

# Climate Change Adaptation: Coping With Malaria

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## Introduction

As the window for avoiding significant climate change closes, there is an increasing emphasis on adapting to the climatic changes that are now likely to occur. One concern is that the prevalence of vector-borne diseases may increase, either because changing temperature and rainfall patterns allow the parasite or its vector to flourish where it is already present or because they allow the disease to spread to new locations. Except in cold regions, an increased risk of malaria is a possible consequence of climate change, and a valuable target for adaptation measures.

This case study describes a model that links temperature changes and adaptation measures to changes in the risk of malaria from the parasite *Plasmodium Falciparum*, the most common and dangerous of the malaria parasites (Martens, 1998). The model, which is based on epidemiological studies, is taken directly from the book *Health & Climate Change: Modelling the Impacts of Global Warming and Ozone Depletion* by Pim Martens (Martens, 1998). This book is a remarkable resource for scenario modelers interested in studying the links between climate change and health. The chapter on vector-borne diseases includes not only *P. Falciparum*, but also other malarial parasites, dengue and schistosomiasis.

An explicit set of scenarios is presented in this case study, in which the model described here is implemented using the IPAT-S scenario scripting language. Three scenarios are considered: climate change without adaptation, climate change with adaptation and adaptation without climate change. The full script is included as an appendix to this case study, and it can also be downloaded from the IPAT-S web site. Readers who are interested in exploring and modifying the scenarios can download the script and the free IPAT-S software from <http://www.ipat-s.org/>.

## Indicators

One of the services that Martens provides in his book is a discussion of relevant indicators for assessing the change in the risk of disease. Many diverse factors can influence the actual spread of a disease. Rather than attempt to represent all of the factors explicitly, Martens uses a product of indices to assess the risk that the disease might become epidemic and the likelihood that it will spread. One (complex) index is temperature- dependent. This captures the climate effects from an increase in temperature. Two other indices reflect adaptation measures: the rate of recovery from the disease, which depends on such factors as health provision and nutrition, and the change in the number of mosquitoes per person, which depends on such factors as eradication efforts and the prevalence of standing water.<sup>1</sup> Using these indices, Martens constructs two indicators: the epidemic potential and

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<sup>1</sup> The number of mosquitos per person therefore depends on climate factors as well, since increased rainfall and sea-level rise will increase the amount of standing water, other things staying the same. However, adaptation measures can counteract these effects.

the reproductive rate. The epidemic potential is an index: if the epidemic potential rises over a scenario, then there is an increased risk of a malaria epidemic. In contrast, the absolute level of the reproductive rate is important, so the base-year reproductive rate must be known in order to use the indicator. If the reproductive rate exceeds 1.0, then the disease is likely to spread.

## The Model

The temperature-dependent index depends on three temperature-dependent variables: the bite frequency  $a$ , the mosquito survival probability  $p$  and the incubation period  $n$  in days. Note that while the bite frequency can depend on adaptation measures (such as the use of bed nets), in the model presented in this case study it is purely temperature dependent. This is also the assumption in Martens' default model. The temperature-dependent factor  $F$  is then given by

$$F_T = \frac{a^2 p^n}{-\ln p} \quad , \quad (1)$$

which is converted to an index  $I_T$  by dividing it by its value in a reference year (year 0):

$$I_T = \frac{F_T}{F_{T,0}} \quad . \quad (2)$$

This index is then divided by the recovery rate index  $I_R$  to determine the index of the epidemic potential,  $I_{EP}$ ,

$$I_{EP} = \frac{I_T}{I_R} \quad . \quad (3)$$

In the model presented in this case study,  $I_R$  is an exogenous variable reflecting adaptation measures.

To determine the reproductive rate  $r$ , which is an indicator of the risk of spreading the disease, the epidemic potential index is multiplied by the reproductive rate in the base year and by the index of the number of mosquitoes per person,  $I_M$ :

$$r = r_0 I_{EP} I_M \quad . \quad (4)$$

If  $r$  is greater than 1.0, then the disease is likely to spread. To complete the model, the temperature-dependent variables  $a$ ,  $p$  and  $n$  must be specified. Using parameters for *P. Falciparum*, Martens (1998) provides the following expressions for these variables:

$$a = 0.4 \times \frac{T - 9.9}{365} \quad , \quad (5)$$

where  $a$  is the bite frequency per day and  $T$  is temperature in degrees Centigrade,

$$p = \exp\left(\frac{-1}{-4.4 + 1.31 T - 0.03 T^2}\right) \quad , \quad (6)$$

where  $p$  is the daily survival rate, and

$$n = \frac{111}{T - 16} \quad , \quad (7)$$

where  $n$  is the length of the incubation period in days.

The calculations given in Equations 1-7, above, constitute Martens' "default model" (Martens, 1998). He provides other factors that might be changed in an alternative model, but that he leaves constant (and hence ignorable when constructing an index over time).

## A Scenario Exercise

The appendix provides a short IPAT-S script that implements the model described above. In the script, which extends from 2000 to 2035, temperature increases by 1.5°C per half-century. Also, adaptation measures are adopted that improve the recovery rate by 10% between 2000 and 2035, and reduce the mosquito population (relative to the human population) by 20%. It is assumed that in the base year the reproductive rate is 0.9, so malaria is not in danger of spreading initially, but is close enough to the critical value of 1.0 that it is in danger of spreading under climate change.

Three scenarios are considered: adaptation with climate change, adaptation without climate change and climate change without adaptation. The results are shown in the following two illustrations. In Illustration 1, it can be seen that the epidemic potential rises in both of the two climate change scenarios. However, the efforts to improve the recovery rate mitigate the effects somewhat in the *Adaptation With Climate Change* scenario, as discussed below.

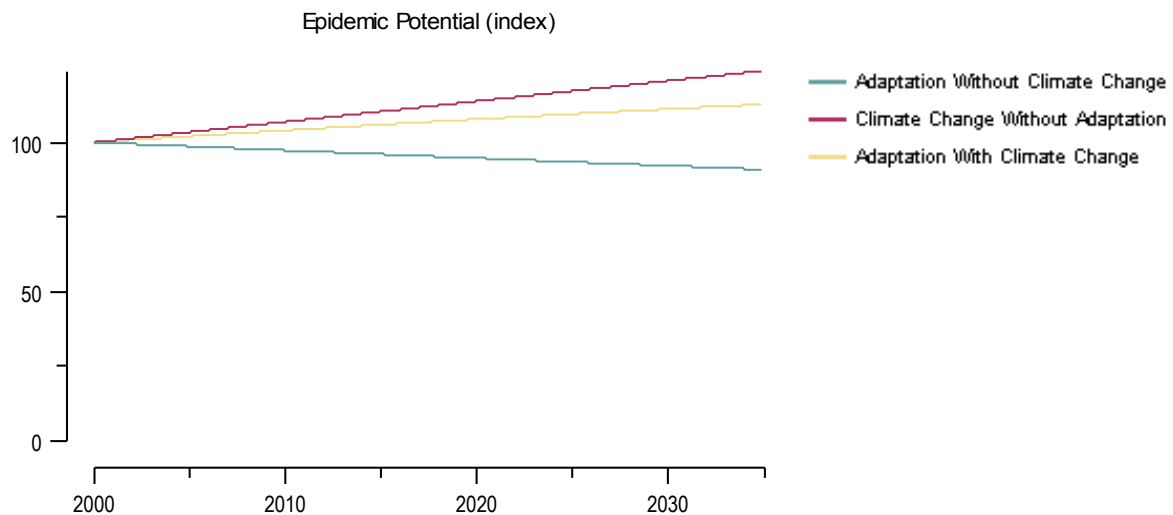


Illustration 1: Epidemic potential in the scenarios, as an index (2000 = 100)

Considering the recovery rate (Illustration 2), the further adaptation measure of reducing the mosquito population keeps the recovery rate well below the critical threshold value of 1.0. In the *Climate Change Without Adaptation* scenario, the recovery rate exceeds the critical threshold of 1.0 by 2020.

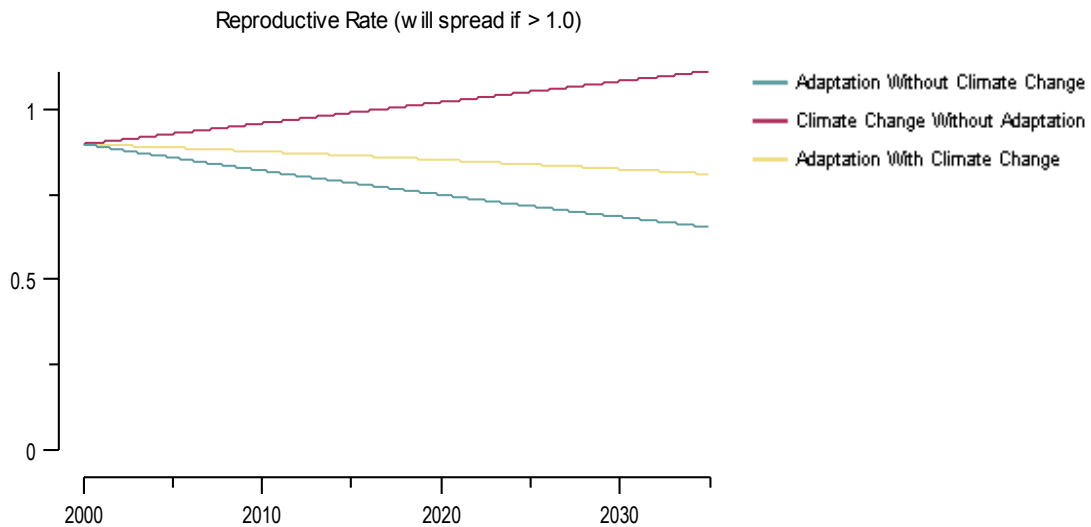


Illustration 2: Reproductive rate in the scenarios

## Conclusion

Climate change adaptation, as opposed to mitigation, is unfortunately set to become a growing concern. One area of interest is in the links between climate change and vector-borne disease. The interesting and timely book by Pim Martens (Martens, 1998) documents one of the few attempts to construct simple models for estimating the health impacts of climate change in scenarios. This case study presented an application of Martens' model of malaria risk. The model is simple, but nevertheless can give interesting insights. Particularly useful is the information the model can potentially provide on the effectiveness of different adaptation measures in reducing the risk that the disease might spread in areas where it is not already endemic.

## References

Martens, Pim. 1998. *Health & Climate Change: Modelling the Impacts of Global Warming and Ozone Depletion*. London: Earthscan Publications Ltd.

## Appendix: IPAT-S Script

```
base year 2000
scenario years 2005 to 2035 by 5

dim scenario 'Adaptation Without Climate Change' 'Climate Change Without Adaptation' \
            'Adaptation With Climate Change'

var Temp{scenario}, BiteFrequency{scenario}, IncubPeriod{scenario}, SurvProb{scenario}
ratio RecoveryRate{scenario}, MosqPerPerson{scenario}

number TempRate = <1.5>
var ScenTempRate{scenario}
ScenTempRate = TempRate
ScenTempRate{scenario='Adaptation Without Climate Change'} = 0
:: 25 + (y - y.0) * ScenTempRate/50 -> Temp

:: 111/(Temp - 16) -> IncubPeriod
:: 0.4 * (Temp - 9.9)/36.5 -> BiteFrequency

:: exp(-1/(-4.4 + 1.31 * Temp - 0.03 * Temp^2)) -> SurvProb

number RRincr = <10%>
number MosqRed = <20%>

RecoveryRate = index[(1+RRincr)^(1/(y.count - 1))]
MosqPerPerson = index[(1-MosqRed)^(1/(y.count - 1))]
ditto scenario='Climate Change Without Adaptation':
RecoveryRate{' '} = index[1.0]
MosqPerPerson{' '} = index[1.0]

var EpidPotential{scenario}
EpidPotential.0 = 100
var ReproductiveRate{scenario}
ReproductiveRate = <0.9>

:: BiteFrequency^2 * SurvProb ^ IncubPeriod/(-ln(SurvProb)) >> \
  1/RecoveryRate -> EpidPotential >> MosqPerPerson -> ReproductiveRate

report EpidPotential as "Epidemic Potential (index)"
report ReproductiveRate as "Reproductive Rate (will spread if > 1.0)"
```