GIS for Health and the Environment

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# Contents

**Foreword**

*Don de Savigny, Luc Loslier, and Jim Chauvin* .......................... v

**Preface**

*Don de Savigny, Lori Jones-Arsenault, and Pandu Wijeyaratne* . . . vii

**Context**

The Present State of GIS and Future Trends

*Steven Reader* .......................................................... 3

Geographical Information Systems (GIS) from a Health Perspective

*Luc Loslier* ..................................................................... 13

Spatial and Temporal Analysis of Epidemiological Data

*Flavio Fonseca Nobre and Marilia Sá Carvalho* ............ 21

**Case Studies from the South**

Towards a Rural Information System

*David le Sueur, Sipho Ngxongo, Maria Stuttaford, Brian Sharp,*  
*Rajendra Maharaj, Carrin Martin, and Dawn Brown* ............... 35

A GIS Approach to the Determination of Catchment Populations around
Local Health Facilities in Developing Countries

*H.M. Oranga* ............................................................... 53

GIS Management Tools for the Control of Tropical Diseases:
Applications in Botswana, Senegal, and Morocco

*S.S. Mokgweetsinyana, A.H. Sylla, and I. Talla* .................. 59

The Use of Low-Cost Remote Sensing and GIS for Identifying and
Monitoring the Environmental Factors Associated with Vector-Borne Disease Transmission

*S.J. Connor, M.C. Thompson, S. Flasse, and J.B. Williams* .... 75
Geographical Information Systems for the Study and Control of Malaria

Gustavo Brêtas ................................................................. 89

Spatial Analysis of Malaria Risk in an Endemic Region of Sri Lanka

D.M. Gunawardena, Lal Muthuwattac, S. Weerasingha,
J. Rajakaruna, Wasantha Udaya Kumara, Tilak Senanayaka,
P. Kumar Kotta, A.R. Wickremasinghe, Richard Carter,
and Kamini N. Mendis ..................................................... 99

Diagnostic Features of Malaria Transmission in Nadiad Using Remote Sensing and GIS

M.S. Malhotra and Aruna Srivastava .................................... 109

Monitoring Zoonotic Cutaneous Leishmaniasis with GIS

L. Mbarki, A. Ben Salah, S. Chlif, M.K. Chahed,
A. Balma, N. Chemam, A. Garraoui, and R. Ben-Ismail ......... 115

Use of RAISON for Rural Drinking Water Sources Management

C. W. Wang ................................................................. 127

Appendices

Interests, Problems, and Needs of GIS Users in Health: Results of a Small Survey

Luc Loslier ................................................................. 135

GIS, Health, and Epidemiology: An Annotated Resource Guide

Steven Reader .............................................................. 145

Workshop Agenda .......................................................... 161

Workshop Participants .................................................... 167
Introduction

Vector-borne diseases require an intermediate living agent for their transmission. They are a heavy burden on human populations, a major cause of work-loss, and a serious impediment to economic development and productivity. Their epidemiology is influenced by attributes of their vectors, which in turn are closely linked to environmental conditions.

Over the past decades, the increased demands upon the landscape for food and shelter and an increased number of by-products of man’s living environment have led to unparalleled changes. Some of these changes have led to an increase in the distribution of several vector-borne diseases, including malaria.

Malaria is a serious vector-borne disease affecting a greater proportion of the world’s population than any other vector-transmitted disease. Over two hundred million cases of malaria occur every year, and the number is increasing. Large areas of regions where malaria had been controlled are now suffering again from this significant public health problem.

The increase in malaria prevalence is determined by several factors: mosquito resistance to insecticides, parasite resistance to drugs, changes in land-use patterns, and reductions in funding and manpower dedicated to control activities. Most of the determinants are heterogeneously distributed, changing over both space and time. Factors such as topography, temperature, rainfall, land-use, population movements, and degree of deforestation have a profound influence on the temporal and spatial distribution of malaria vectors and malaria.

Despite its importance, the study of environmental determinants of malaria has been hampered by the difficulties related to collecting and analyzing environmental data over large areas, and to the speed of change in the malaria epidemiological situation. Geographical Information Systems (GIS), Remote Sensing (RS), and Geographical Positioning Systems (GPS) are important new tools for the study and control of malaria.

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GIS for the Study and Control of Malaria

Over the past 20 years, researchers have been developing automated tools for the efficient storage, analysis, and presentation of geographical data (for example, Aronoff 1989). This rapidly evolving technology has come to be known as "geographical information systems" (GIS). These systems, resulting from the demand for data and information of a spatial nature, may be widely used across varied scientific fields. Their ability to use topological information and spatial analysis functions distinguish them from a number of other information systems.

Geographical information systems may be summarily defined as a constellation of software and hardware tools capable of integrating digital images for the purpose of dealing with geographically-localized data.

Large amounts of information are necessary for almost all aspects of malaria control programs. GIS offer the ability to process quantities of data beyond the capacities of manual systems. Data is stored in a structured digital format, which permits rapid data retrieval and use. In addition, data may be quickly compiled into documents, using techniques such as automatic mapping and direct report printouts (Bernhardsen 1992).

Data Integration

GIS facilitate the integration of quantitative malaria determination and control data with data obtained from maps, satellite images, and aerial photos. Frequently, socioeconomic data and qualitative information on health facilities have a spatial basis, and can also be integrated with malaria data from the same areas. The integration of operational and logistical data for malaria control program planning with epidemiological data will serve to strengthen both the epidemiological analysis and the planning and execution of control programs.

Stratification (Spatial Decision Support)

Malaria stratification aids in the development of community-based malaria control programs, by accumulating past experiences with and solutions to different factors associated with malaria outbreaks (Orlov et al. 1986). Stratification can also point to the existing inequalities in resources, allowing for a more equal and homogeneous distribution of available resources (Kadt and Tasca 1993).

Stratification of malaria emerged as a strategic approach in Latin America in 1979. Since the 1980s, it has become recognized as a useful tool for attaining an objective epidemiological diagnosis, and as a basis for planning strategies of malaria prevention and control.
The ability of GIS to deal with large data sets and to incorporate satellite images increases the feasibility of studying the environmental determinants of malaria. The epidemiological mapping of high-risk areas of malaria transmission has helped national level malaria control programs to recognise those populations and geographical areas where it is possible to identify the main determinants of malaria morbidity and mortality.

One of the main functions of GIS is the selection of areas according to some specified characteristics, in a search for regularities. These characteristics may be both or either spatial or nonspatial data from a map or database within the GIS. Data may be selected according to geographic criteria or content. Most GIS incorporate the use of Structured Query Language, which allows logic and arithmetic operations. Queries may be built to stratify areas according to inundation potential, proximity to treatment sites, availability of transport, incidence of malaria, quality of housing, and so on. Characteristics may also be combined: one could ask the GIS to find areas where the houses are of poor quality and the drainage of the terrain slow, as possible candidates for a control strategy with emphasis on drainage instead of spraying.

The stratification of areas according to their epidemiological situation is also useful to development agencies implementing agricultural projects. Many such projects require environmental and health impact assessments, which could be used as a working base by malaria control programs in the early stages of land occupation. At the same time, the projects would benefit from the control programs' previous data. It is thought that a GIS would be an adequate tool to integrate these different data-sets and information.

Heuristic Modelling

Maps are heuristic models, used to communicate, interpret, and explain data. They aid in the visualisation of differences, clustering, heterogeneity, or homogeneity within data. Spatial patterns can be perceived and correlations visualized through the use of maps. Symbols and colours can communicate detail or the relative importance of certain features.

Malaria control program staff tend to be familiar with maps, using them for their daily activities. Maps can consequently be used to communicate ideas and explanations about the determinants of malaria and strategies of control. A map's heuristic potential can also be exploited as the media of communication between a control program and the public.

Analysis

A number of analysis methods may be used on data acquired through a GIS. Data may be selected according to geographic criteria or content using some
form of Structured Query Language. Geometric operations involve the computation of distance, areas, volumes, and directions. Flow analyses calculate geometric computations to find the shortest routes between designated points. This type of analysis is frequently important for the planning, logistics, and operation of malaria control programs.

Statistical operations are performed primarily on attribute data, but may also be applied to some types of geometric data. Most GIS support a range of statistical operations, including sum, maxima, minima, average, frequency distribution, bi-directional comparison, standard deviation, and multivariate analysis. Pattern recognition and statistical modelling are also incorporated in some GIS (Bernhardsen 1992), allowing for the identification of spatial and/or temporal clusters of malaria occurrence. The relationship between these clusters and environmental or socio-economic characteristics can then be investigated.

GIS also open new possibilities of data analysis not limited to spatial analysis. Data generated within GIS, distances, areas, and selections based on spatial criteria, can all be used as inputs to statistical modelling.

Global Changes and Malaria

It is expected that changes in the global environment will lead to changes in malaria occurrence patterns. These changes are currently being studied and modelled, and their impact on malaria can now be examined. For example, researchers are looking at the impact of increased temperatures on the spatial distribution of malaria, and on the impact of deforestation and temperature increases on the latitudinal limits and intensity of highland malaria.

The occurrence of malaria under different land occupation strategies can be studied with the combination of remote sensing and GIS. The results could be used as guidelines for new development projects in areas receptive to malaria.

Integration with other Information Systems

WHO technical report no. 839 (1993) recognizes that a change from specialised information systems for malaria towards integrated health information systems is essential if the general health services are to take full responsibility for managing malaria. An integrated health information system will allow the malaria problem to be related to other health problems...

Taken further, it can be seen that the main determinants of malaria are not restricted to health. Consequently, there is a need to integrate other types of data into a malaria information system. Since data is collected to fulfil different objectives and with different formats, one of the few possible strategies for its integration is the use of a geographic base. A strategy for the comprehensive
integration of data for the planning and execution of health promotion activities (access to water, sanitation, housing, and so on) has been developed using a GIS as a central tool (Project Blade Runner, see Kadt and Tasca 1993). A similar instrument could and should be developed by malaria control programs.

Tools Complementary to GIS

Satellite Remote Sensing (RS)

Satellite imagery in digital format allows for the acquisition of environmental data and land occupation patterns and features over large areas. Sensors in satellites record multispectral data from different wave bands in digital format. Different features of the terrain reflect differently in each waveband, allowing for their recognition in the images. The digital image is fed into the computer, where it is stored. The digital images can then be displayed and further processed to extract the desired information. They may also be integrated with other types of data and information within a GIS.

The information found within a digital image is contained in a grid constructed of spatial units called pixels. Each pixel number is related to colour intensity and brightness. The main limitations of satellite images are cloud cover\(^2\) and resolution. Even with the best resolutions available (pixels < 30m), it is not possible to see houses, to adequately classify some types of agricultural practice, or to localise some breeding sites. Some of these problems may be circumvented using satellite navigation receivers.

By using the data from the different wave bands, it is possible to identify and track environmental characteristics and changes useful to the study of malaria and other tropical diseases. Vegetation, land use patterns, surface waters, quality and humidity of the soil, roads, built-up areas, and climatic changes may all be monitored by satellite.

Satellite Navigation System (SNS)

The satellite navigation system (SNS) was originally designed to enable a user to obtain an instantaneous three-dimensional position, anywhere on the earth, at any time, under any weather condition. Clock information in satellites is emitted by radio wave.

The difference between the time when a message is sent and the time when the message is received allows for the calculation of the distance between the

\(^2\)Earth Resources Satellites pass over the tropical areas early in the morning, a period when clouds and mist are most prevalent.
receiver and the satellites. Since the orbits of the satellites are known, exact positions can easily be calculated.

The SNS can be used in a number of ways to calculate absolute and relative positions with varying degrees of accuracy. The complete system consists of 24 satellites which are distributed in such a way that an adequate number of satellites are available for positioning at any time.

When associated with a GIS, a SNS receiver is a powerful mapping tool. It can provide quick and accurate positioning of terrain features and dynamic mapping. The data received can be transferred to a computer and read by a GIS, where it is transformed into map format.

Project InfoMal³

Objectives
This project, funded by the International Development Research Centre (IDRC), has been designed to assess the environmental determinants of malaria in the Brazilian Amazon using satellite remote sensing, geographical information systems, and a satellite navigation system. Its objectives are:

• To compare the risks of malaria infection under different environmental situations, controlling for the impact of socioeconomic determinants,
• To compare the risks of malaria infection within different socioeconomic groups, controlling for the impact of environmental determinants,
• To derive the rank of risk situations from the relationship of environmental and socioeconomic factors, and
• To build a rank of malaria risk situations for agricultural areas in the Amazon. It is also intended to organise an information system based on a regional GIS.

Methods
The methodological approach relies upon the integrative capabilities of GIS (Aronoff 1989). The data will be submitted to further multivariate statistical analysis to seek the best predictive indicators of malaria risk.

Different data sets, environmental data, and land occupation patterns from satellite imagery, coordinates of houses, and features of the terrain obtained with

³More information about the project can be obtained by sending an e-mail to gbretas@lshtm.ac.uk or writing to Gustavo Bretas LSHTM/THEU, Keppel St., WC1E 7HT, London, UK, fax 071-9272216.
SNS, map data from military and road maps, data from the malaria control program, and collected socioeconomic, household microenvironment and malaria data will be integrated into the GIS. The analysis will be conducted in parallel within the GIS and with statistical software. Results from the preliminary analysis will feed back to further analysis (for example, distance from water bodies, amount of deforestation, and land use will be calculated within the GIS and used in the multivariate modelling of malaria determination).

The Information System

In the past, information systems for malaria control were designed for use by eradication programs. The data was analyzed and used centrally with little or no feedback to the source of the information and with no impact on local activities.

The World Health Organization soon recognized, however, that information systems are a vital element for strengthening the national and local capacities for assessing malaria situations, for selecting appropriate control measures, and for adapting activities to changes in the malaria situation. It was seen that information systems should, therefore, be reoriented to deal with malaria, and decentralized in such a way that information is available to and used by those who need it.

Since malaria occurrence is influenced by numerous phenomena outside the habitual framework of health systems (including population movements, environmental changes, and agricultural practices), the information system should be able to incorporate and use these different types of information.

Each of these different types of data and information has a spatial basis. It was, therefore, decided that it was important that an information system to be used for malaria control should be able to deal with geographical aspects of information.

The Necessary Capabilities

It was decided that the system chosen should be able to:

- Use to the existing databases of the malaria control program,
- Be open to the future incorporation of data from other sources (rs, agricultural, roads, and so on),
- Deal with the spatial aspects of this information,
- Produce routine epidemiological evaluations,
- Stratify areas based on a set of rules,
- Automate maps,
- Produce feedback to the peripheral level, and
- Produce feedback to the general public.
Main Constraints of and Problems With the Current Use of GIS

Cost
Costs are currently the main constraint to the use of GIS. Software is relatively expensive in relation to the budgets of malaria control programs. Expansion of GIS use will probably decrease its cost. In the meantime, a compromise would be to use available shareware, or to have a software tailored for use in malaria control programs by a nonprofit organization.

Adequate Training
There exists at present a lack of trained personal. The new windowed interfaces, however, are easier to use and will speed up the process of training. Computing skills are useful in the labour market; consequently, staff from control programs should be willing to be trained.

GIGO (Garbage In, Garbage Out)
GIS is not a tool designed to increase the quality of data. Frequently, much of the data collected by malaria control program staff are not used. GIS use could lead to a relaxation in data collection and consolidation. It is necessary to review all the steps in the information flow to guarantee quality and adequacy.

Misinformation and Misinterpretation
The powerful tools of GIS can easily lead to misinformation and misinterpretation, particularly by someone unfamiliars with their use. Ecological fallacies, problems of scales, and propagation of error are frequent, and should be given serious consideration (Monmonier 1991). The same problem is also true with other types of software which have helped to advance our capacity to study and control malaria, such as spreadsheets, graphic software, and data analysis software. GIS is not a magical solution to all the information difficulties of malaria control, but is a powerful tool capable of transforming the way with which information is dealt.

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