Review

Challenges in using geographic information systems (GIS) to understand and control malaria in Indonesia
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Abstract

Malaria is a mosquito-borne disease of global concern with 1.5 to 2.7 million people dying each year and many more suffering from it. In Indonesia, malaria is a major public health issue with around six million clinical cases and 700 deaths each year. Malaria is most prevalent in the developing countries of the world. Aid agencies have provided financial and technical assistance to malaria-prone countries in an effort to battle the disease. Over the past decade, the focus of some of this assistance has been in the provision of geographic information systems (GIS) hardware, software and training. In theory, GIS can be a very effective tool in combating malaria, however, in practice there have been a host of challenges to its successful use.

This review is based, in part, on the literature but also on our experience working with the Indonesian Ministry of Health. The review identifies three broad problem areas. The first of these relates to data concerns. Without adequate data, GIS is not very useful. Specific problem areas include: accurate data on the disease and how it is reported; basic environmental data on vegetation, land uses, topography, rainfall, etc.; and demographic data on the movement of people. The second problem area involves technology – specifically computer hardware, GIS software and training. The third problem area concerns methods – assuming the previous data and technological problems have been resolved – how can GIS be used to improve our understanding of malaria? One of the main methodological tools is spatial statistical analysis, however, this is a newly developing field, is not easy to understand and suffers from the fact that there is no agreement on standard methods of analysis.

The paper concludes with a discussion of strategies that can be used to overcome some of these problems. One of these strategies involves using ArcView GIS software in combination with ArcExplorer (a public domain program that can read ArcView files) to deal with the problem of needing multiple copies of GIS software. Another strategy involves the development of a self-paced training package that can be used to train individuals

Background
Malaria is a mosquito-borne disease of global concern with 1.5 to 2.7 million people dying each year and many more suffering from it [1]. In Indonesia, malaria is a major public health issue with six million clinical cases and 700 deaths each year [2]. Malaria is most prevalent in the developing countries of the world. Aid agencies have provided financial and technical assistance to malaria-

prone countries in an effort to battle the disease. Over the past decade, the focus of some of this assistance has been in the provision of geographic information systems hardware, software and training. In theory, GIS can be a very effective tool in combating malaria, however, in practice there have been a host of challenges to its successful use. In 1991, Taylor [3]:3 argued that ..."While GIS has the potential to be of utility in the struggle for development – that potential remains to be realised." One of the issues this paper will attempt to address is whether any progress has been made over the past twelve years.

The focus of this review is to provide some balance in the discussion of GIS and malaria. A review of this type is needed because much of the literature in this area is written by advocates of GIS, and generally does not discuss its limitations This is not very useful to those in under-resourced situations attempting to use GIS for the first time. They quickly find out that there is a gap in the literature which deals with problems. The purpose of this paper is not to suggest that GIS technology should not be used in malaria control/management, but instead to provide some balance by discussing the limitations of GIS in the developing world context.

This review is organised in four sections. The first section provides the literature review which focuses on how and where GIS is currently being used and what limitations it has with respect to malaria control and research. The second section focuses on problems and limitations of GIS from an Indonesian perspective. The third section suggests some strategies to overcome these problems. The final section provides a summary and conclusions.

Literature Review
While there is a growing body of literature on the use of GIS for malaria research and control, there has been no review of the state of the art. There has been, however, a recent review [4] of the role of GIS in dealing with health problems in Africa, but the review provided here is different in at least three ways. First, it is more narrowly focused on the use of GIS for managing and understanding one health problem – malaria. Second it is more broadly focused on the use of GIS worldwide – not just in one part of the world. Third, it provides a more balanced review by examining both the potential and the limitations of using GIS to understand and control malaria. The literature review will attempt to answer four questions with respect to the use of GIS specifically for malaria research and control:

How is it being used?

What software is being used?

Where is it being used?

What are its limitations?

How is GIS currently being used in malaria research and control?
To answer this question, the GIS/malaria literature has been divided into five categories as outlined below.

Mapping malaria incidence/prevalence [5,6]
This is the most basic application and involves mapping the incidence/prevalence of malaria over some geographic area. The focus is on examining past trends as well as the present situation and typically does not include any statistical analysis with the possible exception of correlating malaria incidence/prevalence with population in order to calculate populations at risk [5,41]. The goal with these studies is to see if any obvious patterns exist.

Mapping of relationships between malaria incidence/prevalence and other potentially related variables [7-9]
The timeframe is still on past trends and the present situation. The goal of these studies is to see if any relationships exist between malaria incidence/prevalence and a host of other variables including: temperature, rainfall, etc. [10-12]; land use/land cover; elevation; demographics (age and gender); population movement [13]; climate change [12,14-16]; breeding sites [17,18]; and control programmes [8,19-22]. In most cases these studies involve testing to see if any statistical relationships exist.

Using innovative methods of collecting data [11,22-37]
Because data collection is one of the major limitations of using GIS, innovative ways of collecting data are critical to the success of GIS. For the most part this literature deals with remote sensing in the form of aerial photography and satellite imagery.

Modelling malaria risk [5,38-41]
This literature is future-oriented and focuses on predicting areas of malaria risk. Risk models typically use many of the same variables discussed above – the difference being that statistical relationships are established between malaria incidence/prevalence (the dependant variable) and a range of independent variables in an effort to predict future cases of malaria.

General commentary and reviews of GIS use in malaria control and research [3,4,42-53]
For the most part this literature is of a review nature and does not involve the discussion of any particular research study.

What GIS software is being used?

The refereed literature is probably not the best place to get an idea of the type of GIS software that is used by those dealing with malaria research and control. This is because the software used by malaria researchers is typically different than that used by public health practitioners. A range of reasons for this are noted below. Thus this discussion is based on information obtained primarily from websites and with communications with those working in public health in Indonesia.

ArcView/ArcGIS and various extensions

This software is produced by ESRI, Inc. and represents one of the standards in the industry. This software is used extensively by researchers and to a lesser extent by practitioners. There are other companies that provide extensions to this package such as the EpiAnalyst Extension for ArcView. These products have extensive capabilities however they involve steep learning curves and their costs are generally beyond the means of public health departments.

MapInfo

This is a commercial GIS package developed by MapInfo. This is another popular commercial GIS product, however it does not have as many capabilities as some of the ESRI products have.

EpiInfo/EpiMap

This software was developed by the U.S. Centers for Disease Control. It is freely available and is geared to helping public health professionals develop questionnaires, customise the data entry process and analyse and map data.

HealthMapper

This software was developed jointly by the World Health Organization and UNICEF in response to problems identified by practitioners with most of the commercial GIS packages. Primarily these problems include: difficulty in learning the software; the high cost of software and training; and lack of customised features for analysis of malaria. HealthMapper is available at no cost to public health departments. While the use of the software is widespread in some countries (predominantely in Africa), it is relatively unknown in others. In Indonesia the software has not yet been introduced.

Where is GIS being used for malaria research and control?

Based on the literature it appears that GIS is most often used in sub-Saharan Africa, which is not unexpected given the high rates of malaria in Africa. There is some use in India and Sri Lanka, but very little in Southeast Asia. However, this review of the literature does not represent an unbiased analysis in that it only covers the literature published in English language journals. Based on our experience in Indonesia, we suspect that GIS is being used throughout malaria-prone countries of the world, but the research is not being published in English language journals and thus is not included in this review.

What are the limitations in using GIS for malaria research and control?

Much of literature in this field is about the promise or potential of GIS and not its problems and/or limitations. As Edralin [52] importantly points out, research studies are not representative of typical field situations – they tend to downplay the difficulties. The limitations that have been noted in the literature have been compiled and put into a number of categories as shown below. The categories are ordered by how frequently the limitation/problem/issue was noted in the literature. It should also be noted that a few of the references focus on GIS generally, particularly in the developing world, but a majority are specifically targeted on the use of GIS for malaria research and control. It is important to note the dates of the literature. Tanser and LeSueur [4] argue that some of the GIS problems noted by Yeh [54], Edralin [52] and Fox [51] in the early 1990s, particularly dealing with computer hardware issues, have become less of a problem today.

Lack of qualified staff [4,16,51,52,54,55]

This is the issue that was most frequently mentioned in the literature. The fact that GIS is a relatively new technology means that staff with GIS training and skills are in high demand and beyond the reach of most health department budgets.

Data limitations [4,32,52,54,56]

This is a problem that has faced GIS users for decades in both developed and developing nations. Finding the money to collect new data and to convert paper maps and data into digital format continues to be a problem. In many cases digital data do exist, but there are issues of confidentiality, national security, etc. which have prevented its use by malaria and health-related departments. In response to this limitation the MARA project [5] has built a malaria dataset for the whole of Africa and has distributed it on CD-ROM.

Financial implications of hardware and software [44,51,54,55]

As Tanser and Le Sueur [4] argue, these issues have become less of a problem over the past decade. Hardware and software has become cheaper and today most GIS software works adequately on a standard desktop computer.

Decision-makers do not understand its application [4,51,52,54]

GIS users have not done a very good job of selling their applications to decision-makers. The focus of the selling tends to get caught up in technical jargon and not in the fact that a GIS can quickly make maps, and that maps are

much easier to understand than tables. Because many do not understand what GIS does and what it could do, getting financial support continues to be a problem. This was a problem identified in the early days of GIS and it remains a problem today.

Scale not understood/misinterpretation of results [4,32,55]
This problem is related to the lack of training. While it is possible to find sources of training for GIS generally, it is far more difficult, if not impossible, for most individuals to find training on the use of GIS for understanding malaria.

Lack of software to perform spatial analysis [32,54,57]
This is a more recent issue dealing with the problem that most GIS software does not adequately handle spatial statistics. In fact, the discipline of spatial statistics is in the early development stage and is not well understood by most users.

Lack of software/controlled by outsiders [4,44]
The most used GIS software typically originates from the United States or Europe. In some cases this results in problems getting copies of the software as well as getting support for the software, particularly if the problem cannot be solved via telephone or email.

Over dominance by GIS technocrats [54]
Yeh [54] argues that many GIS applications are developed by staff trained in computer science and cartography and are more interested in GIS research than in developing practical GIS applications.

This list of problems and limitations of using GIS is not intended to discourage the use of GIS for malaria research and control. The list is provided in an effort to focus attention and effort on overcoming these problems.

Even though potential users may face some of these problems, that is not to say that they should not use GIS. There are ways in which GIS can be useful in malaria research and control and as Sweeney [44] suggests, GIS applications should correspond to the available infrastructure.

Challenges in using GIS in Indonesia
While the review focused on problems and limitation of GIS that have been identified in the literature, this section focuses on how these problems/limitations have presented themselves in the Indonesian context. This section is based primarily on the authors' experiences in working with the Indonesian Ministry of Health and in supervising numerous Master's theses which used GIS in an attempt to better understand malaria in Indonesia.

The challenges in using GIS for malaria research can be organised in three areas. The first relates to data concerns. Without adequate data, GIS is not very useful. Specific problem areas include: accurate data on the disease and how it is reported; basic environmental data on vegetation, land uses, topography, rainfall, etc.; and demographic data on the movement of people. The second area relates to technology – specifically computer hardware, GIS software and training. The third area concerns methods – assuming the previous data and technological problems have been resolved – how can GIS be used to improve our understanding of malaria? As noted earlier spatial statistical analysis is a newly developing field and has no agreed upon or standard methodologies.

Data Problems
Disease reporting problems
Specifically these include:

Repeat visits to a clinic by the same individual in a given reporting period (which gets counted as two or more cases depending on the number of visits);

Out-of-date information or non-reporting of data due to technical problems or because the local clinic does not see the value in sending data to the Ministry for processing – they know what is happening and do not need the head office interpreting the data for them and do not understand the importance of the data in a wider management context;

Difficulties in linking the disease data with the GIS system that resides in the Ministry of Health headquarters;

People not visiting the nearest clinic (for a variety of personal reasons);

People diagnosed with malaria but not verified with blood test;

People not visiting a clinic even though they may have malaria.

Environmental data on vegetation, land use, topography, rainfall, temperature
These problems can include:

Data is too specialised or may not be available;

The spatial scale of data is not appropriate for many types of analyses (land cover may be appropriate for district-wide analysis but not for local/village analysis because small features such as ponds and localised wetlands are not shown)

Data is only available in paper form (and may lack information on date, source, scale, projection, etc.);

Data may exist in digital form but is not readily available due to institutional sharing arrangements (government departments may not share data with one another) or because they do not know that certain data exist or because the data may have military value and is classified;

Weather data (rainfall and temperature) is not usually available at the scale needed for analysis – there are usually only one or two weather stations in a district and some parameters relevant to malaria transmission may not be measured at all, such as wind speed and direction which affects the vector-people interaction;

Movement of people – regional and countrywide
One of the known factors in spreading malaria is movement of people. There are few, if any, timely data on the movement of people within a country – either locally or regionally. What is generally known is anecdotal based on interviews with residents. Also a factor is the movement of workers that occurs over holiday periods when they return to their home villages.

Scale of data
This concept misunderstood by many. The accuracy of a map or dataset is dependent on scale and becomes problematic when map scales are changed or when datasets are merged. For example, problems can arise when a vegetation dataset collected via satellite is combined with village level data on malaria incidence. Trying to establish a relationship between vegetation type and malaria using these two datasets can be misleading. As Oppong [58:2] argues "...availability of spatially referenced health data does not mean that data is suitable or even usable for GIS analysis." However, such datasets can be useful at district or regional scales as demonstrated by the MARA Project [5].

Technology Problems
Computer hardware
Compared to the situation in 1991 [54], this is becoming less of a problem that as noted by Tanser and Le Sueur[4]. However, some problems still exist, such as having to keep up with new operating systems (Windows 95 vs. Windows 2000, etc.)

GIS software
The main problem with software is cost. While a single copy of the software is manageable – what is unmanageable are multiple copies of the software. The cost for site licenses for most mainstream GIS packages is far too expensive for most health departments. This problem will be resolved once HealthMapper is introduced into Indonesia. This is anticipated within the next year or so. With-

out this public domain software, the Indonesian solution to this problem was for the Ministry to write their own simple mapping software for district and sub-district offices. While this saved money, it was a time consuming task and the software does not have the capabilities of ArcView or MapInfo.

Training on how to use the software
There are two levels of training issues. The first relates to how to use a basic GIS package. The second relates to how to use GIS software to better understand and manage malaria. In many ways the first issue is easier to resolve. There are many books written on how to use GIS, ESRI provides on-line training and many Aid organisations provide GIS training. The problem that often occurs is a lack of coordination in this training. For example, people are sent off to get training but then do not have computers or software available when they return. Or the person that gets the training is not the one that really needs to know how to use the software. The other main training issue is how to use GIS specifically for malaria control. There is very little training material in this regard. Just knowing GIS does not mean that one can use it effectively to deal with malaria research and control. A review of the literature does provide some information is this regard, however, as noted in the introduction, much of the GIS and malaria literature focuses on what is possible and not on the problems and limitations of using GIS. Another noted shortcoming of the literature is that it is not appropriate for training purposes – it is geared to promote the application but not to explain in detail how it can be used.

Methodology Problems
Spatial statistical analysis – how can spatial analysis help in understanding malaria? This is closely related to the training problems noted above. There are two aspects to this issue. The first is of not having appropriate software. The second is that even with appropriate software, how does one use it, interpret the results and use this information in a management context? Most GIS software does not deal with spatial statistics and those wanting to perform this type of analysis must use another piece of software or with an add-on module such as ESRI's Geostatistical Analyst. There is little guidance in the literature on how to use spatial statistics. This is a general problem and not limited to public health or malaria. Being able to generate maps that show malaria incidence/prevalence by month or year is clearly a step forward. However, interpreting what it means is another matter altogether.

Strategies to overcome obstacles
Below are some suggested strategies to overcome the obstacles discussed above. Unfortunately, some of these

obstacles have no quick and easy solutions – they will require a concentrated effort, time and money.

Data

One way of approaching data problems is to set up a pilot program. A pilot program would have several benefits including: showing decision makers what is possible; working out problems on a small scale before launching a program nationwide; determining costs for collecting data or converting if from analog format. A good first step would be to canvas other government departments for ditigal data. Often the forestry, mining, and/or natural resource departments are more advanced and have good GIS datasets and may be willing to collaborate and share data.

One particular problem relates to weather data. Typically these data are collected at established weather stations and these are not always appropriate for use in understanding malaria. There are two options if this is the case. One involves interpolating/extrapolating the data by using special tools found in a GIS. This is not a very good solution because it tends to not be very accurate, particularly if there are large variations in the data (rainfall or temperature). The second option is to add more stations. This provides more accurate data but cannot be retrospective and takes time to accumulate the necessary data to perform analyses. A third possibility is to use indicators of weather conditions relevant to malaria transmission, such as rainfall, using remotely sensed data, generally satellite.

If the data exist on paper but not digitally, they can be converted to digital format by hand digitising or automated scanning. Hand digitising is labour intensive, but the equipment costs are low requiring only a digitizing table. The technology has been around for several decades and is simple and easy to use. Automated scanning is far less labour intensive, but it requires more sophisticated hardware and software. First, it requires a large format scanner that can scan A1 or A0 sized paper maps. Such scanners can be expensive and generally cost more than a computer. Second, some special purpose software is needed to convert the scanned image into GIS compatible format. The software to do this task is not overly complicated, but can cost upwards of US$1,500. Depending on the number of maps that must be scanned, this process can be contracted out for less cost than buying a scanner and software.

One critical issue involved in digitising is to make sure that the base maps used for digitising have basic information such as projection, origin (north arrow), scale, source of data, legend, date, author. While this may seem to be a minor concern, our experience suggests that many maps do not have the necessary information to make them use-ful in a GIS environment. A map without a projection or scale can be scanned using the process described above, but it must be adjusted or matched with other data to determine the projection/scale and this can be a technical, tedious and time-consuming process. Date of map may be important if it shows characteristics which may change relatively rapidly, such as population distribution or land cover/ use.

One data problem that is particularly difficult to deal with involves the movement of people – imported malaria from one district to the next. While there may be some data available from the census, it is usually too old or not done frequently enough to be useful for malaria research. The primary option is for health officers to conduct special surveys to determine the movement of people. While this can result in accurate data, it cannot be used historically and takes time and money to collect. This may be a part of a pilot study.

Technology

The main technological issue involves acquisition of multiple copies of GIS software. There are a couple of proposed solutions to this problem. First is to get HealthMapper introduced into the country. It is freely available, is relatively easy to use and is bundled with relevant data. There have also been training packages developed using HealthMapper specifically geared to those working in malaria control (see http://www.malaria.org.zw).

A second proposed solution is to use a combination of commercial software and public domain software together – like ArcView and ArcExplorer. Both of these software packages are produced by ESRI and they are compatible in terms of data formats and the "look and feel" of the program. The main office can take the data collected by the field offices, create maps and perform sophisticated analyses and then send them back to the field offices where they can be displayed and examined. With a developed routine for analysis the feedback could be rapid and useful in focusing attention and resources on emerging problems An added advantage of this strategy is that field personnel get to start using a very simple mapping package that operates in much the same way as the full-featured ArcView. Once funds are available to upgrade to ArcView, there are fewer problems with learning how to use new software and with incompatible file formats.

Methodology

It may take some time before the methodological issues discussed above are resolved. In the meantime, what can be done? Before a great deal of effort is spent on collecting data and setting up a GIS, some thought should be given as to what is to be accomplished. As noted by Yeh [54], the

technical considerations often tend to receive more attention with less effort or thought given as to what analysis needs to be done. Another common problem is to focus too much on data collection. Often just mapping malaria incidence/prevalence is not sufficient. There is a need for more in-depth analysis that often requires different expertise (not that of a GIS technician). It is critical to have someone who is trained (or has skills) in GIS/spatial analysis and malaria. Having expertise in just one of these areas in not enough. There should be an overall strategy to using GIS. While the strategy might begin with data collection and acquisition of GIS software, it must also include the types of analysis that need to be done and how those analyses might be interpreted.

There are many areas where GIS can be used in controlling and understanding malaria and the most promising one is to speed up the time it takes to get field data converted into malaria incidence/prevalence maps. The move to a real-time system would be very helpful in allocating limited resources for mosquito control. At present the maps provide an indication of where there have been cases of malaria – but usually too much time has passed for these maps to be useful in mosquito or disease control.

Conclusions

While the projects such as MARA [5] and others described by Nobre and de Vries [38,57] are encouraging, it should be remembered that they are research projects that have had significant resources devoted to them. They do not necessarily represent the realities of working in a district office in Central Indonesia. From this perspective the potential of GIS remains largely unrealised. While GIS might be making some inroads in central/head offices, this has not necessarily translated into progress in the field. Some progress has been made since Yeh's [54] assessment, however, there are other areas where little has been accomplished. The introduction of software like HealthMapper would improve this situation dramatically.

Does this assessment mean that GIS should not be used in controlling and understanding malaria? No, in fact it points the way forward. There are two important recommendations that emanate from this review. First, as new research is published in this field, it should provide a more balanced view – describing the things that worked as well as those that did not. We believe that focusing on the potential and not on the problems and limitations only holds the field back. In order to resolve problems and limitations they must be identified and discussed. Second, as Sweeney [44] suggests, the ways in which GIS is used should be viewed in light of the available infrastructure. As this review has shown, there are many ways that GIS can be used – from simple mapping of malaria incidence/ prevalence all the way to sophisticated risk models. If a

health district only has a digital base map and records of malaria incidence/prevalence, it should begin its use of GIS by focusing on basic mapping and not on the development of a malaria risk model.

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