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GEOPROCESSAMENTO APLICADO À IDENTIFICAÇÃO DE ÁREAS APTAS PARA IMPLANTAÇÃO DE PIVÔS CENTRAIS NO MUNICÍPIO DE ITATINGA/SP

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1 RESUMO

A acurácia na utilização dos recursos naturais desempenha um papel crucial na preservação da integridade do solo, da água, das plantas e, também, da atmosfera no contexto agrícola. Por isso, é imperativo adotar estratégias de planejamento que visem à eficiência máxima desses recursos. Com uma projeção significativa, espera-se que até 2040 a extensão de terras irrigadas por meio do pivô central alcance aproximadamente 4,2 milhões de hectares. As geotecnologias desempenham um papel de grande importância no cenário agrícola ao possibilitar o monitoramento da dinâmica temporal e espacial das propriedades rurais em todas as etapas da cadeia de produção. Então, objetivou-se avaliar as áreas que são aptas para receber sistemas de irrigação por pivô central no município de Itatinga/SP. Cerca de 52,5% do território do município de Itatinga/SP, que são agricultáveis, possui alta aptidão para a implantação de irrigação por pivô central. Se somarmos as áreas ótimas e boas, obtemos uma porcentagem de 93,8%. O método utilizado revelou eficácia na tomada de decisões e pelo custo acessível, uma vez que os dados foram adquiridos de forma gratuita por meio de plataformas digitais.

Palavras-chave: SIG, Uso do solo, Mapeamento Temático, Manejo de águas, AHP.

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GEOPROCESSING APPLIED TO THE IDENTIFICATION OF AREAS SUITABLE FOR IMPLEMENTATION OF CENTER PIVOTS IN THE MUNICIPALITY OF ITATINGA/SP

2 ABSTRACT

The accuracy of the use of natural resources plays a crucial role in preserving the integrity of soil, water, plants and the atmosphere in the agricultural context. Therefore, it is imperative to adopt planning strategies that aim to maximize the efficiency of these resources. With a significant projection, it is expected that by 2040, the extent of land irrigated through the central pivot will reach approximately 4.2 million hectares. Geotechnologies play a very important role in agricultural scenarios by enabling monitoring of the temporal and spatial dynamics of rural

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properties at all stages of the production chain. Therefore, the objective was to evaluate the areas that are suitable for receiving central pivot irrigation systems in the municipality of Itatinga/SP. Approximately 52.5% of the territory of the municipality of Itatinga/SP, which is arable, is highly suitable for implementing central pivot irrigation. If we add the optimal and good areas, we obtain a percentage of 93.8%. The method used proved to be effective in decision-making and affordable, since the data were acquired free of charge through digital platforms.

Keywords: GIS, Use of the soil, Thematic Mapping, Water management, AHP.

3 INTRODUCTION

The accuracy of the use of natural resources plays a crucial role in preserving the integrity of soil, water, plants and the atmosphere in the agricultural context. Therefore, it is imperative to adopt planning strategies that aim at maximizing the efficiency of these resources.

When the practice of supervising irrigation systems efficiently, with the aim of precisely meeting the water demands of plants, planning seeks to avoid both excess and shortage of water and thus determines the viability of the system that will be implemented to ensure that there are no losses in crop productivity while promoting the economy of these essential resources (Martins, 2018).

The constant technological evolution in agricultural areas has been highlighted as a key element for achieving more effective results. Thus, Alves *et al.* (2015) highlighted notable advances in the field of irrigated agriculture, providing continuous improvements in the practices and technologies associated with water management. Thus, the commitment to maximize the use of irrigation in the field through the application of innovative technologies reflects the desire for optimization not only for production but also for environmental sustainability.

In view of this, the irrigation system known as the central pivot stands out as a widely popular and widespread choice in Brazilian agriculture. With a significant projection, it is expected that by 2040, the extension of land irrigated through this system will reach approximately 4.2 million hectares (ANA, 2021). This preference and expansion of the central pivot highlights its effectiveness and efficiency, highlighting its preponderant role in the search for sustainable and efficient agricultural practices in the Brazilian context.

The municipality of Itatinga, in São Paulo, has great agricultural potential for the implementation of crops such as grains and sugarcane, for example. However, even though sugarcane has favorable physical characteristics for large-scale cultivation, the municipality still has approximately 7,100 ha of sugarcane planted, 1,850 ha of corn, 100 ha of wheat and 1,300 ha of soybeans (IBGE, 2022). This may explain why the use of the central pivot irrigation system is still very small compared with neighboring municipalities, which have high investments in technology, such as Paranapanema, Itaí, Itapeva, Taquarituba and Avaré.

According to data provided by ANA, in 2022, approximately 631 ha were irrigated by central pivots in Itatinga in 2021, whereas in the neighboring municipality of Paranapanema, approximately 14,549 ha were irrigated by pivots in the same year. Therefore, studies are needed to assess whether the municipality of Itatinga has the potential to be included in the development of central pivot irrigation, as estimated by ANA for 2040 (ANA, 2022).

Therefore, geotechnologies play a very important role in agricultural scenarios by enabling the monitoring of the temporal and spatial dynamics of rural properties at all stages of the production chain. These tools, integrated with digital agriculture, not only offer the ability to track site mobility but also perform several other crucial functions for operational efficiency and strategic decision-making in agricultural activities (Mendes *et al.*, 2020). In this context, geoprocessing stands out as a tool of significant relevance, offering rural professionals comprehensive, accurate, quickly available and often less expensive information (Matsushita, 2014).

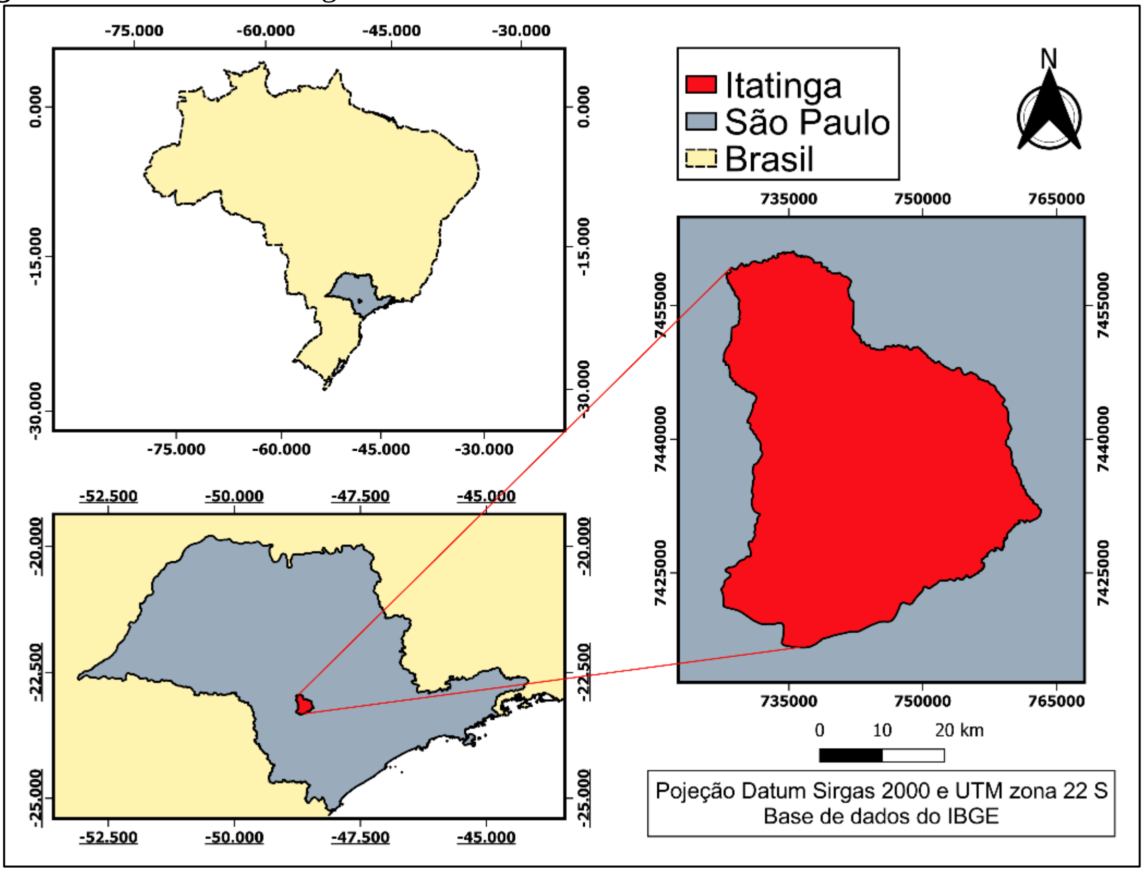
Therefore, the objective was to evaluate the areas that are suitable for receiving central pivot irrigation systems in the municipality of Itatinga/SP . With this, it will be necessary to cross-reference essential data for irrigation, such as soil type, slope and distance from water bodies (economic importance) and land use and occupation, to remove areas that are not suitable for arable farming.

4 MATERIALS AND METHODS

4.1 Area characterization

The region of interest comprises the territory of the municipality of Itatinga shown in Figure 1, belonging to the Mesor region of Bauru and the Microregion of Avaré in the state of São Paulo, with an area of approximately 979,817 km². Its latitude is 23° 06" 05"" south and longitude of 48° 36" 58" west; it is approximately 221 km from the capital of São Paulo, with an altitude of 845 m above sea level and a tropical climate of mild and dry Cwb, with an average temperature of 19.2°C and an estimated population of 19,070 people (IBGE, 2022).

Figure 1. Location of Itatinga.



Source: The authors (2024).

4.2 Factors analyzed

The research was conducted in a geographic information system (GIS) environment with the aid of the free *software* QGIS 3.28.11, which provides the ability to process and integrate different types of data. Four variables were considered material for analysis, which is essential for the feasibility of the implementation of central pivot systems. These variables cover land use and occupation, distance from the water body, terrain slope and soil classes (Barros *et al*., 2020).

4.3 Analytics hierarchy process (AHP)

The methodology called *the analytic hierarchy process* (AHP) was conceived by *Thomas L. Saaty* in the 1970s and represents one of the first approaches developed to guide decision-making on the basis of various evaluation criteria. Its central purpose is to structure the chosen factors in a position that reflects the preferences of decision-makers, with the options located at the lower level of this position (Gomes, 2020).

The method under consideration offers an approach for integrating perceptions and objectives into a comprehensive vision, as highlighted by Santos and Cruz (2013). In the context of decision-making via the *analytic scale hierarchy process* (AHP), pairwise comparison judgments range from 1 to 9, where a value of 1 represents areas considered "less suitable" and a value of 9 indicates ordinary areas as "more suitable".

4.4 Land use and occupation map for the classification of restricted and nonrestricted areas

The land use and land cover data were acquired through the MapBiomas portal, which uses collection 8 with a base year of 2022, presented in *shapefile format*. To ensure geometric accuracy, the GRASS tool was used for corrections, followed by vector clipping delimited to the study area and categorization of classes. The layer was subsequently projected to the SIRGAS 2000 coordinate system and UTM projection zone 22 S. Throughout the process, the data were manipulated according to the previously defined classes, taking into account their agricultural implications and categorizing them as areas restricted and not restricted to agriculture.

The weights were distributed according to Table 1.

Table 1. Distribution of weights for land use and occupation classes.

Land Use Classes	Features	Weights
Agricultural	Pasture, Agriculture and Forestry (Agriculture)	9
Nonarable	Forests, Water, Nonvegetated areas, etc.	restricted

Source: The authors (2024).

4.5 Distance from water bodies

The data for the map of distances between water bodies were obtained from the National Water Agency (ANA). The Ottocoded Hydrographic Base (BHO) used by ANA in water resource management was obtained from Brazilian systematic mapping and is a combination of drainage sections that follow from the mouth to the beginning of drainage, with the largest area upstream from each confluence used as a criterion. Each section is associated with a drainage surface called Ottobacia, to which the Otto Pfafstetter basin coding is assigned. An essential characteristic of this representation is to be topologically consistent, that is, to correctly represent the hydrological flow of the country's rivers and the municipality of Itatinga/SP through connected sections and with the flow direction (ANA, 2021).

As provided by Law No. 12,651/2012, the marginal strips of perennial and intermittent natural watercourses are designated permanent preservation areas (APPs), with the width varying according to the length of the water body. Within the scope of this analysis, a standard 30-meter APP was updated for all water bodies, which was delimited on the basis of the vector layer that represents the municipality's hydrography, and its restriction was fully considered within the scope of the study (Xavier *et al.*, 2021).

A buffer tool was used to generate equidistant areas around the water resources, avoiding overlaps with the realization of the differences in distances. In this way, the distances in relation to the water bodies assume a direct relationship with the costs of implementing the central pivot supervision system, since greater distances result in higher expenses related to motor pumps and pipes (Martins *et al.*, 2015).

The distance classes from the water source and their respective weights were defined on the basis of the cost of implementing the system presented in Table 2.

Table 2. Distribution of weights and classes of distances to water bodies.

Distances (m)	Features	Weights
0 to 1000	Low cost	9
1000 to 2000	Medium cost	7
2000 to 4000	High cost	5
> 4000	High cost	3

Source: Adapted from Martins *et al*. (2015).

4.6 Soil types

Soil data for the Brazilian territory, with a scale of 1:250,000, were obtained from the map portal of the Brazilian Institute of Geography and Statistics (IBGE) and were standardized according to the guidelines of the Brazilian Society of Soil Science (SBCS). Vector data delineating the boundaries of the municipality of Itatinga/SP, also acquired by IBGE, were used as an overlay layer to cut out the different soil classes.

The following dominant classes were identified through the attribute table of these soils, and weights were distributed while accounting for the first categorical level, as shown in Table 3.

Table 3. Distribution of weights and classes of soil types

Soil Classes	Features	Weights
LVAd - Dystrophic Red–Yellow Latosol	Mature, deep and structured	9
LVd - Dystrophic Red Latosol	Mature, deep and structured	9
LVdf - Dystroferric Red Latosol	Mature, deep and structured	9
LVef - Eutroferric Red Latosol	Mature, deep and structured	9
PVAd - Dystrophic Red–Yellow Argisol	Mature, deep and susceptible to erosion	7
NVef - Eutroferric Red Nitosol	Good on flat ground and limited on undulating ground	5
RQo - Neosol Quartzarenic Orthic	Shallow and rocky	1
Water		Restricted

Source: Adapted from Gomes *et al.* (2017).

The allocation of weights for each soil class was based on specific characteristics considered crucial for safety practices, such as texture, drainage, infiltration rate, water retention capacity and agricultural potential conditions associated with the soil structure, which directly influence plant root development. This approach aims to ensure optimized vigor, resulting in increased productivity through irrigation. Thus, the assignment of weights to the different classes was determined on the basis of their relevance (Santos, 2015).

4.7 Ground slope

An elevation model (DEM) from the *Shuttle Radar Topography Mission (SRTM)* was used, which was accessed through *Earth Explorer and* made available by the *United*

States Geological Survey. *Survey* (USGS). The use of this model allowed the creation of a surface map, thus enabling the accurate *design* of the terrain slope.

First, a *raster* of the slope calculation is used, setting it to a percentage instead of degrees. After this first process, a reclassification was carried out with the slope percentages preestablished for the work, focused on the use of central pivot irrigation systems, taking into account the viability and relevance of their implementation, as shown in Table 4.

Table 4. Distribution of weights and slope classes.

Slope classes (%)	Features	Weights
0 to 5	Excellent	9
5 to 15	Good	7
15 to 30	Average	3
> 30	Bad	Restricted

Source: Adapted from Xavier *et al.* (2021).

4.8 Preparation of the suitability map

The evaluation layers were subjected to reclassification, in which weights were assigned according to their specific characteristics, following the essential scale proposed by *Saaty* (1984). After completing the spatial analyses and their corresponding reclassifications, the multicriteria analysis method was implemented through the weighted superposition of the four layers. Then, the standard established by Martins *et al.* (2015) and Gomes *et al.* (2017) for the importance of the layers for the installation of a central pivot irrigation system was followed, and this standard was confirmed through calculations in which these values have an RC (consistency ratio) well below 0.10 or 10%, as proposed by Saaty (1987), without the need for restructuring; to calculate the areas, the *r.report* tool of GRASS GIS was used, as shown in Table 5.

Table 5. Weighting of the importance of layers for the installation of a central pivot irrigation system.

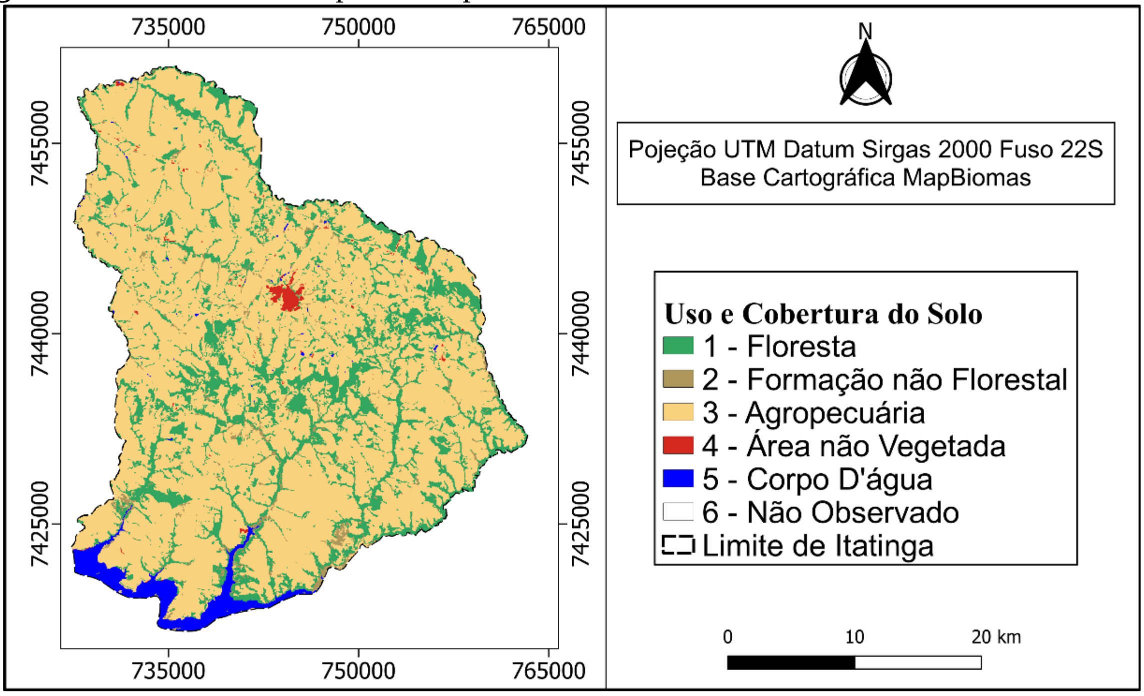
Layers	Importance (%)
Slope	35
Distance from water bodies	35
Soil types	20
Land use and occupation	10

Source: Adapted from Martins *et al.* (2015) and Gomes *et al.* (2017).

5 RESULTS AND DISCUSSION

The land use and occupation map of the municipality of Itatinga/SP was prepared to remove only the agricultural class for suitability analysis, which corresponds to 74,743.4 ha, which is equivalent to 76% of the entire territory. Figure 2 shows the land use map.

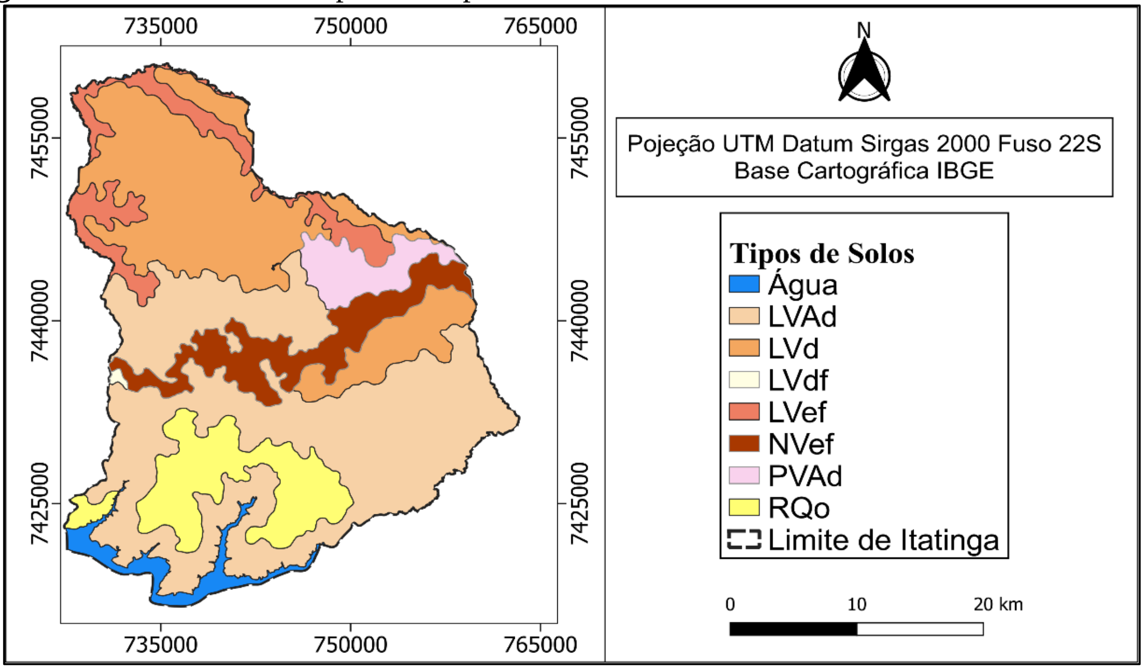
Figure 2. Land use and occupation map.



Source: The authors (2024).

The area calculations are distributed for each soil type of the 1st categorical level, which are those that begin with L – Latosols, N – Nitosols, P – Argisols and R – Neossolos; the colors of the map followed the classification of the Brazilian Society of Soil Science with small variation in tone to differentiate, as shown in Figure 3.

Figure 3. Land use and occupation map.



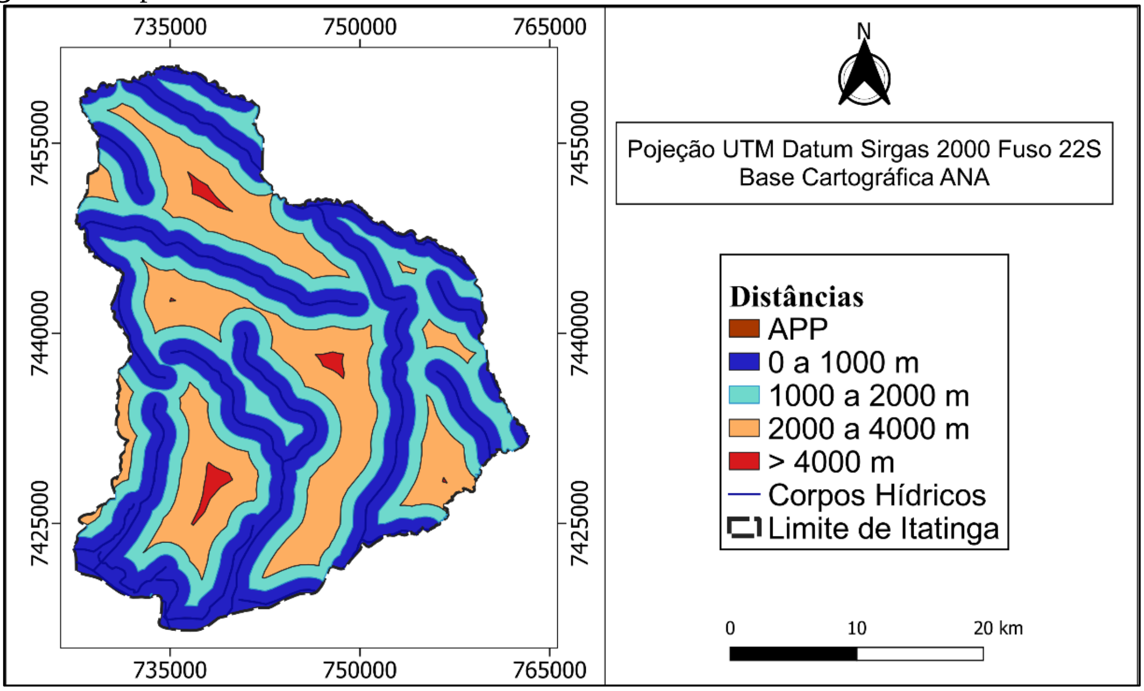
Source: The authors (2024).

With respect to soil pedology, a value of 72,897.8 ha was observed for Latosols, which corresponds to approximately 76.6%; that is, more than half of the soils in the municipality received excellent prospects for the implementation of central pivot irrigation systems, presenting the best possible characteristics. However, these prospects also depend on the slope of the soil and the distance from water bodies so that the potential may vary from more to less favorable.

Argisols are present in 3,942.4 ha, corresponding to only 4.1% of the territory's soil. Nitossolos account for 8,173.3 ha, with 8.6% of the soil. Finally, the soils that have the lowest evaluation among the others and that offer the greatest difficulty for the system are Neossolos, with approximately 10,207.6 ha, which is equivalent to 10.7%. Water was not accounted for because it is restricted.

For the map of the distances of perennial water bodies (Figure 4), only 996.7 ha are over 4000 m away or represent 1% of the total area. This 1% corresponds to those that are considered economically unviable owing to the costs of pipelines, motor pumps and others (Gomes *et al.*, 2017). Approximately 72.3% of the total area ranges from 0--2000 m, with an area of 69,915.2 ha. The area corresponding to 30 m of APP was considered restricted and was not included in the calculations.

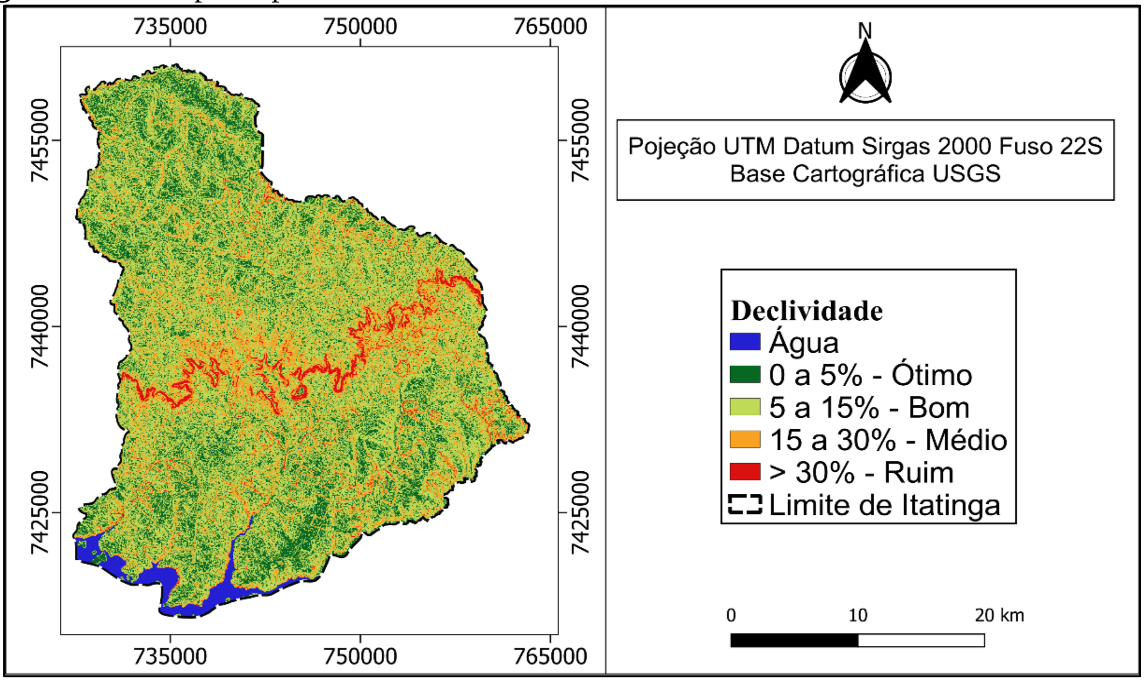
Figure 4. Map of distance from water courses.



Source: The authors (2024).

With respect to soil slopes (Figure 5), approximately 22,583.8 ha are classified as excellent, accounting for approximately 23.7% of the territory. The good class corresponds to 52,749.3 ha, or 55.3% of the total area. Therefore, approximately 79% of the soil has excellent slope conditions for receiving central pivots. The medium class corresponds to 17,007.9 ha, accounting for 17.8%, and the poor class is equivalent to 2967.8 ha or 3.1% of the territory. Water was considered restricted.

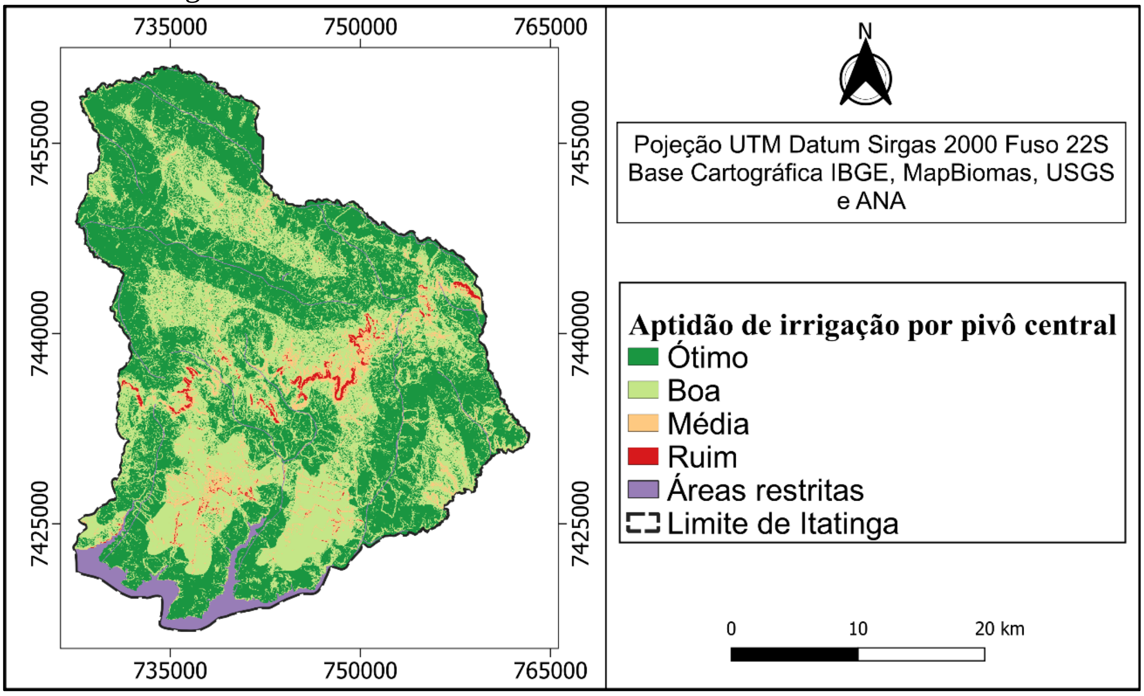
Figure 5. Soil slope map.



Source: The authors (2024).

Figure 6 is the result of crossing the land use and occupation maps, which have the least final influence, of the soil types that receive a considerable percentage in the analysis and the two that most influence the final result, which is the slope and the viability of the water supply to the pivot calculated by distance.

Figure 6. Map of suitability for the implementation of central pivots in the municipality of Itatinga/SP.



Source: The authors (2024).

Table 6. Total area of each suitability class.

Fitness classes	Area (ha)	Percentage (%)
Excellent	49,160.7	52.5
Good	38,597.7	41.3
Average	4.848.1	5.2
Bad	954.2	1.0

Source: The authors (2024).

With the final results obtained from the final suitability map, we arrive at the results of the areas that represent the classes in Table 6.

Approximately 52.5% of the territory of the municipality of Itatinga/SP, which is arable, is highly suitable for the implementation of central pivot irrigation. If we add up the excellent and good areas, we obtain a percentage of 93.8%. This shows the potential that the municipality of Itatinga has to expand its agriculture with the security of the viability of irrigating with any pressurized irrigation system, since the central pivot is the one with the most restrictions; even so, 93.8% of the arable area can receive this type of irrigation.

This high potential (suitability) is explained by the fact that the municipality has soils with excellent characteristics to work and manage, several water sources with rivers and lakes available and soils that in few areas exceed 30% of slope, which justifies the predominance of Latosols, as they develop in environments of this type.

6 CONCLUSIONS

Research has shown that the municipality of Itatinga/SP has the potential to implement central pivot irrigation systems to contribute to the expansion of agriculture and productivity and thus help with food security.

The use of geoprocessing proved to be effective, allowing the identification of regions with high suitability and those with a lower propensity for the practice of central pivot irrigation. This method provides valuable technical and scientific information, standing out for its capacity for spatial analysis to characterize different levels of demand for specificity in specific areas.

The method used proved to be effective in decision-making and affordable since the data were acquired free of charge through digital platforms.

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