GIS for Health and the Environment

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Towards a Rural Information System

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Introduction

The findings presented in this paper are based on a project currently being carried out in South Africa entitled "Towards a Spatial Rural Health System." The information system being used for the project is termed the malaria information system (MIS), as it is based on the infrastructure provided by the Malaria Control Program. This paper will outline the control program and the use of global positioning systems (GPS) and geographical information systems (GIS) for malaria control, as well as the role of such information for the development of other programs for schools, clinics, electricity, water supply, and so on.

The malaria information system was established using the existing health infrastructure in a rural region of South Africa. This region has a high incidence of disease, a poor socioeconomic infrastructure, and one of the lowest per capita incomes in the country. It is also important to note that people do not live in villages, but in patriarchal homesteads usually separated by 50–500 m, depending on the terrain. This situation poses some unique issues related to malaria control.

Incidence of Malaria in South Africa

The annual malaria incidence for South Africa rarely exceeds 10,000 cases, with approximately 50% of cases occurring in KwaZulu/Natal Province. This relatively low incidence is directly attributable to the control program, which covers some 28,000 km² within the province. It is important to note the relative increase in cases over the past 10 years, which is largely attributable to factors such as agricultural development (Sharp 1990; Ngxongo 1994), vector drug resistance (Freese et al. 1988), population migration (cross border), and an alteration in malarial mosquito behaviour (Sharp and le Sueur 1990).

The historical perspective of the disease is also important, as it helps to contextualize the successes achieved by the program to date. In 1932, every magisterial district within KwaZulu/Natal Province reported cases of malaria;

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¹National Malaria Research Program, Medical Research Council. Sipho Ngxongo is with the Malaria Control Program, KwaZulu Health and Welfare.
estimated deaths over a 6-month period were in excess of 22,000 for a population at risk of 985,000 (le Sueur et al. 1993). The impact on the economy was enormous: construction of the Stanger Railway line ceased, and the sugar and tourist industries were crippled. Malaria is currently held at bay by extensive control efforts.

**KwaZulu Malaria Control Efforts**

Within the KwaZulu region, 52 malaria control areas have been established. For control purposes, the two northern districts of Ingwavuma and Ubombo have been subdivided into 27 malaria areas. Each of these is divided into 10 sections (Fig. 1). Within each section, every homestead is numbered by means of a malaria green card, which is stored in the eaves of one of the structures on the homestead.

The numbering system is updated every second year to account for population movement and growth. Several malaria control teams are stationed in the region, and are responsible for the annual application of a residual insecticide to the wall of every structure within one or more control areas. This insecticide application constitutes the major thrust against the mosquito vector.

In addition, the teams are responsible for carrying out active surveillance, whereby the population is routinely screened for infection. Infected cases are then treated and followed up to ensure parasite clearance. In this manner, the parasite reservoir is controlled, and transmission becomes limited.

This control infrastructure has been used to establish a computerised database which includes data on every homestead in the areas of malaria control (Table 1). The database is printed every second year and updated by control program staff during their annual spraying; changes recorded are subsequently made to the existing database. In the current update, information on Chief and Induna are being collected so that the database can be related to the tribal address system.

The database contains information on the head of the homestead, his "malaria home number", the type of structure, and the population living on the homestead. A set of GPS coordinates is subsequently added using a handheld GPS. Position is accurate to 50m, with a 95% confidence limit. A year was spent assessing the suitability of three different units in terms of accuracy, robustness, battery consumption, portability, and ease of use.
Fig. 1. Subdivision of malaria areas into sections. Each homestead within a section is numbered by a "malaria card" stored under the eaves.
Table 1. Homestead Database for Areas Under Malaria Control

<table>
<thead>
<tr>
<th>Data Field</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>Aaron Siyaya</td>
</tr>
<tr>
<td>Area</td>
<td>Mamfene</td>
</tr>
<tr>
<td>Section</td>
<td>8</td>
</tr>
<tr>
<td>Homestead Number</td>
<td>145</td>
</tr>
<tr>
<td>Population</td>
<td>12</td>
</tr>
<tr>
<td>Bed Bugs Present</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Insecticide Used</td>
<td>DDT/FICAM/CYFLUTHRIN</td>
</tr>
<tr>
<td>Longitude</td>
<td>28° 12' 43 2&quot; S</td>
</tr>
<tr>
<td>Latitude</td>
<td>30° 58' 39 7&quot; E</td>
</tr>
<tr>
<td>Wall Surface</td>
<td></td>
</tr>
<tr>
<td>Mud</td>
<td>3</td>
</tr>
<tr>
<td>Reed</td>
<td>1</td>
</tr>
<tr>
<td>Wood</td>
<td>0</td>
</tr>
<tr>
<td>Cement</td>
<td>0</td>
</tr>
<tr>
<td>Painted</td>
<td>1</td>
</tr>
</tbody>
</table>

During the collection of homestead position data, information on clinic and school attendance was also collected. Table 2 shows the database format in which every malaria case is recorded. It is important to note that the malaria area, section, and house number are common to both databases, and act as a relational link between the two. It thus becomes possible to plot all cases at an area and section level; in areas where GPS coordinates have been added, it is possible to plot cases at the homestead level.

Research Findings

The implications of the data produced thus far are important, at both the "micro" (individual homestead) and "macro" level (geographic area such as the malaria area or section).

As outlined earlier, current control efforts have to a degree been compromised by factors such as drug resistance, changes in vector behaviour, agricultural development, and so on. It therefore became necessary to investigate supplementary control efforts.
This was the central theory on which this project was conceptualised. Le Sueur and Sharp (1988) have demonstrated the occurrence of a seasonal contraction and expansion of the malaria vector population. In winter the vector population is localized, and the larval cycle of the mosquito population increases from approximately 8 days in summer to 44 days in winter. As a result, the production of adult mosquitoes is reduced and the population is concentrated in the larval stages. If the winter sites could be located, they could be targeted for supplementary control measures, thereby enhancing overall control efforts. This was the central theory on which this project was conceptualised.

In instances when malaria cases can be pinpointed to specific coordinates, and when these coordinates can be plotted on a topographical map, control measures can often be easily determined. For example, it was discovered in the Mamfene Area that a prevalence of cases was occurring recurrently at a specific
geographical location (Fig. 2). It was expected that a breeding focus probably existed at that location as well. Although little could be determined from first attempts to plot the findings at a 1:250,000 scale, when these coordinates were plotted on a 1:50,000 topographical map, they coincided with a water body in the area. Thus, it was determined that this location could be targeted for environmental management, to permanently alter or remove the breeding site. This action may or may not involve the provision of an alternative water source. The long term benefits would, however, be cost effective, when considered against the background of ongoing, long term control costs. Digitising of all the high risk areas at a scale of 1:50,000 is currently in progress. Should this level of detail be insufficient, then digitising of 1:10,000 ortho-photos will be carried out.

One example at the microlevel centres on the issue of agricultural development in malarious areas. Between 1976 and 1986, the Mamfene Area had an annual average of 12.6 cases of malaria. This increased to approximately 700 cases in 1987 as a result of excess water spillage due to agricultural irrigation. This spillage could have been avoided by proper planning in the development phase of the scheme, and highlights the need for intersectoral collaboration. The association between malaria cases and the scheme becomes evident when plotted onto a map: mosquito flight ranges and breeding sites were affected or created by the irrigation process, and almost all malaria cases which occurred in 1987 fall within the buffers of these new ranges/sites (Fig. 2). The cases which occurred along the canal were probably associated with breeding sites formed as a result of the interruption of natural water runoff during construction, as well as leakage from cracks in the canal.

At the macrolevel, a map indicating the annual incidence of malaria in Ingwavuma and Ubombo between 1980 and 1991 demonstrated that cases were not evenly distributed throughout the region, but were in fact highly concentrated (Fig. 3). It is likely that within these sections there will once again be a focus relating to the proximity of vector breeding sites. Such data can play an important role in the management of a malaria control program. These two northern districts generally contribute in excess of 75% of malaria cases occurring within the Province. Two important factors should be noted: the low incidence in the coastal region and the localization of high incidence to the Ndumu/Makanisdrift area.

In the coastal regions (Fig. 4), the incidence of malaria is extremely low (< 0.2% per year), with many of the malaria sections reporting only one or two cases per year. The data has as yet not been divided into active and passive case detection. The almost negligible number of cases suggests that no local transmission is occurring; the cases reported are probably infected migrants entering the region.
Fig. 2. Malaria cases associated with the Makhatini Irrigation Scheme.
Fig. 3. Annual malaria case incidence 1980–1991, Northern Natal malaria control regions.
Fig. 4. Areas with an annual case incidence of 0.2% or less, 1980–1991.
This argument is strengthened by extensive surveys that have been conducted in the region, in which almost no presence of vector mosquito species was found. The plotting of the actively detected cases will strengthen this argument. In 1938, the same area constituted the only region of continuous transmission in the country. This change can be largely attributed to the eradication of *Anopheles funestus* from the region and the fact that this vector's breeding sites are not utilised by the remaining vector, *Anopheles arabiensis*. Control measures do not currently exist in Mozambique, thus a need exists to continue with residual spraying to prevent the re-introduction of the former species into South Africa. Nevertheless, it can be concluded from the available data that the risk of future disease within this region is negligible. The malaria control management implications of this are discussed later.

The data does, however, have implications for tourists visiting the popular coastal region, with regard to the taking of prophylaxis. Due to chloroquine resistance within the region, tourists are required to take prophylaxis, which varies in cost between USD $25 and $45 per course. Residents in the area do not need to take prophylaxis. To facilitate dissemination of such information to the public, maps are published in the newspaper showing the transmission areas for the 4 weeks prior to publishing.

**Mapping of Research Findings**

Maps were created showing incidence data divided into two periods: 1980–1986 and 1987–1991. This division illustrates the recent increase in the number of cases within the area, which can be attributed to three factors:

- The advent of chloroquine resistance, first detected in 1985;
- Increased cross border population movement, which is highlighted by the extremely high number of cases occurring in the Mbangweni corridor between Ndumu Game Reserve and Thembe Elephant park, the main "corridor" for population movement to and from Mozambique; and,
- Agricultural development and the spillage of excess irrigation water into the veld (natural bush/grassland), which has altered the vector breeding patterns in the two southern areas. (These areas comprise the Makhatini Irrigation Scheme. There is also little doubt that the movement of infected, job seeking migrants to the scheme also plays an important role.)

**House Construction** Building materials used for house construction play a role in malaria transmission. The current insecticide of choice, DDT has a number of problems involved with its use, including high levels (30 x ADI) found
in the breast milk of primiparous mothers, social resistance due to the bedbug and
cell discolouration problems, environmental contamination, and malaria vector
avoidance.

Many of the alternatives such as pyrethroids, however, are bio-degradable
and thus not as stable as DDT. As a result, their lifespan (residual efficacy) is
often limited on certain surfaces; thus consideration of the material of which house
walls are constructed becomes important.

To be effective, these insecticides must have a residual effect for at least
5 months. In the laboratories of the project team, trials are currently being
conducted on alternative insecticides with three different substrates.

The large number of nonmud substrates in the northern regions is largely
a result of the sandy nature of the soil. Grass and reeds are therefore often used
in construction, and generally provide a residual lifespan in excess of 9 months.
This data can be used to target certain areas for cost effective, alternative
insecticide applications.

**Population Density** Maps showing population density are also of use.
Such data is currently being used to select a site in which bed nets (horizontal
vector control) can be compared to residual spraying (vertical vector control) in
terms of efficacy and cost-effectiveness. Similarly, this data can be used in
conjunction with clinic catchment data to look at the potential for restructuring the
parasite control component such that it can be carried out horizontally at the
clinic/community health worker level.

Such investigations are essential to ensure that the restructuring of control
efforts does not result in a loss of the enormous control gains made thus far, with
the population within the area being placed at increased risk. This is especially
important given the low levels of immunity in the population, in most areas, due
to in excess of 40 years of control and consequent low levels of exposure.

The implications of such data to other sectors is obvious. There are approx-
imately 100 malaria sectors in a district such as Ingwavuma. Data generated
through the malaria information system is far more accurate than any other
gathered to date, in relation to population distribution and density.

Maps on the population density/km², number of structures per sector, and
distribution of infrastructure (schools, clinics, shops, tribal authority, and so on)
are currently being prepared for the department of economic affairs for inclusion
in a proposal to the Electricity Supply Commission. In some areas, distributions
can be demonstrated at the individual homestead level.

This data would be extremely valuable for the provision of primary water
supply in an area. Such provision is currently complicated in the Province due to
the dispersed fashion in which the community lives. Thus, actual geographical
distribution is important for the placement of such facilities/infrastructure and determination of the catchments they serve.

**Other Uses for Maps** Maps may be used to show all houses in the Ndumu area to give a quick, accurate picture of school catchments. Children within this area attend 14 different schools; not all are within the Ndumu malaria area. The majority of these are primary schools, with only a single high school. A map may, for example (Fig. 5a), show the homes of all pupils attending Ndumu High and St. Philliph (primary school).

Distance calculations (straight line) would show that the average pupil in the Ndumu area, attending Ndumu High, travels 4.7km each way to school, every day. One pupil lived 20.1km from the school. It is assumed that the pupil would be boarding with friends. This data has to be considered in the light of the poor transport infrastructure within the region, as well as the extremely low per capita income to pay for such transport.

By overlaying the MIS population data with catchment areas of local hospitals, it was also possible to get a measure of the actual population that the hospital was serving as opposed to what it was officially supposed to serve (Fig. 5b). Such data, when combined with population distribution/density, is useful in planning projected resource needs and the distribution/requirement for satellite clinic facilities.

The number of imported cases of malaria per annum could also be presented in map form. It was discovered that between 1980 and 1991, the two main entry points into the country were Mbangweni corridor (between Ndumu and Tembe Game Reserves) and the Musi area.

It is interesting to note that the high level of imported cases in the Ndumu area coincides with this being the highest transmission area for the country. This highlights the importance of infected migrants acting as parasite carriers when entering the country.

The fact that no such correlation occurs in KwaNgwanase Area supports the earlier conclusion that vectors are largely absent from this region and thus transmission from migrants to locals does not occur.
Fig. 5a. Determination of school/clinic catchments.

Statistics of direct distance between School and Pupils home (Ndumu area of Malaria Control).
Number of Pupils = 85
Average Distance = 4.7km
Maximum Distance 20.1km

Fig. 5b. Catchment boundaries/population for Bethesda Hospital.

Official

Functional

sum(Population) 47031

sum(Population) 59735

National Malaria Research Programme, 1994
Implications of Research Findings

The foregoing data have numerous implications relating to the management of malaria in the country. Some of these are listed in the following.

Incidence of Malaria

The low incidence of malaria in coastal areas reflects very low transmission rates, and the high incidence in Ndumu, Makanis and other surrounding areas a high transmission rate. Malaria surveillance agents are currently deployed throughout malarious areas.

The project has shown that:

• More resources should be channelled to high risk areas, i.e., the need for redeployment of surveillance agents from low risk areas to high risk areas;
• Parasite surveillance staff members remaining in low risk areas will be required to do other primary health care functions; and,
• There is a need to continue with residual spraying in low risk areas.


The above period shows a significant difference with a large increase of malaria incidence during 1987–1991. The factors responsible for this are:

• The intensification of the civil war in Mozambique which resulted in high population cross-border flow;
• The number of Mozambicans registered as Kwazulu/Natal pensioners who return monthly to receive their pension payments, resulting in increased cross border movement;
• The increase in vector drug resistance;
• The ideal climatic conditions for vector breeding;
• The commercial agents from non-malarious areas trading in malaria areas;
• The agricultural and other developments projects which disrupt and/or transform vector breeding sites, resulting in increased transmission; and,
• The recent establishment of two entry points along the Kwazulu/Natal-Mozambique border.

Conclusion

The conclusions that can be drawn from this project are:

• Malaria is not static;
• Malaria is a regional problem needing regional cooperation and uniform control measures in the southern area of South Africa;
• The need for intersectoral collaboration is highlighted by the fact that the government is spending $60,000 per annum for vector control to contain the malaria problem in and around the irrigation scheme. This does not include the cost of house residual spraying and the cost of treating the increased number of cases or their detection. This could have been avoided by consultation between health and agriculture specialists in the planning stages of the development scheme;
• There is a need to establish a parasite screening facility at each entry point to the country;
• There is a need to continually monitor the malaria situation. To facilitate this, the GIS has been disseminated to control program staff. This allows for a weekly production of maps based on notified cases, and highlights high risk focal points, enabling additional control measures such as larviciding to be applied. These maps will be used by management to facilitate decision-making regarding control activities at the weekly staff meetings; and,
• The establishment of such a "health based information system" using existing infrastructures can facilitate inter-sectoral collaboration. The information system built on the malaria control program (using the existing infrastructure and thus only utilizing an annual budget of $3,000 to establish the database) has wide implications throughout the region, for such sectors as education, water provision, sanitation, electrification, establishment of Primary Health Care, and so on. We believe that widespread usage of the information aids to offset the cost of malaria control, facilitates targeted development, and ensures that the system is sustainable.

Acknowledgments

The entire control program staff are thanked for their contribution to making this project possible. The Health System Trust is acknowledged for its financial support of this project, without its assistance, the project would not have progressed as rapidly as it has over the past six months. The Medical Research Council is acknowledged for baseline funding over the past 3 years.
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