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Geographic information systems (GIS) in veterinary science and sustainable resource management: A comprehensive review

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Abstract
This review explores the transformative role of Geo-informatics, specifically Geographic Information Systems (GIS), in veterinary science and sustainable resource management. It defines GIS as a powerful computer-based methodology for collecting, analyzing, and visualizing spatial data to support decision-making in agricultural and animal health sectors. The paper outlines the fundamental components of GIS—hardware, software, data, and personnel—and examines the shift towards open-access educational tools like QGIS and the European Rabies Bulletin. Key applications discussed include disease epidemiology, where GIS is used for surveillance, outbreak monitoring, and forecasting climate-driven diseases such as Rift Valley Fever. Furthermore, the review highlights advanced applications such as Precision Livestock Farming (PLF) for grazing management, spatial analysis of veterinary service accessibility to identify care gaps, and the mapping of antimicrobial resistance (AMR) within the One Health framework. The paper concludes that GIS is an indispensable tool for bridging complex spatial data with practical solutions for sustainable development and improved animal health outcomes.

Keywords: Geographic information systems (GIS), veterinary application, epidemiology, resource management, data, livestock

Introduction

Geo-informatics is an integrated technology combining Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS) to manage spatial data for agricultural and veterinary development (Narayanan, 2012) [10]. Defined as a computer-based methodology, GIS allows for the collection, storage, manipulation, and analysis of geo-referenced data—information linked to specific latitudes and longitudes—to study events on Earth (Elangovan, 2006) [9]. The field's roots trace back to Dr. Roger Tomlinson of the Canada Department of Forestry, known as the "Father of GIS," who developed the first operational system. In the veterinary domain, the concept was introduced by Sanson in 1994 to enhance disease management strategies (Sanson *et al.*, 1994) [13].

Components and modern educational tools refer to the essential elements of a functional GIS, which include robust computer hardware with high-resolution graphics, specialized software, diverse data sources, and trained personnel, and while commercial programs such as ArcINFO and AutoCAD are still widely used, there is a growing shift toward open-access tools like QGIS and Epi Map. Recent educational initiatives now integrate web-based platforms, such as the European Rabies Bulletin, into veterinary curricula. These tools allow students and professionals to visualize epidemiological patterns and disease distributions cost-effectively without requiring expensive licenses (Contreras *et al.*, 2025) [7].

As a part of data types and storage models, data in GIS is categorized into spatial data, which represent location, and attribute data, which describe characteristics such as soil type or crop yield. Spatial features appear as points. (e.g., wells, disease outbreaks), lines (e.g., roads, rivers), or areas (e.g., fields, administrative boundaries). To reduce interpretative bias in One Health research, modern studies often replace traditional administrative boundaries with hexagonal grids (e.g., 20 km² cells) to characterize wildlife-livestock interfaces more uniformly (Contreras *et al.*, 2025) [7]. These spatial entities are stored in two primary formats: Vector, which uses X, Y coordinates to define features, and Raster, which divides the study area into a regular grid of cells, ideal for continuous data like elevation.

As part of sources, workflow, and analytical capabilities, GIS data is derived from hard-copy maps, remote-sensing satellite imagery, and GPS field surveys. The standard workflow involves data capture from these primary and secondary sources, followed by input (digitizing), editing for topological accuracy, storage, and finally, output generation in the form of maps or charts. The system's power lies in its analytical capabilities, which support complex decision-making. Key functions include overlay analysis to superimpose thematic layers, buffer analysis to create proximity zones around risk factors, and network analysis to model transport routes. Additionally, GIS can perform terrain analysis to calculate slope and aspect from contour data and use interpolation to estimate unknown values, making it indispensable for precision resource management and disease surveillance.

Procedure

Data capture includes the collection of primary data from the field through conventional survey methods or by using GPS, remote sensing data obtained from satellites, aircraft, or ground platforms, as well as secondary data from existing sources such as government records, published maps, and R&D institutions. Data input refers to the conversion of hard copy paper maps into digital data using scanning. Data editing involves the correction of spatial and attribute data with respect to topology and real-world referencing. Data storage refers to storing both spatial and attribute data in specified formats suitable for fast and easy retrieval and analysis. Data output involves the preparation of data for the required outputs, which can be presented in various forms according to user requirements, such as maps, charts, bar graphs, and images.

Analytical capabilities of GIS

GIS has strong analytical capabilities that support spatial decision-making. Overlay analysis helps users to superimpose different thematic layers over one another and determine the proximity of one feature to another. Buffer analysis allows users to create buffer zones around features based on user-defined specifications. Network analysis modules support real-time modeling of traffic flows, including underpasses, overpasses, and one-way routes. From input contour data, GIS systems assist in calculating terrain-related parameters such as slope and aspect. GIS software also provides real-time shading of spatial features based on the sun illumination angle with respect to the time of day. In addition, GIS systems support interpolation of values using regression equations to estimate unknown data points.

Application of GIS in veterinary

Use in Disease Epidemiology: The epidemiology of animal diseases could be understood in a better way by using advancement of mapping locations of farms and other facilities for livestock. In case of a disease outbreak, it could make the management of the situation efficient and easier and also provide a tool to evaluate different strategies in preventing the spread of infectious diseases. GIS is useful in veterinary surveillance, record and reporting disease information. GIS can be used to produce maps of disease incidence, prevalence, mortality and morbidity on farm regions (Amin *et al.*, 2012) [2].

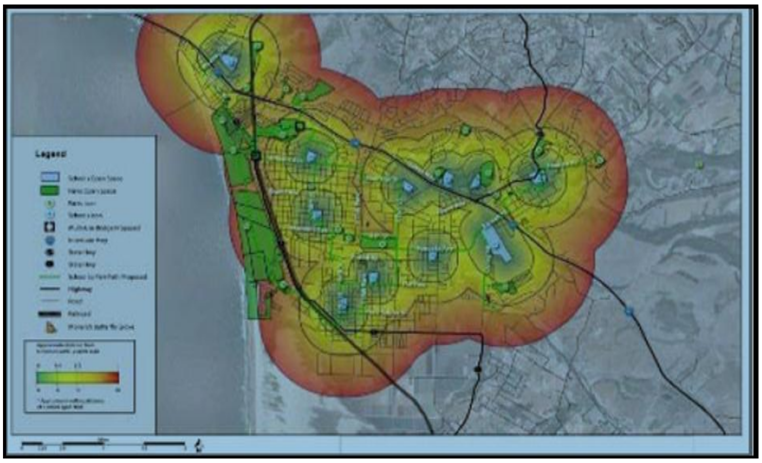

Fig 1: Shows the disease epidemiology map

GIS is an important tool to locate the farm or outbreak place and identification of areas at risk if an infectious disease occurs. The GIS provides an excellent tool to identify the location specific to case farms along with those at risk within a particular area of outbreak. Buffer zones can be designed so the farms that are at risk can receive notification of outbreak within a short period of time (Sanson et al., 1994) [13]. GIS may aid in analysis of disease clusters in terms of space and time. Geographical analysis is an important method from an epidemiology as well as public health point of view to identify space–time relationships concerning disease. Model disease spread simulation models using program packages can be integrated within a GIS. These models include farm information like number of animals, type of animals, and spatial factors like source of outbreak, population density and climatic conditions (Dhama *et al.*, 2013) [8].

One Health and Wildlife Interfaces: GIS is increasingly used in the One Health framework to analyse the wildlife-livestock interface. For example, in managing Bovine Tuberculosis (TB), GIS helps visualize the interaction between domestic cattle and wild ungulate reservoirs (such as wild boar and deer). Fine-scale mapping and heat maps allow students and professionals to identify "hotspots" of disease risk where these species interact, facilitating better control measures like movement restrictions (Contreras *et al.*, 2025) [7].

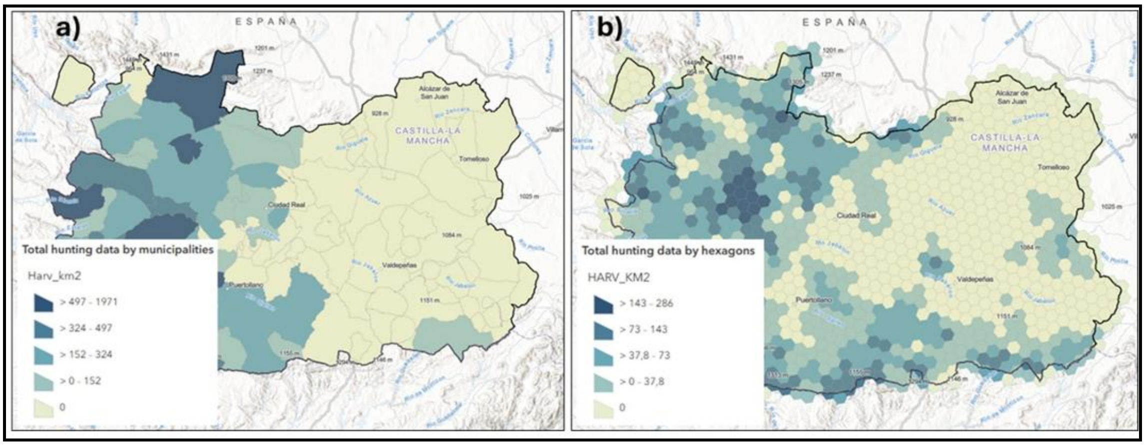

Fig 2: Density maps showing the harvest of wild ungulates per km² in Ciudad Real to analyze wildlife-livestock risks

Disease Prediction and Forecasting: GIS can correlate disease trends with climatic variation for prediction. For instance, Rift Valley Fever (RVF) outbreaks in East Africa are closely associated with heavy rainfall occurring during the warm phase of El Niño. Scientists use remote sensing satellite imagery to measure vegetation response to rainfall; this monitoring helps design risk maps and early warning systems to detect animal cases before a full outbreak occurs (Asaye and Fesseha, 2020) [3]. Similarly, forecasting models for fasciolosis have been created by mapping survey data against climatic and edaphic conditions (Asaye and Fesseha, 2020) [3].

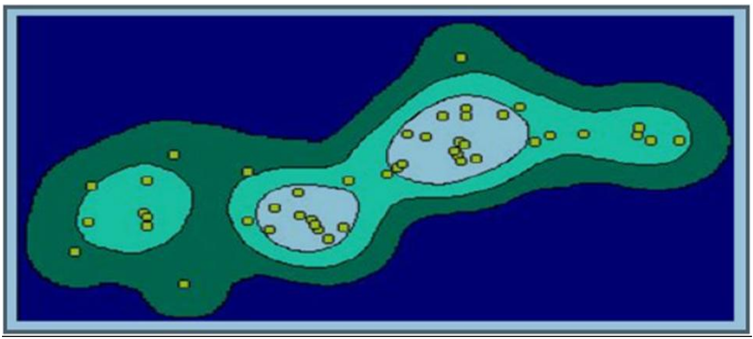

Fig 3: Showing cluster outbreaks with buffer zones

Infrastructure Planning: In addition to disease surveillance, GIS is applied to the design of abattoir site suitability models. Database management systems are integrated into a GIS database to identify optimal locations in the form of map layers with associated attributes, ensuring facilities are placed in suitable environmental and economic locations (Asaye and Fesseha, 2020) [3].

Disaster Management: Disaster planning, response, mitigation, and recovery all become more efficient through the use of GIS. Geographic Information System (GIS) is a tool that can assist flood plan managers in identifying flood-prone areas in their community. By overlaying or intersecting different geographical layers, flood-prone areas can be identified and targeted for mitigation or strict flood plan management practices after all of the information has been collected and organized in a GIS database (Abbas *et al.*, 2008) [1].

Fig 4: High-resolution satellite analysis compares pre- and post-flood scenarios in Kedarnath.

Livestock Monitoring: With help of spatial analysis by GIS we can know methane emissions by livestock. Spatial analysis in GIS indicates that districts with high livestock populations may not truly correspond to methane emission inventories because methane emissions depend on livestock category. Dairy buffalo contribute the highest share, with 1.78 Tg/year (56.4% of the total) despite accounting for only 33.2% of the milching livestock population. In contrast, goats are the dominant milching livestock with a population share of 33.1%, but their contribution to methane emissions is only 0.14 Tg/year (4.5% of the total) (Chhabra *et al.*, 2009) [5].

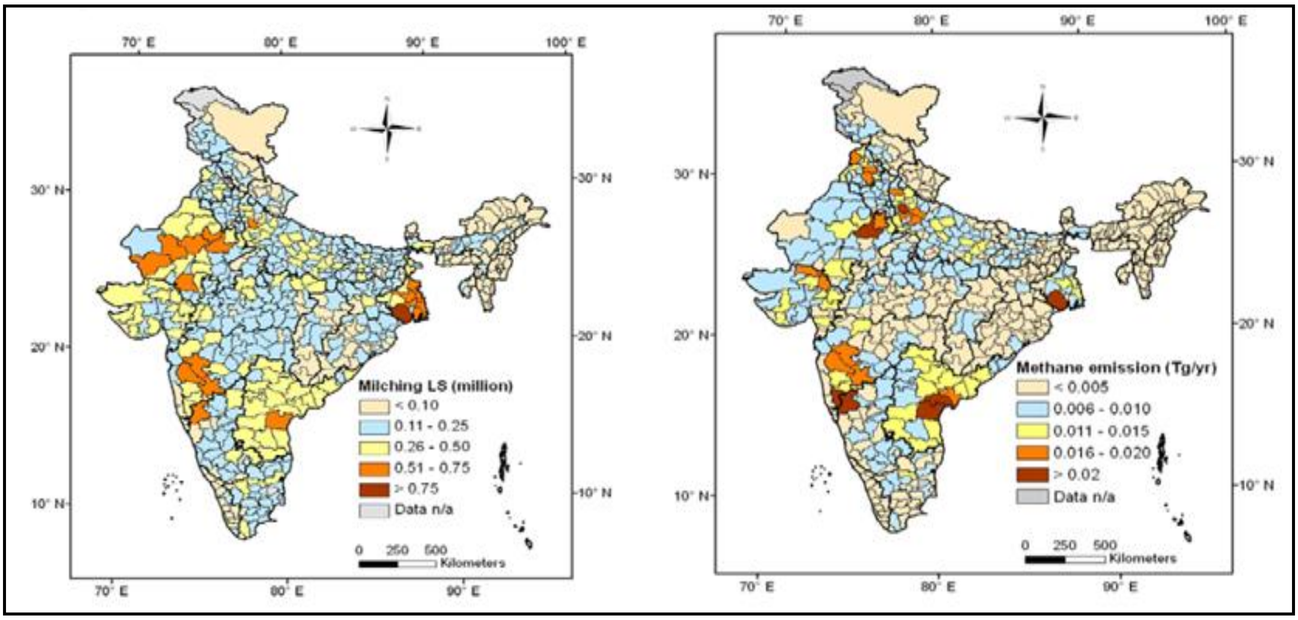

Fig 5: Spatial distribution comparison of district-level milching livestock population versus methane emissions in India.

Use by GCMMF: GCMMF is using the Geographical Information System (GIS) at its Head Office and key Marketing Offices. It is in a position to plot zone and depot boundaries as well as pointers for zone, depot, and distributor locations, which are superimposed with product-wise sales data. The same system is used for sales and distribution planning and review. GIS is also used for business planning activities at milk centers, covering animal census data. This has helped in understanding average milk production and productivity of cows and buffaloes in Gujarat, as well as tracking animals and conducting trend analysis (Bowonder *et al.*, 2002) [4].

GIS in Pasture Selection: Remote Sensing and Geographical Information System (GIS), when combined with conventional pasture mapping methods, provide a methodology to create a cost-effective and reliable inventory of large areas. GIS provides accurate data on the quality and quantity of pastures as well as information on the availability of natural forage resources, thereby promoting the sustainable use of pastures (Price *et al.*, 2001) [12].

Precision Livestock Farming (PLF) and Grazing Management

Modern extensive farming utilizes GIS paired with Global Positioning System (GPS) collars and sensors to optimize grazing management.

Virtual Fencing: GIS-based virtual fencing systems allow farmers to draw boundaries on a digital map, which interact with collars on the animals. This technology eliminates the need for physical fencing, reduces labor costs, and protects environmentally sensitive areas from overgrazing (Tzanidakis *et al.*, 2023) [14].

Behavioral Monitoring: By integrating GIS with accelerometers, farmers can monitor specific animal behaviors (grazing, resting, or walking) across different pasture zones. This spatial data helps optimize pasture usage and identify health issues, such as lameness, early by tracking reductions in movement range (Tzanidakis *et al.*, 2023) [14].

Accessibility of Veterinary Services: GIS is increasingly used to assess social equality regarding access to veterinary care.

Service Gap Analysis: Recent studies have used GIS to measure the spatial accessibility of veterinary clinics (both general practice and 24-hour emergency centers). By calculating travel times and distances relative to population density, researchers can identify "veterinary deserts"—areas where pet owners or livestock farmers have insufficient access to care.

Socioeconomic Correlation: These models often reveal that accessibility is unequally distributed, with lower-income areas facing significantly longer travel times to reach emergency veterinary services compared to wealthier regions. This data is crucial for policymakers to plan new clinic locations and mobile veterinary units (Ng *et al.*, 2022) [11].

Mapping Antimicrobial Resistance (AMR) in the Environment

As part of the One Health initiative, GIS is used to track the environmental spread of antimicrobial resistance (AMR), identifying potential transmission routes between human, animal, and environmental sectors.

Source Tracking: GIS enables the mapping of potential "hotspots" for AMR, such as areas downstream from hospital effluent or intensive agriculture sites. By overlaying hydrological maps with land-use data, researchers can model how resistant organisms travel through waterways, predicting risk zones for livestock drinking water and public health (Chique *et al.*, 2019) [6].

Conclusion

Geographic Information System (GIS) has evolved from a foundational tool for spatial data storage into a critical instrument for advanced veterinary and resource management. By integrating diverse data sources—ranging from satellite imagery and topographic maps to real-time sensor data—GIS facilitates complex analytical functions like overlay, buffer, and network analysis, which are essential for informed decision-making. Its scope has now expanded significantly beyond traditional disease mapping to include sophisticated predictive modeling for climate-driven outbreaks like Rift Valley Fever and the strategic tracking of antimicrobial resistance (AMR) within the One Health framework. Furthermore, the technology is revolutionizing modern agriculture through Precision Livestock Farming (PLF) applications, such as virtual fencing and automated behavioral monitoring, while simultaneously addressing social challenges by identifying disparities in veterinary service accessibility. Ultimately, GIS serves as an indispensable decision-support mechanism, bridging the gap between complex spatial data and practical solutions to ensure sustainable agricultural development and improved animal health outcomes globally.

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