ENVIRONMENTAL CHANGE AND MALARIA RISK

Global and Local Implications

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ENVIRONMENTAL PROBLEMS

• Air Quality
• Pollution
• Toxicity
• Destruction of Ozone Layer – first global problem?
• Destruction / Change of ecosystem
• Population Expansion / Infrastructure
Figure 2. Contextual determinants of malaria, modified from^{12}

Infrastructure Development

Environmental Factors
- Climate & weather
- Topography
- Surface water & creation of breeding sites
- Vegetation
- Soils & drainage

Agricultural & water management practices

Socio-economic & Behavioural Factors
- Poverty
- Population density & movement
- Health Systems
- Knowledge, attitudes & practices

Biological Factors

Parasite
- Species & strain
- Drug resistance
- Population density

Mosquito
- Species & strain
- Population density
- Insecticide resistance
- Survival

Human
- Population density
- Nutritional status
- Immunity level
MALARIA EPIDEMICS

- Occurs in areas of unstable malaria transmission
- When environmental conditions favourable

![Diagram of the malaria cycle: Host, Agent, Vector]
Table 1. Examples of models developed to predict malaria epidemics and assess malaria risk in relation to environmental change. Input data and output parameters are given together with the area for which they were developed.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>Area</th>
<th>Goal</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall and maximum temperature</td>
<td>Epidemic risk</td>
<td>Kenya</td>
<td>Early warning</td>
<td>Githeko and Ndegwa (2001)</td>
</tr>
<tr>
<td>Number of presumptive malaria cases</td>
<td>Epidemic risk</td>
<td>Madagascar</td>
<td>Early warning</td>
<td>Albónico et al. (1999)</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>Malaria seasonality</td>
<td>Kenya</td>
<td>Predicting malaria transmission seasonality</td>
<td>Hay, Snow and Rogers (1998)</td>
</tr>
<tr>
<td>Rainfall and temperature</td>
<td>Distribution of <em>An. gambiae s.s.</em> and <em>An. arabiensis</em></td>
<td>Africa</td>
<td>Facilitating species-specific vector-control activities</td>
<td>Lindsay, Parson and Thomas (1998)</td>
</tr>
<tr>
<td>Temperature, NDVI, cold-cloud duration and elevation</td>
<td>Distribution of 5 sibling species of the <em>An. gambiae</em> complex</td>
<td>Africa</td>
<td>Forecasting malaria</td>
<td>Rogers et al. (2002)</td>
</tr>
<tr>
<td>Rainfall and temperature</td>
<td>Distribution of malaria transmission</td>
<td>Africa</td>
<td>Providing basis for predicting impact of climate change</td>
<td>Craig, Snow and Le Sueur (1999)</td>
</tr>
<tr>
<td>Rainfall, temperature and population data</td>
<td>Distribution of population exposed</td>
<td>Africa</td>
<td>Providing risk map for malaria mortality</td>
<td>Snow et al. (1999)1</td>
</tr>
</tbody>
</table>

1 Based on the model of Craig, Snow and Le Sueur (1999)
TEMPERATURE & MALARIA CASES
TEMPERATURE & MALARIA CASES
Figure 4. Comparison of Martens and Birley-Lindsay models of predicted incidence for various average temperature values. Different values of gonotrophic-cycle survival are simulated.
CLIMATE & MALARIA

TEMPERATURE

Parasite development

Mosquito development

No. of days

9

5

8°C  18°C  27°C  40°C
ENVIRONMENTAL CHANGE AND MALARIA EPIDEMICS: CONTRASTING IMPACTS

↑ Epidemics (WMO, 1999)

Eastern Africa

El Nino

Heavy rainfall, flooding

Tanzania

↓ Cases (Lindsay et al 2000)
Malaria vs Environmental change

- Historical Patterns: ↑ in cases / epidemics could not be explained by
  - ↑ in Temp
  - Climate change
Studies: Rakotomanana et al 2010. Antananarivo, Madagascar

• Methods
  – GIS for data integration on altitude, temp, rainfall, pop dens & surface area (rice field)
  – Entomological for species determination, breeding sites & infectivity (risk of transmission)
  – Incidence by PCR on dried blood spots & rapid tests for febrile school children

• Results
  – PCR = 5.1%; An arabiensis; rice fields
  – Travel report related to P falciparum
Rakotomanana et al 2010. Antananrivo, Madagascar

• Conclusion: Environmental Factors
  – No direct relationship with incidence
  – Ensuring the suitability of vector development
Macro vs Micro-scale
The Need For Peridomestic Analysis

• Macro-scale: global impact assessment
• Micro-scale (Peridomestic):
  – Local assessment
  – Highlight major contribution of environmental features (EF) to malaria incidence (MI)
  – Stefani et al 2011: multivariate peridomestic landscape characterisation that maximises chances of identifying relationships between EF & MI

• Conclusion: environment-based predictive model of MI in neotropical rainforest area
<table>
<thead>
<tr>
<th>Action Envisaged</th>
<th>Individual and family protection</th>
<th>Community protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction of man-mosquito contact</td>
<td>Bednets, repellents, protective clothing, screening of houses</td>
<td>Site selection, zooprophylactics</td>
</tr>
<tr>
<td>Destruction of adult mosquitoes</td>
<td>Use of domestic space spraying (aerosols), space spraying</td>
<td>Residual indoor insecticides, ultra-low volume, sprays</td>
</tr>
<tr>
<td>Destruction of mosquito larvae</td>
<td>Peridomestic sanitation, intermittent drying of water containers</td>
<td>Larviciding of water surfaces, intermittent irrigation, sluicing, biological control</td>
</tr>
<tr>
<td>Source reduction</td>
<td>Peridomestic sanitation, Small-scale drainage</td>
<td>Environmental sanitation, water Management, drainage</td>
</tr>
<tr>
<td>Destruction of malaria parasites</td>
<td>Early diagnosis and treatment, chemo prophylactics</td>
<td>Establishment of diagnosis and treatment facilities, chemo prophylactics for pregnant women, mass treatment</td>
</tr>
<tr>
<td>Social participation</td>
<td>Motivation for personal and family protection</td>
<td>Health education, community participation</td>
</tr>
</tbody>
</table>
Hematophagy – the evolutionary brilliance of female mosquitoes to feed on the rich nutrient source of human blood is a critical link in the chain of events leading to the scourge of malaria.
Distribution of spatial clustering trends of high and low EIR values for *An. gambiae* s.s, *An. arabiensis* and *An. funestus*. Note: Z score > 0 indicates a clustering trend of high EIR values (red dots) and Z score < 0 indicates a clustering trend of low EIR values (black dots).
Figure 4. Effects of season on mosquito populations and malaria transmission. Mosquito populations typically lag slightly behind rainfall, such that rainfall increases are often followed by a peak in mosquito numbers (see also Figure 1). Leading up to the peak, mosquito populations are undergoing huge recruitment, will be relatively young and therefore have low salivary-gland infection rates with *Plasmodium* sporozoites. As the population declines, the ageing mosquito population has few if any new recruits and will have an increasingly high sporozoite rate. During periods where the mosquito populations are more stable (short rains for example), the age of the mosquito population can be very mixed and the sporozoite infection rate hard to predict. RA undertaken at any of these times must account for the differences in mosquito population characteristics as well as densities that seasonality will induce.
Comparisons of mean entomological and environmental measures by district. Mbogo et al 2003.
A temporal and spatial comparison of mean larval mosquito density (A, C; mean ± SE) and the proportion of sites containing *An. farauti* larvae (B, D).

Bugoro *et al.* Malaria Journal 2011 10:262
FAVOURABLE ENVIRONMENT

BREEDING PLACES
FAVOURABLE ENVIRONMENT

BREEDING PLACES
Anopheles vs Breeding Sites

- Natural vs man made?
- Why?
RAINFALL & MALARIA CASES
Figure 6. Sensitivity of simulated incidence to variation in rain for 17.5oS 25.0oE using ERA-40 weather. Calculated rainfall is multiplied by a constant (0.8, 1, 1.2) for the entire simulation.
<table>
<thead>
<tr>
<th>Variable</th>
<th>$P. vivax$</th>
<th></th>
<th></th>
<th>$P. falciparum$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson r</td>
<td>P value</td>
<td>Pearson r</td>
<td>P value</td>
<td></td>
</tr>
<tr>
<td>% bare soil#</td>
<td>-0.17</td>
<td>0.381</td>
<td>-0.69</td>
<td>&lt; 0.001**</td>
<td></td>
</tr>
<tr>
<td>% secondary forest</td>
<td>0.00</td>
<td>0.999</td>
<td>-0.03</td>
<td>0.891</td>
<td></td>
</tr>
<tr>
<td>% primary forest</td>
<td>0.08</td>
<td>0.688</td>
<td>0.54</td>
<td>0.003**</td>
<td></td>
</tr>
<tr>
<td>% deep water</td>
<td>0.28</td>
<td>0.149</td>
<td>-0.39</td>
<td>0.043*</td>
<td></td>
</tr>
<tr>
<td>% burned land#</td>
<td>-0.24</td>
<td>0.218</td>
<td>-0.43</td>
<td>0.022*</td>
<td></td>
</tr>
<tr>
<td>% low vegetation</td>
<td>-0.09</td>
<td>0.665</td>
<td>0.06</td>
<td>0.761</td>
<td></td>
</tr>
<tr>
<td>% medium vegetation#</td>
<td>-0.05</td>
<td>0.783</td>
<td>0.24</td>
<td>0.227</td>
<td></td>
</tr>
<tr>
<td>% high vegetation</td>
<td>0.17</td>
<td>0.396</td>
<td>0.68</td>
<td>&lt; 0.001**</td>
<td></td>
</tr>
<tr>
<td>% river banks/shallow water#</td>
<td>0.30</td>
<td>0.124</td>
<td>-0.24</td>
<td>0.212</td>
<td></td>
</tr>
<tr>
<td>No. of inhabited dwellings#</td>
<td>-0.30</td>
<td>0.116</td>
<td>-0.60</td>
<td>0.001**</td>
<td></td>
</tr>
<tr>
<td>Length of river banks#</td>
<td>0.32</td>
<td>0.097</td>
<td>-0.44</td>
<td>0.018*</td>
<td></td>
</tr>
<tr>
<td>Length of creeks#</td>
<td>-0.06</td>
<td>0.771</td>
<td>0.48</td>
<td>0.01*</td>
<td></td>
</tr>
<tr>
<td>Landscape division 1</td>
<td>0.46</td>
<td>0.013*</td>
<td>-0.10</td>
<td>0.601</td>
<td></td>
</tr>
<tr>
<td>Landscape division 2</td>
<td>0.49</td>
<td>0.008**</td>
<td>0.48</td>
<td>0.009**</td>
<td></td>
</tr>
</tbody>
</table>

Buffers radii = 100 m and 400 m for $P. vivax$ and $P. falciparum$ incidences, respectively.

Correlations between larval *An. farauti* presence and the 6 environmental factors in the study streams: filamentous algae, emergent aquatic plants, current rainfall, rainfall lagged by one month, salinity and sun exposure. The factors with a pink top-panel were significantly associated with *An. farauti* presence.

A temporal and spatial comparison of the environmental factors recorded the study streams: filamentous algae (A, E; mean ± SE), emergent aquatic plants (B, F; mean ± SE), salinity (C, G; mean ± SE) and rainfall (D; monthly total).

Bugoro et al. Malaria Journal 2011 10:262
flood
FLOOD
WATER RECEDING

DROUGHT
TSUNAMI

GLOBAL PHENOMENA
LOCAL IMPACT
Tsunami Destruction of Aceh Province in Sumatra

before

after
Changing Environment
Post Tsunami
POST – TSUNAMI

? IMPACT ON MALARIA
Tsunami and *malaria*
Environmental Change
Local Variations

• Geographical characteristics
  – Highland
  – Valley

• Land cover / Land Use
  – Bare highland
  – Marshes / Bushes
  – Agriculture

• Infrastructure / Township
Malaysia: New Epidemics

Top: A 'true' epidemic, i.e. an infrequent event occurring in areas where the disease does not normally occur. This type of epidemic is often associated with warm dry regions. This type of epidemic may be cyclical in nature.

Middle: An unusually high peak in transmission in areas where malaria is normally seasonal. This type of epidemic often happens in the highland fringes. These epidemics may also be cyclical in nature.

Bottom: A 'resurgent outbreak' where neglect or breakdown in control allows malaria to try to return to its higher 'pre-control' level. May be associated with more complex emergency situations involving political instability and displaced populations. [14]
Ecology & Landscape

A large portion of the area designated for latex timber clone plantations in Johor consists of freshwater swamps which logically, should be preserved as they act as water storage facilities.
Electric fencing and deep ditches, built to keep elephants away from rubber tree estates, can instead, impede wildlife migration and fragment important habitat.
Ecology & Landscape

1996

2012
Plasmodium knowlesi

- Potentially life threatening
- Misdiagnosed as P malariae until recently
  - Distinguished by nested PCR assays

- Short 24-hour asexual life cycle
  - high parasitaemia
  - prompt treatment
KNOWLESI MALARIA
NEW OR UNRECOGNISED THREAT?

Thin & thick films of a real patient