King Fahd University Of Petroleum & Minerals

College of Environmental Design
Department of City and Regional Planning

CRP-514

GEOGRAPHIC INFORMATION SYSTEMS
(Introduction to GIS)

Term Paper

Spatial Analysis Tools to Analyze Health Related Problems

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declining transmission, April–July. The scales for cases per household and incidence were held constant throughout the seasons for each species.

Figure 16: Location of mosquito capture stations and results of adult anopheline mosquito collections, April–August 1998. The underlying distribution of malaria incidence for the corresponding months is also shown.

Abstract

GIS is a technology which has vast applications. And obviously the health field is also not away from being benefited from GIS. This is because the inherent characteristic of health data is that it has a location component. This characteristic makes Geographic Information Systems (GIS) an ideal and sometimes indispensable tool for analyzing environmental and health data.

Case studies demonstrate how GIS can be used to monitor tropical diseases, water quality, environmental toxicology, and overall rural health. GIS can certainly be a tool of prime importance to health research and education, and in the planning, monitoring, and evaluation of health programs. Hence overall GIS has served to be a very helpful tool in various fields related to health.

A variety of analytical tools are available within GIS, extending the capabilities of traditional Spatial Decision Support System to include the ability to analyze data based on their spatial characteristics.

The present study emphasizes the power of GIS technology to better understand and evaluate spatial data by creating graphic displays using information stored in the database. As GIS does more than just display the data; it enables the user to dynamically analyse and update the information linked to those locations spatially. This study disuses some of the GIS tools which are useful to analyze health related problems. Also this paper extensively touches on the role of Spatial Decision Support System in monitoring, analyzing, and overall preventing diseases like malaria. This has been explained through various case studies all around the world.

Last but not the least, this study also gives a brief knowledge of how GIS integrated with other software is more effective for disease prevention and control, and the use of programming and programmers in the GIS field for development of tools to analyse spatial issues can be a rich source to save time, cost and resources.

1. Introduction

GIS can be a useful tool in exploring health technicalities. This is because the inherent characteristic of health data is that it has a location component. This characteristic makes Geographic Information Systems (GIS) an ideal and sometimes indispensable tool for analyzing environmental and health data.

Case studies demonstrate how GIS can be used to monitor tropical diseases, water quality, environmental toxicology, and overall rural health. Many researchers demonstrates how GIS can provide health researchers, planners, program managers, and policymakers with novel information about the distribution and interaction of disease risk factors, patterns of morbidity and mortality, and the allocation of health resources. Hence overall GIS has served to be a very helpful tool in various fields related to health.

In the developing world, GIS has been used for many years in the agricultural, natural resource, urban and regional planning, and tourism sectors. The health sector, however, has only recently begun to use this powerful tool as far as its applications are concerned.

Arc GIS can be a useful tool for health researchers and planners because, as expressed by **Scholten and Lepper (1991),**

> Health and ill-health are affected by a variety of life-style and environmental factors, including where people live. Characteristics of these locations (including socio-demographic and environmental exposure) offer a valuable source for epidemiological research studies on health and the environment. Health and ill-health always have a spatial dimension therefore. More than a century ago, epidemiologists and other medical scientists began to explore the potential of maps for understanding the spatial dynamics of disease.

2. Problem Statement

Lots of health problem arise throughout the world due to various reasons and to track all these diseases time and again will be too much of a task in terms of manpower, money, resources and more importantly time. In order to optimize and solve the problem, customized spatial analysis tools made in GIS by software programmers will help in analyzing and unraveling the dearth of problem and hence time, money, resources and manpower can be saved.

Understanding the determinants of a disease, and its spread from person to person and community has become increasingly global **(ESRI White Paper, 1999).**

High-risk areas can be identified using GIS and remote sensing technologies that would otherwise be difficult to detect using traditional methods. Control and education programs can be directed toward these areas with more confidence and effectiveness.

GIS provides excellent means for visualizing and analyzing epidemiological data, revealing trends, dependencies and inter-relationships. GIS serves as a common platform for convergence of multi-disease surveillance activities. Public health resources, specific diseases and other health events can be mapped in relation to their surrounding environment and existing health and social infrastructures. Such information when mapped together creates a powerful tool for monitoring and management of epidemics. GIS helps us out in many ways. These include the following applications. **(Gupta, Shriram, Map India 2004)**

3. Objectives

The main objective of this paper is to analyze tools related to application of GIS in the field of health. The more important objective is giving a realistic view regarding the implementation of these tools.

Another objective is to get a realistic view regarding the effective role of decision support system for disease control, especially malaria.

Last but not the least; objective is to analyze how far spatial data can be effective in developing a model for disease control.

4. Methodology

1. The Methodology will include study of literature to find out how GIS was implemented in various parts of the world in the field of its applications in health.

2. Sample tools to demonstrate the use of spatial analysis tools to solve health problems, which include detailed analysis of these tools.

3. Presenting of case studies to demonstrate the use of Spatial Decision Support System where programming languages are used to link the health related software with GIS for analyzing the decision making.

5. Literature Review

5.1 GIS and Health

The area of GIS and Public Health has risen to prominence with the recognition that health surveillance practices and health service allocations need to become more sensitive to the needs of people in local geographic areas. The collection, storage and manipulation of geographic information have undergone a revolution in recent years with the development and widespread availability of GIS software. Many health professionals can benefit from further education in this area, and with their new knowledge, they can influence the progress of health surveillance, environmental health assessment and the geographic allocation of health resources.

In Health and Human Services alone GIS has a wide range of applications,

1) GIS provides a common analytical framework in which public health authorities can understand problems and formulate a response, improving incident management and health planning.

2) GIS is becoming a vital tool for scientists and public health officials investigating the cause and spread of deadly diseases around the world. **(Map India 2001 Conference).**

Improvements in the following areas are contributing to the rapid adoption of GIS:

- Health information systems—the increasing availability of geo-coded health data;
- Availability of digital geographic files that contain layers of geographical information;
- Availability of environmental exposure information;
- GIS technology—inexpensive software is easier to use, contains increased functionality and runs on a wider range of hardware, including PCs.

The tremendous potential of GIS to benefit the health care industry is just now beginning to be realized. Both public and private sectors are developing innovative ways to harness the data integration and spatial visualization power of GIS. The types of companies and organizations adopting GIS span the health care spectrum—from public health departments and public health policy and research organizations to hospitals, medical centers, and health insurance organizations.

ESRI has over 5,000 health care clients worldwide who are using the resource integration capabilities of GIS to create analytical and descriptive solutions. GIS plays a critical role in determining where and when to intervene, improving the quality of care, increasing accessibility of service, finding more cost-effective delivery modes, and preserving patient confidentiality while satisfying the needs of the research community for data accessibility.

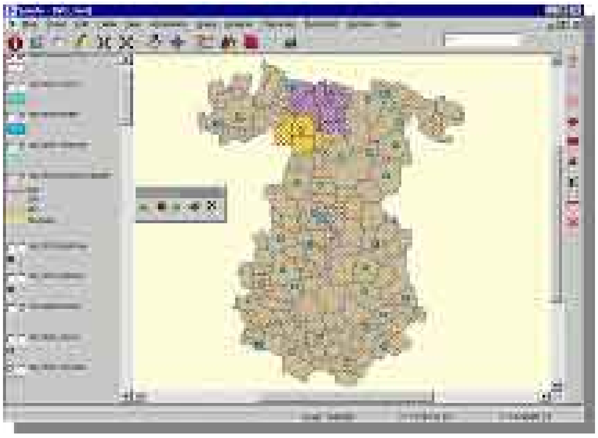

Fig 1: GIS and Health- Gadag District India

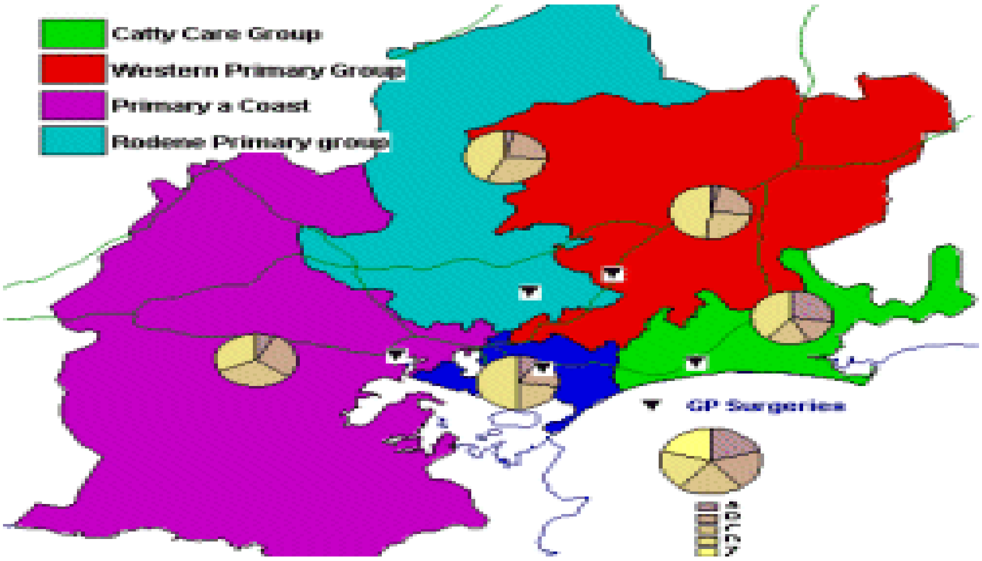

Fig 2: GIS and Health- Visualizing patient flows

5.2 GIS tools for Health

5.2.1 GIS-EPILINK

This is a simple spatial search tool that can be used to link environmental and health data when distance between an environmental site and the location of the maternal address of a case or control is used as a proxy for exposure. The tool was used in a research project and it successfully provided the necessary data for epidemiological analyses. This tool should be very useful to epidemiologists in environmental health research. (**Zhan, Brender, Han, Suarez, Langlois, 2006)**

5.2.2 GATHER

Geographic Analysis Tool for Health and Environmental Research (GATHER) is an online spatial data access system that provides members of the public health community and general public access to spatial data that is pertinent to the analysis and exploration of public health issues.

Besides these tools there are many more tools health where GIS is used. One such tool which is at high demand nowadays is use of GIS and exposure modeling in study of cancer.

With the advancement of technology, another such method to tackle health problems is the use of Spatial Decision Support System. (**http://gis.cdc.gov/**)

5.2.3 HEALTH FACILITY VIEWER (HFV)

The health facility viewer is a versatile tool which is essentially an informational tool that is available to users with no specific GIS knowledge. It provides a user-friendly interface for viewing the results a Health Facility Survey through map-based navigation. The survey gathered three types of information: the GPS coordinates of the facility, digital photographs of the building's exterior and interior conditions, and information on the facility's staff, conditions, available services, utilities, and financing.

Fig 3: Snapshot of the Prototype Health Facility Viewer

The user can zoom into a district of interest, and then use the map to select a facility (hospital, health center, or health unit). This pulls up the survey information for that facility, including a 'photo viewer' that allows the user to flip through the set of facility photos gathered during the survey, as well as tables of information and statistics about the particular facility. At any time, the user can step back to select a different facility within the district, or view a new district. **(Ghio, Landry, Nuemen, Attieg, 2005)**

The health facility viewer is not so complicated, and as mentioned earlier is user-friendly, much easy for the user to interact and use. It is a standalone product that does not require the user to have expensive GIS software.

5.2.4 SPATIAL DECISION SUPPORT SYSTEM

It is a customized computer-based information system that utilizes decision rules and models and incorporates spatial data. This system has been used to help decision-makers solve complex spatial problems; this also includes problems related to health. This paper will deal essentially with the link between spatial decision support system and its application in the field of health.

spatial decision-support systems are interactive and computer-based. They help prioritize dataset development and information gathering and put geographic information in a decision-making context. These systems are used to set data and information requirements in terms of time, scale, accuracy, and methods, and make it possible to link spatial decision-support efforts with other planning efforts, such as economic development, transportation planning, or poverty reduction programs. **(Malczewski, 1997)**

A spatial decision-support system allows a decision-maker to (1) build relationships, both spatial and process-based, between different types of data, (2) merge multiple data layers into synthetic information, (3) weigh outcomes from potentially competing alternatives, and (4) forecast. To do this a spatial decision-support system uses three basic elements: (1) data (2) known relationships between data, and (3) analysis functions and models to synthesize relationships or to test scenarios of different policy or decision-making alternatives. **(Ghosh, Lal, Nathawat, 2001)**

One of the best examples of the use of Spatial Decision Support System in prevention and control of Malaria is The Malaria Information System.

Accurate malaria case information is critical for the planning of malaria control as well as the assessment of the efficacy of the intervention in the region.

Malaria Information Systems have been set up in the malarious provinces of South Africa. These computerized systems allow the input, management and output of malaria case information which is central to disease management, research and the regional evaluation. The MIS has been adapted for implementation in Mozambique and Swaziland.

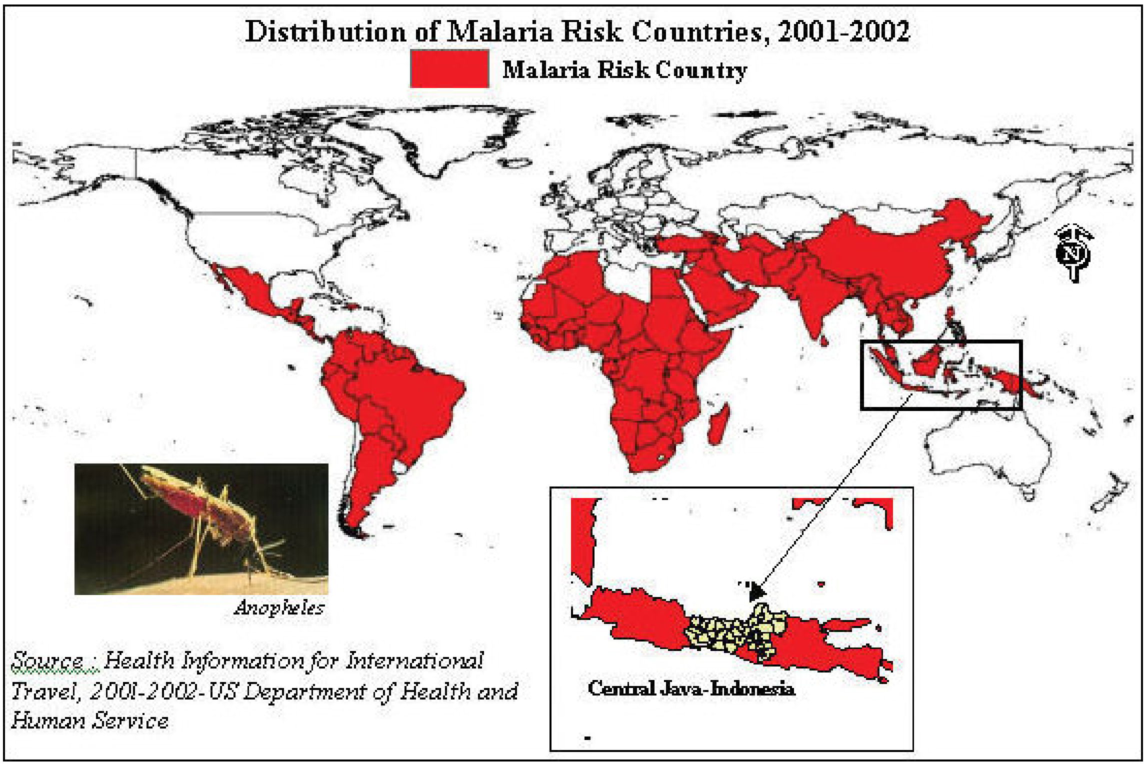

Fig 4: Distribution of Malaria Risk Countries, 2001-2002

The MIS provides the ability to identify areas of risk and to assist decision makers in directing resources and strategies. The ready access of data, its rapid entry, analysis and output in the form of graphs, tables and maps, allows for stream-lining of the data within the region, and for rapid management and evaluation of the situation on an on-going basis, enabling the cost effective use of resources. The SDI's GIS-based MIS and the resulting availability of spatially-referenced data will have implications for the development of historically disadvantaged communities, for example, the electrification of health facilities, the optimal placement of roads, new schools, clinics and other infrastructural developments.

Spatial Analysis of MIS data

A stand-alone spatial component of the MIS application is based on the Health Mapper application developed by the World Health Organization (WHO) and is customized to minimize end-user skill requirements and optimize access to spatial data sets.

The vector-based desktop GIS software package MapInfo is generally used in MIS to provide the spatial platform of the MIS. Microsoft Access provides the database platform as well as the front-end data entry and output screens. The outputs designed are in perfect confirmation to meet the management needs and were provided in graphs, tables and maps. (**http://www.malaria.org.za/lsdi/Overview/gis_component.html)**

6. Case Studies

6.1. Case Study from Sri Lanka

Spatial analysis of malaria risk in an endemic region of Sri Lanka

Sri Lanka is a country which always faced health problems, especially those associated with Malaria. In Sri Lanka yearly 30,000 infections of Malaria are reported, in a growing population of 16 million.

The main seasons which give rise to increase in Malaria infections are June-July and December-January. The Malaria strain more prevalent in this region is P.falciparum.

A combination of factors contribute to the difficulties associated with trying to achieve a reduction in malaria transmission. These include:

- Environmental and geographic features of the area, such as climate, land-use patterns, and development of irrigation schemes;
- The movement of people and the creation of new settlements;
- Behavioral aspects relating to the population;

- The health care delivery system; and
- The socioeconomic and educational status of the population **(Ministry of Health 1987-1991)**.

Even in moderately endemic areas of the country, it is well known that malaria infections are not homogeneously distributed; some individuals and families are subject to repeated malaria infections, while others experience no infections at all **(Gamage-Mendis et al. 1991).** This clustering of malaria infections seen within a population led to an investigation of malaria risk factors in endemic communities in Sri Lanka. One such risk factor was house construction type; poorly built houses with mud walls and thatched roofs afforded a significantly higher risk to their inhabitants than houses constructed of plastered brick walls and tiled roofs **(Gunawardena et al. 1994.).**

The present study includes monitoring of human malaria infections occurring in an endemic population of Kataragama in southern Sri Lanka. Particular attention was paid to the spatial and geographic features of the area. This enabled an analysis of the malaria risk of this community with respect to three potential risk factors: location of houses in relation to distance from the forest edge and a source of water, and the construction type of houses.

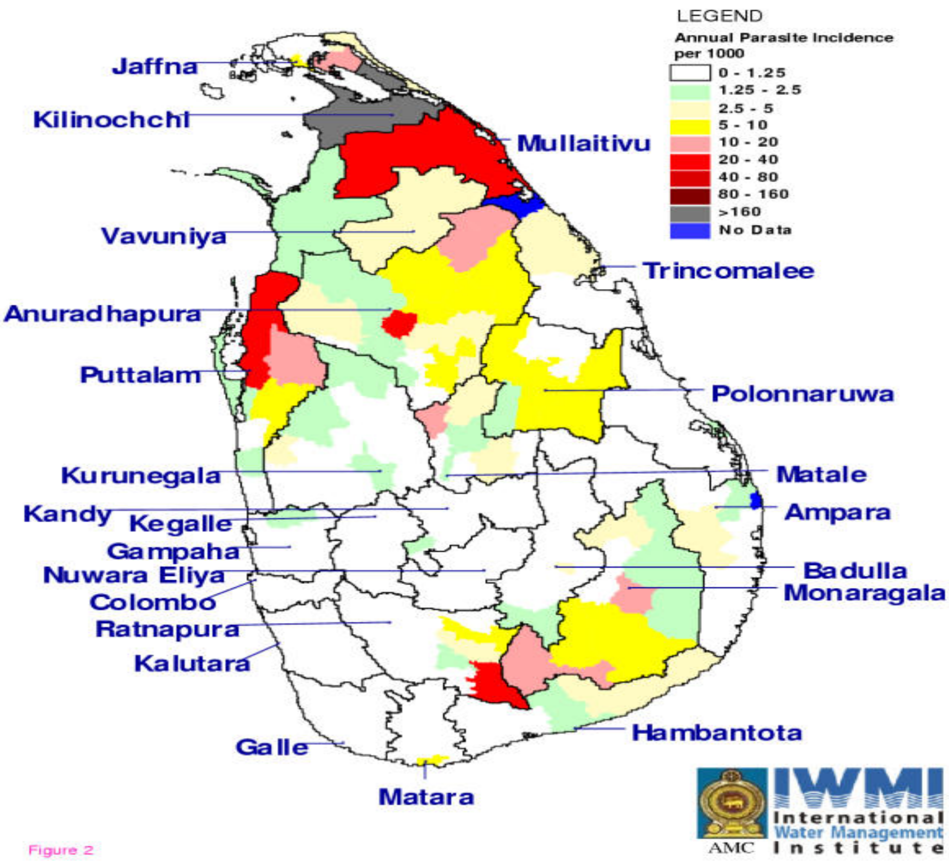

Fig 5: P. Falciparum parasite strain in Sri Lanka

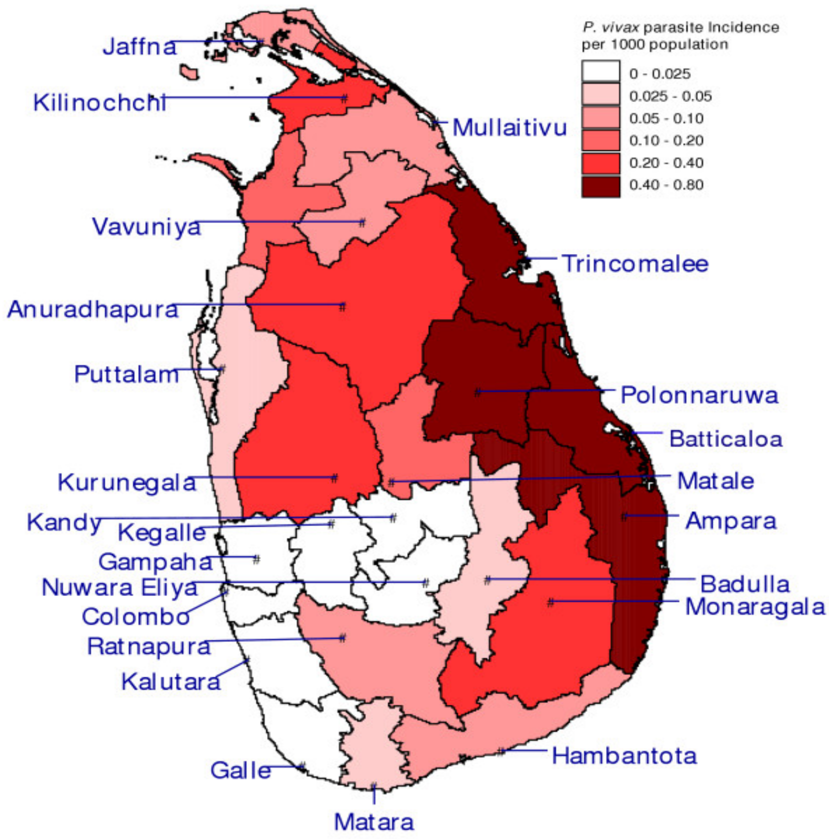

Fig 6: P. Vivax parasite strain in Srilanka

Materials and Methods

<u>Mapping</u>

For Spatial Analysis Aerial photographs of the study taken in 1993 at an altitude of 10,000 m were obtained from the Survey Department. These photographs were enlarged four times to obtain a map having a scale of 1: 5000 with real world coordinates. The exact location of the houses, roads, land use, and forest cover, and significant water bodies like rivers, small streams, and reservoirs, were marked on the map. The accuracy of the exact location of such landmarks was confirmed by geographic reconnaissance (GR) carried out during the preparatory stage of the study.

These analyzed maps were digitized and the GIS package ARC/INFO was used to obtain the nearest distance of a particular house from the forest edge and a source of water. In the case of flowing water bodies, the centre of the flow was used to measure the distance from the water source to the house. All the houses in the study area were numbered, and every house and individual residents in a house were assigned a unique identification number to enable us to monitor malaria infections.

The Monitoring of all malaria infections in the study area was carried out by two methods.

- Passive case detection (PCD)
- Active case detection (ACD)

The Passive case detection entailed the presentation of fever patients for blood film examination and treatment, either at the Field Research Station which is very close to the study area, or at the Government Hospital, Kataragama, which is about 3 km from the study area. Active case detection (ACD) was done by a series of six mass blood surveys at intervals of 2-3 months. ACD was carried out using three or four teams, with each team doing a house-to-house survey and obtaining thin and thick blood films from all residents. A diagnosis of malaria was established by demonstration of malaria parasites on microscopic examination of thin and/or thick blood films stained with Giemsa stain. It is estimated that a very high proportion of all malaria infections occurring in the population was recorded using these methods.

Malaria Incidence Rates according to Type of Houses

All houses in the study area were categorized into two broad classes according to the type of house construction. This categorization was based on the nature of, and building material used for, the walls and roof. Those houses which had incomplete and/or mud walls and roofs made of thatched coconut palms were classified as being of poor construction type and those with complete plastered brick walls and tiled or corrugated iron roofs were classified as being of good construction type.

The nearest distance from a source of water and from the forest edge to each house was determined using the GIS software package ARC/INFO. In estimating the incidence rates of malaria for each house, those houses with two or fewer residents were excluded from the analysis as they may have given unstable rates, thereby leading to errors in inference.

Terms used in the study

The incidence rate in a house was defined as the total number of malaria infections that occurred in individuals resident in the house during the 18-month period, divided by the number of residents in the house.

The average incidence rate for a group of houses (e.g., of a particular construction type) was estimated as the mean incidence rate of the house in that group.

The incidence rate of a population was defined as the number of infections that occurred in that population divided by the size of the population.

Results

Of a total of 423 houses and 1875 residents in this population, only 343 houses and their resident population of 1744 were considered for analysis, the rest being houses with fewer than three residents.

A significant difference was found in average malaria incidence rates among the populations resident in good and poorly constructed house types, being 0.51 and 1.23 infections per person, respectively.

Discussion

Malaria has been prevalent in most parts of the tropical and subtropical world, including parts of Africa, Asia, and Central and South America, for a long time, the disease has been the single most important cause of morbidity in some of these areas. Yet, a desirable level of control has not been achieved during the past two decades, especially by implementation of sophisticated technologies which include GIS.

In a previous study, it was demonstrated that malaria infections in an endemic area were clustered in particular individuals and households **(Gamage-Mendis et al. 1991).** It has also been shown that the incidence of malaria is associated with the construction type of houses. Residents of poorly built houses with incomplete mud walls and thatched roofs were at a higher risk of acquiring malaria than those living in better built houses with complete plastered brick walls and tiled or corrugated iron roofs **(Gunawardena 1994).**

The present study supports earlier findings of an association between malaria risk and house construction type, this study taking place in a different population and conducted over a different period of time. In addition, this study presents a more detailed examination of two other ecological factors that could determine the malaria risk: the proximity of the house to the forest edge and a source of water. Both these factors could, by their association with the mosquito vector, be expected to influence the malaria risk in an endemic community. The forest edge is thought to provide ideal resting places for the mosquito, thus influencing its survival and the level at which malaria transmission is sustained. The water bodies and rivers examined in this analysis are known to be potential breeding places of the mosquito vector. Thus, proximity to both might be expected to impose an added risk for acquiring malaria.

The findings of this study indicate that the risk of contracting malaria was on average 2.5-fold greater for a resident of a poorly constructed house than for one who lives in a well built house. In the first study which demonstrated an association between house types and malaria risk **(Ministry of Health 1991)**, higher densities of mosquitoes were measured and found resting within poorly constructed houses, than in houses of better construction type.

This finding suggests that the risk of being bitten by a mosquito might have been greater within the poorly constructed houses, given that the construction type of the house itself afforded a better respite for the vector. It is nevertheless believed that several other factors associated with the type of house, such as socioeconomic status, education levels, and occupations of the residents, might independently influence the malaria risk. Thus, for the purpose of the discussion that follows, the house construction type is considered as much a marker of the general standard of living, as of the construction type itself.

Houses of both construction types were distributed fairly equally in relation to the sources of water. The relationship between malaria risk and proximity to a source of water was different for houses of the two construction types. For the poorly constructed houses, a significant negative correlation was found with the distance from water, demonstrating a decrease in malaria risk with increasing distance from the water. This was not so in the better constructed houses, in which such a correlation was not apparent. In fact, a trend in the reverse direction was evident, i.e., a tendency for the malaria risk to decrease as the house moved closer to the water source, although at a borderline level of significance. The water bodies considered here are potential breeding sites for the vector mosquito. The increasing risk of malaria in houses located close to these water sources is therefore to be expected, for the reason that a higher density of mosquitoes must prevail in the vicinity and the probability exists for a higher man-mosquito contact closer to the water.

This appears to be so in the case of poorly constructed houses, but not in houses of the better construction type. It thus appears that the risk imposed by being close to a source of water is transcended by an improvement in the house type, be it because of the construction type itself or the associated life styles or characteristics of its residents. If the trend of a decreasing malaria risk in residents of good house type closer to water reaches a level of statistical significance, it would suggest that other factors pertaining to its residents and the house which have not been examined here are more important determinants of malaria risk than the distance from water.

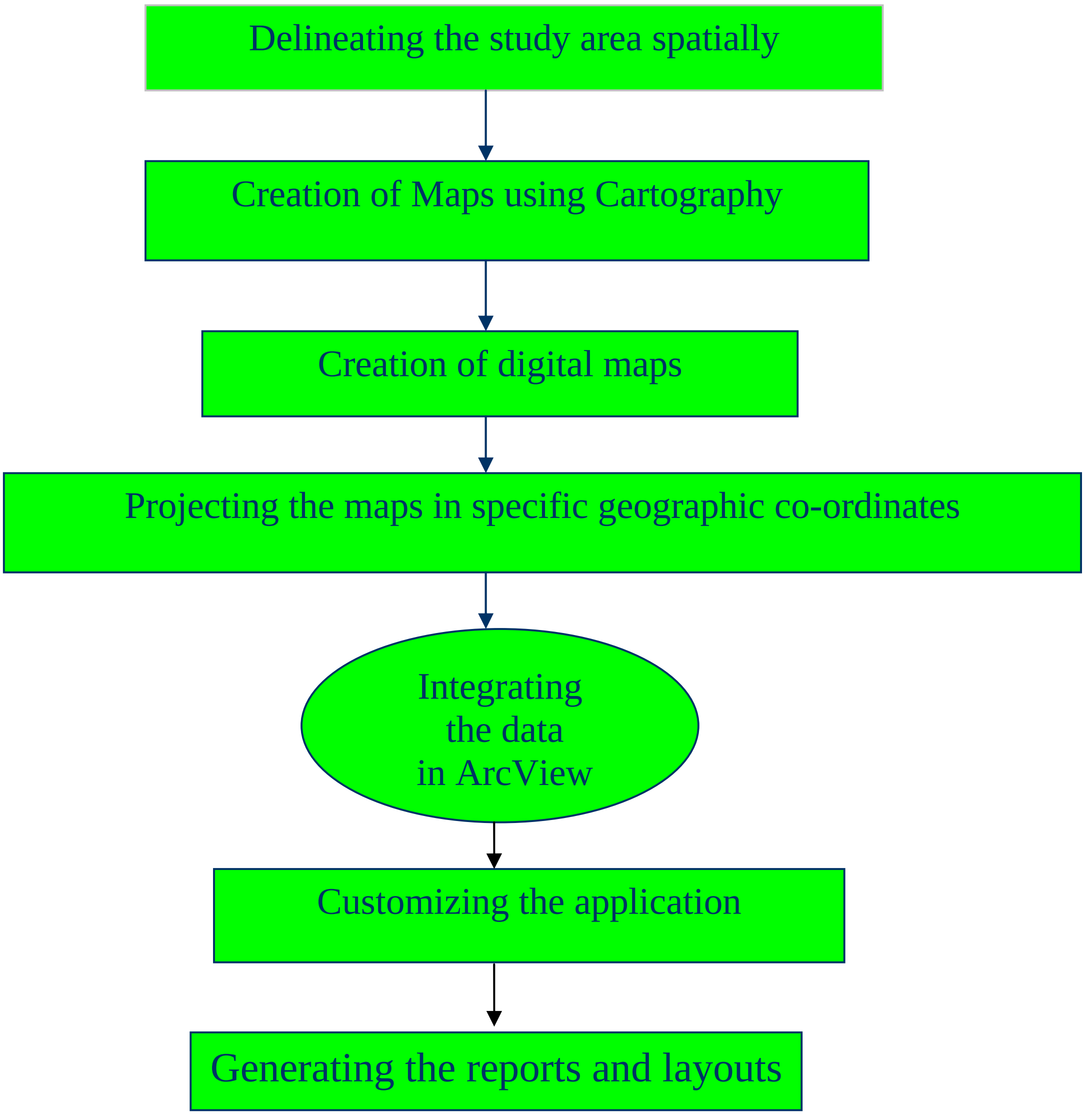

Fig 7: General Map showing link between Spatial Decision Support System and Health

Relevance of GIS to this Study

This study constitutes an example of the use for GIS in health research. The specific advantages offered for this analysis by GIS were as follows:

- The display of the data pertaining to the study area provided an overview of the malaria incidence in relation to geographically and ecologically important entities. It also provided clues for further analysis, e.g., the fact that the better built houses were seen to be spatially clustered around the major roads suggested that house construction type may have confounded the relationship between malaria risk and the two ecological entities — the distances from the forest edge and water; this prompted an analysis of the correlations with these two ecological risk factors separately in the two different house types. The program offered the obvious advantage of reproducibility of high-quality maps for presentation and publication.

- It was possible to obtain accurate distances between selected landmarks which were essential to this study.

The present investigation did not make use of topological features and, therefore, utilized only a fraction of the full potential of a GIS. However, as malaria transmission is dependent on many ecological factors, many more uses for GIS are envisaged, especially in developing models for malaria control.

It is obvious that the usefulness of GIS and the value of inferences made from spatial analyses will depend on the quality of the data used. This analysis was based on data of a very high quality both in terms of accuracy and detail, obtained from a research project. It is probably unrealistic to expect data of such high quality from disease control programs. This study and analysis therefore exemplifies the use of GIS primarily as a tool for health research. Our ultimate goal, however, includes the development of a GIS that will be useful as a decision support system for a malaria control program.

6.2. Case Study from India

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

Malaria is one of the most prevalent diseases in India. Its vast spread has made experts in all fields to think about it in relation to its prevention and control. Nadiad taluka of Kheda district, Gujarat, is situated in western India. Epidemiological investigations demonstrate that malaria is endemic in the state. Kheda district showed the highest incidence of malaria in Gujarat state, with Nadiad taluka consistently being the most affected area. Occasional deaths have occurred due to falciparum malaria, although the area is constantly sprayed with residual insecticides. In 1981, a serious epidemic of *P. falciparum* malaria resulted in the deaths of 31 people in one village alone (Sharma et al. 1986).

A feasibility study using a geographic information system (GIS) was initiated in April 1993 to identify the specific factors responsible for high receptivity and vulnerability to malaria in Nadiad taluka. The aims of this study were to:

- Map various geomorphological, physical, and climatic characteristics of the region;
- Develop a georeferenced database related to malaria; and,
- Identify relevant factors having a direct or indirect bearing on malaria transmission in Nadiad taluka.

Materials and Methods

Agriculture is the predominant source of income in Nadiad taluka. Since 1966 **(Chowdhary et al. 1983)**. The average annual precipitation is about 800 mm, all of which falls during a rainy season of 35 days **(Ashok and Nathan 1983).**

Since stagnation of water for long periods of time is likely to create mosquitogenic conditions, the following factors related to water stagnation were taken into consideration: soil type, water table, irrigation, surface water bodies, topography, climate, drainage, and hydrogeomorphology.

Topological sheets at a scale of 1: 250,000, showing topography and terrain of Nadiad, were obtained from the Survey of India, Dehradun. These sheets were incorporated with satellite images, and a composite map of Nadiad was drawn showing important physical features of the region, such as slope, forest/vegetation, rivers, streams, reservoirs, other water bodies, human settlements, roads, and so on. This map was used to extract the relevant features and specific characters of the region.

Findings

Topography

The Nadiad region is characterized by a generally flat topography, restricted natural drainage soils, and a semi-arid climate. The area slopes northeast to southwest, with an average gradient of about 1-1600 m toward the Gulf of Cambay. There are, however, a few isolated local high spots and ridges. Without the existence of efficient water drainage systems, each of the factors mentioned above can lead to the creation of stagnant water pools, which, in turn, encourage the breeding and survival of mosquitoes.

Hydrogeomorphology

Two categories of geomorphology may be found in Nadiad. Flood plains are found near the shores of the Shedi river and its tributaries. This land feature has developed relatively recently, and its moisture content is very high. Alluvial plains exist throughout the rest of the Nadiad region. The moisture content of the alluvial plains is relatively lower than that found in the flood plains.

Irrigation, Drainage, and Surface Water Bodies

The Mahi River is one of the major river systems in western India. In 1978, a reservoir was constructed on this river for irrigation. The command area of this irrigation system includes the southern half of Nadiad taluka. The abundance of water in irrigated areas is due to seepage, silting, and stagnation, creating innumerable breeding sites for mosquitoes. A thematic map showing details of the irrigation system was prepared and digitized.

Tank irrigation was one of the earliest systems of irrigation to be used in the Nadiad region. Irrigation tanks and ponds, when used together with canal irrigation, act as storage reservoirs. Excess irrigation water is diverted to these tanks, for use for when canal sources become scarce.

Every village in the Nadiad region has at least one pond from which water is gathered. These ponds receive both rain and canal water. In an attempt to fight famine in the Nadiad area, the village ponds were deepened. Although this has created a year-round supply of pond water, it has also created a high local humidity level conducive to heavy vector breeding. The information on pond location was extracted from topological sheets and remote sensing composite maps.

Climate

Climatic features such as rainfall, humidity, and temperature have a direct influence on the propagation of mosquitoes and their survival. This data was plotted to study the relationship between climate and malaria transmission.

Conclusion

ARC/INFO was used to overlay eight maps, producing a composite map of soil type, water tables, topology, hydrogeomorphology, irrigation, drainage and surface water bodies, and climate. The resulting georeferenced data analysis divided Nadiad into four water-holding areas.

When this map was superimposed onto a map showing high, low, and average API (number of malaria cases per 1000 population per year) of 5 years at the local level, the resulting picture is difficult to explain: high API villages do not show any visible correlation to the water holding capacity of the four areas of the composite map.

This result demonstrates that to establish determinants of malaria in Nadiad, it is necessary to analyze other data in addition to that generated by a study of water holding capacity. Additional parameters that could be examined include population movement, labour settlement, intervillage migration, rice cultivation, creation of borrow-pits which supports the breeding of A. *culicifacies*, the outreach of health services, and so on.

It was established that malaria was more prevalent in areas with high water tables, the presence of surface water, and canal irrigation systems, than in riverine villages.

Analysis of climatic data has demonstrated that during years in which the relative humidity (RH) was above 60%, malaria transmission was high, while during years when the RH was below 60%, transmission rates were low. Humidity is, therefore, seen as an important conditioning factor for vector presence, as it governs longevity and, therefore, the reproduction rate of *A. culicifacies*.

It may be noted that the Kheda district in Gujarat does not have a regular malaria transmission pattern. Ground water stagnation is more pronounced where the water table is shallow. In years with favorable climatic conditions, such as high rainfall levels and high humidity, malaria transmission increases within the nonimmune population, creating epidemic situations.

Because of population movement, migration, and poor surveillance, it is difficult to analyze the data at a micro or village level. GIS should, therefore, be applied to macro level analysis to

- Bring out broadly the conditions conducive for vector breeding and malaria transmission and
- Suggest integrated control methods that is both cost effective and sustainable.

6.3. Case Study from Peru

Spatial Patterns of Malaria Case Distribution in Padre Cocha, Peru

Peru is a country which is prone to Malaria. Malaria in Peru has undergone explosive growth during the 1990's, particularly in the Amazonian region of Loreto where more than 60% of the cases have occurred (Figure 1). Causes for the epidemic rise in *Plasmodium vivax* (*P. vivax*) and *Plasmodium falciparum* (*P. falciparum*) infections are thought to include the arrival of the highly efficient vector, *Anopheles darlingi* (*An. darlingi*); the dismantling of household residual insecticide spraying programs that took place prior to the 1990's; the changing patterns of river use; and the ecological disruption related to increasing jungle settlement and natural resource exploitation. **(Aramburu, Ramal, Witzig. 1999)**

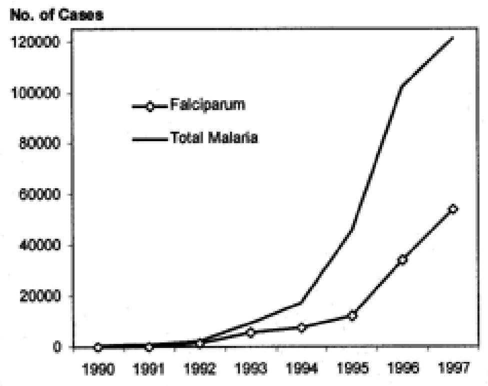

Figure 9: Malaria in Loreto, Peru, 1990–1997.

There has been relatively little study of specific factors related to malaria acquisition and transmission in the Amazon basin, despite the resources that have been expended on treatment and control. In the Department of Loreto, Peru, malaria is more common in adults, particularly males, suggesting occupational risk as well. There have been no studies investigating specific malaria risk factors or spatial relationships in malaria transmission in Loreto to date. As part of an ongoing study of the epidemiology and transmission of malaria in Padre Cocha, Peru, the village was mapped using differential global positioning system (GPS) technology and spatial patterns of the distribution of malaria during the 1997–1998 transmission season were explored.

Method of Application

<u>About Padre Cocha</u>

- Population: 1,400
- Location: 5 km from Iquitos, the Capital of Loreto, at the side of Nanay River (See Fig. 2)
- Rainfall: Mean Annual Rainfall of 4.5m
- Number of Household: 235 Households with a mean of 6 occupants.

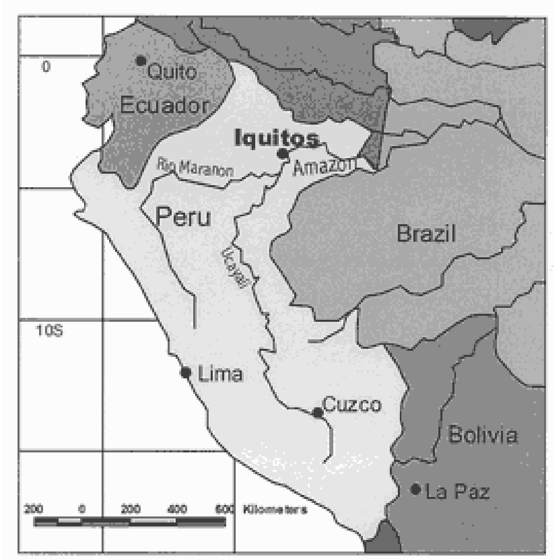

Figure 10: Map of Peru. The study site of Padre Cocha is located 5 km northwest of Iquitos.

In November 1997, all houses, streets, public buildings, and other features of interest in Padre Cocha were mapped in a five-day period using Trimble ProXR GPS receivers. GPS receivers capture radio frequency signals continuously emitted by 21 navigational satellites orbiting the earth at an altitude of approximately 20,200 km (12). During the Padre Cocha mapping, data were received from at least four satellites at any given time, permitting the calculations of latitude, longitude, and altitude. **(French, Herring. 1996)**

To circumvent errors in GPS, post-processing differential correction of locational data, or differential GPS, was employed. For this technique, two receivers storing simultaneous signal information and subject to the same sources of error are required. One receiver is placed at a fixed known location, the base station, while the other is used to record information at remote sites of interest. The data from each receiver are downloaded to a computer program with differential correction capability, are synchronized, and the base station information is used to calibrate the positions recorded by the mobile unit.

For the mapping purpose, one receiver was placed on the middle of a marker with coordinates previously identified by a US Geologic Service survey at the Peruvian Naval Base in Iquitos (latitude 3°44'05" S; longitude 73°14'25" W; altitude 95.5 m). This receiver served as the base station and collected data continuously, while the second receiver simultaneously recorded village feature positions. The locations of all village point features (houses, shops, public buildings, wells) were measured for two minutes with positional fixes taken at one-second intervals. For line and area features, positions were recorded at three-second intervals as lengths or borders were walked. The perimeter of the cocha was recorded from a canoe paddled around its circumference, using a constant offset from the shore. Each house was assigned a unique household identification number at the time that it was mapped, and information about construction type and the presence of home businesses was also recorded. Pathfinder Office software, version 1.10 (Trimble Navigation, Sunnyvale, CA) was used to perform differential correction of all feature locations and to create a locational database for use in geographic information system (GIS) analyses..

While Mapping at Padre Cocha, a community-wide census was performed to obtain basic demographic information. Each identified resident was assigned a unique personal identifier and household address. During the course of the study year, the census database was updated as new residents were identified and former residents moved away.

Malaria case data were collected continuously at the Padre Cocha Health Post from August 1, 1997, through July 31, 1998. Individuals with symptoms suggestive of malaria received Giemsa-stained blood smear examinations by experienced Ministry of Health (MOH) microscopists. Those whose blood smears demonstrated malaria parasites were considered cases and were treated in accordance with Peruvian MOH protocols. Information about smear positivity and treatment response was entered into a registry kept at the Health Post, and was subsequently abstracted and entered into an EpiInfo, version 6.04 (CDC, Atlanta, GA), computer database. Individual malaria case data were grouped by the household in which the infection occurred, and incidence for each household was calculated as the number of malaria episodes occurring during a given time period in each home, divided by the number of people residing in that home during that time period. Because there was movement of residents in and out of households during the year, the incidence for the study year was determined by calculating household incidence for each half of the year, and then summing the two six-month incidences. Household incidence for the low-transmission dry season (August–November), high-transmission wet season (December–March) and the transitional season of declining transmission (April–July) were calculated in the same manner.

Role of GIS:

ArcView software, version 3.0 (Environmental Systems Research Institute, Inc., Redlands, CA), was used for GIS analysis. The Pathfinder locational database was exported as ArcView shape files, entered into ArcView and then merged with household malaria data exported from EpiInfo in Dbase format. Surface interpolations were performed with ArcView Spatial Analyst in order to make patterns of household-specific malaria transmission easier to interpret. This methodology summarizes information collected for all data points within a fixed distance from a given location; or, for a predetermined number of nearest neighbors, computes the mean or median and applies this smoothed estimate to the entire area under consideration. Observations are weighted proportionally to their distance from the center of the defined area. We used linear weighting and restricted consideration to only those households lying within 50 m of each specified point.

This work was conducted under research protocols approved by the scientific and human use committees of the Walter Reed Army Institute of Research (WRAIR Protocol No. 727) and the United States Army Medical Research Institute of Infectious Diseases (USAMRIID, HSRRB Protocol Log No. A-7421, DoD Protocol No. 30558), and the corresponding ethical review committee of the Direccion Regional de Salud de Loreto. In addition, the studies were conducted under Technical and Scientific Letters of Intention between the US Naval Medical Research Center Detachment (NAMRCD), Lima, Peru, and the Direccion Regional de Salud de Loreto and the Vice-Minister of Health (RM No. 237-97-SA/DM of 5 May 97) for the government of Peru.

Results

The Results after the GIS analysis and differential correction are explained below.

Figure 3A shows the map of Padre Cocha using the corrected locations of the November 1997 and May 1998 mappings. The village lies along two main axes with fairly straight streets and house alignments. Figure 3B shows the results of the initial village mapping prior to differential correction. Of note, the cocha appears wrapped over on itself; streets and paths appear crooked and haphazard, and houses have lost relation to each other and the streets. Figure 3C shows readings that were taken at the fixed base station during a five-hour mapping session. Rather than showing a single point, the recorded locations follow a randomly meandering line with occasional abrupt changes in direction or position that reflect moments when satellites enter or leave receiving range. The linear pattern signifies that the errors are highly correlated from one reading to the next, and not statistically independent. Thus, readings taken over short periods of time contain approximately the same error term, and averaging them will not eliminate the error. This persistent error is the underlying cause of the inaccuracies that produced the chaotic uncorrected village map. Once differential correction was performed, the mean standard deviation of point feature positions measured in Padre Cocha was 0.2 m (sd=±0.09).

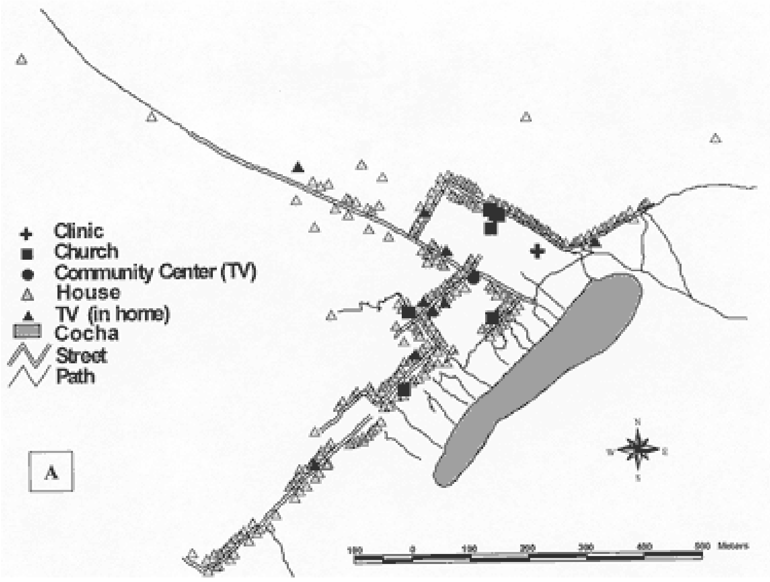

Figure 11: Map of Padre Cocha after differential correction of GPS readings.

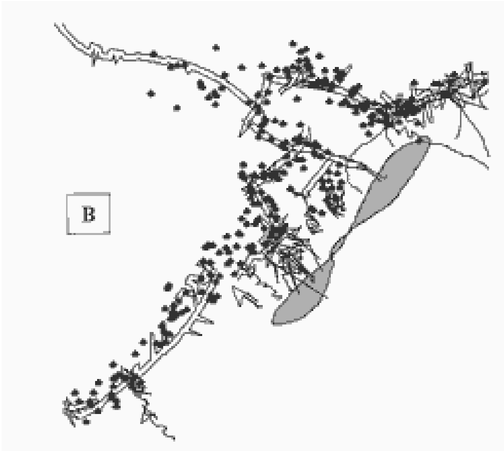

Figure 12: Map of Padre Cocha before differential correction.

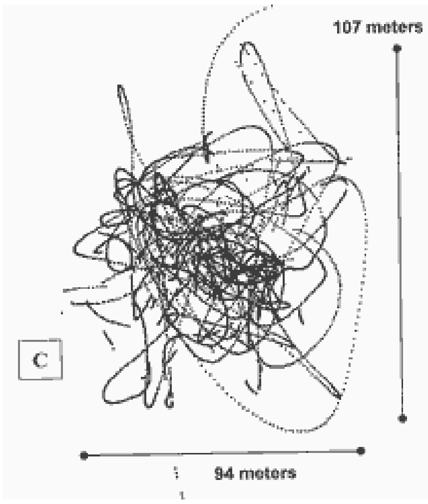

Figure 13: Plot of 5 hours of uncorrected GPS readings at the fixed base station.

During the study year, there were 232 episodes of *P. falciparum* infections (incidence of 16.6%), 1,157 episodes of *P. vivax* (incidence of 82.6%), and a total of 1,300 independent episodes of malaria of either or both species (incidence of 92.9%). Mean household incidences for the year were 15.3% for falciparum malaria, 82.1% for vivax, and 96.7% for either or both. Figure 4 shows the monthly distribution of malaria attack rates in Padre Cocha during the study year.

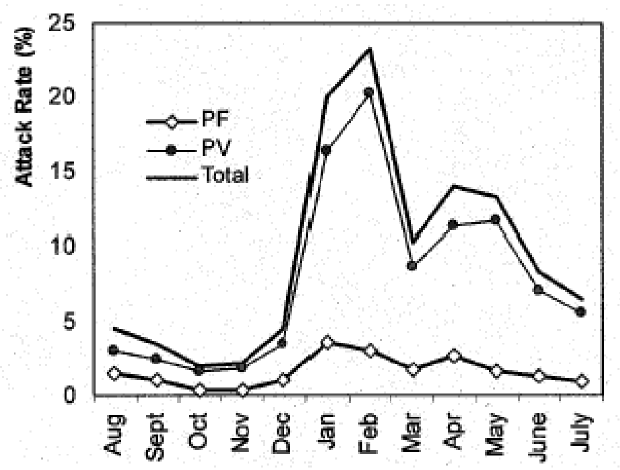

Figure 14: Monthly malaria attack rates in Padre Cocha, 1997–1998.

In Figure 5A, the cumulative number of malaria episodes occurring in each household during the study year was mapped using GIS. Several areas appear to have greater concentrations of infections, while one central area appears to have fewer. To control for household size, household incidence was calculated and plotted, and a surface interpolation was performed to determine area incidence distribution. Clusters of high malaria density and the central area of low malaria intensity were confirmed (Figure 5B).

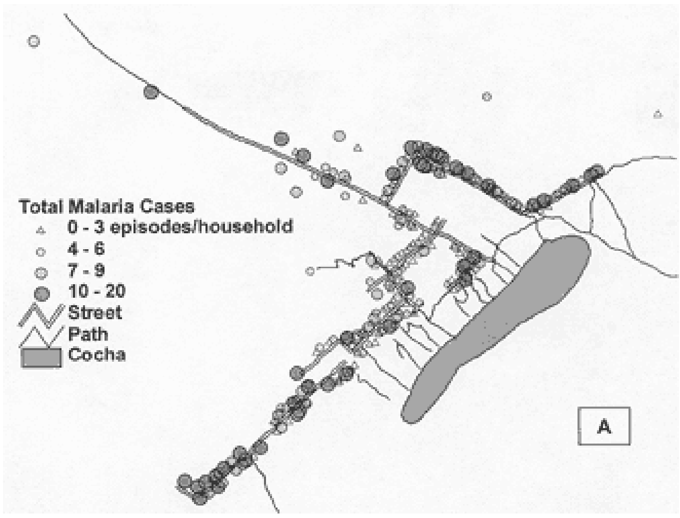

Figure 15: Household distribution of the cumulative number of malaria cases in Padre Cocha, 1997–1998. (GIS Application)

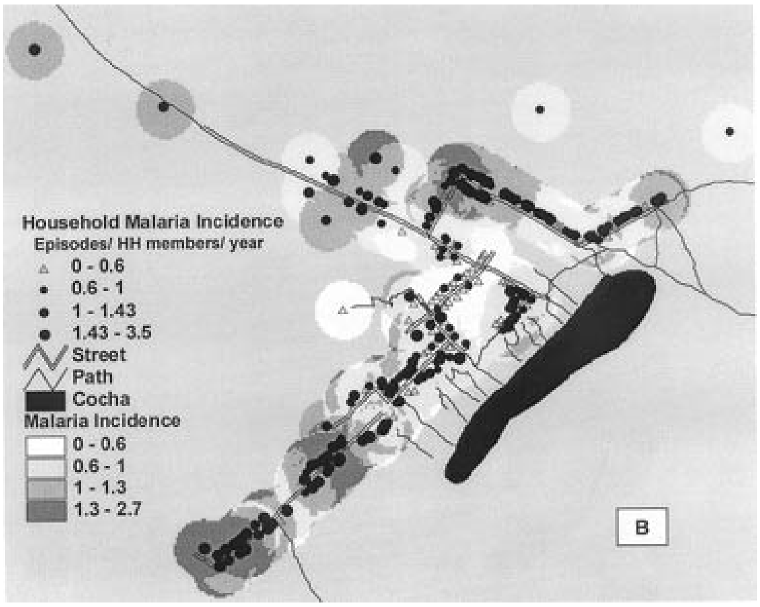

Figure 14: Household malaria incidence and surface interpolation of household incidence demonstrating the spatial distribution of malaria for the study year. (GIS Application)

To exclude neighborhood population density as a factor in malaria occurrence, plots and interpolations of household size were performed. These analyses demonstrated a homogenous population distribution in the inhabited areas of the village throughout the year, supporting the conclusion that population density and household size are not significant determinants of malaria distribution. Similarly, altitude variation within the village perimeter was small and did not match the pattern of malaria distribution. Analysis of the spatial distribution of houses of the two construction types also showed a homogenous pattern throughout the village, and analysis of the relationship of household malaria cumulative incidence to house construction type showed no association (one-way analysis of variance: F=0.5; p=0.61).

Figure 6 demonstrates the results of the examination of spatial patterns of *P. vivax* (left) and *P. falciparum* (right) during the three phases of transmission during the year. At the top (sections A and B), the distribution of infections during the dry season from August through November 1997 is shown. The 1997 dry season was unusually prolonged, and little malaria occurred during that time. The middle sections (C and D) depict the dramatic rise in both vivax and falciparum malaria during the wetter months of December 1997 through March 1998. In the lower sections (E and F), the declining intensity of infections that occurred during the transitional period of April through July 1998 is shown. The general pattern of high and low density clustering noted in Figure 5 was again apparent for each species, and for all three parts of the year.

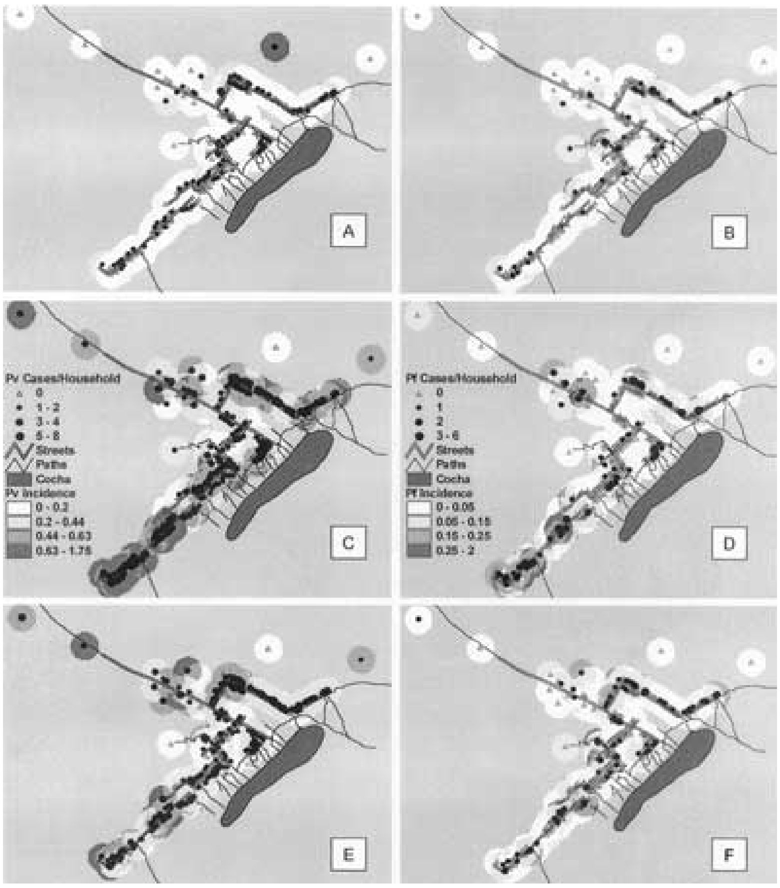

Figure 15: The distribution of cases and incidence of *P. vivax* infections (on left: A, C, E) and *P. falciparum* infections (on right: B, D, F) during the three transmission phases of the study year. A & B depict the dry season of low transmission, August–November. C & D represent the peak transmission period, December–March. E & F show the transitional period of declining transmission, April–July. The scales for cases per household and incidence were held constant throughout the seasons for each species.

The results of adult female mosquito collections are displayed in Figure 7. The total number of mosquitoes collected indoors and outdoors at each of the four stations is listed in the legend. Virtually all mosquitoes collected (>97%) were identified as *An. darlingi*. The underlying surface interpolation represents the malaria incidence for the months of April through August 1998, months during which new human malaria infections would likely have been caused by mosquitoes of the same generations as those being captured. Of note, the capture stations with lower total numbers of indoor and outdoor mosquitoes catches were situated in areas of low malaria density, while those with higher numbers of mosquitoes captured were located in high malaria density areas.

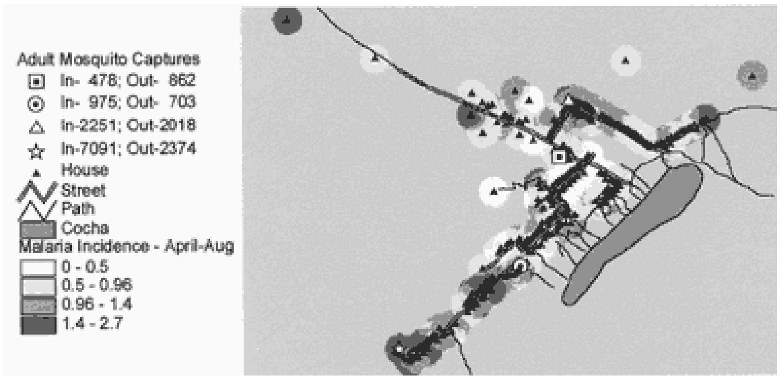

Figure 16: Location of mosquito capture stations and results of adult anopheline mosquito collections, April–August 1998. The underlying distribution of malaria incidence for the corresponding months is also shown.

Discussion

The use of GPS to map study sites is essential for GIS investigations of spatial relationships between exposure factors and disease occurrence in areas for which accurate maps are not available. Further, when the distances between features are small, differential GPS is necessary for adequate discrimination among sampling units. Our study of malaria distribution in Padre Cocha, Peru, is a good example of the importance and power of this technology. In an area of approximately 1 square kilometer, there was clear and consistent spatial clustering of high and low malaria infection density. This spatial heterogeneity was true for both malaria species transmitted in the area, and was evident during periods of both high and low transmission.

A number of potential determinants of the distribution of malaria in Padre Cocha were investigated. Population density distribution, neighborhood altitude, and the spatial distribution of house construction type were unassociated with the pattern of malaria occurrence.

The addition of GPS and GIS technologies to malaria and other vector-borne disease studies affords the possibility of exploring spatial dimensions of disease transmission not easily examined in the absence of these capabilities. Further, the incorporation of these techniques can be performed with a limited addition of time and resources.

The single greatest cost in performing the GPS/GIS work at Padre Cocha was that of the GPS equipment and software, which totaled approximately $20,000. Our system was extremely easy to learn and use, and provided accuracies that met our need for analysis within a small area. The very simplicity of the system eliminated any ongoing need for personnel with prior technical training, reducing personnel costs significantly. However, sophisticated GPS units that offer such ease of use are costly, and if site mapping is likely to be accomplished in a few sessions, leasing units may be preferable to purchase. Further, it is now possible to subscribe to a satellite service that can provide real-time differential correction, abrogating the need for a base station unit. Taking advantage of these cost-reducing measures could make the application of GPS/GIS techniques more feasible for projects with limited budgets.

In summary, differential GPS and GIS systems can add critical information to the understanding of malaria transmission and epidemiology. Technologies that are currently available can be used by researchers without specialized backgrounds, and for moderate cost. In our work at Padre Cocha, spatial analysis contributed to generating study hypotheses, to understanding malaria distribution in the community, and to focusing entomologic research and MOH vector control efforts.

7. Conclusion

1. GIS is a tool which provides a mechanism to integrate different data sets, analyze their spatial and statistical components and model possible scenarios to provide planning and management tools.

2. GIS aids in faster and better health mapping and analysis than the conventional methods. It gives health professionals quick and easy access to large volumes of data. It provides a variety of dynamic analysis tools and display techniques for monitoring and management of epidemics.

3. The study shows the successful integration of Health related problems with GIS for better spatial analysis and results.

4. This study also analyzed the extensive use of spatial decision support system (SDSS) as a tool for solving problems.

5. This study integrated the role of GPS and GIS in one of the case studies; as a result we were able to understand that GPS is very useful for GIS investigation of spatial relationship between exposure factors and disease occurrence in areas for which accurate maps are not available.

6. It is also an important fact that addition of GPS and GIS technologies to Malaria and other vector borne disease studies affords the possibility of exploring spatial dimensions of disease transmission not easily examined in the absence of these capabilities.

7. Finally last but not the least the study made us aware of the fact that GIS integrated with other software is more effective for disease prevention and control, and the use of programming and programmers in the GIS field for development of tools to analyse spatial issues can be a rich source to save time, cost and resources.

8. Recommendations

Although this study mostly indicated the positive aspects of GIS, but sometimes lack of proper understanding and improper implementation can lead to opposite results. Hence following are the possible recommendations related to this study and application of GIS.

1. In developing a GIS application that can be used effectively in a disease control program, it is essential that the important variables are identified and accurate data obtained.

2. Whenever applying GIS, it is pertinent to address the following questions:

   - Should GIS applications for disease control be scientifically evaluated?
   - If these applications are to be evaluated, what criteria should be used?
   - At what point should the evaluation be carried out?

3. It is necessary that if a GIS is to be introduced as a tool to aid control programs, then such applications should be subject to rigorous evaluation.

4. GIS activities require an enormous amount of resources, both in terms of hardware and human resources. Unless there is sufficient scientific evidence to show that GIS applications help in reducing malaria transmission or to prevent any other disease via a better decision support system and implementation of such decisions, it would be an arduous task to convince both policymakers and control personnel of the need to use GIS applications in disease control programs.

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