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Role of Geographical Information System (GIS) in Surveillance and Monitoring of Animal Diseases

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Abstract: Monitoring animal diseases and mapping of affected farms have been arduous challenging task in the field of veterinary epidemiology and its the bedrock of coordinated disease control programme. Advances in the discipline of Geography (GIS) have provided tools to evaluate different strategies to manage and prevent the spread of infectious animal diseases. This paper describes an overview of the possibilities and potential uses of a Geographical Information System (GIS) in the field of surveillance and monitoring of animal diseases. The areas in which GIS and special GIS-functions could be incorporated are presented: recording and reporting information, epidemic emergency, cluster analysis, modeling disease spread, and planning control strategies. The paper further presents few examples of where the GIS have been applied to studies of epidemiology and surveillance of animal diseases, which demonstrate the significant value of GIS in these areas.

Keywords: **Epidemiology, Geographical Information Systems, Monitoring, Mapping and Surveillance.**

Introduction

The emergence and re-emergence of zoonotic diseases pose serious challenges to both the veterinarians and other professionals who are usually the first line of defence of public health (Sharubutu, 2008). Over the last fifty years, up to 75% of emerging disease outbreaks in humans such as avian flu, Ebola virus, infection, rabies, West Nile virus infection, Salmonellosis, lyme disease, tuberculosis, severe acute respiratory syndrome(SAR) and gastroenteritis are zoonotic disease are trans-boundary, respecting no territorial or geographic borders, stealthily spreading worldwide. As aptly illustrate by the ongoing worldwide occurrence of avian flu (and other emerging diseases) outbreaks, animal diseases and human health problems transcend local and international borders and requiring attention of their geographic, spatial and temporal patterns before effective prevention and control can be implemented. Going-by, the emerging need to support a bioterrorism preparedness effort, animal diseases are coming under increased scrutiny for early warning signs of intentional introduction of infectious agents, either directly aimed at human targets or indirectly at the food supply and economy.

Geo-Information (Information Tie)

The Animal Disease Surveillance application is one component of an integrated decision management system that integrates animal and communicable disease reports, syndromic and sentinel surveillance efforts, and environmental health to develop an interactive knowledge base to support an early warning capability for disease surveillance.

The system can be used by veterinarians and veterinarian epidemiologists at:

- Department of Health (DOH) to track zoonotic diseases.
- Department of Agriculture (DOA) to track livestock diseases.
- Department of Natural Resources (DNR) to track wildlife diseases; and
- Zoo.

Geographical Information System

As quoted in Bailey (1990) the Association of Geographical information has defined GIS in terms of a computerized data base management system for capturing, storing, validating, maintaining, analyzing, displaying and management spatially referenced data with a primary function to integrate data from a variety of sources." There are only few systems which would satisfy all these criteria.

A Geographic Information Systems shares all the advantages of any computerized information management system, and is able to go much further. Its ability to include the spatial component of any type of data enables powerful spatial analysis, essential for any epidemiological investigation, as well as greatly simplifying the interpretation of animal health information through the presentation of disease and risk factor maps (Angus, 1997) . GIS technology needs strong analysis and modeling capabilities, if it is to meet up with its potential as a general-purpose tool for handling spatial data. GIS consists of four major components for input, storage, manipulation and output of geographical data. They are used as tools for analysis, modeling and decision- making.

Component of GIS

When considering the use of a GIS there are number of issues in relation to the four major GIS components (Table I) which have to be taken into account.

Table 1: Components and Functionalities of GIS

GIS Component	Use	Issues
Input	digitizing, scanning	cost, quality
Storage	data structures	volume vs. speed, raster vs. vector, Layers vs. objects
Manipulation	analysis, modeling	function, Response time, Menus vs. commands Error propagation
Output	plot, print, display	cartographic design. Visualization

Source: Authors Work, 2010

Input

Capturing of spatial data is widely done through manual digitizing, despite its high cost and tediousness. The cost for digitizing or scanning can vary for US$ 500.000 to US$ 20 million. However, it is a strenuous exercise when the size of the area is large and amount of detail required is also much. In situations, where the coverage is large modern data-capture technology including Global Positioning Systems (GPS), remote sensing with improved spectral and temporal resolutions (SPOT-4 and Landsat-7), scan digitizing, field computers. Possibly in the near future numerical cameras can provide accurate and up-to-date geographical data which does not have to be digitized manually from maps (Muller 1993). Meanwhile, the linkage of remote sensing information with GIS is still seen as major challenge (Dobson 1993).

There are a number of problems with regard to data quality. Any digital representation of geographic data introduces bias and error. The National Committee for Digital Cartographic Data Standards identified six components of digital cartographic data. These are lineage, positional accuracy, attributes accuracy, logical consistency, completeness and temporal accuracy. Errors can be due to temporal changes since the data was captured, they can occur during capturing and through the process of discretization required to represent within GIS real continuous or stochastic variation. Given the availability of spatial data from various sources, one major problem is the conversion and translation between the different formats which are used for storage. During this process, information can be lost.

Storage

A GIS database captures real geographic variation in the form of a finite number of discrete digital objects. As geographical variation is typically continuous and complex, the process of capturing reality must involve abstraction, generalization and approximation. The rules defining the objects and their relationships are termed data model. Data models of GIS take two broad forms; one represents reality as an empty space populated by objects while the other refers to a set of layers or fields, each defining the spatial variation of one variable (Godchild, *et. al.* 1992). The layer view predominates in currently available GIS software but the object-oriented approach is emerging as an attractive alternative.

Both object and layer view produce sets of points, lines and areas which can be represented digitally using two types of data structure: raster- or vector- format. In raster-based systems, geographical variation is represented by dividing the world into discrete, uniform-sized elements, normally rectangular, called cells, pixels or grid cells, and specifying their content in a standard sequence, normally row by row from the top left corner. In vector-based systems, geographical variation is represented by identifying all point, line and area objects present and specifying each one's location. Raster-based systems are convenient for storage and manipulation of region-type features and information from remotely sensed image data. However, processing speed can be extremely slow. In order to achieve high resolution, cell size must be very small, and this may result in large data sets which are time-consuming to process. Line-type of features is also difficult to represent. However, resolutions in vector-based systems can be very high; this is because the actual coordinates of geographical features are stored. With arc-or polygon features the number of points used to define the shape of the feature determines the resolution. The disadvantage of vector-based system has to do with manipulation of information which tends to be much more complex.

Manipulation

Manipulation of geographical information is one of the strengths of GIS technology. The simplest form of manipulation would be querying of data. Different layers of information can be overlaid and logical or arithmetic transformations between them can be performed. Measurement within and between layers can be carried out to determine the size of areas, the length of lines and the distance between features. Buffer zones can also be generated around geographical features.

There is a wide range of specific GIS functions available. Godchild (1992) listed 60 generic functions for data manipulation and analysis. Commercial software such as ARC/INFO (Environmental Systems Research Institute, Redlands, California, U.S.A.) already has about a 1000 different functions. Despite this proliferation of GIS function it is widely acknowledged that there is still lack of integration between GIS and spatial analysis. The analytical functionality of GIS is still comparatively simple. It is limited to primitive geometric operations such as calculating the centroid of polygons, or building buffers around lines and may include more complex operations such as determining the shortest path through a network. There are currently developments where separate spatial analysis software is loosely coupled with GIS (SpaceStat, S-Plus), but there is no effective form of tight coupling where data can be passed from the GIS to the analysis module without loss of spatial structures, such as topology (Godchild 1992).

Fotheringham and Rogerson (1993) describe a number of impediments of spatial analysis. Amount these include the modifiable areal unit problem, boundary problems, spatial interpolation, spatial sampling procedures, spatial autocorrelation and goodness-of-fit in spatial modeling which all could lead to miscues of spatial analytical techniques, all these become available as standard functions in GIS. Decision analytical capabilities are just being integrated into GIS systems and will probably become more widely used in the future.

Over the last couples of years GIS software has become more user-friendly, but most systems still require extensive training. More functionality typically results in more complex systems in the early stages of development of such new technologies, until the size of the user group begins to expand rapidly and attention of developer's shifts to making the software useable to non-experts. This process is currently in the early stages for GIS.

From the collection of the original data to data analysis and manipulation, error propagation occurs which (depending on the quality of the original information and the procedures during processing) can produce completely erroneous results. It is now generally recognize that GIS systems should provide the user with confidence limits associated with the results of modeling (Burrough 1992). GIS can be made to operate at various administrative levels to suit the nature of the particular disease problem. For example, the endemic disease system can handle disease control decisions down to the district level. It was developed in New Zealand and used by district managers for controlling of tuberculosis in wildlife. It could also be used by farmers in developing individual farm control plans. Vegetation/ land use data will be derived from satellite photographs, and linked to farm boundary information plus information on farm and animal ownership, in order to plan control programs.

GIS in Veterinary Health

GIS has variety of applications in veterinary public health. It is used particularly for situations where environment or habitat factors influence disease occurrence. Occurrence of rabies is one obvious example where the technique has particular application, but there are numerous examples among other disease in various countries. GIS will mainly be adopted first in research on zoonoses. Here, GIS will be in form of integrated decision support systems which make field disease control programs more effective, and target them more precisely to control needs.

Usefulness of GIS functions in Veterinary Surveillance

The potential applications for GIS in animal disease control range from use in epidemiological field studies and simulation to use in animal disease surveillance. The main two areas of use in epidemiological field studies include the ***visual display of geographical patterns*** and ***spatial analysis***. GIS provides digital maps which can be used in epidemiological simulation to contribute realistic geographical information. In the area of disease surveillance GIS can be used to produce maps of disease occurrence which provides an effective means of disease spread control.

Recording and Reporting Disease Information

The visual display of phenomena provides a very effective descriptive analytical tool. Pfeifer (1994) used this method to describe the spatial occurrences of different strains of *Mycobacterium bovis* in a wild animal population which allowed inferences on the importance of specific disease transmission paths. Lawrence (1991) used GIS to display the distribution of brown ear ticks in South Africa, retrospectively comparing the eco-climatic favourability of particular locations for *Rhipicephalus appendicultus* with the occurrence of East Coast fever.

In the area of disease reporting GIS is very a useful tool for providing maps of the spatial distribution of disease. By its up-to-date database, new maps representing the most current situation can be studied over time. The level of aggregation of the original information is under the control of the user who can decide whether to present the location of actual cases or the incidence on a local, regional, country and international level. GIS can be used to produce maps of disease incidence, prevalence, and mortality, morbidity on farm, region, or national levels. The information is more easily understood when visualised on a map.

Spatial Analysis

Spatial analysis using GIS provides wide range of operations. Typically they relate to analyses within or between layers of geographical data provided by the GIS. In spatial analysis, three different types of spatial data can be analysed. These include: *pointpattern*, *geostatistical data* and *lattice data*.

i. ***Point Patterns***:

The analysis of point patterns in veterinary epidemiology is pertinent as it allows inferences on the occurrence of spatial clustering. The presence of clustering would suggest infectiousness of the presence of specific environmental risk factors. Statistical methodology allows us to assess if a point pattern or regular, random or clustered had occurred. Based on this information further analyses can be conducted to identify areas of locally increased risk or even factors which influence transmission probability. *Kitron. et. al.* (1991) studied the occurrence of Lyme disease and identified environmental factors as the major cause of the disease spread. *Perry, et. al.* (1991) used GIS to investigate the occurrence of *Rhipicephalus appendiculatus* in Africa by identifying the factors controlling the distribution of the vector tick which transmits the parasite *Theileria parva* causing East Coast fever, Corridor disease and January disease in cattle.

Pfeiffer (1994) used GIS to locate points of disease incidence of specific geographical variables such as the height above sea level, aspect, slope and distance to features of interest which were then used as variables in multivariate statistical analysis. Clifton-Hadley (1993) used spatial descriptive measures, spatial autocorrelation and distance to particular features of interest to analyse patterns of occurrence of badger-related tuberculosis breakdowns of cattle herds in south-west England.

ii Geostatistical data

This type of data represents continuous variation of a feature attribute such as height above sea level in space. GIS cannot represent true continuous variation. An approximation can be achieved by increasing the resolution of map layer. With geostatistical data techniques, spatial interpolation become important as this kind of data is collected using a sampling and values between sampling points have to be interpolated. Some GIS provide the technique of Thiessen polygons (voronoi or Dirichlet cells) which divides a region up into polygons around each sampling point assuming that the values for unvisited points within a particular polygon are likely to be similar to the value at the nearest sample point. Pfeiffer (1994) used this technique to generate polygon from point locations describing the areas where particular Mycobacterium bovis strains occurred. This technique can be appropriate for presence/absence type information. If the data at the sample points is measured on a continuous scale it is necessary to use statistical model for the generation of the surface. Technique such as trend surface regression and kriging are available for this purpose. Kriging is the preferable technique as it allows the interpolation error to be mapped and is considered from the statistical viewpoint as the most satisfactory method for interpolation (Oliver and Webster, 1990). Pfeiffer (1994) used kriging geostatistical spatial interpolation technique to produce surface of disease prevalence estimates at sample point and *Lessard et al* (1990) used an inverse distance-weighted mathematical algorithm to interpolate climatic measurements between sample points.

iii Lattice data

Lattice data represents discrete variation in space based on regular or irregular units. These units can be farm or administrative boundaries for example. GIS are particularly strong in the area of manipulation of lattice data. For further statistical analysis, it is necessary to quantify spatial dependence in such data sets which requires generation of contiguity or spatial weights matrices. This is quite difficult to achieve in currently available GIS software and there are only few specialized spatial statistics software packages (e.g. spaceSTAT) which can perform such operations.

Simple manipulations of lattice data include overlay operation which allow mathematical or logical operations between layers of data. It is possible to generate layers of data representing the smallest common geometry which contain the attribute information from all original layers. This data can be used for further analysis and evaluation (Haslett, 1990).

Lattice data can be analysed within the same layer of information by testing for the presence of spatial autocorrelation. The Moran and Gary autocorrelation coefficients measure the average relationship between areal units. Hungerford (1991) analyzed the spatial distribution of cattle anaplasmosis between counties within the state of Illinois using second-order analysis and detected significant spatial clustering within the state.

If spatial autocorrelation has been done, further analyses are required to describe the underlying spatially stochastic process using spatially autoregressive and/or moving average processes. Explanatory analyses can be conducted between layers of information using simple methods such as multivariate spatial correlation or more sophisticated spatial regression procedures. Hungerford (1991) analyzed the relationship between cattle density and anaplasmosis prevalence on a county basis in Illinois using measures of spatial correlation.

Epidemiological simulation

GIS can provide geographical data which allows computer simulations of the dynamics of infectious diseases for specific geographical locations. Spatial heterogeneity can be represented in simulation models resulting in more realistic representations of reality. There are only few examples where this approach has been in veterinary epidemiology.Sanson (1993) described a model of foot-and-mouth disease which represents inter-farm spread of the disease on a true geographical area, using various transmissions. Pfeiffer (1994) developed a geographic simulation model of the dynamics of bovine tuberculosis infection in wild possum populations. The geographical component is a major feature of this model. The model uses vegetation maps to represent the ecological conditions of particular environments.

Animal Disease Information System

Diseases information systems are beginning to replace largely manual systems which have been used by decision makers and epidemic diseases. The larger amount of data which can be processed easily, their objectivity and the quickness of response are some of the advantages of computerized animal disease information system. Here, GIS provides an essential component of such systems. An example of an animal disease information system is EpiMAN which was developed in New Zealand for the management of an outbreak of foot-and-mouth disease (Morris et al., 1992). The system incorporates expert system elements and allows rapid integration of important information specific to the geographical setting where the emergency is occurring. Geographical data used by the system includes property boundary maps, topography, locations of dairy-and meat-processing plants, sale yards and other animal congregation points, and wild animal distribution maps. Simulated plumes of the air-borne spread of FMD virus can be overlayed over property boundaries using the GIS to identify properties at different levels of risk given certain farm characteristics. The system acts as a decision support tool by permitting the expected effects of various control option to be simulated. The system is currently being extended to produce versions for other purposes. These include endemic disease control and product quality assurance in international trade. They are intended to operate at various administrative levels to suit the nature of the particular diseases problem.

Conclusion

Animal disease surveillance and monitoring can serve as sentinels for bioterrorist or natural infectious disease epidemics. As such, it is important to understand how animal disease affects human and how this information can be obtained and monitored on regular and timely basis (Rebbecca and Micheal, 2002). The close association of human and animals in modern society, including the globalization of agriculture, the pet trade, tourism and recreation , combined with ecological pressures such as habitat transformation, climatic change, and human overpopulation will continue to facilitate unpredictable zoonotic disease threats (Mira and Jennifer, 2007). GIS has great potential as decision support tool in mapping animal resource distributions, disease occurrence and risk assessment as georeferenced data are vital for monitoring the progress of disease control programs and also enable predictive modelling of the likely effects of different control options. GIS can greatly facilitate epidemic management. Rapid advancement of techniques for Spatio-temporal analysis has greatly advanced the ability to understand patterns of disease population. Thus, the significance of GIS in animal disease control can not be overemphasized.

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