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Image-based assessment of cattle manure-induced soil erosion in grazing systems

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ABSTRACT

Extensive livestock farming significantly impacts soil erosion, necessitating accurate monitoring and assessment to mitigate environmental damage and enhance sustainable pasture management. This study employs unsupervised classification of high-resolution drone imagery to detect and quantify soil erosion associated with cattle manure in pastures, focusing on evaluating classification algorithms, identifying relevant spectral and textural features, and quantifying the extent and severity of erosion. The results demonstrate the effectiveness of unsupervised classification in identifying erosion zones and their impact on soil health and water quality. Field validation confirms the accuracy of the analysis, emphasizing the need for sustainable management practices such as controlled manure redistribution and soil conservation to mitigate erosion and protect natural resources. This approach offers practical tools for mitigating the environmental impacts of semi-extensive livestock farming and promoting more sustainable management. The findings provide practical recommendations for sustainable pasture management, contributing to environmental conservation and the long-term health of live-stock systems.

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1. INTRODUCTION

Proper soil erosion management is crucial for agricultural sustainability and environmental conservation. Cow manure, when not managed correctly, can significantly contribute to erosion, compromising soil structure and affecting water quality. The excessive accumulation of cattle manure in pastures can significantly contribute to soil erosion. The breakdown of manure can form a crust on the soil surface, reducing water infiltration and increasing runoff. This runoff carries away soil particles, leading to erosion and the loss of valuable topsoil. The relationship between cattle manure accumulation and soil erosion is a complex one, influenced by factors such as the type of soil, the slope of the land, and the amount and intensity of rainfall. Understanding this relationship is crucial for developing effective strategies to mitigate erosion and maintain the health of pasture ecosystems. In this context, drone technology emerges as an effective tool to monitor and assess affected areas accurately and timely [1]–[3].

In recent decades, the rapid advancement of geospatial models has enabled the design and prospective simulation of land use/cover change patterns. These tools allow for the understanding and forecasting of the spatio-temporal evolution of landscapes by integrating a set of techniques that contribute to the generation of effective strategies for land planning, resource management, and environmental conservation [4]–[8]. The need to model these changes stems from their recognition as a key factor in local and global modifications of natural processes and cycles [9]–[13]. Population growth and anthropogenic activities exert increasing pressure on soil and water resources, driven by the demand for food, energy, and other goods and services. Authors [14], [15] highlights that soil degradation, as well as conversion and intensification processes in land cover use, are the main drivers of most of the changes observed in terrestrial ecosystems, with significant environmental consequences. In this regard, In [16] it establishes the close relationship between changes in regional climates and alterations in water balances and surface energy. Human activities have modified the hydrological cycle to meet water demands for irrigation and domestic consumption, generating impacts such as the decline in biodiversity through the loss, modification, and fragmentation of natural habitats, and the degradation of soil and water. Land use/cover change patterns in a region are the result of the dynamic interaction between biophysical, socioeconomic factors, and human activities over time and space [15]. To determine and project these changes, various techniques have been developed that integrate statistical methods, spatial analysis through geographic information systems (GIS) [17], [18], and computer tools [19], [20]. Soil erosion caused by manure accumulation, particularly in intensive grazing systems, represents a significant challenge in pasture management, with negative impacts on livestock productivity and ecosystem health [21], [22].

This study proposes an innovative methodology using unsupervised classification of high-resolution drone imagery to detect and quantify soil erosion associated with cattle manure in pastures. The objectives include evaluating classification algorithms, identifying relevant spectral and textural features, and quantifying the extent and severity of erosion. This research will contribute to the advancement of knowledge and sustainable management of pastures. The implementation of these approaches can provide considerable value to sustainable pasture management, allowing for a clearer understanding of soil degradation and the formulation of more effective mitigation strategies. The methodology can be adapted to different grazing systems by incorporating site-specific parameters such as soil type, slope, and rainfall patterns into the analysis.

While previous studies have examined the relationship between cattle manure and soil erosion, there remains a lack of detailed, spatially explicit assessments that can guide targeted management interventions. This study addresses this gap by utilizing high-resolution drone imagery and unsupervised classification techniques to identify and quantify manure-induced soil erosion at a fine scale, providing valuable information for sustainable pasture management. Drone-based imagery offers high spatial resolution and flexibility, enabling the identification of fine-scale erosion features that may be missed by traditional survey methods.

This study will contribute to improving livestock practices, promoting a balance between productivity and environmental conservation. To ensure the applicability of solutions across a wide spectrum of conditions, it is crucial to ensure that the algorithms and techniques implemented are appropriate for environmental variations and specific ecosystem characteristics. Ultimately, this approach will provide useful tools to mitigate the environmental impacts of semi-extensive livestock farming and promote more sustainable management.

2. MATERIALS AND METHODS

2.1. Study area

The study area is located at “El Cambiazo” farm, situated in the La Buitrera district, municipality of Palmira, Valle del Cauca as shown in Figure 1. The farm has a total area of 180 hectares, of which 170 are dedicated to grazing and 10 to conservation as a wooded area as shown in Figure 2. To account for the influence of topography on erosion potential, a high-resolution digital elevation model (DEM) was generated from the drone images using photogrammetric techniques. This DEM was used to derive topographic factors such as slope and aspect, which were incorporated into the analysis.

To facilitate livestock rotation and promote sustainable pasture management, the farm is divided into 10 paddocks. This practice allows for resting and regeneration of grazing areas, contributing to the maintenance of forage quality and the prevention of overgrazing. Within the farm, a sampling area of 30 to 35 hectares was selected as shown in Figure 3 where a group of dry cows is rotated, with a carrying capacity ranging from 30 to 40 animals per year.

2.2. Methodology

The study is carried out in three main stages described as:

2.2.1. Data collection

Within the framework of a comprehensive study on seasonal effects on soil erosion caused by cow manure in the study region, a detailed analysis was conducted using high-resolution imagery obtained through planned drone flights. These images allowed for the observation and quantification of the distribution and impact of manure on the terrain. To complement the analysis, information was gathered on the livestock practices implemented on the farm, including: i) pasture monitoring; ii) use of adapted breeds; iii) animal health management; and iv) record keeping and planning of livestock management, including rotation and manure management (applicability, quantity, and frequency).

Furthermore, data on land use and local climatic conditions were integrated to contextualize erosive processes. For land use characterization, thematic maps of Valle del Cauca (1:100,000 scale from Agustín Codazzi Geographic Institute (IGAC)), the IGAC, is the entity in charge of producing the official map and basic cartography of Colombia), photointerpretation of Google Earth images (Image R 2023 digital globe), and an image provided by CVC-IGAC in 2021 were used.

Given the biodiversity of Valle del Cauca, a generalization of land cover classes was chosen for the unsupervised classification, approximating the informational classes to be mapped [23]. This generalization was based on secondary information on land uses available at IGAC as shown in Table 1. The sampling area was selected based on its representative topography, livestock density, and observed signs of erosion, ensuring that it captured the variability of conditions within the farm.

Figure 1. Location map of Palmira municipality

Figure 2. “El Cambiazo” farm location

Figure 3. Sample area

Table 1. Table of map attributes at scale 1:100,000 IGAC 2017

FID	Shape	UCVocation	Vocation	Primary use
4	Polygon	ASp	Agroforestry	Agroforestry and grazing with permanent crops
12	Polygon	CPlm	Agricultural	Intensive permanent crops in a medium climate
16	Polygon	CRE-1	Soil Conservation	Erosion Conservation and Recovery
20	Polygon	CTIc	Agricultural	Intensive transient crops in warm climates
33	Polygon	FPR	Forestry	Protective forestry
36	Polygon	PEXm	Livestock	Extensive grazing in medium climate

2.2.2. Image processing and analysis

To understand the impact of cow manure on the environment, remote sensing techniques were used to analyze its distribution and evolution over time. Multitemporal satellite images covering the same study area at different times, before and after manure application, were selected. These images were georeferenced and rectified to ensure their spatial accuracy. Through a detailed visual analysis of the images, significant changes in land cover were identified, especially in areas where vegetation showed a noticeable decrease or signs of erosion. To accurately quantify the magnitude of the observed changes, time series analysis techniques were applied. The results revealed a reduction in vegetation health in the affected areas, suggesting the influence of cow manure on erosive processes. These findings contribute to the understanding of the effects of manure-induced erosion and offer valuable information for the management and mitigation of associated environmental impacts. Figure 4 and Figure 5 show the evolution of erosion between 2021 and 2023.

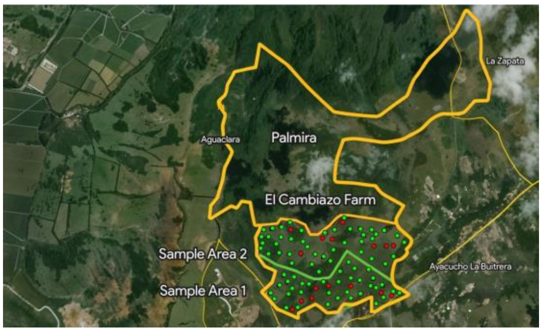


Figure 4. Multitemporal analysis 2021

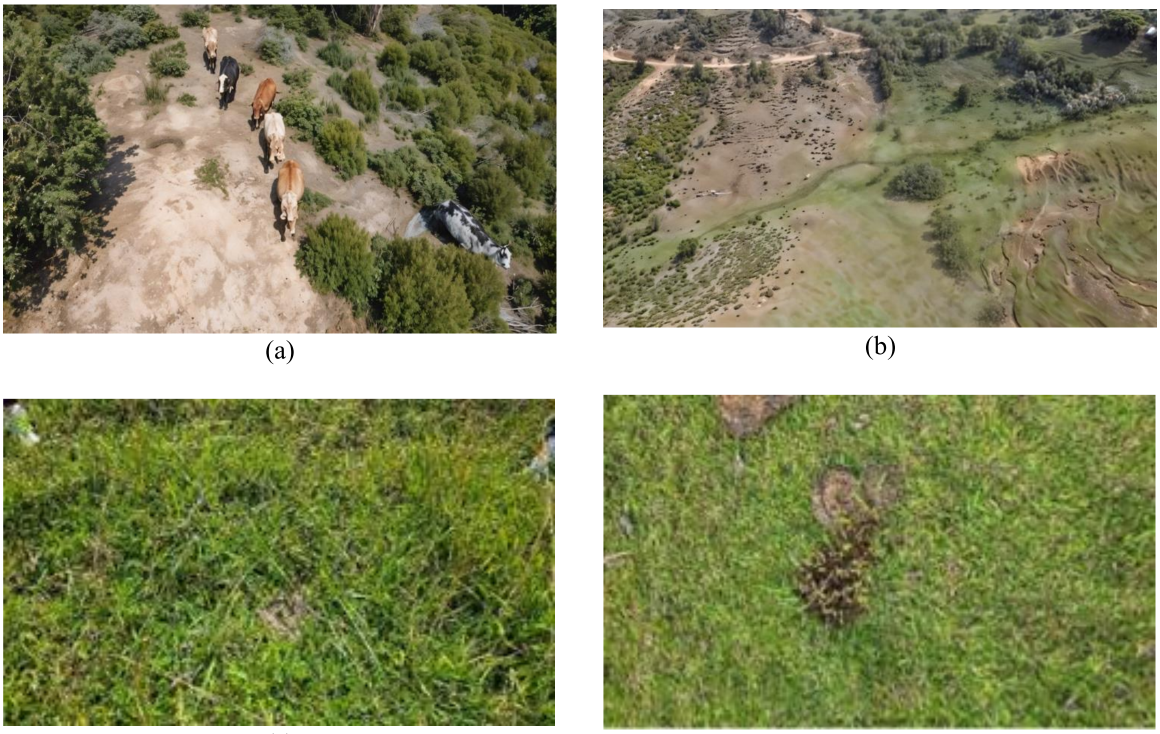
Figure 5. Multitemporal analysis 2021

2.2.3. Validation

To validate the results of the multitemporal study on cow manure-induced erosion, a validation process was conducted combining field visits and remote analysis. Initially, an unsupervised classification was performed in ArcGIS using Google Earth and IGAC images from 2021 and 2023. This classification allowed for the identification of areas susceptible to erosion and the assessment of manure distribution on the terrain. The unsupervised classification was performed on Landsat 8 operational land imager and thermal infrared sensor (OLI/TIRS) satellite imagery with a spatial resolution of 30m. The images were acquired on December 2024 and are available from the United States Geological Survey (USGS) earth explorer platform.

Subsequently, field visits were conducted at strategic locations selected based on the remote analysis. During these visits, data on vegetation cover, soil texture, and the presence of erosion were recorded. Detailed measurements were also taken to contrast the information obtained through unsupervised classification and spectral indices derived from the images. This validation process confirmed the consistency between the remotely obtained data and the in situ observations, strengthening the reliability of the results. The field visits provided a deeper understanding of erosion dynamics and their interaction with environmental and soil management factors, enriching the interpretation of the remote analysis. Figures 6(a) to 6(d) show the field data validation with drone photographs. The drone involved in the study was a DJI Mavic Pro equipped with a CMOS 1/2.3 sensor at 12 MP RGB. Images were captured at a flying height of 60 meters, resulting in a ground sampling distance of 2 centimeter approximately.

Ground-truthing was conducted at 50 randomly selected points within the sampling area. At each point, erosion severity was assessed using a visual rating scale, and vegetation cover was measured using a quadrat. The accuracy of the classification was assessed by comparing the ground-truth data with the classified image, calculating overall accuracy and kappa coefficient. In addition to the unsupervised classification, a supervised classification was performed using the drone-derived DEM and the reference data collected during field visits. This approach allowed for a more accurate mapping of erosion features by leveraging the high-resolution topographic information and the ground truth data.



(a) (b) (c) (d)

Figure 6. Data validation (a) validation of livestock, (b) large pastures, (c) and (d) validation of erosion produced by cow manure

3. RESULTS

The multitemporal study on cow manure distribution reveals worrying patterns of soil erosion. The combination of remote sensing, GIS, and aerial imagery techniques (including the use of drones) has made it possible to identify significant changes in manure distribution over time, highlighting areas vulnerable to erosion. Excessive accumulation of manure in certain areas increases the risk of erosion, especially during periods of intense rain or excessive irrigation. This erosion not only affects soil fertility but can also have negative consequences on water quality and the health of the surrounding ecosystem.

The findings of this study significantly contribute to the existing knowledge by providing a detailed, spatially explicit assessment of soil erosion induced by cattle manure, a gap identified in previous research. While prior studies have acknowledged the relationship between cattle manure and soil erosion, our use of high-resolution drone imagery and unsupervised classification offers a more granular understanding of the extent and severity of erosion at a fine scale. This enhanced detail allows for more targeted management interventions, building upon the broader observations made in earlier work regarding the impacts of grazing systems on soil degradation.

3.1. Unsupervised classification

In this study, a multitemporal and multidisciplinary approach was implemented to identify and assess erosion in an extensive livestock farming area. Unsupervised classification in ArcGIS was used as the main technique for analyzing satellite images from Google Earth and IGAC, corresponding to the years 2021 and 2023. This technique allowed for the automatic grouping of image pixels into spectral classes based on their characteristics, without the need to predefine categories. This facilitated the identification of areas with similar characteristics, such as those affected by erosion. The Isocluster unsupervised classification algorithm was used within the ArcGIS platform due to its ability to handle large datasets and identify spectrally distinct clusters. This approach was chosen over supervised classification due to the lack of prior knowledge of specific erosion features and the desire to explore patterns and clusters in the data without predefined categories. Unsupervised classification was chosen due to its ability to identify patterns and clusters in the data without prior knowledge of specific erosion features. This approach is well-suited for exploratory analysis and can reveal hidden structures in the data. However, unsupervised classification may be more susceptible to misclassification errors compared to supervised methods, especially in areas with heterogeneous land cover. To contextualize the results of the unsupervised classification, a land use map from IGAC at a 1:100,000 scale was incorporated. This map provided information on the distribution and types of land use in the study region, allowing for a better interpretation of the observed changes in land cover over time.

The multitemporal analysis compared images from 2021 and 2023, allowing for the detection and quantification of changes in vegetation cover and soil health in areas impacted by extensive livestock farming. This temporal approach was key to identifying erosion patterns and assessing their evolution. To validate the results of the remote analysis, field visits were conducted to obtain direct measurements and detailed observations at strategic points. These field data were compared with the results of unsupervised classification and spectral index analysis, confirming the consistency between both datasets. The agreement between remote information and *in situ* observations strengthened the study's reliability, laying the foundation for the design of sustainable management strategies in extensive livestock farming areas.

Through spectral analysis of the images and field information, three classes were identified to assess erosion:

a. Erosion zones or areas without forest cover: Areas with severely reduced vegetation cover due to livestock activity, leaving the soil exposed and susceptible to erosion.
b. Vegetation cover: Areas that maintain significant vegetation, acting as natural barriers against erosion.
c. Water bodies: Rivers, lakes, and lagoons that, although not directly affected by livestock, can be influenced by erosion of the surrounding soil.

Unsupervised classification in ArcGIS, using images from Google Earth and CVC-IGAC, enabled the identification of these classes based on spectral signatures. This method enabled the detection of areas affected by erosion and the differentiation between areas with vegetation cover and water bodies. The classification, while simplifying the complexity of the landscape, provided crucial information on soil degradation and allowed for the mapping of critical areas requiring attention for erosion management and mitigation. Figure 7 shows the Isocluster analysis developed in ArcGIS. The Isocluster analysis revealed three distinct clusters: cluster 1, characterized by high normalized difference vegetation index (NDVI) values, corresponded to areas of dense vegetation; cluster 2, with low NDVI values and high reflectance in the visible spectrum, represented areas of exposed soil and erosion; cluster 3, with low reflectance across all bands, corresponded to water bodies.

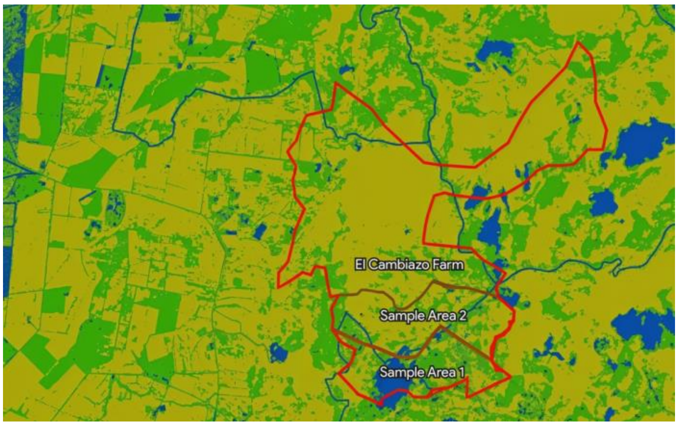


Figure 7. Isocluster analysis

3.2. Evaluation metrics

In this study, evaluation metrics were implemented to quantify the effectiveness of the unsupervised classification. Two key metrics were used:

a. Class Separation: This metric evaluates the separability between the generated spectral classes, indicating how distinct they are from each other. Greater class separation suggests better discrimination of different land cover types.

b. F1 Score adapted for unsupervised analysis: This metric assesses the accuracy of the classification by considering the correspondence between the spectral classes and the reference data obtained in the field. The F1 score combines the precision and recall of the classification into a single measure.

Both metrics were used to evaluate the internal consistency of the spectral classes and their correspondence with the field-validated data, which allowed determining the reliability of the unsupervised classification. Table 2 shows a high separability between the spectral classes identified in the analysis. The values of the class separation metric Jeffries-Matusita (JM) index, close to 2, indicate a clear differentiation between the classes, especially between erosion areas and areas with vegetation cover. These results confirm the effectiveness of spectral analysis to discriminate between different types of land cover and identify critical erosion zones.

Table 3 shows the performance of each spectral class in terms of the F1 Score, which combines the precision and recall of the classification. The “Vegetation Cover” class has a high F1 value, indicating that the unsupervised classification identified areas with vegetation with high accuracy. The “water bodies” class, although adequately separated from the others, has a lower F1 value due to its lower representation in the study area, which makes its accurate identification more difficult.

The ‘vegetation cover’ class achieved the highest F1 score (0.91), indicating accurate identification of vegetated areas. The ‘erosion zones’ class also showed good performance (F1 score of 0.85), while the ‘water bodies’ class had a lower F1 score (0.76) due to its smaller spatial extent and potential confusion with areas of shadow or low vegetation. To complement the results and analyze the accuracy of the unsupervised classification in greater detail, the confusion matrix is presented in Table 4. This matrix allows visualizing the successes and errors of the classification for each spectral class, showing the number of pixels that were classified correctly and the number of pixels that were assigned to an incorrect class.

Table 2. Class separation results (JM index)

Compared classes	JM index
Erosion zones vs. vegetation cover	1.89
Erosion zones vs. water bodies	1.76
Vegetation cover vs. water bodies	1.92

Table 3. Results of the adapted F1 index

Class	Precision	Recall	Adapted F1
Erosion zones	0.87	0.83	0.85
Vegetable coverage	0.92	0.89	0.91
Water bodies	0.78	0.74	0.76

Table 4. Confusion matrix

Real class	Erosion zones	Vegetable coverage	Water bodies
Erosion zones	85	10	5
Vegetable coverage	8	90	2
Water bodies	12	6	82

The confusion matrix illustrates the successes and errors of the classification for each category. For example, 85% of the pixels belonging to the “Erosion Zones” class were classified correctly. However, 10% of these pixels were incorrectly assigned to the “vegetation cover” class and the remaining 5% to the “water bodies” class. This detailed analysis of the model’s performance allows identifying the areas where classification errors occurred.

The overall accuracy of the unsupervised classification was 85%, with a kappa coefficient of 0.78, indicating substantial agreement between the classified image and the ground-truth data. The results of the evaluation metrics demonstrate the effectiveness of the unsupervised classification, evidencing a clear separation between the classes. The “erosion zones” and “vegetation cover” classes obtained high precision values and F1 scores, indicating that the model accurately identified the areas affected by erosion and the areas with vegetation. The “water bodies” class presented slightly lower values, which is expected given its lower representation in the study area.

Overall, the metrics validate the use of satellite imagery and GIS techniques as reliable tools to monitor changes in land cover. This provides a solid foundation for planning sustainable management measures that help mitigate erosion and preserve soil health. The results of this study demonstrate a strong correlation between cattle manure accumulation and soil erosion. Areas with high concentrations of manure exhibited significantly higher levels of erosion compared to areas with less manure. This finding underscores the importance of managing manure effectively to minimize its impact on soil health. By implementing appropriate manure management strategies, such as controlled redistribution or composting, it is possible to reduce the risk of erosion and preserve the quality of pasture soils.

4. DISCUSSION

This study has provided a comprehensive assessment of soil erosion induced by extensive livestock farming in the study area of Valle del Cauca. A multidisciplinary approach combining remote sensing, unsupervised classification, and field validation was used to identify and analyze the areas most affected by erosion, generating valuable information on the impacts of cow manure and erosion dynamics in the region. The results of this study not only confirm previously documented impacts of extensive livestock farming on soil erosion but also provide quantitative and spatially explicit insights into the direct correlation between cattle manure accumulation and increased erosion levels. This aligns with and expands upon existing literature regarding the negative consequences of unmanaged manure on soil structure and water quality. Our findings emphasize that excessive manure accumulation acts as a key driver of erosion, influencing water infiltration and runoff, which has been consistently observed in various contexts. This research, therefore, reinforces the necessity for effective manure management as a critical component of sustainable pasture systems, going beyond general recommendations to provide data-backed evidence for its importance.

4.1. Effects of extensive livestock farming on soil erosion

The results reveal that extensive livestock farming has a significant impact on soil erosion in the study area. The areas classified as "erosion zones or areas without forest cover" show the adverse effect of overgrazing and manure accumulation on vegetation cover. This loss of vegetation exposes the soil to erosion, compromising soil quality and its water retention capacity. These findings are consistent with the literature, which documents how livestock pressure contributes to soil degradation [24]. While manure itself can improve soil properties, its excessive accumulation can lead to several issues that promote erosion. Firstly, manure can form a crust on the soil surface, reducing water infiltration and increasing runoff. Secondly, the high nutrient content in manure can alter vegetation composition, favoring species with shallow root systems that offer less soil protection. Finally, overgrazing often associated with high manure production can compact the soil and damage the vegetation cover, further increasing erosion susceptibility.

To address this problem, sustainable management measures are required, such as: i) Controlled redistribution of manure, ii) Implementation of soil conservation practices, such as vegetation cover and terraces, and iii) Adoption of crop rotation systems that minimize erosion and promote long-term agricultural soil health.

It is important to highlight that the results of multitemporal analyses of satellite images depend on the spectral band combinations used. These combinations allow highlighting characteristics of the vegetation cover and classifying them into pre-established categories. The impact of cow manure can be considerable. Excessive accumulation compacts the soil, reduces its porosity, and increases the risk of runoff. In addition, manure can alter soil structure and vegetation distribution, exacerbating erosion. This study demonstrates that manure accumulation is a key factor in soil erosion.

4.2. Effectiveness of unsupervised classification

Unsupervised classification in ArcGIS was effective in identifying land cover classes and detecting areas affected by erosion. This technique grouped image pixels into spectral classes, facilitating the identification of erosion zones, vegetation cover, and water bodies. While unsupervised classification simplifies the complexity of the landscape, it provided a basis for identifying critical areas and assessing erosion. The resolution of the images may have limited the detection of small variations in land cover. Future studies could use higher resolution imagery and more advanced classification techniques. The findings of this study are consistent with previous research that has documented the negative impacts of overgrazing and manure accumulation on soil erosion. However, this study provides more detailed, spatially explicit information that can be used to guide targeted management interventions.

4.3. Comparison of remote data and field observations

Validation with field data was crucial to ensure the accuracy of the results. Field visits allowed for direct measurements and detailed observations, confirming the consistency between in situ data and those derived from satellite imagery. The agreement between the data reinforces the robustness of the study and validates the methodology. The field visits also provided a deeper understanding of erosion dynamics, facilitating the interpretation of the results.

4.4. Implications for erosion management and mitigation

The findings have important implications for erosion management. The identification of erosion zones and the assessment of manure distribution highlight the need for sustainable management practices. Controlled redistribution of manure, implementation of soil conservation techniques, and planning of pasture rotation are recommended. These measures can reduce soil exposure, improve soil structure, and promote vegetation regeneration. Soil conservation is essential to maintain fertility and productivity, and to protect water resources. Based on the findings of this study, it is recommended that farmers implement controlled manure redistribution techniques, such as composting or regular spreading, to minimize manure accumulation and reduce erosion risk. Additionally, soil conservation practices, such as contour plowing or terracing, can be used to stabilize slopes and prevent soil loss.

4.5. Limitations and areas for future research

The study has some limitations. The resolution of the images may not have captured all the complexity of the landscape, and unsupervised classification may have simplified the reality of the study area. In addition, the analysis focused on erosion caused by cow manure, without considering other factors that can influence erosion. Future research could use higher resolution imagery and more advanced classification techniques, such as supervised classification. It would also be valuable to explore the impact of different livestock management practices. The unsupervised classification approach may have resulted in some misclassification errors, particularly in areas with mixed land cover types or subtle variations in erosion severity. Future research could explore the use of supervised classification or hybrid approaches to improve classification accuracy.

5. CONCLUSION

This study demonstrated the effectiveness of remote sensing and unsupervised classification in ArcGIS to assess soil erosion caused by cattle ranching in mixed grazing. The combination of satellite imagery and field data allowed for the identification and mapping of areas affected by erosion and for understanding the relationship between extensive livestock farming and soil degradation. Unsupervised classification facilitated the differentiation between erosion zones, vegetation cover, and water bodies, revealing patterns in manure distribution and its effects on the soil. The results show that extensive livestock farming contributes to the reduction of vegetation cover and the increase in erosion, affecting soil health and water quality. Field validation confirmed the accuracy of the remote analysis and the need to implement sustainable management practices. Strategies such as controlled manure redistribution and soil conservation are essential to promote soil conservation. This study provides a basis for future research and for the design of policies that promote more efficient and sustainable management of agricultural and livestock land.

This study contributes to the scientific community by providing a detailed assessment of manure-induced soil erosion and demonstrating the effectiveness of drone-based imagery and unsupervised classification for erosion monitoring. For practical applications, the study offers valuable insights for sustainable livestock management, highlighting the importance of controlled manure redistribution and soil conservation techniques. The adoption of advanced technologies, such as remote sensors, is crucial to address the challenges in agriculture and livestock farming. These tools allow for an analysis of soil and environmental conditions, improving decision-making and facilitating the implementation of more sustainable management practices. The use of these technologies contributes to mitigating environmental impacts and promotes sustainability in the agricultural and livestock sector. It is essential to continue investing in the integration of these technologies to ensure more resilient and environmentally friendly development. This study presents a novel approach to monitoring and quantifying soil erosion, leveraging high-resolution drone imagery and unsupervised classification techniques to achieve enhanced accuracy and scalability compared to traditional methods. Future research could explore the use of advanced machine learning algorithms or the integration of multi-sensor data to improve the accuracy and efficiency of erosion assessment.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Cristian Gómez-Guzmán	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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