The Application of GIS in Malaria Control Programs

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Abstract

Computerised spatial databases and GIS mapping software provide powerful tools for management and analysis of malaria control programs. The use of this technology can be tailored to suit a wide range of applications. These include: practical operational maps to assist with resource allocation; analytical tools to facilitate program monitoring and evaluation; and sophisticated research projects to investigate various spatial aspects of malaria epidemiology. This paper provides examples of the use of GIS with particular reference to the South West Pacific Region.

Introduction

Malaria is maintained under the influence of diverse ranges of interacting conditions, many of which are not well understood. These conditions are closely related to the habits and lifestyle of different communities; the behaviour of the mosquitoes which transmit the disease; as well as climatic and other environmental attributes. The full grasp of the facts about malaria in a particular place is therefore a complex matter. Malariologists working in the field in the first half of this century, in the decades following the elucidation of the malaria cycle in man and mosquitoes, appreciated that it was a focal disease and that the topography of the land was an important consideration in understanding the local epidemiological situation (Christophers, Sinton, and Covell, 1941). In the DDT residual spraying campaigns of the 1950's and 1960's an important activity of the preparatory phase was geographical reconnaissance (GR) which involved, not only the preparation of large scale maps with location of houses which were to be sprayed, but also data on road access, health facilities, population movements and other relevant facts (Pampana, 1963).

These kinds of spatial information have continuing significance for current malaria control strategies and they are ideally suited for use with modern GIS technology which permits the integration and spatial analysis of data from different sources (e.g. from census departments, mapping authorities, other government agencies) as well as health statistics. Digitised data from existing maps can provide base layers (topography, land use, roads, rivers, surface water) on which other data can be overlaid. These could include data on population distribution (towns, villages and hamlets); location of health centres and other facilities (hospitals, health posts, dispensaries, schools, government offices); meteorological indices (rainfall, temperature, humidity); epidemiological data (morbidity, mortality, parasitological indices, mosquito distribution records); and any other data which can be referenced geographically.

This computer based technology has been available for a number of years but it is only recently that it has been widely appreciated as a powerful new tool to augment existing monitoring and evaluation methods (Connor et al., 1997). For example, the prospects for mapping the risk of malaria in Africa using remotely sensed satellite data to highlight epidemiologically significant trends in vegetation and weather data have been foreshadowed (Thomson et al., 1997). Remoptely sensed data can also be employed to identify mosquito habitats and predict the likely range of vector species (Hay et al., 1998). This paper illustrates the contribution which GIS can make to malaria control programs as an operational planning aid; as a monitoring tool to assist with evaluation of control efforts; and as a research approach to investigate spatial associations of relevance to malaria epidemiology and control. It is illustrated with examples derived from the field situation in the South West Pacific Region.

GIS as an Operational Planning Aid

GIS databases can be used as operational tools to support planning and implementation of control activities**.** For example, in impregnated bed net programs for community based malaria control, they can constitute simple and practical visual aids for detailed planning of bednet distribution and retreatment schedules.

Villages in many of the Pacific Islands are not static as houses, hamlets and sometimes whole villages may be relocated to remain within convenient walking distance of garden crops which are periodically moved to different places to reflect agricultural practices within traditional land tenure areas. Over the years villages may merge or be split up. In some instances they may be relocated close to roads or coastal anchorages. In the Solomon Islands mobile census teams have recently updated village localities throughout the country using GPS equipment. Difficulties caused by lack of consistent spelling of village names have been overcome by the use of unique numerical identifiers in the digitised databases. The Pacific Regional Vector Borne Diseases Project of the Secretariat of the Pacific Community is currently assisting the National Malaria Program on the island of Malaita to increase the distribution of impregnated bed nets throughout the various communities in the Province. Field staff are well aware of the location of villages within their local area of responsibility but this information can be part of a powerful management tool if it is collated into spatial databases. Malaria control zone maps with the positions of villages in relation roads, rivers, coastal anchorages and other topographical features can provide an important overview so that resources (manpower, vehicles and boats) can be allocated most efficiently to get the job done. Similarly, in urban situations, where it is feasible to undertake larval control, purpose-generated large scale maps of larval habitats in relation to residential areas can guide the most efficient application of larvicides.

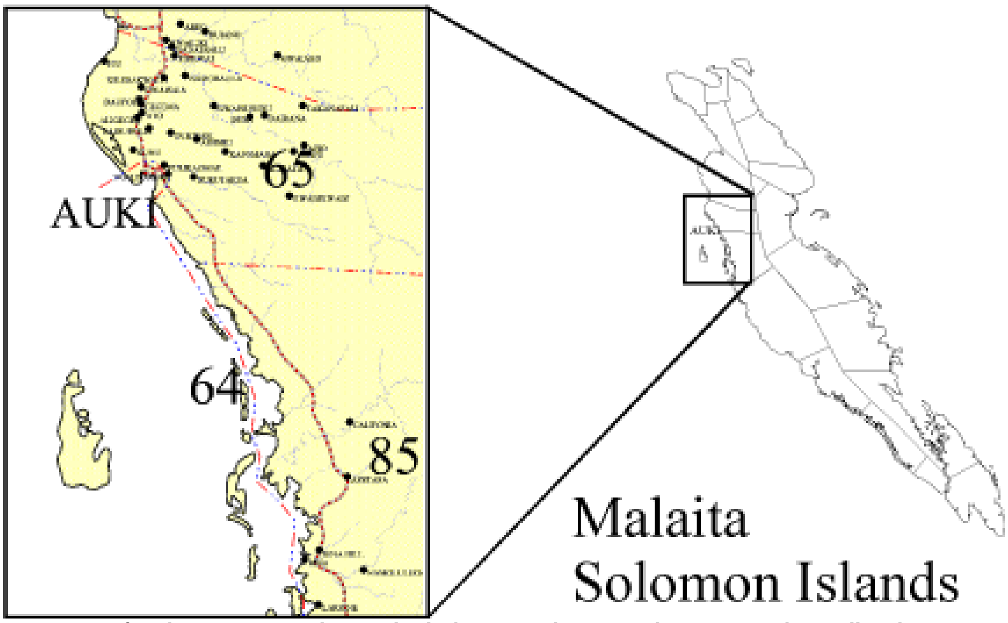

Figure 1: Map of Malaita Province, Solomon Islands showing malaria control zones. Inset shows village locations in relation to rivers, roads and malaria control zone boundaries.

GIS as an Evaluation Tool

It is known that the mosquitoes which transmit malaria usually have a restricted distribution within their geographical range. In Australia, analyses of several hundred collections of anopheline mosquitoes throughout the malaria receptive areas of far north Queensland and the Northern Territory have shown that *Anopheles farauti* 1, the most common coastal vector of malaria in the South West Pacific Region, was almost exclusively found within 5 km of the sea. (Cooper et al., 1996). Although larvae of this species are often found in brackish water they are also able to breed in fresh water near the coast. Larval habitats of *An farauti* 1 are typically partly shaded with emergent vegetation. On the other hand, *Anopheles punctulatus* prefers small pools exposed to direct sunlight without any associated plant growth. This species has been incriminated as a major factor influencing "man made malaria" in the South West Pacific, particularly during the Second World War when wheel ruts, trenches, and bomb craters, provided an ideal environment for this mosquito and resulting in massive malaria epidemics among the combatant forces. A helicopter based survey of anopheline mosquitoes in the Gulf Province of Papua New Guinea during 1994 showed that *Anopheles punctulatus* was the predominant species along logging tracks and roads throughout the province (Cooper, Waterson, and Sweeney, unpublished data). Thus, changes to local environment due to man made activities, or natural disasters such as tidal waves and cyclones might directly influence distribution patterns of malaria vectors. Data on the distribution of vectors obtained from field surveys can be incorporated as GIS vector layers. The use of satellite imagery (Landsat TM or Spot) should reveal areas of environmental change which could then be subjected to further investigation to analyse whether such factors might have an impact on malaria control efforts.

Computer based GIS resources can also provide powerful analytical tools to establish and confirm spatial relationships among data sets which are epidemiologically significant. The computing power of relational databases can be applied to investigate correlations between two or more interacting factors while maintaining the spatial relationships between them. Thus, geographical clusters of malaria cases can assist with delineation of problem areas as a starting point for further analysis to identify possible reasons for the higher incidence of malaria in these localities. This approach can therefore be of direct benefit to the evaluation of malaria control programs.

Use of GIS for Malaria Research

Climatic factors, particularly rainfall, temperature and relative humidity are known to have a strong influence on the biology of mosquitoes. GIS can be used to investigate associations between such environmental variables and the distribution of the different species responsible for malaria transmission. During the last 15 years entomological teams from the Australian Army Malaria Institute, operating from vehicles and helicopters, have collected more than 30,000 *Anopheles* specimens from over 1,000 localities in northern Australia and Papua New Guinea. This represents the largest quantity of data on the distribution of malaria vectors which has yet been gathered from this region. GIS software is being used to correlate the climatic attributes of the collection localities with the presence or absence of the various species (Sweeney, 1997).

Historical meteorological data has been collated from more than 1500 weather stations throughout this area by the Australian Bureau of Meteorology. Climate averages of station records were imported into TNTmips software as 3D vectors with station localities expressed as X and Y co-ordinates and with the climate element of each station designated as the Z co-ordinate. These 3D vectors were then converted to 3D rasters with the various climatic attributes expressed as height. A grid size of 1km has been chosen as appropriate for this purpose as the flight range of most mosquitoes is considered to be in the order of 1-2 km. The mosquito collection data were imported as database points into vector layers and linked to the corresponding cells of the elevation rasters. By this means it was possible to generate annual and seasonal estimates of key climate indica-

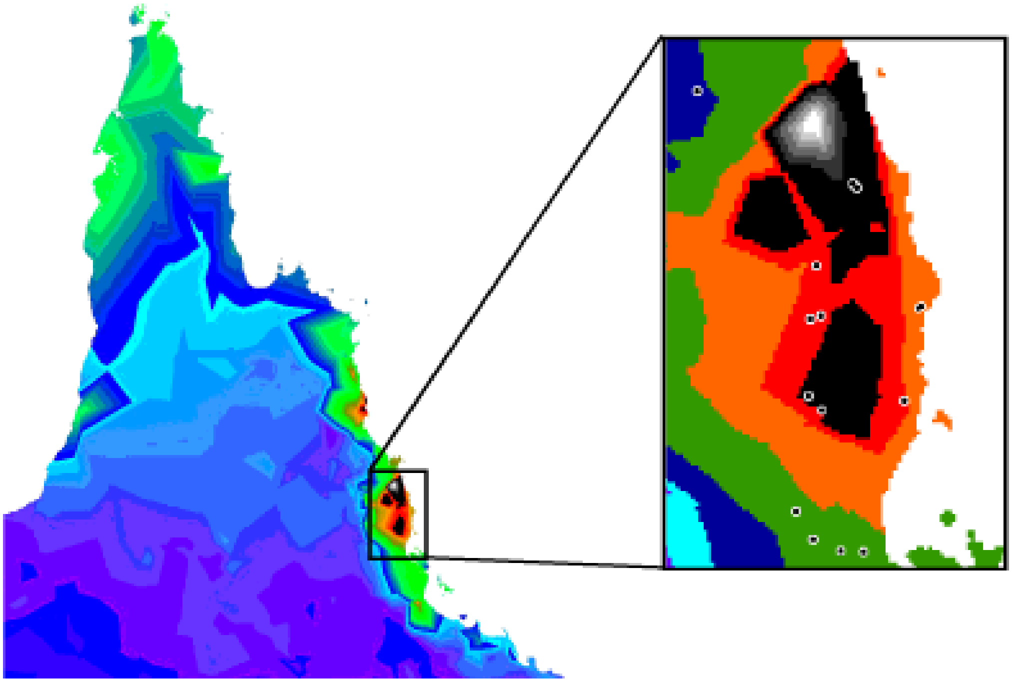

Figure 2: Elevation raster of mean annual rainfall in northern Queensland. Inset shows mosquito collection localities overlaid on one kilometre rainfall grid.

tors (rainfall, relative humidity, maximum temperature and minimum temperature) for the different collecting sites.

The relationships between the various environmental parameters and the presence of the different species is being investigated by computer induction techniques using KNOWLEDGE SEEKER, a commercially available decision-making software program, to highlight climatic factors which might contribute to observed mosquito distribution patterns. The outputs are then subjected to further analysis in HABITAT, a program devised by P. Walker and C.D. Cocks, of CSIRO Division of Wildlife and Ecology, which delineates an environmental envelope within which a species may persist. This program examines the environmental parameters within which a species has been found and then suggests other potential localities which have similar environmental characteristics. The outputs of these procedures are potential distribution ranges of the different species which can be viewed as vector layers on digitised map imagery.

These analyses can be further extended to include seasonal vegetation data from Normalised Difference Vegetation Index (NDVI) images generated by NOAA satellites. Land cover maps, derived from Landsat TM and MSS satellite imagery, could also be utilised as an additional environmental parameter. The final step in this research will be to validate the predicted distribution patterns by ground truthing. It is hoped that the ultimate result of this approach will be a better understanding of the environmental factors which underpin the distribution of malaria vectors as well as a deeper appreciation of the contribution of such factors to malaria epidemiology. This approach could also provide useful insights into likely distribution of malaria vectors in the future as a result of climate change induced by global warming.

Conclusions

The above examples indicate that there is a wide spectrum of possibilities over which GIS can contribute to malaria control programs. Its application as an operational planning aid is an extension of geographical reconnaissance to promote better program management at both the peripheral and national levels. Its use as an evaluation tool provides an additional means of spatially analysing outputs generated by health information systems in graphic visual formats which can be readily understood by field workers and program managers. However, the application of GIS in this way must be commensurate with the existing infrastructure within malarious countries where limits on human and financial resources may constrain the widespread use of advanced computer technology. For example, it may be appropriate to consider the use of sophisticated GIS software such as MapInfo at the national level for high level planning and epidemiological analysis. At the provincial level, data generated in Epi Info may be linked spatially to simple data sets in Epi Map to provide practical GIS outputs to support the local and regional malaria control efforts.

The use of GIS as a malaria research tool is a worthy objective of academic research institutions at national or international levels. The products of this research should lead to further insights into malaria epidemiology and the complexity of its transmission potential in endemic areas.

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