Use of GIS in Malaria Research: Three Case Studies

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Geographic information system (GIS)

- A GIS is a combination of maps (cartography) and database: a *spatial database*
- A system that captures, stores, analyzes, manages, and presents data that are linked to location
- GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit data, maps, and present the results of all these operations
• Three case studies:
  – MAP: the Malaria Atlas Project
  – Laos
  – Kenya
Case Study 1: MAP (the Malaria Atlas Project)

• MAP, the Malaria Atlas Project, develops global maps of malaria risk

• *Plasmodium falciparum* parasite rate (PfPR):
  – the proportion of the population found to carry asexual blood-stage parasites
  – related to the entomological inoculation rate (EIR), the number of bites on a person by sporozoite positive vectors at the steady state
  – follows a well-established pattern as a function of age and transmission intensity
  – rises during infancy and childhood, settles to a plateau in older children, and declines in adults as malaria immunity develops

*A World Malaria Map: Plasmodium falciparum Endemicity in 2007*
Goals

- last global map of *P. falciparum* endemicity was published in 1968, and had some deficiencies
- this project describes the generation of a new global map of malaria endemicity
- **Malaria cartography**: an increasingly important tool for planning, implementing, and measuring the impact of malaria interventions worldwide
- the map provides an explicit geographical framework for monitoring and evaluation of the impact of the malaria control
- **Objective**: use a contemporary database of PfPR surveys to make a continuous, global, *P. falciparum* malaria endemicity surface for 2007
Methods

• PfPR surveys:
  – a total of 8,938 surveys were identified from 78 of the 87 *P. falciparum* malaria endemic countries
  – 7,953 passed data fidelity tests for inclusion into a global database of PfPR data
  – data age-standardized (PfPR$_{2-10}$)

• Used a predictive framework known as model-based geostatistics (MBG) for the spatial prediction of malaria endemicity
• Areas defined as: no risk (light grey), unstable risk (medium grey), stable risk (dark grey)

• Shown as a continuum of yellow to red from 0%–100%

• Dataset was stratified into three major global regions:
  • the Americas, Africa+ and CSE Asia
The model-based point estimates of the annual mean PfPR$_{2-10}$ for 2007 within the stable spatial limits of *P. falciparum* malaria transmission

- Displayed as a continuum of yellow to red from 0%-100%
- The rest of land area was defined as unstable risk (medium grey areas) or no risk (light grey areas)
From spatial Limits to the continuous predicted surface

• Geostatistical algorithms were used to generate continuous maps by predicting values at unsampled locations

• The confidence attached at a given unsampled location depended on:
  – the distribution of survey points around that location,
  – the number of people sampled in each survey etc.

• An MBG (model-based geostatistics) approach was implemented in a Bayesian statistical framework

• Because data were collected at different times throughout 1985-2008, it was important to extend the spatial-only geostatistical approach to a space-time framework
• Categorized as **low risk** (\(\text{PfPR}_{2-10} \leq 5\%\), light red), **intermediate risk** (\(\text{PfPR}_{2-10} > 5\%\) to \(< 40\%\), medium red), and **high risk** (\(\text{PfPR}_{2-10} \geq 40\%\), dark red).

• The map shows the class to which \(\text{PfPR}_{2-10}\) has the highest predicted probability of membership.
Figure: Pie Charts Showing the Populations At Risk (PAR) of *P. falciparum* Malaria in 2007

- The charts, scaled proportionally to the total population at risk, show the proportion of the population living in each predicted PfPR$_{2-10}$ endemicity classes
- “*The world is substantially less malarious than would be predicted from the inspection of historical maps, both through a shrinking of the spatial limits and through a reduction in endemicity*”
- Of the ~1.4 billion people exposed to stable malaria risk in 2007, ~0.8 billion live in *extremely low* malaria endemicity with PfPR$_{2-10} <= 5$
  - CSE Asia (~80%), Africa+ (~15%), and America (~5%)
Summary

• This cartographic resource will help countries determine their needs and serve as a baseline to monitor and evaluate progress towards interventional goals

• Mapped surfaces made available in public domain

• The MAP team anticipate providing annual updates of this *P. falciparum* global malaria endemicity map and the accompanying PfPR database
Case Study 2: Laos

• Using GIS maps to malaria control monitoring: intervention coverage and health outcome in distal villages of Khammouane province, Laos

• GIS mapping allows:
  – visualization of field survey results,
  – essential information in targeting limited financial and human resources for malaria control
  – easy to use maps: outputted as html so could be viewed with any standard browser

Geographic information system (GIS) maps and malaria control monitoring: intervention coverage and health outcome in distal villages of Khammouane province, Laos
conducted questionnaire interviews and malaria RDTs from June to July (during the rainy season) in 2005.

GPS locations of the villages and health facilities

GPS is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense, officially called NAVSTAR satellite system. The interception of a minimum of three satellite signals allows the GPS receiver to calculate its position on the earth with respect to latitude and longitude. A minimum of four satellite signals is required to include altitude calculations. GPS receivers are accurate to within 15 meters on average. Garmin Geko™ 201, a GPS handheld receiver used in this study has a special system called Wide Area Augmentation System (WAAS) which can improve accuracy to less than three meters on average [22]. GPS locations (latitude, longitude, altitude) of the health facilities and the study villages were registered as Waypoints, and the study team's path of travel, called a Track, was also recorded throughout the field survey. When conducting a survey in rural areas without accurate maps available, nor roads, GPS is particularly useful.

Components of GIS

Figure 1 shows the components of GIS of this study. The data were collected through questionnaire interviews and malaria RDTs at each household.

**Definition of malaria health outcome**
The Paracheck immunochromatographic test was used (Orchid biomedical system, Goa, India). The test detects the presence of *P. falciparum*-specific histidine-rich protein-2 (HRP-2) in a finger-prick blood sample and considered to be the most appropriate test kit [23-25]. The test was performed by medical doctors and local health staff according to the manufacturer's instructions.

**Development of GIS maps**
GPS data was downloaded from the GPS handheld receiver. For GIS-mapping and analysis, Kashmir 3D Version 8.0.9 Beta [26], and Mandara for Windows Version 9.10 were used [27]. Both software programmes are available free-of-charge on their respective websites, limited to the purpose of academic or non-commercial use. All GIS maps were converted into '.html' format so that GIS maps can be accessed using a standard internet browser without need for a specific viewing programme. Each variable was outputted into the map only in percentage, the number of each factor of interest divided by the total number of observations in each village.

**Study ethics**
Approval for this study was obtained from the Lao Ministry of Health and the Ethics Committee of the Graduate School of Medicine, University of Tokyo, Tokyo, Japan (reference no. 1129, dated 23 March 2005). Written informed consent was obtained from each participant after the objectives of the study were explained. Free treatment was offered to patients diagnosed with malaria during the field survey.

**Figure: Components of GIS**

- Data were collected through questionnaire interviews and malaria RDTs (rapid diagnostic tests) at each household
- **1711** study participants, **403** households
Results

On the developed maps, the provincial hospital and three district hospitals are shown as red cross icons, and blue lines are the Track, the study team's path of travel. Height above sea level ranged from 157.3 m to 546.6 m.

Socio-demographic characteristics

Figure 2 shows the number of study participants at each study site. Other maps are not presented in this paper, but each socio-demographic characteristic, i.e., sex, age, ethnicity, religion, income, ownership of a vehicle, TV, and radio, availability of electricity, and school education, can be outputted to a map. Out of the 1711 study participants, 46.5% were male and 22.0% were children under five. 68.8% were Lao Lum major ethnic group and 52.8% were Animist.

Malaria health outcome

Figure 3 shows malaria health outcome. In total, 12 *P. falciparum* malaria positive cases were detected by RDTs. The proportion of positive cases was 0.7% (12/1,711) with a range in each village of 0~8.2%. Apart from these 12 positive cases, the medical doctors suspected that nine patients were *P. falciparum* malaria false-negative cases or were infected with other types of malaria, based on clinical signs such as fever, chills vomiting and headache. Those nine cases were also indicated on the maps.

The intervention coverage and adherence to the intervention

It is recommended that the number of persons who share the same ITN should be smaller than three in this project. In 76.7% (309/403) of households, the recommended intervention coverage was achieved (Figure 4), with a range in each village of 42.9-100%. In 73.9% (298/403) of households, ITNs were re-treated annually before the start of the rainy season (Figure 5) with a range in each village of 21.4-95.0%. 92.1% (1,575/1,711) reported that they slept in bed nets every night (Figure 6) with a range in each village of 53.4-98.9%. 87.3% (352/403) of household heads have attended a malaria education program at least once. The proportion of household heads who mentioned mosquito bites as the cause of malaria was 39.0% (157/403). 10.2% (174/1,711) visited the hospital for diagnosis and treatment of malaria. 57.6% (232/403) reported that they make sure to take all tablets of antimalarial drugs as prescribed. To the question “How often do you get mosquito bites?” 68% (1,164/1,711) answered “Often” (Figure 7) with a range in each village of 49.1-83.3%.

The coverage and health outcome in the distal (remote) villages

Out of the 12 malaria positive cases, almost all of them were detected in the distal villages. The villages with the best access to the district hospital, the central part of the district, were malaria-free. Six cases were detected from one remote village of Bourapar district. The risk of malaria infection in this village (8.2%, 6/73) was statistically significantly higher than that in other villages (P < 0.001, chi-square test). To travel to this remote village from the district hospital, it requires not only a road trip by car, but also three hours by boat on the flooded river during the rainy season. Notable characteristics specific to this village

Figure: Number of the study participants in each site.

- The provincial hospital and three district hospitals are shown as red cross icons
- Blue lines represent the Track, the study team's path of travel
- Other socio-demographic characteristic, i.e., sex, age, ethnicity, religion, school education etc., can also be outputted to a map
• 12 *P. falciparum* malaria positive cases were detected by RDTs (rapid diagnostic tests), nine more false-negative cases suspected
• Almost all of the 12 cases were detected in the distal (remote) villages (which need a road trip by car, and three hours by boat on the flooded river during the rainy season)
• Villages with best access to district hospital, central part of the district, were malaria-free
• Recommended: number of persons who share the same ITN should be smaller than **three**
• In **76.7%** (309/403) of households, the recommended intervention coverage was achieved, with a range in each village of 42.9-100%

**Figure: ITN (insecticide-treated nets) coverage.**
In addition to the remote village with six positive cases, four more villages had malaria positive cases. These five villages with malaria cases were located in the area with least access from the central part of each district, and had lower re-treatment (Figure 5: 59.3% mean of proportions in the five villages vs. 76.4% mean of proportions in the other 15 villages) and higher proportion of people reporting frequent mosquito bites (Figure 7: 77.8% vs. 63.3%).

Discussion
GIS maps visually indicated the uneven distribution of intervention coverage and health outcome within one province. They highlighted where malaria cases occurred, as well as villages with lower coverage of ITNs or lower adherence to the intervention. Based on the data and the maps, feedback was given to decision-makers and local health staff and helped with prioritizing where malaria control activity could be strengthened under limited financial and human resources.

In the distal villages located far from the district hospitals, malaria cases were detected, while the villages with the best access were malaria-free. Malaria control center staff stationed in the central provincial hospital and at each district hospital were not aware of the situation in those villages. When there were no more malaria patients at the hospital or in villages with easy access by car, they assumed an optimistic situation in the whole district and province. Through this community-based survey visiting every household in the villages, including ones in the most remote areas with poor access, and conducting a screening of malaria at the site, we were able to demonstrate that malaria did not vanish, but remained unevenly distributed within districts. Malaria control staff should...
Summary

• GIS maps visually indicated the uneven distribution of intervention coverage and health outcome within one province

• Highlighted where malaria cases occurred, as well as villages with lower coverage of ITNs or lower adherence to the intervention

• Based on the data and the maps, feedback was given to decision-makers and local health staff

• Helped with prioritizing malaria control activity under limited financial and human resources
Summary

• Malaria cases were detected in the *distal* villages, while the villages with best access were malaria-free

• They demonstrated that *malaria did not vanish, but remained unevenly distributed within districts*
Case Study 3: Kenya

• **Objective**: to develop a GIS-based model that establishes the relationship between malaria incident rates and its underlying environmental factors using maximum likelihood estimation method

• The model would help:
  – decision-makers involved in policy, planning & prevention of malaria
  – to select intervention procedures such as supplying insecticide-treated nets, drugs & draining of standing water
  – to provide information on not only *where* but also *when* malaria are most likely to occur

*Understanding Malaria Incident Rates in Kenya using GIS-Based Multivariate Spatial Econometric Models*
Mohamed Ismael Ahmed, Master’s Project,
School of Economic, Political & Policy Sciences, University of Texas at Dallas
Data source

- Environmental data: downloaded from the International Livestock Research Institutes’ website
- Malaria incident data: from the KEMRI-Welcome Trust Research Program, the Kenya government’s Ministry of Health (MOH) etc.
Variables

• The model starts with one dependent variable (rate) & seven independent environmental variables:
  – mean daily rainfall,
  – mean maximum daily temperature,
  – elevation,
  – soil pH,
  – population density,
  – percentage tree cover &
  – a dummy variable for the presence of large water bodies (1 if present, 0 otherwise)
Figure: Malaria incidence rate (dependent variable)
Figure: Elevation & Mean maximum daily temperature
Figure: Percentage tree cover & Population density
Figure: Water bodies (1 if present, 0 otherwise) & Mean daily rainfall
Methods

• The environmental layers are overlaid (intersected) with malaria incident cases
• Created common layer is then summarized using averages of each field of interest
• A new ‘rate’ field is added into the created layer
• The study covers 69 districts in the country
• The malaria incident rate is then calculated by dividing each district’s malaria incident cases by its respective total population
• After creating one GIS-layer of Kenya containing all the fields, the layer is linked with the spatial regression methodology using GoeoDA, Spatial Econometrics Toolboxes & R
Summary

Four questions answered:
1. Which top 10 districts suffer from highest malaria risks?
   Bondo, Homa Bay, Kisumu, Kuria, Migori, Nyando, Rachuonyo, Siaya, Suba & Kilifi
2. Are spatial autocorrelation effects present? Yes
3. Which model best describes the data (OLS, spatial lag or spatial error)?
   Both spatial models are significant improvements from the OLS model; the best fit for the data was given by the spatial error model
4. Based on the, which environmental factors are the most significant predictors of malaria incident rates?
   Mean daily rainfall,
   Elevation,
   Mean maximum daily temperature &
   Water bodies