THE LOCAL ECO-EPIDEMIOLOGICAL MALARIA RISK ASSESSMENT (LEMRA) MODEL

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Summary
An increased incidence of malaria is to be expected as a result of environmental and socio-economic change. The LEMRA model is developed to assess the impact of these changes. The structure of the model and some preliminary results are presented.

INTRODUCTION

Each year 1.5 to 2.7 million people die from malaria (WHO, 1997). This is only a small proportion of the 300 to 500 million people who suffer from this disease. Malaria is constantly present in at least 91 countries, exposing approximately 40% of the world population to the risk of contracting the disease. By undermining people's health and capacity to work, malaria significantly hampers the social and economic development of the countries involved (Gallup and Sachs, 1998, Wang'ombe and Mwabu, 1993).
In the 1960s and 1970s a world-wide decrease in cases of malaria took place due to both the socio-economic developments in the developed countries and the implementation of control programs in the developing countries (Kitron, 1987). However, the hope that this process would lead to eradication of the disease turned out to be false. The disease is currently present in most countries where it had previously been controlled, sometimes even more seriously than ever before. Amongst the reasons for the resurgence of the disease are the difficult access to anti-malarial drugs, landcover changes (deforestation), lack of education, migration waves etc. Future projections based on climate change show a further increase in the number of people at risk from malaria (Martens, et al., 1999).
The main objective of the CAMERA (**C**ellular **A**pproach for **M**alaria **E**co-Epidemiological **R**isk **A**ssessment) project is to assess the impact of environmental and socio-economic factors on the risk of vector-borne diseases, with a focus on malaria. The project aims to develop a general integrated approach for the impact assessment of both global and local change. The CAMERA project covers processes that take place at various temporal and spatial scales (see Figure 1), involving field research, GIS (Geographical Information Systems) and the development of models on various scales. Within the CAMERA project the **L**ocal **E**co-Epidemiological **M**alaria **R**isk **A**ssessment (LEMRA) model concentrates on malaria risk on a local scale (an area of 100km^2). In this paper the LEMRA model framework is discussed.

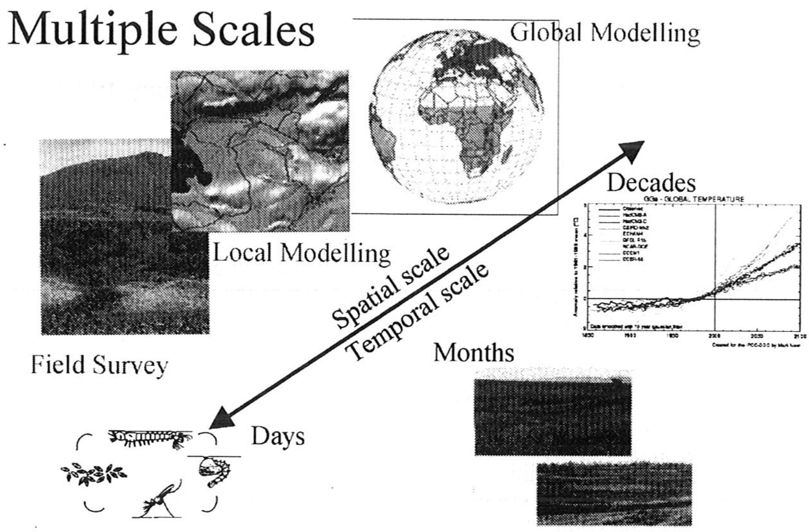

Figure 1 *The CAMERA project investigates vector borne disease risk at many different spatial and temporal scales.*

The LEMRA model

The dynamics of malaria can be subjected to substantial local variation. This variation can be the result of various mechanisms, for example differences in the characteristics of mosquitoes, the environmental situation or the housing of people. The combination of field surveys and the focus of the model on a small area allows to acknowledge this and to model the specific malaria dynamics associated with the area. This is why two research areas were selected: Rondonia area (Brazil) and Kisumu area (Kenya). The LEMRA model is developed for both these areas. Although both models have many similarities, they also have substantial differences in both their parameters and structure, reflecting, for instance, the difference in breeding behaviour of the mosquitoes in the two areas. Some preliminary results for the Kisumu area are presented.

Next to the integration of scales and the integration of methods, the LEMRA model aims to integrate the environmental, social and economic factors influencing malaria risk and the processes that underlay changes in these factors. So the objective is to include factors as diverse as climate change, migration and housing conditions, and furthermore to include processes which influence these factors. The aim of such an integrated approach (Rotmans, 1998) is to assess the impact of possible future changes on malaria risk.

Figure 4 shows Kisumu area, located on the border of Lake Victoria in Kenya. The modelled area is divided in cells of 1x1 km. For each cell the malaria risk is determined based on the conditions within the cell (Figure 2). The malaria risk is expressed in 20 risk classes where 0 indicates no risk and 20 high risk. The exact details and meaning of the risk classification is currently subject of further research.

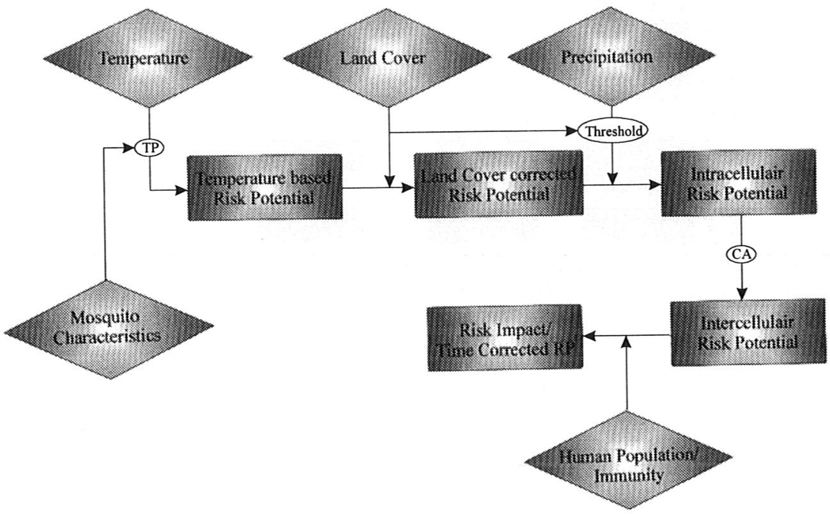

Figure 2 *The structure of the LEMRA model.*

MATERIAL AND METHODS

There are four major steps in the model: assigning a risk category to the cell (1), adjusting the risk to the conditions in the cell (2), adjusting the risk to the risks of the surrounding cells (3) and finally assessing the impact of the risk on the population (4).

Assigning a risk category to each cell is done using the Transmission Potential (TP). The TP is calculated using temperature and the characteristics of the mosquitoes in the area (for more details see (Martens, et al., 1999)) and is a derivative of the VC (Vector Capacity).

After the risk category of a cell is determined, the landcover and precipitation in the cell are used to perform the second step, adjusting the risk to these conditions in the cell.

The small spatial scale of the model means that the interactions between cells cannot be ignored. Malaria risk in an area of 1 km^2 cannot be seen as independent of the malaria risk in its close surrounding. By taking into account the risk in the neighbouring area, the LEMRA model translates, in the third step, the intracellular risk category to an intercellular risk category. This process leads to a higher risk if the cell is surrounded by a high-risk area (see bottom-right in Figure 3) and a lower risk if it is surrounded by a low-risk area (see top-right in Figure 3).

Finally, the impact of the intercellular risk potential is estimated using the characteristics of the human population in the cell. On the one hand the size, composition and immunity of the population determines the availability of hosts and their vulnerability for malaria. On the other hand the percentage of immune and infected people in the population reflects the history of malaria in the cell and gives an indication of the chances for an epidemic to occur.

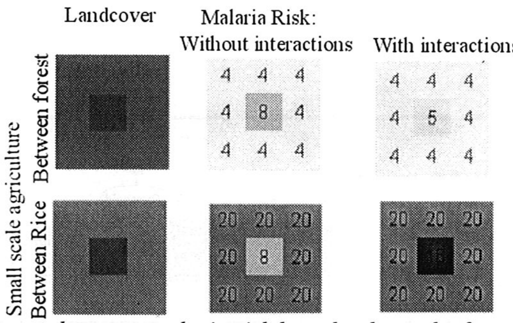

Figure 3 *The difference between malaria risk based only on the factors within a cell (the intracellular risk) and the risk determined using the risks of surrounding cells and the intracellular risk.*

RESULTS

The case of highland malaria in Kericho presented here is an example of how the LEMRA model is used to analyse and make explicit certain phenomena connected to malaria. Figure 4 shows an example of the modelled malaria situation in the Kisumu area. In the Kisumu area the difference between the highest and lowest point is about 1500 m. Altitude has a significant effect on temperature, which in turn has a significant influence on malaria risk. This is reflected in the model results of Figure 4, where the lowest altitudes (around Lake Victoria) have the highest risk, whereas the highest altitudes (east and south-east) are associated with none or only very low risks.
Our three field-study sites are very differently located; Miwani is in the risk area the whole year through, whereas Fort Ternan is in or out of the risk area depending on the time of the year; Kericho is on the edge between the areas with no risk at all and risk for a few months a year. Depending on the climatic conditions of each year, it belongs to either the first or the second area. If a population is irregularly exposed to malaria, and especially if this happens with large intervals between, the population cannot develop any form of immunity. In this situation, any substantial period of malaria has a severe impact on the population, leading to high morbidity and mortality. In Kericho malaria incidence indeed shows a pattern of irregular outbursts of epidemics. (Malakooti, et al., 1998).
The evolution of modelled malaria risk over time is represented in **Figure 5***a* for a cross-section of Kisumu from west to east through Kericho. (This cross-section is visualised in Figure 4 with the dotted line.) **Figure 5** also shows the altitude of this cross-section, again showing the influence of altitude on malaria risk. Furthermore, the figure shows that the exposure of Kericho to malaria depends not only on the time of the year but also varies considerably between years. Some years hardly any malaria risk is present while in others Kericho is threatened for almost half the year.
Between 1991 and 1995 two epidemic outbreaks took place in Kericho; one in 1992 and one in 1994 (Malakooti, et al., 1998). Two smaller eruptions took place in 1991 and 1995. **Figure 5***a* indeed appears to show a qualitative correspondence with this data, acknowledging the fact that there is a delay of one or two months between the moment of risk and the actual impact of this risk. This delay is due to the time a mosquito population needs to grow, the latent periods etc.

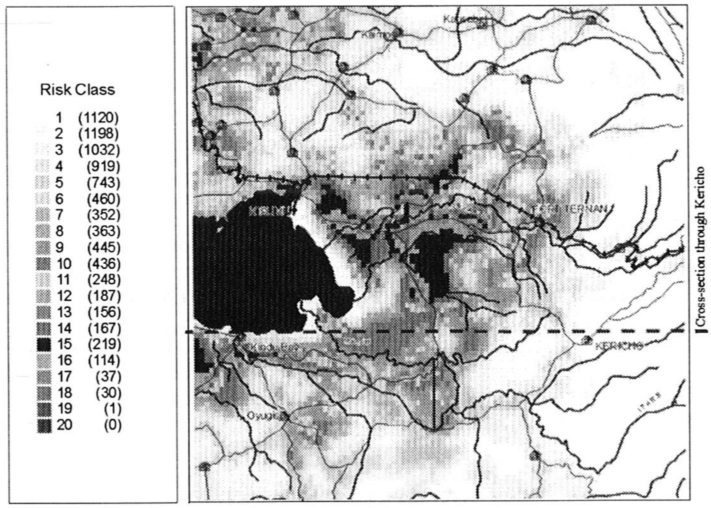

Figure 4 *The research area in Kenya, at the west border of lake Victoria. Notice Kericho at the edge between the risk and no risk area.*

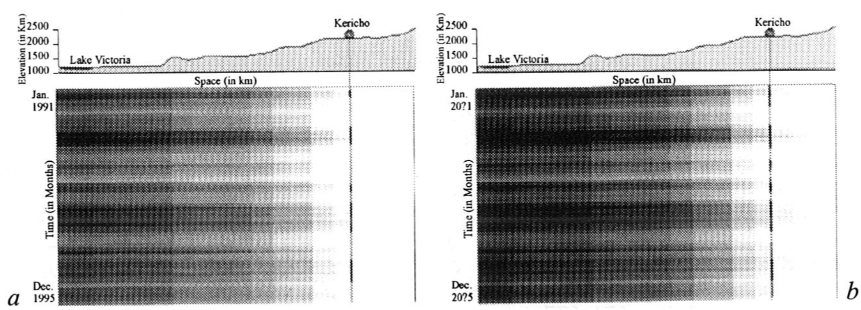

Figure 5 *A time-space plot of the modelled malaria risk showing a cross-section of Kisumu area from west to east through Kericho. The risk in the cross-section is visualised with a range from black (highest risk) to white (no risk). Each row represents one month. From top to bottom this shows the evolution of risk over time between 1991 and 1995. Figure (a) is the historical situation; figure (b) is the situation as it would be if a temperature increase of 1 °C took place.*

Using LEMRA we can investigate what the consequences of climate change might be for the malaria situation in Kericho. **Figure 5***b* shows how a 1 °C increase would affect the malaria situation in Kericho. The transition between the region with malaria risk and that without risk clearly shifts to the east, moving uphill. As a consequence the exposure of Kericho to malaria will increase both in terms of time of exposure and severity of exposure. However, the increase in exposure is not so large that the irregularity/periodicity of malaria risk for Kericho disappears. Thus, although currently the immunity in the population is not modelled, it can be expected that despise the fact that the exposure increases, this probably does not lead to an increased immunity within the population. Consequently the impact of a 1°C increase of temperature is likely to be an increase in both the number of malaria cases during an epidemic and the number of epidemics that will take place.

DISCUSSION

The case of highland malaria in Kericho and the effect of climate change on the malaria situation in Kericho is an example of the kind of exercises the LEMRA model can be used for. The Kericho example shows that climate change may lead to an aggravation of the malaria situation.
Currently the existing parts of the LEMRA model are being improved. An important point of improvement will be the simulation of the immunity development in the population. In the near future the model will be applied to the Brazilian research area. The results of the field study will be used for further improvement of the LEMRA model.
In combination with field studies and the other model studies of the CAMERA project, the LEMRA model will develop into a model that can be used to investigate various phenomena, such as deforestation, agricultural changes, breakdown in public health measures and population movements.

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