AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY: GLOBAL ISSUES & LOCAL PERSPECTIVES

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Published By:

Society for Agriculture, Environmental Resources & Management (SAEREM)

First published 2026

SAEREM World

Nigeria

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

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Typeset in Times New Roman

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AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY (GLOBAL ISSUES & LOCAL PERSPECTIVES)

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Printed at: SAEREM

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

TABLE OF CONTENTS

Preface

Editorial Note

Table of Contents

Acknowledgement

Dedication

Part one: AGRICULTURAL AUTOMATION Chapter One

Chapter One

Organic and Mineral Soil Amendments as Enablers of Climate-Smart Agricultural Automation: Implications for Soil Water Management and Food Security

*Paul Omaye Joseph[1,4], Enya Anari Akpa[2,4], King Ndeari Dedan[3,4],

Chapter Two

Climate Change–Driven Shifts in Plant Pathogen Epidemiology

IVOKE, Michael Anaelechi

Chapter Three

Bridging the Post-Harvest Loss Gap: Modernizing Middle-Mile Logistics to Eliminate Food Loss

Uzoma Uloma Onyewuchi (Ph.D)

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Chapter Four

Transforming Agriculture with Smart Technologies: Benefits,Challenges and Implementation Pathways

[1]Igbojionu, Donatus Okwudiri,[2]Igbojionu, Juliet Nnennaya and [3]Anyika, Felicia

Part two: THE CONCEPT OF CLIMATE CHANGE-ACTION

Chapter Five

Impact of Climate Change on Growth in Nigeria.

Tanimu Joseph[1] & Rebecca Yusuf Auta[2]

Chapter Six

Assessment of Conveyance Efficiency and Its Effect on Agricultural Activities in the Falalia Sector of Middle Rima Valley Irrigation Scheme, Goronyo, Nigeria.

***Sadiq Salihu Kumu[1]; Ibrahim Bala[1]; Umar Ibrahim Chonoko[2]; Fiddausi Salihu Kumu[3]**

Chapter Seven

Digital Veterinary Extension and Statistical Modelling for Climate-Resilient Livestock Disease Surveillance in Nigeria

[1]Chidinma Theresa Nwosu[1], Aren Fatandi Peter[2,] Silas Yibarga Gani[3] & Baridanu Hope Mbube[4]

Chapter Eight

Review of Environmental Degradations in Nigeria From 1960 To 2026: Threats, Policy Frameworks, and Strategic Responses

[1,3]Salami, K. D. [2]Iroko, O.A., [4]Pius, Emmanuel Ekomki and [3]Soba, T. M.

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Part three: THE CONCEPT OF FOOD SECURITY

Chapter Nine

Musa Paradisiaca (Plantain) Production In A Climate Change Agriculture

Omu, Paul B.

Chapter Ten

Building Climate Resilience in Nigeria's Food Systems: Integrating Adaptation Strategies for Sustainable Food Security:

Chapter Eleven

Snake Gourd as a Neglected and Underutilized Crop for Food Security and Climate Resilience in Southeast Nigeria
Dr. Ogechukwu Anulika Umeh

Chapter Twelve

Climate-Smart Livestock Production: Adaptation, Mitigation and Sustainable Strategies for Resilient Livestock systems

Amaechi, C.I. and Adeyemi, E.A

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous Agricultural Automation, Climate Change-Action and Food Security issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which Agricultural Automation, Climate Change-Action and Food Security issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue Agricultural Automation, Climate Change-Action and Food Security necessary in policy making process that will stimulate increase in food production and environmental sustainability. Agricultural Automation, Climate Change-Action and Food Security**:** *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of Agricultural Automation, Part Two is concerned with The Concept of Climate Change-Action and Part Three deals with the Concept of Food Security

Eteyen Nyong; October 2026

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Chapter Seven

CHAPTER TITLE:

Digital Veterinary Extension and Statistical Modelling for Climate-Resilient Livestock Disease Surveillance in Nigeria

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Chapter outline

I. INTRODUCTION

II. CONCEPTUAL FOUNDATIONS AND EMERGING APPROACHES

A. Digital Extension in the Veterinary Context

B. Smart Veterinary Services and Their Key Components

C. Digital Approaches to Livestock Disease Surveillance

D. Climate-Resilient Livestock Health and Disease Management

E. Agricultural Automation in Livestock Health and Veterinary Services

F. Perspectives on Digital Technology Adoption and Extension Delivery

III. OVERVIEW OF LIVESTOCK DISEASE SURVEILLANCE IN NIGERIA

A. Traditional Livestock Disease Surveillance Systems and Challenges

B. Priority Livestock Diseases for Surveillance in Nigeria

C. Challenges of Disease Reporting, Timeliness and Data Quality

D. Climate Change, Livestock Disease Dynamics and Surveillance Implications

E. The Need for Digital Transformation in Livestock Disease Surveillance

IV. MOBILE APPLICATIONS FOR VETERINARY EXTENSION AND DISEASE SURVEILLANCE

A. Types and Functions of Mobile Applications

B. Mobile Applications for Disease Reporting and Surveillance

C. Real-Time Reporting, GPS Mapping and Diagnostic Support

D. Mobile Applications for Farmer Education and Veterinary Extension

E. Adoption and Use by Farmers, Veterinarians and Extension Personnel

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

V. ARTIFICIAL INTELLIGENCE, MACHINE LEARNING AND STATISTICAL MODELLING IN LIVESTOCK DISEASE SURVEILLANCE

A. AI for Early Warning and Disease Outbreak Prediction

B. AI-Assisted Image Recognition and Clinical Diagnosis

C. Natural Language Processing and Veterinary Chatbots

D. Statistical Modelling of Livestock Disease Surveillance Data

E. Predictive Modelling Using Climate, Animal Movement and Disease Data

F. Time-Series and Spatiotemporal Analysis

G. Model Validation, Data Quality and Interpretation

H. Opportunities and Limitations in the Nigerian Context

VI. INTEGRATION OF DIGITAL TOOLS INTO VETERINARY EXTENSION SERVICE DELIVERY

A. Public Veterinary and Agricultural Extension Services

B. Private Sector and Development Organisation Initiatives

C. Capacity Building and Digital Literacy

D. Digital Communication Among Farmers, Veterinarians and Extension Agents

E. Data Integration and Institutional Collaboration

VII. CHALLENGES TO DIGITAL VETERINARY EXTENSION AND DISEASE SURVEILLANCE IN NIGERIA

A. Infrastructure Challenges

B. Digital Literacy and Capacity Constraints

C. Data Privacy, Ownership and Trust

D. Cost, Sustainability and Maintenance

E. Policy and Regulatory Gaps

F. Institutional Coordination and Interoperability

VIII. OPPORTUNITIES, RECOMMENDATIONS AND FUTURE DIRECTIONS

A. Digital Surveillance within One Health Approaches

B. IoT, Wearables and Remote Monitoring

C. Public-Private Partnerships

D. Strengthening Digital Veterinary Extension Systems

E. Policy and Institutional Recommendations

F. Linking Digital Disease Surveillance to Livestock Productivity and Food Security

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

IX. CONCLUSION

A. Summary of Key Issues

B. Implications for Veterinary Practice and Agricultural Extension

C. The Way Forward for Smart and Climate-Resilient Livestock Health

X. REFERENCES

XI. ACKNOWLEDGEMENTS

I. INTRODUCTION

Livestock production is vital to Nigeria's agriculture, contributing to food and nutrition security, livelihoods, employment and the supply of animal-source foods (Food and Agriculture Organization of the United Nations [FAO], 2026). However, livestock production is threatened by endemic, emerging and transboundary diseases, including foot-and-mouth disease, *peste des petits ruminants*, African swine fever and highly pathogenic avian influenza, which can cause substantial production losses and threaten food security. Recent analysis of official disease reports confirms a substantial burden of notifiable animal diseases in Nigeria and the need for stronger surveillance and response systems (Al-Mustapha et al., 2025). Climate change adds to these challenges by altering pathogen survival, vector ecology, livestock production systems and disease patterns. These changes can increase animal health risks and complicate livestock disease surveillance and control, making timely monitoring and early response increasingly important (World Organisation for Animal Health [WOAH], 2024). Conventional animal health surveillance systems may also face challenges related to delayed reporting, limited diagnostic capacity, inadequate field-level resources and gaps in surveillance coverage, which can reduce the timeliness of disease detection and response (Kahariri et al., 2024).

Digital technologies and agricultural automation can strengthen livestock disease surveillance and veterinary service delivery. FAO's EMA-i+ supports real-time, georeferenced disease reporting, while artificial intelligence and statistical modelling can support disease-risk assessment, prediction and decision-making (FAO, 2024).

This chapter examines smart veterinary services and digital extension for climate-resilient livestock disease surveillance in Nigeria, focusing on mobile applications, artificial intelligence, and statistical modelling. It highlights their potential to strengthen surveillance, veterinary and extension service delivery, and food security, while addressing key implementation challenges.

II. CONCEPTUAL FOUNDATIONS AND EMERGING APPROACHES

A. Digital Extension in the Veterinary Context

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Digital extension refers to the use of information and communication technologies (ICTs) to deliver advisory services, knowledge and decision-support tools to farmers (Mulungu et al., 2025). In the veterinary context, it extends beyond face-to-face services to include mobile-based disease reporting, teleconsultation, digital training and access to timely animal health information. Digital extension platforms also facilitate two-way communication between farmers and service providers, enabling timely feedback and targeted interventions (Begho & Ogisi, 2025). These channels allow veterinary and extension personnel to disseminate disease alerts and preventive messages while receiving field-level information from livestock producers, thereby improving the reach and responsiveness of animal health services, particularly among smallholders in remote areas.

B. Smart Veterinary Services and Their Key Components

Smart veterinary services involve the integration of digital technologies, data analytics and automation into veterinary practice to improve the efficiency and responsiveness of animal health delivery. The concept draws from smart agriculture and precision livestock farming, where real-time data support more precise management decisions (Muhammad & Milala, 2026; Jhilta et al., 2025). Four components are central:

i. **Digital data capture** through mobile applications and electronic forms;
ii. **Connectivity and communication** linking farmers, veterinarians, laboratories and policymakers;
iii. **Decision support** using AI and statistical models for risk assessment and diagnostics; and
iv. **Automation** of reporting, mapping and data processing to reduce manual bottlenecks (Polapragada, 2026; Engdawork & Negussie, 2025).

Together, these components support a shift from reactive disease control towards proactive, data-driven animal health management.

C. Digital Approaches to Livestock Disease Surveillance

Digital disease surveillance uses electronic technologies to collect, transmit, analyse and disseminate animal health information for early detection and response. Core functions include event detection, data aggregation, geospatial mapping, dashboard visualisation and automated alerts. Platforms such as FAO's EMA-i+ enable veterinary officers to submit georeferenced reports and communicate with central authorities in real time (FAO, 2024). By improving the timeliness and spatial resolution of animal health data, such systems support outbreak investigation, risk mapping and evidence-based decision-making. In Nigeria's diverse livestock production systems, digital approaches offer opportunities to strengthen disease detection, monitoring and coordination among producers, veterinarians and relevant institutions (Engdawork & Negussie, 2025).

D. Climate-Resilient Livestock Health and Disease Management

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Climate-resilient livestock health refers to the capacity of animal health systems to anticipate and adapt to climate-related pressures while maintaining effective surveillance and response functions. Climate change can alter vector distribution, pathogen survival and disease patterns, while smallholder livestock systems are particularly vulnerable because of their dependence on natural resources and limited capacity to absorb shocks (Ojo et al., 2024). Digital technologies can support climate-resilient management by integrating meteorological and animal health information for early warning and targeted advisories. For example, linking rainfall forecasts with disease reporting platforms can support timely alerts on vector-borne diseases during high-risk periods. Strengthening these capabilities is therefore important for protecting livestock productivity and food security under changing climatic conditions.

E. Adoption of Digital Technologies in Veterinary Extension

The effectiveness of smart veterinary services depends on their integration into existing extension and veterinary systems rather than on technology availability alone. Adoption is influenced by perceived usefulness, ease of use, training and compatibility with local contexts (Davis, 1989; Rogers, 2003; Achille & Velamuri, 2025). In Nigeria, challenges include poor network coverage, high costs of data and devices, inadequate digital skills and limited institutional support (Deji et al., 2024; Makinde et al., 2025). Addressing these challenges through capacity building, affordable service models and user-centred design is essential for sustainable adoption of digital technologies in veterinary extension.

III. CURRENT STATE OF LIVESTOCK DISEASE SURVEILLANCE IN NIGERIA

A. Overview of Existing Surveillance Systems

Livestock disease surveillance in Nigeria is coordinated by the Federal Department of Veterinary and Pest Control Services in collaboration with State veterinary authorities, NVRI, diagnostic laboratories and other stakeholders. The system combines passive surveillance through reports from farmers and animal health personnel, active surveillance through targeted investigations, and laboratory-based diagnosis and confirmation (Al-Mustapha et al., 2025). Although this provides an important surveillance framework, delayed reporting, weak feedback mechanisms and limited resources constrain its timeliness and effectiveness.

B. Institutional Roles and Stakeholder Involvement

Livestock disease surveillance involves multiple actors at national, state and community levels:

i. **Federal Veterinary Authorities:** Provide policy direction, set surveillance priorities and coordinate national animal health programmes.

ii. **State Veterinary Services:** Implement surveillance, investigation, reporting and control activities and link field observations with national structures.

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iii. **NVRI and Diagnostic Laboratories:** Provide laboratory support for investigation and confirmation of suspected diseases.

iv. **Development Partners and NGOs:** Support surveillance and control programmes, particularly for priority transboundary diseases.

v. **Research and Academic Institutions:** Contribute through disease research, epidemiological studies and capacity building.

vi. **Private Veterinarians and Animal Health Personnel:** Support disease detection, treatment and reporting, particularly where public services have limited reach.

vii. **Community-Based Animal Health Personnel:** Provide early information on unusual events and facilitate communication with authorities.

viii. **Livestock Farmers and Producers:** Often provide the first indication of animal health changes, making their willingness to report important for timely detection.

Despite this broad stakeholder involvement, coordination and information sharing remain weak. Clearer reporting pathways and stronger feedback mechanisms are needed to improve surveillance efficiency (Al-Mustapha et al., 2025).

C. Challenges of Current Surveillance Practices

Surveillance effectiveness is constrained by underreporting resulting from limited awareness, poor access to services and concerns about trade restrictions following disease reports (Akangbou & Amanawa, 2024). Reliance on manual, paper-based reporting also delays data transmission and analysis, while limited diagnostic capacity and weak specimen referral systems hinder disease confirmation. Poor integration of animal health data with climate and production information further limits timely and evidence-based decision-making (WOAH, 2022).

D. Climate Change and Gaps in Real-Time Data

Climate change is altering disease patterns in Nigeria through changes in temperature, rainfall and vector ecology, while droughts and floods can affect livestock movement and disease transmission (Ojo et al., 2024). A major surveillance gap is the limited availability of real-time data, as manual reporting through multiple administrative levels can delay detection and response. Digital tools such as mobile applications, GIS and dashboards can improve data timeliness and accuracy (FAO, 2024), but uneven adoption and limited interoperability remain challenges. Strengthening digital infrastructure and data integration is therefore critical for more responsive surveillance.

IV. MOBILE APPLICATIONS FOR VETERINARY EXTENSION AND DISEASE SURVEILLANCE

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Mobile applications are among the most practical digital tools for extending veterinary services and strengthening livestock disease surveillance. Their value lies in the ability to connect field-level observations with veterinary professionals, laboratories and decision-makers through relatively accessible digital devices. In disease surveillance, mobile applications can support data capture, reporting, communication, geospatial location, information sharing and decision support. Their potential is particularly relevant to livestock systems where conventional reporting processes may involve delays between field observation and institutional response. Evidence from livestock surveillance initiatives in sub-Saharan Africa demonstrates that mobile reporting can improve the timeliness and volume of disease information reaching veterinary authorities (Njenga et al., 2021).

A. Types and Functions of Mobile Applications

Mobile applications used in veterinary services can be broadly distinguished according to their primary functions. These include:

i. **Disease reporting and field data collection:** These applications allow veterinary personnel to record suspected disease cases, clinical observations, vaccination information and other animal-health events electronically.

ii. **Diagnostic and decision support:** Some applications provide access to diagnostic information, clinical reference materials and decision-support tools that can assist veterinary personnel in assessing animal-health conditions.

iii. **Communication and extension:** Communication and extension applications facilitate the delivery of advisory messages, training materials, disease alerts and other animal-health information to livestock producers.

iv. **Surveillance data management and visualisation:** Some applications are linked to web-based dashboards that enable veterinary authorities and other authorised users to review, analyse and visualise surveillance information.

The integration of several functions within a single platform is particularly valuable because it reduces the need for separate systems for data collection, communication and analysis. FAO's EMA-i+ illustrates this approach by enabling veterinary field officers to submit standardised, georeferenced animal-health reports from the field, with the information subsequently made available through the EMPRES-i+ platform for analysis and surveillance management (FAO, 2024). Such systems demonstrate how mobile technology can connect field-level reporting with wider animal-health information systems.

B. Mobile Applications for Disease Reporting and Surveillance

Mobile applications can strengthen disease reporting by replacing or complementing paper-based processes with electronic data capture and transmission. Field officers and community animal health workers can

record suspected disease events using standardised forms and transmit reports directly to central surveillance databases. The use of mobile devices can also enable the capture of the time and GPS location of reported events, thereby improving the completeness, timeliness and spatial utility of surveillance data.

Evidence from the region demonstrates the practical value of this approach. In Kenya, the introduction of the Kenya Animal Biosurveillance System led to a substantial increase in disease reporting and broader geographic coverage of reported events, highlighting the potential of mobile platforms to improve the timeliness and reach of animal health surveillance (Njenga et al., 2021). Similarly, FAO's EMA-i+ platform supports real-time, georeferenced reporting and communication between field personnel and veterinary authorities (FAO, 2024). In Nigeria, the application of similar mobile reporting systems could help reduce delays in transmitting disease information from local and field levels to state and national surveillance structures. By facilitating timely submission of field reports with geospatial information, such tools could support earlier outbreak detection, more targeted response and better integration of field-level data into animal-health decision-making.

C. Real-Time Reporting, Geospatial Mapping and Decision Support

One of the major advantages of mobile applications is their ability to combine field data with location information. GPS-enabled reporting allows disease events to be associated with specific geographic locations, creating opportunities for disease mapping, identification of areas of increased risk and more targeted deployment of veterinary interventions. When connected to web-based dashboards, mobile reporting can also enable authorised users to monitor disease events and reporting patterns without waiting for periodic paper-based summaries.

Mobile applications can further incorporate decision-support functions. These may include structured clinical questionnaires, diagnostic reference materials, links to laboratory services and automated feedback based on submitted information. More advanced systems may incorporate artificial intelligence or analytical models to support risk assessment and preliminary decision-making. However, such tools should complement rather than replace professional veterinary diagnosis and laboratory confirmation. Advanced surveillance systems increasingly combine digital data capture with analytical tools to support earlier detection, monitoring and control of animal diseases (Engdawork & Negussie, 2025).

D. Mobile Applications for Farmer Education and Veterinary Extension

The usefulness of mobile technology extends beyond disease reporting to veterinary extension and farmer education. Mobile applications and related digital channels can provide livestock producers with information on disease prevention, vaccination, biosecurity, nutrition and general animal husbandry through text, audio, video, infographics and alerts. These channels can extend veterinary and extension messages without requiring a physical visit for every advisory interaction. Evidence from agricultural

extension research indicates that ICT-based channels can improve farmers' access to timely and actionable information, although their effectiveness depends on appropriate content design, user training and adaptation to local languages and production contexts (Mulungu et al., 2025).

The interactive value of mobile applications is particularly important during periods of increased disease risk. Veterinary authorities and extension personnel can disseminate preventive recommendations and disease alerts while receiving questions, observations and feedback from farmers. This creates a two-way communication pathway through which farmers can contribute field-level information that may support surveillance and early response, thereby strengthening their connection with formal animal-health services. However, effectiveness depends on accessibility, usability and integration with existing veterinary and extension systems. Where connectivity, digital literacy or access to smartphones is limited, complementary communication channels may be required. Mobile applications should therefore complement rather than replace conventional veterinary and extension services.

E. Adoption and Use by Farmers, Veterinarians and Extension Personnel

The availability of a mobile application does not guarantee its sustained use. Adoption depends on whether the technology is perceived as useful, accessible, affordable and relevant to users' needs. Digital literacy, network availability, device and data costs, ease of use, language, trust and compatibility with existing work practices can influence uptake and continued use. Evidence from Nigerian agricultural extension indicates challenges relating to infrastructure, skills, training and institutional support (Deji et al., 2024; Makinde et al., 2025).

These considerations are important because users may include farmers, community-based animal-health personnel, private veterinarians, government veterinary officers and extension personnel with different digital experiences and information needs. Applications designed with user participation are more likely to reflect field conditions, while features such as offline data entry, simple interfaces, locally relevant content, multilingual communication and feedback mechanisms can improve usability.

Sustained use also requires integration with existing veterinary information systems rather than isolated digital platforms. Interoperability can facilitate information exchange among field personnel, laboratories and veterinary authorities. Investment in training, connectivity, technical support and institutional coordination should therefore accompany the development and deployment of mobile applications, enabling them to function as communication and service-delivery pathways within the wider animal-health system.

V. ARTIFICIAL INTELLIGENCE, MACHINE LEARNING AND STATISTICAL MODELLING IN LIVESTOCK DISEASE SURVEILLANCE

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Advances in artificial intelligence (AI), machine learning (ML) and statistical modelling are expanding the capacity of animal health systems to process large and complex datasets for surveillance and decision-making. These approaches can be used to identify patterns, assess disease risks and support the interpretation of surveillance information. Although their application remains at an emerging stage in many low- and middle-income countries, they offer opportunities to complement conventional surveillance and strengthen the transition from predominantly reactive reporting towards more proactive and evidence-based disease management.

A. AI for Early Warning and Disease Outbreak Prediction

Artificial intelligence (AI) and machine learning (ML) can analyse large datasets from multiple sources to identify patterns, assess disease risks and support predictive epidemiology. In veterinary medicine, AI has potential applications in disease surveillance, epidemiological analysis and risk assessment, providing opportunities to strengthen early detection and targeted disease-control interventions (Akinsulie et al., 2024). Recent research demonstrates how an AI-based cattle health monitoring system can integrate image classification, mobile data collection and real-time monitoring to support earlier identification of cattle diseases (Rao et al., 2026). More broadly, advanced animal disease surveillance systems increasingly combine digital information systems with analytical approaches to strengthen disease detection, monitoring and control (Engdawork & Negussie, 2025).

The usefulness of AI-based early warning systems depends on the availability of timely, standardised and sufficiently representative data. Model outputs must also be interpreted by appropriately trained personnel and incorporated into established surveillance and response procedures. AI should therefore be regarded as a decision-support tool rather than an autonomous replacement for veterinary expertise. Its value lies in complementing conventional surveillance by helping veterinary authorities identify potential risks and prioritise events requiring further investigation.

B. AI-Assisted Image Recognition and Clinical Support

AI-based image recognition has potential applications in the assessment of photographs showing clinical signs, lesions and other visible indicators of animal disease. When incorporated into mobile or digital platforms, image-analysis tools can assist field personnel in identifying conditions that warrant further investigation. Rao et al. (2026) demonstrated this potential through an AI-powered cattle health monitoring system that combined image classification with mobile data collection and real-time dashboard monitoring. The system achieved internal testing accuracies of 98.36% for lumpy skin disease and 99.84% for foot-and-mouth disease, demonstrating the potential of image-based AI to support rapid disease screening and livestock health surveillance.

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Such applications could be particularly useful where veterinary personnel are limited or where livestock producers have difficulty obtaining immediate professional assistance. However, differences in animal breeds, disease presentation, image quality and field conditions can affect model performance. The reported results were based on internal validation and should not be interpreted as evidence of definitive field diagnosis. Consequently, AI-assisted image recognition should complement professional veterinary assessment and laboratory confirmation rather than be treated as a substitute for them.

C. Natural Language Processing and Veterinary Communication

Natural language processing (NLP) provides an important application of AI in livestock health by enabling computers to analyse and interpret unstructured textual information. In veterinary medicine, NLP and machine-learning models can extract disease-related information from clinical narratives, identify patterns and support automated disease coding and surveillance. Davies et al. (2024) demonstrated the potential of language models to analyse large volumes of veterinary clinical records, identify disease signals and support earlier detection of outbreaks. Such applications show how text-based veterinary data can complement conventional surveillance by converting previously underused clinical narratives into structured information for epidemiological analysis.

Beyond clinical records, NLP could potentially support veterinary extension and communication by enabling conversational systems to process farmer enquiries, provide responses to routine animal-health questions and facilitate the collection of field-level information. However, such applications require reliable veterinary information, appropriate language resources and mechanisms for referring complex cases to qualified professionals. In multilingual settings such as Nigeria, the effectiveness of digital communication may also depend on how well systems recognise and accommodate linguistic diversity. Consequently, NLP-based veterinary communication tools should consider relevant local languages, linguistic variation and the communication contexts of livestock producers.

D. Statistical Modelling of Livestock Disease Surveillance Data

Statistical modelling provides important methods for analysing livestock disease surveillance data and estimating patterns of disease occurrence and risk. Descriptive statistics can be used to summarise disease frequency, distribution and reporting patterns, while regression models can examine relationships between disease occurrence and relevant explanatory factors. More advanced models can also be used to account for characteristics of disease surveillance data, such as overdispersion and excess zeros, and to generate estimates of future disease occurrence.

A recent analysis of Nigeria's animal disease surveillance data provides a practical example of this approach. Using 3,362 official reports from the World Animal Health Information System (WAHIS)

covering 2006–2023, Al-Mustapha et al. (2025) used descriptive statistics and Bayesian zero-inflated negative binomial regression models to analyse reported disease patterns and forecast future outbreaks. The model accounted for overdispersion and excess zeros in disease-count data and generated forecasts for selected diseases through 2030. The study demonstrates how statistical modelling can move livestock disease surveillance beyond describing past disease occurrence towards risk estimation and forward-looking disease forecasting.

However, the usefulness of statistical modelling depends on the quality and completeness of the surveillance data. The Nigerian study also identified potential underreporting and limitations associated with surveillance data, highlighting the need for improved reporting systems, diagnostic capacity and data quality. Consequently, statistical models should be interpreted alongside veterinary knowledge, field observations and other sources of epidemiological evidence rather than being treated as independent substitutes for professional judgement (Al-Mustapha et al., 2025).

E. Predictive Modelling Using Climate, Animal Movement and Disease Data

Predictive modelling extends conventional statistical analysis by combining historical surveillance records with environmental, animal movement and other relevant data to estimate future disease risks. In livestock disease surveillance, models can use previous disease occurrence together with variables such as temperature, rainfall, livestock movement patterns, animal population characteristics and environmental conditions to identify periods and locations that may have an increased probability of disease occurrence. This approach shifts surveillance from describing past disease patterns towards anticipating potential risks and supporting earlier intervention.

Climate and animal movement data are particularly relevant because disease transmission can be influenced by environmental conditions, vector ecology, livestock mobility and patterns of animal contact. Integrating these data streams can therefore improve the identification of high-risk periods and locations. Spatial analysis of livestock disease data in sub-Saharan Africa has demonstrated the use of spatial risk prediction and modelling approaches to investigate disease distribution and risk, while also highlighting the potential for more prospective applications to support early warning (Ngwira et al., 2024).

In Nigeria, predictive modelling can build on existing animal disease surveillance data and progressively incorporate climate, livestock movement and other relevant information. However, effective prediction requires reliable datasets with adequate temporal and geographical coverage, as well as collaboration among veterinary authorities, meteorological agencies, livestock institutions and other relevant stakeholders. Limitations in data quality, reporting completeness and interoperability may therefore affect model performance and should be considered when interpreting predictive outputs.

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F. Time-Series and Spatiotemporal Analysis

Time-series analysis can be used to examine changes and seasonal patterns in livestock disease occurrence, while spatial and spatiotemporal methods can identify geographical clusters, disease distribution and changes in disease risk over time. These approaches can support the identification of high-risk locations, investigation of factors associated with disease occurrence and more targeted allocation of surveillance and control resources. A scoping review of livestock disease studies in sub-Saharan Africa found that spatial methods have been used to examine disease distribution, risk factors, space–time interactions and spatial risk prediction, although much of the existing work remains retrospective rather than focused on prospective early warning (Ngwira et al., 2024).

The integration of georeferenced disease reports with spatial and temporal analytical methods can therefore strengthen livestock disease surveillance. GPS-enabled mobile reporting, GIS and statistical models can help veterinary authorities visualise disease events, detect spatial clusters and monitor changes in disease patterns over time. However, the effectiveness of such approaches depends on the availability, completeness and quality of surveillance data. In sub-Saharan Africa, under-reporting, paper-based records, limited diagnostic capacity and inadequate spatial data remain important constraints to the development of more advanced livestock disease models (Ngwira et al., 2024). Strengthening digital data capture and integrating spatial and temporal analysis into veterinary surveillance systems could therefore improve the capacity for risk assessment and early warning in Nigeria.

G. Model Validation, Data Quality and Interpretation

The usefulness of AI, ML and statistical models in livestock disease surveillance depends heavily on the quality, completeness and representativeness of the underlying data. Incomplete, biased or unevenly collected surveillance records may introduce systematic errors and produce unreliable estimates or misleading predictions. Differences in disease detection, reporting, testing and surveillance coverage across locations or livestock populations may also distort observed disease patterns and affect model performance (Cross et al., 2024; Mesquita et al., 2025).

It is therefore important to validate models using appropriate datasets and assess their performance under the conditions in which they are intended to be applied. Model development should also consider potential sources of bias, missing data and limitations in surveillance systems to improve the reliability and generalisability of analytical outputs.

Interpretation is equally important. Model outputs should be considered alongside veterinary knowledge, field observations and laboratory evidence rather than being treated as definitive conclusions. Strengthening data governance, staff capacity, quality assurance and feedback mechanisms is therefore essential for

ensuring that analytical tools generate information that is credible and useful for veterinary policy, disease surveillance and control.

H. Opportunities and Limitations in the Nigerian Context

Nigeria has considerable potential to apply artificial intelligence (AI) and statistical modelling to livestock disease surveillance as digital reporting, mobile connectivity and access to environmental and climate data continue to develop. Existing national and international animal-health surveillance datasets can support disease-risk assessment, forecasting and targeted surveillance, particularly when integrated with climatic, environmental, livestock movement and laboratory data.

Opportunities

i. **Expanding digital and mobile infrastructure:** Increasing access to mobile technologies and digital communication provides a foundation for technology-enabled veterinary services, including digital disease reporting and information dissemination.

ii. **Availability of existing surveillance data:** Existing surveillance records can support statistical and AI-based disease-risk assessment, forecasting and targeted surveillance. Improving their quality, standardisation and accessibility would increase their usefulness for analytical applications (Al-Mustapha et al., 2025).

iii. **Potential for locally adapted AI applications:** AI can support animal-health diagnostics, disease surveillance and livestock monitoring, but effective applications will require models and datasets that reflect local breeds, production systems and agro-ecological conditions (Ayandiji & Ajibade, 2026).

Limitations

i. **Infrastructure and connectivity constraints:** Limited digital infrastructure, fragmented connectivity and high hardware costs may restrict access to AI-enabled veterinary services, particularly among smallholder and remote livestock producers.

ii. **Data quality and availability:** Incomplete, inconsistent and unevenly distributed surveillance data can limit the reliability of predictive models, while limited datasets on indigenous breeds and local production environments may affect their applicability and generalisability.

iii. **Limited technical and digital capacity:** Inadequate data science expertise, digital literacy and training may constrain the adoption and sustained use of AI-enabled veterinary technologies.

iv. **Data governance and institutional coordination:** Fragmented information systems, limited interoperability and weak data-governance arrangements may hinder data sharing and collaboration among relevant institutions (Ayandiji & Ajibade, 2026).

Way Forward

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Phased and Context-specific Implementation: Adoption should begin with improved data capture, standardisation and interoperability, followed by capacity building and carefully evaluated AI and predictive-modelling applications within existing veterinary surveillance structures. Locally trained models, affordable low-bandwidth solutions and coordinated policy support will be important for translating AI into practical livestock health services (Ayandiji & Ajibade, 2026).

The objective is not to replace conventional veterinary surveillance but to strengthen it through better use of data, improved analytical capacity and timely decision support. Emerging technologies should therefore complement veterinary expertise while remaining responsive to Nigerian livestock production systems.

VI. INTEGRATION OF DIGITAL TOOLS INTO VETERINARY EXTENSION SERVICE DELIVERY

Digital tools are increasingly becoming integral components of veterinary extension and animal-health service delivery, with the potential to improve the reach, timeliness and accessibility of veterinary information and advisory services. Their effective integration, however, requires more than the introduction of digital platforms. It involves aligning technologies with existing veterinary and extension structures, developing the capacity of service providers and users, and establishing effective coordination among relevant actors. Evidence from Nigeria indicates that extension personnel are increasingly exposed to digital tools, although knowledge gaps, infrastructural limitations and institutional constraints can affect their effective integration into extension practice (Makinde et al., 2025).

A. Public Veterinary and Agricultural Extension Services

Public veterinary and agricultural extension services remain important channels for delivering animal-health information, particularly to smallholder livestock producers. Integrating digital tools into these services can support disease reporting, veterinary advisories, farmer education, disease-prevention messages and follow-up communication. Digital platforms can also complement physical visits by enabling extension and veterinary personnel to maintain communication with farmers between field contacts.

For effective integration, digital tools should be incorporated into existing workflows rather than introduced as separate systems. This requires appropriate devices, reliable connectivity, technical support, supervision and institutional arrangements for managing digital information. Digital tools should therefore complement, rather than replace, established veterinary and extension services. Their effectiveness is likely to be greater when they are designed around existing service-delivery structures and the practical needs of both service providers and livestock producers.

B. Private Sector and Development Organisation Initiatives

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Private companies, non-governmental organisations and development organisations can complement public veterinary extension through mobile applications, SMS services, digital advisory platforms, teleconsultation services and other technology-enabled solutions. Such initiatives may provide specialised services, reach particular livestock value chains or serve as platforms for testing innovative approaches to animal-health communication and service delivery.

However, the existence of multiple platforms can also create fragmented systems when initiatives operate independently. Differences in data formats, reporting procedures and institutional priorities may limit the contribution of information generated by private platforms to wider surveillance and veterinary planning. Greater coordination among public agencies, private providers and development organisations is therefore important to reduce duplication and improve the potential for useful data and services to contribute to broader animal-health systems. Recent work on digital livestock governance in West Africa similarly highlights institutional fragmentation and weak coordination as challenges to scaling digital veterinary innovations (Gbaguidi et al., 2025).

C. Capacity Building and Digital Literacy

Effective integration of digital tools requires adequate skills among veterinarians, veterinary paraprofessionals, extension personnel and livestock producers. Capacity building should therefore address both basic digital literacy and the specific competencies required for using digital platforms for data collection, interpretation, communication and decision-making.

Training for veterinary and extension personnel should extend beyond learning how to operate an application. Users need to understand how information generated through digital systems can be interpreted and applied to disease surveillance, advisory services and field-level decision-making. Farmers similarly require support to access, interpret and respond appropriately to digital animal-health information. Continuous technical support is also important because digital platforms, applications and procedures may change over time. Nigerian evidence on agricultural extension personnel highlights the importance of strengthening knowledge and capacity for the effective digitisation of extension services (Makinde et al., 2025).

D. Digital Communication Among Farmers, Veterinarians and Extension Agents

Digital platforms can facilitate two-way communication among livestock producers, veterinarians and extension agents. Farmers can use mobile applications, messaging platforms and other digital channels to report suspected disease events, request veterinary advice and provide feedback, while veterinary and extension personnel can respond with preventive recommendations, referrals and follow-up information.

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This two-way communication can strengthen the responsiveness of veterinary extension by allowing information to move in both directions rather than treating farmers solely as recipients of technical messages. However, communication channels should reflect differences in language, literacy, digital skills, connectivity and preferred modes of interaction among user groups. Digital communication should therefore be complemented by appropriate interpersonal and community-based approaches where necessary to ensure that livestock producers with limited access to digital technologies are not excluded.

E. Data Integration and Institutional Collaboration

The effectiveness of digital veterinary extension at scale depends on relevant systems and institutions' ability to exchange and use information. Key areas of integration include:

i. **Data interoperability:** Data generated through field reporting, veterinary consultations, laboratory investigations, livestock identification and other activities should, where appropriate, be captured using compatible standards and linked to relevant information systems. Interoperability can reduce the need for field personnel to enter the same information into multiple disconnected platforms and improve the flow of information from local-level reporting to surveillance, planning, and response.

ii. **Institutional collaboration:** Effective integration requires collaboration among veterinary authorities, agricultural ministries, research institutions, meteorological agencies, private-sector providers and other relevant stakeholders. Such collaboration facilitates information exchange and improves coordination of surveillance, extension and disease-control activities.

iii. **Data governance:** Clear arrangements for data ownership, access, sharing, security and use are necessary to build trust and support responsible information exchange. Appropriate governance mechanisms are particularly important where information is shared across institutions and digital platforms.

iv. **Linkage with surveillance and early warning systems:** Digital extension data can contribute to broader animal-health surveillance when information generated at field level is appropriately linked to disease monitoring, livestock identification and early-warning systems. Recent efforts to harmonise the pastoral livestock data ecosystem in Nigeria illustrate the importance of common data elements, standards and interoperability across these areas (AU-IBAR, 2025).

Such linkages can also strengthen the data foundation for predictive and spatiotemporal analyses discussed in Section V by improving the availability, consistency and connectivity of relevant information.

Overall, the integration of digital tools into veterinary extension should be viewed as a systems approach rather than a technology-only intervention. Digital platforms are most likely to contribute to improved animal-health service delivery when they are supported by capable personnel, appropriate infrastructure,

effective communication pathways, interoperable information systems and coordinated institutional arrangements.

VII. CHALLENGES TO DIGITAL VETERINARY EXTENSION AND DISEASE SURVEILLANCE IN NIGERIA

Despite the potential of digital technologies to strengthen veterinary extension and disease surveillance, their adoption and effective use in Nigeria face several interconnected challenges. These challenges extend beyond access to technology and involve infrastructure, human capacity, data governance, financial sustainability, policy and institutional coordination. Addressing these constraints is essential if digital approaches are to contribute meaningfully and sustainably to animal-health service delivery and disease surveillance.

A. Infrastructure Challenges

Reliable digital and physical infrastructure remains a fundamental requirement for effective digital veterinary extension. In many rural areas, inadequate electricity supply, poor internet connectivity and limited mobile network coverage can affect the deployment and consistent use of digital platforms. The availability and affordability of devices such as smartphones and tablets for extension personnel and livestock producers may also vary considerably. Without adequate infrastructure, even well-designed digital tools may be difficult to operate consistently or reach their intended users.

B. Digital Literacy and Capacity Constraints

Effective use of digital tools requires appropriate skills among both service providers and livestock producers. Gaps in digital literacy among veterinarians, veterinary paraprofessionals, extension personnel and farmers can limit the adoption and effective use of digital platforms. Training may also focus primarily on operating applications, with less emphasis on interpreting digital information and applying it to decision-making. In addition, staff turnover and limited opportunities for continuous technical support may make it difficult to sustain digital competencies over time (Makinde et al., 2025).

C. Data Privacy, Ownership and Trust

The collection, storage and sharing of animal-health information through digital platforms raise important questions concerning data privacy, ownership, access and use. Livestock producers may have concerns about how information relating to herd health, animal locations or production activities is collected and used. Where clear arrangements for data governance and confidentiality are lacking, such concerns may discourage participation and information sharing. Building trust among livestock producers, veterinary personnel and institutions is therefore important for encouraging the responsible use of digital systems and strengthening participation in disease surveillance.

D. Cost, Sustainability and Maintenance

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The development, deployment and maintenance of digital systems can involve substantial costs. These may include expenditure on devices, internet and data services, software development, platform maintenance, system upgrades and technical support. Dependence on donor funding or short-term projects may also create sustainability challenges when external funding ends. Within public veterinary systems, limited financial resources may restrict the ability to scale successful pilot projects and maintain digital platforms over the long term.

E. Policy and Regulatory Gaps

The policy and regulatory environment for digital veterinary services continues to evolve. Important areas requiring clearer guidance include digital-data standards, validation of digital tools, data protection, professional responsibilities and the integration of digital services into formal veterinary practice. Where appropriate policy and regulatory frameworks are lacking, uncertainty may arise among public agencies, private technology providers and users. Clear and adaptive policies are therefore important for guiding the safe, ethical and effective use of digital technologies in animal health.

F. Institutional Coordination and Interoperability

Fragmentation across institutions can limit the effectiveness of digital veterinary systems. Data may be collected by government agencies, research institutions, non-governmental organisations and private platforms using different formats and standards, with limited mechanisms for information sharing and integration. Weak coordination among veterinary authorities, agricultural ministries, research institutions and other stakeholders may result in duplication of efforts and missed opportunities for data use. Strengthening interoperability, institutional collaboration and common data standards is therefore important for ensuring that digital information can contribute effectively to surveillance, planning and disease response at scale.

VIII. OPPORTUNITIES AND FUTURE DIRECTIONS FOR DIGITAL VETERINARY EXTENSION AND DISEASE SURVEILLANCE IN NIGERIA

Despite existing challenges, Nigeria has significant opportunities to strengthen veterinary extension and disease surveillance through digital innovation. Realising this potential requires improved infrastructure and capacity, stronger institutional coordination and technologies aligned with animal health and food security goals.

A. Digital Surveillance within One Health Approaches

Digital platforms can link animal-health data with human-health and environmental information within a One Health framework. Such integration can strengthen early detection of zoonotic diseases, risk assessment and cross-sector coordination for prevention and response. Improved data sharing among veterinary, public health and environmental agencies is therefore essential.

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B. IoT, Wearables and Remote Monitoring

Sensors, GPS devices and wearable technologies can support continuous monitoring of livestock health, behaviour and movement. Data on temperature, activity and location may provide early indications of disease. Although cost and connectivity remain constraints, targeted pilot projects in commercial and pastoral systems can generate evidence for context-specific scale-up.

C. Public-Private Partnerships

Collaboration among public veterinary services, technology providers, research institutions and development organisations can strengthen digital veterinary systems. Private partners can provide technical expertise and user-centred solutions, while public institutions provide regulatory oversight, veterinary expertise and links to national systems. Such partnerships can improve sustainability, capacity and data integration.

D. Strengthening Digital Veterinary Extension Systems

Digital tools can be further integrated into public extension systems by aligning platforms with existing workflows, providing field staff with appropriate devices and connectivity, and strengthening digital skills. Adapting content to local languages and production contexts can improve reach and usability, particularly for producers with limited access to conventional veterinary services (Makinde et al., 2025).

E. Policy and Institutional Recommendations

Adaptive policies are needed to guide the development and use of digital technologies in animal health. Key priorities include data standards and interoperability, data governance and protection, validation of digital tools, and coordination of data collection and sharing across institutions. Recent efforts to harmonise livestock data in Nigeria demonstrate the importance of common standards for coordinated digital services (AU-IBAR, 2025).

F. Linking Digital Surveillance to Productivity and Food Security

The value of digital surveillance ultimately depends on its contribution to livestock productivity and food security. Earlier risk detection, targeted interventions and improved access to animal-health information can reduce losses and support more reliable production and market participation. Linking digital investments to these outcomes strengthens the case for sustained support for digital veterinary services.

Overall, the future of digital veterinary extension in Nigeria depends on integrated, affordable and locally appropriate systems that strengthen existing structures and respond to the needs of producers and service providers.

G. Recommendations for Implementation and Adoption

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To maximise the contribution of digital veterinary extension and AI-driven statistical modelling to climate-resilient livestock disease surveillance and food security in Nigeria, the following evidence-informed measures are recommended.

1. Strengthen Digital Veterinary Extension Infrastructure

Federal and State Ministries of Agriculture should prioritise investment in rural internet connectivity, Unstructured Supplementary Service Data (USSD)-compatible mobile reporting platforms, and interoperable digital tools to facilitate timely information exchange among livestock farmers, veterinarians, and extension agents. Such investments should consider the affordability, accessibility, and usability of digital technologies, particularly in rural communities. Evidence from Nigeria highlights the importance of addressing adoption barriers to digital farming technologies, while research on information and communication technology-based extension demonstrates the potential of digital platforms to improve agricultural information delivery (Achille & Velamuri, 2025; Deji et al., 2024; Mulungu et al., 2025).

2. Institutionalise AI-Driven Statistical Modelling for Early Warning

Veterinary research institutions and relevant animal disease surveillance authorities should collaborate to develop, validate, and implement predictive models that integrate livestock disease records, climatic variables, animal movement patterns, and other relevant risk factors. Artificial intelligence and statistical modelling could support disease forecasting, risk mapping, and targeted early warning interventions. Their application should be accompanied by rigorous model validation, assessment of prediction errors, and evaluation of potential biases to ensure that model outputs are reliable and appropriate for veterinary decision-making (Akinsulie et al., 2024; Cross et al., 2024; Polapragada, 2026). Nigeria's existing animal disease reporting challenges and documented disease burden further underscore the need to strengthen surveillance data and analytical capacity (Akangbou & Amanawa, 2024; Al-Mustapha et al., 2025).

3. Integrate Climate Services into Disease Surveillance

Collaboration among the Nigerian Meteorological Agency (NiMet), veterinary authorities, livestock research institutions, and extension services should be strengthened to incorporate seasonal climate forecasts, temperature and humidity indicators, and heat-stress indices into livestock disease risk assessment and advisory services. Climate information should be combined with disease surveillance records to identify emerging risks, improve preparedness, and support timely veterinary interventions. This approach is particularly relevant in Nigeria, where climate change presents challenges for livestock production and health management (Ojo et al., 2024), and aligns with research priorities for climate adaptation and resilience in smallholder livestock systems across sub-Saharan Africa (Slayi et al., 2026).

4. Build Digital and Analytical Capacity

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Continuous professional development programmes should be provided for livestock farmers, veterinarians, and extension personnel, focusing on digital disease reporting, data literacy, statistical interpretation, and the practical use of predictive model outputs. Training should be complemented by accessible, farmer-friendly interfaces, local-language communication, and offline or low-bandwidth functionality where feasible. Evidence from Nigeria indicates that the adoption of digital extension depends partly on users' knowledge, attitudes, and perceived usefulness of the technologies (Deji et al., 2024; Makinde et al., 2025). Extension approaches should therefore be adapted to the needs and capabilities of different user groups.

5. Strengthen Data Governance and Institutional Coordination

Relevant government agencies should establish or strengthen a coordinated framework for data sharing, privacy protection, interoperability, data quality assurance, and institutional accountability. Clear protocols should define reporting responsibilities, data access, validation procedures, and information-sharing arrangements among veterinary services, research institutions, meteorological agencies, and other relevant stakeholders. Harmonising livestock data systems is particularly important for improving surveillance coordination in Nigeria, while evidence from Peste des petits ruminants surveillance highlights the importance of network structure and strategically positioned surveillance nodes (African Union Inter-African Bureau for Animal Resources, 2025; Mesdour et al., 2024). These efforts should also support a coordinated One Health approach to disease surveillance and response.

6. Ensure Sustainability and Assess Food Security Impacts

Digital veterinary surveillance initiatives should be supported by sustainable funding, technical maintenance, institutional ownership, and partnerships among government agencies, research institutions, telecommunications providers, and private-sector stakeholders. Their performance should be assessed using measurable indicators, including reporting timeliness, data completeness, outbreak detection rates, response time, livestock morbidity and mortality, and disease-related production losses. Where feasible, evaluations should also examine livestock productivity, household livelihoods, and the availability of animal-source foods. Nigeria's documented animal disease burden provides a basis for emphasising surveillance improvements and assessing their contribution to reducing disease-related losses (Al-Mustapha et al., 2025). Evaluation frameworks should distinguish improvements in surveillance performance from demonstrated changes in livestock productivity and food security.

Overall, implementing these recommendations requires an integrated approach that combines agricultural automation, digital veterinary extension, AI and statistical modelling, climate information, and institutional collaboration. Their effectiveness will depend on reliable surveillance data, appropriate technologies, adequate funding, user capacity, and sustained stakeholder participation. Addressing these requirements

can strengthen the contribution of livestock health management to climate adaptation and food security in Nigeria.

IX. CONCLUSION

A. Summary of Key Issues

Digital technologies are increasingly recognised as important tools for strengthening veterinary extension and livestock disease surveillance. Mobile applications, cloud platforms, remote sensing, artificial intelligence and statistical modelling can improve the timeliness, coverage and quality of animal-health information and services. However, effective deployment requires alignment with existing veterinary and extension systems, investment in human capacity, attention to data quality and governance, and institutional coordination. In Nigeria, progress remains constrained by infrastructural limitations, capacity gaps, fragmented data systems and sustainability challenges. Despite these constraints, digital tools have considerable potential to support animal health, agricultural development and food security.

B. Implications for Veterinary Practice and Agricultural Extension

Digital tools can support disease reporting, diagnostics, surveillance and decision-making in veterinary practice, but should complement rather than replace clinical judgement, laboratory confirmation and field engagement. In agricultural extension, digital platforms can expand service reach and facilitate two-way communication between service providers and livestock producers. Realising these benefits requires user-centred tools, adequate training and integration into routine workflows. Veterinary and extension personnel therefore require technical skills and the capacity to interpret and apply digital information effectively (Makinde et al., 2025).

C. The Way Forward for Smart and Climate-Resilient Livestock Health

Moving towards smart and climate-resilient livestock health systems requires a systems approach. Priority actions include:

- strengthening infrastructure, connectivity and access to appropriate digital devices;
- investing in digital literacy and capacity building for veterinarians, extension personnel and livestock producers;
- developing policy and governance frameworks for data standards, privacy, interoperability and validation of digital tools;
- promoting institutional collaboration to harmonise data and reduce fragmentation; and
- linking digital disease surveillance with livestock productivity, food security and One Health.

With sustained investment and institutional coordination, digital approaches can support earlier disease detection, targeted interventions and improved livestock health outcomes. Ultimately, the value of smart veterinary services will depend on developing affordable, interoperable and locally appropriate systems

that strengthen existing veterinary and extension structures and contribute to resilient livestock systems capable of responding to disease threats and climate variability in Nigeria and the wider region.

X. ACKNOWLEDGEMENTS

The authors acknowledge the contributions of veterinary and agricultural extension personnel involved in livestock disease surveillance and service delivery in Nigeria. We also acknowledge the support of institutions and organisations working to strengthen digital approaches to animal health and livestock development. The views expressed in this chapter are those of the authors and do not necessarily reflect the views of any supporting institution or organisation.

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