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Research Article

Spatial Evaluation of the Potential of Potato Culture by Multicriteria Analysis and GIS: Case of the Wilaya of Bouira (Algeria).

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ABSTRACT

Optimizing potato cultivation is crucial for enhancing food security in Algeria. To guide decision-makers, this study undertakes a comprehensive site suitability analysis for potato farming. Our methodology integrates Geographic Information System (GIS) techniques with multi-criteria analysis (MCA) methods. We rigorously examine diverse geographical and socio-economic factors to identify areas that best meet the specific requirements for potato cultivation, thereby contributing to improved production. The results reveal a notable spatial disparity, with the central region of the Province exhibiting different suitability patterns compared to its eastern and western extremities. Overall, approximately 82.29% of the Province's surface area is identified as potentially suitable for potato cultivation.

Keywords:, Bouira, Cultivation Suitability, GIS, Multi-criteria Analysis, Potato, Spatial evaluation.

INTRODUCTION

The agricultural sector is one of the most important sectors, and Algeria possesses significant resources that need to be optimally exploited to contribute to the development of Algerian exports outside of hydrocarbons on the one hand, and to improve the food security situation on the other (Yahi, M. Djaafour, N. 2022).

The priority of ensuring food security is a universal concern. Algeria is no exception; it has opted for strengthening certain strategic sectors, including the potato sector, due to its role in improving food security and its potential for creating added value. Food security constitutes one of the fundamental components of the sustainable development process (BENABDELLAH, M., & EL HARRAK, M. 2020). Thus, sustainable soil management conditions sustainable agriculture (Chabi, A. 2015). In Algeria, the agricultural sector is of paramount importance. It contributes, on average, 35% to the GDP. It represents a strategic weight in the country's social and economic fabric in terms of contribution to food security, employment, income generation, and the creation of goods and services.

Since 2000, Algeria has paid great attention to rural areas, which have always deserved better integration into agricultural policy for the sake of regional balance, preservation of the country's potential, environmental protection, and as a corollary to food security. Indeed, a real and courageous agricultural development policy has more or less succeeded in reversing the trend, materialized by the National Agricultural Development Plan (PNDA), which focused on horticultural agriculture to ensure food self-sufficiency and end food dependence on agricultural products (potato cultivation, date palm cultivation, cereal production, etc.).

The importance of potatoes in global food security is well established. It is one of the most important food crops in the world (SBAI, H. et al. 2025). It has extraordinary production potential. Although its cultivated area is smaller than that of wheat or rice, it ranks second in terms of total production (Ranaivoson, Lalaina. 2023). The potato sector, in all its aspects of seeds and consumption, has considerable economic weight in Algeria and occupies a strategic place in the new agricultural and rural renewal policies. It represents an economic, social, and cultural opportunity that the rural and agricultural environment, in particular, must seize to make it a major asset for implementing agricultural development strategies.

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It is clear that ensuring food security for the Algerian population without affecting the agroecological balance requires the adoption of what is known as precision agriculture, based on the use of geospatial technology. Thus, precision agriculture requires an estimation of all factors involved in the potato value chain (BENABDELLAH, M., & EL HARRAK, M. 2020). The cultivation of the potato sector in Algeria is no longer at the project or embryonic stage but is a tangible reality. Today, several regions of the country are supplied with fruits and vegetables from Bouira, El Oued, Biskra, and Ouargla.

The purpose of this communication is to provide a rapid overview of the current situation of the Province of Bouira and to understand the reality of this territory, which ultimately experiences a paradox: it is both fragile and promising. It is fragile because the Province of Bouira is considered an urban expansion zone for the North-Central region, a dumping ground for the population and activities of the entire Northern region of Algeria. Paradoxically, however, it has become an important supplier of many agricultural products for the North.

However, despite all the efforts and implementations, it cannot be said that the objective of agricultural development in the sector, improvement of farmers' living conditions, or the retention of local populations has been achieved. This confusing situation invites us to develop and experiment with methodological approaches that lead to an operational and concrete tool aimed at implementing geographic information as a tool for popularizing potato cultivation. The adaptation of multi-criteria tools to the field of potato cultivation optimization is not easy, especially since very few local works deal with this subject, and most studies addressing the theme of localization focus on industrial enterprises by describing the factors influencing the location choices of industrial companies. In this context, multi-criteria methods constitute a scientifically valid instrument, based on quantitative formulations (Kuria, D. et al. 2011). A large number of methods have been developed, and the number of academic publications related to MCA is constantly increasing (Bensaid, A et al. 2008). Several studies have addressed the question of identifying soils suitable for agriculture; (Kêdowidé, C.M.G., 2018) used MCA to evaluate performance based on the physicochemical characteristics of soils for corn cultivation.

Our objective is to establish a Geographic Information System (GIS) to implement an effective tool for evaluating suitable sites for potato cultivation, based on adequate integrated territorial indicators. This will enable the outlining of a decision-making tool for local authorities with a view to optimizing the potato sector.

Currently, the application of GIS has touched all aspects of society such as agriculture, forestry, water conservation, land, resources, economy, commerce, and the environment. Specific applications include natural resource management, agricultural and commercial planning, political and economic analysis, urban land use planning, technical design management, science, education, culture, etc. (Huang, X et al. 2022). This tool can be used in mitigation, management, monitoring of agricultural production, vulnerability and risk assessment, pest control, precision agriculture monitoring, climatology, water and soil resource management, and disaster recovery (Yao et al, 2021; Ramos, A., et al., 2014). New technologies can indeed meet multiple challenges in agriculture. In an effort to improve yields in the Province of Bouira, this work illustrates the methodology and results obtained by geomatic modeling leading to the identification of sites favorable for potato production. The combination of GIS and Analytic Hierarchy Process (AHP) tools simplifies and improves the understanding of geographical information.

GEOGRAPHICAL LOCATION OF THE STUDY AREA

A description of the physical geographical characteristics of the study area and its components .(Bouchama&Lounes.2024).The Province of Bouira is strategically situated in the north-central region of Algeria, encompassing an area of 4,456.26 km², which represents 0.19% of the national territory. Its provincial capital lies approximately 120 km southeast of Algiers, the nation's capital.

This region is endowed with substantial water resources, fed by several major watersheds that provide an average annual supply of approximately 561 million cubic meters. The climate within the Bouira Province exhibits considerable variation, influenced by terrain features and proximity to the Mediterranean Sea. Generally, it experiences hot, dry summers and cold, rainy winters.1 Average annual rainfall ranges from 660 mm in the northern areas to 400 mm in the south.

From a broader regional and national perspective, Bouira holds a pivotal position due to its robust basic infrastructure network, including national roads and railways. This makes it an important crossroads for significant flows of goods and passengers traveling to various parts of the country. Its geographical location uniquely positions

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it as a privileged transition zone between the major central cities like Algiers and metropole cities such as Constantine and Annaba (Figure 1).

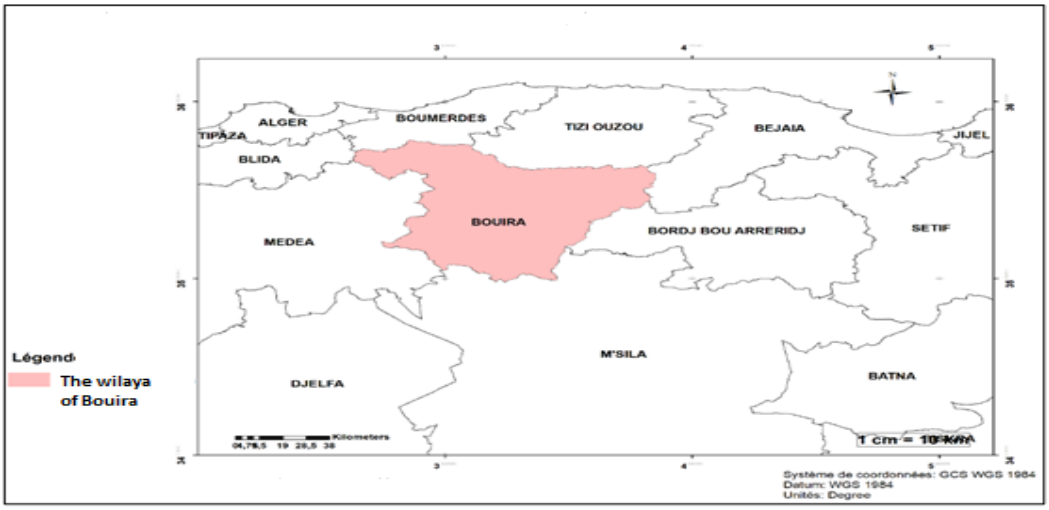

Figure 1. Geographical location of Bouira

METHOD

Objective and relevant evaluation criteria are identified in relation to the search for areas suitable for potato cultivation. The criterion is the basic element of a decision. It is either a factor or a constraint and can be measured or evaluated. The constraint is a Boolean criterion that limits our analysis to specific areas and therefore excludes plots declared unsuitable for potato cultivation. For each of the identified criteria, the procedure calculates a criterion map that measures the level of suitability or unsuitability of the spatial unit for potato cultivation for the specified criterion. These 'degrees of suitability' must then be ranked according to the relative importance of the contribution made by this particular criterion, with a view to achieving the ultimate objective. This results in a series of maps that will be aggregated by weighted linear combination. In this study, ten main criteria were selected based on the knowledge of local experts (Table 1).

Table 1. Main criteria

Criteria	Indicators
Geographical Criteria	- Hydrographic network - Soil type - Slope
Socio-demographic Criteria	- Structure of activities - Size
Economic Criteria	- Presence of markets (market zones) - Structure of cold storage - Road network
Environmental Criteria	- Risks

Our study employs a multi-criteria analysis (MCA) approach, leveraging the Analytic Hierarchy Process (AHP) method to determine the suitability of land for potato cultivation. This method allows us to assign weights to various criteria based on their relative importance.

Before weighting, all criteria undergo a crucial standardization process to ensure comparability. Following standardization, these weighted and normalized criteria are then aggregated. This aggregation forms the basis for mapping soils suitable for potato production. It's important to note that this method necessitates meticulous and

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precise data processing, as the quality of the output directly depends on the accuracy of the underlying data for each criterion.

Table 2: Comparison matrix and calculation of its eigenvector

Criteria	C1	C2	C3	...	Cn	Wi
C1	1/∑C1	W21/∑C2	W31/∑C3	...	Wn1/∑Cn	∑C1/n
C2	W12/∑C1	1/∑C2	W32/∑C3	...	Wn2/∑Cn	∑C2/n
C3	W13/∑C2	W23/∑C3	1/∑C3	...	Wn3/∑Cn	∑C3/n
...	...	...	...	...	...	...
Cn	W1n/∑C1	W2n/∑C2	W3n/∑C3	...	1/∑Cn	∑Cn/n
	∑C1	∑C2	∑C3	...	∑Cn	

Source : Saaty(2008)

When wij represents the quantitative judgement of the pair of characteristics Ci and Cj, it is defined by the following rules:

If wij = α, then wij = 1/α, α ≠ 0..... (1)

If Ci is considered to be of equal relative importance to Ci, then wij = 1, wji = 1 and wii = 1, for all i..... (2)

The eigenvector of the matrix can be found using the following formula:

$$Wi = (\prod nj\text{-}1\ wij)1/n \quad \text{.....(3)}$$

STANDARDISATION OF CRITERIA

The implementation of criteria maps requires prior standardisation, which allows them to be quantified according to their capabilities. This is based on continuous reclassification (Jiang and Eastman, 2000). Standardisation was based on the data in Table 2. Based on this table, we must normalise so that the sum of its elements is equal to unity. To do this, simply calculate the proportion of each element relative to the sum.

T = [W1 / ∑Wi W2/∑Wi ... Wn/∑i] ..... (4)

Let T be the normalised eigenvector used to quantify and evaluate the importance of each criterion.

Weighting table

The weighting table was drawn up on the basis of previous studies and fieldwork. It enabled each criterion to be weighted. Saaty's AHP method (2008) was used. This involved comparing the criteria in pairs in terms of their relative importance in relation to the objective defined on the basis of Saaty's weighting scale. The weight resulting from the comparison of each pair of criteria was then determined. In order to test the consistency of the response, which indicates whether the data are logically related to each other, Saaty (2008) proposes following the procedure set out in equations 5, 6 and 7:

Value calculated on the basis of Saaty's index

$$\lambda \max = \Sigma (\Sigma Ci . Wi) \qquad (5)$$

Consistency index (IC) :

$$Ic = \frac{\lambda \max - n}{n-1} \qquad (6)$$

The consistency ratio (RC) :

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RC= IC (7) IA

C = column, n = number of factors, λ max = value calculated based on Saaty's matrix, IC = consistency index.
If RC > 10%, there is no consistency in the pairwise comparison of criteria. The matrix must be re-evaluated. IA is a random index set according to the number of criteria. Table 2 shows the random indices according to the number of criteria.

AGGREGATION

After defining and assigning weights to the partial units, the aggregation process was carried out using a weighted linear combination, as described by Equation 4, within the ArcGIS software environment. In this formula, x represents the factor, w the corresponding weight, and c the constraint.
This approach is implemented in GIS through map algebra, a fundamental technique in cartographic modelling. Map algebra enables the integration of spatial data by expressing cartographic operations within a mathematical framework, where information layers act as variables and spatial analysis functions serve as operators (Amaya et al., 2021). When applied to input layers, these operations generate new output layers that reflect the combined spatial characteristics.
The spatial analysis module in ArcGIS, through its map algebra capabilities, facilitated this process by enabling the algebraic manipulation of geospatial data layers. This functionality allowed for the effective synthesis of diverse spatial inputs into meaningful aggregated outputs.

RESULTS

The results are divided into three main parts: the development of criteria maps, the weighting and aggregation of criteria, and the identification of areas suitable for potato cultivation.

Development of criteria cards

These different cards are based on several criteria.

-Water potential
In the Bouira province, water is the main constraint to the development of potato cultivation (Figure 2). The availability of water resources is one of the key parameters for agriculture in general and for potato cultivation in particular. Indeed, no agricultural activity is possible without water (MEZRHAB, A. 2024). For potatoes, the proximity of this water resource is a fundamental criterion.

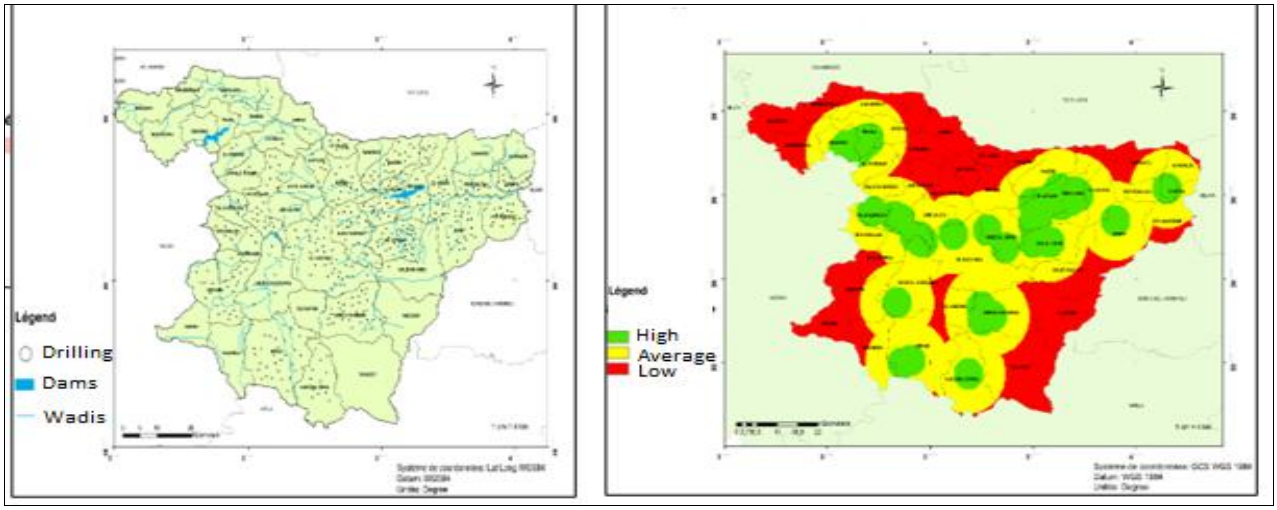

Figure 2 . The standardized water potential criterion

-Soil Type
Soil plays a crucial role in determining suitable locations for future potato cultivation and represents a primary factor in potato production in the Bouira region. Bouira features a diverse range of soil types, each with distinct physical and chemical properties that influence their agricultural potential.

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Potatoes grow in a variety of soils, ranging from sandy to clayey textures, each offering different water retention capacities. However, the ideal soil is well-structured, providing adequate drainage for tuber development and sufficient aeration to promote healthy root systems and reduce disease risk (Lucie et al., 2022). Potatoes also prefer soils with a pH between 5.5 and 7.0 and low salinity levels (Chemak, 2014).
Due to the absence of a detailed soil map for the region, a geological map is used to identify areas suitable for potato cultivation. The geological layer corresponding to the marine Oligocene formation is selected as a reference, as it offers conditions favorable for potato growth (Figure 3).

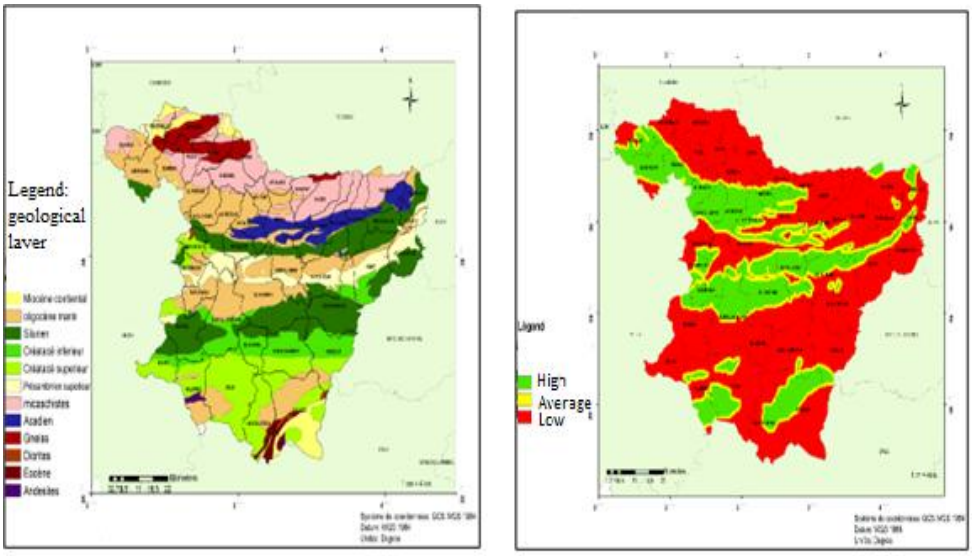

Figure 3. The standardized soil criterion

-Slope factor
The slope of the terrain is an important parameter to consider when identifying sites for potato cultivation. Rugged areas are less suitable. The 'slope' variable for the Bouira province is derived directly from the DTM (Digital Terrain Model)
The slope layer obtained shows values ranging from 0 to +25%. Potato cultivation is suitable in areas with slopes of less than 1 and 2%. (Dadjo, A et al. 2022)

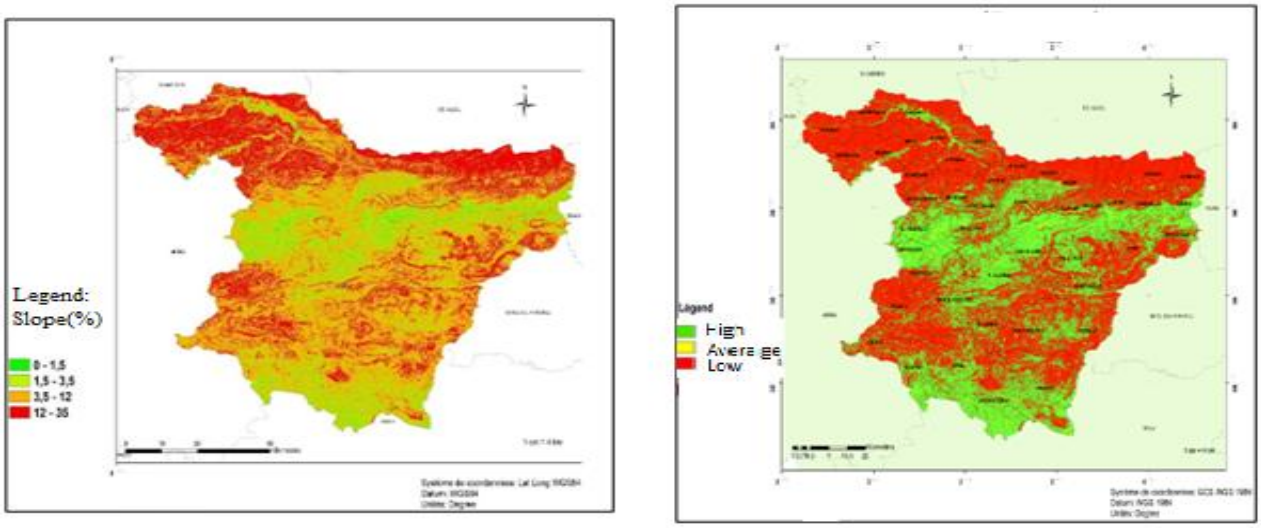

Figure 4. The standardized slope criterion

-Road Network Factor
The road network represents a key factor in determining suitable areas for potato cultivation. Efficient accessibility facilitates the timely delivery of agricultural inputs such as seeds, fertilisers, and pesticides, and ensures the smooth transport of harvested products to collection, storage, and processing centres.

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The Province of Bouira covers a vast area situated between the Djurdjura and Bibans mountain ranges, with central zones consisting of flatter terrain. The region benefits from a relatively well-developed road infrastructure, including national and regional roads, as well as rural paths that connect various agricultural zones (Figure 5).

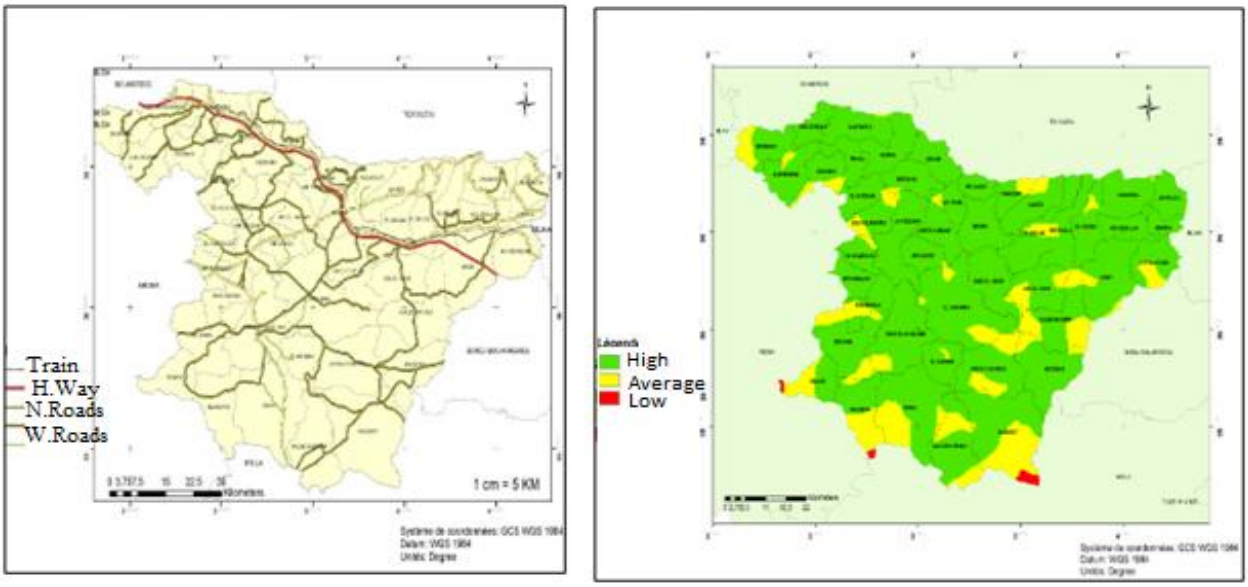

Figure 5. The criterion of the standardized road network

-Proximity of cold storage facilities

Cold storage facilities are storage facilities that extend the shelf life of potatoes and maintain their quality. Areas with good cold storage infrastructure can facilitate potato preservation and storage, reduce post-harvest losses, and improve product quality (Figure 7).

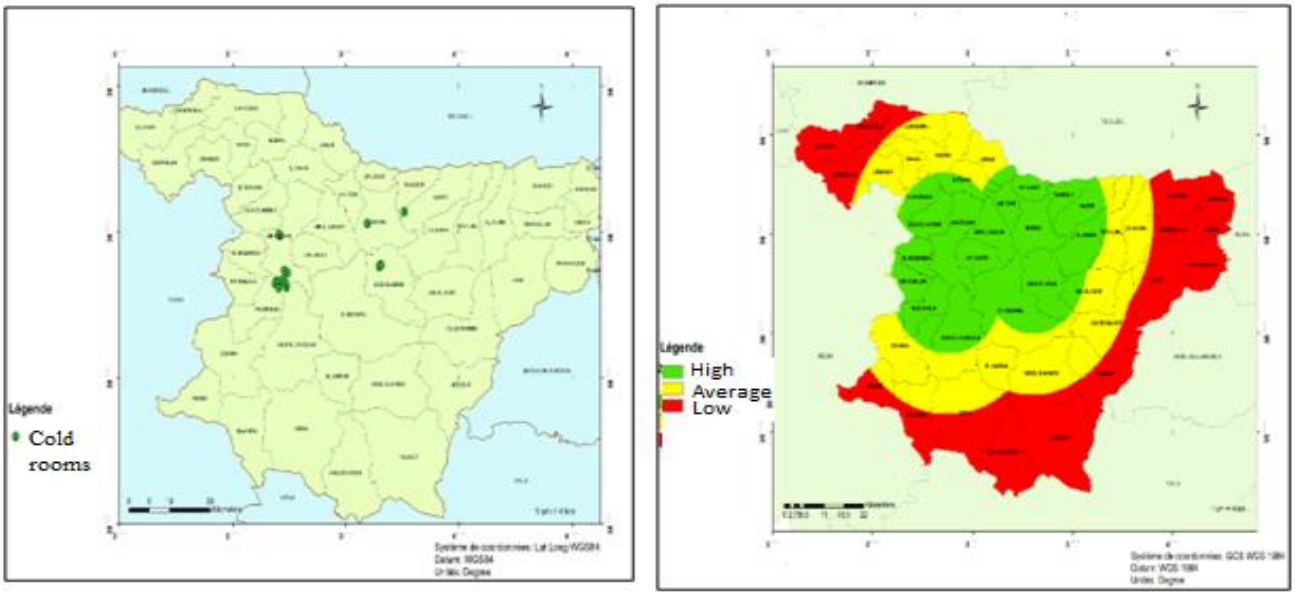

Figure 6. standardization of the criterion of proximity of cold rooms

-Risk factors

The Hierarchical Multi-Criteria Analysis method was used to map industrial areas and landslide zones in the region in order to integrate this data with other geographical data. This mapping will make it possible to determine the areas where potato production is most profitable, avoiding industrial areas and landslide zones (Figure 8).

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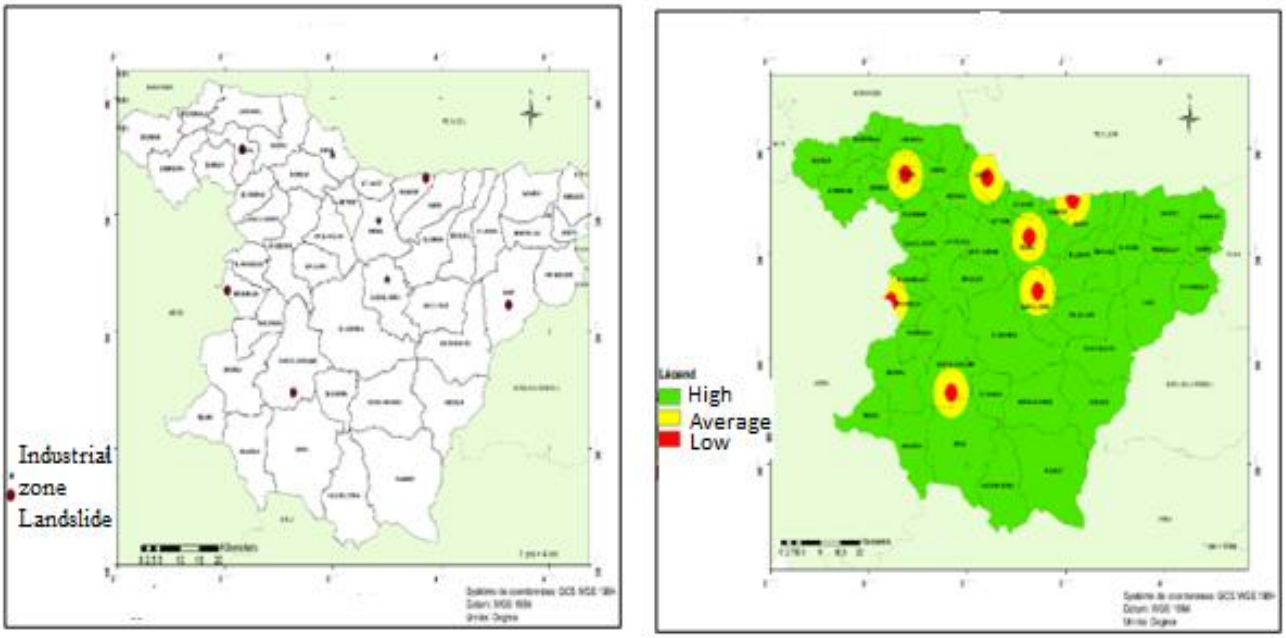

Figure 7. Standardization of risk criteria

-Proximity to wholesale markets factor

Identifying potato growing sites based on the presence of markets can help producers optimise their production and marketing. Producers can focus on areas where demand is highest and transport costs to markets are lowest.

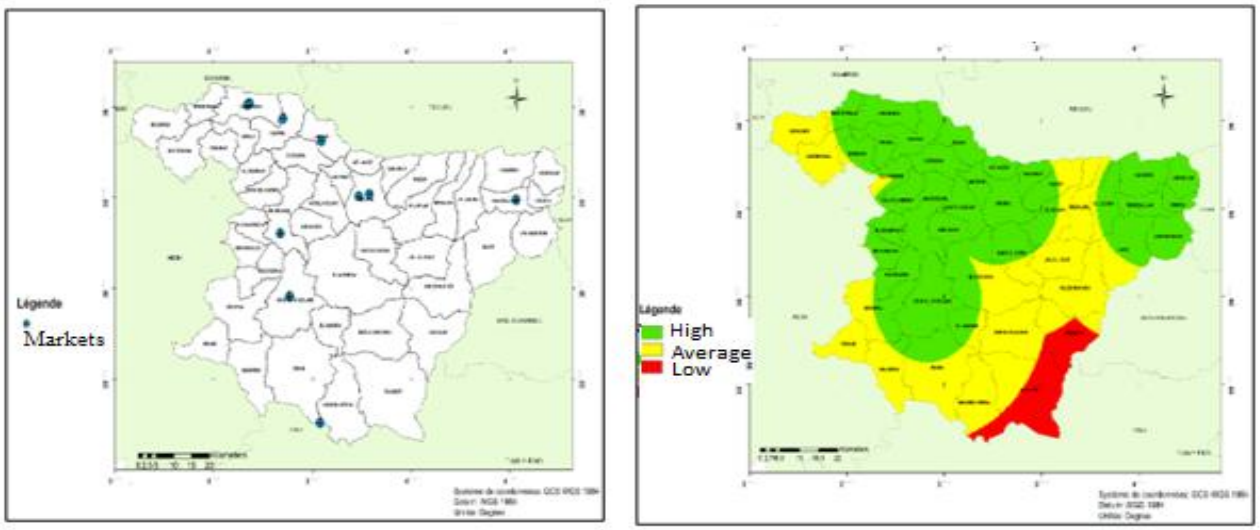

Figure 8. standardization of wholesale markets

- Population Activity Structure as a Factor

The structure of the population's economic activities plays a key role in determining the availability of agricultural labour and the local demand for agricultural products. In regions where agriculture is the dominant occupation, there is typically a more experienced and readily available workforce, which can positively impact potato production. To assess this, we mapped the population's activity structure across the Province of Bouira. This information was then integrated with other geographical and socio-economic data—such as soil type, climate conditions, irrigation availability, road networks, and population density. By combining these datasets, the mapping allows for the identification of areas where potato cultivation is likely to be most profitable, particularly in relation to the local labour force. (Figure 10)

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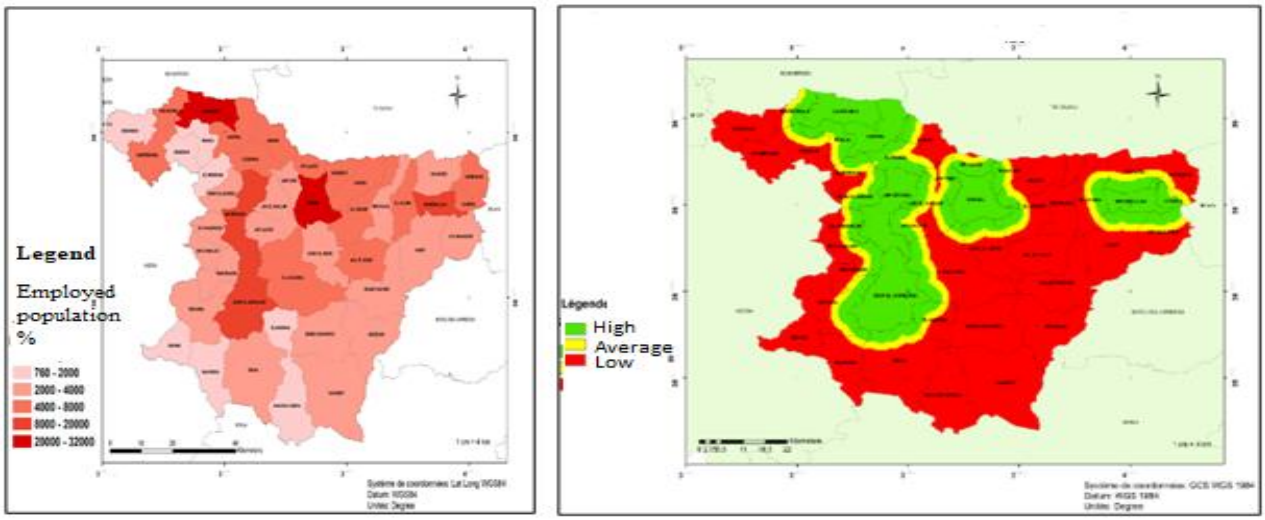

Figure 9. standardization of the structure of the working population.

-Population size

Population size can influence local demand for potatoes, as well as the availability of agricultural labour in the region. Areas with larger populations may have higher demand for local agricultural products, which can provide opportunities for potato producers.

Criteria	Hydrographic network	Soil type	Slope	Road network	Cold storage structure	Risks	Market presence (market zones)	Population structure (age)	Activity structure	Population size
Hydrographic network	1	3	3	3	3	5	5	5	5	7
Soil type	0.33	1	2	2	2	4	4	4	4	6
Slope	0.33	0.5	1	2	2	2	2	2	2	4
Road network	0.33	0.5	0.5	1	2	2	2	2	2	2
Cold storage structure	0.33	0.5	0.5	0.5	1	2	2	2	2	2
Risks	0.2	0.25	0.5	0.5	0.5	1	2	2	2	2
Market presence (market zones)	0.2	0.25	0.5	0.5	0.5	0.5	1	2	2	2
Population structure (age)	0.2	0.25	0.5	0.5	0.5	0.5	0.5	1	2	2
Activity structure	0.14	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1	2
Population size	0.2	0.17	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1

Table 3. Pairwise Comparison Matrix Based on the AHP Method

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Criteria	Hydrographic network	Soil type	Slope	Road network	Cold storage structure	Risks	Market presence (market zones)	Population structure (age)	Activity structure	Population size
Sum	3.28	6.67	9.25	11.00	12.50	18.00	19.50	21.00	22.50	30.00

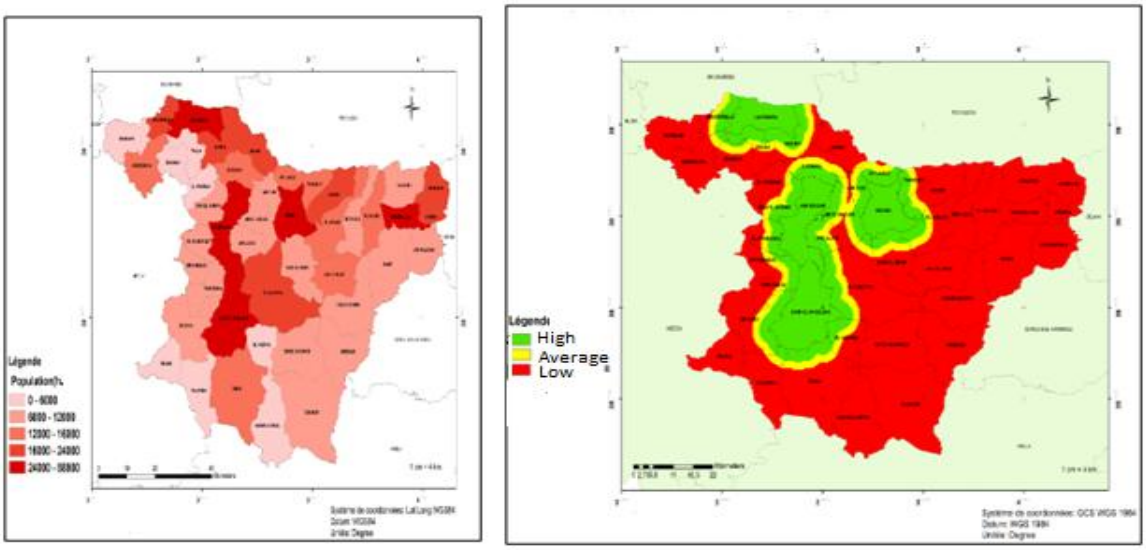

Figure10.standardization of population size

WEIGHTING OF CRITERIA

In multi-criteria analysis, it is essential to recognize that not all factors carry the same level of importance. To reflect their relative influence on the decision-making process, each factor must be assigned an appropriate weight. This weighting
process forms the foundation of all multi-criteria evaluations, as it significantly affects the outcome of the analysis. The weights used in this study were derived through a pairwise comparison of the criteria, following the Analytic Hierarchy Process (AHP) method. The resulting comparison matrix is presented in Table 2.
The pairwise comparison table was created based on the requirements for potato cultivation components and Saaty's weighting scale. Thus, based on the pairwise comparison table, the weighting table for each criterion was established (Table 3).

Table 4. Calculation of weights used

Criteria	**Hydrographic Network**	**Soil Type**	**Slope**	**Road Network**	**Cold Storage Structure**	**Risks**	**Market Presence (Market Zones)**	**Population Structure (Age)**	**Activity Structure**	**Population**	**Weight**
Hydrographic Network	0.3052325	0.45	0.3243	0.272727273	0.24	0.277777778	0.256410256	0.238095238	0.222222222	0.233333333	0.282012298
Soil Type	0.1017441	0.15	0.2162	0.181818	0.16	0.222222	0.205128	0.190476	0.177777	0.2	0.180538
Slope	0.1017441	0.07	0.1081	0.181818	0.16	0.111111	0.102564	0.095238	0.088888	0.133333	0.115780

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Criteria	Hydrographic Network	Soil Type	Slope	Road Network	Cold Storage Structure	Risks	Market Presence (Market Zones)	Population Structure (Age)	Activity Structure	Population	Weight
Road Network	0.1017441	0.07	0.05 40	0.090909	0.16	0.111111	0.102564	0.095238	0.088888	0.066666	0.094617
Cold Storage Structure	0.1017441	0.07	0.05 40	0.045454	0.08	0.111111	0.102564	0.095238	0.088888	0.066666	0.082072
Risks	0.0610465	0.03	0.05 40	0.045454	0.04	0.055555	0.102564	0.095238	0.088888	0.066666	0.064696
Market Presence (Zones)	0.0610465	0.03	0.05 40	0.045454	0.04	0.027777	0.051282	0.095238	0.088888	0.066666	0.056790
Population Structure (Age)	0.0610465	0.03	0.05 40	0.045454	0.04	0.027777	0.025641	0.047619	0.088888	0.066666	0.049464
Activity Structure	0.0436046	0.0375	0.05 40	0.045454	0.04	0.027777	0.025641	0.023809	0.044444	0.066666	0.040895
Population Size	0.0610465	0.02	0.02 70	0.045454	0.04	0.027777	0.025641	0.023809	0.022222	0.033333	0.033131

Using the matrix created for each pair of factors, we calculated the normalised weight for each factor; the consistency ratio was also calculated using SAATY's (2008) equation, which gave a value of 0.070.

Table 5. Calculation of the normalised weight

10,9493741	λmax
0,10548602	CI
1,49	RI (10)
0,07079598	RC

Aggregation and Identification of Suitable Areas for Potato Cultivation

To identify areas suitable for potato cultivation, an additive combination aggregation method was employed. This technique produces a quantitative raster map in which each pixel value reflects the cumulative contribution of all weighted factors (Figure 7).

The results indicate that:

- Highly suitable areas cover 42,925.13 hectares, representing approximately 9.67% of the total area of the Province.
- Moderately suitable areas account for 313,393.4 hectares, or 70.60% of the Province's territory.
- Less suitable areas cover 78,703.47 hectares, corresponding to 17.73% of the total surface area.

This spatial distribution provides valuable insight for agricultural planning and highlights the regions with the greatest potential for profitable potato cultivation.

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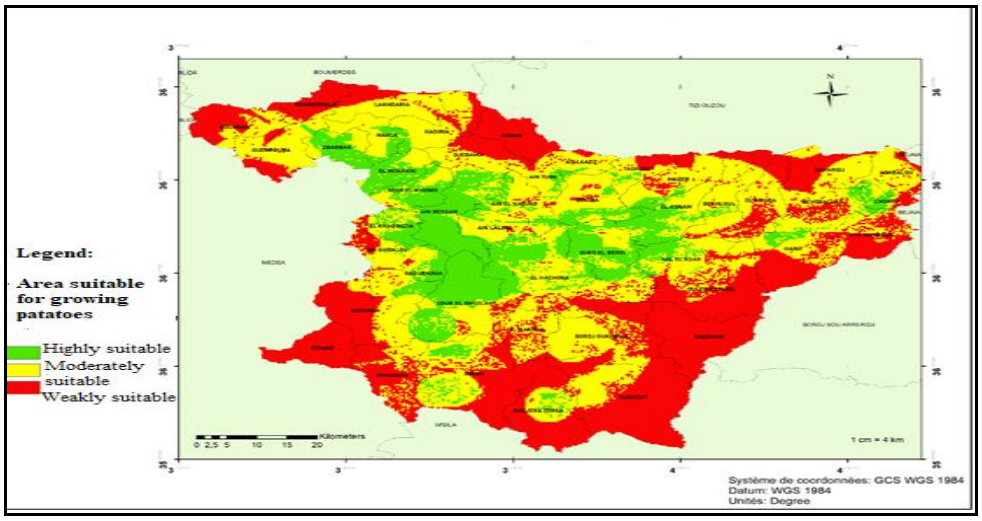

Figure 11. Identification of areas suitable for potato cultivation in the Province of Bouira

DISCUSSION

The final suitability map indicates that the most favourable sites for potato cultivation in the Province of Bouira are predominantly concentrated near permanent water sources, sandy and clay soils, road infrastructure, proximity to markets, and cold storage facilities, as well as in areas with readily available agricultural labour. Two distinct classes of suitable areas emerge from the analysis: favourable and less favourable. Despite varying suitability levels, these areas collectively encompass nearly the entire territory of Bouira, underscoring the region's broad potential for potato production. Soil characteristics and the hydrographic network are critical components of land resources, forming the foundation of both agricultural productivity and long-term ecological sustainability. Meanwhile, socio-economic factors, such as infrastructure and population characteristics, play a key role in determining the economic viability and development potential of land for specific crops, including potatoes.

These findings are consistent with those of Konan-Waidhet et al. (2013), who identified suitable areas for rice cultivation using four main criteria: topography, soil type, population density, and rainfall. However, unlike the current study, their approach did not account for the spatial influence of storage infrastructure and market accessibility, which are crucial for post-harvest logistics and market integration.The results also align with research by Sanogo and Salifou (2024), as well as Feizizadeh and Blaschke (2012), who emphasized that the overall suitability of an area is a function of the weighted combination of multiple factors. A low score in one criterion can be offset by a higher score in another, depending on the relative importance assigned during the weighting process. Among the most commonly used techniques in such analyses is weighted linear combination (WLC), which effectively integrates all relevant criteria into a single composite output.

Furthermore, the integration of Geographic Information Systems (GIS) with Multi-Criteria Analysis (MCA) has proven instrumental in overcoming the limitations of traditional spatial evaluation methods. GIS enhances spatial reasoning and visualization, while MCA ensures that decision-making accounts for multiple, often conflicting, factors. Together, they offer a comprehensive framework for land suitability assessment and spatial planning.

However, the reliability of the results is inherently tied to the quality and resolution of the input data. One noted limitation of the method is the use of a limited scoring scale (1 to 3), which may reduce the granularity of factor differentiation. Nevertheless, as Kangah and Coulibaly (2024) argue, this approach remains effective when the number of variables or alternatives is relatively small, as in the present case.

CONCLUSION

This study tackled the critical challenge of identifying optimal sites for potato cultivation in Bouira province. Our goal was to develop a robust method for selecting locations that meet specific agricultural criteria while considering various objectives.

We developed a multi-criteria decision-making (MCDM) model rooted in the Analytic Hierarchy Process (AHP). This model is a powerful tool designed to support decision-makers in choosing sites that align with predefined

criteria. A key advantage of our AHP-based approach is its ability to facilitate sensitivity and adaptation analysis, allowing for a more nuanced selection of the most suitable sites.

The decision support model we created offers significant value to local officials and decision-makers. It provides comprehensive insights into the multifaceted issue of site selection, aiding in a deeper understanding of all relevant factors. Furthermore, the AHP method is particularly effective at incorporating qualitative information and fostering better communication between researchers and system experts. This enhanced collaboration improves information accessibility for researchers and strengthens experts' confidence in the model's utility. This approach is especially noteworthy as it operationalizes the "actor's model" and allows for the construction of scenarios to analyze the potential consequences of various decisions.

Among the various MCDM methods available, AHP stands out for its simplicity of implementation as a total aggregation method. It calculates a concise summary score (between 0 and 1) by hierarchically structuring and weighting all criteria relevant to the decision.

Ultimately, this study underscores the immense value of Geographic Information Systems (GIS) in spatial planning. It highlights the conceptual, logistical, and scientific importance of using GIS to streamline land-use decision-making. By doing so, it demonstrates GIS's substantial contribution to the economic and regional development of the Bouira province.

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