Global Veterinaria 26 (2): 70-78, 2024
ISSN 1992-6197

DOI: 10.5829/idosi.gv.2024.70.78

Review of the Application of Geographical Information Systems in Veterinary Medicine

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Abstract: Geographical Information System (GIS) is a computer system that displays stored digital data developed over the last decade. GIS is a platform consisting of hardware, software, data and people and encompasses a fundamental and universally applicable set of value-added tools for input, transforming, data management and storage, analyzing and output information that is geographically referenced. The use of GIS tools in the routine activities of the majority of countries of the World is not optimal. While there is a general understanding of the advantages of using GIS in the control and prevention of animal diseases, only a few countries apply this tool regularly. This is mainly due to a lack of training for personnel and the difficulty of accessing good quality data, including digital data. GIS can be applied to different veterinary activities. It can help to understand and explain the dynamics and spreading pattern of a disease and increase the speed of response in the case of a disease emergency. In an outbreak of a disease it could make the management of the situation easier and it could also provide a tool to evaluate different strategies to prevent the spread of infectious diseases. The following areas in which GIS and special GIS functions could be incorporated in to the following areas: surveillance and monitoring of animal diseases, recording and reporting information, epidemic emergency, modeling disease spread and planning control strategies. The technology has many features that make it ideal for use in animal disease control, including the ability to store information relating to demographic and causal factors and disease incidence on a geographical background and a variety of spatial analysis functions.

Key words: Geographic Information System · Application In Disease Epidemiology · Remote Sensing · Spatial Analysis

INTRODUCTION

A geographic information system is a computer-based system to aids in the collection, preservation, storage, analysis, output and distribution of spatial data and information [1, 2]. The association of geographical information has described GIS in phrases of computerized database management systems for capturing, storing, checking, integrating, manipulating, analyzing and showing information which might be spatially referenced to the Earth with a primary role in integrate information from a variety of sources [3]. There is a general agreement that GIS technology needs strong analysis and modelling capabilities as to a general-purpose tool for handling spatial data. Hence it can be defined as a special case of information systems where the database consists of observations on spatially distributed features, activities, or events, which are definable in space as points, lines, or areas to retrieve data for queries and analysis [4, 5].

Therefore, GIS is a powerful set of tools for storing and retrieving spatial data at will, transforming and displaying spatial data from the real world for a particular set of applications [6]. GIS was developed in the 1950s and 1960s, primarily in the public sector in Canada. In the 1960s and 1980s, a vigorous GIS industry developed, with clear USA leadership [7]. In the mid-1980s, with the maturing of the GIS industry and the development of the Global positioning system surrounding the technology (GPS), GIS was started to be applied for military purposes [8 , 9].

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The Spatiotemporal distribution patterns of most of the livestock diseases are complex. In this regard, the application of Geographical Information System (GIS) is valuable as it has many features that make it an ideal tool for use in animal disease surveillance, monitoring, prediction and its control strategy. The GIS can store demographic information, etiological factors and prevalence records of disease in a geographical setting, which enables a range of spatial analysis purposes. A GIS provides noteworthy additional value to general-purpose routine data that is perceived to be inadequate epidemiologically or for supervision purposes in the veterinary profession and noticeably increases the efficacy of networking and communication strategies [7, 10]. Establishing GIS which can involve many challenges relative to data collection, analytical methods and response. Analytical challenges include dealing with unknown time, place and size of an outbreak, trying to adjust for natural spatial and temporal variations and the lack of suitable population-at-risk data. While detection of disease clustering in time or space may be accomplished by mapping or plotting cases as a time series, it may be difficult to detect and visualize the interaction between time and space. The use of geographic information systems (GISs) and spatial statistical analyses is needed to fully explore time-space clustering of disease and mortality events precisely [11].

One of the main strengths of a GIS is its ability to integrate different types of spatial data. For example, a GIS can be used to map available epidemiological information and relate it to factors known to influence the distribution of infectious diseases, such as climate and other environmental factors. The ability to acquire relevant climatic information, particularly in the tropics, where there is an inadequate infrastructure for the collection of meteorological data, has been enhanced by remote sensing (RS) techniques that can provide proxy environmental information derived from satellite sensors [12].

Geographic information system is a new cutting-edge technology that is being used as a biological risk visualization, management and tracking tool in veterinary epidemiology [13]. Presently these systems are widely used by professionals in research, government and industry, in dealing with spatially related data [14]. With the use and analysis of data obtained by contemporary technology based on GIS and GPS (Global Positioning System), it is possible to get relevant data on the location and size of mosquito larval sites, estimate the density of insect populations, decide on insecticidal product to be used and employ optimal techniques to create a rational, environmentally friendly strategy to control nuisance mosquitoes and vector-borne diseases [15].

Therefore the objectives of this review paper are:

- To highlight the basic science in geographic Information Systems
- To review the application of GIS in disease epidemiology

Geographic Information Systems (GIS): One of the first major uses of GIS was in 1964 when the Canadian Geographical Information System (CGIS) was launched to assess the productivity of Canadian farmland[16]. GIS is "a powerful set of tools for collecting, retrieving, transforming and displaying spatial data from the real world". Overall, a GIS is a platform consisting of hardware, software, data and people and encompasses a fundamental and universally applicable set of value-added tools for capturing, transforming, managing, analyzing and presenting information that is geographically referenced [17]. GIS has greatly advanced from its initial use in the 1960s by cartographers (map makers) who wanted to adopt computer techniques in map-making to the versatile tool kit it is today. In earlier days, computerized GIS were only available to companies and universities that had expensive computer equipment. Now, anyone with a personal computer or laptop can use GIS software. GIS is more than just software, it refers to all aspects of managing and using digital geographical data.

Basics on Geographic Information Systems

Major Components Within the System: GIS is an automated system for the input, storage, analysis and output of spatial information. These data combined with population data and previous disease records are useful for prediction of diseases [18].

Data Input: Data input refers to the process of identifying and gathering the data required for specific application, thus involving acquisition, reformatting, geo-referencing, compiling and documenting the data. The data input component converts data from their existing form into one that can be used by the GIS. The data to be used in a GIS may be available in different formats including paper maps, tables of attributes, electronic lies of maps and associated attribute data, aerial photos, satellite images and other sources in digital format. One important virtue of a GIS is its efficient capability of integrating different data in different format acquired from a wide range of data sources into compatible format [19] (United States Geological Survey (USGS, 2001) .

Data Management and Storage: Data management include linking, integrating and editing many kinds of data that are located on the Earth's surface, such as health, social, environment data. GIS facilitate the integration of quantitative determination and control data with data obtained from maps, satellite images and aerial photos. Frequently, socioeconomic data and qualitative information on health facilities have a spatial basis and can also be integrated. GIS allows analysis of data generated by Global Positioning Systems (GPS). Combined with data from surveillance and management activities, GIS and GPS provide a powerful tool for the analysis and display of areas of high disease prevalence and the monitoring of ongoing control efforts. The coupling of GIS and GPS enhances the quality of spatial and non-spatial data for analysis and decision-making by providing an integrated approach to disease control and surveillance at the local, regional and national level. Spatial and ecologic data are combined with epidemiologic data to enable analysis variables that play important roles in disease transmission. This integration of data is essential for health policy planning, decision-making and ongoing surveillance efforts [20].

Data Manipulation and Spatial Analysis: When dealing with problems of space, the step beyond simple cartography and mapping is spatial analysis, which in geographic research is the tool used to compare the spatial distribution of a set of features to a hypothetically-based random spatial distribution [21]. These spatial distributions, or patterns, are of interest to many areas of geographic research because they can help identify and quantify patterns of features in space so that the underlying cause of the distribution can be determined [22]. The process of identifying unique spatial distributions, or statistical pattern recognition, can range from simply "eye-balling" features on a map to complex computer-based spatial algorithms that can detect very minute differences on a surface [21].

Visualization: Can be used in novel ways to explore the results of traditional statistical analysis. Displaying the locations of outlier and influential values on maps and showing variation in values over space can add a great deal to epidemiologic research. Although such tools are being developed and explored, they would benefit greatly from a closer and more seamless link between statistical packages and GIS [23].

Neighborhood Operations: Evaluate the characteristics of an area surrounding a specified location. Operations included in this category incorporate search, Line-in-Polygon and Point-in-Polygon, thiess Polygons, interpolation and contour generation. They determine whether points/lines are inside or outside a polygon boundary. The attributes of these points/lines identified as being within the polygon can then be processed for analysis by display on a map, computing statistics of attribute values, listing attribute values in tabular form and so on. Point/ line-in-polygon operations are typically performed by topological overlay procedures [19].

Buffer Analysis: GIS can create buffer zones around selected features. The user can indicate the size of the buffer and then join together this information with disease incidence data to establish how many cases fall within the buffer. Buffer or proximity analysis can be used to map the impact zones of vector breeding sites, where control activity needs to be strengthened. The buffer analysis capabilities of GIS are used for computing the health events located within a specified radius of each grid intersection [20]. Buffering is a GIS tool that creates a circle of specified radius for point data such as a well, or parallel lines of specified distance from linear data such as a river or a road [24].

Overlaying: Involves superimposing thematic plane of GIS features containing geographically and logically related data in two or more map layers to produce a new map layer. Map overlay operations allow us to compute new values for locations based on multiple attributes or data layers and to identify and display locations that meet specific. This allows the analyst to compute new values for locations based on multiple features or data layers. GIS can overlay diverse layers of information [20].

Data Output: The data output component of GIS provides a way to see the data or information in the form of maps, tables, diagrams and so on. The results may be output in hard copy, soft copy, or electronic format. Maps and tables are commonly output permanently in hard copy format. The hardcopy output takes longer to produce and requires more expensive equipment. However, it is permanent and easily transported and displayed. A large map can be shown at whatever level of detail is required by making the physical size of the output larger. Outputs in electronic formats, on the other hand, consist of computer-compatible files. They are used to transfer data to another computer system either for additional analysis or to produce a hardcopy output at a remote location [19, 25].

Sources of Data for GIS: The data for GIS can be derived from paper map, remote sensing and Global Positioning System (GPS).

Paper Map: Is one of the most known sources of GIS, in which the information is plotted within a coordinate system that allows us to find its location. Mapping is a common technique of displaying the geographical distribution of disease and associated risk factors with the aid of digitizing maps [26]. To digitize paper maps into a digital format, first, we must convert data from analogue to digital format. Then, convert the digital map into a scanned document and finally transform the digitized map from a source coordinate system to the geographic coordinate system using tics marks [27].

Remote Sensing: Remote sensing is the science and art of obtaining information about an item, area, or phenomenon through the analysis of data obtained by a device that isn't in physical contact with the object, area, or phenomenon under investigation. In such conditions, information is gathered in the form of digital photos of the earth's surface from airborne or satellite platforms and transforming them into maps [28]. Usually, sensor devices are mounted on satellites or aircraft or are installed at fixed coastal locations, they measure the electromagnetic radiation (EMR) that is emitted or reflected by features of the earth's surface and then convert the EMR into a signal that can be recorded and displayed as either numerical data or as an image [28].

Global Positioning System: GPS is a satellite-based navigation system made of a network of twenty-four satellites placed into orbit that transmits precise microwave signals. The microwave signals latter allow the GPS receiver to determine its location, direction and time. Data from GPS can be utilized in association with existing spatial databases for a range of applications in spatial decision making [29].

Satellite Imagery: Satellite imagery, are an increasingly important component in understanding and monitoring the Earth. There are a wide variety of satellites now lying; the United States alone had more than 80 civil Earth observation instruments operating (National Research Council [NRC] 2012).

The Link of Spatial Data and GIS: Spatial data are the backbone of GIS. In GIS the use of geo-coded data with coordinates is being promoted. The geo-referenced data are used as theme layers. Theme layers are spatial representation of analyzed data of elements of the same type. Moreover, they can be displayed singly or as overlay one above the other. Such data include an overhead projector that requires a geo-relational database and each of its features has linkage of attributed data for storage in a table and joining with the geographical data via a common identifier. Therefore, each spatial data can be easily depicted as a map using GIS [30].

Applications of GIS in Veterinary Medicine: GIS has a wide-range of applications in veterinary medicine, such as outbreak notification, prevention and eradication of disease, disease surveillance, understanding and explaining disease dynamics and spreading patterns and correlation of disease trends with climate and other risk ecological risk factors [31]. Spatial tools were used for collection of data and outbreak mappings were recorded [13]. GIS was used in the geospatial analysis and for monitoring the spread of disease outbreaks, herd proximity and outbreak locations and topography, distribution of disease serotypes and closeness to features that can spin off the agent within the study area [7]. The variety and type of applications that can be accomplished with the aid of a GIS are as large and diverse as the available geographic data sets [4].

As far as veterinary medicine is involved GIS has wide-range of applications, such as outbreak response in general and specifically, GIS can be used for prevention and eradication of disease, disease surveillance, understanding and explaining disease dynamics and spreading patterns, as well as the correlation of disease trends with ecological factors for disease predictions [32].

Use of GIS in the Surveillance of Animal Diseases: To prepare a control strategy, the exact disease status is obligatory to be known. Currently, various monitoring and surveillance networking programs are active. Some of these are the Global Early Warning System (GLEWS) for surveillance of animal diseases such as avian influenza, BSE and FMD[33]. One good example of the use of GIS in the surveillance of animal diseases is, GIS applied to the international surveillance and control of transboundary animal diseases, a focus on highly pathogenic avian influenza. Occurrences and distribution of HPAI observed from 19 January to 19 July 2006[33].

Recording and Reporting Disease Information: GIS can be used to record information on disease incidence, prevalence, mortality and morbidity on maps of farm, region, or national levels and that information is more easily understood when visualized on a map. For example, the spread of a disease can be determined from two or more interpretations of the extent of a disease made at different times [34]. A Published a paper showing the reported annual spread of disease in Uganda from the years 2001 to 2006 is a good example. The data were collected by a nationwide participatory action where farmers were urged to report disease, which was then verified by extension officers. Then, recorded and reported results clearly showed that there is a strong decline in the newly affected area from the year 2004 to 2005, which is likely a result of the control measures taken during that time [7, 34].

The density function is another way to describe the incidences of diseases in a defined area by recording disease information, creating density maps. The density function creates a grid with defined cell size and gives each cell in the area a density value of the infected farms. To adjust for the underlying population, a density map of the whole population at risk is recorded with the same cell size. The density maps are then divided to provide a map that shows the incidence of the particular disease in each area unit at the time unit chosen. This further provides maps that show the spread of the disease by displaying the maps as a movie [4 , 32]. Maps displaying the updated situation in a region, together with farm information are important tools for field personnel and can also be incorporated in reports to producers, administrators and the media. Therefore, the GIS incorporated maps are the basic element in recording and reporting of real-time outbreak notifications [2 , 32].

Understanding Disease Dynamics and Spreading Patterns: GIS helps in understanding and explaining disease with the environment and spreading patterns. In this case, environmental changes have a major contribution to the pattern of disease spreading and distribution [35]. Suppose GIS was used to develop a risk assessment model for fasciolosis in Ethiopia where both Fasciola hepatica and Fasciola gigantic a occur as a cause of major economic losses in livestock. A regional *F. hepatica* and *F. gigantica* forecast index maps are created; then, results were compared to environmental data parameters and to available Fasciola prevalence survey data that is mapping survey data and then iteratively fitting them to associated climatic and edaphic conditions [2 , 36].

Buffer zones that are generated around risk areas or point sources, such as roads where infected cattle have been driven or around marketplaces, show outbreak areas. Buffer zones can be drawn around those farms and with a link to tables of the addresses of the farms at risk, then farms can be informed within a short time after a notified outbreak. In such cases an outbreak of an infectious disease, GIS can provide an excellent tool for identifying the location of the case farm and all farms at risk within a specified area of the outbreak [1, 32]. GIS has been widely applied to the understanding and explaining of malaria. For example, in Africa, GIS has been used to generate models of malaria occurrence, seasonality and transmission intensity using climatic and remotely sensed data. The outputs of such models have been combined with population data to estimate population exposure, mortality and morbidity and to analyze and project the effects of climate change on malaria [9 , 37].

Planning Disease Prevention and Eradication Strategies: An essential part of disease control is the ability to document the occurrence of disease with the goal of prevention and eradication by the use of overlay analysis [1]. Hence, GIS can synthesize and continuously update information on disease causes and associate this information with environmental factors and overlay the thematic layers to analyze databases and produce maps that combine spatial and temporal information from various sources (disease cases, vector breeding sites so on). Details on disease risk and fundamental perspectives of where (distribution), why (environmental determinants), how much (transmission intensity) and when (seasonality) disease occurs can be stored and analyzed.

Thus, trends and seasonal changes can be predicted using multi-date data so that strategies going to be taken are planned for the prevention of diseases [2, 6 , 38].

GIS has the possibility of neighbourhood analysis functions. The strategies involve finding high or low-risk areas for diseases that depend on geographical features or conditions related to geography [39]. The neighbourhood analysis function identifies all adjacent features with certain criteria for a particular feature. For instance, it can be used to identify all adjacent farms to an infected farm in which contact patterns such as common use of grasslands or sources of purchasing, etc. could be visualized with a so-called spider diagram. This could provide insight into the possibility of transmission of infectious diseases between herds, so that action can be taken to control diseases [32, 39].

Correlation of Disease Trends with Climate for Disease Prediction: GIS can correlate disease trends with climatic variation and other information such as environmental variables that could be used for predictions. Diseases and vectors are often related to environmental variables, such as elevation, humidity and precipitation. Many viruses are spread by insects that may dislike high altitudes, whereas most fungal diseases require high relative humidity for growth. In this condition, a correlation is seen between disease incidence and environmental variables [2 , 29]. Rift valley fever (RVF) has been recognized in African countries, with an underlying association with high rainfall and dense populations of vector mosquitoes. The response of vegetation to increased levels of rainfall can be easily measured and monitored by Remote Sensing Satellite Imagery. The quantities of rains reflect on the vegetation coverage which becomes higher than normal and can be monitored by satellite images. This monitoring of the situation can help in designing risk maps of the possible occurrence of outbreaks of RVF. These findings have enabled the development of forecasting models and early warning systems for RVF using satellite images and weather forecasting data. Early warning systems, such as these, could be used to detect animal cases at an early stage of an outbreak, enabling authorities to implement them[29].

GIS in Animal Disease Mapping: One of the most useful functions of GIS in epidemiology continues to be its utility in basic mapping. Usually, data collected either routinely or for some purpose are presented in tabular forms, which can be exploited for analytical usage. However, the reading and interpretation of such data is often a laborious and time-consuming task and does not permit easy decision-making. On the other hand, representation of these data in the form of a map facilitates interpretation, synthesis and recognition of frequency and clusters of phenomena [40].

GIS for Modeling Disease Spread: To model the disease spread simulation model using program packages such as @Risk (Palisade Corporation, New- field, NY, USA) can be integrated within a GIS. The simulation 16 models can incorporate farm information such as herd size, production type as well as spatial factors like distance from the source of the outbreak, population density and climate conditions, vegetation and landscape, all of which have been defined as risk factors for the spread of the modelled disease[41].

Application of GIS and its Current Status in Ethiopia: GIS applications are very wide and are used in routine human activities. It is used for marketing studies, telecommunications and location of restaurants, museums, abattoirs and hospitals; in tracking trucks traffic; in establishing maps of animal population density by species or maps of vegetation coverage change; in locating forests, rivers and mountains; and in determining soil compositions to name few in developed countries [29]. However, the application of GIS tools in the routine activities of the majority of developing countries including Ethiopia is not optimal. Factors that are not optimizing the use of GIS include lack of awareness by decision-makers; low stock of base data; uncertain data discovery, access and exchange mechanisms; and insufficient human and technical resources [3]'.

While there is a general understanding of the advantages of using GIS in all human activities particularly in veterinary medicine for animal disease surveillance and other applications, only a few countries apply this tool regularly [39].

One of the challenges in GIS science and many other fields is the efficient and economical processing of massive data sets [39].

Future Perspectives of Geographic Information Systems: A continuing challenge in GIS science and many other fields is the efficient and economical processing of massive data sets [2, 23]. This describes how to leverage a massive Global processing unit (GPU) for raster GIS operations. Using video-gaming cards to create parallel processing solutions within the GPU is relatively new and almost non-existent in GIS science. So, in the future by designing a software add-on built to run select raster analysis operations on GPU will able to achieve a 7 times speed improvement compared to the traditional raster processing system [2, 6, 39]. The power of GIS relies on its ability to merge geographic information with the information of veterinary medicine [39].

Thus, it is certain that the scope of application for GIS will rapidly increase. For instance, once an individual animal identification (e.g. microchips and passports) is developed and widely used, GIS could be used to track animals from farms of origin through sale yards to slaughterhouses and even cross state boundaries. Monitoring the movement of food from farm to table will assist food safety and quality assurance programs in locating potential sources of contamination. Furthermore, GIS can define sub-regions for export based on natural geographic or animal production characteristics instead of political boundaries. This information then could be used to ensure the quality of foods intended for national and international markets [4, 31].

Many factors undermine the ability of a developing country to use spatial information effectively in the planning process. However, the way to meet these challenges is the creation of options, collectively known as spatial data infrastructures (SDI), which flourishes a country's ability to use geo-information effectively, have been identified. They are a robust response to the challenges that country confronts in the use of spatial data and its transformation into information and knowledge that are needed for decision making and the creation of veterinary SDI, using developed countries geo-information that is an imperative requirement if the impact of animal diseases on developing countries is to be solved [9 , 10].

CONCLUSION AND RECOMMENDATIONS

GIS represent a new technology in veterinary epidemiology for the reporting of animal disease information and the study and modelling of specific disease problems. However, the technology is not a panacea in its own right and any adoption of such a system must be preceded by a careful evaluation of information needs. GIS can add a significant value to epidemiological data that lacks a spatial component. It adds value to enhance the usefulness of displayed information to make better-informed decisions. GIS is believed to play an increasingly crucial role in surveying, monitoring and assessing infectious diseases at national or international levels and to aid in rapid controlling of economically important diseases. Moreover, GIS can link spatial and non-spatial data which facilitates powerful analysis of spatial and temporal disease distribution and related issues. In veterinary science using GIS is possible and easy to draw the maps and visualize possible temporal and spatial risk factors, outbreak distribution and areas at risk of developing the outbreak. Using GIS, the surveillance and monitoring system can be strengthened and the collection, storage, management and reporting of data can be improved to enable policymakers take better-informed decision. There are three situations in veterinary science where it is suggested that GIS will play an increasingly important role in the future: the need to solve epidemiologically complex disease problems, the need rapidly to monitor highly contagious diseases that might cross international boundaries and the need to deal with politically sensitive diseases for which prompt and accurate reporting is essential.

Based on the above conclusion and points, the following recommendations are forwarded:

- The concerned body of government should develop and support GIS application in veterinary science to prevent and reduces the spread of disease and its economic impact
- Veterinary clinicians, fieldworkers, researchers and university instructors should be trained in the use of GIS and its application at their respective activities.

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