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Leveraging Geospatial Technologies for Resource Optimization in Livestock Management

Luwaga Denis[1,2,3]*, Mavuto Denis Tembo[1,2], Mtafu Manda[2], Alimasi Wilondja[4,5,6], Ngagne Ndong[7,8], Joshua Koskei Kimeli[9], Nansamba Phionah[3]

[1]African Centre of Excellence in Neglected and Underutilized Biodiversity (ACENUB), Mzuzu, Malawi
[2]Department of the Built Environment, Faculty of Environmental Sciences, Mzuzu University, Mzuzu, Malawi
[3]Department of Environmental Sciences, Faculty of Agriculture, Uganda Martyrs University, Kampala, Uganda
[4]Department of Biological Sciences, Faculty of Science Technology and Innovation, Mzuzu University, Mzuzu, Malawi
[5]Center for Research in Biodiversity, Ecology, Evolution and Conservation, Bukavu, Democratic Republic of the Congo
[6]Unité d'Enseignement et de Recherche en Hydrobiologie Appliquée (UERHA), Biology and Chemistry Department, Institut Supérieur Pédagogique de Bukavu (ISP), Bukavu, Democratic Republic of the Congo
[7]Department of Forestry, Faculty of Environmental Sciences, Mzuzu University, Mzuzu, Malawi
[8]Department of Plant Biology, Faculty of Science and Techniques, University of Cheikh Anta Diop, Dakar, Senegal
[9]Department of Fisheries and Aquatic Sciences, Faculty of Environmental Sciences, Mzuzu University, Mzuzu, Malawi
Email: *luwagadenis@gmail.com

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Abstract

Geospatial technologies can be leveraged to optimize the available resources for better productivity and sustainability. The resources can be human, software and hardware equipment and their effective management can enhance operational efficiency through better and informed decision making. This review article examines the application of geospatial technologies, including GPS, GIS, and remote sensing, for optimizing resource utilization in livestock management. It compares these technologies to traditional livestock management practices and highlights their potential to improve animal tracking, feed intake monitoring, disease monitoring, pasture selection, and rangeland management. Previously, animal management practices were labor-intensive, time-consuming, and required more precision for optimal animal health and productivity. Digital technologies, including Artificial Intelligence (AI) and Machine Learning (ML) have transformed the livestock sector through precision livestock management. However, major challenges such as high cost, availability and accessibility to these technologies have deterred their implementation. To fully realize the benefits and tremendous contribution of these digital technologies and to address the challenges associated with their widespread adoption, the review proposes a collaborative approach between different stakeholders in the livestock sector including livestock farmers, researchers, veterinarians, industry professionals, technology developers, the private sector, financial institutions and government to share knowledge and expertise. The collaboration would facilitate the integration of various strategies to ensure the effective and wide adoption of digital technologies in livestock management by supporting the development of user-friendly and accessible tools tailored to specific livestock management and production systems.

Keywords

Geospatial Technologies, Resource Optimization, Smart Livestock Management, Artificial Intelligence, Machine Learning

1. Introduction

Livestock farming plays a significant role in societies because it provides various resources for human consumption, contributes to nutritional security and helps improve economic stability (FAO, 2021). According to FAO, livestock contributes to nearly 40% and 20% of total agricultural output in developed and developing countries, respectively, supporting the livelihoods of at least 1.3 billion people worldwide and providing about 34% of global food protein. However, the livestock sector faces several challenges including limited resources such as land for grazing, scarcity of pasture and water, limited workforce, and market constraints (Eeswaran et al., 2022).

The Food and Agriculture Organization (FAO) attributes the environmental challenges, such as scarcity of pasture and water to the unprecedented levels of climate change, while the limited land for grazing is attributed to socioeconomic pressure resulting from increased population growth and urbanization. Furthermore, argues that the limited workforce is partly a result of the ever-increasing shift of the population, mostly the youth from rural to urban areas. This shift leaves fewer people, especially the aging group in the rural setting where extensive animal husbandry is practiced, hence affecting the labor demands of the livestock sector.

Previous livestock management approaches heavily depend on human labor, which is place-based and intensive, meaning when a worker knocks off, the labor power goes home as well leaving the livestock unattended to, which results into livestock theft (Ilyas & Ahmad, 2020). The earlier methods rely on the farmer's personal judgement and observational techniques, where a keen eye and a wealth of experience are the primary tools for identifying location, diseases, detecting behavioral changes, and determining the optimal time for breeding or weaning. Challenges such as weather limitations and observer fatigue are also associated with the earlier methods (Taban et al., 2018).

Smart livestock management has the potential to address the challenges facing the livestock sector (Sallam et al., 2022). *Smart* livestock management involves the application of modern technology to enhance efficiency, sustainability, productivity, feed quality, traceability and animal welfare in livestock farming (Sallam et al., 2022). The technologies used in smart livestock management include remote monitoring, GPS-based animal care, robotic milking, smart health collars, predictive disease control, and other innovations to achieve improved overall farm productivity (Aquilani et al., 2022).

Geospatial technologies can be leveraged to optimize the available resources to achieve better productivity and sustainability. GPS, GIS and Remote sensing are used to optimize livestock management by analyzing various geographical and environmental factors such as animal movement, pasture preferences, disease diagnosis and prediction, and allocation of land for pasture production (Turner et al., 2000). This enhances productivity and reduces resource wastage (Kohila et al., 2024).

Resource optimization enhances the allocation of strategies, processes, technologies and information management to improve efficiency and effectiveness aimed at decreasing operational costs hence achieving better productivity and informed decision-making (Srinivas et al., 2022). The resources can be human, software and hardware equipment and their effective management can enhance operational efficiency, improve business outcomes, and ultimately provide a competitive advantage through better and informed decision making (Rendel et al., 2020). **Figure 1** illustrates the process of Optimal Resource Management.

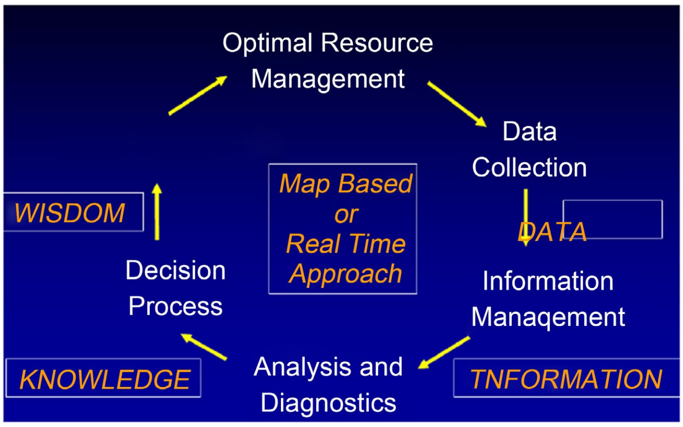

Figure 1. Steps to resource optimization (Rendel et al, 2020).

This systematic review overviews the application of geospatial technology in livestock management in the context of resource optimization in comparison with traditional approaches and suggests solutions for future challenges. Numerous applications of the technology at various stages of livestock management, including monitoring animal movement, behavior and health, optimizing feeding tactics, and diagnosing diseases, are discussed and presented.

2. Methodology

An exhaustive literature search was conducted in Google Scholar and Scopus using keywords such as "livestock management", "livestock farming", "resource optimization", "geospatial technology", "GPS", "GIS", "artificial intelligence", "machine learning", and "precision livestock farming". Boolean search commands such as AND, OR, and NOT were used to combine relevant information and to avoid duplications. Due to the high number of search results, only studies in which the search string was found either in the "Title", "Abstract", or "Key words" were screened and evaluated. All studies were screened for their relevance to the field of livestock management using geospatial technology in areas such as traceability management, disease management, behavior monitoring, feeding optimization, welfare assessment, environmental monitoring, and reproduction management. The inclusion criteria covered peer-reviewed articles published in indexed journals and reports by government and non-government organizations to ensure the quality of data and information sources. The exclusion criteria comprised of conference proceedings, duplicated articles, articles with restricted access and articles that did not have a direct link to the objective of the review. All studies in languages other than English were also excluded. A total of 80 articles were synthesized to compile this systematic review.

3. Historical Perspective: Traditional Livestock Management Systems

Livestock management involves both intensive and extensive approaches (Jahnke, 1982). Intensive and extensive management practices are widely applied in Africa and the world at large to manage animals (Mortimore, 1991; Turner & Schlecht, 2019). Intensive management on one hand involves rearing animals in a controlled environment to ensure that they are properly monitored by keeping them indoors and not allowed to roam around the farm. Some of the advantages of this system include controlled breeding and indiscriminate mating, monitored feeding and easy management of disease outbreaks, while the disadvantages include being capital and labor-intensive (Turner & Schlecht, 2019).

On the other hand, extensive management involves allowing the animals to roam freely around the farm in search of pasture and water (Naudé, 2017). One of the advantages of this system is facilitating the management of very large stock, while the disadvantages of the extensive approach include inadequate land for grazing, the requirement for more labor to monitor the animals and exposing the animals to predators and thieves (Casasús et al., 2012). Other challenges facing the industry, in general, include but are not limited to lack of pasture and quality feed, scarcity of water resources, climate change, undeveloped breeding and management of livestock, poor marketing and trade, and socioeconomic constraints (Eeswaran et al., 2022).

Traditional methods of animal management offer several advantages because they have been developed over time and are based on local traditions and practices (Deb, 2015). They often involve a deep understanding of animal health and disease management, as well as effective herd and pasture management techniques. Traditional methods also tend to be cost-effective and accessible, particularly in areas with limited veterinary services (Usman et al., 2016). Additionally, traditional practices can help improve animal welfare outcomes by selecting breeds that enhance resistance to diseases or improve temperament. These methods have been used for generations and have proven to be effective in sustaining livestock populations and meeting the demand for animal-based products within smallholder communities (Deb, 2015).

However, traditional animal management practices are associated with several challenges, such as they require close hands-on monitoring of herd health, location, and individual animal behavior, which is labor-intensive and time-consuming (Conteh et al., 2021). Formerly, farmers relied heavily on observational techniques to manage their herds where a keen eye and a wealth of experience were the primary tools for identifying location, diseases, detecting behavioral changes, and determining the optimal time for breeding or weaning. These methods present several challenges for example they rely heavily on individual human judgment, which can vary from person to person and is susceptible to error (Sallam et al., 2022).

Besides, the earlier approaches heavily depended on human labor which is place-based meaning when a worker knocks off, the labor power goes home as well leaving the livestock unattended to, which may result into livestock theft. Moreover, previous management practices have major limitations, such as weather (rainfall and extreme heat) and time (night), which renders livestock vulnerable to predators (Ilyas & Ahmad, 2020).

Due to over dependency on human labor especially in Africa, parents who perceive a lack of benefit of education involve their children who would otherwise be going to school in assisting with farm labor in form of looking after livestock and cultivation of animal feeds. This has resulted into a high rate of school dropout and is partly responsible for the increased rate of teenage pregnancies and HIV prevalence (Zdunnek et al., 2018).

4. Current Opportunities: Livestock Management in the Digital Era Using Sensor Technology

Digital technologies have advanced more rapidly than any innovation in history (The United Nations, 2020). The advancement in digital technology has given birth to cutting edge technologies including Geospatial technology, Computer programming, Internet of Things (IoT), Wireless Sensor Networks (WSN), Cloud Computing, Big Data Analytics, Artificial Intelligence (AI), Machine Learning (ML), and Robotics (Haldar et al., 2022).

Geospatial technology can facilitate the creation, processing, storage, and sharing of geographic data related to a location on the surface of the earth, which descriptive attributes can be tagged (Jin et al., 2022). The widely adopted geospatial technologies in the livestock sector include Global Positioning System (GPS), Geographic Information Systems (GIS) and Remote sensing (RS). These technologies (GPS, GIS and RS) can allow livestock farmers to optimize their operations by creating more efficient production systems that reduce environmental impacts, lower production costs, and enhance productivity (Neethirajan, 2020).

According to Haldar et al. (2022), the livestock farming industry is now the hotspot for the application of advanced technologies to monitor farm animals in a real-time basis, optimize food intake, predict diseases, and improve animal health through analyzing various geographical and environmental factors such as animal movement, pasture preferences, pasture planting seasons and weather patterns. By using geospatial technology, farmers can automate repetitive tasks and processes that are manual and time-consuming hence enhancing productivity and reduce resource wastage (Groher et al., 2020).

Several authors for example, Ilyas and Ahmad (2020); Sallam et al. (2022) have cited numerous applications of geospatial technology in livestock management, some of which have been synthesized and crafted in this review to illustrate the potential contribution of geotechnology towards achieving resource optimization in the thematic areas highlighted from section 4.1 to 4.7.

4.1. Animal Tracking

GPS-enabled sensors combined with geofencing technology have transformed livestock tracking and location management (Ilyas & Ahmad, 2020). Farmers can accurately track the real-time location of their animals using wearable GPS devices and define virtual boundaries on digital maps using geofencing (Park & Han, 2023). The GPS-enabled animal monitoring enhances the security of animals from thieves and predators, improves grazing management through gaining insights into animal movement patterns to enable optimized pasture usage and increases operational efficiency through streamlined monitoring, which saves time and resources, allowing for focused management efforts (Dhanasree & Shwetha, 2024). For example, a study conducted by Drewry et al. (2019) indicated that about 3000 livestock farmers in Wisconsin, US had adopted digital technologies, including animal monitoring technology, precision harvesting equipment (yield monitors), precision planting equipment, driver-assisted steering on farm equipment, sensor data, Unmanned Aerial Vehicles (UAVs), soil sensor data, and robotic milking machines.

Geofencing involves the use of GPS or Radio Frequency Identification (RFI) technology to create a virtual geographic boundary, enabling software to trigger a response when a device enters or leaves a particular designated area (Brown-Brandl et al., 2019). The virtual fencing system allows the management of animals at pasture without physical fences and human intervention but relies on associative learning between audio cues and an electric shock delivered if the animal does not change direction after the acoustic warning (Aquilani et al., 2022). This capability prevents livestock loss due to wandering and potential theft, while also promoting harmonious relations with neighbors by avoiding livestock straying onto their land (Ilyas & Ahmad, 2020). The system sends a notification via SMS or email to immediately alert the farmer or caretaker through their mobile devices when animals approach a predetermined radius or eventually move out of the designated area. As a result, implementing such a system saves resources like labor and capital, which would be used to establish physical fences and pay workers who would monitor and take care of the animals, hence minimizing operational costs (Setiawan et al., 2021).

4.2. Feed Intake Monitoring

Animal tracking technology has been signaled as being evolutionary in understanding animal feeding behavior (Trappes, 2023). Studies over time have established simultaneous GPS-based tracking as a productive approach for generating new insights into animal feeding (Francis et al., 2018; Schieltz et al., 2017; Turner et al., 2000). GPS technology explicitly captures where and when individual animals go and what they eat, which offers useful insights into animal grazing efficiency (Ermetin et al., 2022).

Wearable GPS trackers combined with accelerometers can continuously monitor animal movement and activity patterns (Bailey et al., 2018). Despite all animals grazing under the same conditions, substantial variations in pasture consumption among individual animals can be observed using dedicated sensors. These sensors have the potential to measure individual pasture intake by considering the metrics of time spent grazing, resting and ruminating, walking, drinking and utilizing shade (Draganova et al., 2010). This allows farmers to evaluate pasture utilization, animal performance, and behavior by capturing both the inputs (pasture intake) and the outputs (weight gain or milk production) for each animal hence understanding the feed efficiency of individual animals and the amount of pasture required for a unit of production to avoid resource wastage (Banhazi et al., 2012).

A study conducted by Draganova (2012) used sensor technologies to investigate the feeding patterns of 180 cows under commercial conditions at an intensively managed dairy farm at Massey University, Palmerston North, New Zealand. The results from the study revealed that the activities of cattle varied greatly according to site ($p < 0.05$) and they spent more time grazing and less time lying down during the AM than PM grazing period. Similarly, Assouma et al. (2018) assessed fodder intake by livestock (total of 11,000 cattle and 1800 small ruminants) grazing rangelands in semi-arid Sub-Saharan Africa over a one-year cycle using GIS, GPS and remote sensing. The results showed that the annual mean of the daily dry matter fodder intake was 68.4 ± 6.4 g/kg $LW^{0.75}$ or 17.2 ± 1.7 g/kg LW for cattle, 73.1 ± 5.3 g/kg $LW^{0.75}$ or 34.3 ± 2.8 g/kg LW for sheep, and 74.7 ± 8.7 g/kg $LW^{0.75}$ or 37.1 ± 4.4 g/kg LW for goats. The annual mean organic matter digestibility of grazed fodder was higher for goats (67.4% ± 3.9%) than for sheep (64.1% ± 3.2%) and cattle (59.3% ± 3.8%). This helped to estimate forage intake every month from hand plucking simulations of all the bites of forage taken in 24 h out of 48.

Furthermore, farmers can optimize land use by identifying the most feed-efficient animals potentially increasing stocking rates or allowing pastures to rest without sacrificing output. This capability helps to more effectively manage resources underscoring the importance of integrating feed efficiency into livestock selection criteria (Jennings, 2018). Moreover, feed efficiency also has profound implications for sustainability, particularly in reducing methane emissions which is a big concern in livestock farming. Animals that convert feed to weight more efficiently produce less methane per kilogram of weight gain, highlighting the environmental benefits of feed efficiency.

4.3. Disease Monitoring

Animal health, animal welfare, and food safety have gained significant global recognition as crucial factors in safeguarding livestock and the livelihoods of farmers (FAO, 2002). Within the realm of animal husbandry, GIS plays a central role as an integrated technology for collecting, transforming, and generating information from spatial and non-spatial databases (Raja, 2017). It offers spatial analysis and mapping capabilities that are highly beneficial in various aspects of livestock management. Additionally, it aids in veterinary surveillance, mapping disease patterns, and facilitating early intervention. GIS also helps with location-based management, identifying veterinary resources and enabling targeted interventions during outbreaks (Yukun et al., 2019). When integrated with GPS, it provides real-time location data for efficient livestock management, optimizing grazing and improving overall productivity (Javaid et al., 2022).

Animal health tracking and disease management are also crucial for preventing and controlling outbreaks (FAO, 2002). The utilization of GIS in animal health tracking and disease management is instrumental for identifying the precise location of farms or outbreak sites, as well as assessing areas that are potentially at risk in the event of an infectious disease (Tadesse & Amare, 2021). Through the integration of various spatial data pertaining to animal health, GIS enables the visualization of disease patterns, analysis of transmission routes, and identification of high-risk areas using multiple analytical tools. This integration of data supports the creation of early warning systems, aids in the allocation of resources for targeted interventions, and enhances response planning in the face of disease outbreaks (Tadesse & Abadi, 2021).

Monitoring the vaccinations of animals is a critical aspect of animal health management. Regular monitoring ensures that animals receive timely and appropriate vaccinations, protecting them from various diseases and preventing the spread of infectious agents (Di Lorenzo et al., 2023). GIS enables real-time monitoring of animal vaccinations through collecting vaccination data in the field using GPS and remote sensing which is then mapped to visualize vaccination points providing an accurate assessment of vaccination coverage. Furthermore, GIS analysis allows for the identification of areas with low coverage, enabling targeted interventions and timely vaccination reminders. Overall, the integration of GIS in monitoring animal vaccinations enhances the efficiency and effectiveness of vaccination programs by ensuring accurate data capture, informed decision-making, and improved coverage rates (White Paper, 2023).

4.4. Selection of Optimal Sites for Grazing and Pasture Production

Site selection for pasture land in animal husbandry optimizes livestock production and ensures animal nutritional welfare (Rana et al., 2023). An integral part of a sustainable livestock production system is the selection of appropriate land areas that meet several environmental and socioeconomic constraints considering factors such as soil quality, water availability, vegetation type, topography, and climate. Proper site selection promotes adequate nutrition, reduces disease risk, and enhances grazing efficiency, leading to healthier and more productive livestock (Acutis et al., 2013).

GIS can help to identify suitable locations for livestock farms or grazing areas based on factors such as soil quality, topography, proximity to water sources, and environmental constraints. By overlaying diverse spatial datasets and employing spatial analysis tools, GIS enables the evaluation of these factors, facilitating the determination of optimal locations for animal production facilities (Acutis et al., 2013). This approach contributes to the effective management and development of animal husbandry infrastructure, leading to improved productivity and sustainability (Panda et al., 2020).

Fodder development involves the deliberate cultivation and management of various crops, grasses, legumes, or other plant species that serve as food sources for animals (Hannaway et al., 2022). By leveraging GIS to evaluate factors such as soil type, topography, climate and land use, suitable areas for fodder production can be analyzed and identified. This enables land suitability assessments, ensuring optimal locations for cultivating fodder and efficient resource allocation (Rana et al., 2023).

GIS can also be used for mapping yield potential by incorporating data on environmental conditions, nutrient availability, and crop growth models. This aids in identifying areas with higher productivity and provides valuable insights to decision-makers for fodder crop selection and management. Moreover, the utilization of a Web-based GIS portal facilitates the monitoring and mapping of fodder resources, enabling improved inventory planning and sustainable fodder production and management (Worqlul et al., 2022).

4.5. Rangeland Management

Although there is an increasing effort in the promotion of sustainable livestock management, rangeland degradation still occurs because animals' foraging behavior is highly selective at different spatial scales (Sivakumar et al., 2023). The assessment of the ecological mechanisms modulating the spatial distribution of grazing and how to control it has critical implications for the long-term conservation of resources and the sustainability of livestock production (Plaza, 2022).

Conservation efforts have entered a new era of effectiveness and precision due to the transformative power of geospatial technology (Suzzi & Devarajan, 2023). Traditionally, the protection of natural resources relied heavily on physical monitoring and human intervention, which were labor-intensive, costly, and less effective in vast or remote areas (Yashaswi & Renaud, 2018). Geospatial technology allows conservationists to map and identify biodiversity hotspots, regions of high species richness and endemism. By using satellite imagery, GIS data, and advanced mapping techniques, farmers can pinpoint areas that require special attention and protection (Rhodes et al., 2022). This information helps to guide conservation strategies, aiding in the preservation of fragile ecosystems and unique species (Yashaswi et al., 2018).

For instance, Rivero et al. (2021) summarized and analyzed the scientific literature that has addressed the site use preference of grazing cattle using global positioning systems (GPS) collars from 2000-2020. This was intended to support the development of more sustainable grazing livestock systems. The 84 studies identified were undertaken in several regions of the world, in diverse production systems, under different climate conditions and with varied methodologies and animal types. The main findings were categorized according to the information reviewed, covering management and external and animal factors driving animal movement patterns. The results showed that some variables, such as stocking rate, water and shade location, weather conditions and pasture (terrain and vegetation) characteristics, have a significant impact on the behavior of grazing cattle.

Intelligent systems leveraging remote sensing, wearable devices, robots and UAVs have been developed to simulate an automatic grazing management system as shown in **Figure 2** (Cao et al., 2023). The system uses a UAV to carry feed supplements in a preferred direction while attracting animals thus controlling disorderly grazing, which leads to grassland ecological crises but also limits human interaction, which minimizes on operational costs (Cao et al., 2023). Furthermore, describe robotic cattle grazing system which uses GPS technology to discriminate between the foraging areas of dairy cattle at a pasture-based dairy farm at WK Kellogg Biological Station, Michigan State University. The results from GPS collars showed an 82% - 86% probability of estimating animal locations with a 7 m error. GPS data further revealed that 94.6% of cows were on pasture within their designated paddocks which concurs with the claim made by Cao et al. (2023).

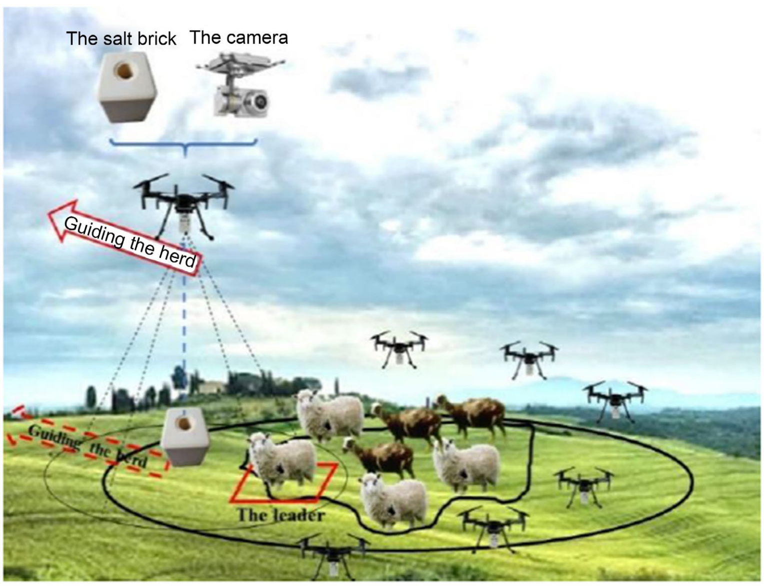

Figure 2. The schematic diagram of UAV carrying a salt brick to attract sheep to move in the planned direction (Cao et al., 2023).

4.6. Farm Equipment Monitoring

GPS tracking is a great tool for improving the efficiency of equipment and vehicles used on livestock farms (Yang, 2020). Sensor based monitoring can be used to monitor the location and usage of tractors, combines and other farm equipment. This information can be used to schedule maintenance and repairs, ensuring that equipment is always in good working order. Additionally, GPS tracking technology can also be used to monitor fuel consumption, allowing farmers to identify and address any issues that may be affecting fuel efficiency (Jin et al., 2022).

4.7. The Case for Agro-Pastoralists

The sharp increase in population and demand for more farmland and conservation have reduced the quantity of grazing resources which is a big threat to agro-pastoralism. The significant decrease in grazing spaces has resulted into spatially distributed conflicts between cattle keepers and other actors around forested areas, water sources and protected areas for biodiversity conservation (Bauer & Magri, 2011). This is because authorities consider the forests and protected areas as fragile ecosystems for conservation while agro-pastoralists regard them as reliable sources of grazing resources (Davis, 2022).

Essentially, Participatory GIS (PGIS) mapping can be a useful tool for examining conflicts and their spatial temporal distribution (Huck, 2023). Through PGIS the community, herders and scientists can dialogue and understand the dynamics of each other thus gaining insights about "why" and "how" people live in regard to the available natural resources (Bauer & Magri, 2011). Participatory GIS mapping can be used to assess land use land cover and vegetation resource use patterns among the community aimed at characterizing and identifying areas where agro-pastoralists can operate while not damaging the ecosystem (Bauer & Magri, 2011). This can inform decision-makers about the situation of the different communities thus helping to integrate knowledge about coping mechanisms between communities and extra-local actors (Tembo, 2013).

Section 4 presents a wide spectrum of immense contributions and applications of geospatial technologies in livestock management, including data acquisition, management, analysis, and dissemination. However, challenges associated with their utilization such as data privacy issues, high cost of technology, illiteracy levels, poor digital infrastructure, availability and accessibility of the technology, lack of awareness, and how the adoption of these technologies impacts the return on investment should be recognized and addressed.

5. Future Perspective: Revolutionizing Livestock Management with Artificial Intelligence (AI) and Machine Learning (ML)

Livestock management is a difficult task that is fraught with obstacles like disease outbreaks, environmental hardship, and poor feeding practices (Tadesse, 2021).

Despite previous livestock management techniques being affordable and accessible, they are labor-intensive, time-consuming, and vulnerable to subjectivity since they heavily depend on personal judgement and observational experience of the farmer (Fuentes et al., 2022). The application of Artificial intelligence and Machine learning approaches have demonstrated tremendous contributions towards automating the manual processes involved in livestock management (Mijwil et al., 2023).

These technologies (AI & ML) produce more precise and timely results by analyzing large databases of animal movement patterns, behavior, and environmental data to detect trends and make predictions aimed at enhancing animal welfare and productivity as well as reducing operational costs (Cockburn, 2020). However, the high cost of technology tools, illiteracy levels among farmers, poor digital infrastructure, availability and accessibility of the technology, lack of awareness, and how the adoption of these technologies impacts the return on investment, are cited as major obstacles to their wide spread adoption (Groher et al., 2020).

Artificial intelligence (AI) has the ability of computers to perform functions associated with the human brain, including perceiving, reasoning, learning, interacting, problem solving, and exercising creativity (Khalifa et al., 2021). Machine learning enables computers to perform tasks without explicit instructions, often by generalizing from patterns in data. Machine learning includes deep learning that relies on multilayered artificial neural networks to model and understand complex relationships within data (Yasir et al., 2023). Artificial intelligence systems work by using machines and algorithms to recognize patterns and associations from a massive amount of data collected by sensors and Internet of Things devices including GPS trackers, accelerometers, temperature and humidity sensors, and video cameras to make predictions in a process known as training (Owczarek, 2022).

The application of Artificial Intelligence and Machine Learning (**Figure 3**) in livestock management include among others: traceability management, disease detection and prediction, nutrition optimization, behavior monitoring and welfare evaluation, environmental monitoring and reproductive management (Singh et al., 2023). Some of the major areas where AI and ML have been applied are explained in sections 5.1 to 5.4.

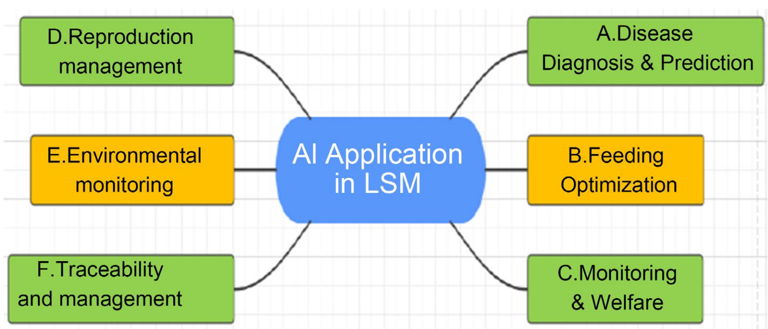

Figure 3. Application of AI in Livestock management (Yasir et al., 2023).

5.1. Animal Traceability and Management

AI and ML approaches can enhance traceability and livestock production management by monitoring the location of specific animals using computer vision and deep learning methods (Wei-Tse & Chang, 2020). Computer vision (CV) enables machines to recognize and understand visual information, convert pictures and videos into data, and make decisions based on the results. The ability to precisely identify and follow specific animals in real-time can help livestock managers to operate more effectively and lower the risk of disease transmission (Tzanidakis et al., 2023). For example, Singh presents a case where AI grazing assistants are used to manage the movement of animals in vulnerable riparian settings leveraging location intelligent sensors in virtual fences by applying audio signals and minimal electric shock to deter animals from accessing unauthorized premises (Muminov et al., 2016).

5.2. Feeding Optimization

Livestock managers can optimize feeding procedures using AI and ML techniques by creating deep learning-based systems capable of assessing and estimating animal body weight in relation to feed intake using picture analysis (Qiao et al., 2021). This method can be used to forecast feed consumption and the conversion effect in terms of production hence optimizing feed intake, enhance animal welfare and decrease costs for farmers (Qiao et al., 2021). For example, Neethirajan (2023a) analyzed chicken vocalizations using AI models in relation to measure feed uptake by broilers using a pecking sound by attaching a microphone to the feeder pan. This sound detection system helped to perform and analyze sound measurements in real time in a fully non-invasive but still automated manner during the full growth process of the chicken.

5.3. Disease Management

AI and ML models can be used to detect and forecast animal diseases based on its health history, genetics, and other characteristic (Raghuwanshi, 2022). These algorithms can find trends and risk factors linked to certain diseases by analyzing vast volumes of data, including veterinary records and genetic data. This enables farmers and veterinarians to take precautions aimed at lowering the risk of infection. Furthermore, AI and ML models such as computer vision technology can be used to recognize visual cues linked to animal disease symptoms (Oliveira et al., 2021). For example, computer vision software-enabled cameras can monitor animal's behavior and movements and check for any unusual or distressing behaviors that can point to a medical condition (Zhou et al., 2022). These instances show how AI and ML could improve animal welfare by identifying health problems before they become severe by triggering early interventions and treatment (Tzanidakis et al., 2023). AI models coupled with ICT systems are vital in assessing the welfare, social separation and thermal comfort to detect diseases like respiratory problems in pigs (Lagua et al., 2023). Moreover, by using data from temperature and humidity sensors, AI and ML models can identify and predict heat stress in among animals (Bao & Xie, 2022).

5.4. Reproduction Management

AI has the potential to significantly impact animal breeding programs by revolutionizing genetic selection and optimization (Malhotra et al., 2023). Utilizing machine learning algorithms, AI can process vast amounts of genetic data, enabling breeders to identify desirable traits and predict breeding outcomes accurately. This facilitates the selection of superior animals for reproduction, genetic diversity preservation, and the development of healthier and more productive livestock (Neethirajan, 2023b).

6. Conclusion

Geospatial technology has been credited by several authors and researchers as having the potential to transform livestock management. The review presents the increasing use of geospatial technologies in livestock management to optimize resources by improving traceability management, disease detection and prediction, nutrition optimization, behavior monitoring and welfare evaluation, environmental monitoring and reproductive management.

The future of the livestock sector has various prospects for advancing the field of Artificial intelligence and Machine learning which are capable of producing more precise and timely results by analyzing large databases of animal movement patterns, behavior, and environmental data to detect trends and make predictions aimed at enhancing animal welfare and productivity as well as reducing operational costs.

However, several challenges and constraints associated with their implementation have been cited including economic conditions (cost of adoption, facility maintenance, skilled labor), access to financial assistance, lack of government intervention, availability of technological infrastructure (mobile internet, mobile device, broadband internet), technical knowledge (digital training), age of farmers, type of organization, reliability of technology, concerns about security and privacy, learning and adoption capacity of farmers, lack of trust in the technology, incompatibility and complexity of new technology, inadequacies in extension intervention, farm physical characteristics (size, ownership status) among others.

To fully realize the benefits and tremendous contribution of geospatial technologies, Artificial intelligence and Machine learning and address the challenges and constraints associated with their wide spread adoption, the review in consensus with other studies proposes collaboration between different stakeholders in the livestock sector including livestock farmers, researchers, veterinarians, industry professionals, technology developers, the private sector, financial institutions, Government, NGOs and Civil Society organization to share knowledge and expertise to facilitate the integration of various methodologies to ensure the effective and wide adoption of digital technologies in livestock management. The collaboration will not only support the development of user-friendly and accessible tools tailored to specific livestock management and production systems but also help address issues related to data availability, interoperability and quality, as well as ethical and regulatory considerations. The alliance will provide farmers with access to affordable technologies to boost their productivity and standards of living while also supporting sustainable and ethical practices in livestock management.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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