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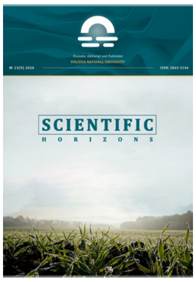

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Application of analytical hierarchical process in assessing the suitability of land for growing grain crops

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Abstract. Assessing the suitability of land for growing grain crops is a relevant issue for ensuring sustainable agricultural production and improving food security. The Analytical Hierarchy Process (AHP) is an effective method of multi-criteria evaluation that systematically addresses all parameters. The study aimed to analyse the usage of the AHP method to determine the weight and priorities of different soil and climate

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characteristics to analyse the suitability of land for cereal crop cultivation, using wheat as an example. The study identified key factors affecting yields and developed recommendations for effective land management. An AHP was employed to weight various criteria, including physical, chemical and climatic characteristics. The data were processed to determine the impact of each factor on land suitability, with consistency checks to ensure the reliability of the results. The study showed that Flood and erozion hazard characteristics (32.2%) and Soil pysichal characteristics (25.6%) are the most important physical factors. Acidity (pH) and Cation Exchange Capacity (CEC) have a significant impact on nutrient availability, while average temperature and precipitation determine the main climatic conditions for wheat growth. Flood and erosion risks are also addressed for the long-term suitability assessment. The AHP was used to assess the suitability of land for wheat cultivation, identifying the most important factors and their weights. Practical recommendations included applying agronomic measures to reduce erosion risks and improve soil fertility. The results of the study can be used by agronomists, land managers and policymakers to improve land management, which will contribute to increased agricultural production efficiency and food security in the face of climate change

Keywords: assessment criteria; soil fertility; erosion risk; climatic factors; land management; agronomic measures

INTRODUCTION

Assessing the suitability of land for growing crops has been a critical process for ensuring food security, sustainable use of resources and optimising land use. In the context of global population growth and limited agricultural land resources, there is a need for accurate and scientifically sound approaches to determining the most efficient use of each plot. The production of cereals such as wheat has become a staple of the diet of many countries, and optimising their cultivation processes has had a significant impact on food independence and ecosystem resilience. Therefore, it was important that the land allocated for this crop met agricultural and ecological criteria and provided the highest yields while preserving soil quality and the environment.

Despite significant advances in the assessment of land suitability for crops, numerous challenges remained related to the objectivity and accuracy of decision-making in this area. The Analytical Hierarchy Process (AHP) method developed by T. Saaty (1980) is widely used in management research, including in the agricultural sector. It ensures the formalisation of multi-criteria decision-making processes and provides by ranking criteria based on their weight. This method was used to address both quantitative and qualitative indicators, making it particularly suitable for complex tasks such as land suitability assessments. However, studies that have applied this method to the valuation of land for growing grain crops have remained limited. Numerous scholars have applied AHP to land valuation in various environmental and economic contexts. S. Abate and M. Anteneh (2024), as well as E. Nungula *et al*. (2024) demonstrated how the physical and chemical characteristics of soils can be assessed using Geographic Information System (GIS) and AHP approaches, which ensures accuracy in determining the optimal conditions for growing grain. J. Oladimeji (2024) highlighted the use of GIS-based AHP to assess land suitability for rice, confirming the importance of multi-criteria analysis in decision-making, which is also critical for cereals. D. Ming (2024) and K. Nabiollahi *et al*. (2024) emphasised that integrating machine learning into traditional valuation models can further improve the accuracy of the results.

R. Makar *et al*. (2024) and A. Dutta *et al*. (2024) demonstrated the successful application of AHP in various agronomic contexts, showing the potential of the method to improve land suitability assessment. Nevertheless, a gap in the integration of socio-economic factors remains, which highlights the need for further study of this aspect. P. Bazkiaee *et al*. (2024) demonstrated how modern remote sensing technologies can support and improve land suitability assessment, but there is a need to develop standards for the effective integration of different data sources into a single AHP model, which will be an important step for practical implementation in the field of grain production. The study of Ukrainian scientists M. Lubskyi *et al*. (2024) modelled the vulnerability of the steppe landscape and climatic zone of Ukraine to climate change using remote sensing data. Satellite imagery for vulnerability modelling was used to address the impact of climate change on crop productivity, which is also necessary for predicting changes in land suitability in the face of global warming.

The problem of multi-criteria selection of alternatives, which is relevant for land suitability assessment tasks, where various factors (climate, soil, accessibility, etc.) need to be integrated into a single model, was studied by S. Sveshnikov *et al*. (2024). This study provides a methodological framework for the application of multicriteria analysis in agricultural and environmental research and decision-making based on criteria weighting, similar to the application of the AHP method for land suitability assessment. Albanian researchers and world scientists assessed the suitability of land based on a multi-criteria analysis to determine the optimal conditions for agriculture, addressing various factors such as climate, topography, hydrology and infrastructure parameters. The use of multi-criteria decision-making methods in combination with GIS provides a detailed assessment of environmental and socio-economic parameters that are key to sustainable land use planning in Albania. The study is also carried out by international experts who use various methods to assess land suitability, including a specific approach to structuring multifactorial problems, such as AHP methods, which provides greater transparency in the process of determining the weighting of criteria.

In these studies, the authors concluded that AHP is a consistent way of prioritising factors affecting yield and environmental sustainability. Despite significant progress in the use of AHP to assess land suitability, researchers have noted gaps in the study of specific criteria for growing cereals, namely wheat. For instance, studies have addressed general factors such as soil structure, depth and acidity, but have not sufficiently considered aspects such as erosion risk, water availability and climatic characteristics that are crucial for grain yields. In addition, the study of different environmental conditions, including those in specific regions such as Albania, remained underrepresented, limiting the applicability of existing methods to other climatic zones.

Thus, the study aimed to analyse the weighting coefficients of the criteria for the suitability of land for grain crops on the example of wheat in the context of Albania and Ukraine in more detail. This study provided a detailed description of the main criteria that influence the productivity of cereal land and weighs them using AHP.

MATERIALS AND METHODS

The study was conducted on the research plots of the Agricultural University of Tirana and Mykolaiv State Agrarian University. The data collection included physical, climatic, chemical and biological soil characteristics, as well as erosion risks, which were used for further analysis using the AHP method. In the current research, AHP was applied to describe the multi criteria evaluation. AHP is a multi-criteria decision-making approach. AHP technique is the most important point of this assessment, because careful organization of sub-criteria of main criteria if weights properly, represent perfect suitability order and fulfills the goal. The pair-wise comparison matrix (PWCM) was carried out for rating and weighting of sub-criteria in each group as well as for the final main group. For comparing the two sub-criteria the fundamental scales given by T. Satty (1980) were used. A nine-point rating scale, based on a criterion, used by T. Satty is showed in Table 1, in making this judgment.

***Table 1**. Importance ranking of pairwise combination of factors*

Scale	Degree of preferences	Explanation
1	Equally	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one activity over another
5	Strongly	Experience and judgment strongly or essentially favor one activity over another
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation
2,4,6,8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

***Source:** T. Saaty (1980)*

The AHP method was chosen as the main method for weighting and prioritising land suitability criteria. The AHP can be used for a structured division of complex tasks into separate hierarchical levels, starting with the research objective (hereinafter referred to as criteria) and ending with sub-criteria, and provides the possibility of allocating weights based on expert assessment of each criterion.

The following criteria were used to assess the suitability of the land:

1. Climate indicators: average daily temperature during the crop cycle and total rainfall during the crop cycle, which significantly affect crop productivity (Sys *et al.*, 1991).

2. Physical and quality characteristics of the soil: data on soil depth (cm), texture, drainage, water availability (mm/m), and coarse particle content.

3. Biological and chemical characteristics of the soil: fertility class (soil fertility classes are determined by the analysis of 7 agrochemical parameters (pH (H_2O), organic matter %, assimilable P ppm, exchangeable K me/100 g, exchangeable Mg me/100 g, Ca:Mg ratio, K:Mg ratio), electrical conductivity (EC), exchangeable sodium (ESP), and cation exchange capacity (CEC).

4. Flood and erosion risk: slope (%), aspect of the terrain, erosion risk and flood frequency.

5. Availability: distance to water sources (m) and roads (km).

This data was analysed using Excel, where the values were weighted and normalised for each group of criteria to obtain the final weighting factors. The weighting process was carried out employing expert assessments using pairwise comparisons, where each criterion was assigned relative importance according to its impact on the suitability of land for growing grain crops. The obtained values of the pairwise comparisons were used to calculate the weighting coefficients of each criterion and then to calculate a generalised assessment of land suitability.

The weightings for each criterion were calculated in five separate groups, as well as for all criteria together to provide a comprehensive assessment of suitability. The share of each criterion was presented in tables, which were used to assess the compliance of land plots with the criteria for growing grain crops. To process and analyse the data, Excel was used to calculate weights, which identified the factors affecting land suitability. This methodology provides a comprehensive approach to assessing land suitability, addressing the various environmental and technical factors that influence the choice of sites for growing grain crops.

RESULTS

General results of the assessment of land suitability for growing grain crops. The results of the assessment of the suitability of land for growing grain crops, using wheat as an example, using the AHP method showed the importance of various factors affecting agricultural production. Five main groups of criteria were considered, each of which contributed to the overall suitability score. Table 2 shows the weights of each group of criteria based on their importance for successful grain production.

***Table 2**. PWCM for five main groups of criteria*

Flood and erosion hazard	Soil physical characteristics	Soil biological and chemical characteristics	Climate	Accessibility	Weights (%)	Rank
1	1	2	3	4	32.2	1
1	1	1	2	4	25.6	2
1/2	1	1	2	4	22.3	3
1/3	1/2	1/2	1	4	14.1	4
1/4	1/4	1/4	1/4	1	5.8	5
		Consistency ratio = 4%			∑=100	

***Source:** compiled by the authors*

The evaluation of land suitability for grain crop production, exemplified by wheat, was conducted using the AHP. The analysis focused on assessing the importance of various factors that influence agricultural productivity. The criteria were grouped into five major categories, each contributing differently to the overall suitability score. With the highest weighting of 32.2%, flood and erosion hazard are the most critical factor. This category reflects the significant impact of environmental hazards on soil stability and crop sustainability. Ranking second with a weight of 25.6%, the physical properties of the soil, including texture and depth, play a crucial role in determining water retention and root development. Weighted at 22.3% (rank 3), these attributes include organic matter and soil pH, both vital for fertility and nutrient availability.

At 14.1% (rank 4), climatic conditions, such as precipitation, influence water availability and crop viability but are less influential compared to soil-related factors. This criterion has the lowest weight of 5.8% (rank 5), as logistical and infrastructural considerations, while important, are secondary to biophysical and environmental factors. The consistency ratio of the pairwise comparisons was calculated at 4%, indicating reliable and consistent assessments. The weights and rankings underscore the dominant role of soil and environmental hazards in land suitability assessments for grain crop cultivation.

The impact of climatic characteristics on land suitability. To assess the suitability of the land for climatic characteristics, data were collected average daily temperature during the crop cycle and total rainfall during the crop cycle in the selected areas. Climate parameters, such as temperature and precipitation, have a significant impact on grain production, as they determine the availability of heat and moisture needed for optimal plant growth. The weight in % for temperature and precipitation are 50% for each. Air temperature is a critical factor in determining the development cycle of wheat. The ideal temperature range for growing wheat is usually between 10°C and 25°C. Wheat has an optimum temperature for seed germination (15-20°C) and grain development (20-25°C). If the temperature exceeds or falls below these limits, it can cause plant stress, stunted growth or even complete crop failure. For example, excessively high temperatures during the pollination period can cause grain formation disorders and reduce yields (Kalenska *et al.*, 2023). Low temperatures, especially during germination, can slow down development and make plants more vulnerable to disease.

Precipitation is another important factor that determines the availability of water to plants. Wheat needs sufficient water throughout the growing season, although the requirements vary depending on the stage of development. Optimal rainfall for wheat is typically 350-1250 mm: total rainfall during the crop cycle, depending on the type of soil and climatic conditions in the region (Sys *et al.*, 1991). Insufficient precipitation can lead to drought, which causes the soil to dry out and reduces the availability of water to the root system. This, in turn, significantly reduces yields and can make land unsuitable for cultivation. On the other hand, too much rainfall can be just as damaging as too little.

Excessive moisture can cause waterlogging, increase the risk of diseases such as root rot, and even lead to floods that destroy crops.

These two climate factors do not act separately but interact with each other. For instance, in regions with high temperatures, the need for water increases significantly, and if there is insufficient rainfall, the soil can dry out quickly, which worsens conditions for wheat. In colder regions, where evaporation is less, the same precipitation may be sufficient to maintain an optimal water balance. Therefore, the analysis of these factors should address their interaction and seasonal fluctuations. The results confirm that average temperature and precipitation levels have a significant impact on land suitability. For instance, areas where the average temperature exceeds 25°C or where rainfall is less than 600 mm had lower suitability scores.

Analysis of the physical characteristics of the soil. The assessment of the physical characteristics of the soil included parameters such as depth, texture, drainage, overall water availability and coarse particle levels. The weighting factors are shown in Tables 3 and 4.

Table 3. *The weight of physical characteristics of soil*

Criterion	AHP value	Percentage
Texture	0.37	37%
Soil depth (cm)	0.247	24.7%
Drainage	0.189	18.9%
Coarse particle content	0.122	12.1%
Water availability (mm/m)	0.073	7.3%

Source: *compiled by the authors*

Table 4. *PWCM for physical criteria*

Texture	Soil depth	Drainage	Coarse particle content	Water availability	Weights (%)
1	2	2	3	4	37
1/2	1	2	2	3	24.7
1/2	1/2	1	2	3	18.9
1/3	1/2	1/2	1	2	12.1
1/4	1/3	1/3	1/2	1	7.3
		Cosistency ratio=2%			∑=100

Source: *compiled by the authors*

The physical characteristics of the soil, such as soil depth, texture, drainage, water availability and coarse particle content, are crucial in determining the suitability of land for wheat production. Each of these factors is substantial in providing favourable conditions for crop growth, affecting water balance, aeration, erosion resistance and other important aspects. The depth of the soil determines the amount of space for the development of the root system and moisture reserves. Soils with a depth of more than 100 cm are the best for growing wheat, as they provide sufficient water and nutrients to promote sustainable plant growth. The weight of this criterion is 24.7% which indicates its significant impact on the overall suitability of land. Deep soils also have an advantage in terms of drought tolerance, while shallow soils with a depth of less than 50 cm are often unsuitable for cultivation because they cannot retain enough moisture.

Texture determines water permeability, aeration and nutrient retention. Loamy, clay loam and silty loam soils are the most favourable for wheat due to their ability to hold water well and provide good aeration. Sandy soils have the worst suitability due to their low water-holding capacity. The weight of this criterion is 37%, making texture the most important factor in this assessment. Research shows that loamy soils promote uniform plant development and yields, while excessively sandy or heavy clay soils create difficulties for the root system. Drainage determines how quickly the soil can remove excess water. Poor drainage can lead to waterlogging, which is harmful to wheat, while too much water can be removed too quickly, causing moisture deficits. A balance in drainage characteristics is key to maintaining optimal moisture. Wheat requires soils with moderate drainage, where water is retained long enough to moisten, but not so long as to cause root rot.

The next indicator determines the amount of moisture that the soil can hold for plant use. High water availability ensures long-term moisture in the root zone, which contributes to healthy plant development and reduces dependence on precipitation. Under conditions of moisture deficit, wheat yields decline sharply, therefore this factor is substantial in the selection of suitable land. The content of coarse particles in the soil determines how well the soil can retain structure and store moisture. A high content of coarse particles such as gravel can reduce the soil's ability to hold water and nutrients, making it less suitable for wheat production. The results of the study show that areas with optimal soil depth, good drainage and water availability have significant advantages for growing grain crops. On the other hand, a high level of coarse particles reduces the suitability score.

Assessment of chemical and biological characteristics of the soil. The analysis of the chemical and biological characteristics of the soil included an assessment of parameters such as soil fertility, EC, ESP and CEC. Tables 5 and 6 shows the weighting factors and the corresponding suitability indicators.

***Table 5**. The weight of bio-chemical characteristics of soil*

Criterion	AHP value	Percentage
Fertility class	0.5	50%
CEC	0.25	25%
ESP	0.125	12.5%
EC	0.125	12.5%

***Source:** compiled by the authors*

***Table 6**. PWCM for bio-chemical criteria*

Soil fertility classes	CEC	EC	ESP	Weights (%)
1	2	4	4	50
1/2	1	2	2	25
1/4	1/2	1	1	12.5
1/4	1/2	1	1	12.5
		Cosistency ratio = 1%		∑=100

***Source:** compiled by the authors*

The chemical and biological characteristics of the soil have a decisive influence on its fertility and suitability for wheat production. The correct balance of these indicators provides optimal conditions for the development of the root system, nutrient absorption and overall plant growth. The pH value of the soil is one of the most important chemical parameters that affect the availability of nutrients to plants. Wheat grows best in slightly acidic or neutral soil with a pH of 6.5 to 8. At this pH value, nutrients such as nitrogen, phosphorus and potassium are most readily available to the plant root system. If the pH drops below 6.5, the soil becomes too acidic, which can lead to toxicity for plants due to excessive accumulation of metals such as aluminium and iron. Under alkaline conditions (pH greater than 8), the solubility of nutrients such as phosphorus decreases, limiting their availability to plants.

Organic matter plays an important role in improving soil structure, retaining moisture and providing nutrients to the soil. High organic content promotes the development of beneficial microflora, which helps to break down organic compounds and convert them into forms available to plants. Soils with an organic matter content of more than 1.5% are very fertile, providing optimal conditions for wheat cultivation. Reducing the organic content to less than 1% can negatively affect the water-holding capacity of the soil, reduce its aeration and lead to a decrease in fertility. CEC measures the ability of soil to hold cations such as calcium, magnesium, potassium and sodium, which are essential for plant nutrition. A high CEC indicates that the soil can hold more nutrients and supply plants during the growing season. For wheat cultivation, a CEC level of more than 24 resin (+)/kg clay is desirable. This indicates a high content of nutrients, which contributes to good plant growth. A low CEC level (less than 5 resin(+)/kg) means that the soil is not able to retain enough cations, which leads to rapid leaching of nutrients and a decrease in yield.

Soil EC is an indicator of the concentration of dissolved salts. A high EC level may indicate salinity, which harms wheat growth, as excess salts in the soil can cause osmotic stress in plants, reducing their ability to absorb water. The ideal level of EC for wheat is low to moderate, which ensures normal conditions for plant growth without the risk of salinity. If the EC increases, measures to improve soil quality, such as salt washing or gypsum application, are necessary. The chemical and biological properties of soil are interrelated and together determine its fertility. For instance, organic matter can influence pH and CEC levels, increasing the soil's ability to retain nutrients. At the same time, maintaining a healthy soil microflora helps to decompose organic matter and enrich the soil with nutrients. Assessment of these characteristics is critical for making decisions about land use in agriculture.

Flood and erosion risk assessment. Flood and erosion risk was assessed based on site slope, aspect and flood frequency. Tables 7 and 8 shows the weighting coefficients for each parameter and the suitability indicators under optimal conditions.

The assessment and weighting of slope are a critical indicator as it directly affects soil erosion and moisture loss. Land with a slope of less than 4% is suitable for agricultural use, as it has a minimal risk of erosion and retains moisture better. As the slope increases to 8-16%, the risk of erosion increases, which reduces soil productivity. The weighting value for slope is 22%, emphasising its importance in the overall analysis. When the slope exceeds 16%, soils become almost unsuitable for wheat cultivation, as the rapid washing away of the top fertile layer significantly limits plant growth. Flood risk and erosion are among the most important factors affecting the suitability of land for agricultural use. These natural phenomena can cause severe crop losses, and soil degradation and adversely affect land fertility. Floods are caused by excessive rainfall, overflowing rivers, or rising groundwater levels, and can lead to significant damage to agricultural land. Wheat is a crop that is sensitive to stagnant water, and prolonged flooding can cause root rot and plant death. Flood risk assessment includes an analysis of the frequency and intensity of precipitation, proximity to water sources such as rivers, and topographical characteristics that may affect water accumulation.

***Table 7**. Flood and erosion risk weights and land suitability*

Criterion	AHP value	Percentage
Slope (%)	0.372	37.2%
Erosion risk	0.292	29.2%
Flood frequency	0.246	24.6%
Terrain aspect	0.09	9%

***Source:** compiled by the authors*

***Table 8**. PWCM for flood and erosion risk criteria*

Slope	Erosion risk	Flood frequency	Terrain aspect (slope direction)	Weights (%)
1	1	2	4	37.2
1	1	1	3	29.2
1/2	1	1	3	24.6
1/4	1/3	1/3	1	9
		Cosistency ratio = 2%		∑=100

***Source:** compiled by the authors*

To assess flood risk, it is necessary to address factors such as historical data on the frequency and extent of flooding, as well as the geographical location of the land plot in relation to water bodies. For instance, land located in low-lying areas or in proximity to rivers has a significantly higher risk of flooding. This analysis uses flood frequency data to rank land parcels by risk level, from low (where flood risk is minimal) to high (where there is a significant likelihood of flooding). Floods can not only destroy crops but also wash away fertile topsoil, reducing its fertility in the long term. Flooding also causes nutrient leaching and increases the risk of plant diseases, making it essential to consider flood risk when planning agricultural operations. In regions with a high risk of flooding, agronomists can decide to select alternative crops that can better tolerate excess moisture or plan drainage systems to protect crops.

Soil erosion is the process of losing the top, most fertile layer of soil due to water or wind (Yermakov *et al.,* 2021). Water erosion is particularly dangerous on agricultural land where the natural vegetation has been removed for crops. Assessing the risk of soil erosion involves analysing the slope, rainfall intensity, soil structure and vegetation type. Lands with steep slopes or loose soils that lack sufficient vegetation cover are particularly vulnerable to erosion. The slope of the surface is one of the most important factors in erosion. The steeper the slope, the higher the likelihood that the water flowing downhill will wash away the topsoil. In regions with frequent and intense rainfall, the risk of erosion increases even more. The lack of vegetation also contributes to erosion, as plants not only protect the soil from the impact of raindrops but also help to anchor the soil with their roots.

Erosion leads to the loss of the fertile soil layer that contains the most nutrients and organic matter. This reduces land productivity and requires additional measures to improve soil conditions, such as fertilisation or erosion control. To reduce the risk of flooding and erosion on agricultural land, various management methods are used. These can include planting forest belts, terracing slopes, using cover crops and creating drainage systems. It is also necessary to monitor weather conditions and forecasts to minimise potential damage to crops. Planning land use with flood and erosion risk in mind helps to protect soils from degradation and preserve their fertility for future generations. The results indicate that areas with a slope of less than 10% and low flood levels are more suitable for growing grain crops. The slope has a particularly significant impact, as it significantly affects the risk of erosion.

Assessment of accessibility to water sources and routes. The accessibility of land plots, namely their distance from water sources and roads, is an important factor in assessing the suitability of land for agricultural use. This criterion has a significant impact on the efficiency of land use, as proximity to key infrastructure elements is directly related to logistical costs and ease of resource management. Accessibility was considered one of the important components of the analysis, as it facilitates the process of land cultivation, transportation of products, and provision of water, which is critical for growing grain crops. Sites located closer to water sources received higher scores for suitability. Water is one of the key elements for sustainable crop growth, and proximity to natural water sources or artificial irrigation systems reduces irrigation costs. Land that requires high costs for water delivery may be less suitable for intensive agricultural use, as this significantly affects its profitability. The distance to water sources also determines the possibility of prompt water supply during periods of drought, which ensures more stable yields and reduces the risks associated with moisture shortages. Thus, proximity to water sources contributes to the suitability of land for agricultural use, especially for crops that require regular irrigation, such as grain.

The availability of transport infrastructure, namely proximity to roads, is an equally important criterion for determining land suitability. Land located closer to roads receives higher scores because convenient access to transport routes reduces the logistical costs of delivering agricultural products to markets or storage facilities. Transportation is an important component of profitability, and distance from roads can significantly increase costs and delivery times, which is especially important for perishable products (Bulgakov *et al.*, 2019). In the context of cereals, which require significant volumes of transport after harvest, good transport links are a crucial factor for optimal land use. Thus, plots located close to roads are more attractive in terms of suitability, as they facilitate access to necessary services and resources.

In general, the accessibility criterion addresses key aspects that affect the profitability and convenience of land cultivation. Proximity to water sources reduces irrigation costs and ensures a stable water supply, which is important for agricultural production, especially in regions with changing climatic conditions (Yeraliyeva *et al.*, 2017). Proximity to roads reduces the cost of transporting products, making land more attractive for agricultural investment. Application of the AHP method to assess the suitability of land for agriculture in Albania and Ukraine. The application of the AHP method to assess the suitability of land for agriculture is of particular importance for countries such as Albania and Ukraine. Both countries have large agricultural areas, but face unique challenges, making the AHP method particularly valuable for comprehensive land valuation.

Albania due to its mountainous landscape, should efficiently use domestic resources (Shahini, 2024). For this country, every available plot, especially in the face of growing demand for food and the increased threat of environmental degradation, should be employed with maximum efficiency. The AHP method can be used to thoroughly assess various factors such as soil texture, depth, climatic conditions, access to water resources and flood risk. This allows for science-based decisions on land management and contributes to sustainable agricultural development, which is a priority for Albania. In addition, AHP is affordable and can be effectively integrated with GIS tools, enabling spatial analysis that addresses the geographical complexity of the country.

As one of the largest agricultural countries in Europe with fertile soils and a large volume of agricultural exports, effective land management is critical to the economy. However, due to the diversity of climatic zones and significant variations in soil quality across different regions, there is a need for methods that allow for a comprehensive assessment of land suitability. The AHP method accounts for both agroecological factors, such as soil moisture, acidity and temperature, as well as socio-economic aspects, such as access to infrastructure and logistics, which are important in the context of Ukraine's large territory. For crops such as cereals, which are strategically important for Ukraine, AHP can help identify the most productive areas and optimise resource allocation. The AHP method provides a structure for complex decisions by combining different criteria and allowing for the optimal use of land. This is especially relevant in the context of climate change and the threat of soil degradation. For both countries, the application of AHP can be the basis for developing effective agricultural policies aimed at increasing productivity with minimal environmental impact.

DISCUSSION

The study, based on the AHP, confirmed the importance of a comprehensive approach to soil assessment, which includes a detailed analysis of physical, chemical, biological and climatic characteristics. This approach was used to more accurately determine soil quality, fertility and ability to support different types of vegetation. Physical characteristics such as soil texture and structure affect water-holding capacity, while chemical properties, including pH and nutrient content, determine the ability of plants to grow. Biological characteristics, such as microbial activity, play a key role in the decomposition of organic materials and the supply of essential elements to the soil (Drobitko & Kachanova, 2023). Finally, climatic conditions, such as temperature and humidity, also have a significant impact on all other aspects, shaping the overall soil ecosystem. An integrated approach that addresses all these factors is therefore essential for effective land management and sustainable agricultural development.

Various studies have used AHP methods to assess land suitability in different agricultural and environmental conditions, confirming the effectiveness of these methods in multicriteria analysis. A study by A. Ezra *et al.* (2023) in Nigeria employed AHP to create maps of suitability for growing certain cereals, addressing climate and soil characteristics. This study emphasised the importance of spatial analysis for effective management of agricultural areas. C. Singha *et al.* (2023) in West Bengal employed the Fuzzy AHP method to determine the suitability of land for rice and potato cultivation. The focus was on climatic indicators, such as rainfall, which proved to be an important factor in ensuring optimal conditions for crops. These conclusions were consistent with the results of studies where climate factors also played an important role in determining land suitability.

In Turkey, B. Sarğın and S. Karaca (2023) conducted a study to assess the suitability of land for wheat and barley in semi-arid conditions. In that study, drainage and soil physical characteristics were considered as the main criteria affecting productivity, which was slightly different from the focus of this study. Shaloo *et al.* (2022) employed the AHP method and geospatial techniques to analyse the suitability of land for cereals in North India. The study showed that factors such as climatic conditions, soil physical characteristics, and access to water resources have a decisive impact on crop productivity. The results highlighted the importance of multi-criteria analysis in land valuation to accurately identify the most productive areas, which is similar to the approach used in this study to the integrated land valuation for agriculture.

In Nigeria, M. Ahmed and D. Jeb (2014) conducted a study that also used the AHP method to assess the suitability of land for sorghum cultivation. This study demonstrated that the key factors affecting productivity include topography, climate conditions and access to water. The study demonstrates the similarity in the importance of multi-criteria methods for justifying agricultural decisions in different regions, in particular in conditions that require accurate analysis of water availability for crops. A study by D. Debalke *et al.* (2023) in Ethiopia addressed physical soil properties, such as depth and texture, to assess the suitability of land for crop production in a rainfed area. This study showed that these factors had a significant impact on productivity, especially for crops that depend on a stable water supply.

A study by F. Garbaba and B. Wolteji (2024) in the Guder sub-basin, Northwest Oromia, Ethiopia, also used geospatial technologies to assess the suitability of land for wheat and maize cultivation. The researchers studied how the combination of physical soil characteristics and climatic conditions can affect the efficiency of crop production. The results confirmed that GIS in combination with multi-criteria analysis (as in this study) provide accurate data to determine the optimal areas for agriculture. This makes it possible to assess the potential of land at the regional level, considering the specific climatic and soil conditions of each site. The study confirms the importance of adapting methodologies such as AHP and GIS for agricultural regions with different climatic conditions.

In China, L. Xue *et al.* (2023) assessed the suitability of land for integrated rice culture using AHP and GIS for detailed spatial analysis. The study showed that the AHP method was used to more accurately determine the optimal conditions for crops in specific climatic zones. Thus, the results of the study confirmed the importance of multi-criteria methods for analysing the suitability of land for different crops in different climatic and geographical conditions. H. Abbasi and M. Zeeshan (2023) also used an integrated GIS and AHP approach to determine the suitability of sites for hybrid solar-biomass power plants. Although the scope is energy-related, the approach is consistent with the methodology used in this study of land suitability for crops. The study addressed a multi-criteria analysis that included environmental and infrastructural factors such as resource availability, which is similar to the analysis of accessibility to water sources and transport routes for determining the productivity of agricultural areas. Thus, the study showed the versatility of AHP and GIS that can be adapted to different sectors to assess the suitability of land, whether for agricultural purposes or energy projects.

According to a study by A. Wubalem (2023), using AHP to model land suitability in the semi-arid regions of Ethiopia, demonstrated that the method effectively assesses topographic and soil features. The study emphasised the importance of surface slope and soil structure for irrigated agriculture, which is consistent with the findings of this study on the importance of topographic characteristics for soil fertility and efficient drainage. F. Sadiq *et al.* (2023) assessed the suitability of land for soybean production in Nigeria using a multi-criteria GIS-based approach. Parameters such as soil quality and climatic conditions are significant in their modelling. This confirms the importance of climate factors, which were also included in this study. The values of average air temperature and total precipitation as the main climatic parameters were justified because they determine the moisture supply of the soil and affect the wheat development cycle.

Notably, M. Günal *et al.* (2022) also applied AHP in the semi-arid region of Central Anatolia to assess the suitability of land for wheat production. They found that soil texture, pH, and slope were the key parameters that determined land productivity. This is in line with the findings of this study, where soil texture was given the highest weight among physical factors (27%) and slope (22%) was also found to be highly relevant. Soil pH was also emphasised in this study as one of the most important chemical factors affecting plant nutrient availability. A. Pilevar *et al.* (2020) used the integration of fuzzy logic, AHP and GIS to assess land in semi-arid regions for wheat and maize production. This study confirmed that a combination of different analytical methods can address the complex relationships between climate and soil characteristics. The consideration of complex environmental conditions and the use of a multi-criteria approach ensured accuracy in determining land productivity, which is consistent with the findings of this study that multiple assessment methods should be integrated to increase the reliability of results.

M. Tadesse and A. Negese (2020) used GIS and AHP to assess land in the Agamsa sub-basin of Ethiopia and found that slope and soil texture were key factors for sorghum production. This highlights the importance of topography and soil texture, which were also demonstrated in this study to be significant factors for wheat production. The similarity in the results indicates the universality of these factors in the agriculture of different crops. A. Al-Hanbali *et al*. (2022) studied the suitability of land for rice cultivation in Tanzania, with a focus on the use of GIS and AHP to address topographic and soil characteristics. The approach, which included an analysis of topography and soil structure, is consistent with the findings of this study, which also highlighted the importance of slope as a factor affecting erosion and water conservation.

S. Han *et al*. (2021) addressed climate change and its impact on land suitability in Jilin Province, China, using remote sensing techniques combined with AHP. The research highlighted the importance of climate change adaptation, which is a critical aspect of this study. The study confirmed that climate change can affect the long-term productivity of land and that considering seasonal fluctuations in temperature and precipitation is important to ensure sustainable agricultural production. V. Ramamurthy *et al*. (2020) focused on assessing land suitability for maize in the semi-arid conditions of South India using an integrated GIS and AHP approach. The authors concluded that such an approach allows for more accurate identification of productive land plots, which coincides with the results of this study on the benefits of multi-criteria land assessment.

K. Naima *et al*. (2022) developed a comprehensive model of land suitability for cereal production in the remote Sahara region of Algeria, considering the specific extreme climatic conditions that characterise this arid region, as well as the problems associated with soil salinity. The study highlighted the importance of soil chemistry, in particular parameters such as pH and CEC, which correlates with the findings of this study on the critical importance of soil chemistry for the successful cultivation of wheat and other cereals. The impact of soil salinity was also considered in detail as a potentially limiting factor for agronomic productivity in some parts of this project. This highlighted the need to address not only the physical but also the chemical characteristics of the soil when planning agricultural activities in regions with similar environmental conditions. B. Kalaiselvi *et al*. (2024) highlighted the importance of sustainable agricultural production in semi-arid regions of India, using GIS and AHP to promote crop diversification. The authors determined that the introduction of modern technology can improve the efficiency of land planning and management, which is consistent with the recommendations of this study on the use of remote sensing and GIS for monitoring and planning.

Lastly, a study conducted by G. Tesfaye *et al*. (2024), focuses on mixed cereal and legume cultivation in Ethiopia, which is a relevant aspect of modern agriculture. The authors emphasise the importance of a balanced approach to the use of natural resources, which can have a significant impact on the sustainability of agricultural systems. Their findings, which emphasise the need to address the interactions between different crops, point to the importance of integrating agronomic practices to improve overall production efficiency. This is also of great importance in the context of land suitability assessments, as optimising the use of resources can not only increase yields but also help to maintain ecological balance in the region. Thus, the study highlights the importance of integrating physical, chemical and climatic factors for a comprehensive land use assessment, which is consistent with the results of many previous studies. Further research could focus on modelling climate change scenarios and improving land management practices to enhance adaptive strategies for food security.

CONCLUSIONS

This study applied the AHP before assessing the suitability of land for cereal production using wheat as an example. This approach made it possible to accurately determine the impact of various physical, chemical, biological and climatic factors on the potential yield of land. As a result, clear qualitative and quantitative indicators were obtained that were used to rank land plots according to their suitability. The analysis highlighted the critical factors influencing land suitability for grain crop production, emphasising the dominant role of soil and environmental characteristics. Flood and erosion hazard, with a weight of 32.2%, emerged as the most significant factor, reflecting its substantial impact on soil stability and long-term agricultural viability. Soil physical characteristics ranked second with a weight of 25.6%, underscoring the importance of texture, depth, and slope in water retention, aeration, and root development. Soil biological and chemical characteristics, with a weight of 22.3%, were ranked third, demonstrating the crucial influence of soil fertility parameters such as pH, organic matter, and CEC on nutrient availability and plant growth. Climate, accounting for 14.1%, was identified as the fourth most influential criterion, as precipitation and climatic conditions play an essential but less critical role compared to soil-related factors. Accessibility, with a weight of 5.8%, was the least significant factor, as logistical and infrastructural considerations are secondary to the biophysical attributes of the land. The consistency ratio of 4% validated the reliability of these weightings, ensuring a robust and systematic evaluation of land suitability for grain crop production. Climatic factors, including average temperature and total precipitation, determine the main conditions for wheat growth. The optimum temperature range (15-25°C) and adequate rainfall (350-1250 mm per year) provide the best conditions for the development of the crop. At the same time, the risk of flooding and erosion affects the long-term suitability of land, as excess water and soil loss can cause substantial agronomic issues.

The AHP method is relevant for agricultural countries such as Albania and Ukraine, as it can be used to efficiently assess and plan land use, accounting for specific soil and climatic conditions. In Albania AHP can bey used to optimise ground use, accounting for food growth demand and environmental risks. In Ukraine, which is a major exporter of agricultural products, AHP can be used to assess both natural and infrastructural factors that are critical for productive and sustainable agriculture. In this way, AHP contributes to the development of agricultural policies that increase productivity and minimise environmental impacts, ensuring the rational and sustainable use of land resources in both countries.

Practical recommendations include the use of appropriate agronomic measures to reduce the risk of erosion, such as terracing on slopes and the use of cover crops. In regions with a high risk of flooding, drainage systems and protective plantings are recommended. To improve fertility, organic fertilisers can be used to increase CEC levels and improve soil structure. Key areas for further research include a deeper analysis of the impact of seasonal climate change on wheat yields and modelling of climate change scenarios to assess long-term risks to farmland. In addition, consideration should be given to integrating modern technologies, such as remote sensing and GIS, to better map land and monitor its suitability.

The limitations of the study include the dependence of the results on the accuracy of the data used for the analysis and the limitations of the AHP method, which may require additional verification in real-world conditions. Moreover, the impact of seasonal and long-term climate change has been partially considered, which may affect the conclusions on land suitability. Further research should address the impact of seasonal climate change and the use of modern technology to more accurately assess land resources.

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CONFLICT OF INTEREST

None.

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Застосування аналітичного ієрархічного процесу в оцінці придатності земель для вирощування зернових культур

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Анотація. Оцінка придатності земель для вирощування зернових культур є актуальним питанням для забезпечення сталого сільськогосподарського виробництва та підвищення продовольчої безпеки. Метод аналізу ієрархій (МАІ) є ефективним методом багатокритеріальної оцінки, який систематично враховує всі параметри. Метою дослідження був аналіз використання методу аналізу ієрархій для визначення вагомості та пріоритетності різних ґрунтово-кліматичних характеристик для аналізу придатності земель для вирощування зернових культур на прикладі пшениці. В результаті дослідження було визначено ключові фактори, що впливають на врожайність, та розроблено рекомендації щодо ефективного управління земельними ресурсами. Для зважування різних критеріїв, включаючи фізичні, хімічні та кліматичні характеристики, було використано метод аналізу ієрархій. Дані були оброблені для визначення впливу кожного фактору на придатність землі з перевіркою на узгодженість для забезпечення надійності результатів. Дослідження показало, що найбільш важливими фізичними факторами є характеристики небезпеки повеней та ерозії (32,2 %) та фізичні характеристики ґрунту (25,6 %). Кислотність (pH) та ємність катіонного обміну (ЄКО) мають значний вплив на доступність поживних речовин, тоді як середня температура та кількість опадів визначають основні кліматичні умови для росту пшениці. Ризики повеней та ерозії також розглядаються для довгострокової оцінки придатності. Для оцінки придатності земель для вирощування пшениці було використано метод аналізу ієрархій, що дозволило визначити найважливіші фактори та їхню вагу. Практичні рекомендації включали застосування агротехнічних заходів для зменшення ерозійних ризиків та покращення родючості ґрунтів. Результати дослідження можуть бути використані агрономами, землевпорядниками та політиками для вдосконалення управління земельними ресурсами, що сприятиме підвищенню ефективності сільськогосподарського виробництва та продовольчої безпеки в умовах зміни клімату

Ключові слова: критерії оцінки; родючість ґрунтів; ерозійний ризик; кліматичні фактори; управління земельними ресурсами; агротехнічні заходи