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Research Article

# THE APPLICATION OF DRONE TECHNOLOGY AND IMAGE ANALYSIS FOR MONITORING GRAZING PATTERNS AND RANGELAND CAPACITY IN CATTLE FARMING

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## Abstract

The increasing demand for sustainable cattle farming and the pressure on rangeland resources have highlighted the need for efficient monitoring of grazing patterns and land carrying capacity. Traditional methods of monitoring rely on manual field surveys, which are labor-intensive and have limited coverage. Recent advancements in drone technology and image analysis present new opportunities for data-driven decision-making in livestock and rangeland management. This study explores the use of drone technology combined with image analysis techniques to monitor grazing patterns and assess rangeland capacity. A research and development design was employed, with drones capturing high-resolution aerial imagery of grazing areas at regular intervals. Image analysis techniques, including vegetation index extraction and spatial pattern analysis, were used to assess grazing intensity, vegetation cover, and biomass distribution. Data from the drone-based imagery were validated through ground observations and rangeland productivity records. The results show that drone-derived imagery accurately captured spatial variations in grazing behavior and vegetation condition, allowing for precise mapping of grazing zones and reliable estimates of rangeland carrying capacity. Compared to traditional methods, the drone-based approach was more efficient, offered greater spatial accuracy, and reduced the need for field surveys. In conclusion, integrating drone technology and image analysis offers a scalable solution for sustainable rangeland and livestock management.

**Keywords**: Drone Technology, Grazing Patterns, Image Analysis, Precision Livestock Farming, Rangeland Capacity

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## INTRODUCTION

Sustainable cattle farming increasingly depends on effective management of grazing patterns and rangeland capacity (Walsh et al., 2026). Overgrazing and uneven pasture utilization can lead to land degradation, reduced forage availability, and long-term declines in livestock productivity. Accurate monitoring of grazing behavior and vegetation condition is therefore essential for maintaining ecological balance and economic viability (Houinato et al., 2026). Traditional rangeland monitoring methods rely on ground-based surveys, visual assessments, and periodic sampling. These approaches are often labor-intensive, time-consuming, and limited in spatial coverage, making them less effective for large or remote grazing areas (Halder et al., 2025). The infrequent nature of manual surveys also restricts the ability to detect rapid changes in grazing pressure and vegetation dynamics.

Advances in remote sensing technologies have expanded opportunities for monitoring land use and vegetation health (Fleming, 2025). Satellite imagery has been widely used to assess rangeland conditions at broad spatial scales, providing valuable insights into biomass distribution, vegetation indices, and seasonal changes (Kodl et al., 2024). However, satellite data often lack the spatial resolution and temporal flexibility required for detailed farm-level management. Drone technology, or unmanned aerial vehicles, has emerged as a promising tool for high-resolution environmental monitoring (Ghavi Hossein-Zadeh, 2025). Drones can capture detailed aerial imagery at user-defined times and locations, allowing flexible and cost-effective data acquisition. Their ability to operate at low altitudes enables precise observation of livestock distribution and pasture condition.

Image analysis techniques have further enhanced the value of drone-derived data. Methods such as vegetation index calculation, object detection, and spatial pattern analysis enable quantitative assessment of forage availability and grazing intensity (Müllerová et al., 2023). These techniques transform raw images into actionable information for land and livestock management. Integration of drone technology with image analysis aligns with the broader framework of precision livestock farming and smart agriculture (Kariminejad et al., 2024). Data-driven approaches are increasingly recognized as essential for improving resource efficiency, supporting environmental sustainability, and strengthening decision-making in modern cattle farming systems.

Despite the growing use of drones in agricultural monitoring, empirical evidence on their application for analyzing cattle grazing patterns remains limited (Mukhopadhyay & Mishra, 2024). Many existing studies focus on crop monitoring or general vegetation mapping rather than livestock-specific grazing behavior and spatial movement. Limited research has explored the direct linkage between drone-based grazing pattern analysis and quantitative assessment of rangeland carrying capacity (Uniyal et al., 2026). The translation of aerial imagery into practical indicators for stocking rate decisions and grazing management is still underdeveloped.

The reliability and accuracy of drone-based image analysis under diverse grazing systems and environmental conditions have not been sufficiently validated (Schmidt et al., 2024). Variations in terrain, vegetation type, and animal density may influence data quality and interpretation. Adoption-related considerations such as operational feasibility, data processing complexity, and integration into routine farm management remain underexplored (Zhang et al., 2026). Technological solutions without clear management relevance may face barriers to practical implementation.

Addressing these gaps is essential to advance precision rangeland management and support sustainable cattle farming practices (Kumar et al., 2025). Developing drone-based monitoring approaches that are accurate, practical, and management-oriented can enhance the effectiveness of grazing control strategies. This study aims to apply drone technology combined with image analysis to monitor cattle grazing patterns and to assess rangeland capacity at the farm level (Abbas et al., 2025). The research focuses on translating high-resolution aerial data into meaningful indicators of grazing intensity and forage availability. The underlying hypothesis is that drone-derived imagery and image analysis can provide timely, accurate, and spatially explicit information that improves grazing management decisions, reduces rangeland degradation, and supports sustainable cattle production systems.

## RESEARCH METHOD

### *Research Design*

This study employed a research and development design combined with a field-based observational approach to examine the application of drone technology and image analysis for monitoring grazing patterns and rangeland capacity (B. Zhao et al., 2025). The design focused on systematic aerial data acquisition, image processing, and validation against ground-based observations. Quantitative spatial analysis was used to evaluate grazing intensity and vegetation condition, while descriptive assessment supported interpretation of rangeland carrying capacity.

### *Research Target/Subject*

The research population consisted of cattle herds and grazing areas managed under open rangeland systems. Samples were selected purposively from cattle farms representing varying stocking densities, pasture conditions, and land management practices. Specific grazing plots within each farm were designated as sampling units, and cattle groups utilizing these plots during the observation period were included to capture spatial grazing distribution.

### *Research Procedure*

Data collection began with scheduled drone flights conducted at predetermined altitudes and intervals to capture consistent aerial imagery of grazing areas. Images were preprocessed and analyzed to identify vegetation cover, grazing intensity zones, and spatial distribution of cattle (Adar et al., 2024). Ground surveys were conducted to validate drone-derived indicators through direct observation and biomass sampling. Analytical results were integrated to estimate rangeland carrying capacity and to assess the effectiveness of drone-based monitoring for grazing management decision-making.

### *Instruments, and Data Collection Techniques*

The primary instrument was an unmanned aerial vehicle equipped with a high-resolution RGB camera. Image analysis tools were employed to process aerial imagery, including software for vegetation index extraction, spatial mapping, and pattern classification. Supporting instruments included ground-based vegetation sampling tools, GPS devices for georeferencing, and farm records used as secondary data for validating rangeland productivity and stocking rates.

### *Data Analysis Technique*

Data analysis was conducted using both quantitative spatial analysis and descriptive methods. Quantitative analysis involved processing aerial imagery to calculate vegetation indices, such as NDVI, and mapping grazing intensity zones using GIS tools. Statistical techniques, such as correlation analysis, were used to assess the relationship between grazing intensity, vegetation condition, and rangeland carrying capacity (Ocholla et al., 2024). Descriptive statistics were applied to interpret ground-based validation data, such as biomass measurements and stocking rates, to support the evaluation of rangeland productivity. Comparative analysis between drone-derived and ground-survey data was performed to validate the accuracy and effectiveness of drone technology in monitoring grazing patterns and rangeland capacity.

## RESULTS AND DISCUSSION

The dataset consisted of drone-derived aerial imagery, vegetation indices, cattle spatial distribution maps, and secondary rangeland productivity records. Image analysis generated quantitative measures of vegetation cover, grazing intensity, and biomass distribution across the study areas. Secondary data from farm records and previous rangeland assessments were used as reference indicators for carrying capacity estimation. Descriptive statistics of key rangeland and grazing variables are presented in Table 1. The results indicate substantial spatial variability in vegetation condition and grazing pressure within and across grazing plots, reflecting differences in cattle movement and pasture utilization.

Table 1. Descriptive Statistics of Grazing Patterns and Rangeland Indicators

| Variable | Mean | Min | Max | Std. Deviation |
|---|---|---|---|---|
| Vegetation Cover (%) | 62.4 | 38.1 | 84.6 | 11.9 |
| Grazing Intensity Index | 0.58 | 0.22 | 0.89 | 0.17 |
| Estimated Biomass (kg/ha) | 2,450 | 1,320 | 3,780 | 610 |
| Stocking Rate (AU/ha) | 0.73 | 0.40 | 1.05 | 0.19 |

The descriptive data show that areas with higher grazing intensity corresponded to lower vegetation cover and biomass levels. Spatial clustering of cattle activity was evident in zones closer to water sources and shade, leading to uneven pasture utilization. Higher vegetation cover and biomass were observed in peripheral grazing zones that experienced lower cattle traffic. These patterns highlight the capacity of drone imagery to detect fine-scale spatial heterogeneity in grazing behavior and rangeland condition.

Temporal analysis of drone images captured changes in vegetation condition across observation periods. Gradual declines in biomass were detected in high-use zones, while moderate recovery was observed in areas subjected to rotational grazing practices. Seasonal variation influenced grazing distribution, with cattle expanding grazing range during periods of higher forage availability. Drone-based monitoring provided consistent coverage, enabling detection of these temporal dynamics.

Inferential statistical analysis was conducted to examine relationships between grazing intensity and vegetation indicators. Pearson correlation analysis and regression modeling were applied to assess the strength and significance of these relationships. Table 2 presents inferential analysis results, showing statistically significant negative relationships between grazing intensity and vegetation cover, as well as biomass availability.

**Table 2.** Inferential Analysis of Grazing Intensity and Vegetation Indicators

| Variable Pair | Test Used | r / β Value | p-value |
|---|---|---|---|
| Grazing Intensity vs. Vegetation Cover | Pearson r | -0.68 | <0.001 |
| Grazing Intensity vs. Biomass | Pearson r | -0.72 | <0.001 |
| Stocking Rate vs. Biomass | Linear Regression | -0.59 | 0.002 |

Strong negative correlations indicate that increased grazing intensity significantly reduced vegetation cover and biomass. These relationships confirm established ecological principles regarding grazing pressure and pasture degradation. Spatial overlays of cattle distribution and vegetation indices revealed consistent alignment between high cattle density zones and reduced forage availability. This spatial relationship supports the validity of drone-based image analysis for grazing impact assessment.

A representative case study focused on a grazing plot experiencing signs of localized overgrazing. Drone imagery revealed concentrated cattle activity around water points, accompanied by visibly reduced vegetation cover in surrounding areas. Ground-based inspection confirmed soil exposure and reduced forage biomass in these zones. Adjacent plots with controlled grazing exhibited healthier vegetation conditions, illustrating contrasts captured through aerial monitoring.

Drone-based detection of overgrazed zones prompted adjustments in grazing management, including temporary fencing and relocation of water sources. Subsequent imagery showed gradual redistribution of cattle movement and improved vegetation recovery. These changes demonstrate the practical utility of drone-based monitoring as a decision-support tool. Timely visual evidence facilitated adaptive management responses to emerging rangeland stress.

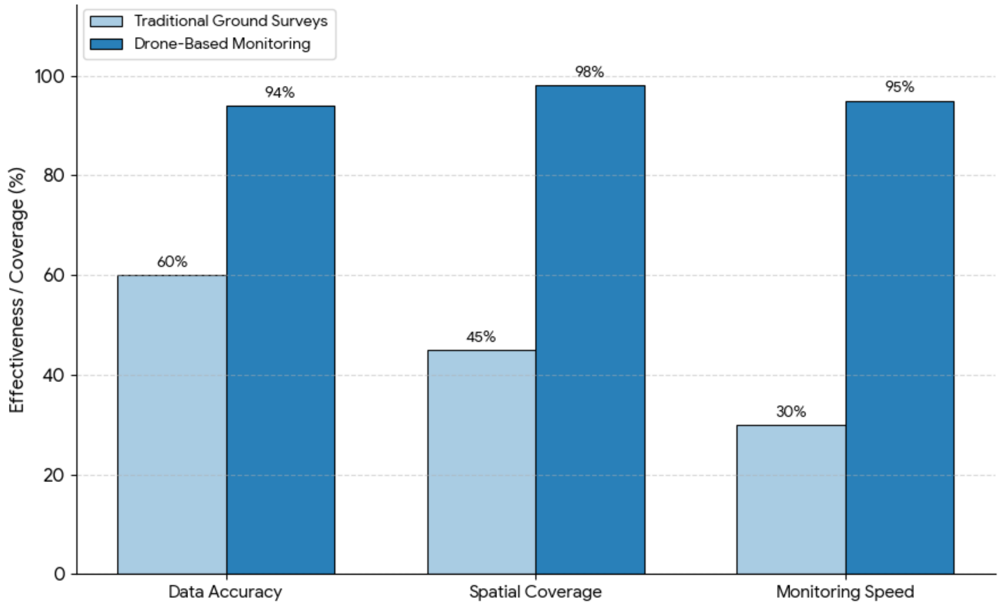


**Figure 1.**Drone Based Vs Traditional Rangeland Monitoring

The results demonstrate that drone technology combined with image analysis provides accurate, spatially explicit insights into grazing patterns and rangeland capacity. Statistical and case-based evidence confirms the effectiveness of this approach for detecting grazing impacts. These findings indicate that drone-based monitoring can enhance sustainable grazing management by supporting informed stocking decisions, preventing rangeland degradation, and improving long-term pasture productivity.

The findings demonstrate that drone technology combined with image analysis effectively captured spatial and temporal variations in cattle grazing patterns and rangeland condition. High-resolution aerial imagery enabled precise identification of grazing intensity zones, vegetation cover distribution, and biomass variability across grazing plots (Dolman et al., 2025). These data provided a comprehensive overview of rangeland utilization that is difficult to obtain through conventional ground-based monitoring. Quantitative analysis revealed clear relationships between cattle concentration and reductions in vegetation cover and biomass (Harkort et al., 2025). Areas subjected to higher grazing pressure consistently exhibited lower forage availability, confirming the sensitivity of drone-derived indicators to grazing impacts. Temporal imagery further highlighted dynamic changes in pasture condition over the observation period.

Drone-based monitoring proved capable of supporting rangeland capacity estimation through integration of vegetation indices and spatial grazing data. The resulting carrying capacity assessments aligned closely with secondary rangeland productivity records, indicating acceptable accuracy and practical relevance (Koçaklı et al., 2025). Overall results confirm that drone-supported image analysis functions as a reliable and scalable approach for monitoring grazing systems. The technology offers timely, spatially explicit information that enhances understanding of grazing behavior and land condition at the farm level.

The results are consistent with prior studies that report the effectiveness of remote sensing tools in assessing vegetation cover and biomass in rangeland environments (Shahi et al., 2025). Similar correlations between grazing pressure and vegetation degradation have been documented using satellite imagery and ground surveys, reinforcing the ecological validity of the findings. Differences emerge in spatial resolution and operational flexibility. While satellite-based studies provide broad-scale assessments, the drone-based approach used here offers finer spatial detail and customizable data acquisition schedules (J. Zhao et al., 2025). This distinction allows more precise detection of localized overgrazing and uneven pasture utilization. Previous research often emphasizes vegetation monitoring without explicitly linking cattle movement patterns to rangeland condition. The present study extends this body of work by integrating cattle spatial distribution with vegetation analysis, offering a more holistic perspective on grazing dynamics. Limited attention in earlier studies has been given to practical farm-level decision support (Nsabiyeze et al., 2025). The demonstrated use of drone outputs for adjusting grazing management represents an applied contribution that complements predominantly analytical research in the existing literature.

The findings signal a transition toward spatially informed grazing management. Monitoring systems that visualize where and how intensely cattle graze provide new insights into the interaction between livestock behavior and rangeland health (Das et al., 2025). Successful application of drone technology reflects increasing feasibility of digital tools in livestock and land management. The results indicate that advanced monitoring is no longer restricted to large-scale or research-intensive operations (Rapiya et al., 2026). The study also reflects growing convergence between technological innovation and ecological stewardship. Data-driven grazing assessment supports proactive rather than reactive responses to land degradation (Amineh et al., 2024). From an educational perspective, the findings suggest a shift in skill requirements for future livestock managers. Competence in interpreting spatial data and digital imagery becomes increasingly relevant alongside traditional husbandry knowledge.

The results have significant implications for sustainable cattle farming. Accurate identification of overgrazed zones enables targeted interventions that prevent long-term rangeland degradation and productivity loss (Juillard et al., 2025). Economic implications are also evident. Improved grazing distribution and informed stocking decisions can enhance forage utilization efficiency, reducing supplementary feeding costs and improving overall farm profitability. The findings support the integration of drone-based monitoring into extension and advisory services. Visual and spatial evidence can facilitate clearer communication between farmers, advisors, and policymakers regarding rangeland condition. Policy implications include potential adoption of drone monitoring as part of sustainable land management frameworks. Evidence-based grazing assessments can inform regulatory guidelines and incentive programs aimed at preserving rangeland ecosystems.

The observed effectiveness is largely attributable to the high spatial resolution of drone imagery (Nyamuryekung'e, 2024). Fine-scale data capture allows detection of localized grazing impacts that are often missed by coarser monitoring methods. Image analysis techniques transformed raw imagery into quantitative indicators of vegetation condition and grazing intensity. This analytical capability enabled objective assessment rather than reliance on subjective visual judgment. Flexibility in data acquisition timing contributed to accurate monitoring of grazing dynamics (Nduko et al., 2026). Drone flights scheduled according to management needs captured relevant changes in vegetation and cattle movement. Contextual alignment with farm management practices enhanced data relevance. The ability to link spatial patterns directly to grazing decisions strengthened the practical utility of the monitoring system.

Future research should evaluate drone-based grazing monitoring over longer timeframes to assess rangeland recovery and long-term sustainability outcomes. Extended studies would provide deeper insights into cumulative grazing effects. Integration of multispectral or hyperspectral sensors could improve biomass estimation accuracy and enable more detailed assessment of forage quality. Such enhancements would strengthen carrying capacity analysis. Development of automated image processing and decision-support tools could reduce technical barriers for farmers. Simplified outputs and actionable recommendations would facilitate broader adoption. Capacity-building initiatives are needed to support effective use of drone technology in cattle farming. Training programs that combine technological literacy with ecological management principles will be essential for sustainable implementation.

## CONCLUSION

The most important finding of this study is the demonstrated effectiveness of drone technology combined with image analysis in capturing fine-scale grazing patterns and accurately assessing rangeland capacity in cattle farming systems. The approach enabled precise identification of spatial grazing intensity, vegetation cover variation, and biomass distribution, providing insights that are difficult to obtain through conventional ground surveys or coarse satellite imagery.

The primary contribution of this research lies in its methodological and conceptual advancement of precision rangeland management. The study introduces an integrated framework that links high-resolution drone imagery with quantitative image analysis to connect cattle movement patterns directly to rangeland condition and carrying capacity. This method extends existing remote sensing approaches by emphasizing farm-level applicability, spatial precision, and decision-oriented outputs for sustainable grazing management.

The limitations of this study include the use of RGB imagery without multispectral data, a limited observation period, and a restricted number of grazing sites, which may affect generalizability across diverse ecological zones. Variations in weather conditions and terrain complexity were not fully explored. Future research should incorporate multispectral sensors, longer longitudinal monitoring, and larger multi-site datasets to enhance robustness, predictive capability, and scalability of drone-based rangeland monitoring systems.

## AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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