INTRODUCTION

The potential application of Geographic Information Systems (GIS), to Health in South Africa can be divided into a macro- and a micro- level. These levels can be applied to health issues such as the provision of health infrastructure, the mapping of disease, the investigation of the spatial dynamics of communicable, environmental and infectious disease transmission , and lastly to the modelling of health service utilisation and disease control intervention. The macro-level consists of the broad overview whereby the placement of facilities and the health status of the community is mapped out in relation to the underlying demography. The micro-level is illustrated by the investigation of facility placement and utilisation and the dynamics of disease transmission under localised conditions which take into account spatial cultural aspects such as population distribution (e.g. Village versus scattered homesteads) and migration.

The use and potential use of GIS in the above mentioned applications is however in its infancy. It has to a large extent been hampered (in health and other development areas) by the previously restricted ability of managers, researchers, planners and consultants to "position their data". Data here refers in the broad context to physical, epidemiological, demographic, cultural, behavioural etc. This restriction has to a great degree been removed with the "democratisation" of positioning which occurred with the advent of the Navstar Global Positioning System (GPS). As with many other development areas the rural regions represent those for which there is a paucity of spatial data and in which the use of GIS has been most limited.

In the rest of the report, we will;

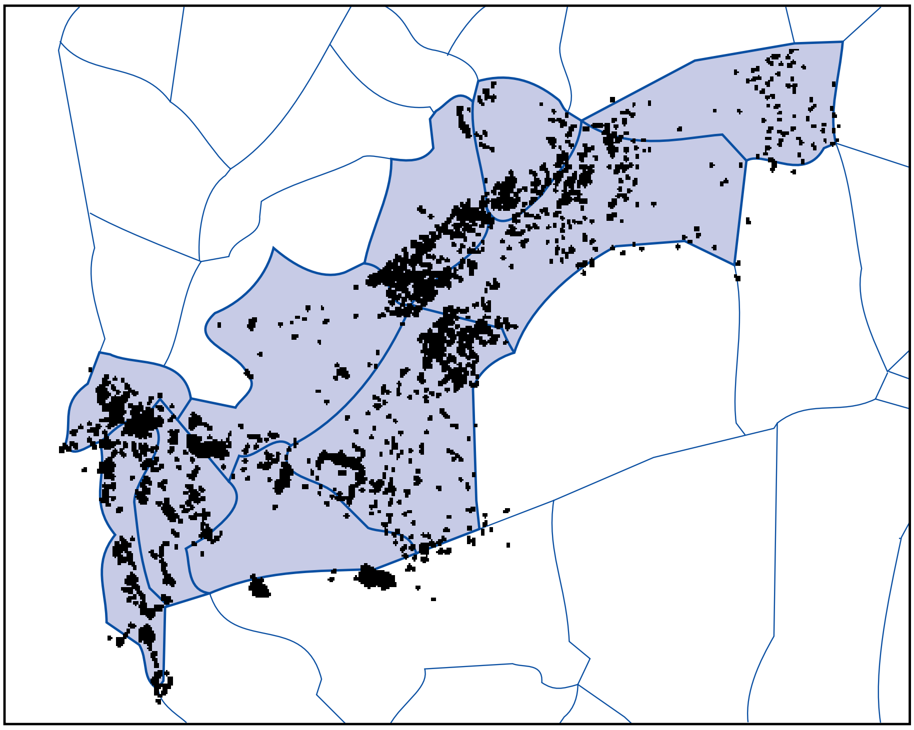
1. present a case study to demonstrate that GIS and GPS are practical, integrative and cost effective tools which can facilitate all aspects of rural development, including health.
2. motivate the use of existing "vehicles/infrastructure" to gather data essential for "informed" planning.
3. demonstrate that GIS is an integrative tool which fosters inter-sectoral collaboration.
4. illustrate a cost effective method of geo-referencing hand-drawn Community Health Worker maps for subsequent spatial query and update.

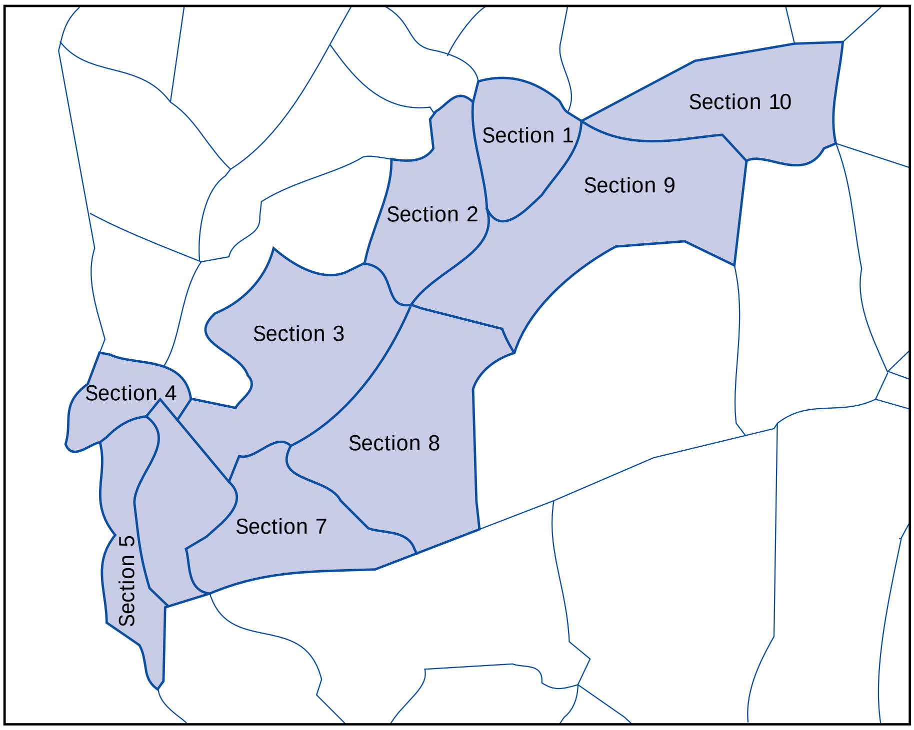
An appendix on the use of the Navstar Global Positioning System, explaining how it functions, sources of error, accuracy and how to overcome or avoid some of the limitations of using cheap hand-held units is included.

THE USE OF GIS IN HEALTH IN SOUTH AFRICA

The use of GIS in Health in South Africa is limited to a few studies. These can be categorised as epidemiological investigations (Abdool Karim et al.,(1992); le Sueur et al., 1995; Ngxongo, 1993, Stuttaford, 1994) and as an inventory/management tool (Krige, 1990; Zwarenstein et al., 1991). More recently the department of health has started the Regional Health Management Information System (ReHMIS) which is linked to MapInfo and aims to provides an inventory of health care infrastructure as well as the human and physical infrastructure associated with individual facilities.

Figure 1: Division of magisterial districts for malaria control into malaria sectors





National Malaria Research Programme, 1994

Owner	Area	Section	House No.	Facility	Longitude	Latitude
Mourice Nxumalo	Mamfene	2	256		32.1908	-27.4033
Dliwayo Gumede	Mamfene	2	257		32.192	-27.4039
George Makhanya	Mamfene	2	258		32.1927	-27.4034
Joseph Gwala	Mamfene	2	259		32.1916	-27.4033
Victor Mahlobo	Mamfene	2	260		32.1934	-27.4029
Ellias Nkosi	Mamfene	2	261		32.1924	-27.4018
Calalini Ntshangase	Mamfene	2	262		32.194	-27.4027
Mseshi Mabaaso	Mamfene	2	264		32.1944	-27.4037
Thembisa Store	Mamfene	2	264	Shop	32.1951	-27.4034
Mambas's Compound	Mamfene	2	265	Compound	32.1948	-27.4028
Fano Mkhabela	Mamfene	2	266		32.1945	-27.4024

Motivation For The Initiative

The motivation for initiating the project described in this report was based on the fact that malaria control activities are generally carried out in some of the more rural regions of the country. In these regions the activities of the control programme require that every family is visited at least twice per year thus providing a vehicle for data collection. The need for a malaria GIS came from the need to map malaria incidence and thus provide an insight into the relative distribution of the disease and to support the "focusing" of control efforts. The human and financial resources which are currently committed to malaria control are large and when viewed in terms of the current disease incidence, this may at first glance be an "over capitalization" of resources. It is however this effort and commitment of resources which is responsible for the low annual incidence. That this was not always the case is clearly illustrated by looking at the historical perspective of the disease (le Sueur et al., 1993). In 1932 the mortalities of Natal Province were estimated at in excess of 22 000 of a population at risk of 985 000. (Thus more than 2% of the population died of malaria in six months).

The question however arose as to whether the control programme could not serve as a data collection programme and vehicle for the establishment of a GIS which could be beneficial to all aspects of development.

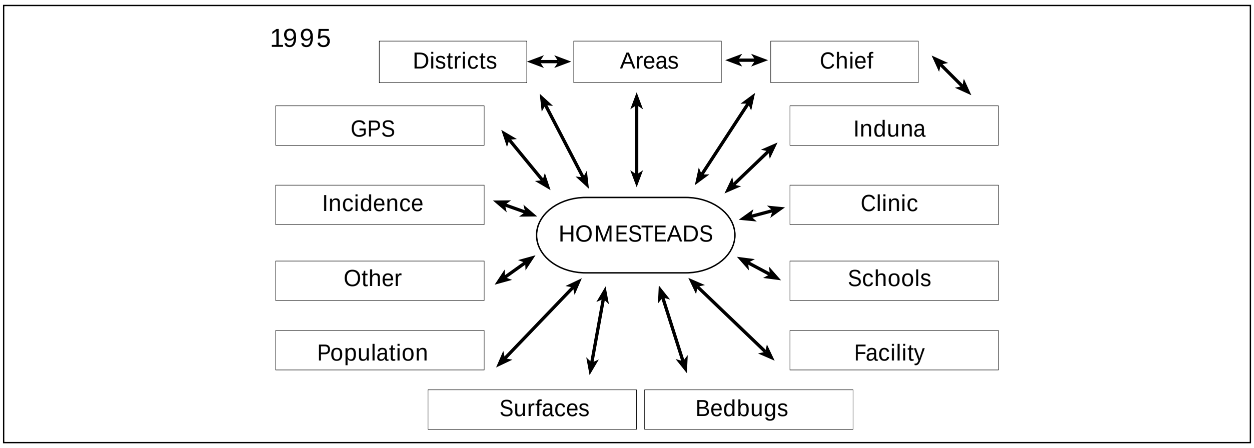
Malaria

Using Malaria Control to build a spatial rural information system

The area in which this initiative was piloted includes the two northern magisterial districts (Ingwavuma and Ubombo) of the Province of KwaZulu-Natal. The implementation of malaria control has led to each magisterial district being divided into approximately 20 malaria areas, which are again sub-divided into 10 sections (**Figure 1**). One team of 8-12 personnel is responsible for malaria control activities in two areas. Each house within a section is numbered by means of a malaria green card stored under the eaves of the roof. This card also records visits by surveillance personnel who take thick smears for parasite detection, as well as that of the personnel responsible for the annual application of residual insecticide.

Thus each house is visited annually and it was during these routine visits that a database was built for every house. The current status of information which has been collected to date is shown in **Figure 2**. 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. With each update, additional information is added.

Figure 2: Conceptual model showing current status of the database



In the current update, the entire database was printed and the sheets for each malaria control area were bound into a folder and given to the spray team leader for updating. Information on school and clinic attendance were also obtained. Collaboration was established with the Department of Agriculture and a total of 23 GPS units were deployed in the field. This enabled many of the teams to be equipped with a GPS to obtain the Longitude and Latitude for individual family units. It is important to note that people in the area do not live in villages but in patriarchal homesteads which are scattered.

The Macro-epidemiology of Malaria in South Africa

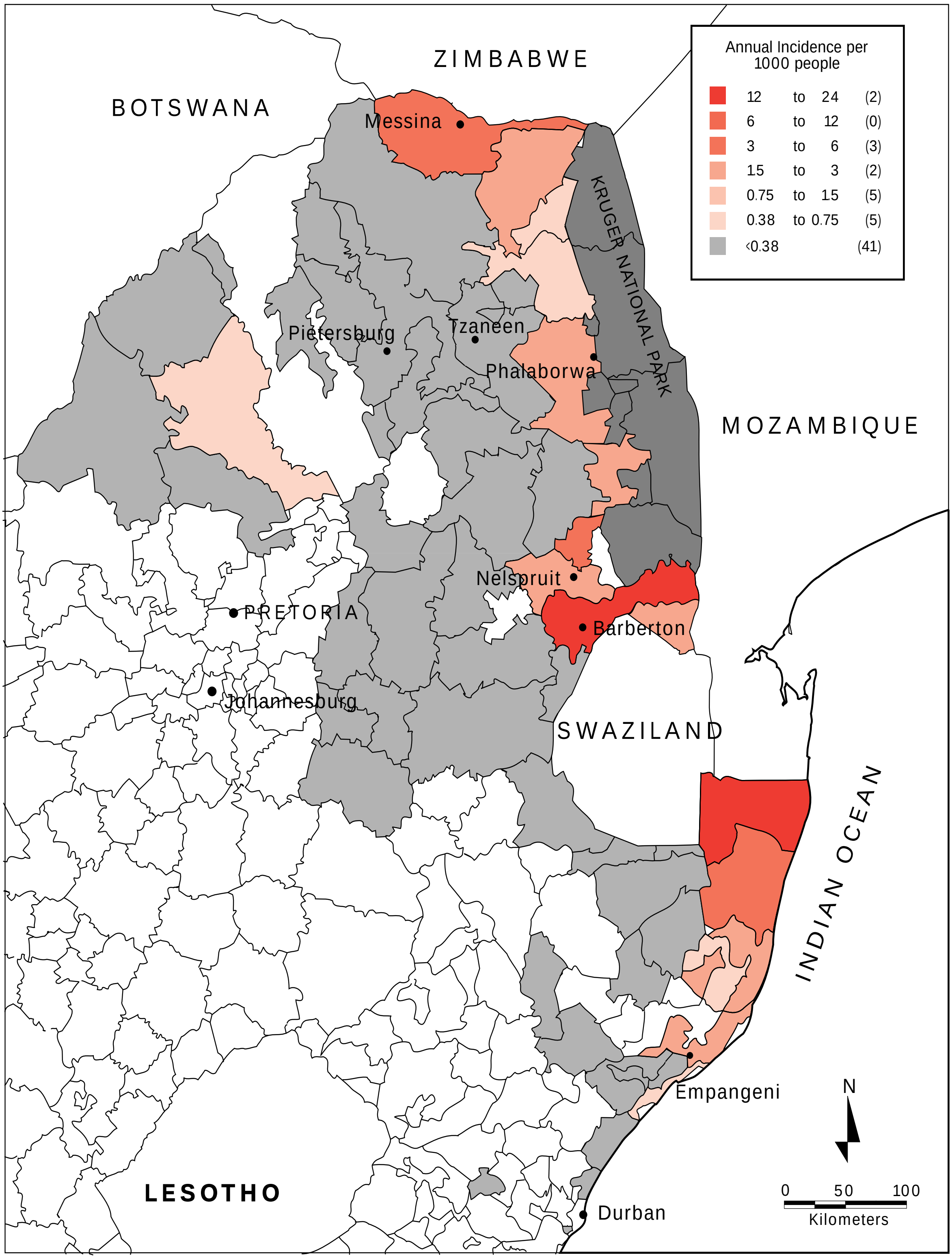
The aim of this section is to overview the distribution of malaria in South Africa. **Figure 3** shows the distribution of malaria in South Africa at magisterial district level between 1987 and 1993 (Sharp & le Sueur). The association between areas of high risk and corridors / proximity to Mozambique is clearly evident as well as the buffering effect of the Kruger National Park.

Currently data for Mpumalanga and Northern Province can only be geo-referenced at the district level, which results in the inclusion of low risk areas such as Nelspruit. The establishment of village based risk maps for Mpumalanga is currently underway as a joint Department of Health, Medical Research Council (MRC) and Human Science Research Council (HSRC) initiative, funded by the MRC. The value of more accurately georeferenced malaria data is clearly evidenced by data for KwaZulu. **Figure 4** shows two incidence (chloropleth) plots, one at magisterial district and one at malaria sector. This breakdown into the smaller sections of approximately 30 square kilometres is very useful for highlighting the focused nature of the high risk areas. There are two high risk areas in the region, one in the north west, close to the Mozambican border, and the other further south near the inland town of Jozini. The former is associated primarily with the influx of infected migrants from Mozambique as well as the Pongola floodplain. The latter is associated with the Makhatini irrigation scheme, which will be discussed in detail later. This matter of geographic scale and its relevance is summarised in **Figure 5**, where incidence is shown at provincial, district and then household level aggregated up to 2.5km^2. As mentioned above, at the upper end of aggregation (province / district), high risk areas may be "diluted out" and the maps are of limited value. Data at sector level (village probably similar) provides a useful level of geographical reporting. Reporting at 2.5km^2 may be useful in showing small area geographic association with environmental risk but has the negative of highlighting certain areas as high risk, which have inadequate denominators (population, 1 family within grid and 1 case constitutes a high incidence). This problem can be overcome either by setting lower limits of exclusion or by aggregating data for a number of years.

Incidence maps at the district level are thus useful in helping to focus overall efforts and resources (human and financial) to areas of most need and are particularly relevant as South Africa moves towards district based health systems. However such maps often result in the inclusion of low risk areas (high altitude, urbanised) within a district and are often confusing for the public and travellers in terms of prophylactic advice (e.g. Tourist coastal area of northern KwaZulu-Natal). Similarly as illustrated in **Figure 4** more finite data allows us to move away from a blanket approach towards control activities such as parasite surveillance and to focus our effort and resources on areas of most need and greatest return for effort invested.

With disease mapping (more so with tabular data) there is a tendency to focus on high risk areas and to ignore a more detailed study of low risk areas. Plotted data in **Figure 6** shows that from 1980-1991 the low annual case incidence of 0.2% or less is concentrated along the coast, with the figure increasing closer to the high risk areas in the north west. This is a marked change from 1938 (**Figure 7**) when this same coastal area between Lake St. Lucia and Kosi Bay was considered the highest risk in South Africa. This is due to the efforts of the malaria control programme which has resulted in the eradication of one of the mosquito vectors, *Anopheles funestus* by control measures. The breeding sites in this area are those favoured by *funestus* (which was recorded to have occurred in the region in 1931 and been sporozoite positive– i.e. infected with malaria). The remaining vector *Anopheles arabiensis* does not favour these

Figure 3: Average Malaria Case Incidence 1987 - 1993 at District Level



National Malaria Research Programme, 1995

sites and is therefore largely absent from the area. Extensive entomological surveys have been carried out in the entire region and were published in 1988 (le Sueur and Sharp, 1988).

Comparative plots of cases for the periods, 1980-1986 and 1987-1991 (**Figure 8**), shows a low incidence between 1980-1986, largely as a result of severe drought. The high incidence between 1987-1991 is a result of improved rains, irrigation development, the advent of chloroquine (drug) resistance and increased population migration from Mozambique due to the civil war.

Figure 4: Distribution of malaria cases in Ingwavuma and Ubombo

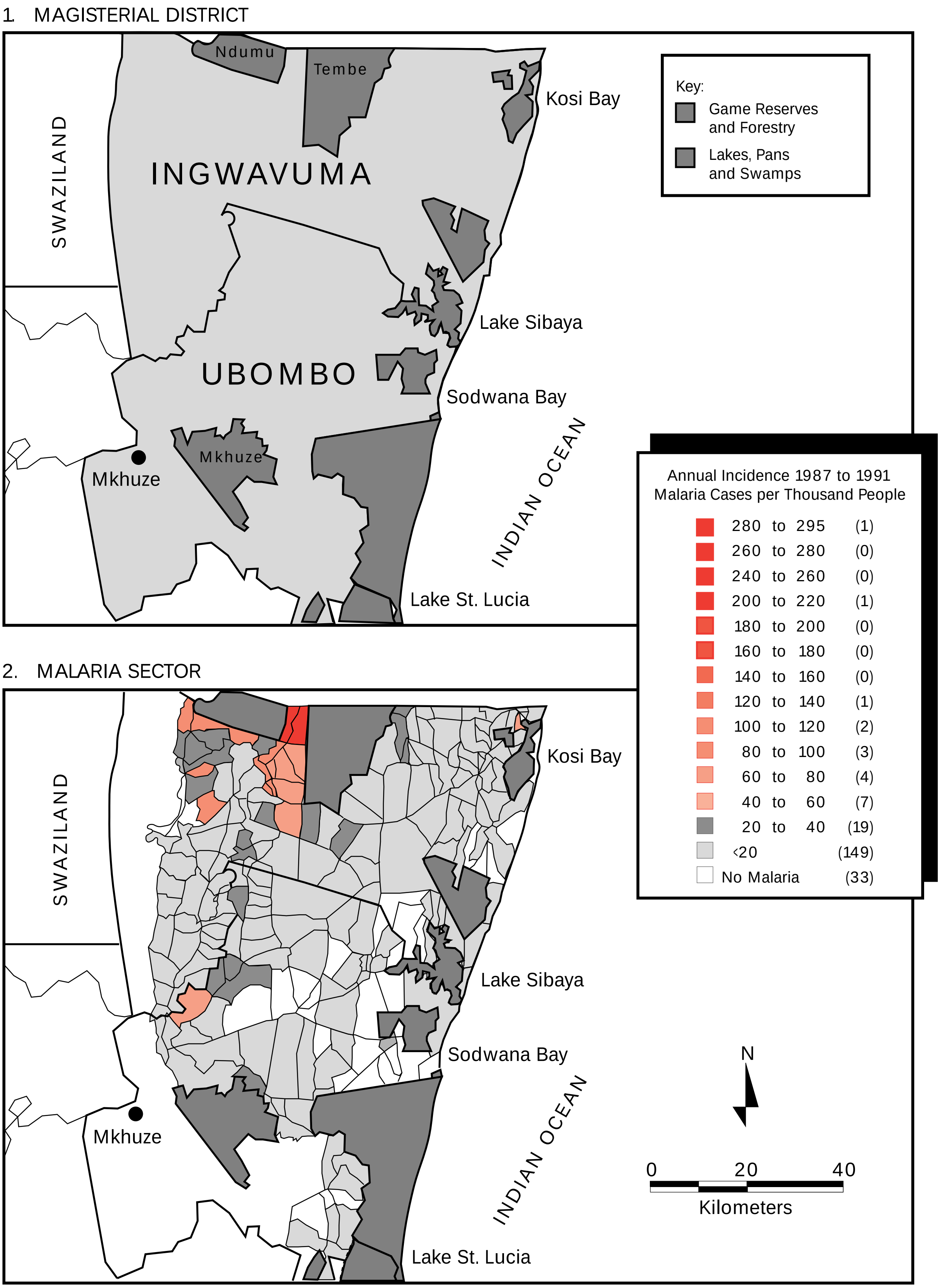


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Figure 5: Malaria case incidence at varying geographic scale in Ingwavuma and Ubombo, KwaZulu-Natal

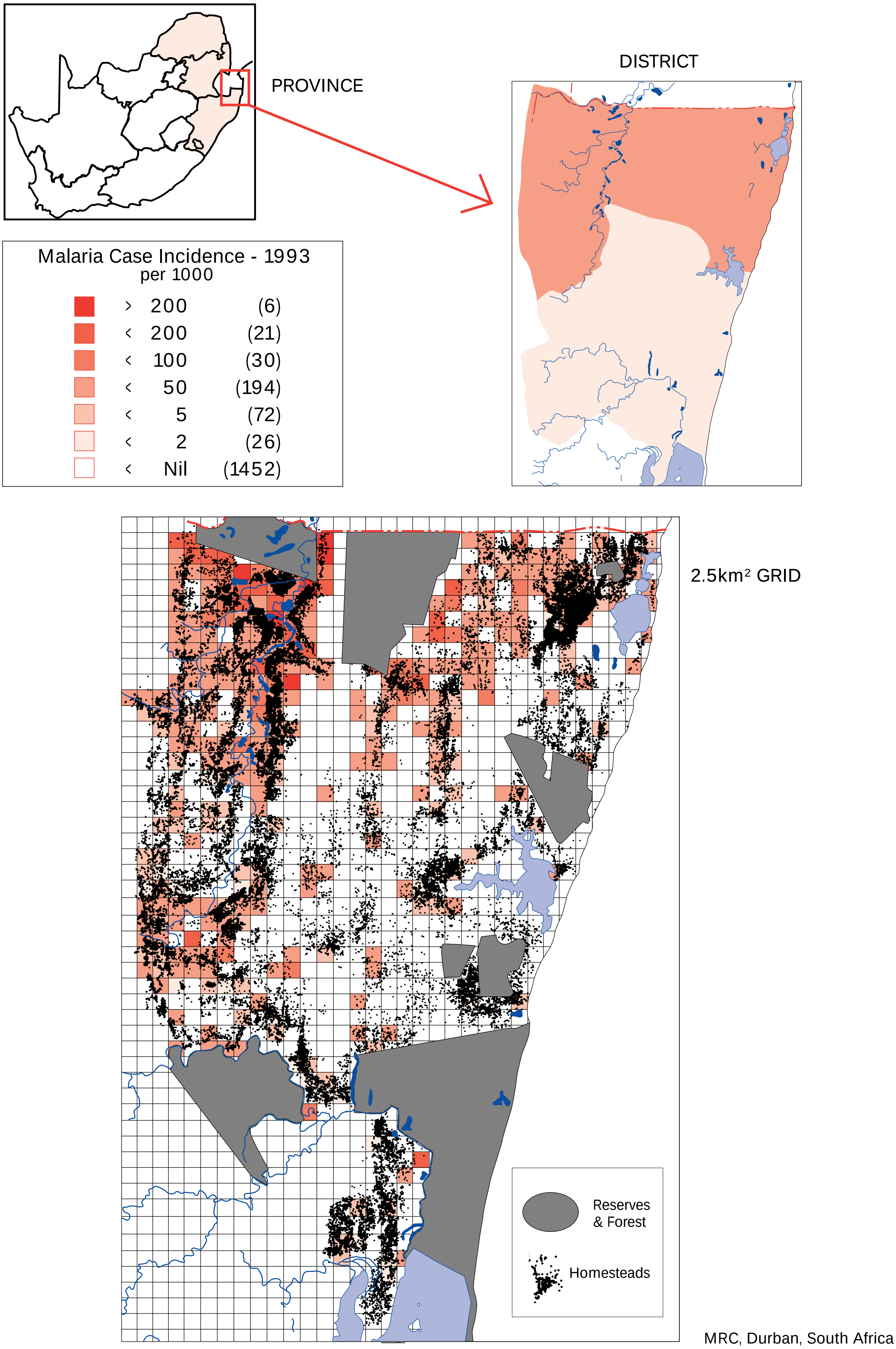

Figure 6: Low malaria incidence areas in Ingwavuma and Ubombo (per 1000 people)

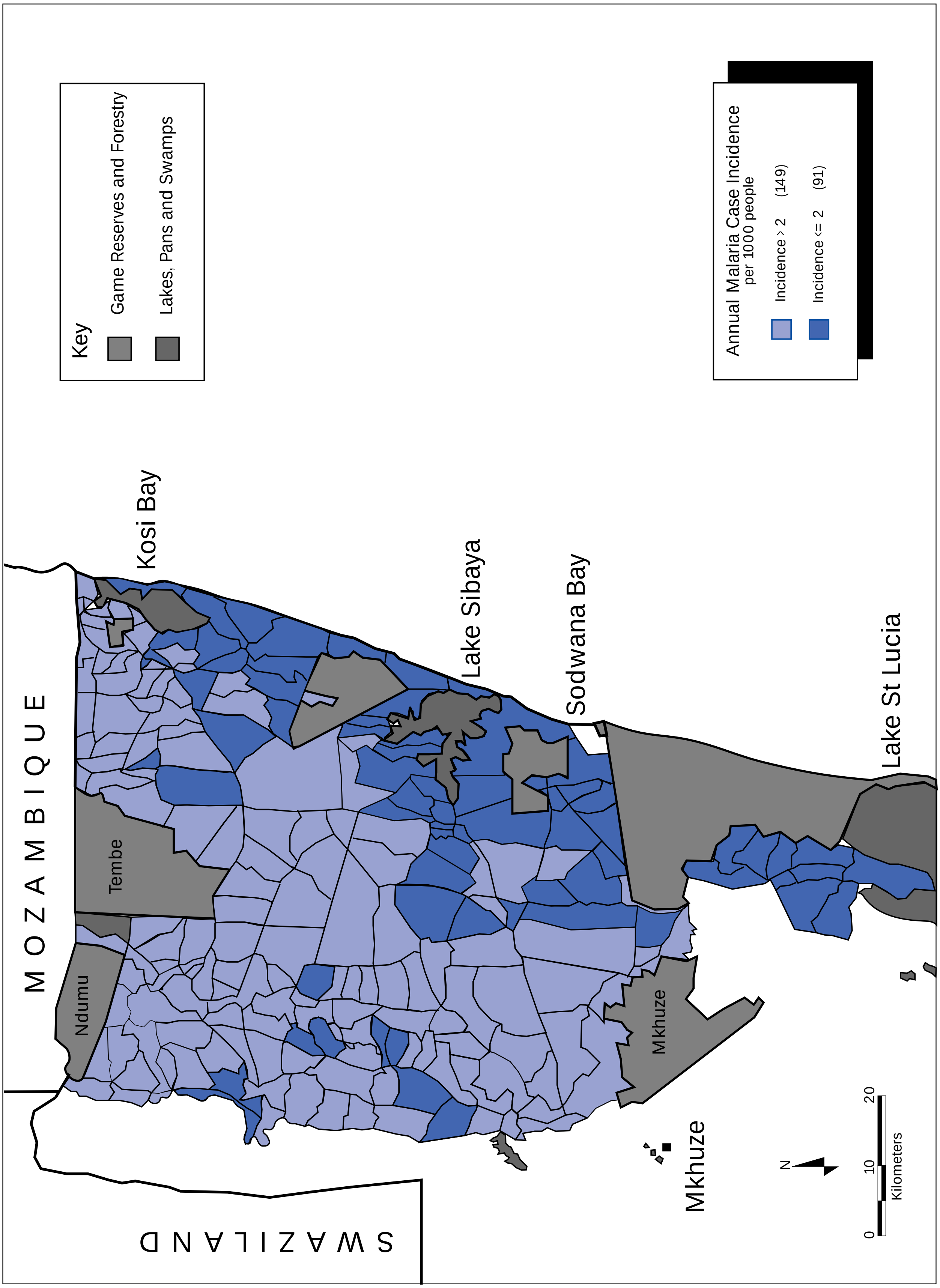

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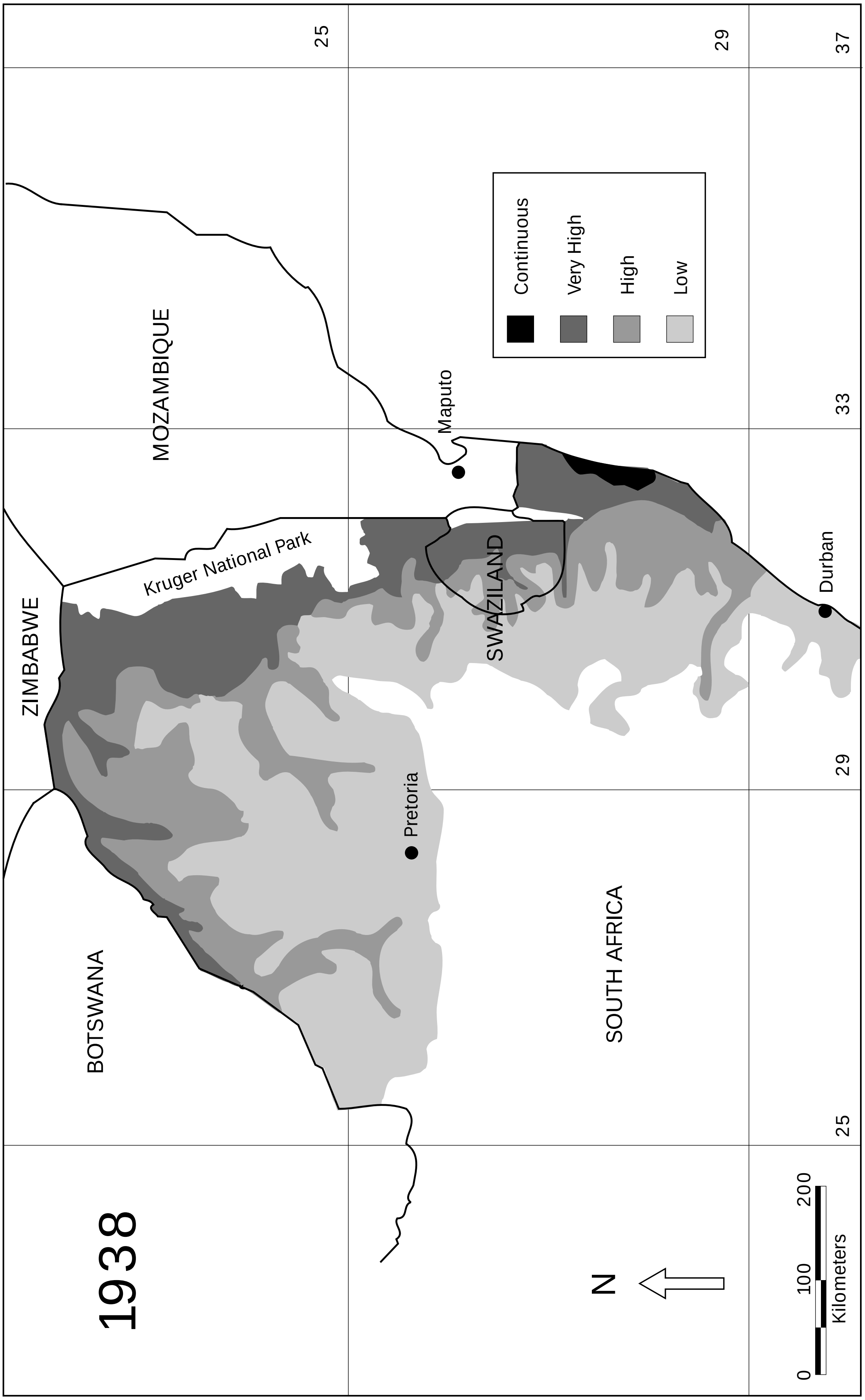
Figure 7: Malaria distribution in 1938



Records are kept of the country and region of origin of the infected people with many Mozambicans being tested and found to have the disease while in South Africa. Many of these asymptomatic migrants play an important role in starting focal and seasonal epidemics. No malaria control is currently carried out in rural Mozambique. Maps of the imported cases recorded from 1980-1991 show that they are focused in the western section of the region and coincide with the high incidence areas of the Province (KwaZulu-Natal) and the main entry points for travellers from Mozambique.

A study of this nature addresses three issues that are relevant not only to malaria but to diseases in general. They are: origin, incidence and geographic distribution, all of which need to be considered for the effective management of the disease.

The usefulness of this study can be determined in terms of the management implications. The maps that have been produced give a clear indication of the significance of the proximity of Mozambique which has no control programme and whose residents carry the disease into South Africa. Mozambicans account for 30-60% of all reported cases of malaria in South Africa, highlighting the need for regional cooperation as the disease is not a country specific problem.

The changes in incidence of the disease can be linked to various factors such as new irrigation schemes, chloroquine resistance and the movement of people from surrounding countries, some of whom come across to work. It is important to monitor these incidence changes in order to be able to react promptly to situations as they arise. New projects and schemes in the region need to take into consideration the possible impacts that they may have in promoting environmental conditions which could increase the incidence of malaria.

Changes can clearly be seen in the geographical distribution of the disease since 1938, as a result of effective control. In addition current long term distribution maps have important implications for deploying the malaria control staff (mainly parasite surveillance personnel) to meet the increased needs in the high risk areas and to be used in other primary health care functions in the low risk areas. The residual spraying of the whole area will have to be continued as *Anopheles funestus* could “re-invade” from Mozambique in the absence of vector control efforts.

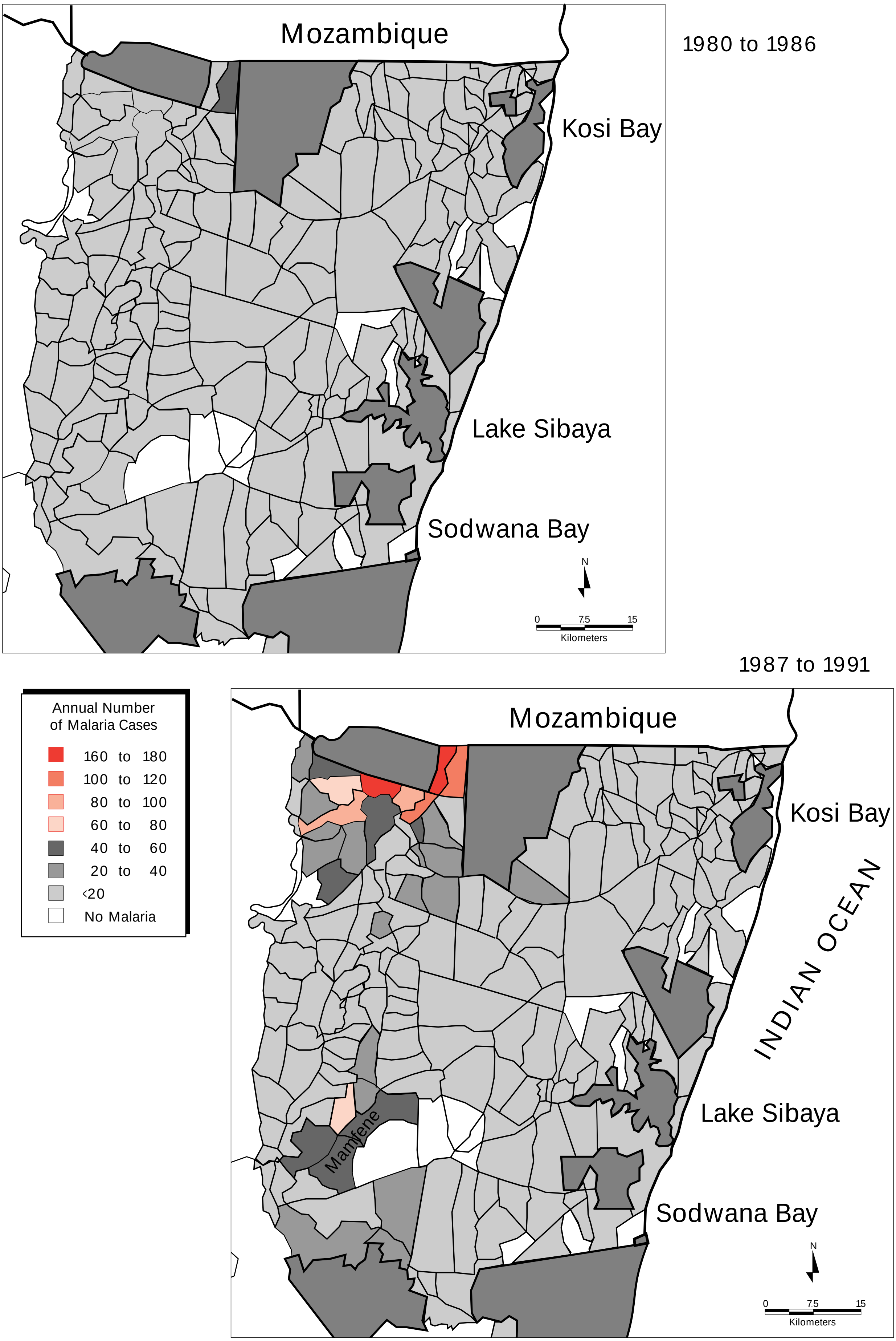
The Micro-epidemiology of malaria

This section will look at malaria cases at the point data level (down to individual family units). In the section above it was demonstrated that polygon based data can be a useful tool in the control of malaria and that the polygon size used to define malaria distribution is critical if they are to allow a “focusing” of control efforts. If the polygons (geographic units) are too large, then areas of intense transmission may be masked by the inclusion of large areas of lower risk and areas of negligible population may be listed as high risk. The finest data which one can achieve is that relating to individual family units. Considerable effort has to however be expended in the obtaining and maintenance of such a data set. Thus it is important that we carefully assess the implications and value of setting up such a “detailed GIS” system. It is our belief that although such a system could not necessarily be implemented on a large scale at present (countrywide), it plays an important role in using GIS as a research tool (as opposed to a management tool). Many of the findings from such research will be of value to managers and data will be presented to support this.

Three examples are given where GIS has been used in this study, at the micro-epidemiological level:

1. Malaria and agricultural development.
2. Malaria incidence and location of breeding sites.
3. The use of GIS and the micro-epidemiology to design an impregnated bednet study.

Figure 8: Recent trends in the distribution of malaria in Ingwavuma and Ubombo Districts 1980 - 1986



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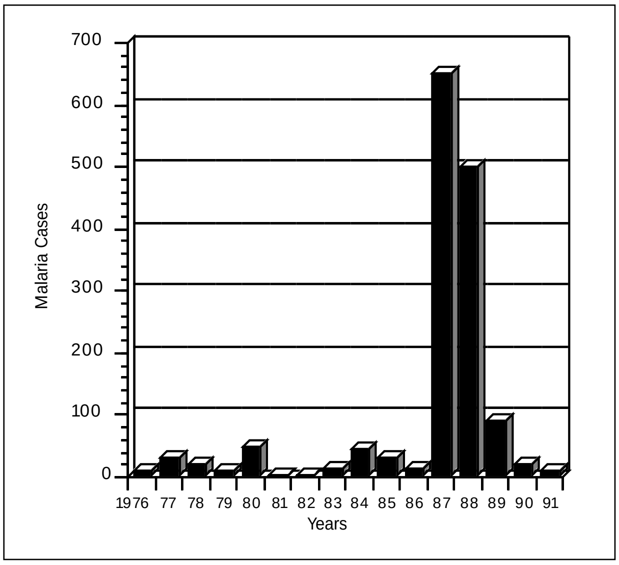
Mamfene is an agricultural irrigation development area (Area labelled in **Figure 8**, 1987 to 1991) within the northern control regions. This area had an annual incidence of 12.6 cases per annum between 1976 and 1986. Irrigation development then led to the occurrence of localised epidemics in the region with an annual incidence in excess of 600 cases from 1987 to 1989 (**Figure 9**).

Figure 9: Malaria cases at Mamfene 1976 - 1991



The two causes were:

1. The dumping of excess irrigation water.
2. The introduction of rice paddies into the region. The rice paddies themselves were not a direct contributor as their flooding period was largely in the non-malarious season. However overflow water from the rice paddies was dumped and resulted in the provision of winter breeding sites.

The location of every homestead in Mamfene, was obtained using GPS and the number of cases per homestead for 4 months (high incidence period, March to June) of 1993 was plotted (**Figure 10**). 2km buffers were generated around the exacerbating features, resultant from the irrigation scheme, to estimate vector mosquito range. From this it was evident that almost all the cases (excluding those at Point A. **Figure 10**) fall within these buffers, thus supporting the association between the scheme and malaria incidence. The question may be asked: "What about the surrounding area? Is this just not a matter of scale?"

A plot of the same area was thus made at polygon level (**Figure 8**, 1987-1991), so that areas surrounding the scheme, but outside of the 2 km buffers, could be viewed comparatively to those falling within the buffers. This clearly showed that the scheme was an "island" of high incidence, with risk of infection decreasing away from it.

The next example illustrates how the plotting of cases at the "micro-epidemiological" level can be used to identify environmental features which constitute an increase in transmission risk, for a given geographic area. Cases plotted on a monthly basis showed that cases were occurring recurrently at Point A (**Figure 11**), but with an interruption period of up to two months. The reason for the interruption is that the control programme had intervened with treatment, thus eliminating the parasite reservoir. When a new parasite carrier enters the area, a localised epidemic outbreak occurs. This suggests that certain environmental factors predispose the area to the continued presence of vector species. Initial digitising was done at 1:250 000 scale and no unusual geographical feature associated with the focus could be seen (**Figure 10**). Digitising was then carried out at 1:10 000 scale from orthophotos and the association between the cases and a number of perennial and non-perennial water bodies was clearly evident once the two were overlaid (Insert in June plot, **Figure 11**). Such sites can then be targeted for environmental management to remove or modify the hazard point such that it is no longer suitable for vector breeding. In this manner GIS and epidemiology can be used to target areas for more focused, long term, non-chemical methods of control.

The theory on which this project was conceptualised was that malaria is seasonal in southern Africa and that breeding is thus localised to permanent water bodies, in the winter months. The aim was thus to use the first malaria cases of the season to localise these winter sites and then target them for control. Winter control would be enhanced by the fact that the bulk of the vector population are present as larvae in winter, due to the long duration of the larval cycle (Egg to adult, Summer = 8 days, Winter = 44 days, le

Figure 10: Malaria cases associated with the Makhatini Irrigation Scheme

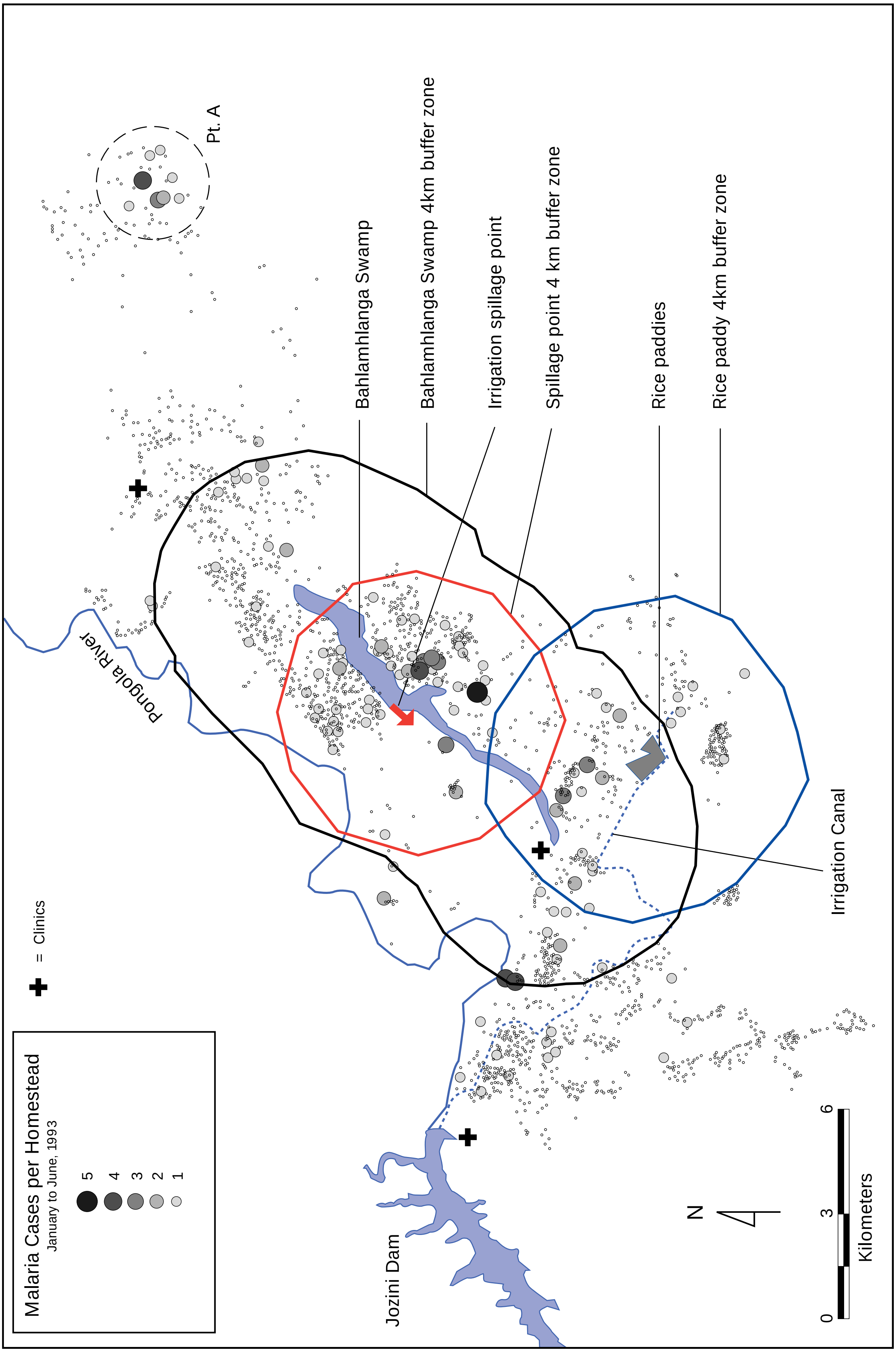


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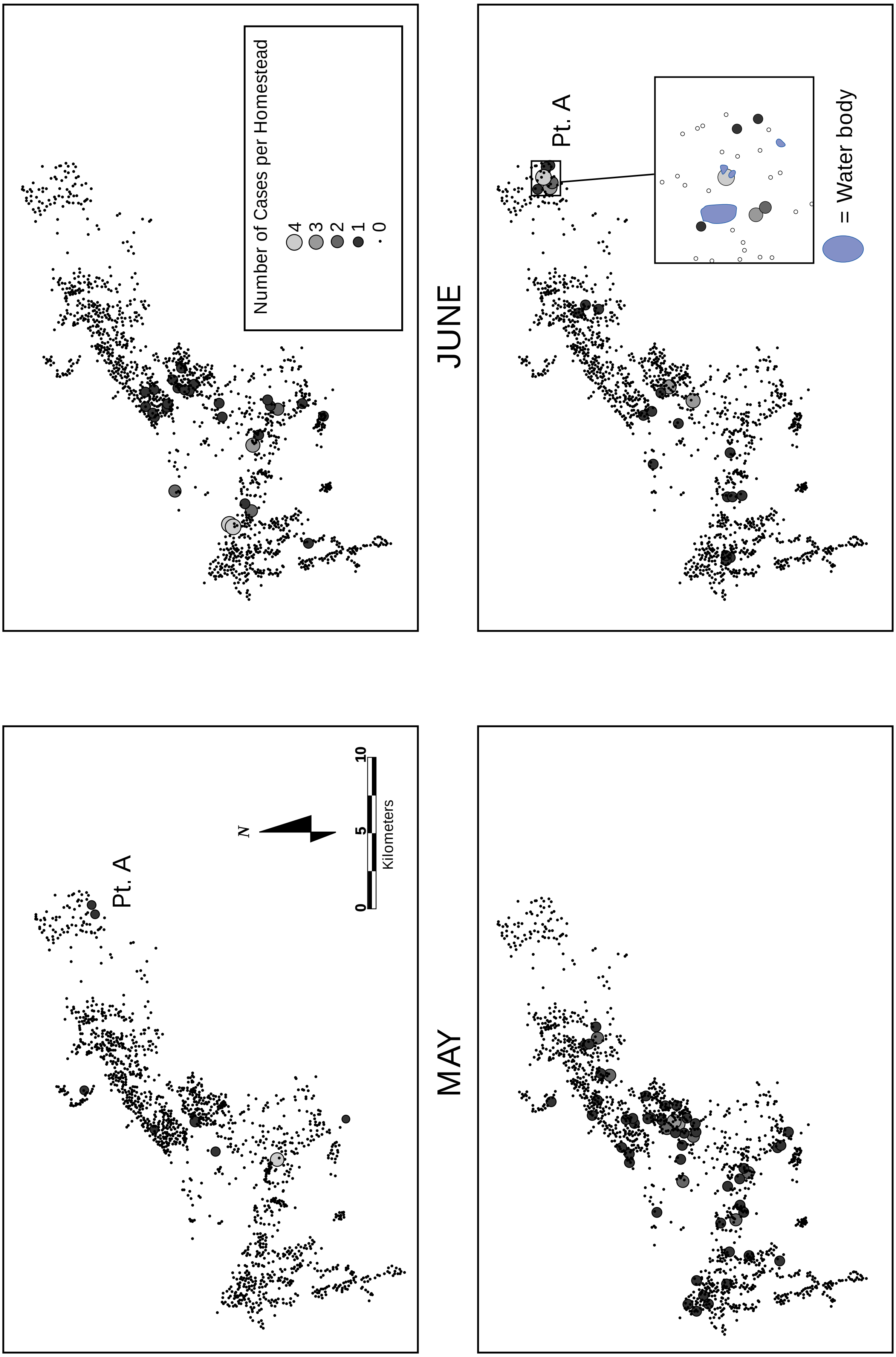
Figure 11: Plotting of cases at a micro-epidemiological (household) level



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Sueur, 1991). We believe that it is important that the initiation of any GIS project, should be "hypothesis-needs driven" if it is to succeed. A study is currently being conducted in collaboration with Cally Roper (London School of Hygiene and Tropical Medicine) which will use DNA micro-satellite technology and this spatial platform to investigate vector and parasite population localisation / gene flow.

The last example is the use of micro-epidemiology and GIS in designing a study. We used the GIS to design a study, which will compare the use of insecticide treated bednets to the application of residual insecticide to house walls, for malaria control. The latter is the current method of vector control. The importance of conducting such a study is that modern trends favour "horizontal" methods of disease control, which are viewed as being more cost effective and sustainable. The existing control programme is essentially vertical but has been extremely effective. A comparison with treated bednets would thus allow the validity of replacing existing vector control efforts with a more horizontal / community based method and is in line with the current national policy of moving towards a district based health system.

International funders to whom the proposal was submitted were not convinced that sufficient malaria occurred in the country to allow such a study to be conducted, with a statistically significant outcome. The existence of such a detailed GIS platform allowed the localisation of the study to the highest risk area for the province and for an approach to be developed which had a high degree of sensitivity. This is described below. All the cases occurring over a 7 year period (1987-1993) were allocated to the individual homesteads, from which they originated (point data) (**Figure 13**). An experimental block layer was then overlaid and the boundaries of the block were manipulated such that the annual incidence for the areas encompassed by each block was in the region of 5% (i.e. Such that the total number of cases for all the points {homesteads} within each block was 5% of population per annum). The data for each year was then split into the individual years and the experimental block layer was overlaid and the incidence occurring within each block was "extracted" (**Figure 12**). The incidence between blocks over time was then compared statistically (Breslow Day test for homogeneity). In this manner it was possible to pair blocks in which the long term epidemiological patterns of malaria incidence are the same (**Figure 12**).

Figure 12: Blocks paired in terms of similar transmission patterns over a 7 year period

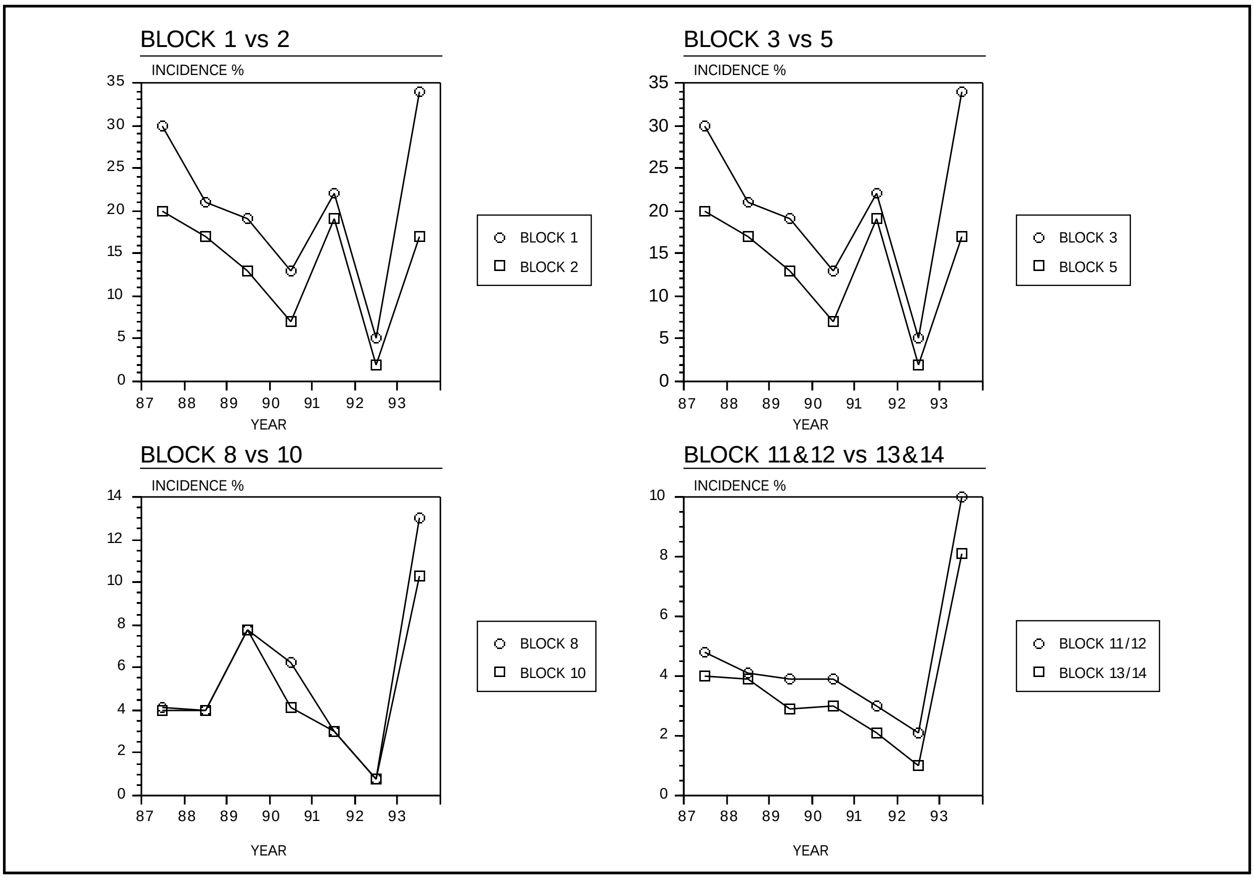
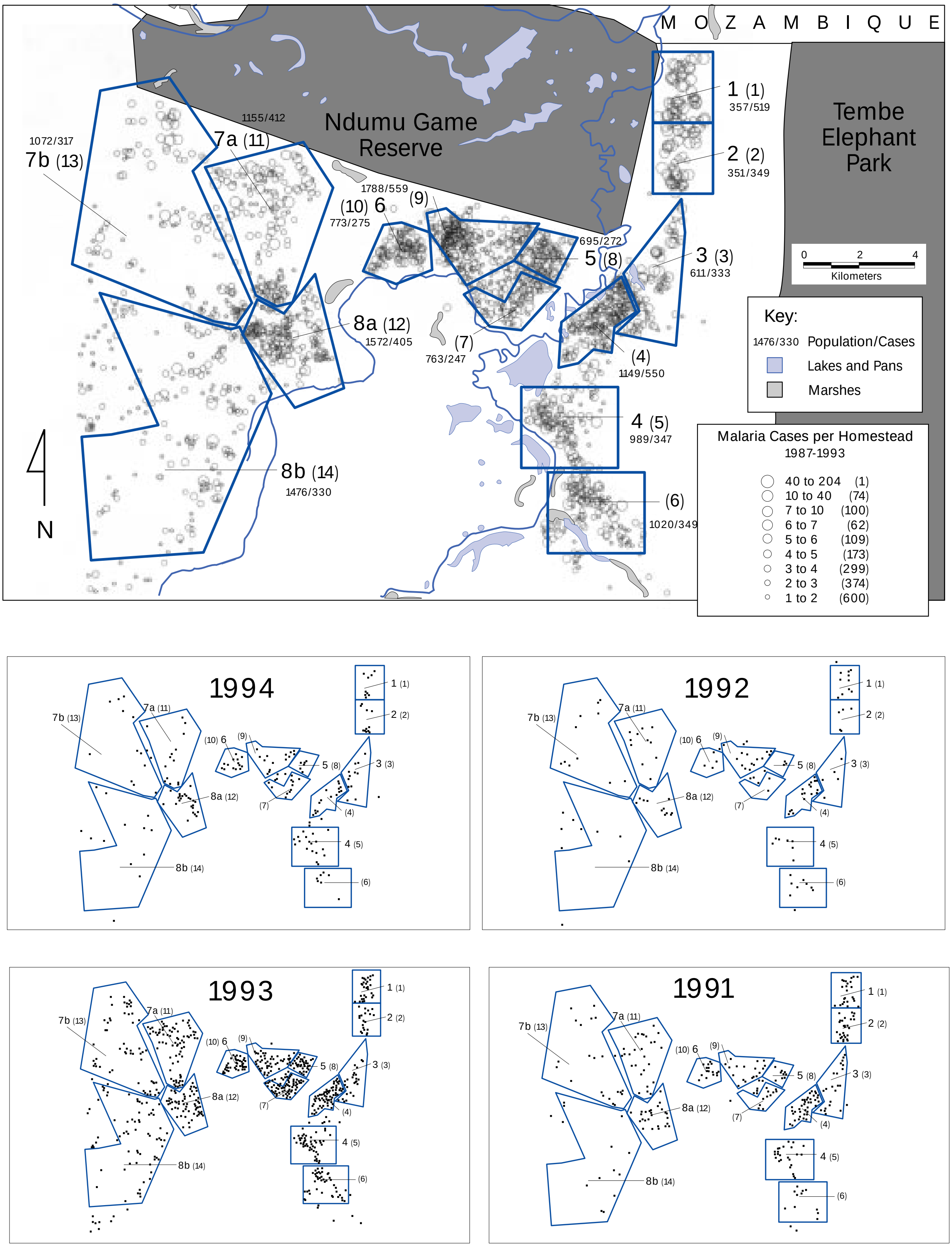


Figure 13: Use of GIS to design an intervention trial comparing bednets to the existing practice of spraying house walls with residual insecticide



This process allows for a 3% change in incidence between block pairs (one under bednets and the other under residual application of insecticide), to be significant at the 95% confidence level. Thus using the GIS it was possible to prove that such a study was feasible, with a high degree of sensitivity in terms of measuring efficacy, despite the low overall incidence at district/province level. This study would not have been possible in the absence of the Malaria Information System (MIS).

Facility Placement And Utilisation

One health and three non health examples (electrification, water and schools) are used to indicate the value of such a GIS effort for development in general.

Clinic Placement and Utilisation study

Data from the Malaria Information System (MIS) is used in this study. The MIS contains data on all facilities (shops, clinics, schools etc) in the Ingwavuma and Ubombo districts. In addition to the facilities every family unit (> 34 000) has been mapped using GPS (**Figure 14**). While carrying out the mapping exercise, data on actual clinic and school attendance was collected for every family. The MIS in its current status is thus able to plot exact catchments for every clinic and provides a unique opportunity to assess the current availability of facilities to the community, identify areas of need and develop a model of clinic placement which will foster utilisation in communities which live in a dispersed fashion (patriarchal homesteads as opposed to villages).

The study is divided into 2 phases. The main objectives are:

1. To assess the factors other than distance which affect clinic "choice" in an area of poor transport.
2. To investigate whether clinic attendance for varying services is differentially affected by distance.
3. To combine the outcome of the above into a basic model outlining what factors should be taken into account when placing new facilities in rural areas with poor transport infrastructure.

Phase 1: Clinic catchment and placement assessment

i. Define exact catchments for 11 clinics in the magisterial districts of Ingwavuma and Ubombo study areas based on actual attendance (as stated by household inhabitants).

ii. Define 'logical' catchments for clinics based on distance, assuming people will attend the nearest clinic.

iii. Overview the current placement/availability of clinics and assess "population load" on each (i.e. population within a 5 and 10 km radius of each clinic).

iv. Compare populations using two methods, to define;

   a. percentage of population utilising nearest clinic,
   b. percentage of population not using nearest clinic.

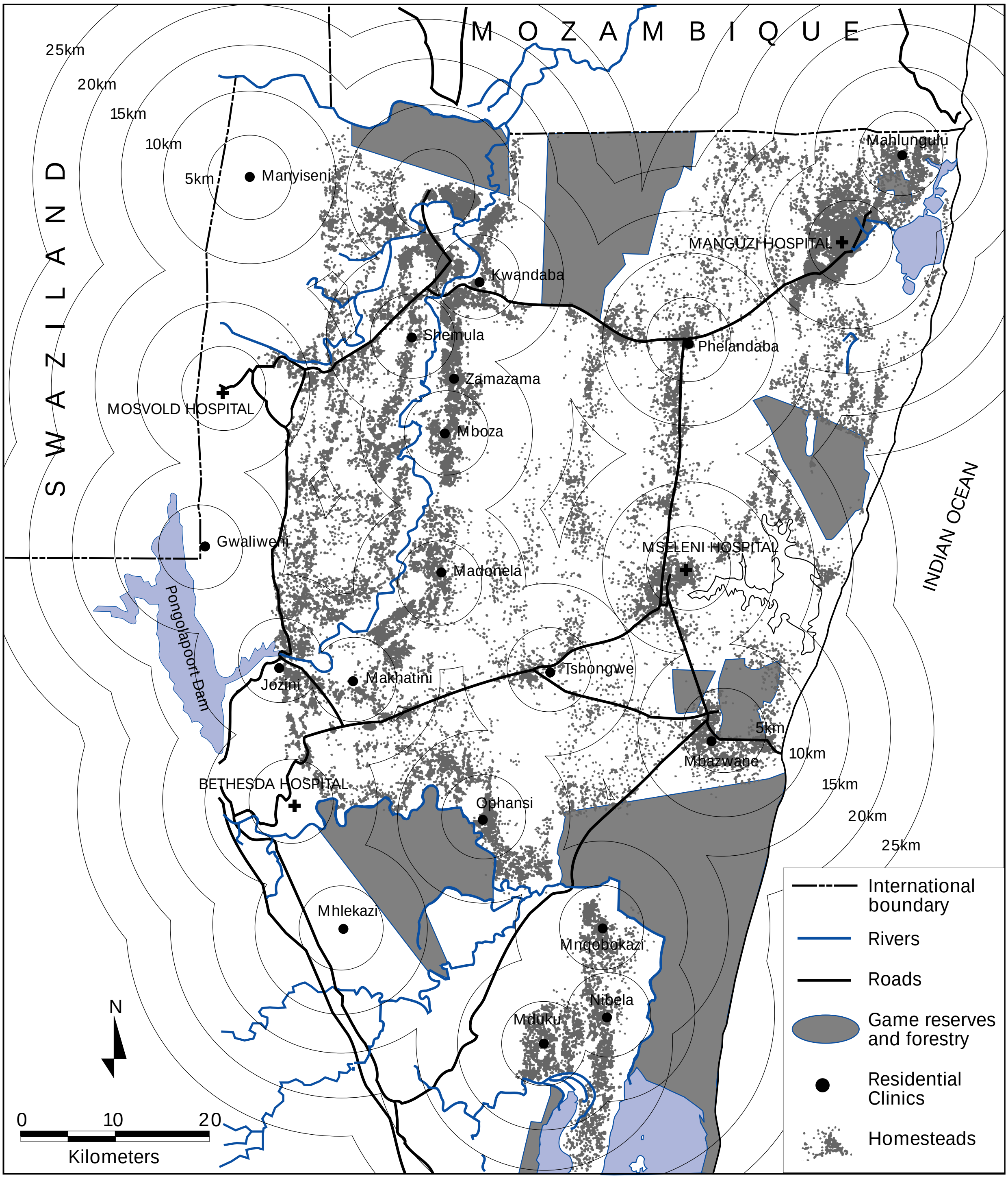
iv. Compare in a GIS actual catchments and those defined by nearest clinic allocation to highlight areas where people do not attend the nearest clinic.

v. Use the GIS to spatially randomise the population falling into these areas and then distribute questionnaires to a sub-sample to establish what factors are causing people to travel further than they need to. Phase 1 will enable an assessment of existing clinic infrastructure in the region, identify areas which are under served and highlight factors besides distance which might influence clinic attendance in a rural area where transport infrastructure is poor.

Phase 2: Service specific utilisation

The second part of the study focuses on clinic utilisation by household for specific services and the effect that distance can have on use. This will be carried out by randomly sub-sampling households at different distances from the clinic within the user-defined catchment area to assess the prevalence of

Figure 14: Hospitals and Residential Clinics in Ingwavuma and Ubombo KwaZulu-Natal, 1995



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Maternal and Child Health (MCH) problems and the utilisation of MCH services. The following health service and status issues will be used:

1. Road to health card coverage
2. Vaccination coverage rates
3. Number of attendances for growth monitoring
4. Utilisation of clinic for delivery
5. Use of family planning

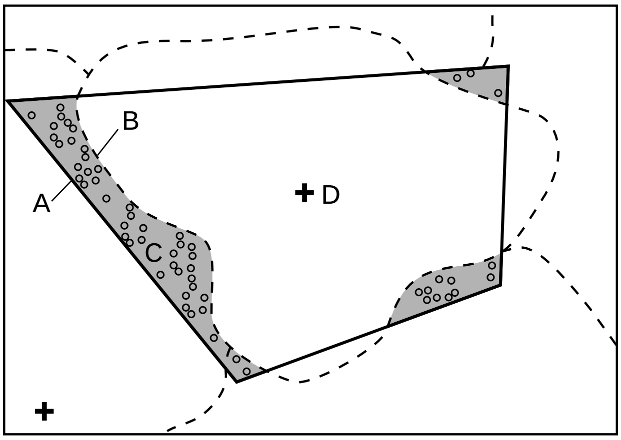
6. Antenatal Clinic attendance
7. Knowledge and practice of Oral Rehydration Therapy (ORT)
8. Anthropometric status

The data will be analysed according to the distance the population is from the clinic to allow a spatial component to be introduced into this part of the study.

These two phases will be combined to develop a provisional model of factors which should be taken into account in terms of the placement of clinic facilities to maximise utilisation and accessibility.

Explanation of GIS procedures

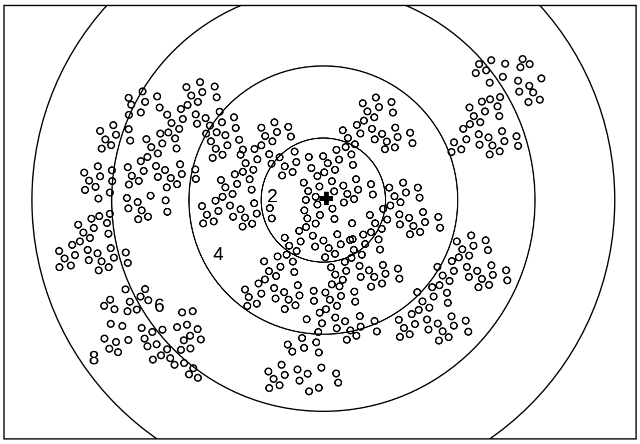
Figure 15



Phase 1

Figure 15 graphically illustrates how phase 1 is being carried out using the GIS. The polygon defined using the solid line (A) represents the catchment if everyone went to clinic D. The dotted line (B) indicates the actual catchment based on attendance data currently available for every family (› 34 000) within the magisterial districts of Ingwavuma and Ubombo. The shaded areas (C) represent areas where people are not attending the nearest clinic. The households falling in such areas (illustrated by points), will be randomised and household specific questionnaires printed from the database, for a sub-sample of the families falling in these areas. The questionnaires will assess what factors are affecting this bias in attendance, whereby people do not attend the nearest clinic.

Figure 16



Phase 2

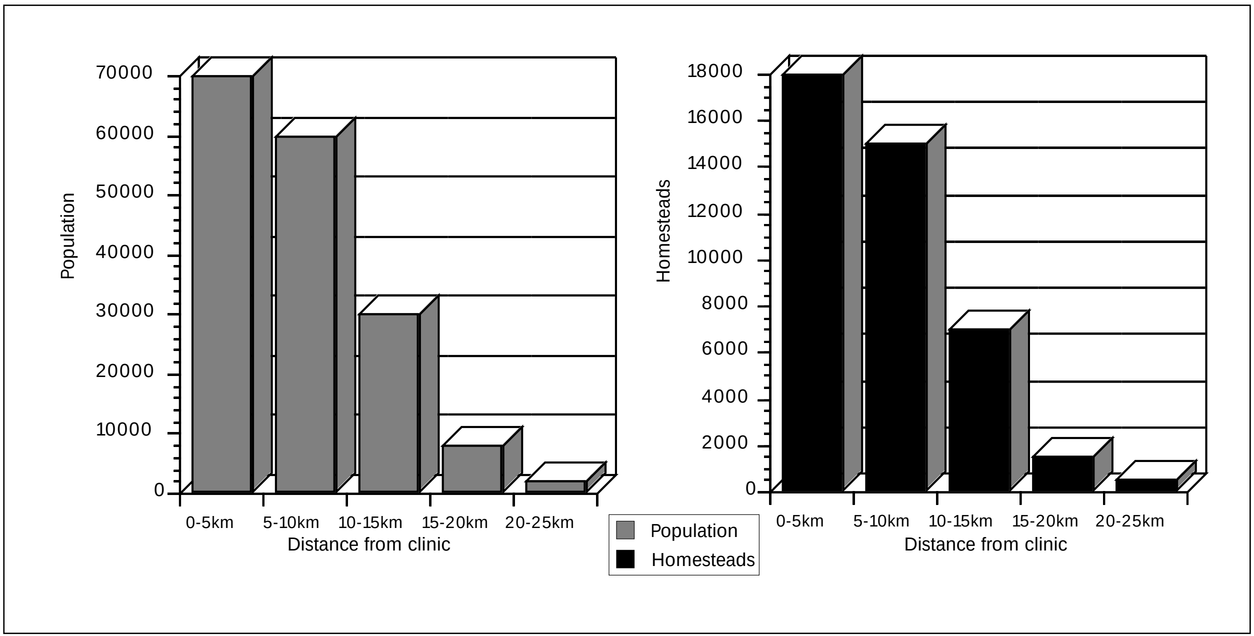
In phase 2, buffers will be thrown at 1km intervals and the houses falling in each of these regions "extracted" from the database (**Figure 16**). The houses in each sub-sample will be randomised and a portion will be selected for administration of the questionnaires relating to clinic services utilised. This will be repeated in successive buffers (i.e. 0-1km. 1-2km 2-3km, etc). In this manner the impact of distance / accessibility on service specific utilisation will be assessed and an optimum maximum distance per service determined.

Figure 17 shows a provisional analysis of population distribution in relation to clinic and hospitals in the region. Buffers have been thrown around each facility at 5km intervals and the population and homesteads falling into each buffer is shown in **Figure 17** below. Of the total population of 217 655, 22.6% are more than 10km from a clinic. The distance values are however line of sight and thus will underestimate actual distance by 15 -18%. Distances for all 34 000 odd homesteads will be calculated using the distance module shown in the tap example below. The areas most in need of a fixed health facility (i.e. permanent clinic vs mobile) are easily identified in **Figure 17**.

Electrification and Telecommunications

The database shown in **Figure 17** is being used by Electricity Supply Commission (ESCOM), to plan electrification in the region. The value of the data in ergonomically positioning power lines is obvious from **Figure 17**. It is essential that power lines are positioned correctly in relation to the population, otherwise substantial line charges are incurred by the user and the resulting costs exceed the financial resources of potential users.

Figure 17: Population and Homesteads In Clinic Buffers



Similarly the database is being used by TELKOM to plan its telecommunication activities within the region

Water supply

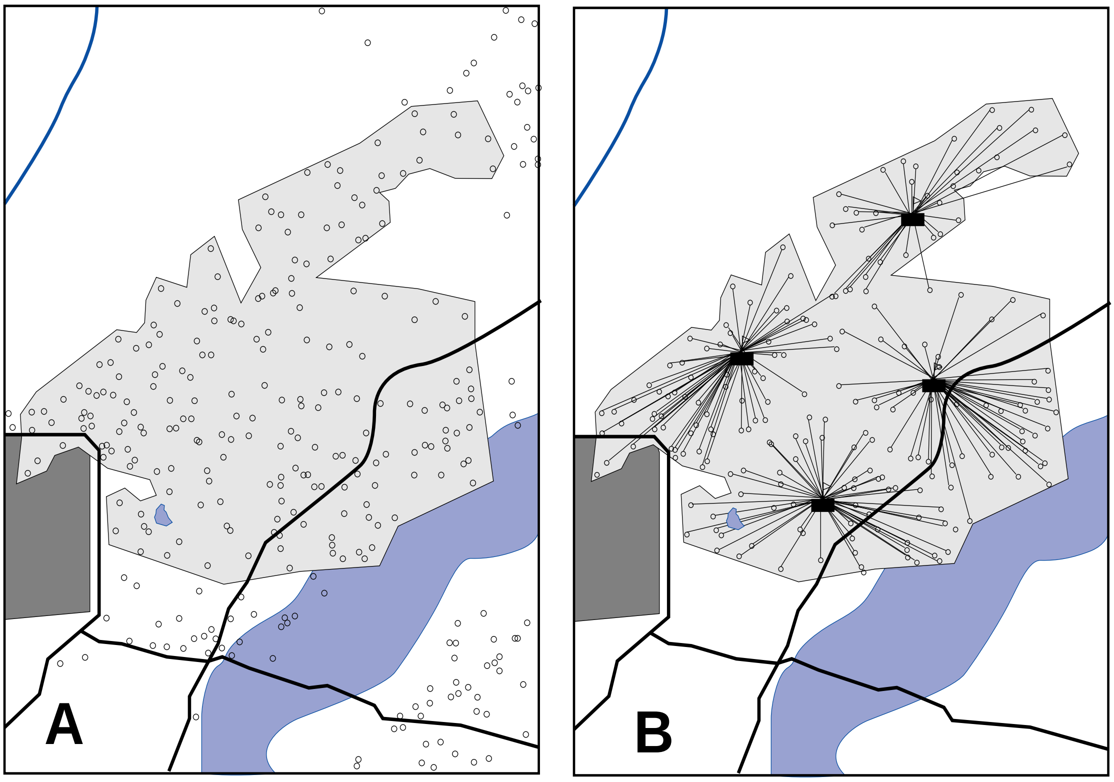
In **Figure 18** a planned study on using the Malaria Information System (MIS) to position water supply is illustrated. The example illustrates a process whereby the community selects tap locations and place a pile of white stones at the location. The position of the tap is then obtained using GPS and overlaid on the distribution of households. Distance to be travelled by individual families is calculated and a map with homesteads labelled with the owner's name is produced to facilitate community discussion of the selected sites. The community sites are then compared with sites selected by the GIS, using the optimise location module (GPS is then used to position a pile of red stones at this site). This process will facilitate community involvement and give an insight into the factors affecting community site selection.

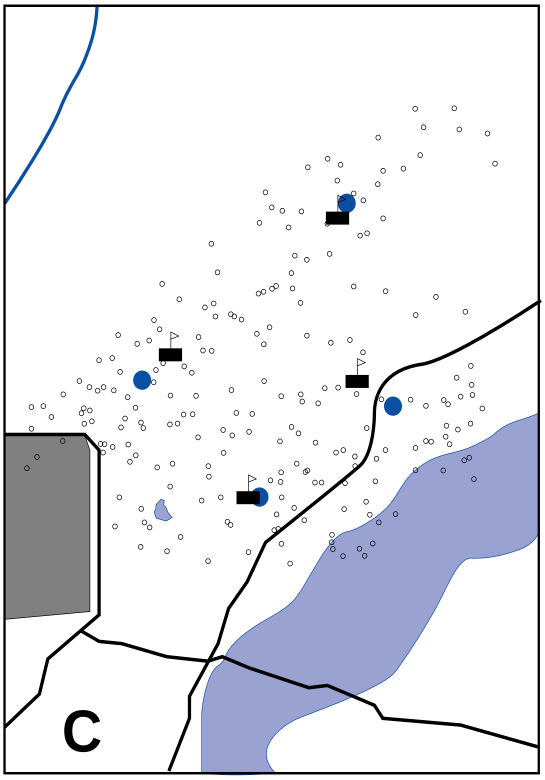
To date data has been supplied to seven engineering consultants involved with various water schemes in the region (e.g. Shemula, Josini, Tshongwe, Malobeni etc), upgrading of roads and construction of a shopping centre.

Education

During the course of the 1994/1995 update, every family was asked how many children they had at school and what school they attended. In addition the location of all 230 schools was determined (**Figure 19**, Appendix 1). Thus the exact catchment for each school can be determined at a household level.

Figure 18: Plotting the position of community water taps





Owner	DISTANCE
ELLIAS NHLENYAMA	864.000
PHILIP GUMBI	558.000
ZACCHARIA SIKHOSANA	414.000
NYATHELA ZUNGU	324.000
SHISIZWE GUMBI	198.000
MPIYEZWE DLAMINI	306.000
ZITHINZANA MATHE	252.000
PHILA NHLENYAMA	216.000
ELLIAS NHLENYAMA	54.000

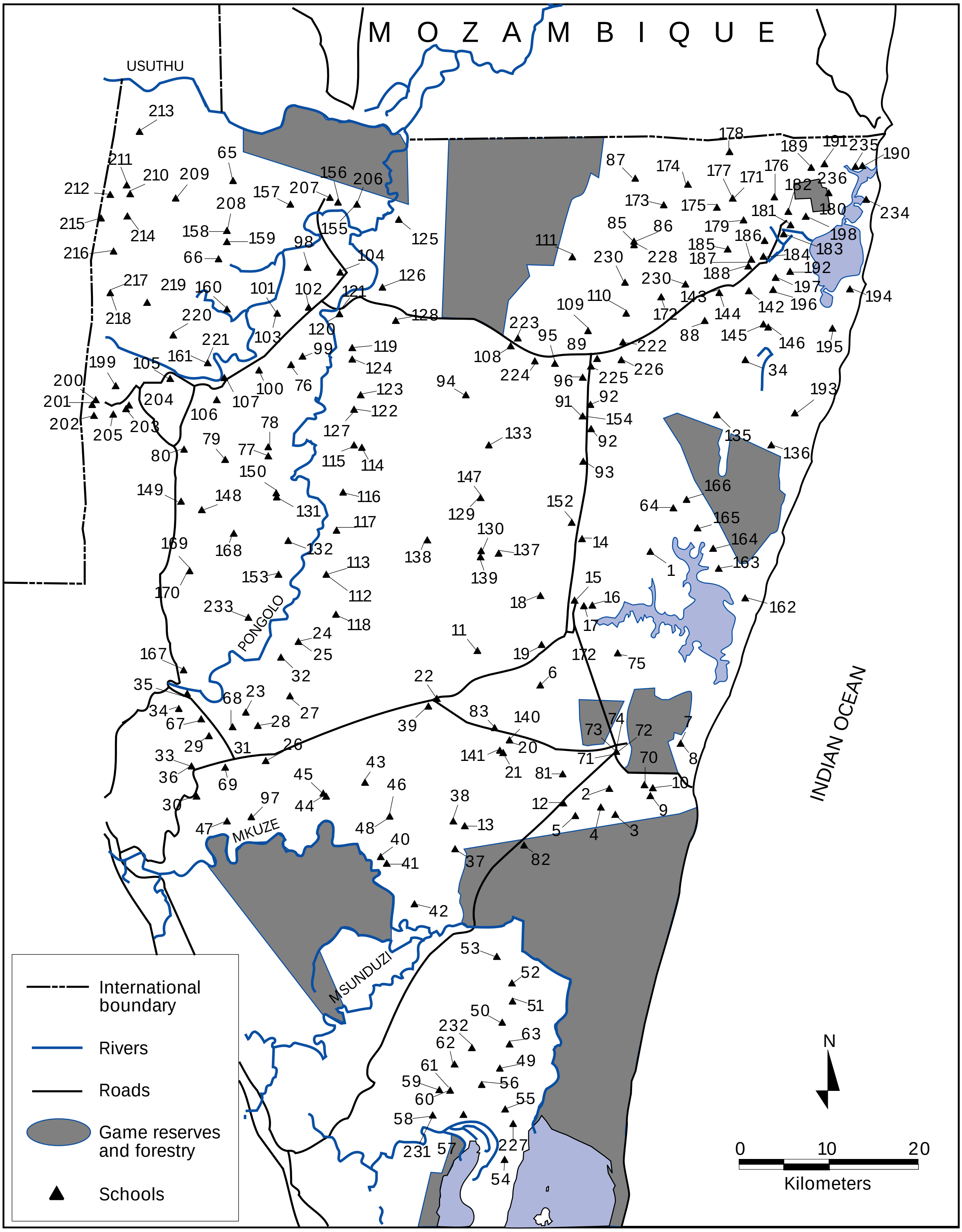
In **A**, the community targeted for supplementary water services is identified.

In **B** the community selected sites for the placement of taps are shown and the distance between each household and the supplementary water supply is shown in metres (sample data for each household shown in the adjacent tables).

In **C** a comparison of the community selected sites and the optimal positions (dots) calculated by the GIS, to ensure maximum access are shown.

This example is based on data sets from the Makhatini irrigation scheme, Mamfene area in Ingwavuma district, KwaZulu Natal.

Figure 19: Schools in Ingwavuma and Ubombo, KwaZulu-Natal

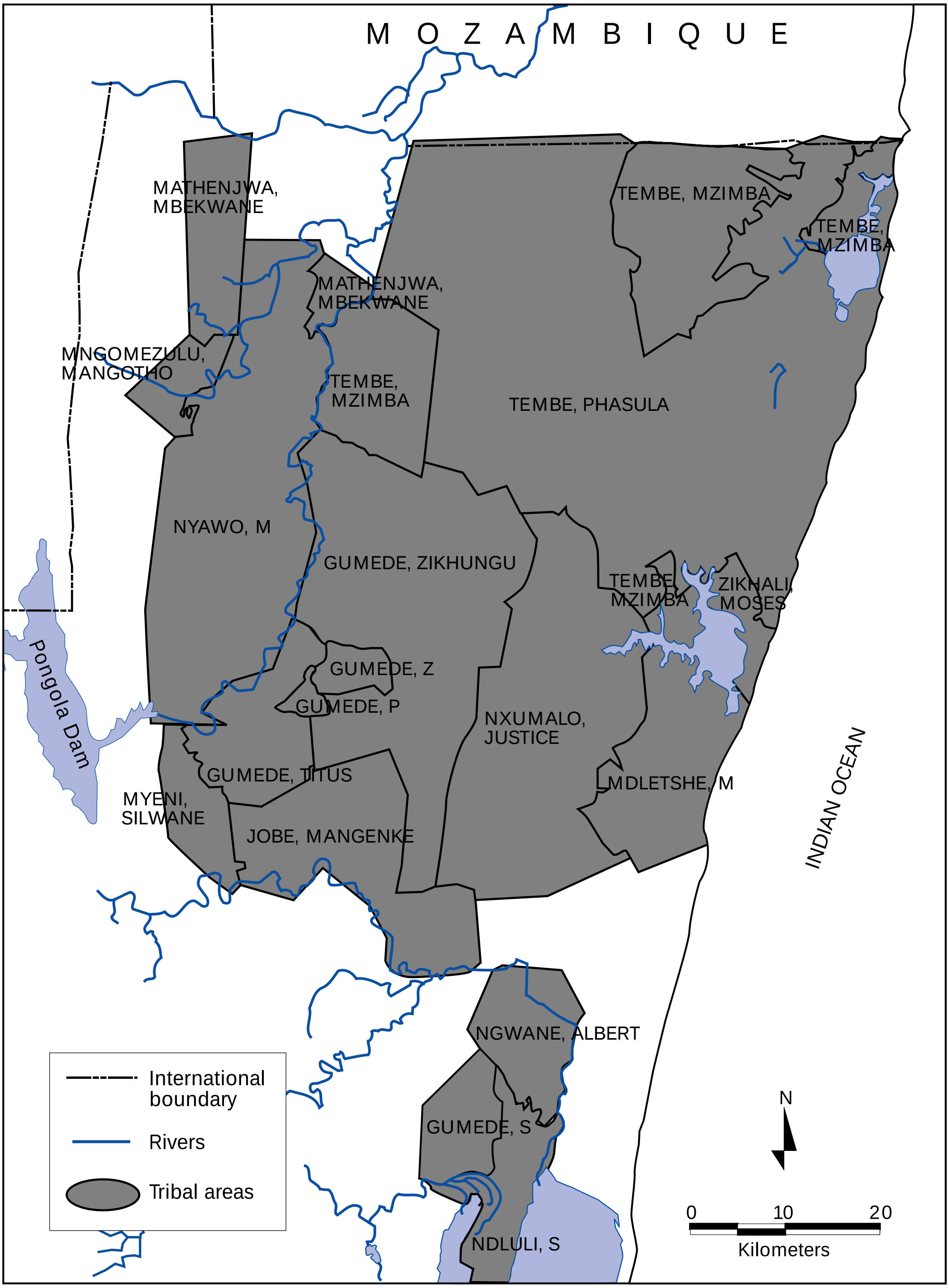


Medical Research Council, 1995

Tribal address system

In order to allow a link to be established between the Malaria Information System and the tribal address system, all families were asked who their Chief and who their Induna was. This enabled exact catchments for traditional leaders to be established at both Chief and Induna level (**Figure 20&21**). The usefulness of such data is demonstrated by its use in a recent regional workshop to establish community

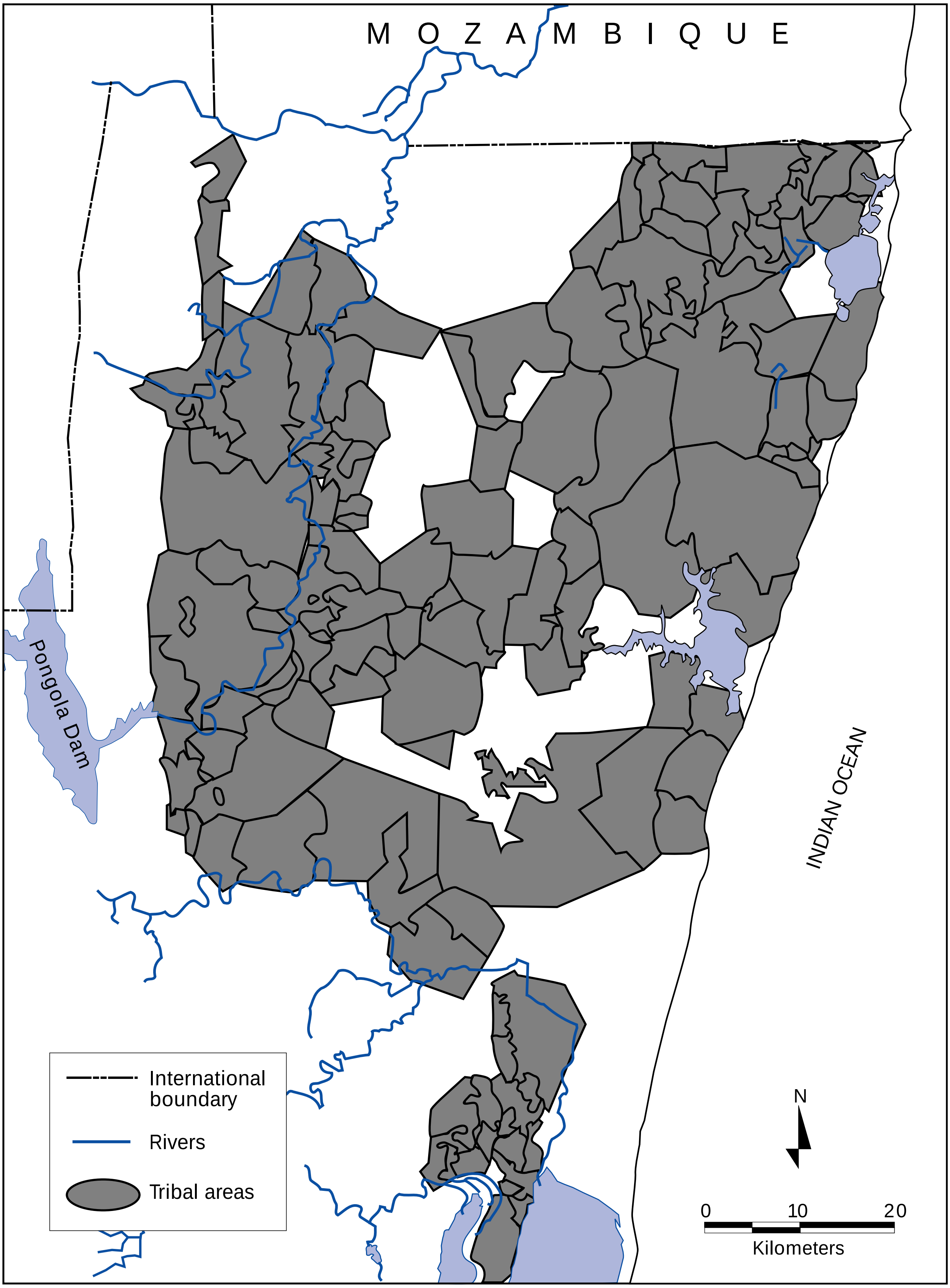
Figure 20: Tribal Areas (Chiefs) in Ingwavuma and Ubombo, KwaZulu-Natal, 1995



National Malaria Research Programme, MRC, 1996

representation on the hospital board. To facilitate this hospital catchments were overlaid onto the tribal data allowing the traditional leaders falling within each catchment to be identified.

Figure 21: Tribal Areas (Indunas) in Ingwavuma and Ubombo, KwaZulu-Natal, 1995



National Malaria Research Programme, MRC, 1996

Using Community Based Field Teams To Create a Village Level Spatial Database

In collaboration with the Health Systems Development Unit (HSDU), an effort was undertaken to spatially georeference village based data from the 20 villages in their study site. In order to facilitate long term investigation into population studies in these villages, hand drawn maps were established by community field workers. The function of these maps was to establish an address system for the annual demographic and health survey (DHS). This annual DHS aims to support district level planning and facilitate long term investigation into the health and population dynamics of these villages. Existing maps contain insufficient detail and are out of date. The main aim of this section is to demonstrate the use of relatively simple and cost-effective technology to obtain such a georeferenced village map.

Once again the study was approached at a macro (village) and household level (micro). Sample plots of the geo-linked database at village level are shown in **Figures 22 - 24**. In **Figures 25 - 27**, the process whereby, individual household plots were geo-referenced is shown. **Figure 25** shows a scanned image of the hand-drawn community field worker map. Visits to the site were made and coordinates of a number of locations within the map were obtained using differential GPS, to ensure coordinate accuracy of approximately 5 metres. This process was carried out for all 21 villages in a one week period. The scanned images were then “stretched” in Mapinfo by fitting these coordinates to them. They were then on screen digitised (**Figure 25 & 26**) and the resultant village based map is shown in **Figure 27**. This map is now georeferenced and allows queries to be conducted at the household level.

In Figures **28 - 30** a sample query of a single village, Justicia B, is shown. In **Figure 28**, the age of mother giving birth is shown, while in **Figure 29** the number of children per household is shown. An obvious correlation between family size and the occurrence of young mothers is evident as well as the fact that there is a degree of geographic aggregation of the trend. The reason for this become clearer when the status of households, is plotted and it becomes evident that the central area represents a newly established area (**Figure 30**).

The accuracy of this technique of capturing hand drawn maps into a digitised georeferenced format was assessed in order to get an estimate of its usefulness when overlaid with other more accurate geographic data as well as to develop a methodology which would improve or ensure a reasonable level of accuracy. When carrying out this process a number of factors need to be considered.

1. The overall size of the village
2. The dispersion of the locations within the village, for which differential coordinates are obtained.

Figure 31 shows a plot of the error of the geo-referenced community field worker map (end product and actual ground location), against the size of the village in square kilometres. These data are not corrected for differences in Positional Dilution of Precision (PDOP, see Appendix III); however a distinct trend between the accuracy of the map and the size of the village is evident. This is largely related to the fact that an average of 8 readings were taken for each village and this thus indicates the need for more readings to be taken in larger villages. The trend of decreased accuracy with increasing village size, when size is not taken into account when determining how many differential GPS points will be captured, is obvious (**Figure 31**).

Overall a mean accuracy of 148 metres was obtained with the stretching process causing less correction in the larger areas where there were fewer coordinates (Appendix II). However the relational position of inhabitants and facilities within the village would be correct. The above should however be considered in

Figure 22: Community Practice Project - Deaths by Gender 1993 - 1995
(As a ratio of total no. of people of that gender in that village)

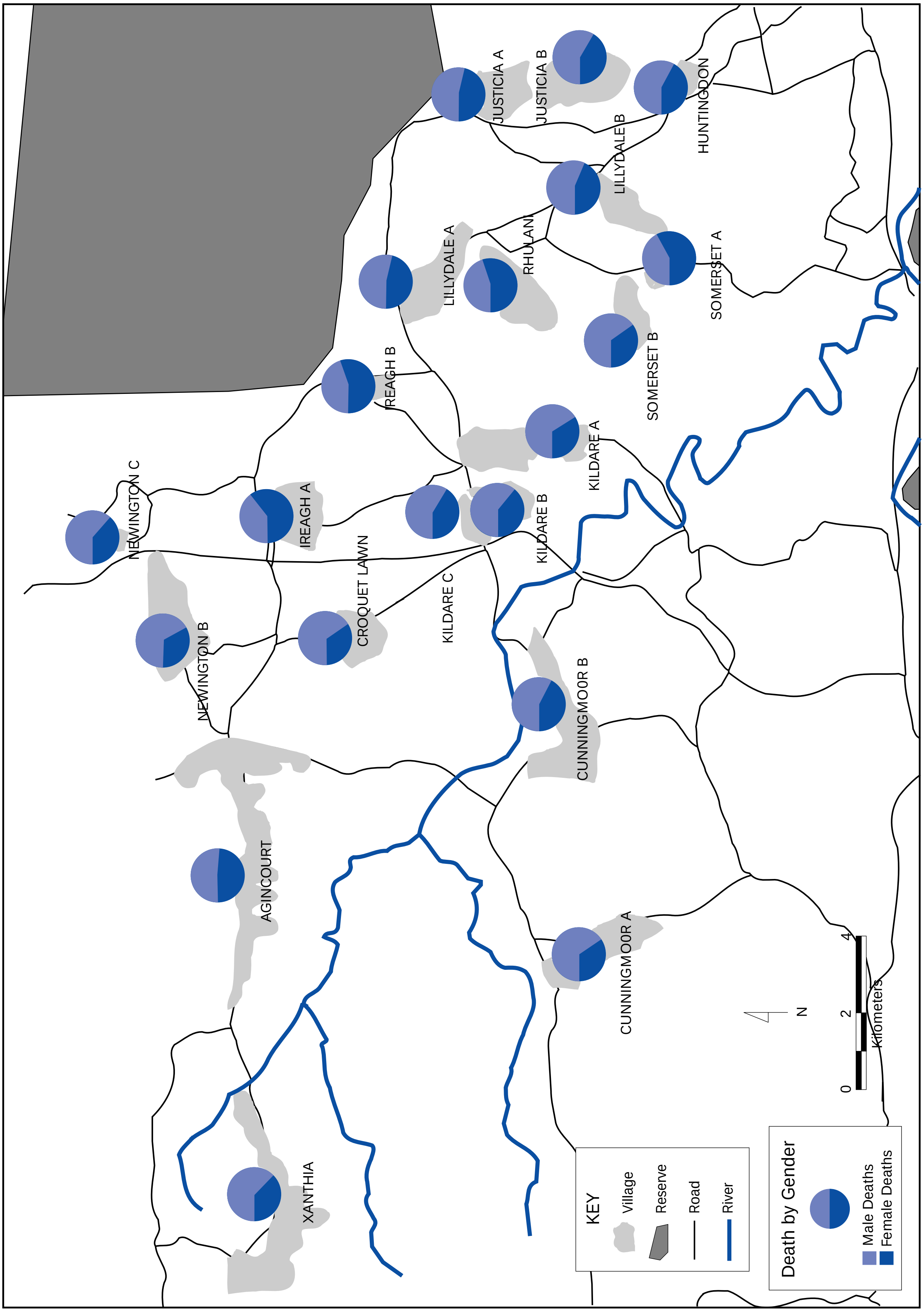


Figure 23: Community Practice Project - Place of Birth 1993 - 1995

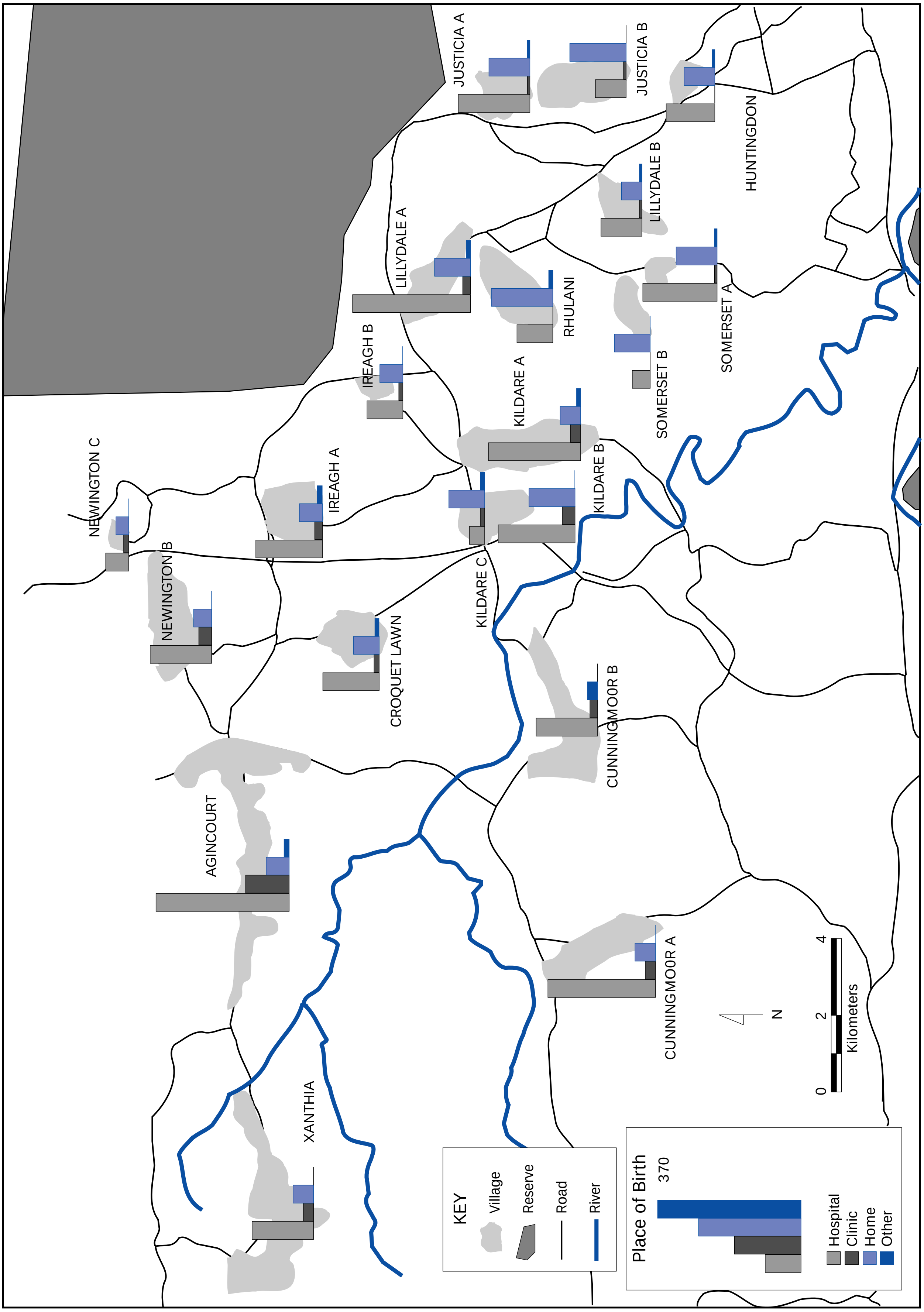


Figure 24: Community Practice Project - Deaths by Age Group 1993-1995
(As ratio of total no. of people per age group in that village)

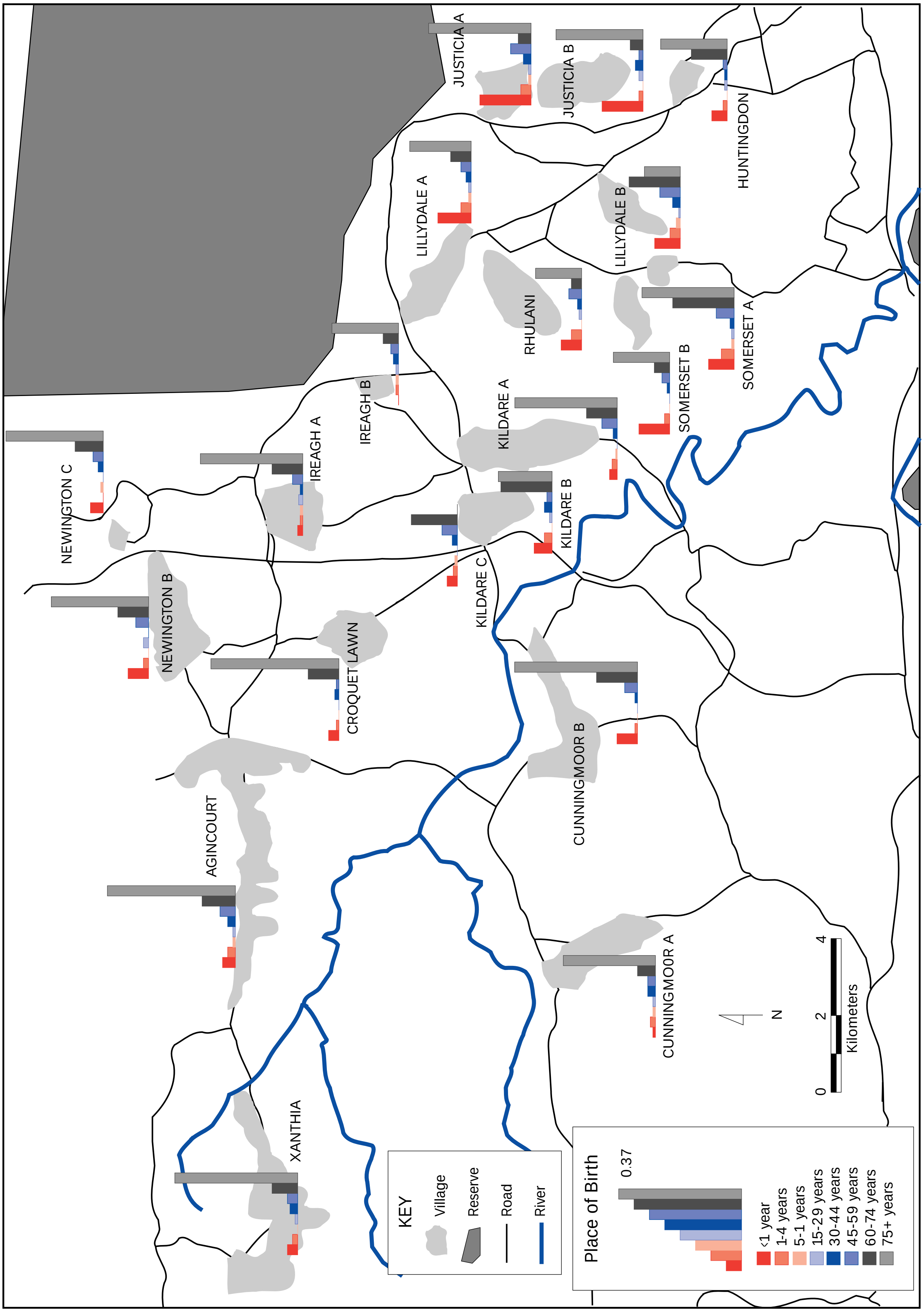
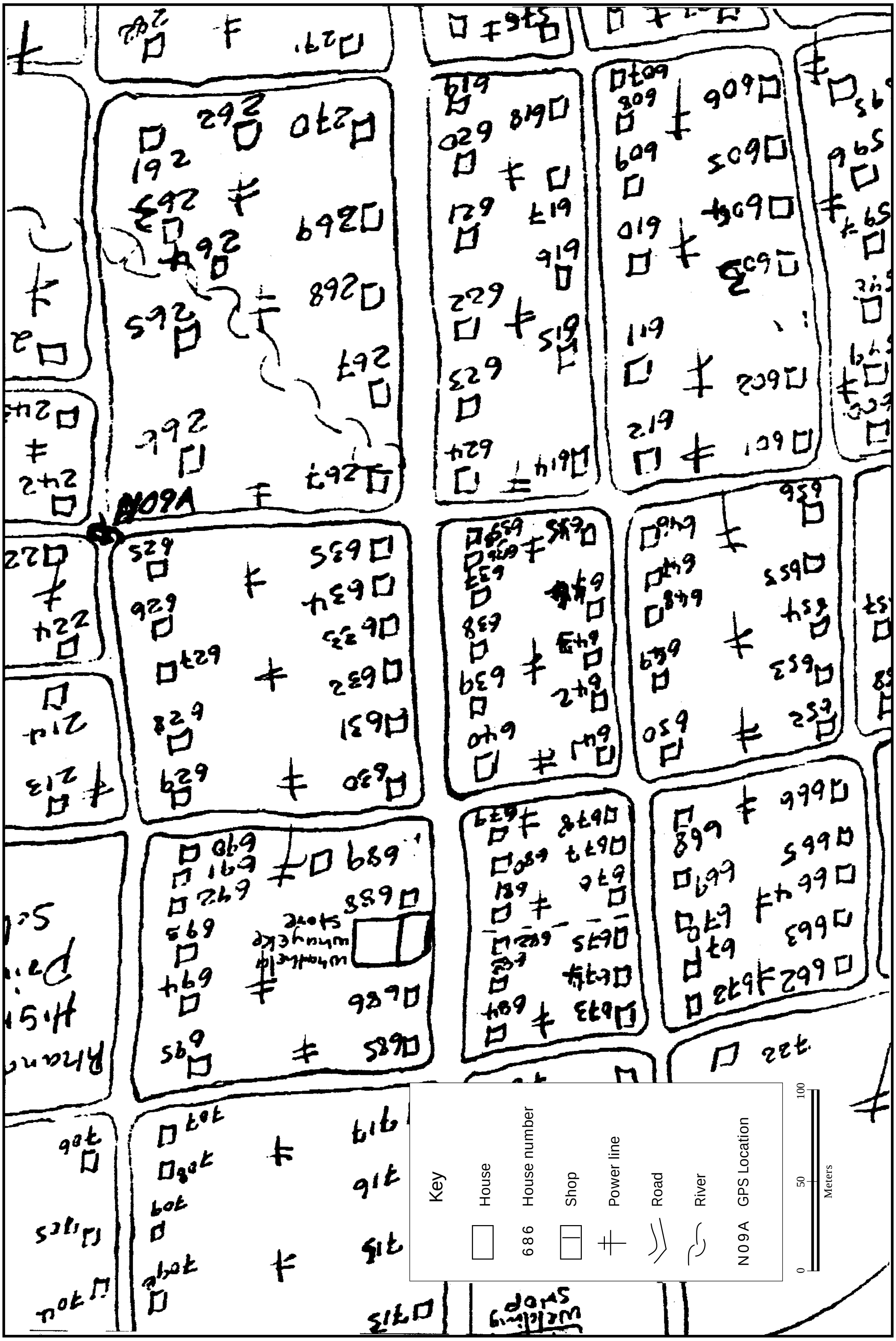
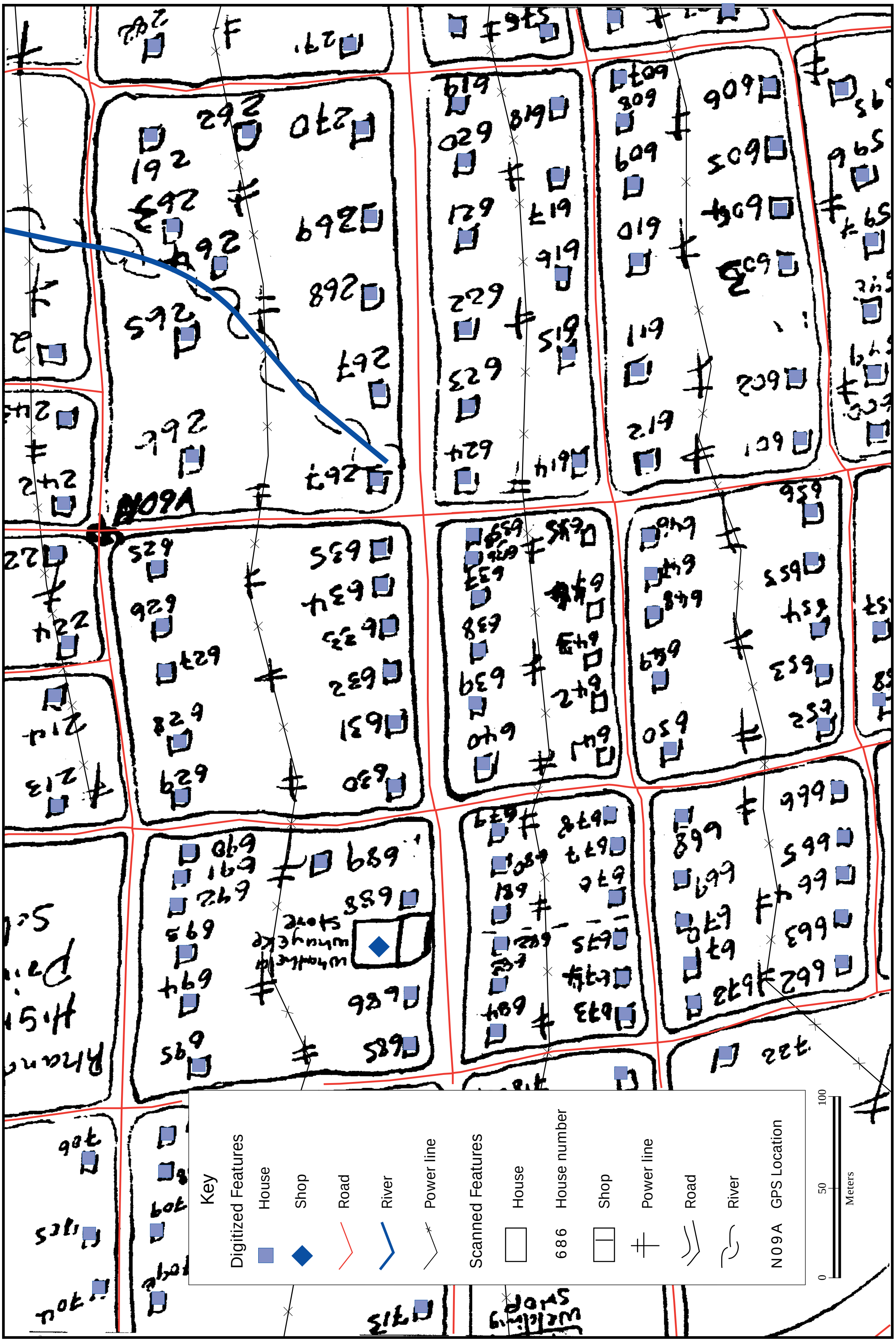


Figure 25: Scanned Image of a Portion of Lillydale - A Village



MRC/HSDU 1996

Figure 26: Portion of Lillydale - A Village Partially Digitised



MRC/HSDU 1996

Figure 27: Digitised Map of Lillydale - A Village

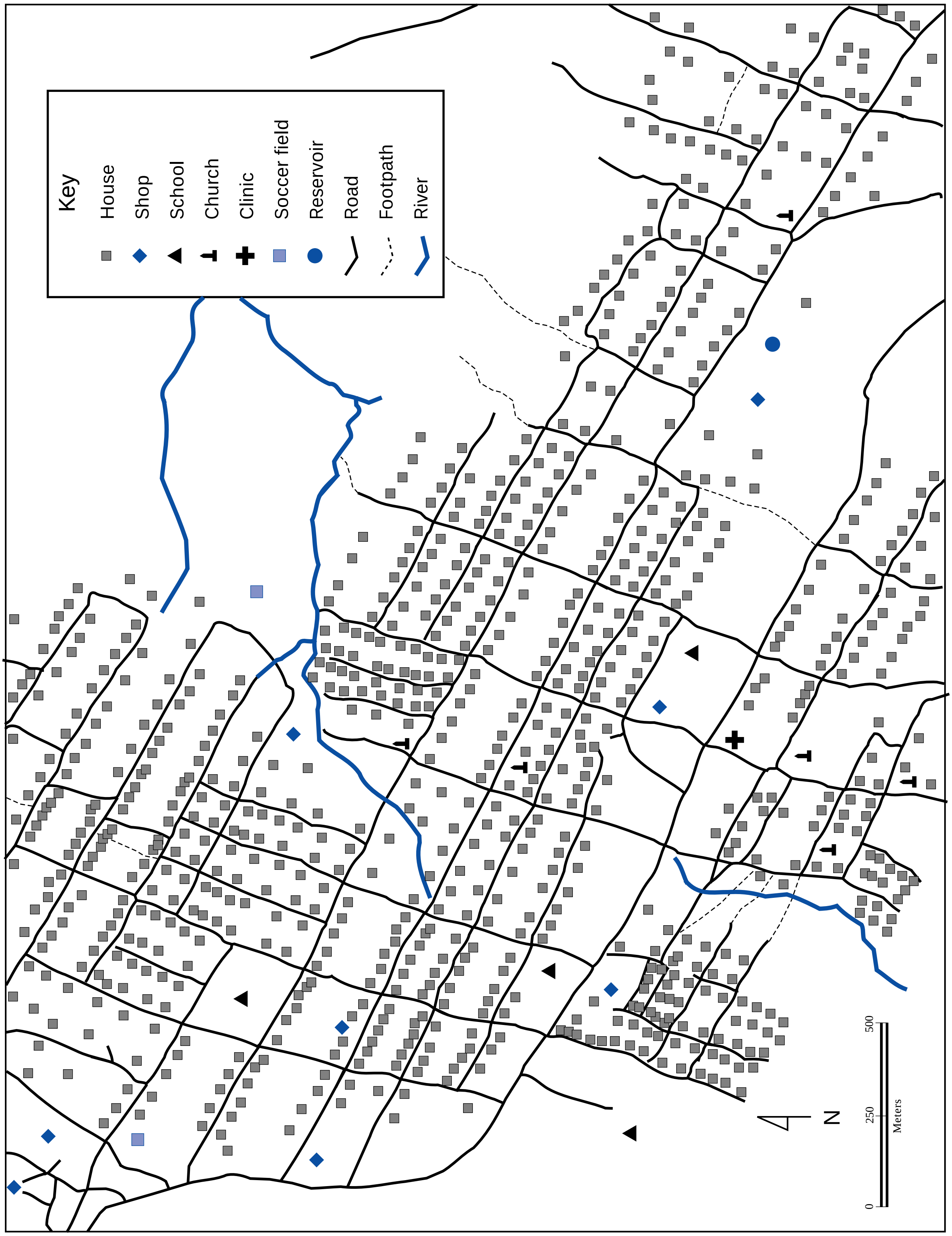


Figure 28: Mother's age at births in Justicia B, Mpumalanga, 1993 - 1995

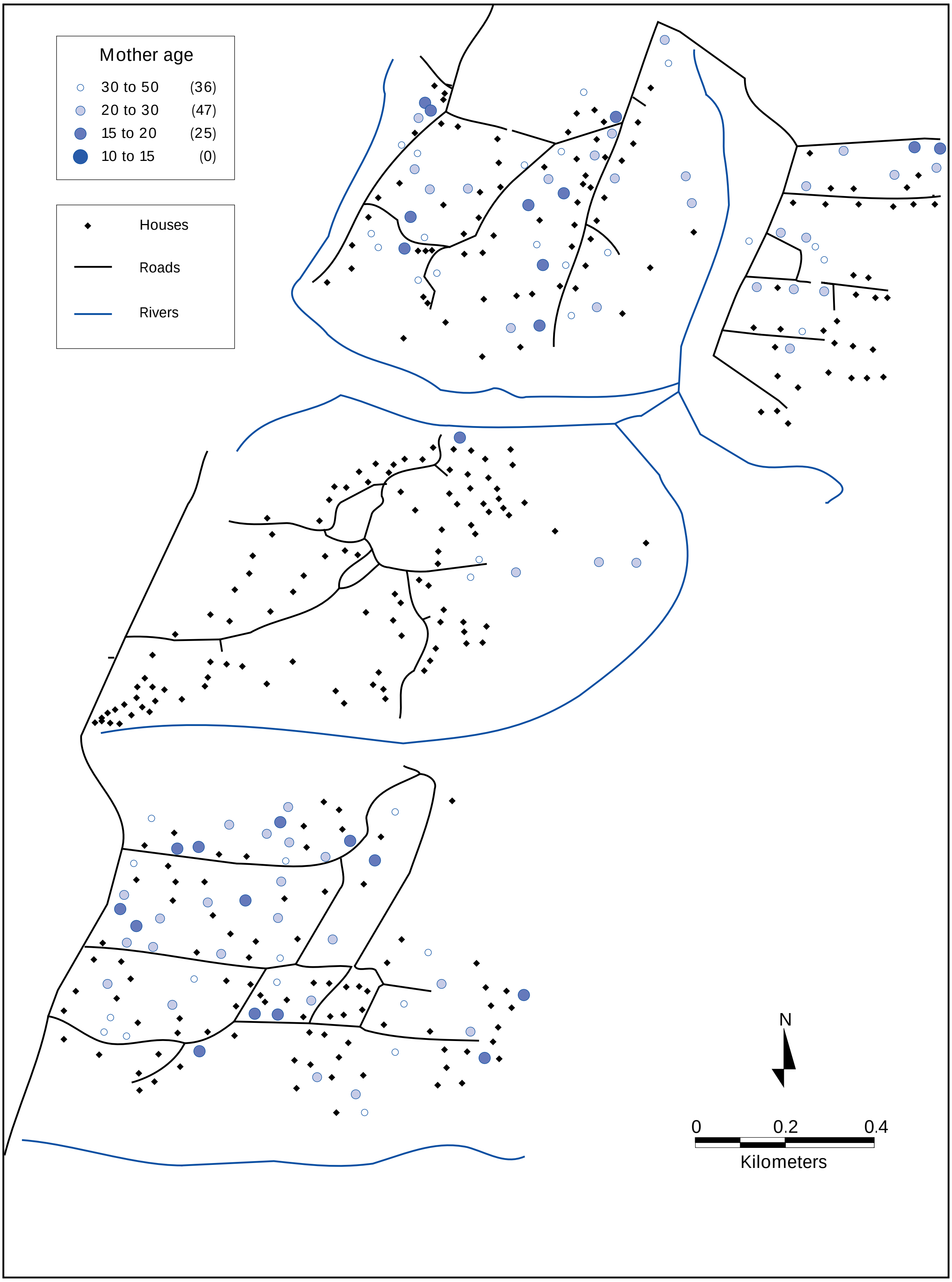


Figure 29: Number of children per house in Justicia B, Mpumalanga, 1993-1995

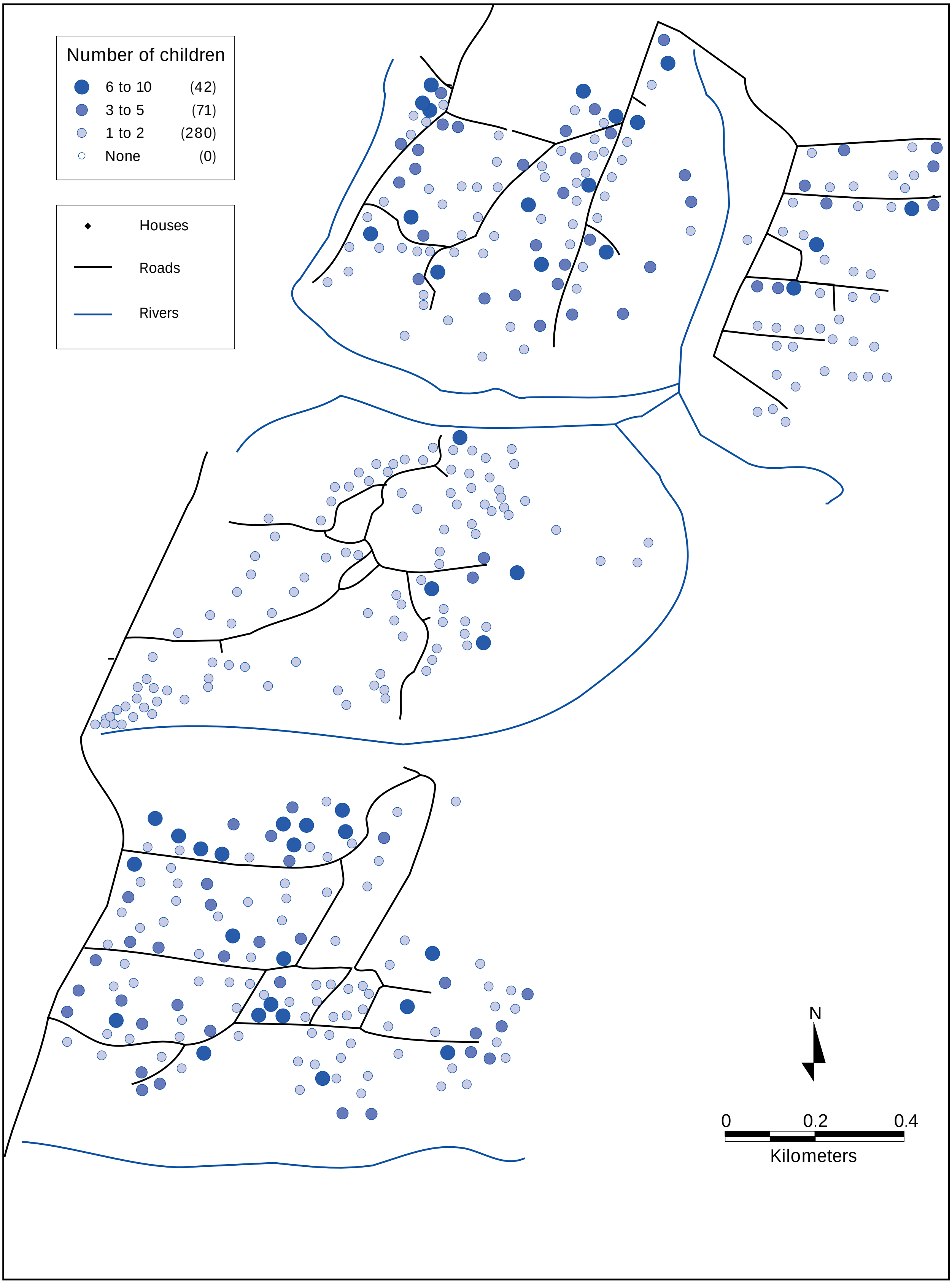
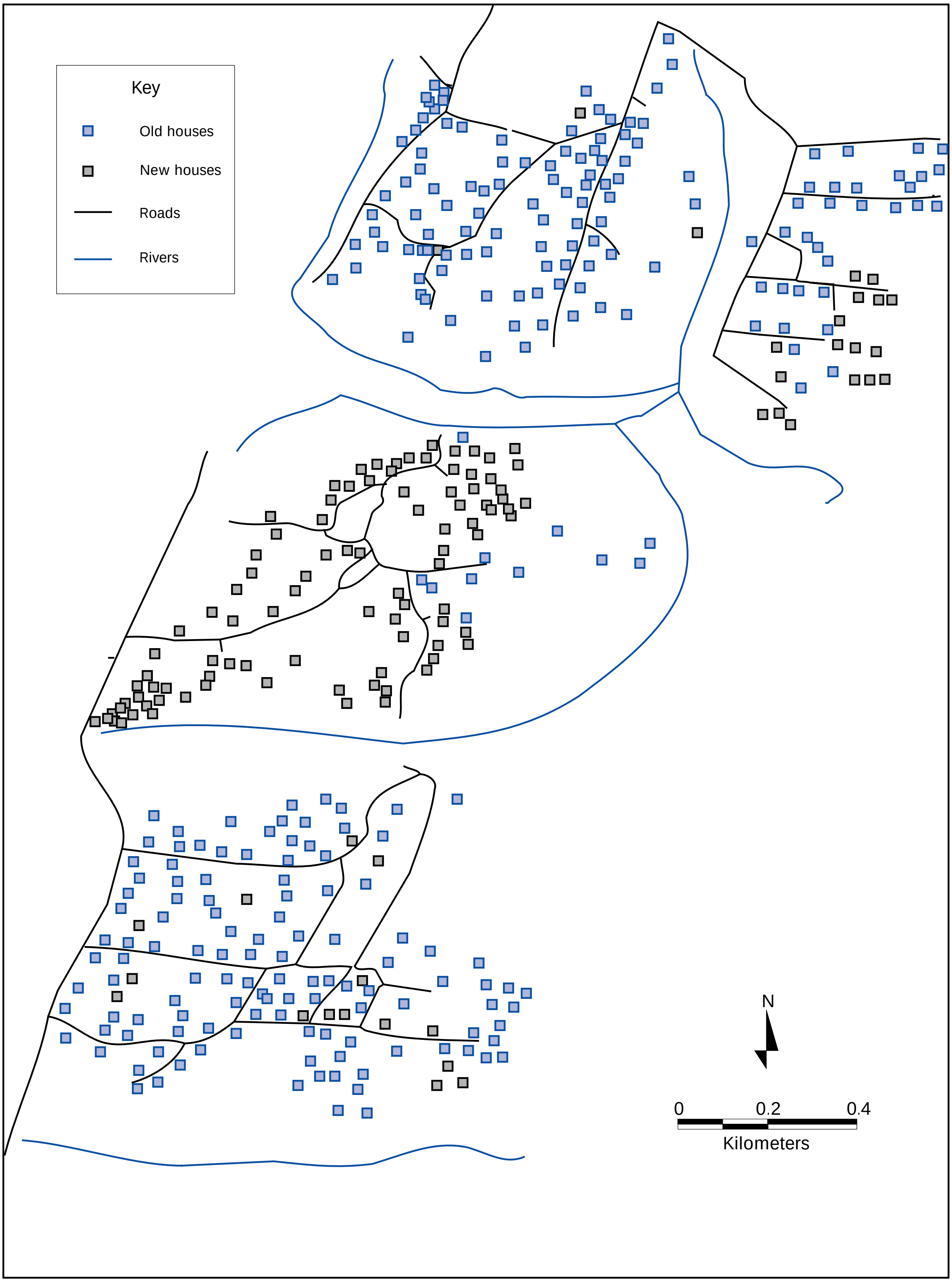
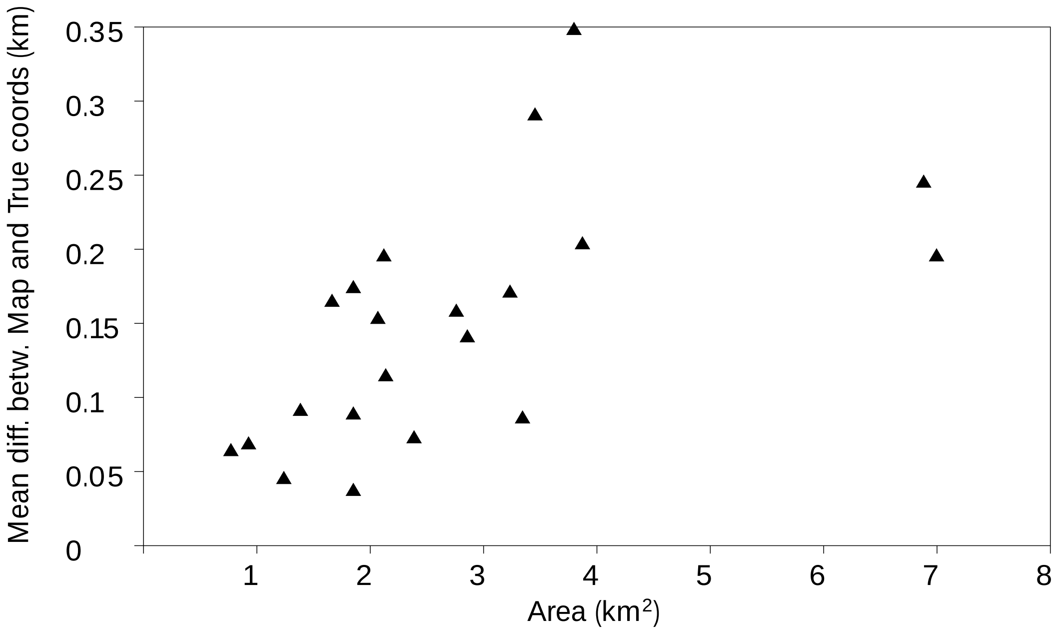


Figure 30: Houses in Justicia B, Mpumalanga, 1993 - 1995



conjunction with the fact that a 1:50 000 topographic map has a quoted accuracy of 75m. Further improvement in accuracy could be obtained by carrying out the process in a GIS package which supports "rub-sheeting" as opposed to the x,y axis process which MapInfo is capable of carrying out and by refining the number and position of coordinates per village.

Figure 31: Comparison between healthworker drawn maps and true co-ordinates



Although the above reports on the initial and exploratory findings of geo-referencing such community based maps which are not drawn to scale, it is without a doubt an extremely useful procedure with great potential. The value in the production (printing) of maps each year for the carrying out of the demographic and health survey and the on site updating of such a spatial information system is enormous. The value that spatial querying of such a database may yield is at this stage in its infancy. However the cost-effectiveness of the process when linked to the community based efforts of the HSDU, make it an extremely interesting approach for gathering information in village style rural communities. The use of such data in applications other than health has been clearly demonstrated above.

CONCLUSIONS

This study has clearly illustrated both the values and limitations of a so called "macro vs micro" approach to mapping disease. The homogeneity of disease distribution will vary from disease to disease. Thus, in the case of environmental or environmentally dependent diseases (e.g. directly and indirectly due to the involvement of a vector and parasite which are subject to environmental limitations), a greater degree of spatial non-uniform distribution is likely to occur.

The macro approach often gives us "good value for money" in terms of rapidly focusing our attention on the areas of most need. However the risk of diluting out areas which are more severely affected is very real. These principles apply to disease, health facility access, education levels, socio-economic status i.e. to virtually everything we want to map.

Motivation thus exists for us to undertake more detailed studies or GIS exercises once our attention has been focused by the initial macro approach. We are starting to make an impact at this macro-level in the country, in contrast at the micro-level, our efforts are sorely lacking. Obviously we cannot undertake detailed micro-approaches as described in this study, in all parts of the country. The importance however of establishing a number of such detailed platforms in representative rural and urban situations cannot be over emphasized. It is these platforms which will allows us to develop models of the spatial aspects of:

i. disease dynamics,

ii. facility placement (school, clinics etc.) and utilisation,

iii. representative population sub-sampling and the study of human population dynamics (e.g. census data, burden of disease etc),

iv. the validity of using existing infrastructure to collect sentinel data (e.g. schools, malaria control programmes, community health workers etc.),

v. disease intervention programmes, health promotion efforts, the identification of vulnerable groups and many others.

The spatial aspects of many of these may not be immediately obvious; however for example, both iv) and v) above require catchment data. With the former it is important to know the geographical catchment that the sentinel data can be attributed to, while with the latter, catchment would be critical to a clinic based intervention. It can also be stated that in addition to the health sector, points i) to v) have applications to all public sector departments, local government in general and the efforts of the community itself.

Lastly we believe this project provides "inter or cross-sectorial collaboration" and illustrates the enormous value of a single data set–population distribution.

REFERENCES

1. Abdool Karim, Q., Abdool Karim, S., Singh., B, Short, R and Ngxongo, S., (1992) Seroprevalence of HIV infection on rural South Africa, AIDS, 6, 1535-1539.

2. Krige, D. (1990) The basic needs approach to development: the question of health care for black people in Natal. Development South Africa, 7 ,(1), 53-66.

3. le Sueur, D and Sharp, B.L. (1988). The breeding requirements of three members of the *Anopheles gambiae* Giles complex (Diptera:Culicidae) in the endemic malaria area of Natal, South Africa. Bulletin of Entomological Research, 78, 549-560.

4. le Sueur, D. (1991). The ecology, over-wintering and population dynamics of the pre-imaginal stages of the *Anopheles gambiae* Giles complex (Diptera:Culicidae) in northern Natal, South Africa. PhD thesis, University of Natal. pp 244.

5. le Sueur, D., Sharp, B.L., and Appleton, C.C. (1993). Historical perspective of the malaria problem in Natal with emphasis on the period 1928-1932. South African Journal of Science, 89, 232-239.

6. le Sueur, D., Ngxongo, S., Stuttaford., M.C., Sharp., B.L. (1995) Towards a spatial rural health System in GIS for Health and the Environment. International Development and Research Centre, Canada.

7. Ngxongo, S.M. (1993). The Epidemiology of Malaria in KwaZulu 1980-1991. M.Sc. thesis, (p215), University of Natal.

8. Sharp, B.L. and le Sueur, D. (1996). Malaria in South Africa-the past, the present and selected implications for the future. South African Medical Journal; 86:83-89.

9. Stuttaford, M.C. (1994). Aspects of a Geographic Information System for Medical Geographers and Malaria Control. M. Soc. Sc. thesis, (p166), University of Natal.

10. Zwarenstein, M., Krige, D. and Wolfe, B. (1991). The use of a geographical information system for hospital catchment area research in KwaZulu/Natal. South African Medical Journal, 80, 497-500.

Appendix I

List of schools relating to Figure 19

1	KWASONTO
2	OZABENI
3	ENGWENYENI
4	MTANENKOSI
5	MANZIBOMVU HP
6	DUMILE HP
7	OTHUNGWENI HP
8	EMBETHE JS
9	ESIPHAHLENI HP
10	NHAMBANYATHI JS
11	ESIBHOWENI HP
12	VIMBUKHALO HP
13	QONDWENI HP
14	MLAMULA HP
15	ZENZELENI H
16	MZILA HP
17	MSELENI LP
18	PHUZAMTHONJENI LP
19	MAGCEKENI LP
20	MPHAKATHINI JS
21	MPHAKATHINI OLD
22	BHUKWANA JS
23	GUGULESIZWE H
24	MAMFENE
25	MJINDI H
26	GEDLEZA COMMUNITY
27	EBWA HP
28	MKHONJENI PUBLIC
29	MAKHONYENI LP
30	VEZUKUSA LP
31	ISETHEMBISO
32	NTENGO
33	OPHANDE
34	MAPHAYA
35	EZIBUKWINI H
36	NOBIYA SEC
37	EKUDILIKENI
38	MOZI
39	BHEVULA H
40	OPHANSI HP
41	MABANDLENI JS
42	EZINESHE
43	EKUVELENI
44	CEZWANA
45	FALETHU JS
46	SIQAKATHA
47	GUJINI
48	KWADONSA
49	BANGIZWE CP
50	MANQOBA CP
51	BHEKAMANGWANE CP
52	GIBA H
53	MNQOBOKAZI CP
54	NIBELA CP
55	QOMUKUPHILACP
56	KHATHAZILE LP
57	S.H.GUMEDE CP
58	MUDINWA LP
59	MAKHASAJS
60	EKUSENI CP
61	MDUKU H
62	MDLUDLA LP
63	NQOBOZIZWE LP
64	PHUMANI LP
65	MPOLIPOLINI
66	MGEDULA LP
67	SINETHEZEKiLE LP
68	BHANJANA
69	G.G. PRIMARY
70	SIPHAHLENI HP
71	MPIYAKHE H
72	MBAZWANE CRECHE
73	MBAZWANA HP
74	NYAKANYAKA SEC
75	KWAMBOMA HP
76	KONYA LP
77	MDLADLA JS
78	HOLY FAMILY HP
79	MZONDI CP
80	EMLAMBONGWENYA CP
81	KUYASA LP
82	HLULABANTU
83	BHUKWANA SEC
84	VIMBUKHALO LP
85	MZIBA/UMHLUPHEKI SEC
86	MFIHLWENI HP
87	MFAKUBHEKA HP
88	MALANGABI LP
89	MAKABONGWE LP
90	DAY SCHOOL H Q.
91	NSALAMANGA H
92	DAY SCHOOL H .Q.
93	MQHIYAMA LP
94	MANQAKULANI HP
95	IZWI-LINJE LP
96	KHOFI LP
97	MTHINDLWE
98	MZIKI CP
99	SHEMULA CP
100	ENKULISWENI CP
101	MBODLA HP
102	MAQHAWE LP
103	SENZOKUHLE
104	MAKHANE CP
105	NTABAYENGWE CP
106	SAMBANE CP
107	PHUNGAZA H
108	ESIBENISWENI HP
109	PHOHLO HP
110	ZAKHELENI LP
111	JULUKANI
113	WELCOME LP
112	VUKANI JS
114	SIPHONDWENI H
115	MBOZAHP
116	HLOKOHLOKO
117	HLAZANE
118	MADONELA
119	MENGUC.P.SCHOOL&T.C.
120	NTOKOZWENI
121	NODINEKA JS
122	ZAMAZAMA
123	ZAMAZAMA CP
124	THONGWANA
125	BHEKABANTU CP
126	SIHANGWANA CP
127	NOTHANDO JS
128	MBANDE LP
129	MAFA
130	MANABA CP
131	MZINYENI
132	KWASHUKELA HP
133	SINQOBILE LP
134	MPHAYENI
135	MOYE N I
136	VULULWAZI HP
137	MANABA H P
138	MANYAMPISI LP
139	MSHANGUZANE H
140	MPHAKATHINI LP
141	MPHAKATHINI HP
142	NONIKELA LP
143	THENGANI HP
144	HAMBISANANI H
145	MNYAYIZA HP
146	SHENGEZA SEC
147	MAFA LP
148	BHEKINDODA CP
149	LUBAMBO CP
150	MZINGENI LP
151	MANGUZI LP
152	MLAMULA SEC
153	KWAPHAWENI HP
154	NDLONDLWENI HP
155	THELAMAMA
156	NDUMU JS
157	MAPHINDELA HP
158	MBADLENI HP
159	MBADLENI
160	MADEYA HP
161	MSONGWENI
162	MABIBI HP
163	EKUKHANYENI
164	MLINGO H
165	MANZENGWENYA
166	NTOMBENHLOPHE
167	OTHOBOTHINI CP
168	MANQAWASHU CP
169	MAVELA H
170	OPHONDWENI CP
171	KWA-MSHUDU HP
172	VIMBUKHALO LP
173	MLOLI HP
174	GAZINI HP
175	KWA-MSHUDU LP
176	LIBUYILE CP
177	KWA-MSONDO HP
178	BAMBISANANI LP
179	KWA-NDWANGU HP
180	HLUMULA CP
181	STAR CP
182	STAR H
183	ZAMINQUSEKO CP
184	MANGUZI LP
185	THANDIZWE CP
186	SHAYINA H
187	MAPUTA HP
188	MAHLUNGULA C P
189	CP SCHOOL
190	MANDLA JS
191	MAZAMBANE LP
192	MASAKENI LP
193	MQOBELA CP
194	UBANGANEK LP
195	MALANGENI C P/LP
196	MASHALAZA JS
197	N KATHWINI CP
198	NOVUKENI LP
199	THETHWAYO LP
200	SICELOSETHU HP
201	OUR LADY CP
202	LUNDINI CP
203	MAGUGU CP
204	INGWAVUMA H
205	NANSINDLELA LP
206	EKUKHANYENI LP
207	ST PHILLIPS H P
208	ZANDLAZENI SEC
209	KHUME HP
210	SIBHAMU H
211	MANYISENI HP
212	MAYALUKA LP
213	EKUHLEHLENI H P
214	ENDABENI HP
215	NJAKAZANE LP
216	EMNGCELENI HP
217	NKUNGWINI HP
218	ZOMBIZWE SEC
219	OSHABENI HP
220	NYATHINI LP
221	EMHLANGENI LP
222	MAKABONGWE HP
223	SIBONISWENI HP
224	ZWELINYE HP
225	PHOHLO CP
226	MAKHANYA LP
227	MAVUSO JS
228	MFIHLWENI PRE SCHOOL
229	PRE SCHOOL
230	PRE SCHOOL
231	MZINENE LP
232	MGADLA
233	MFINGOSE CP
234	NKOVUKENI
235	THRELFALL CP
236	HLOMLA HP

Appendix II

Table of accuracy measurement for georeferenced community field worker maps

	ACCURACY (Difference between actual and map coordinates)				DISPERSION (Average distance to centroid / Area of village)	
	Mean	Std Error	Std Deviation	Count	Avg/Area	Area
Aginc-a	0.34983	0.04331	0.10608	6	0.27928	3.37100
Aginc-b	0.19871	0.05940	0.15717	7	0.16287	7.11800
Crocquet	0.08817	0.01709	0.04186	6	0.22420	3.42700
Cuning-a	0.20575	0.4423	0.12510	8	0.22420	3.92600
Cuning-b	0.07450	0.00554	0.01566	8	0.40487	2.47300
Hunting	0.09025	0.01553	0.04391	8	0.47024	1.36500
Ireagh-a	0.17163	0.04424	0.12513	8	0.28135	3.30100
Ireagh-b	0.29438	0.07290	0.20619	8	0.34162	3.51600
Justic-a	0.11400	0.01256	0.03552	8	0.29529	2.12500
Justic-b	0.08920	0.02551	0.05705	5	0.54211	1.88300
Kildare-a	0.15988	0.03281	0.09280	8	0.31119	2.76600
Kildare-b	0.04220	0.00890	0.02181	5	0.36822	1.89400
Kildare-c	0.06960	0.02824	0.06316	5	0.47373	0.90600
Lilydale-a	0.13757	0.02882	0.07626	7	0.29155	2.86300
Lilydale-b	0.16829	0.03881	0.10269	7	0.33715	1.63300
Newing-b	0.24738	0.04447	0.12577	8	0.18022	7.00100
Newing-c	0.15625	0.01633	0.04620	8	0.48339	2.06200
Rhulani	0.17567	0.03334	0.08167	6	0.42125	1.83700
Somers-a	0.04957	0.00741	0.02095	7	0.36269	1.29000
Somers-b	0.06500	0.02196	0.04910	5	0.39823	0.78900
Xanthia-b	0.20000	0.04719	0.10553	5	0.49777	2.15600
Xanthia-a	0.0000	0.0000	0.0000	3	1.12679	0.74400

APPENDIX III

THE NAVSTAR GLOBAL POSITIONING SYSTEM

INTRODUCING THE GPS

Space-based positioning had its origin in the TRANSIT satellite system, established by the USA military and NASA (Space agency) in the early 1960's. This system played an important role in establishing modern geo-centric data systems (national vs local). However this system had a number of problems:

1. Only 6 satellites were available, thus giving only limited global coverage, and with waiting times of up to 90 minutes between satellite passes.
2. The satellites' ability to position accurately was also affected by the fact that they were only at 1100km above the earth surface and thus were affected by gravity.
3. The satellite transmissions were at a relatively low frequency (150 and 400 MHz).
4. The clocks within the satellites were of limited accuracy compared to modern day clocks.

The relevance of all of these points will become clearer once we have discussed the operation and problems of the system. However the above points are important as they led to an initiative in 1974 which resulted in more satellites being launched in the second quarter of 1989. Twenty one satellites are needed to give 24 hour world wide coverage. There are however also three active spares and four replacement satellites. On average 5 satellites per year excluding the first, were launched between 1989 and 1994. Two dimensional (position on the ground) worldwide coverage was available from 1991 and 3D (in the air and altitude, when on the ground) from 1992. The system was designed to provide worldwide accuracy at the 100m level for non-military applications. The advantages of the system are that the satellites are positioned at 20 600km above the earth, signals are transmitted at high frequency, and the clocks, especially those within the satellites, are very accurate. Thus the system gives worldwide positional coverage which is not affected by weather, is continuous, does not restrict the number of users (is passive) and costs nothing (to use).

HOW DOES THE SYSTEM OPERATE?

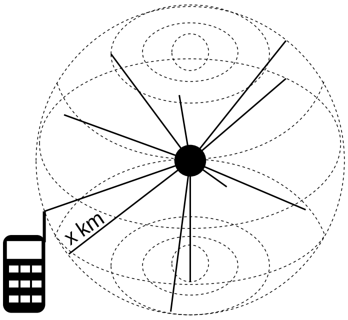
The system in principle is in fact very simple and based on a system of clocks measuring the difference in time from when a signal leaving leaves the satellite to when it arrives at the receiver. Since the signal travels at the speed of light, the distance between the receiver and the satellite can be calculated.

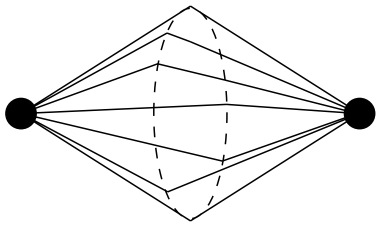
Once the distance of several satellites is known, the position of the receiver (the GPS unit in the hand of the user) can be calculated by trilateration. To fix the position of the receiver in space, you need to know its distance from at least four satellites.

Trilateration:

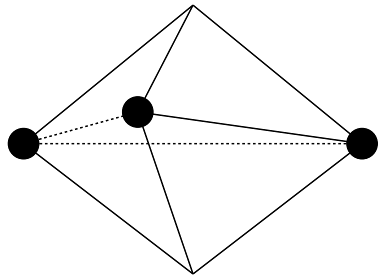
To fix the position of an object in space, you need to know its distance from at least FOUR points.

If you know its distance from a SINGLE point, the object could be anywhere on the surface of a hollow sphere surrounding the point. All over the surface of the sphere the distance to the point is the same.

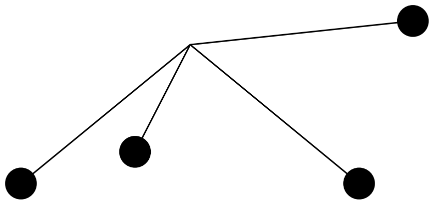




If you know the distance of the object from TWO points, its possible position is narrowed down to a circular path between the two points. All along the circle the distance from the two points is constant.

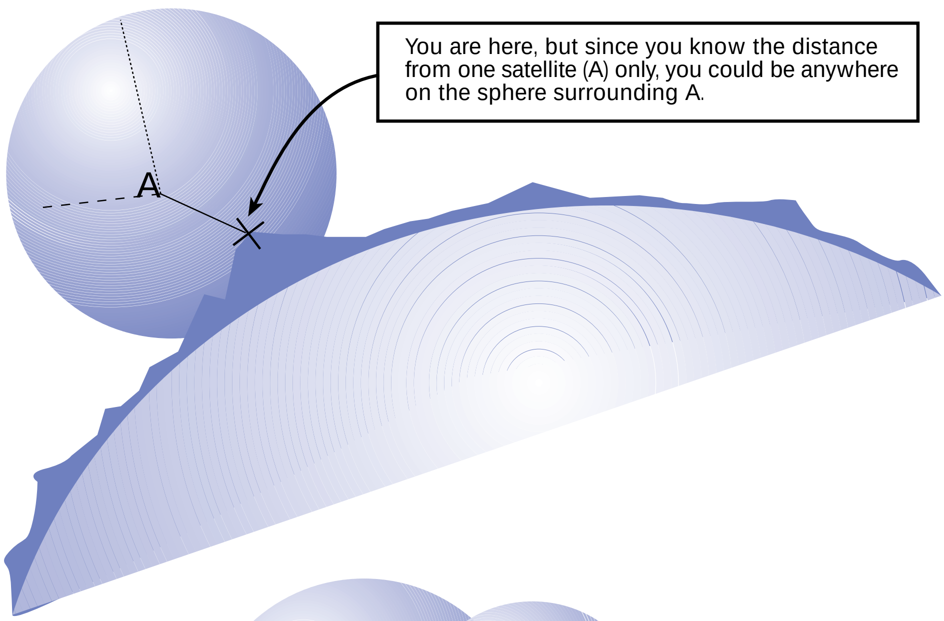


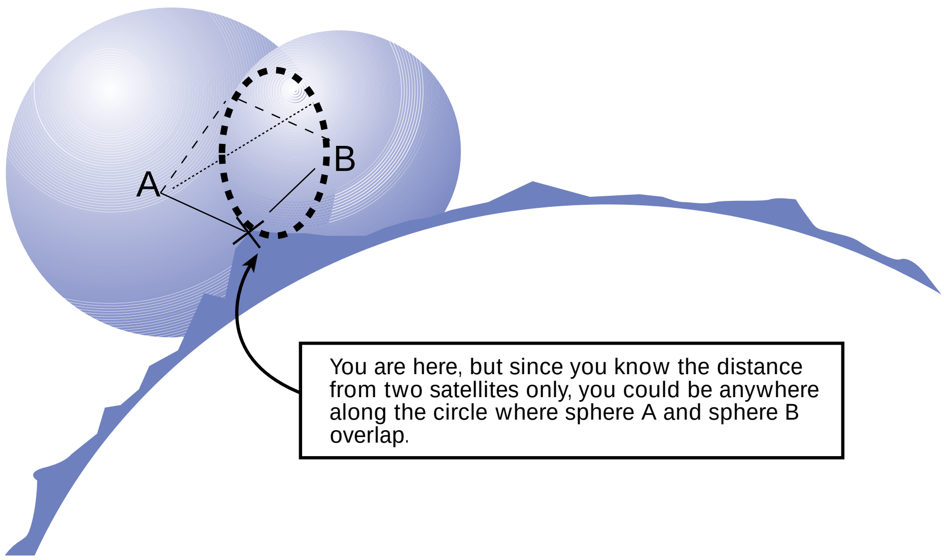
If you know the distance of the object from a THIRD point, there are only two possibilities left: either the object is above or below the triangle formed by the three points.

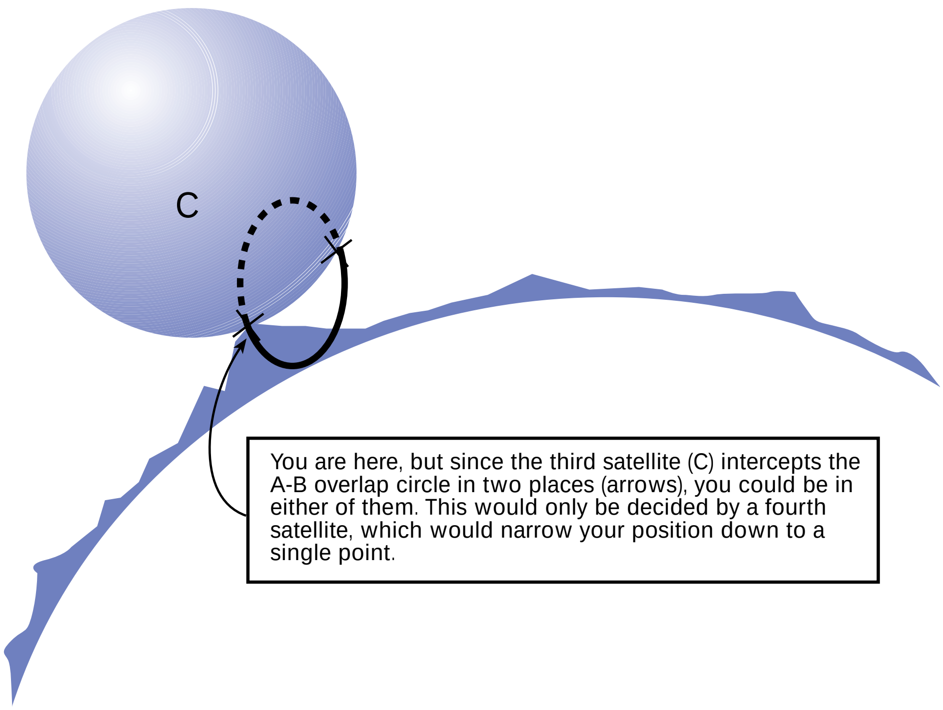


Once you have the distance from a FOURTH point, the position of the object is fixed in space.

Let us now consider the above in terms of the earth and satellites







Inherent Limitations and Practical Problems

With the use of the commercial channel (Receivers using this channel are known as C/A code receivers) and the military channel (P code) there are a number of inherent limitations to accuracy.

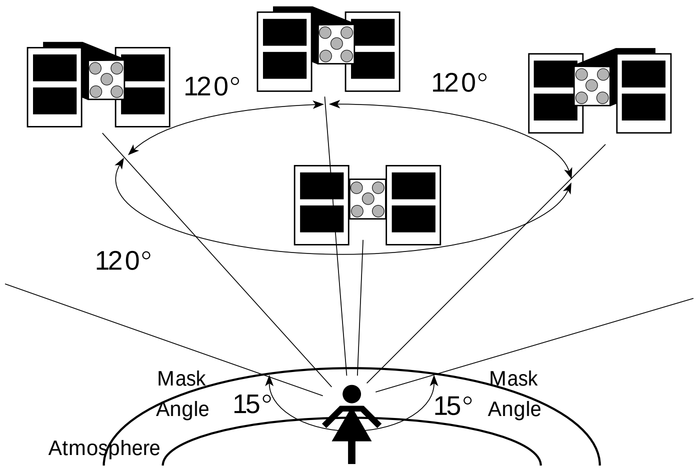
Below is a list of the types and approximations of errors inherent to the system:

Sources of error:

1.	Satellite clock error	0.66 metres
2.	Ephemeris Error	0.66
3.	Receiver Errors	1.3
4.	Atmospheric/Ionospheric	4.0
5.	Selective availability (SA)	8.0
	(Worst case and if "switched on" - see later)	
TOTAL		5 to 10m, depending on SA

To calculate the actual error we have to multiply this error by the Geometric Dilution of Precision (GDOP). The GDOP is a function of the Positional Dilution of Precision (PDOP) and the error in time which is obtained from the fourth satellite. PDOP is a measure of the angle of the satellites relative to the user and to each other.

Firstly if the satellites are positioned too close together, then the accuracy of triangulation is affected. Optimally, one satellite should be directly above the user and the other three on the horizon, 120° relative to each other. In this case the PDOP will be 1.639, i.e. this is the lowest value that will be achieved.



Secondly, when satellites are too low above the horizon (at angles of 15° or less) then the transmitted signal has to travel a greater distance through the "thick" portion of the atmosphere and is subject to greater distortion.

The PDOP will decrease as more signals are received from additional satellites.

Selective Availability (SA) is a deliberate distortion of signals by the US military, especially in times of war. SA is generally switched off nowadays, but it is possible to get an estimation of this by observing the Speed Over Ground (SOG) while standing in a stationary position. If the SOG shows a high degree of movement, then SA may be active and the accuracy of your fix will be degraded. SOG can be observed in the Navigation mode of the Trimble Ensign.

The Measurement of Accuracy

Thus accuracy of a positional reading may be defined as:

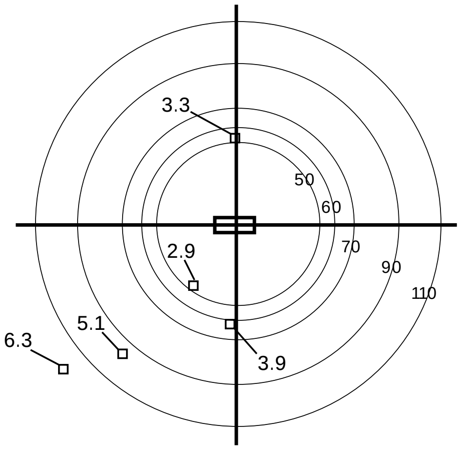
Sum of Source Errors x GDOP (PDOP, Time error)

Thus the higher the PDOP, the higher will be actual error, as the Source Errors are multiplied by the PDOP.

For example if the source error is 15 m, then

if PDOP = 2,	then accuracy = 2 x 15	= 30m
if PDOP = 3.5,	then accuracy = 3.5 x 15	= 52.5m

GPS accuracy for GLEN 409 Beacon



This is clearly illustrated in the adjacent figure which shows readings taken at Glen Beacon in the Valley of a Thousand Hills area, just outside Durban. At the centre of the cross hairs is the location of the trigonometric beacon, the concentric lines around this point indicate the distance from the beacon in metres. Five readings of longitude and latitude were taken and these were then plotted in Mapinfo. The positions recorded by the GPS are shown as squares and the value of the PDOP is indicated. In this example it is clear that as the PDOP increases, the accuracy of the recorded position decreases. Thus it is desirable to have as low a PDOP as possible.

Accuracy may be increased by taking a number of readings at the same point and then taking the average of these. This is the first practical exercise. Below is a data table for exercise 1.

GPS EXERCISE 1

Beacon Name	Longitude	Latitude	PDOP	SOG	Number of Satellites	Time after first reading

This table has been included here so that the practical exercise will relate to the theoretical background given. The actual processing of the information will be done in the next section. The processed data (accuracy plot) should be affixed to the following page. Other field exercises will also be carried out during the visit to the malaria region / control programme.

GPS EXERCISE 2

Environmental Feature	Longitude	Latitude	PDOP	SOG	Number of Satellites	Time after first reading

Projections and GPS Setup

Fundamental to the process of mapping is the need to view a round World with three-dimensional (3D) features in a two dimensional plane (2D). This is achieved by “translating” the 3D earth surface into 2D mode (i.e. on a piece of paper) using a specific mathematical formula. The result is a “Map Projection”. There are many different ways of converting the 3D world into a 2D map, resulting in different kinds of projections. In South Africa, the projection used is the Trans Mercator (Gauss Conform) and the associated datum system is the Cape, South Africa.

The Navstar Global Positioning System however is based on the World Geodetic System 1984 (WGS84). Thus to collect spatial data using a GPS, we need to set up the GPS to perform a coordinate transformation from WGS84 to the local datum system (Cape, S. Africa in our case). GPS units have this facility built into them and it is simply a process of going into the Units SETUP mode and selecting the appropriate datum system. Some GPS’s have a larger number of coordinate transformation possibilities than others. It is thus important to ensure that a particular make has the ability to transform from WGS84 to your local coordinate system. An example is the Sony Pyxis versus the Trimble Ensign; the former does not have the Cape, S. Africa datum system whereas the latter does. The Ensign has 123 alternative datum system installed internally.

When the Ensign loses power (i.e. flat batteries) totally and the batteries are not replaced within 30 minutes, the internal customised SETUP which you selected, will be lost. The unit will revert to its default settings when new batteries are installed. This brings us to some important points regarding power requirements.

Power requirements

All GPS units are expensive in terms of power requirements, some more than others. In our assessment of three GPS units for field use, in which we considered portability, robustness, accuracy, power requirements etc., we found the Trimble Ensign to be the most suitable for field use. The unit was far more power efficient than the other units. Nevertheless four AA alkaline batteries only gave 8-10 hours of continuous operation. Normal acid batteries give only 25% of this and have the added danger of leakage (when the unit is not in use) resulting in permanent damage.

Units should always be stored with batteries (ALKALINE ONLY). A set of alkalines will sustain the memory for up to a year. For extended field use cost can be reduced either by using a battery eliminator which runs from a car cigarette lighter or, if the unit needs to be used away from the car, then re-chargeable 12 V alkalines, which give 7 or more days of continuous operation, can be used.

Units will also contain a power save mode in which the position of the receiver is updated less frequently. For example in the Ensign the update rate is either 1.5 or 5 seconds.

POS and SOG Accuracy Filters

Most GPS units contain ACCURACY FILTERS, which attempt to counteract the effects of selective availability and geometric precision. In the case of the Ensign these are the POS and SOG Filters (Positional and Speed over Ground). The default is 1, which means your position is only made up of a single reading. The error due to Selective Availability GDOP is thus greatest. If several readings are obtained, the inaccuracy due to SA is reduced. The final result is an average of the prescribed number of readings.

It should however be borne in mind that the more readings set in these filters, the more slowly the unit responds. If the unit is also in power save mode (5 sec update interval vs 1.5) then this will cause further delay.

Coordinate Style

Different Geographic Information Systems prefer their coordinate data in different formats (decimal degrees vs. degrees - minutes - seconds), e.g. MapInfo uses decimal degrees. Since the GPS units have the ability to present the positional coordinates in different formats, choose the one most appropriate for your GIS package.

Most packages have the ability to convert from one format to the other. It is important to consider the conversion process when designing your database; e.g. for conversion in MapInfo you will need separate columns; eg. if the GPS gives the readings in degrees - decimal minutes, then you need two columns in the database for the longitude reading and two for the latitude reading. The degrees and decimal minutes must be in separate columns.

Accuracy

Terrain can affect accuracy of the readings. In hilly areas, excellent satellite coverage may be obtained at the top of the hills and poor coverage in the valleys, where satellites are obscured by surrounding hills. Poor coverage will usually be reflected in a high PDOP. You may have to spend a longer time at each data point to get a fix with an appropriate DOP.

If only three satellite signals are available, the accuracy of your position (fix) can be enhanced by entering the altitude, if this is known or if an altimeter is used in conjunction with the GPS.

Errors may occur during transcription of data or even as a result of signal reflectance. These kind of errors can usually be detected quite easily by plotting your data points and looking for outliers, which are obviously in the wrong place.

GPS EXERCISE 3

	SOUTH			EAST			
	Deg	Min	Sec	Deg	Min	Sec	Error (m)
1	-27	32	33.4	32	12	22.6	
	Latitude error						
2	-27	32	34.4	32	12	22.6	
3	-27	33	33.4	32	12	22.6	
4	-28	32	33.4	32	12	22.6	
	Longitude error						
5	-27	32	33.4	32	12	23.6	
6	-27	32	33.4	32	13	22.6	
7	-27	32	33.4	33	12	22.6	

The table above displays the coordinates for seven points. Point 1 is the correct point. Points 2-7 are incorrect transcriptions of the same point. Each time an error has been introduced: first to the Latitude (South reading) then to the Longitude (East reading). In each case the Seconds, then the Minutes and then the Degrees have been increased by 1 unit. To investigate the effect of each of these errors, plot the seven points above in your GIS:

- Create a MapInfo table for the above data.

  Create one column for the point number and six columns for the respective longitude and latitude readings and enter the data. (Chapter 4 of the Introductory Course on GIS in Health manual - National Malaria Research Programme, Medical Research Council, 1996).

- Create two more columns for LONG and LAT. Convert the data to decimal degrees.

  (Section 4.3.3.1 of Chapter 4)

- Use Create Points to create map points for the data.
- Label the points with their number. (Chapter 6).

  Now you should be able to see the six wrong points in relation to point 1.

- Now use the Distance Tool (Ruler button) to measure the error between point 1 and each of the wrong points in turn and write down the distance in the column provided.

Since in each case the degrees, minutes and seconds were altered by one unit, the distances you measured represent the length of one degree, one minute and one second respectively.

Obviously these values change, depending on your position on the globe; eg. a difference of one degree longitude is a smaller distance close to the poles than at the equator.

Coordinate notation

The majority of GIS packages have their origin in the Northern Hemisphere. To distinguish between a latitude of 27 degrees north versus 27 degrees south, a negative is introduced. Similarly with East to West. It is important to get this notation right both in your digitising (leads to inverted or reversed digital data if not correct) and in your database or during the creation of points (Leads to a point being created in the wrong hemisphere if not correct).