DRONES AS A TOOL FOR DIGITAL AGRICULTURE IN SOIL AND WATER MANAGEMENT AND CONSERVATION

ABSTRACT

The objective of this study was to conduct a topographic assessment of an agricultural field in order to understand the terrain characteristics and surface water runoff dynamics, aiming to estimate soil losses caused by water erosion. A DJI Phantom 4 Pro drone was employed in combination with GNSS receivers operating in Real-Time Kinematic (RTK) mode, as well as precision and digital agriculture software, including Agisoft Metashape and AgroCAD®. The adopted methodology enabled the generation of cartographic products such as an orthomosaic, contour lines, slope maps, runoff trend maps, and surface runoff velocity maps. The integration of these datasets allowed the development of a soil loss estimation map, considering the critical soil loss tolerance threshold of 6 t ha^{-1} $year^{-1}$ for a Typic Red Dystrophic Ultisol. The results revealed that 37.67% of the study area exhibited soil losses above the tolerable limit, indicating the need for conservation practices such as terracing, contour farming, and the maintenance of permanent soil cover, while 62.33% of the area remained within the acceptable threshold. The study highlights the importance of Precision and Digital Agriculture technologies for terrain characterization and management planning aimed at minimizing erosion processes and promoting greater agricultural sustainability.

Keywords: Water erosion; Digital Agriculture; Soil conservation.

1 INTRODUCTION

The rapid expansion of agricultural frontiers, combined with intensive land use and climate change, has generated significant negative impacts on Brazilian soils, drastically reducing their productive capacity and increasing production costs. A large portion of these problems is associated with water erosion, which is considered the main factor responsible for soil degradation worldwide and accounts for approximately 56% of degraded areas globally (OLDEMAN; HAKKELING; SOMBROEK, 1991). This process represents one of the greatest barriers to sustainable agricultural development, particularly in sloping landscapes. Inadequate management practices intensify the effects of raindrop impact and surface runoff, promoting soil particle detachment, transport, and deposition (HUDSON, 1977; BERTONI; LOMBARDI NETO, 1990; MORGAN, 2005).

Furthermore, the continuous use of agricultural land accelerates the physical and chemical degradation of soils when compared with forest ecosystems. Changes such as increased bulk density, reduced total porosity, decreased aggregate stability (weighted and geometric mean diameter), and lower carbon and nitrogen stocks (ENCK et al., 2020) increase susceptibility to erosion, particularly in annual cropping systems. It is estimated that annual soil losses in Brazil reach approximately 500 million tons (BERTONI; LOMBARDI NETO, 2010). A study conducted in the state of Paraná and extrapolated to the national scale indicated that economic losses associated with the removal of macronutrients (K, P, Ca, and Mg) exceed R$ 2.11 billion annually (TELLES et al., 2011). These impacts also affect the environment, contributing to sedimentation and pollution of water resources (ALVES; SILVA, 2020).

The severity of erosion, however, varies according to the interaction among rainfall patterns, soil type, management practices, and topographic conditions (PORTELA et al., 2011). When soil loss exceeds tolerable limits, control measures become essential. The challenge is further aggravated by the naturally slow process of soil formation. It is estimated that approximately 300 years are required for the formation of only 1 cm of soil, depending on climatic, edaphic, and vegetation cover conditions (EMBRAPA, 2003). In contrast, degraded areas that have not lost their topsoil layer may partially recover their productive capacity within three to five years when appropriate management practices are adopted (DAILY, 1995). Severely degraded soils, although recoverable, may require up to a century before becoming suitable for agricultural use again (BLANCO-CANQUI; LAL, 2010).

This imbalance between rapid degradation and slow regeneration compromises productive potential, increases production costs, and reduces the economic value of agricultural land. Despite this, effective conservation practices such as maintaining soil cover, contour planting, and terracing are still frequently neglected, often being removed to facilitate mechanized farming operations. This lack of attention contributes to alarming projections indicating that global soil erosion rates may increase by 30% to 66% between 2015 and 2070 (SARTORI et al., 2024).

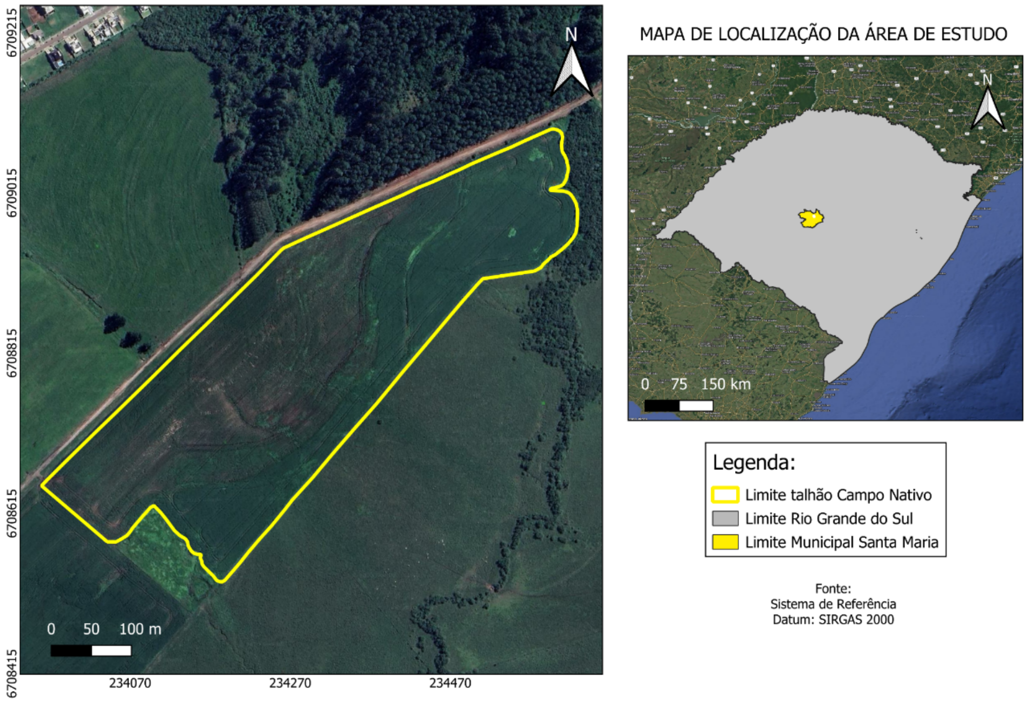
In this context, the modernization of the agricultural sector has stimulated the search for technological solutions capable of mitigating water erosion. Among these technologies, drones and digital platforms stand out because they enable rapid, detailed, and georeferenced surveys, enhancing diagnostic capabilities and improving the planning of conservation practices. Therefore, this study proposes the integration of emerging technologies and scientific knowledge to highlight the erosion problem and demonstrate feasible management alternatives that are essential for reducing soil losses and increasing the resilience of agricultural systems in the face of increasingly extreme climatic events.

2 MATERIALS AND METHODS

The study was conducted at the Agricultural Area of the Polytechnic College of the Federal University of Santa Maria (UFSM), located in Santa Maria, Rio Grande do Sul, Brazil, within an experimental field known as *Campo Nativo*, covering an area of 13.93 ha. The study site is centered at latitude 29°43'20" S and longitude 53°44'48" W. The soil is classified as a Typic Red Dystrophic Ultisol, characterized by clay contents of approximately 20.0% in the surface horizon and greater than 50.0% in the textural B horizon. The soil presents moderate natural fertility and high susceptibility to erosion (SANTOS et al., 2018), mainly due to the presence of the Bt horizon, which promotes water accumulation in the upper soil layers, combined with the high rainfall intensities commonly observed in Rio Grande do Sul.

According to the Köppen climate classification, the study region is classified as Cfa, characterized as a humid subtropical climate with hot summers. The rainfall regime is classified as Isohygrous, with precipitation relatively well distributed throughout the year (ALVARES et al., 2013), although annual variations in rainfall intensity and volume may occur. The Agricultural Area hosts experiments focused on Precision Agriculture and sustainability. These activities integrate teaching, research, and extension programs, aiming to optimize input use and promote the training of future professionals in the application of emerging agricultural technologies (Figure 1).

Figure 1. Location and boundaries of the study field (*Campo Nativo*) within the Agricultural Area of the Polytechnic College of UFSM.



Source: Google Earth (2025).

Initially, a methodological workflow was established to support the generation of the final maps and the definition of conservation practices recommended for the study field. In the first stage, a topographic survey was conducted using a pair of Global Navigation Satellite System (GNSS) receivers operating with Real-Time Kinematic (RTK) correction and a DJI Phantom 4 Pro imaging drone equipped with an FC6310 camera (8.8 mm focal length and 4864 × 3648 px resolution) (Figure 2). The flight plan consisted of parallel flight paths designed to provide complete coverage of the field, with the camera positioned in a nadir orientation (90° relative to the ground surface). Technical flight parameters included an average flight altitude of 98.3 m, front overlap of approximately 75–80%, and side overlap of 70–75%, following standard practices for aerial surveys performed with this platform.

During the flight mission, which was conducted at an average speed ranging from 4 to 6 m s^{-1}, a total of 135 georeferenced images were acquired, covering an area of 0.251 km^2 (approximately 25.1 ha). Of this total, 13.93 ha corresponded to the effective study area. To ensure positional accuracy, eight Ground Control Points (GCPs) were established throughout the experimental area and surveyed using RTK-GNSS receivers. These control points were subsequently used during the image calibration and photogrammetric processing stages.

Figure 2. DJI Phantom 4 Pro imaging drone used in the study.

Source: Author (2025).

Subsequently, the images acquired by the drone were transferred and processed using Agisoft Metashape Professional software. The processing workflow included preliminary image alignment, identification and insertion of Ground Control Points (GCPs), and fine-tuning of the georeferencing process. This procedure ensured the accurate assignment of planimetric and altimetric coordinates while preserving the image overlaps established in the flight plan, thereby improving overall positional accuracy.

Following this stage, an orthomosaic map of the study field was generated (Figure 3), with a spatial resolution of 2.91 cm $pixel^{-1}$. The resulting product was considered highly reliable in terms of positional and dimensional accuracy and served as the primary dataset for subsequent analyses and the generation of derived cartographic products.

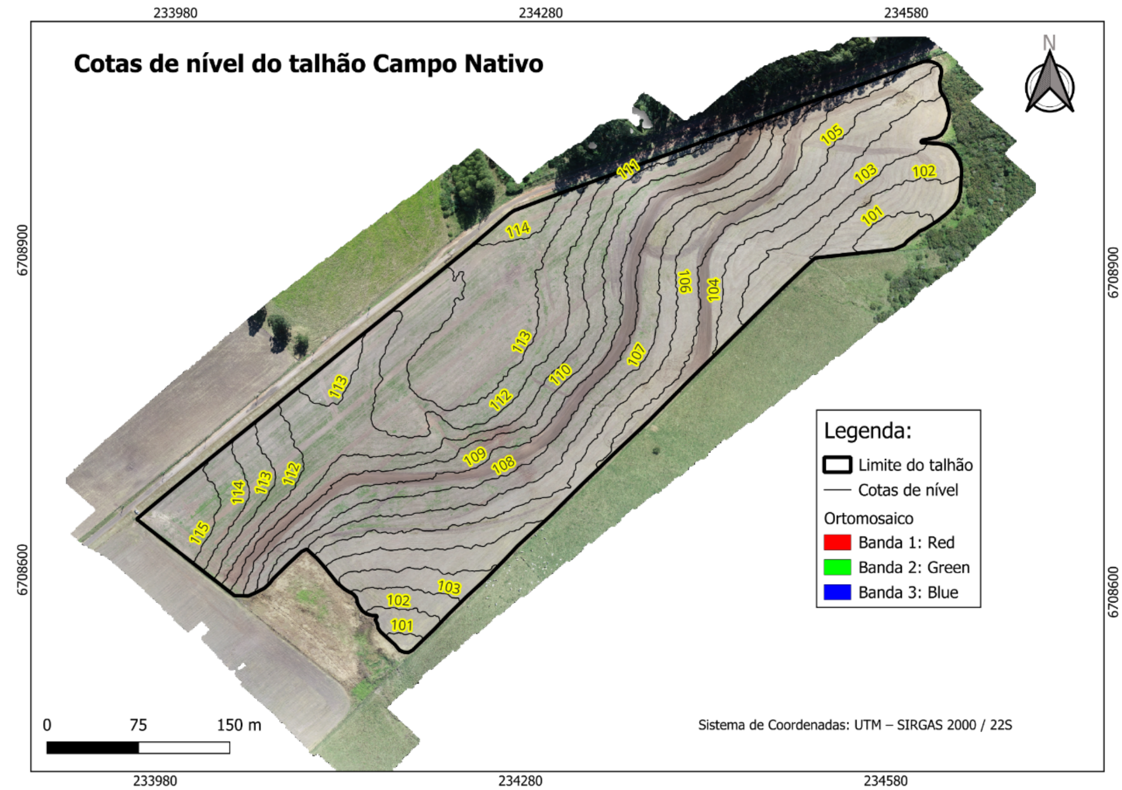
Figure 3. Orthomosaic map and Ground Control Points (GCPs) of the *Campo Nativo* field.

Source: Author (2025).

Subsequently, a dense point cloud was generated, consisting of thousands of three-dimensional coordinates (X, Y, and Z) extracted from the aerial imagery. These points served as the basis for the development of the Digital Surface Model (DSM) and, subsequently, for the generation of terrain contour lines with a vertical interval of 1 m. The contouring process was performed automatically by the software, which connects points located at the same elevation according to the predefined vertical interval.

As a result, a contour line was generated for each one-meter elevation change across the terrain, producing the contour map of the *Campo Nativo* field (Figure 4), with elevations referenced to mean sea level. It is important to note that the closer the contour lines are to one another, the steeper the terrain slope. Therefore, this cartographic product was fundamental for the topographic analysis and, more importantly, for identifying areas requiring a greater adoption of soil conservation practices.

Figure 4. Contour map of the *Campo Nativo* field.



Source: Author (2025).

In the subsequent stage, the generated contour lines became the foundation for the topographic assessment of the study area. The data were converted into shapefile (SHP) format and subsequently imported into AgroCAD® software (TecGraf Agro), where several cartographic products were developed, including a terrain elevation map, a slope map, a surface runoff flow-path map, a surface runoff velocity map, and a soil loss map.

The soil loss map was generated considering the soil loss tolerance threshold of 6 t ha^{-1} $year^{-1}$ for water erosion (BERTONI; LOMBARDI NETO, 1990), which is commonly adopted for the soil type under study, together with an average annual rainfall accumulation of 1,663 mm $year^{-1}$ (LANZANOVA et al., 2009).

Based on these parameters, soil loss classes were established, enabling the identification of critical areas exceeding the tolerable threshold, areas close to the critical limit, and zones remaining below the tolerance level. This analysis provided a better understanding of the surface runoff dynamics within the field and served as the basis for recommending appropriate soil conservation practices.

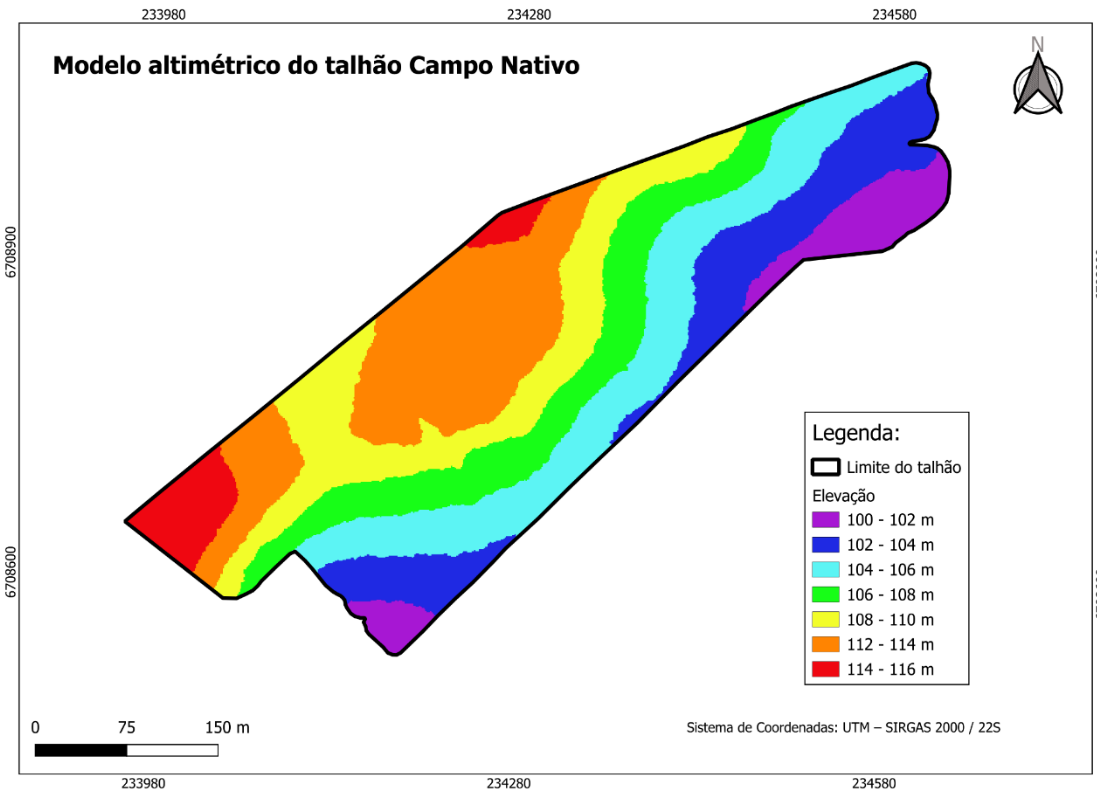
Among the proposed measures, the implementation of agricultural terraces, contour farming, and the maintenance of permanent soil cover were identified as key strategies for reducing soil losses, improving agricultural sustainability, and demonstrating the practical benefits of this approach for farm management and decision-making.

3 RESULTS AND DISCUSSION

Based on the generated maps, the first analysis focused on the terrain configuration of the study field, particularly through the terrain elevation map (Figure 5). This cartographic product highlights the altimetric variations relative to mean sea level, allowing the identification of both the highest and lowest portions of the area and providing an overall representation of the expected water flow patterns across the landscape.

In the present study, the analyzed field exhibited an elevation gradient ranging from 100 to 116 m above sea level. This variation was considered fundamental for supporting the interpretation of surface runoff behavior and for guiding the subsequent identification and implementation of appropriate soil conservation practices.

Figure 5. Terrain elevation map of the study field.



Source: Author (2025).

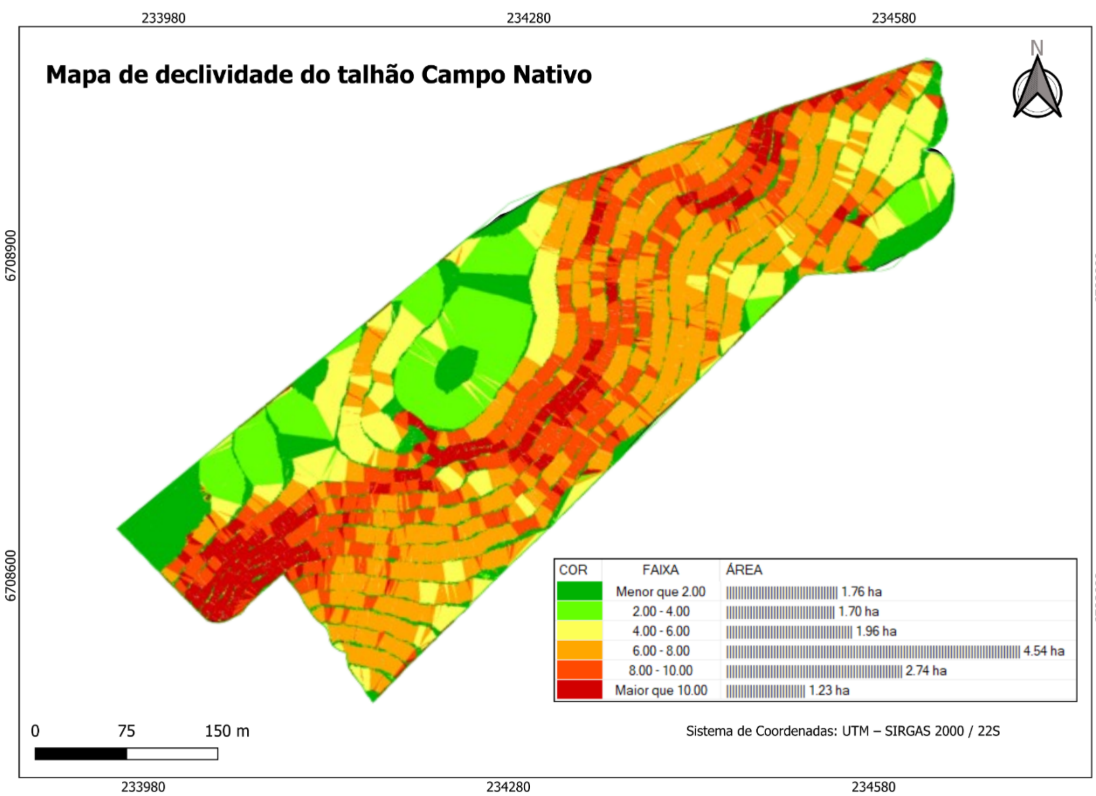
To complement the topographic assessment, a terrain slope map was generated (Figure 6), which is an essential tool for quantifying the inclination of the soil surface relative to the horizontal plane, expressed as a percentage. This cartographic product enables the visualization of areas with greater elevation differences, highlighting critical zones with a higher risk of erosion while providing valuable information for the planning of soil conservation practices, as well as for improving operational safety and agricultural performance.

The slope distribution within the study field was as follows: 1.76 ha with slopes below 2%, 1.70 ha between 2 and 4%, 1.96 ha between 4 and 6%, 4.54 ha between 6 and 8%, 2.74 ha between 8 and 10%, and 1.23 ha with slopes greater than 10%, resulting in an average slope of 8.21%.

According to the Land Agricultural Suitability Assessment System (RAMALHO FILHO; BEEK, 1995), areas with slopes up to 8% are considered to have low susceptibility to erosion and generally require only basic conservation practices, such as contour farming and the maintenance of soil cover. This condition encompasses approximately 71.5% of the analyzed area. In contrast, the remaining 28.5% of the field exhibited slopes exceeding 8%, classifying these areas as moderately susceptible to erosion. For such locations, the adoption of more intensive conservation measures, particularly terracing, is recommended to prevent the formation of rills and gullies that may negatively affect crop productivity, especially in annual cropping systems.

It is important to note that the study field did not present significant limitations for agricultural mechanization, nor did it exhibit areas with severe erosion susceptibility. This characteristic facilitates the implementation of targeted and practical conservation measures, particularly in the critical zones identified in red on the slope map.

Figure 6. Terrain slope map of the *Campo Nativo* field.

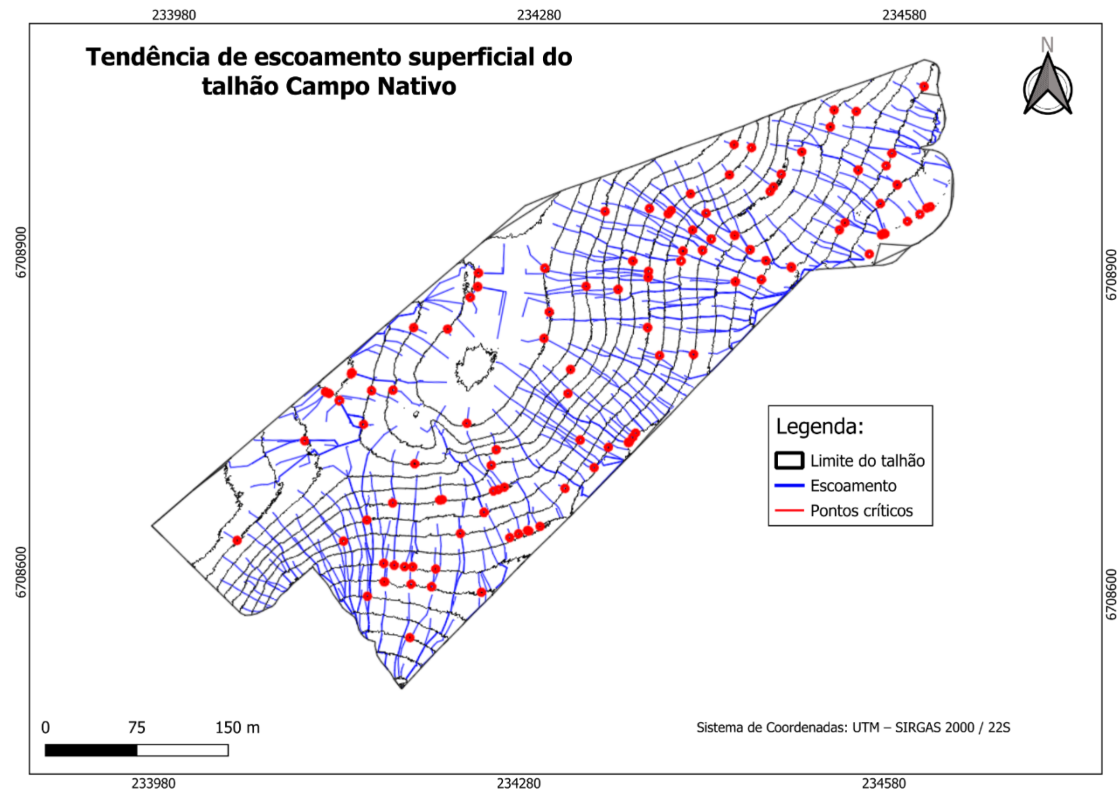


Source: Author (2025).

Based on the identified slope gradients, a surface runoff flow-path map was generated (Figure 7) to represent the direction and travel distance of water flow across the study field through the interpretation of contour lines. The processing was performed automatically within AgroCAD® software using vector-based algorithms that utilize elevation data to determine the preferential pathways of surface water movement.

Consequently, the generated flow-path lines simulate the hydraulic behavior of surface runoff, enabling the visualization of areas where water flow tends to concentrate. This cartographic product provides valuable information regarding the spatial distribution of runoff across the landscape and supports the identification of locations potentially more susceptible to erosion processes.

Figure 7. Surface runoff flow-path map of the *Campo Nativo* field.



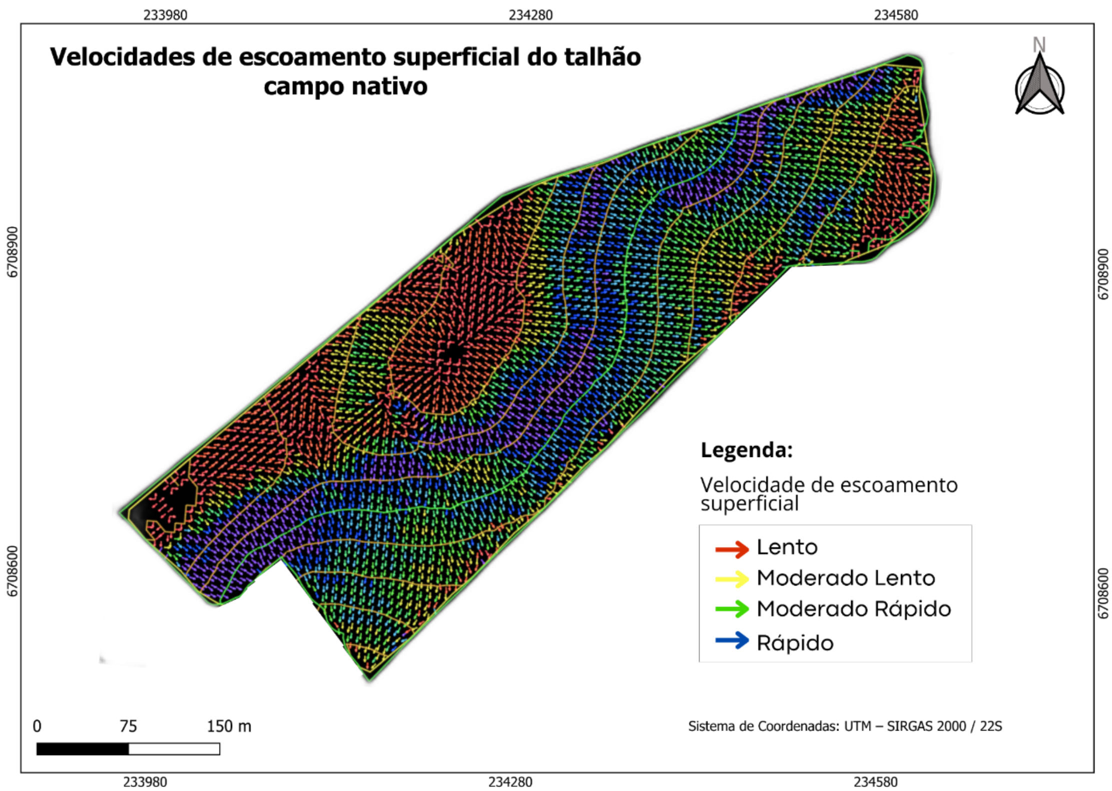
Source: Author (2025).

Areas exhibiting a greater concentration of flow-path lines represent zones subjected to more intense surface runoff and, consequently, a higher susceptibility to erosion processes. This graphical representation makes it possible to identify critical water accumulation zones and supports management decision-making. Furthermore, the software allows the configuration of different rainfall intensity scenarios, enabling a wide range of hydrological simulations and more rigorous analyses, particularly considering the increasing frequency of extreme precipitation events in the state of Rio Grande do Sul, Brazil.

The interpretation of the runoff flow-path map revealed that specific portions of the field concentrate larger volumes of water movement. This information is strategically important for selecting appropriate soil conservation practices and for planning more efficient management interventions.

The final indicator evaluated was the surface runoff velocity map (Figure 8), which was developed to represent the kinetic energy associated with water movement across the soil surface. This parameter is particularly relevant because it highlights areas where runoff forces reach higher magnitudes, thereby increasing the susceptibility of the field to water erosion. In these regions, greater runoff velocities enhance the detachment and transport of soil particles, making the implementation of mechanical, structural, and agronomic conservation practices necessary to reduce water velocity and mitigate erosion impacts.

Figure 8. Surface runoff velocity map of the study field.

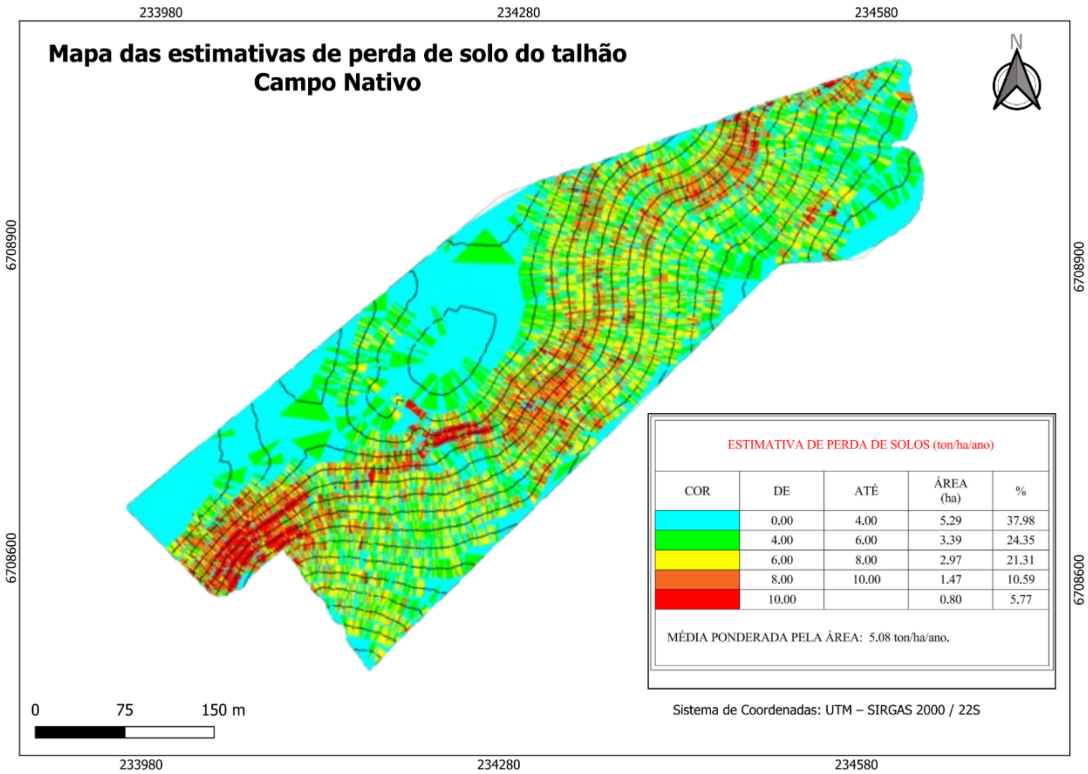


Source: Author (2025).

The development of the runoff velocity map considered the previously defined slope classes (Figure 6) and the average annual precipitation of the region, estimated at 1,663 mm year^{-1} based on a 16-year historical dataset (LANZANOVA et al., 2009). The results showed that the areas represented by green and blue tones corresponded to the highest runoff velocities, coinciding with the portions of the field exhibiting the steepest slopes. This relationship reinforces the importance of directing conservation measures toward these specific areas in order to reduce the risk of soil loss and enhance long-term agricultural sustainability.

Finally, by integrating the slope, runoff flow-path, and runoff velocity maps, it was possible to generate a soil loss estimation map (Figure 9), considering the critical soil loss tolerance threshold of 6 t ha^{-1} year^{-1} for the Typic Red Dystrophic Ultisol (BERTONI; LOMBARDI NETO, 1990). The field was classified into different annual soil loss categories, resulting in the following distribution: 0 to 4 t ha^{-1} year^{-1} over 5.29 ha (37.98% of the area); 4 to 6 t ha^{-1} year^{-1} over 3.39 ha (24.35%); 6 to 8 t ha^{-1} year^{-1} over 2.97 ha (21.31%); 8 to 10 t ha^{-1} year^{-1} over 1.47 ha (10.59%); and greater than 10 t ha^{-1} year^{-1} over 0.80 ha (5.77%).

Figure 9. Estimated soil loss map of the *Campo Nativo* field.



Source: Author (2025).

Based on these results, approximately 37.67% of the study field was found to exhibit soil losses exceeding the critical tolerance threshold, highlighting the need for targeted conservation interventions to reduce surface runoff and, consequently, the transport of soil particles. In contrast, the remaining 62.33% of the area remained within the acceptable tolerance range, indicating no significant compromise to soil productivity or its natural rate of formation. This spatial differentiation enables more precise management strategies by prioritizing areas with greater susceptibility to erosion and promoting enhanced agricultural sustainability.

Furthermore, specific sectors of the field requiring the implementation of conservation measures were identified due to soil losses exceeding the tolerable threshold. Therefore, the soil loss estimation map serves as a strategic decision-support tool, allowing not only the selection of the most appropriate conservation practice but also the identification of the most suitable locations for its implementation.

For areas where estimated soil losses exceeded the critical threshold, terracing was identified as a key conservation practice, as it enables the correction of the most vulnerable zones and significantly reduces the impacts of water erosion. In areas where soil losses remained below the tolerance level, maintaining permanent soil cover throughout the year was recommended as a simple and effective strategy for soil preservation. Additionally, implementing a contour farming design across the entire field was proposed as a complementary practice to promote greater uniformity in conservation management.

Overall, the topographic assessment provided a detailed evaluation of the erosion scenario and enabled the recommendation of site-specific conservation practices. The analysis revealed critical areas that are often overlooked during routine agricultural operations. Consequently, the adoption of the proposed measures may contribute to reducing water erosion, mitigating land degradation, and improving the sustainability of agricultural production systems.

4 CONCLUSIONS

The study demonstrated that detailed topographic analysis provides a more comprehensive understanding of field relief by characterizing key morphological attributes, particularly slope, which plays a fundamental role in determining surface runoff behavior. The spatial quantification of soil losses, both above and below the tolerance threshold, supported informed decision-making regarding the implementation of site-specific conservation practices, thereby promoting soil preservation and the sustainability of future cropping systems.

Furthermore, the application of Precision and Digital Agriculture technologies, including drones, geoprocessing software, and terrain modeling platforms, proved to be essential for the practical characterization of agricultural landscapes. These tools enhance planning capabilities, optimize field management operations, and directly contribute to the conservation of the physical, chemical, and biological properties of the soil. As a result, they support the maintenance of soil productive capacity while improving the economic returns achieved by farmers.

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