggest share of the budget for case management goes to endemic areas. Considering also that the policy of GoK is to deliver LLINs and IRS only in endemic areas, we also estimate that with the current situation, more than 85% of the global budget for both IVM and case management goes to endemic zones.

We assume that the rest of the regions are engaged in maintaining and if possible reducing endemicity in order to avoid any return of malaria, but at the cost of a small share of the budget: Surveillance and case management could be enough in combination with EPR, sensitization, and LLINs for the weakest groups of the population.

Our policy scenarios do not include any temperature increase due to climate change that could lead to higher malaria suitability in some regions. Also the mosquito resistance to IRS, and the parasite resistance to current treatments like ACT are constant and they correspond with the current values.

Based on such assumptions, we simulated to alternative three policy scenarios, with the objective of assessing how different levels of expenditure, and different ways of allocating such expenditure among various types of interventions impact on malaria prevalence and deaths.

Scenario 1: Business as Usual

In the first scenario we fix per capita expenditure to fight malaria at the constant value of 2.75$ and maintaining the same allocation among LLINs (55%), IRS (44.5%) and EM (0.5%). Projections under these assumptions indicate a slow decrease of population fraction affected by malaria, reaching levels of malaria prevalence around 7% in 2030. The next graphs display the results for malaria cases.

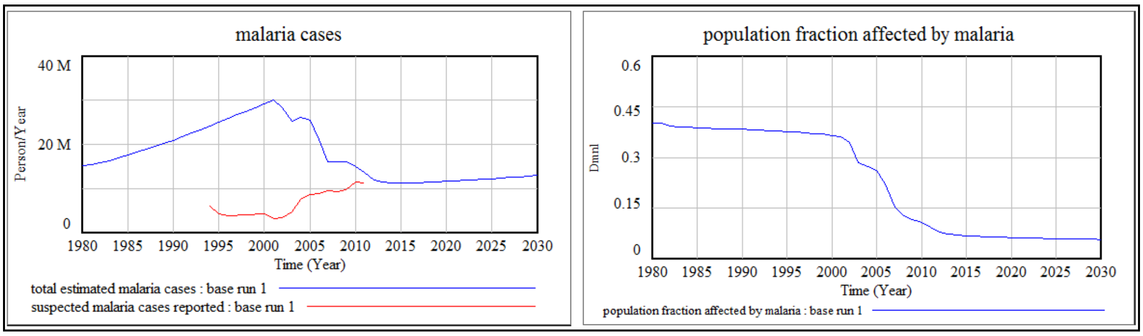

Figure 10: Scenario 1: Constant* expenditure at *2.75* $/person/year, *55% to LLINs, 44.5% to IRS and 0.5% to EM

Total malaria deaths by 2030 are substantially reduced to values below 20,000 per year.

Scenario 2: Budged increase and increasing focus on EM.

In our second scenario we assume a progressive increase of the budget up to 5$ per person per year, allocating more investments to EM, while keeping expenditure for LLINs and IRS in line with that of the BAU scenario (45% to LLINs, 35% to IRS and 20% to EM). Results indicate a more rapid decrease in malaria prevalence, thanks both to the increased overall budget and to the increased share of budget for EM. More precisely, EM reduces the population living in risk areas, and in consequence less LLINs and IRS are needed to reduce malaria transmission. In this scenario malaria prevalence would become less than 3.3% of the total population in 2020.

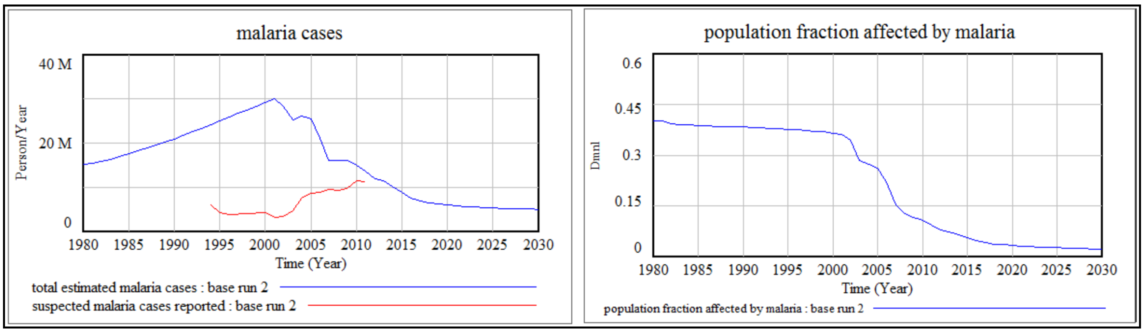

Figure 11: Scenario 2: Scaling up to **5$ per person per year,** *45% to LLINs, 35% to IRS and 20% to EM*

Scenario 3: Budged increase, LLINs universal coverage, and balanced investment in EM.

In our third scenario we progressively increase the budget up to 5$ per person per year (as in our second scenario), and allocate 15% to LLINs, 70% to IRS and 15% to EM. Such shift of resources from LLINs to IRS with respect to our second scenario reflects the fact that 15% of the budget is sufficient to maintain virtually universal coverage of LLINs, and thus more resources can be used for IRS. Expenditure for EM is also limited to 15% of the total budget since EM expenditure is characterized by relevant diminishing returns (it is assumed that EM interventions are implemented first in highly densely populated areas, where interventions affect the larger number of people). Beyond such level of expenditure unit efficacy of EM expenditure would fall below current levels of efficacy of IRS.

As illustrated in Figure 12, in this scenario malaria is eliminated by 2022. However, as indicated earlier on, this scenario does not consider the possible increase in resistance to current IRS products, which could strongly reduce IRS effectiveness. In such case, a larger share of investment towards EM would be a more effective and safe choice.

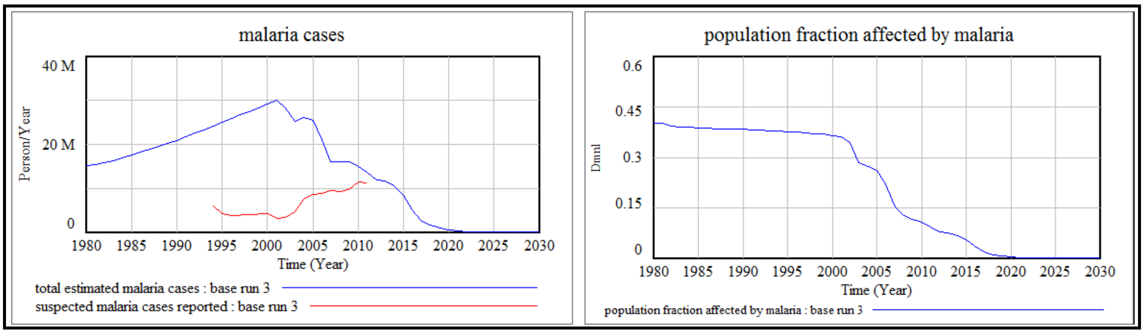

Figure 12: Scenario 3: Scaling up to **5$ per person per year,** *15% to LLINs, 70% to IRS and 15% to EM*

Figure 13 provides a direct visual comparison of the impact of the three scenarios simulated on malaria prevalence and deaths. While in the base run we observe a stabilization of prevalence around 7% in the long run, in scenarios 2 and 3 we observe a continuous decrease in prevalence (and deaths). Such trend is especially marked in scenario 3, where prevalence and deaths are virtually reduced to zero. This indicates that both an overall budget increase and a reallocation of budget across interventions is needed in order to achieve elimination over the coming decade.

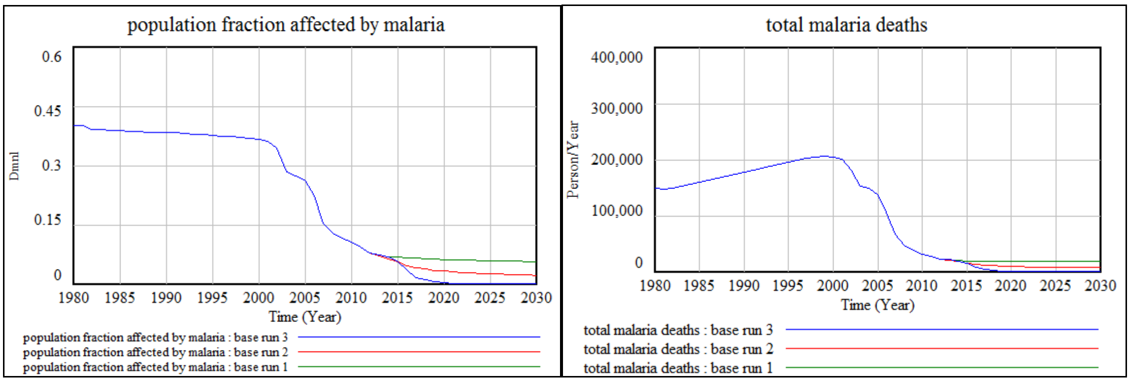

Figure 13: Comparison of scenario results for malaria prevalence and deaths

Benefits from malaria elimination

When it comes to make the overall calculation of the malaria cost accounting, besides the expenditures for prevention and case management, it is necessary to balance the bill with the benefits that would come from malaria elimination.

In Kenya, it is estimated that 170 million working days are lost to the disease each year (MOH 2001) [http].Considering a total of about 230 working days per person per year, and a total labor supply of about 13 Million, malaria causes an economic loss due to the reduction of workable days of about 6% of GDP, which is about 9 times the budget destined to fight malaria nowadays.

Of course malaria does not affect all income groups in the same manner: the estimate above is based on the assumption that all individuals have the same chance of getting malaria. In reality malaria is strongly associated to poverty, meaning that malaria infected population normally corresponds to lower income cohorts than average.

At any rate, beyond direct health benefits, malaria elimination in Kenya would imply a significant increase in the average labor productivity, not mention the positive impacts on important social variables – such as children attendance at school – that should be taken into account when it comes to evaluate IVM strategies.

6. CONCLUSIONS

Much improvement has been done in Kenya with malaria control programs, but more investigation is needed to assess whether the current policy framework will be the optimal one over the coming years. Based on the preliminary analysis carried out with T21-Kenya, it appears that both a substantial increase in malaria budget and a reallocation of such budget across intervention is necessary in order to achieve malaria elimination within the next decade.

In terms of overall budget, maintaining the current program malaria (about 2.75 $/person/year) malaria prevalence will tend to stabilize at about 7% by 2030. When it comes to elimination more funding is needed: our simulations indicate that elimination could be achieved over the next decade by nearly doubling the current budget (about 5 $/person/year). At any rate, malaria elimination in Kenya would provide enough economic benefits to cover the expenditures destined to fight malaria.

In term of budget allocation among interventions, we considered fundamentally three types of intervention: long-lasting insecticide-treated nets (LLINs), indoor residual spraying (IRS), and environmental management (EM). Nowadays in every house in Kenya there is at least one LLIN. Approximately 60% of the population has a bed net, and estimations indicate that the goal of universal coverage defined as one LLIN for every two persons at risk of malaria, is very close to be achieved. Once universal coverage will be reached, the question remains whether it will be necessary to increase the coverage to one LLIN per person, or efforts should move toward the direction of improving people's bed net usage – i.e. appropriate use to increase the protective effectiveness – and toward a more intensive use of other types of intervention.

Our simulations indicate that optimal results are achieved when the LLIN deployment provides universal coverage. More expenditure in LLINs would not provide substantial additional protection, and thus budget resources should be directed to other types of interventions: EM and IRS. EM is a highly cost-effective strategy in densely populate areas, while its cost-effectiveness tends to decrease in less populated areas. IRS interventions do not exhibit such relevant diminishing returns, although their effectiveness is strongly linked to the possible emergence of resistance to IRS products. Therefore the exact mix of interventions is to be established based on close monitoring of the emergence of resistance, and considering location-specific factors that can render