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Malaria risk scenarios for Kisumu, Kenya: blending qualitative and quantitative information

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Introduction

The processes in today's world – including socioeconomic change, demographic change and environmental change – oblige us to broaden our conception of the determinants of population health (Martens and Rotmans 2002). Although the speed and direction of these changes involve great uncertainty, they will for certain affect the future prevalence of all kinds of diseases that may pose a threat to the world's future prosperity. The continuous interaction between a number of factors and processes at different spatial- and temporal-scale levels per definition makes human health, and e.g. malaria, complex to analyse.

Integrated projections of the potential risks of malaria pose a difficult challenge due to a combination of a diversity of related global and local changes. The sensitivity and adaptive capacity amongst exposed populations vary considerably. Malaria prevalence depends on factors such as population density, level of economic and technological development, local environmental conditions, pre-existing health status, and the quality and availability of health care and public-health infrastructure.

The intricate relationships between malaria parasites, hosts and their vectors make the ecological web extremely sensitive to disturbances therein. It is expected that e.g. global climate and other environmental changes will have a significant impact on local malaria risk in the near future.

To explore possible futures of malaria risk and provide sound policy-relevant guidance for decision makers, the value of integrated scenarios has increasingly and widely been recognized. In contrast to many scenario studies, this study elaborates on malaria risk due to the mutual interplay of different simultaneous developments. Often the effects of separate developments have been considered (e.g. (Alene and Bennett 1996; Rogers and Randolph 2000; Craig, Snow and Le Sueur 1999), providing a less comprehensive view on the future of malaria.

CAMERA

The scenarios for malaria risk in Kisumu region have been developed as part of the CAMERA (Cellular Approach for Malaria Eco-epidemiological Risk Assessment) project. The main objective of this research project was to assess the impact of environmental and socioeconomic changes on the risk of vector-borne diseases, and more specific of malaria. Until now integrated future analyses of this region are disregarded.

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The Kisumu study area (Figure 1, see Colour pages elsewhere in this book) is situated in southwest Kenya at the eastern shores of the Winam Gulf of Lake Victoria, and stretches from Kisumu town, on the Kano plains (1100 m altitude), to Kericho (2100 m), 80 km further east. Although the study area straddles the equator, its altitude allows for a relatively mild tropical climate. The climatic conditions make the area quite suitable for agriculture compared to other parts of Kenya. Consequently, due to the fertile grounds and the relatively mild climate, the southwest is amongst the most densely populated areas of Kenya.

The present vector and population density and poverty contribute to a high infection risk in the mainly rural areas. Except for the highland area above 1500 m and the urban areas like Kisumu town, the region can be considered a high-transmission-risk area.

This paper provides a next step towards an integrated 'modelling' framework to elaborate on scenarios for local malaria risk and a long time horizon. Based on a combination of possible images of the future of the area and on computer modelling, scenarios have been developed with regard to plausible changes in local malaria risk. The images give voice to important qualitative factors shaping development such as values, behaviours and institutions, providing a broader perspective than is possible from mathematical modelling alone. The quantitative analysis by means of the computer simulation model offers quantitative underpinning and spatial visualization of malaria risk in relation to the main environmental parameters. As part of the CAMERA project a field study (conducted by Wageningen University in cooperation with KEMRI) took place in Miwani at 1200 m altitude, Fort Ternan at 1500 m and Kericho at 2000 m. The paper continues with a description of the computer model developed to assess local malaria risk, after which the current malaria risk and the analysis of Kisumu region are described. Finally, sketches of possible futures are presented by means of the scenarios, blending qualitative and quantitative information.

Malaria in Kisumu: a local-risk model

A mutual interplay

The transmission of malaria is determined by the combined action of three components (Figure 2), viz., humans and animals serving as hosts, vectors transmitting the disease, and parasites or pathogens infecting both host and vector.

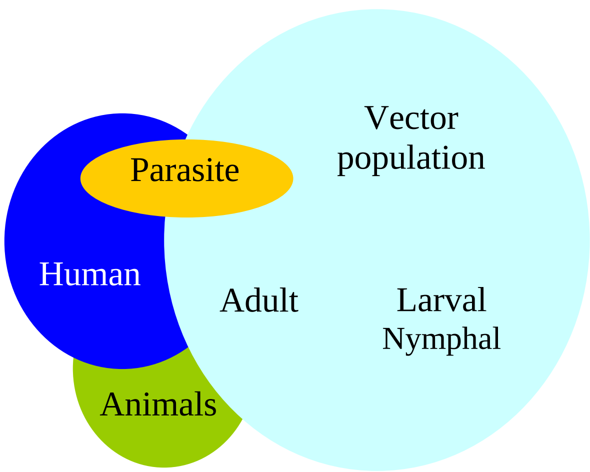

Figure 2. Three main components of malaria (Casman and Dowlatabadi 2002)

The composition, sensitivity, behaviour and adaptive capacity of these components together determine the malaria transmission risk and the mortality and morbidity rate amongst the human population. In turn, these main determinants are affected by a complex interplay of natural, social, economic and institutional aspects. While the basis of potential malaria outbreaks and endemicity lies within the ecological domain, the actual impact of the exposure on the local population is strongly influenced by socioeconomic factors. It is acknowledged that the status and development of these factors in the different domains are intertwined.

The role of computer modelling to elaborate current and future malaria risk has significantly increased in the past few years. Within the scope of this study a specific model has been developed to assess the impact of changes in a diversity of factors underlying malaria risk for Kisumu region. The LEMRA (Local Eco-epidemiological Malaria Risk Assessment) model integrates physical, environmental and partly social factors influencing malaria risk into one dynamic model at a high level of spatial detail (1x1 km^2) (Figure 3, see Colour pages elsewhere in this book).

Model parameters and risk classification

The model, built in a layered-grid-based format, determines for each of the layers the malaria risk based on a qualitative relation between risk and the grid-based input. The layers contain GIS information of temperature, land use, precipitation, infrastructure and population. The population layer was switched off, since the main aim of this study was not to elaborate on the different stages of development of the disease. Moreover, the importance of density and spread of population is taken into account in the qualitative analysis. The following paragraphs will describe in more detail the implemented mathematical relations for the main environmental factors: temperature, land use and precipitation, and infrastructure.

Temperature

The behaviour and survival probability of the vector and the development rate of the parasite are to a large extent determined by temperature. Although human (host) behaviour is also affected by temperature, this has not been taken into consideration explicitly. To assess the malaria risk with regard to temperature the transmission potential (TP), a derivative of the basic reproduction rate (R_0), has been applied. TP is the reciprocal of the critical mosquito density. TP is used here as a comparative index for estimating the impact of changes in ambient temperature patterns on the risk of malaria (Martens et al. 1999), assuming that all other relevant factors remain unchanged. A high TP indicates that, despite a smaller or, alternatively, a less efficient vector population, a certain degree of transmission may be maintained in a given area.

Based on the monthly mean temperature the TP has been derived for each cell. The model has implemented a minimum temperature of 16°C with respect to the development of the parasite, and a minimum temperature of 9.9°C with respect to feeding behaviour. Table 1 illustrates in what way TP has been implemented and translated to a risk classification (translation based on expert judgment; W. Takken personal communication). Drawback of this method is that the minimum temperature, related to the development of a stable vector population, is not taken into account.

Table 1. Malaria risk and transmission potential (TP)

Risk	TP	Classification
No	0	0
Low	0 < TP < 0.01	1
Medium	0.01 < TP < 0.03	2
High	0.03 <TP < 0.055	3
Very high	0.055 < TP	4

Land cover and precipitation

The combination of land cover and precipitation is used as a rough estimate for the suitability of breeding sites. The current model implements the rainfall – 'malaria risk' relation as a threshold (Table 2). According to the field research it has been estimated that in case monthly rainfall in a cell is above its suitability threshold, first signals of increased malaria transmission occur after 2 months. In these months the larvae and nymphs obviously have been able to develop into an adult population. This time delay might be of importance in varying seasonal conditions. If the monthly rainfall is below the threshold, no transmission is possible and no infection risk exists.

Table 2. Malaria risk in relation to land cover and precipitation

Land cover	Precipitation threshold (mm/month)	Risk classification
Water	0	0
Forest	120	1
Cash crops	80	1
Grassland	80	2
Small-scale agriculture	60	4
Rice	20	4

The threshold approach has been used before (Martens et al. 1999; Craig, Snow and Le Sueur 1999). What the LEMRA model adds is the dependence of the threshold on the land cover in the cell (Table 2). The abundance of habitats determines the presence and survival probability of the mosquito population. The presence of undisturbed sunlit pools is a precondition for the existence of the vector, in particular *Anopheles gambiae*, in sufficient densities. *An. gambiae* is the dominant species in rainy periods. *An funestus* is less dependent on rainfall, and more dependent on the presence of stagnant waters. *An. funestus* is the dominant vector in dryer periods (Minakawa et al. 2002). In case of an area with standing water, obviously no threshold is implemented, whereas due to, e.g., dense leaf coverage, a forest provides fewer opportunities for sunlit pools and accordingly needs more rain to provide suitable circumstances.

At the end risk classification is related to the mutual dependence of land cover and precipitation. Water has a low risk classification because of the preferences of the *An. gambiae* and the small chance of human mosquito contact. In contrast, the presence of water (in case of irrigation) in rice fields and the great chance of human vector contact make rice fields rather high-risk areas.

One could argue that the relation between precipitation and vector abundance is not that rigid, and one should rather implement more gradual changes. The way it is currently implemented might show rather rigorous changes and should be interpreted carefully. Other studies (Hartman et al. 2002) have implemented the precipitation–risk relationship in a more fuzzy rather than Boolean way.

Infrastructure

The presence of infrastructure, and in particular roads, might be linked to increased malaria risk. Roads indirectly affect the presence of both hosts and mosquitoes. The construction of roads and railways has facilitated the gradual spread of malaria. Humans, in general, settle near roads, and both humans and cattle travel along the roads. This leads to the creation of many puddles, footsteps and tracks along the roads, which provide suitable breeding sites for the malaria mosquitoes. For the current assessment the effect of changing infrastructure has been neglected.

When quantifying the land-cover – malaria relation, it is not evident which factors should be considered part of this relation and which should be considered separately. For example, many land covers are associated with certain temperature regimes: rice can only grow in warm and humid areas, while tea and coffee are most profitable in less warm and dryer climates. It can therefore be argued that this association with temperature is an inherent part of the malaria risk associated with land cover. However, in the LEMRA model temperature is separately modelled using the Transmission Potential. If the temperature correlation had been considered inherent to the malaria risk associated with the land cover, the temperature influence would be counted double. Therefore, the LEMRA model tries to ignore the association with specific temperature regimes when estimating the amount of influence each land-cover category has on malaria risk. Besides temperature this also applies to precipitation, the presence of humans and the interactions between neighbouring cells, which all are explicitly modelled.

Intra- and intercellular risk

To define the risk in a cell, i.e. the intracellular risk, the index of TP is combined with the discrete risk classification of land cover and precipitation to form a new discrete classification for each cell (Table 3).

Table 3. Intracellular risk based on temperature and land-cover-related risk

		Land-cover-related risk				
		Non	Low	Medium	High	Very high
Temperature-related risk (TP)	Non	0	0	0	0	0
	Low	0	1	2	3	4
	Medium	0	2	4	6	8
	High	0	3	6	9	12
	Very high	0	4	8	12	16

Taking into consideration that the grid cells enclose an area of 1x1 km^2, the malaria risk of a separate cell cannot be considered without regard to the conditions outside this area. The interaction with the surroundings is not simulated for each separate factor; instead interaction is modelled at the level of malaria risk.

It is assumed that the influences of the various factors on neighbouring cells can be generalized to one influence at the abstract level of the risk class. In the preceding steps the intracellular risk class is determined for each cell solely on the basis of the internal conditions of the cell. The intercellular risk class is determined by adjusting the intracellular risk class to the intracellular risk classes of the surrounding cells (Figure 4, see Colour pages elsewhere in this book).

Since the strength of the intercellular influences is not exactly known, neither for the composite of the factors nor for each individual factor, a distance decay function is assumed. The algorithm defines the risk of a cell using a weighted mean of the previously determined intracellular risks of the cell and its neighbouring cells. Currently the extended Moore neighbourhood is used, which exists of the two rings of cells surrounding the cell of interest. The weighted mean is such that the cell and each ring of cells surrounding it have an equal weight in the final result.

The used numbers of rings represent a distance of three kilometres around the centre of the cell. This distance roughly corresponds to the flight range of the *Anopheles* mosquito. Note that this implies that the factors included in the intercellular influences are only concerned with mosquito behaviour and not with human displacement. Human displacement has been 'modelled' separately by means of qualitative scenario analysis. Human migration might be quite significant with respect to the (gradual) spread of malaria. In literature examples are discussed related to the hypothesis that the spread of malaria into low-risk areas may be caused by displacement of infected humans, e.g. in case of tea-plantation workers (Malakooti, Biomndo and Shanks 1998).

The main implemented mathematical relations have been derived in a laboratory setting, in other regions or at other scale levels, and have neither been calibrated nor validated adequately by lack of sufficient appropriate data. In case of the development of regional projections, there is a definite need to validate these relationships by means of field research. Where available and possible, data of the field research have been incorporated in this part of the CAMERA project.

The current results depend on the many assumptions underlying the model. Two examples of these assumptions are the implemented land-use – precipitation threshold relation, and the weighting mechanism used for the intercellular correction e.g. with regard to the validity of the used weights and the acceptance of the three-kilometre range. These and many other assumptions will need further investigation. Notwithstanding the many questions remaining the LEMRA model already provides a framework to underpin the assessment of future change.

It is has proved difficult to identify adequate indicators that could be used to model future adaptation to changes in disease risk associated with climate change and socioeconomic development within an integrated-assessment model (Martens and McMichael 2001). First, malaria incidence is hugely influenced by geography and prevailing climate. The poorest countries tend to be in high-risk tropical and subtropical regions. Apportioning malaria causality between environment, income and social practices is, therefore, problematic. Applying a quantitative relationship between socioeconomic development and malaria incidence has not been seriously attempted. The socioeconomic aspects have, however, been taken into consideration qualitatively in providing the images on the future.

Malaria in Kisumu: A complex web of factors

Malaria prevalence

Malaria is holo-endemic in Miwani (White 1972) with a 70-90% malaria prevalence (Githeko et al. 1996) in much of the population. In the nearby Kericho highlands, however, malaria is unstable with prevalence varying annually between 10% and 60% (unstable non-endemic). Due to this instability, epidemics are common with a high morbidity and mortality as a result. The unstable endemic situation in Fort Ternan is somewhere in between these two extremes. Figure 5 (see Colour pages elsewhere in this book) illustrates current malaria risk as modelled by the LEMRA model.

Due to the poor socioeconomic situation, health infrastructure has poorly developed and people are not able to afford precautionary means to prevent infection, like bednets or drugs to treat the disease. Lack of means increases chances of getting ill, and thus limits labour productivity, consequently affecting the economic growth. The interaction between illness and scarcity of financial means can be characterized as a negative feedback cycle (Gallup and Sachs 2000).

To account for the variability of the available climatic time series of the area (MARA/ARMA 1998) the impact of a relatively wet (1995) and a relatively dry year (1987) has been modelled (Figure 6). Figures below provide an illustration of the potentials of modelling by showing grid-based outcomes for both years. Besides inter-annual differences, seasonal differences could also be identified. The darker the cell, the higher the risk of malaria is.

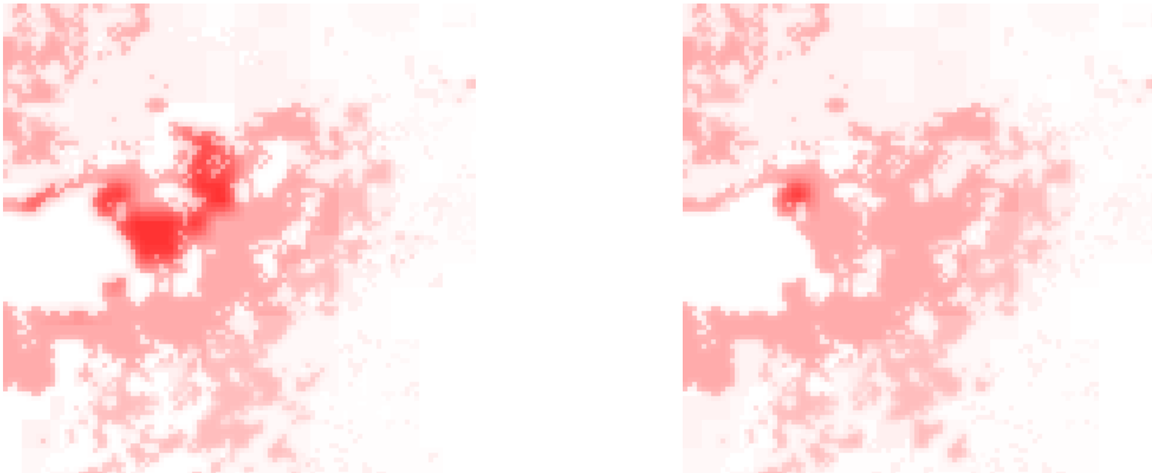

Figure 6. Modelling the impact of precipitation variability (left: relatively wet; right: relatively dry)

Since in general precipitation in Fort Ternan is higher than in Miwani, the vector abundance is not limited by this factor; both areas are more or less equally suitable. However, based on the number of mosquitoes caught, although it is rather limited, it appears that the mosquito density in Fort Ternan is 'much' lower than in Miwani (Koenraadt 2003). One of the main obvious reasons why the model does not illustrate this, stems from the fact that the model does not yet incorporate a relation for the derived minimum temperature. Minimum temperature in Fort Ternan is lower than in Miwani, possibly hampering the development of a stable vector population.

Obviously the process of spread of malaria depends on the properties of the mosquito population and its interaction with the human population. Apart from the factors mentioned in the next paragraphs, which to a certain extent directly influence exposure and the incidence rates, these factors are also intertwined and may have an indirect effect. For example, an increased population density in general puts further pressure on the biological and physical system, manifested as land-use change, downturns in food-producing systems, the depletion of freshwater supplies and the loss of biodiversity. Before we shall elaborate on the future of malaria risk, the main characteristics of the risk-related environmental and socioeconomic conditions of the study area will be described in the next paragraphs.

Malaria and Kisumu's environment

The distribution of malaria is in theory limited by the climatic tolerance of the mosquito vectors and by biological restrictions that limit the survival and incubation of the infective agent in the vector population. The climate in terms of relatively high temperatures and seasonal rain provides rather ideal circumstances for adequate breeding places and for rapid development of both mosquito and parasite.

The main vectors in Kisumu region are the *An. gambiae* and *An. funestus*. The two vectors show a different behaviour and different densities in relation to climatic circumstances. Whether or not a stable population can develop depends on both minimum and maximum temperatures. According to the MARA/ARMA study, below a daily minimum temperature threshold of 4°C the survival probability of the mosquito population is zero, preventing the persistence of a stable year-round mosquito population. Field experiments during the course of the project showed however that the larvae did not survive temperatures below 11°C in Kisumu region (Koenraadt 2003). These results provided a first indication that a stable population cannot develop in spite of ambient temperatures above the minimum threshold for mosquitoes to survive. *Plasmodium falciparum* is the prevalent pathogen. The development rate of the parasite is highly dependent on temperature. At an ambient mean temperature of 23°C the parasite requires 16 days to mature. At a temperature of 27°C the parasite only requires 10 days to become infectious. It is argued that the spread of malaria at higher altitudes, being a proxy for temperature, is limited by the survival probability of the pathogen rather than the vector (Malakooti, Biomndo and Shanks 1998).

Besides precipitation many other factors, such as land use and the development of irrigation systems, largely influence the presence of suitable breeding grounds. Large-scale vector control programmes could only to a certain extent eliminate breeding sites, whether or not done by governmental bodies. Kisumu region's land cover is dominated by rice fields in the valleys and cash crops and to a lesser extent small-scale agriculture in the higher regions (Figure 7, see Colour pages elsewhere in this book). As mentioned, particularly rice fields and small-scale agricultural areas are considered high-risk areas. It should be noted, however, that at the time of the visit, March 2002, the fields were not irrigated and hence provided less suitable habitat conditions. Urban areas are lacking in the distinguished types of land use. In general, urban areas show lower risk profiles than surrounding rural areas. In the case of Kisumu town this is similar, but not simulated.

Figure 8 and Figure 9 illustrate 'current' malaria risk for two representative years, 1987 and 1995. The results are based on the climate series 1951-1995 commissioned and disseminated by the MARA/ARMA initiative. The yearly and seasonal influence can be clearly observed. These differences are caused by the combined effect of a variation in precipitation and monthly mean temperature. The year 1995 will be used as reference year.

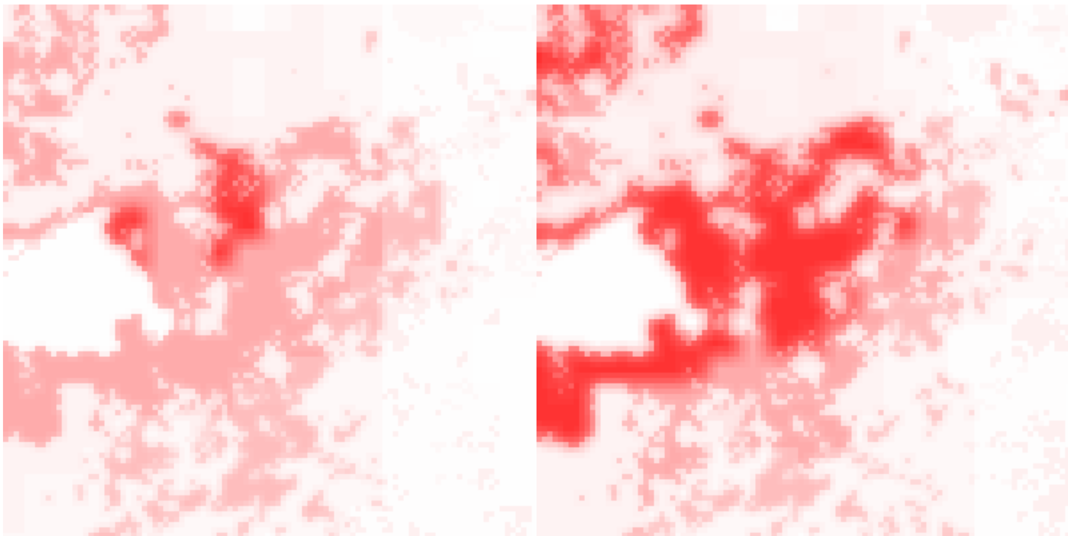

Figure 8. Modelled malaria risk: June (left) and April (right) 1987

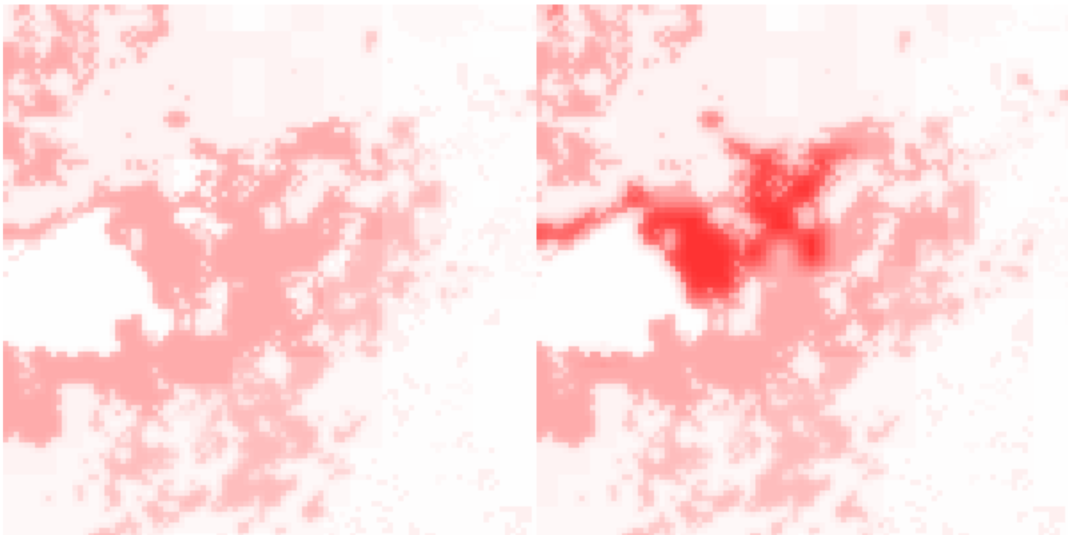

Figure 9. Modelled malaria risk: June (left) and April (right) 1995

Malaria and Kisumu's social-cultural environment

The demographic structure gives an indication of the degree of susceptibility and vulnerability within the affected population. Population density and age structure are main demographic factors that are related to malaria risk. Like in the whole of Kenya the demographic structure of the area can be characterized by a pyramid-like shape, having a broad basis and a small top. Because of its fertile grounds the population density in Kisumu region is amongst the highest of the country.

Within the demographic distribution, the number of persons in the lower fringe indicates the extent to which this factor is significant. Like in the rest of Kenya, the population has a high proportion of young people, i.e. 40-45 % of the population is younger than 14, and solely less than 3% is older than 64. Due to low immunity, malaria morbidity and especially mortality occur to a dominant extent among children. However, in recent years the aids epidemic has also become a major factor of influence. Latest figures show a prevalence of 14% of the sexually active. The decrease in the immunity system makes HIV-infected people more vulnerable to other infectious diseases like malaria, so-called co-infection. An increase in the fraction of these vulnerable subgroups has an aggravating effect on the impact of malaria risk.

Mainly in the rural areas homesteads, which are often built in a traditional way with openings for doors and windows, provide sufficient opportunities for mosquitoes looking for a blood meal to enter during the night. Once people are infected and get ill, it is of utmost importance that these people are treated adequately.

Availability of drugs and access to the public-health infrastructure are of vital interest. These factors depend to a large extent on the economic situation of both households and the nation, but also on political priorities and political willingness, and the availability of (donor) funds. The Ministry of Health administers over 50% of the health-care institutions, and the Ministry of Local Government just over 3%. The private, mission and NGO sectors operate the remainder. In Kenya private hospitals are well equipped with sophisticated diagnostic facilities, but because of their high cost, only a few people can afford these facilities. Mobile outreach services have been established by both the government and NGOs for communities that have no static health facilities.

Malaria and Kisumu’s economic environment

The extent to which an exposed population, or in more general terms a region or nation, is able to adapt to a given ecological risk is primarily considered to depend crucially on the economic resources at its disposal. While national income (growth) can be used to approximate the financial resources available for state-led adaptation measures, like e.g. public-health infrastructure, income per capita or income per household provides a rough indicator for the auto-adaptive capacity of the population. Auto-adaptive measures are those which the individual can take without a change in public policy or state intervention. They range from the use of bednets to prophylactic medical treatment.

The direct costs of treating and preventing malaria morbidity and lost productivity are considerable, in relation to available funds. Malaria has been shown to slow economic growth in low-income African countries, creating an ever-widening gap in prosperity between malaria-endemic and malaria-free countries. The reduced growth in countries with endemic malaria was estimated to be over 1% of GDP per year. The cumulative effect of this ‘growth penalty’ is severe and restrains the economic growth of the entire region (Gallup and Sachs 2001). Although no specific figures are known for Kenya, it is expected that the high malaria prevalence in Kisumu region also has considerably affected economic growth in the past years.

Over the past 50 years the simplicity of paternalism and village-based production has been lost as populations have migrated to new areas and taken on new kinds of jobs. Increasing welfare for the rural population stagnated and declined after the 1990s. The GDP/capita p.p.p. yielded 1000 US$, and 62% of the Kenyan population lived below a 2 US$ expenditure per day in 1999. A higher percentage of the rural families have become food-insecure, have fewer job opportunities and less income per family. This combination of factors has increased the risk of getting ill and has negatively affected the ability to be treated accurately.

Long-term risk assessment implies understanding the processes underlying malaria risk. Although a broad range of literature is available, the assumed relations and relevance of certain factors are often disputed (e.g., Epstein, Haines and Reiter 1998).

Malaria in Kisumu: What if……images of the future

Introduction

Within the scope of the project scenarios have been developed by blending quantitative and qualitative information. The qualitative information consists of different plausible integrated descriptions of images on the development of the previously described factors and actors that affect the future of malaria risk. These images have been translated to changing the input parameters of the LEMRA model. The simulation results have eventually provided spatial illustration of possible shifts in malaria risk in the future. Other than predictions these scenarios provide 'what if' images and are developed to identify knowledge gaps, future important issues (envisioning, early warning), and to anticipate possible futures.

Ideally, the point of departure for the CAMERA project would have been a widely vetted, comprehensive, narratively rich and fully quantified set of scenarios for Kisumu. However, this ideal source does not exist. Available, in particular globally and continentally developed, scenarios provide a wide variety of information on sectoral and regional efforts, which are important sources of insight but could not on their own provide a comprehensive platform for the project.

The scenarios developed for Kisumu region have been inspired by the four storylines as described in Kenya at the crossroads: Flying Geese, Katiba, Maendelo and El Niño (IEA 2000). These scenarios, presented as storylines, assume that Kenya has reached its limits from an economic, political and social point of view, differing in their prediction whether and how political and/or economic reformation will be implemented. The storylines primarily address questions of how Kenya's growing population will be fed, and how the governing institutions can be modernized, given the skills and resources it has.

The 'Crossroads' scenarios have been enriched by the outcomes of the African Environmental Outlook (UNEP 2002), some of our own ideas, the model results, and the results of a workshop attended by about twenty scientists in 1999. Important quantitative information on how the environment might evolve, and in particular the local climatic conditions irrespective of local changes, is not included in these sources. Information of climate-change scenarios has been adopted from the SRES scenarios (Nakicenovic and Swart 2000), and has been regionally disaggregated. Developments on the spatial level of Kisumu region depend on the interaction between local highly dynamic processes and slower processes on a higher, both national and supranational level. Ideally integration across scales takes place both bottom-up and top-down. In the current study only one-way integrating, i.e. top-down has taken place (Figure 10).

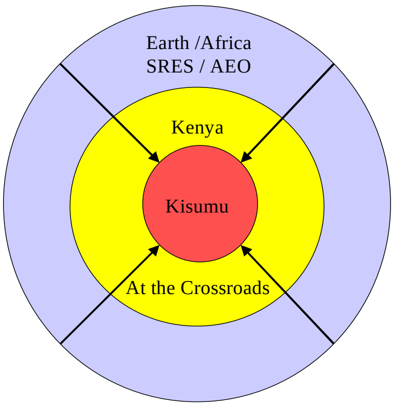

Figure 10. Scenarios for Kisumu imbedded in a wider context

Kenya at the Crossroads
Stories about possible futures

The Kenyan scenario team foresaw four possible outcomes depending on the answers to four crucial questions:

Will confusion and inertia thwart efforts at both economic and political reform? If so, the status quo is maintained, tension heightens and Kenya fractures into ethnic districts with new systems of government within them. This is the El Niño scenario.

Will the transformation concentrate on reordering the economy while resisting agreements on needed changes in the political structures and environment? If so, economic gains will not last long as political tensions will emerge that will require sorting out in order to preserve economic headway. This is a scenario of initial rapid gains, but full of inequalities and instability, labelled Maendeleo.

Will the transformation focus on institutional reorganization and the creation of democratic and locally accountable institutions while ignoring fundamental economic reform? If so, though responsive institutions will emerge, Kenya will not achieve substantial economic transformation. This is the scenario of institutional reorganization labelled Katiba.

Will there be a definite departure from destructive politics? Will the incumbency realize its position is untenable and will it reach a political settlement with the key adversaries? Will a reorganization of the institutions improve representation and participation that reflects the diversity of Kenya's people? Will this be accompanied by radical transformation of the economy to spur growth and improve distribution? If all the major actors engage in this transformation, Kenya can achieve inclusive democracy and growth. This is the scenario of Flying Geese.

The main drawback of using the Crossroads scenarios lies in the policy-oriented assumptions. Rather than focussing on possible societal developments and policy, policy is now regarded as the main steering mechanism. In this way the description of action–reaction mechanisms within society and societal developments as a whole are rather limited and sometimes stereotype.

The time-horizon considered corresponds to the time span of the scenarios described in "Kenya at the crossroads" – until 2020. One generation is considered to be short enough to connect current trends to new futures, and long enough for rather drastic changes.

Although a wider range of scenarios is interesting from a policy point of view, in this paper two of the four scenarios in terms of malaria risk are further elaborated. The developments described within the context of Flying Geese and El Niño are expected to provide the widest range of change in malaria risk in the future.

Flying geese – Simultaneous economic and political reforms

Kenya 2020: In this scenario Kenya has regained respect of the regional and international community. Institutions work (albeit not without some problems). Social tensions have been largely tamed and the country was covered by optimism and hope.

Although initially the dominated agricultural society of Kisumu region had difficulties coping with the transition towards the service economy, at the end society as a whole profited. A well-thought retraining programme and help for small-scale agriculture farmers helped them to integrate and increase their living standard. Small-scale agriculture has to a large extent been replaced by large-scale high-technology agriculture. Consequently, the percentage of land used for cash crops has increased. Prosperity and large-scale irrigation schemes have led to increased production of rice fields. Overall agriculture has become less vulnerable for inter- and intra-annual variation in rainfall.

In the Flying-Geese scenario, small-scale agriculture (light yellow) has been transformed into cash-crop areas (dark yellow) (Figure 11, see Colour pages elsewhere in this book). These areas are less suitable for malaria vectors, and thus in general show a lower malaria risk. In addition, cash crops are related to a higher monthly-precipitation threshold value, than in case of small-scale agriculture, decreasing overall malaria risk.

Climate change has become more profound than expected. Reduced rainfall and increased evapotranspiration have had a strong positive effect in terms of a decrease of months with suitable conditions. On the other hand, both average and minimum temperature have increased. In particular the highland areas, previously less vulnerable, have become (more) suitable from temperature point of view.

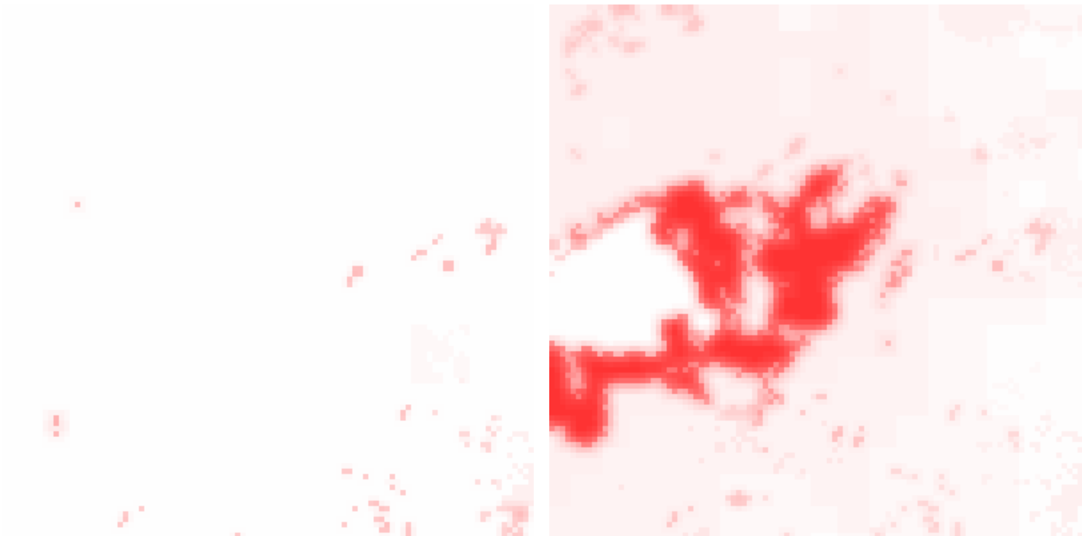

Figure 12. Malaria risk Flying Geese: June (left) and April (right) 2020

Due to the combined effects of a monthly mean-temperature increase between 1.5 °C and 3.4 °C (adopted Hadley SRES results), a reduced rainfall between –0.8 and –4 mm per day, and the projected land-use change, the vast majority of the area has become less suitable for malaria. For the months of April and June a projected temperature increase of 1.7 and 3.4 °C, respectively, and a precipitation decrease of 20 and 120 mm per month, respectively, have had a considerable effect on the distribution of malaria risk. Due to the large decrease, the amount of precipitation has dropped below the threshold value for the month of June. Under these extreme conditions malaria risk no longer poses a serious threat. In the month of April the risk decreases in particular in the northwestern and southern part, due to the combined effects of land-use change and precipitation decrease.

However, due to the temperature increase, the risk has increased considerably along the southern borders of Lake Victoria and halfway between Kisumu and Kericho in April (Figure 13). The rice fields have become the main type of land use being negatively affected.

Obviously future malaria risk is, in our model, strongly affected by land-use changes. To illustrate the sensitivity of land-use change, malaria risk in case of land transformation from cash crops into small-scale agriculture has been analysed (Figure 13). Compared to the previous results the increase in malaria risk is obvious. Moreover, in particular the high-population-density areas, north to northwest of Kisumu town, have become increasingly vulnerable. Whereas these areas did not show malaria risk in Figure 12, now it has become apparent. Obviously the precipitation threshold in relation to the projected change plays a major role. In this case the projected temperature increase has become the dominant factor determining malaria risk, apart from the region east of Kisumu town in June. Beside the northern region, also the highland areas have become more vulnerable. In contrast to Figure 13 the lengthening of the high-risk season can be noticed.

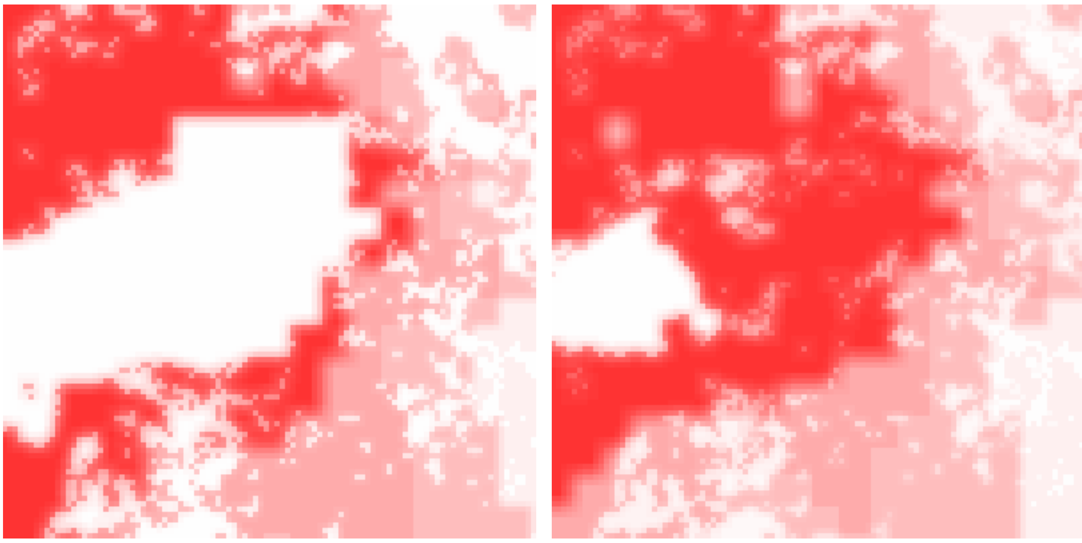

Figure 13. Malaria risk: June (left) and April (right) 2020; land-use change from cash crops to small-scale agriculture

In the transition towards a service economy, the need for educated people increased. Government primarily invested in educational programmes. The higher educational level and abound opportunities in urban areas made many of the young people migrate to urban centres, amongst which Kisumu town. High population densities, and land and previously food shortage have pushed the rural population towards urban areas. Increased urban population density and consequently deteriorating environmental conditions have made urban areas more vulnerable for vector-borne diseases other than malaria, such as dengue. The poor segment of society is pushed off to marginal land into marginal areas.

In Kenya income per head has grown considerably, reducing the number of people below poverty level. In contrast to the increased income per capita, the gap between a rich urban population and the poor though smaller rural population that stayed behind grew. Nevertheless, the increased income per head offers more possibilities to buy precautionary means, and adequate treatment in case one is infected. In addition, like in the rest of Kenya, the increased national income and public interest in human health have provided means to invest in both private and public health care. Due to economic and political reformation the average living standard and public institutions, and social care in general improved significantly. In the past decades a lot of progress was made related to the development of a vaccine. The first results of a prophylactic vaccine seem promising but are not yet available to the public.

In spite of the increased number of irrigated fields, which in theory provide rather ideal circumstances for breeding sites, the number of vectors has decreased. Land-use change, growing awareness, and additionally the implemented biological vector-control programmes have led to a sharp decrease in possible breeding sites. Climate change and human migration towards marginal grounds have however altered the spatial distribution to a certain extent. However, in particular those areas where small-scale agriculture is still, or has become prevailing due to population migration provide suitable conditions. *An. funestus* has become the dominant species due to changed characteristics of habitats.

At the beginning of the century the consequences of climate change were feared. Increased welfare, however, has led to higher adaptive capacity, and has made society less vulnerable. Overall the number of malaria cases has decreased. A combination of less suitable environmental conditions, increased awareness, increased means to buy precautionary measures and increased health in general have made Kisumu region less vulnerable to malaria. A risk of epidemics still exists. Troublesome is the shift of suitable conditions towards higher regions, and in particular the population migration towards marginal grounds. In particular the poor segment of society with fewer means to take precautionary measures and less access to health infrastructure occupies these areas.

El Niño – No political reforms, no economic reforms

In this scenario, Kenya has increasingly been caught up in a system of conflict as a consequence of the absence of political and economic reforms. The existence of Kenya as one nation is not given. As the country degenerated Kisumu region has turned into an enclave. Due to years of militarization and complete chaos, the economy is characterized by low productivity, which has made it impossible for the population to realize upward economic mobility. To survive the majority of people of Kisumu, who did not flee the country, depend on small-scale agriculture and informal and illicit trade. Former land-reform programmes have been abandoned. Due to the wars people have spread over the country looking for new opportunities. To supply their needs for fuel, shelter and food, the local population falls back on their traditional uses of the forest. [1]

In the El Niño scenario small-scale agriculture (light yellow) has replaced previous rice fields (light green) and forest (dark green) to supply basic needs (Figure 14, see Colour pages elsewhere in this book). From a habitat point of view small-scale agriculture is equally suitable as rice fields, and more suitable than forest. Independent of rainfall, due to the land reformation the malaria risk has increased in general.

The combination of vast disappearance of trees and increased heavy rains has considerably increased the risk of landslides. Soil erosion accounts for the majority of

[1] The El Niño scenario sketches a rather pessimistic view of the future of Kenya. It is a scenario in which no political reforms and no economic reforms will be put in place. The current pathway the Kenyan government turned into differs from that assumption. Therefore the scenario might sketch a less likely scenario from current point of view. At the time the Kenyan scenarios were written by the Kenyans, both the political and economic situation was different

environmental degradation in the region. In addition, due to deforestation the local temperature has increased. On top of the microclimate change, the impact of global climate change is clearly visible. Temperature increase due to global warming is less than in the case of Flying Geese, but due to deforestation the average monthly temperature increase also varies between 1.5°C and 3.4°C. Average monthly precipitation has not changed significantly compared to the reference year 1995. However, in particular the climate variability in terms of extremes, both in terms of temperature and precipitation has turned out to be devastating, especially for the poor, who have no means to adapt.

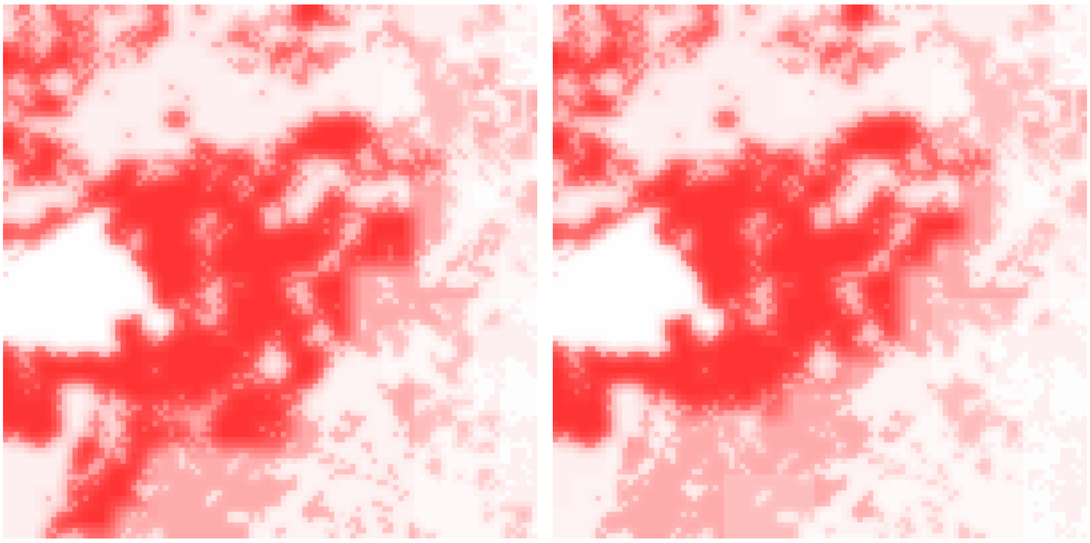

Figure 15. Malaria risk, El Niño scenario: June (left) and April (right) 2020

Due to climate change, in terms of an increase in monthly mean ambient temperature, malaria risk has increased considerably over the whole region (Figure 15). In particular northeast of Kisumu town, the southern borders of Lake Victoria and the highland regions have become more vulnerable. The effect of the deforestation can be clearly observed in the southern part of the study area. The combined effect of an increase in monthly mean ambient temperature and the transformation towards, from a habitat point of view more suitable, small-scale agriculture has likely increased the risk of malaria. Due to the higher temperature increase in June, this month has become even more vulnerable than April. The current difference in malaria risk between April and June has blurred. Hence, in the case of the El Niño scenario the high-risk transmission season most obviously has been prolonged.

Because of the poor economic situation the average household income has declined sharply. Over 80% of the people are currently living below poverty limits. The years of ethnic wars have destroyed much of the public-health infrastructure. What is left is only available and accessible for those very few who gained from the war or from the market mechanism in general. Access to health infrastructure or means to afford precautionary measures is lacking for the majority of society. Human health has declined, which is putting an additional pressure on society as a whole.

The deteriorated environmental conditions and the declined socioeconomic and institutional conditions in combination with a poor health condition have resulted in a sharp increase in the number of people infected and dying of malaria. In addition to the negative societal changes, climate change has led to a visible increase in malaria at higher altitudes. Besides at higher altitudes, newly reclaimed areas, which were not inhabited before, have shown an increasing trend of malaria risk. Since international help is lacking, Kisumu has been caught in a downward spiral with no expectations of improvement on the short and mid term.

Conclusions

Although both scenarios show two extremely different projections of the future of Kisumu region, they also show some striking resemblances. In both scenarios local circumstances for the rural population do not seem to improve significantly, or even seem to decline in the case of the El Niño scenario. A combination of lack of access to health infrastructure, lack of economic means, and climate change have made populations living at high altitudes and particularly those at newly reclaimed areas exposed to higher malaria risk.

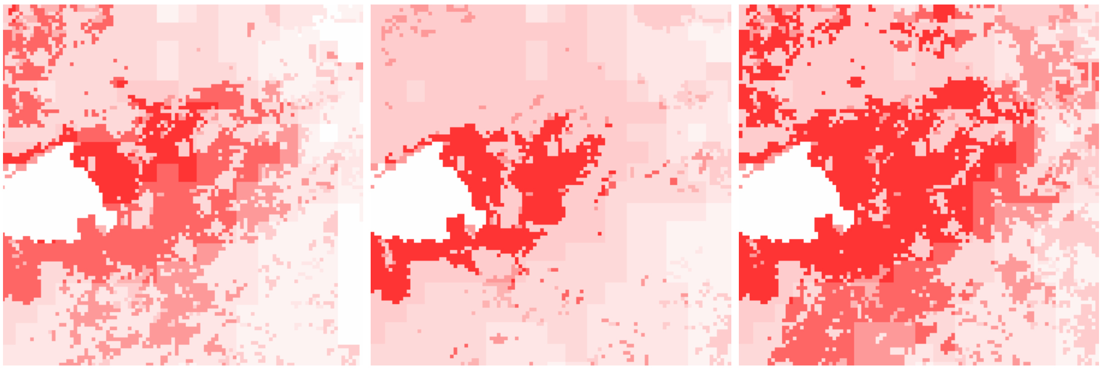

Figure 16. Malaria risk: April 1995 (left), Flying Geese 2020 (centre) and El Niño 2020 (right)

Due to environmental changes in terms of land use, ambient temperature and eventually precipitation, the preconditions for malaria risk are changing. In both scenarios an increase along the southern borders of Lake Victoria and halfway Kisumu town and Kericho, reaching to the higher regions, can be observed (Figure 16).

Depending on the type of land transformation malaria risk may differ considerably according to the implemented land use – precipitation relations in the case of the Flying-Geese scenario. Under projected climate-change conditions, the region might provide a range of more or less suitable environmental conditions for malaria risk, according to the projected land use. In case of a shift towards precipitation-dependent land use, like in the case of cash crops, malaria risk has decreased considerably. Whereas in case of a shift towards less precipitation-dependent land use, like small-scale agriculture, both malaria risk in absolute number as in number of months has increased. The relatively small difference in threshold values between small-scale agriculture and cash crops makes that these results should be treated with care.

In addition, in the case of the El Niño scenario, in particular the northeastern and southern parts of the area are likely to show an increase in the risk of malaria due to deforestation in combination with higher mean ambient temperatures. Unfortunately these are, and might remain, amongst the most densely populated areas. Moreover, also the higher altitudes have become more vulnerable due to temperature increase.

In general the high population growth in relation to the already high densities is considered to be an additional threat for the region. Due to high pressures people are forced to move to more marginal grounds, herewith extending the areas vulnerable for malaria transmission, or to the urban areas. Obviously depending on the socioeconomic developments the high rate of incidence may remain, increase or may decline in case of a combined economic growth, improved health infrastructure and growing public awareness.

Climate change, in particular a temperature increase, does not seem to be a blessing for Kisumu. Besides on the impact on future land use, and hence possibly negative impact on the rural economy, the increasing temperature might shift the limits of malaria transmission to higher altitudes.

Highlands have always been regarded as areas of little or no malaria transmission, mainly because of low temperatures. However, this appears to be changing. There is a lot of recent evidence that shows an increase in the number of epidemics in highland areas, as well as a spread of endemic malaria into the highland fringes. Various reasons for this apparent change in epidemiology have been put forward. Most prominent are those arguments that implicate climatic and ecological change. Unfortunately the lack of reliable malaria data for most highland areas has made analysis of these issues difficult (MARA/ARMA).

Epidemic malaria in highland areas represents a significant public-health problem. Historically, low risk of infection in highland areas has created little functional immunity in local populations, resulting in relatively high mortality in adults and children during epidemics. At the same time, national malaria control programmes have not been well equipped to identify and respond to epidemics. There is, therefore, a need for increased scientific understanding of the epidemiology of highland malaria, as well as greater capacity in epidemic surveillance and response. Multiple factors act simultaneously. Correlations are not well understood, in particular with respect to whether or not specific factors are dominant.

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