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Review of GIS Analysis used in Poultry Livestock Disease Prevention in USA

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ABSTRACT

CoThe use of geospatial analysis in disease surveillance dates to the 1850s, with John Snow's epidemiological work on cholera. In agriculture, Geographic Information Systems (GIS) has been widely applied to crop and livestock disease management, offering tools for outbreak prediction and biosecurity planning. This literature review examines the evolution and effectiveness of GIS for poultry disease surveillance, focusing on outbreak mapping, risk modeling, and disease prevention strategies. Key GIS methodologies for tracking Avian Influenza (AI) in the United States and Newcastle Disease in Nigeria are highlighted, alongside an evaluation of geospatial programs used in poultry disease monitoring. An Evidence Gap Map was used to analyze GIS adoption across 1,964 biosecurity-related articles from seven journals from 2010 to 2024, revealing limited use in biosafety publications but higher adoption in agricultural technology fields. Findings show that while GIS enhances disease prediction and management, its adoption remains inconsistent. Future research should explore AI-enhanced GIS models for real-time poultry disease tracking. Future research should prioritize AI-enhanced GIS tools and increase interdisciplinary integration of spatial analysis into biosecurity frameworks.

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INTRODUCTION

Geographic Information Systems (GIS), sophisticated tools that integrate spatial data and advanced technologies, are pivotal in addressing many issues in agriculture, including international biosecurity concerns and tracking disease outbreaks. In the context of agriculture, GIS plays a significant role by providing detailed geographical information and enabling comprehensive analyses of disease patterns and their impact on crops and livestock. Researchers and practitioners have extensively utilized GIS to enhance situational awareness and devise effective strategies for managing disease outbreaks, particularly within the agricultural domain (Glass et al., 1993; Hijmans et al., 2000). GIS-based disease surveillance systems enable proactive disease management by identifying spatial patterns, forecasting outbreak risks, and guiding biosecurity interventions (Palaniswami et al., 2011). In the event of an infectious disease outbreak, GIS can provide an excellent tool for identifying the location of the case farm and all farms at risk within a specified area (Norström, 2001).

Farming practices and increased human population densities have been linked to disease emergence and amplification, highlighting the complex interplay between human activities, livestock, wildlife, and disease cycles (Shutske, 2004; Jones et al., 2013; Schuck-Paim, 2020). More specific to agriculture, GIS can facilitate predictive modeling for disease outbreaks, aiding in biosecurity planning and resource allocation (Paploski et al., 2021). GIS-based decision support systems offer real-time monitoring and early warning capabilities, crucial for rapid response and the protection of both public health and the global food chain.

The urgency of this research was underscored by the 2022 Highly Pathogenic Avian Influenza (HPAI) outbreak in the Midwest, which had devastating economic consequences for poultry farmers. The HPAI has led to the depopulation of over 43.4 million birds, highlighting the urgent need for improved biosecurity and surveillance measures (Wattagnet, 2022). HPAIV differs from Avian Influenza Virus (AIV) in its severity and mortality rate; while AIV strains can range from low to high pathogenicity, HPAIV strains cause rapid and high mortality in poultry populations, requiring stringent control measures. In essence, GIS is a critical tool in addressing the complex dynamics of disease transmission within agricultural and natural ecosystems, offering insights and strategies to enhance disease surveillance and management.

Geospatial tools have a deep-rooted history for epidemiologists, medical geographers, and health practitioners, with its most popular early example coming from John Snow in the 1850s to better understand cholera by tracing water wells and disease outbreaks (Shiode, 2012). However, connecting people to specific places at certain times can be dated back to 300–900 AD (Knowles, 2008). Whether used for cholera investigations or general tracking, GIS technology developed rapidly in the 1960s with the rise of computing power and was applied to population-level issues, particularly focusing on environmental and socioeconomic concerns (Shi & Kwan, 2015).

GIS technology has advanced rapidly making it a valuable tool for agricultural disease prevention. One of the earliest examples of computer-based GIS use in agricultural disease monitoring occurred in the 1990s when it was employed to track and control the spread of citrus canker disease in Florida (Gottwald, 2007). The system enabled authorities to monitor the disease and develop effective strategies for containment and eradication. This technology has also demonstrated growing importance in veterinary medicine, particularly in the management and deployment of veterinary services during emergencies (Norstrøm, 2001). As a result of such advancements and the increasing demand for GIS applications in agriculture, the past two decades have witnessed significant developments in GIS tools (Shi & Kwan, 2015).

The United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS) and its State Premises Information Management System (State-PIN) or premise registration, provide a framework for animal health traceability and disease monitoring. These systems rely on complementary GIS tools to enhance real-time surveillance, risk mapping, and predictive modeling (Paploski et al., 2021; Pasture, 2023). However, premise registration is not uniformly adopted across states, with only Wisconsin and Indiana mandating participation at the time of this publication. As of September 2008, approximately 40% of potential premises in the United States had been registered. Participation varied significantly by species: poultry and sheep premises had a 95% registration rate, swine 80%, goats 60%, horses 50%, and cattle only 18% (Congressional Research Service, 2009).

GIS-based platforms, such as ArcGIS, QGIS, and PostGIS, play a crucial role in biosecurity management by integrating spatial data with premises registration systems like APHIS and State-PIN. ArcGIS and QGIS, for example, can visualize registered farm locations, overlaying them with outbreak reports and environmental risk factors to identify potential disease hotspots (Morris et al., 2023). PostGIS enhances this capability by storing and analyzing large geospatial datasets, enabling risk assessments and disease cluster analysis across state and national levels (USDA, 2019).

Table 1. Comparison of GIS tools used in poultry disease surveillance, highlighting their data sources, strengths, and limitations in disease outbreak prediction and management.

GIS Tool	Data Type Used	Application in Monitoring	Strengths	Limitations	Reference
ArcGIS	Remote Sensing, Farm GPS, Outbreak Reports	Disease hotspot mapping	High spatial accuracy	Costly for small farmers	(Fuller et al., 2010)
QGIS	Farm GPS, Environmental Data	Open-source GIS mapping	Free and customizable	Less automated features	(Stenkamp-Strahm et al., 2020)
FarmOS	Open-source farm management system with GIS integration	Disease tracking, planning, livestock monitoring	Livestock tracking, field mapping, and disease logging	Requires setup on a server or cloud	(FAO, 2020)
PostGIS (for Databases)	Spatial database extension for managing farm GIS data	Disease cluster analysis, risk assessment, modeling	Scalable for handling large geospatial datasets	Requires knowledge of SQL/database management	(USDA, 2019)
AI-GIS Hybrid Models	Machine Learning, IoT, RFID Tracking	Individual bird health monitoring	Predictive analytics	Requires high computing power	(Ahmed et al., 2021)

The absence of a standardized and federally enforced premise registration system creates gaps in disease surveillance, hindering the ability of GIS tools to provide comprehensive and real-time biosecurity assessments. As a result, GIS-based disease monitoring systems must compensate for missing data, which reduces their effectiveness in identifying and mitigating outbreak risks. GIS tools, such as FarmOS, address this by offering farm-level disease tracking and biosecurity planning, integrating with APHIS databases to provide more granular monitoring (FAO, 2020). Similarly, AI-GIS hybrid models, utilizing machine learning and IoT technologies, enhance individual bird health monitoring, offering real-time disease detection at the flock level (Ahmed et al., 2021). Table 1 demonstrates the capabilities of different common GIS tools used in disease surveillance, highlighting their data sources, strengths, and limitations.

Real-time GIS analytics, combined with epidemiological modeling, further enhance biosecurity decision-making. By integrating APHIS's disease tracking with AI-driven GIS models, researchers, farmers, and policymakers can optimize resource allocation, and improve outbreak response times (Corcoran & Hamilton, 2021; Baughman, 2022; Kanitkar & Wadekar, 2023). Collectively, these technologies provide a powerful spatially informed approach to mitigating biological threats, safeguarding farms, and ensuring food supply chain security

MATERIAL and METHOD

This review examines two key objectives: (i) the historical development of geospatial programs in poultry operations and (ii) the current applications of GIS in agricultural safety, health, and biosecurity, particularly for poultry disease intervention. To achieve these objectives, a literature review was conducted, analyzing peer-reviewed research, federal and state publications, and technical reports from organizations involved in GIS technology development for agriculture. We used an Evidence Gap Map (EGM) approach. EGMs are structured review tools that visually display the availability of evidence across thematic areas and are particularly useful for identifying gaps in research utilization.

To construct the EGM, a keyword-based search was performed on articles published between 2010 and 2024 in seven journals that frequently feature research on agriculture, veterinary medicine, emerging diseases, and biosecurity. The selected journals included Agricultural Systems, Computers and Electronics in Agriculture, Preventive Veterinary Medicine, Transboundary and Emerging Diseases, Journal of Agromedicine, Global Biosecurity Journal, and the Journal of Biosafety and Biosecurity.

The search process was conducted systematically using predefined search terms including "GIS", "Geographic Information Systems", "biosecurity", "avian influenza", "poultry disease surveillance", and "outbreak prediction". Boolean operators (AND, OR) were applied to refine search results. The databases used included Google Scholar, ScienceDirect, PubMed, and specific journal repositories.

Literature sources were identified through Google Scholar, the National Agricultural Library (NAL), and major scientific databases, focusing on studies that evaluate GIS methodologies, disease mapping techniques, and real-time surveillance applications. The selected journals included Agricultural Systems, Computers and Electronics in Agriculture, Preventive Veterinary Medicine, Transboundary and Emerging Diseases, Journal of Agromedicine, Global Biosecurity Journal, and the Journal of Biosafety and Biosecurity.

RESULTS and DISCUSSION

The search identified 1,964 biosecurity-related articles, of which 122 explicitly mentioned GIS. These articles were then categorized based on GIS adoption rate, revealing significant disparities across disciplines. The data was visualized using a heatmap, demonstrating research concentration and gaps in GIS adoption (Figure 1).

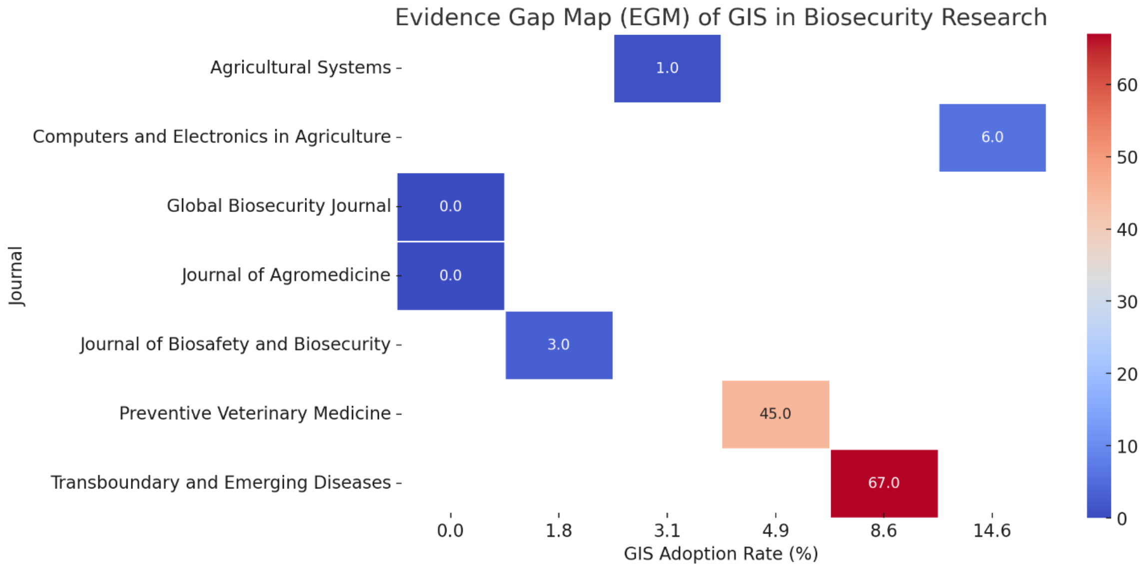

Figure 1. Evidence map analysis demonstrates research concentration and gaps in GIS adoption across journals

The keyword analysis revealed that the incorporation of GIS in biosecurity-related research varies significantly across different academic disciplines. Journals that emphasize technological applications in agriculture and transboundary disease control demonstrated a higher prevalence of GIS integration, whereas journals specializing in biosecurity and biosafety research had fewer GIS-related publications. Results for the journals are indicated in Table 2.

In Computers and Electronics in Agriculture, 14.6% of biosecurity-related articles included GIS applications, the highest proportion among the journals analyzed. This finding aligns with the journal’s focus on technological innovations, spatial analytics, and precision agriculture tools. Similarly, Transboundary and Emerging Diseases exhibited a strong representation of GIS research, with 8.6% of its biosecurity articles discussing GIS applications in disease transmission modeling, international outbreak tracking, and spatial risk assessments.

Table 2. Comparison of the journals with articles on biosecurity and articles mentioning GIS-use or spatial modeling techniques

Journal	Total Articles on Biosecurity (2010-2024)	Articles Mentioning GIS	Percentage of Biosecurity Articles Mentioning GIS
Agricultural Systems	32	1	3.1%
Computers and Electronics in Agriculture	41	6	14.6%
Preventive Veterinary Medicine	913	45	4.9%
Transboundary and Emerging Diseases	781	67	8.6%
Journal of Agromedicine	20	0	0.0%
Global Biosecurity Journal (est. 2019)	11	0	0.0%
Journal of Biosafety and Biosecurity	166	3	1.8%

Despite having the highest number of total biosecurity-related articles (913), Preventive Veterinary Medicine had a lower proportion of GIS-related publications, with only 4.9% of biosecurity-focused studies incorporating GIS technology. This suggests that the journal predominantly covers clinical disease management, epidemiological studies, and public health interventions, rather than geospatial methods for disease surveillance. Agricultural Systems had the lowest GIS representation among agricultural journals, with only 3.1% of its biosecurity-related articles referencing GIS, indicating that spatial technologies are not yet fully integrated into broader agricultural system research.

Journals that focus specifically on biosecurity research showed even lower GIS adoption rates. In the Journal of Agromedicine, none of the 20 biosecurity-related articles included GIS. Similarly, the Global Biosecurity Journal, which has been publishing since 2019, contained no GIS-related articles within its 11 biosecurity publications. The Journal of Biosafety and Biosecurity, which had a more substantial number of biosecurity-focused articles (166), included only three studies discussing GIS applications, resulting in a GIS integration rate of 1.8%.

DISCUSSION

Gis in Poultry Disease Surveillance and Management

The results of the EGM highlight significant inconsistencies in GIS adoption across biosecurity research. Journals focusing on technological applications in agriculture demonstrated higher integration of GIS methodologies. In contrast, journals dedicated specifically to biosecurity contained little or no GIS-related articles, underscoring an underrepresentation of spatial analysis in biosecurity-focused research. Strengthening GIS methodologies in these fields can enhance real-time disease tracking, risk assessment, and outbreak prediction.

Multiple studies highlight the role of GIS in disease surveillance, outbreak prediction, and risk assessment in poultry farming. Hill et al. (2018) mapped Avian Influenza Virus (AIV) outbreaks in Bangladesh, demonstrating that GIS effectively identifies high-risk zones and predicts outbreak persistence in specific geographic areas (Hill et al., 2018). Similarly, Fuller et al. (2010) analyzed spatial distribution of poultry farms in the U.S. and found that farms near wetlands and high-density wildlife areas faced a greater risk of AIV, emphasizing the need for targeted biosecurity measures (Fuller et al., 2010).

In the U.S., Stenkamp-Strahm et al. (2020) applied GIS to analyze AIV outbreaks in South Carolina using NASA and government datasets, finding that outbreaks were geographically clustered. Their research supported the World Organization for Animal Health Risk Assessment Guidelines, reinforcing that targeted surveillance is more effective than broad disease control measures (Stenkamp-Strahm et al., 2020). Belkhiria et al. (2016) expanded on this by using species distribution modeling to predict AIV risk along North American migratory flyways, confirming that 89% of outbreaks occurred in high-suitability zones (Belkhiria et al., 2016).

Beyond AIV, GIS has also been applied to Expanding premise registration requirements across more states could significantly improve biosecurity efforts and enhance GIS-based disease surveillance capabilities.

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surveillance. Bello et al. (2017) mapped ND outbreaks in Nigeria and found that cases were concentrated in rural areas with poor biosecurity, underscoring the need for targeted vaccination efforts (Bello et al., 2017). Additionally, Killian et al. (2016) emphasized that even a single introduction event of AIV can lead to rapid lateral spread, highlighting the importance of early detection systems to prevent virus evolution (Killian et al., 2016). Collectively, these studies demonstrate that GIS enhances disease prediction, risk assessment, and biosecurity planning by integrating environmental, farm, and migratory data into comprehensive disease mapping systems (Fuller et al., 2010; Killian et al., 2016; Bello et al., 2017; Hill et al., 2018). Table 3 demonstrates other studies that have used GIS-based outbreak prediction models, evaluating their accuracy and effectiveness.

Table 3. Comparison of GIS-based outbreak predictions with actual poultry disease spread, demonstrating the accuracy and reliability of spatial modeling techniques.

Study	GIS Method Used	Predicted Outbreak Area	Actual Outbreak Area	Prediction Accuracy (%)
Hill et al. (2018)	Spatial Risk Modeling	4 High-Risk Zones in Bangladesh	3 Matched, 1 Missed	75%
Fuller et al. (2010)	Environmental Suitability Mapping	5 States in U.S.	4 Correct, 1 False Positive	80%
Bello et al. (2017)	Disease Clustering	Rural Nigeria	Matched Outbreaks	100%
Belkhiria et al. (2016)	Species Distribution Modeling	U.S. Flyways	89% Overlap	89%

Beyond its technical applications, GIS-informed strategies have significant implications for public health. Integration into disease surveillance enables policymakers to develop spatially informed regulations that improve disease containment efforts and resource allocation. By visualizing outbreak patterns, officials can implement targeted interventions, such as vaccination campaigns, movement restrictions, and rapid response measures, in high-risk areas- especially under outbreak events.

GIS can strengthen community responses to disease outbreaks by promoting data-driven engagement among farmers, veterinarians, and local authorities. By making GIS-based risk assessments accessible to stakeholders, communities can proactively enhance on-farm biosecurity practices and improve early disease detection efforts, like the State-PIN systems. Finally, GIS applications extend beyond disease management to broader ecological conservation efforts. Disease outbreaks among poultry often have cascading effects on wildlife populations, particularly in cases were avian influenza spreads to migratory bird species. GIS-based ecological modeling allows researchers to track disease transmission pathways between domestic and wild bird populations, informing conservation policies that protect biodiversity. By identifying critical habitats and transmission corridors, GIS helps balance agricultural productivity with environmental stewardship, ensuring that biosecurity strategies align with broader conservation goals.

These findings underscore a critical need for increased GIS integration in biosecurity research, particularly in journals dedicated to disease surveillance and biosafety. Strengthening GIS methodologies in these fields could enhance real-time disease tracking, risk assessment, and outbreak prediction. Future research should focus on expanding GIS adoption in underrepresented disciplines, bridging the gap between spatial analysis and biosecurity policy development.

CONCLUSION

GIS has evolved from an epidemiological tool into a critical component of precision agriculture, offering advanced capabilities in real-time disease surveillance, predictive modeling, and poultry health management. However, this literature review reveals that GIS adoption in biosecurity research is inconsistent across disciplines, with agricultural and veterinary journals showing higher GIS integration than biosecurity-focused publications. The methods and results of this review demonstrate that while GIS is frequently applied in precision agriculture and disease tracking, it remains severely underutilized in biosecurity-specific research and policymaking.

The analysis across several academic journals found that GIS representation in biosecurity research varies widely, with Computers and Electronics in Agriculture having the highest GIS integration (14.6% of biosecurity-related articles) and Preventive Veterinary Medicine having the most total biosecurity articles but a lower GIS representation (4.9%). Journals specializing in biosecurity and biosafety research showed minimal GIS adoption, with the Journal of Agromedicine and Global Biosecurity Journal containing no GIS-related articles, and the Journal of Biosafety and Biosecurity having only 1.8% GIS integration. These findings underscore the need for greater GIS adoption in biosecurity research, particularly in risk-based surveillance, outbreak prediction, and spatial modeling for disease containment strategies.

Despite its proven effectiveness, GIS research in poultry biosecurity faces challenges in standardizing methodologies, integrating machine learning models, and scaling GIS adoption for small-holder farms or dealing with missing data. Publicly available datasets from NASA, WHO, USDA, and other agencies provide a strong foundation for GIS research, yet real-time surveillance tools and AI-driven GIS risk assessment models remain underdeveloped or not mandatory. Future research should address these gaps by improving GIS interoperability between private and government systems, expanding geospatial analytics for farm-level disease tracking, and enhancing GIS adoption in biosecurity-focused research. By strengthening GIS applications in poultry disease prevention, this technology can play a vital role in safeguarding food security, improving biosecurity measures, and mitigating the risks of future poultry disease outbreaks.

Conflict of Interest

The authors have declared that there are no competing interests.

Authors Contribution

The authors contribute equally to the research

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