

Article

GIS-Based Agricultural Land Use Favorability Assessment in the Context of Climate Change: A Case Study of the Apuseni Mountains

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Abstract: With an emphasis on the effects of climate change, this study offers a thorough GIS-based assessment of land use favorability in the Apuseni Mountains. The Apuseni Mountains, a region characterized by its biodiversity and complex terrain, are increasingly vulnerable to the impacts of climate change, which threaten both natural ecosystems and human activities. The territory of 11 territorial administrative units was selected for the investigation because it shows more of an anthropogenic influence due to the migration of people to mountainous areas following the COVID-19 pandemic, which increased the amount of anthropogenic pressure in this area. Factors that describe the climate of the study area, the soil characteristics, and the morphometric characteristics of the relief were used to create a classification for the present on classes of favorability and restrictiveness for the plots of land, using a quantitative GIS model to determine the favorability of the land for the main crops and agricultural uses. The current land favorability was thus initially obtained, taking into account current temperature and precipitation values and using the SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios for the 2020–2099 time frame. The results indicate a variation in the statistical classification of the land for different favorability classes, a decrease of 4.7% for the high favorability class for pastures, an estimated decrease of 4.4% for grassland, and in the case of orchards, the situation reflects a fluctuating variation. There is a decrease of 6.4% in the case of the very low favorability class according to SSP2-4.5 (in the case of reaching an average temperature of 12.7 °C and an annual precipitation of 895 mm), and in case of high and very high favorability, there is an increase in plots falling into better high favorability classes of up to 0.7%.

Keywords: GIS spatial analysis; comparative assessment; agricultural land use; soil favorability; climate change



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1. Introduction

Land use classes are closely connected with both local and regional climatic conditions, demonstrating the delicate interaction between natural components of the environment and human activity [1–3]. Climate variables such as temperature, precipitation, and seasonal patterns have a significant impact on the distribution and features of various land uses [4–6], including agricultural areas [7–10], forests [11,12], urban spaces, and water

bodies [13–15]. Climatic considerations play a crucial role in determining the suitability of specific regions for different land uses, impacting the growth of crops, the density of forests, and the availability of water supplies [16,17]. Nevertheless, the influence of climate on land utilization is not fixed; it transforms in response to evolving climatic conditions, such as those caused by global climate change [18–20]. Consequently, changes in temperature, patterns of precipitation, and occurrences of extreme weather events are anticipated to modify the way land is used, requiring the implementation of adaptive management measures [21,22].

Research conducted at a global or detailed level has highlighted the impacts of global warming such as the decline in biodiversity, an increased susceptibility to wildfires, and structural changes in ecosystems; excessive heat can harm crops by diminishing photosynthesis [23–25], influencing the growth of fruits [26], or inducing heat-related illnesses [27,28], resulting in decreased yields [29]. Certain crops can experience accelerated maturation [30], resulting in encounter delays that disturb the timing of planting and harvesting [31,32].

Global warming causes a rise in mean global temperatures, which can disturb ecosystems [33,34], modify habitats [35], and endanger biodiversity as compared to other scenarios [36]. Global warming perturbs natural weather patterns, resulting in heightened storm intensity [37], extended periods of drought, and irregular precipitation patterns [38–42], therefore impacting agriculture and available water resources [43]. Increasing temperatures and arid conditions amplify the occurrence and intensity of wildfires [44], causing destruction to forests [45–47], emitting carbon, and endangering both animals and human communities [48]. Numerous species exhibit insufficient adaptability to changing climates [49,50], resulting in a decline in biodiversity, therefore undermining ecosystems and diminishing their ability to withstand future environmental pressures [51,52]. Species are migrating to new regions in response to temperature changes, which can cause ecosystem imbalances and lead to the extinction of less adaptable species [53,54].

Beyond climate, anthropogenic activities also have a significant impact. Human activities, such as agriculture, urbanization, deforestation, and industrial growth, position considerable pressure on land resources [55]. The need for natural resources, such as wood, minerals, and fertile land, motivates alterations in land use, frequently resulting in the transformation of natural environments into agricultural or urban zones. Hence, the impact of human activities on land utilization is projected to increase in the coming years, propelled by the escalating demand for natural resources, the expansion of urban areas, and rising population growth [56].

GIS-based models allow for the assessment of land suitability for different purposes by combining diverse environmental, socio-economic, and climatic aspects [57–59]. GIS-based assessments play an important role in determining the most suitable places for agriculture, forestry, and conservation in the context of climate change [60,61]. This technique allows the identification of land that indicates resilience to climatic impacts and supports the achievement of sustainable development initiatives [62,63].

This study focuses on a Geographic Information System (GIS)-based assessment of the suitability of land use in the Apuseni Mountains (specifically the Somesul Mic watershed), taking into account the changing limitations caused by climate change. This project aims to assess the suitability of diverse land parcels for different uses (pasture, grassland, orchards). Its objective is to provide a rational framework that can assist land use planning and policy-making in the region. By including climate scenarios in the GIS-based assessment, it becomes possible to conduct a proactive study that confirms land use decisions are not only successful in the present, but also capable of coping with future climatic changes [64,65].

This study addresses two main research directions. The primary objective is to implement a GIS model to assess the suitability of the land in the research region for use as grassland, pasture, and orchards. This model utilizes a geodatabase that includes characteristics such as topography, soil type, climate variables, and water supplies, providing a precise evaluation of potential sites for different uses.

The second research direction is centered around analyzing the favorability classes of different land uses in the present day. The validation of the GIS model is achieved through a comparison with land parcels that are used according with the classification provided by the model. Furthermore, this study investigates modifications in favorability categories within the context of climate change, using a statistical analysis of the effects of the expected changes in average annual temperature and precipitation fluctuations for the time frame of 2020–2100.

A GIS land favorability assessment is based on a careful analysis of the environmental variables present in the research area. These conditions include factors like slope, altitude, temperature, and precipitation [66], as well as soil qualities such as texture, pH, gleiss, and useful edaphic volume [67].

The investigation of climate change in agriculture from an economic perspective is essential, as agriculture serves as the fundamental support system for many economies, especially in underdeveloped areas [68]. A decrease in crop production can result in an escalation in food costs, heightened volatility in the market, and inflation [69]. Inclement weather conditions such as droughts, heatwaves, and floods inflict direct harm upon crops and livestock, leading to substantial economic losses for farmers, governments, and the insurance industry [70]. A better understanding of climate-related risks allows for more accurate cost assessments and informed decision-making. If left unchecked, the cumulative effects of climate change on agriculture could lead to long-term economic decline, particularly in economies heavily dependent on agriculture [71]. This is why we consider a study such as this one useful, because it will provide a concrete picture of current agricultural suitability and model how this suitability will change in the future under climate change.

2. Methodology and Database

2.1. Study Area

The watershed chosen as the study area has a surface area of 1183.23 km² and is located in the North-West Region of Romania, mostly in Cluj County (Figure 1). The upper Someș Mic watershed is located in the south-western part of Cluj County. From an administrative perspective, the study area comprises a series of 11 administrative territorial units (Beliș, Budureasa, Căpușu Mare, Florești, Gilău, Măguri-Răcățau, Mănăstireni, Mărgău, Mărișel, Rișca, and Săvădisla). The study area has a range of altitudes, with the lowest point being 360 m and the highest point being 1700 m. Within this range, there are different categories of hills and mountains. The area of low and medium hills, with altitudes between 360 and 500 m, covers 109.82 km²; the category of high hills, with altitudes between 501 and 750 m, covers 245.55 km²; the category of very high hills, with altitudes between 751 and 1000 m, covers 185.27 km²; and the category of low-altitude mountains, with altitudes between 1001 and 1500 m, covers 592.51 km². The remaining 50.06 km² falls within the category of medium-altitude mountains, with altitudes between 1501 and 1700 m.

The study area is characterized by steep slopes, with slope values between 11.25° and 22.5°, representing 35% of the entire area. The remainder of the study area is covered by moderately sloping slopes with values between 4.5° and 11.25°, representing 25%. Very steep slopes and horizontal slopes each account for 18% of the area. With the smallest percentages of 1% and 3%, respectively, are very gently sloping slopes, gently sloping slopes, and steep slopes.

As to mean annual temperatures, in the study area they vary between 1.6 °C and 9 °C. Temperatures below 6 °C are considered moderate, while temperatures above 6 °C are considered high and are suitable for agricultural practices in Romania. The multiannual mean precipitation within the study area ranges from 688 mm/yr to 1300 mm/yr. This value, which is considered average, is due to differences in elevation ranging from low and medium hills (360–500 m) to medium-elevation mountains (1501–2000 m). For the largest extent of the study area, the mean annual precipitation ranges from 1000.1 mm/yr

to 1200 mm/yr, an area represented by low-altitude mountains. Therefore, the study area has a good water supply over most of the territory.

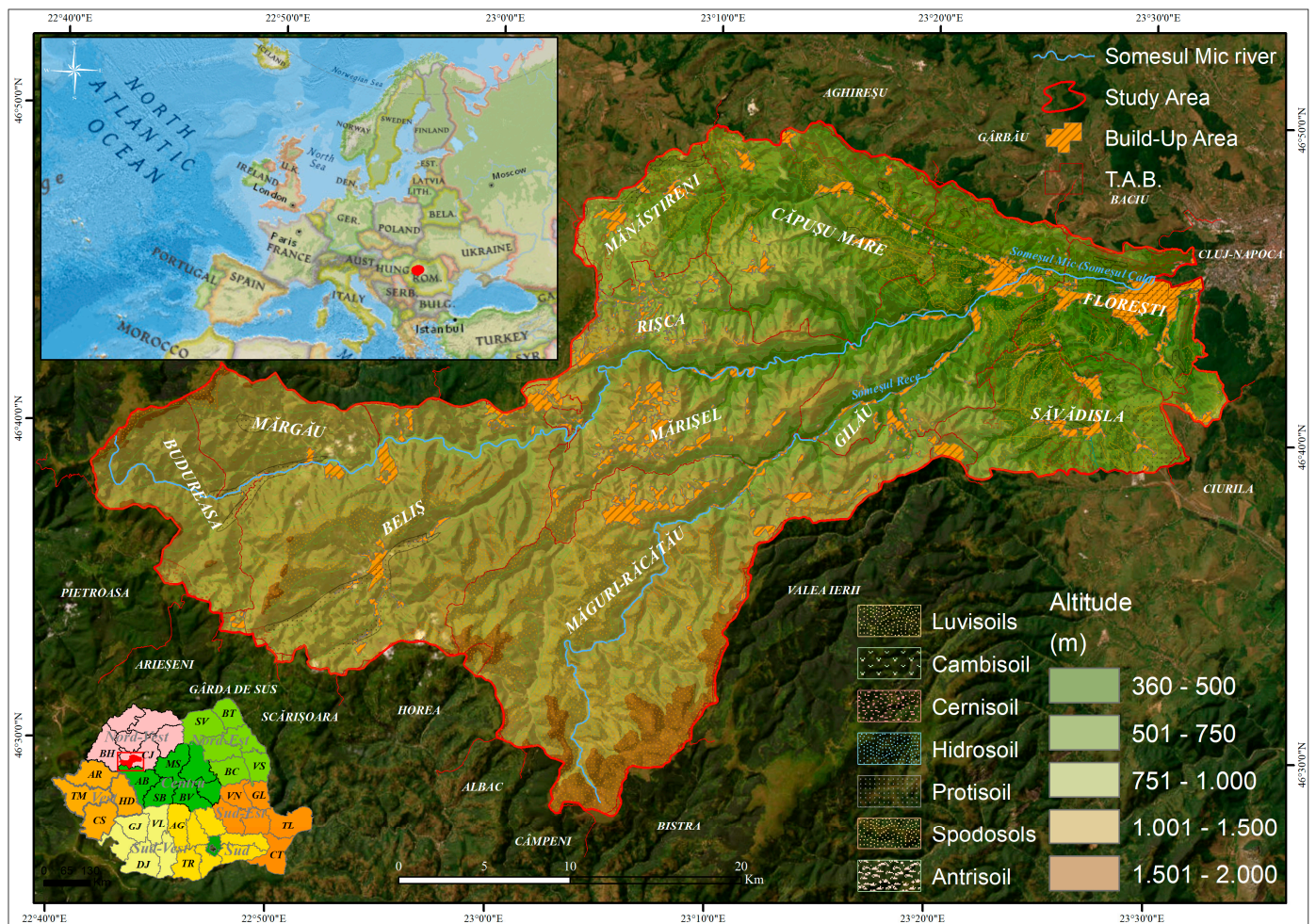


Figure 1. Geographical position of the study area.

The study area is covered by a total of 18 soil types, categorized into 8 soil classes, each of which has different properties. From a pedological point of view, the analyzed territory presents soils of the Cambisols class on the largest area (722 km², representing a percentage of 61% of the analyzed area) and soils of the Spodosols class on an area of 204 km², representing 17%, and Clay-visols cover 114 km² of the studied area (10%). The Antrisol class represents 5%, occupying 59 km². The Cernisols class occupies 4% (43 km²), and the additional class (Waters) 3% covers 38 km², with the remaining area containing soils belonging to the Vertisols and Hidrisols classes.

In the study area, forest vegetation occupies the largest portion, covering 62.64% of the total land. This forest is primarily a mix of coniferous and deciduous species, including *Abies alba*, *Pinus sylvestris*, *Carpinus betulus*, *Populus alba*, and *Salix*. Permanent grasslands account for 19.77% of the area, consisting of alpine and subalpine calcareous grasslands, rupicolous Pannonian grasslands, and basophilic grasslands from the Alysso-Sedion albi group. Unproductive lands, mainly covered by swamp vegetation, make up 6.89% of the total area. Arable lands, used for agriculture, occupy 5.17%. Built-up areas, classified under courtyards and constructions, account for 2.94% of the study region. The remaining 2.58% includes various categories such as permanent crops (excluding vineyards), orchards, hops, and fruit tree nurseries, as well as gravel, sand, rocks, sterile dumps, landfills, and roads. This diverse landscape reflects a combination of natural and human-modified land use patterns across the study area.

2.2. Database

The GIS database used for the current land cover framing contains both quantitative and qualitative vector, raster, and numerical (in the case of climate predictions) databases (Table 1).

Table 1. Databases used in the GIS model.

Dataset	Type/Resolutions	Source
Romania soils map/type of soil/glazing/stagnogenization/useful edaphic volume	vector	Development for Pedology, Agrochemistry, and Environmental Protection [72]
Digital surface model (EU-DEM)	Raster/25 m	Copernicus Land Monitoring Service [73]
CORINE Land Cover (CLC 2012)	vector	Copernicus Land Monitoring Service [73]
Hansen Global Forest Change	Raster/30 m	Global Forest Change [74]
European Settlement Map	Vector	Copernicus Land Monitoring Service [75]
European catchments and rivers network system (ECRINS—dams on rivers)	Vector	European Environment Agency [73]
Roads and railways	vector	Open Street Map [76]
EU-Hydro—River Network	vector	Copernicus Land Monitoring Service [73]
Slope	Raster/25 m	Derived from DEM
Aspect	Raster/25 m	Derived from DEM
Grid of precipitation	Raster/25 m	Modelated
Grid of temperature	Raster/25 m	Modelated
Landslide probability	Raster/25 m	Modelated
Shared Socio-Economic Pathways (SSPs)	Numerical data	The Climate Change Knowledge Portal (CCKP) [77]

Land assessment involves evaluating the capacity of land for multiple uses in order to anticipate the effects of any changes. Land suitability relates to the feasibility of a given area for a specific land utilization. If the landscape characteristics do not correspond to the specific needs of a certain land use, it might be considered a possible restriction [78]. Land assessment is an evaluative analysis of the suitability of the terrain utilized for agricultural purposes, considering the primary attributes of the land, which are influenced by factors such as topography, water features, climate, and soil conditions.

The initial step in the methodology involves acquiring raster-based databases, including the factors relevant to the model used to assess the suitability for various crops and agricultural uses (Stage I) (Figure 2).

In Stage II, the raster database is reclassified using values ranging from 0 to 1. Values closer to 0 indicate a low favorability for each range of each factor included in the modeling, while values closer to 1 indicate a high favorability for a range of a factor suitable for that use (Table 2).

Table 2. Favorability scores used in the GIS model.

Favorability to grassland										
	Very Low		Low		Medium		High		Very High	
Score/Factors	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Slope	>100.0%		50.1–100.0%		25.1–35.0% 35.1–50.0%		20.1–25.0%	15.0–20.0%	10.1–15.0%	<2.0; 2.1–5.0; 5.1–10.0%
Gleization					complete		excessive		very powerful	non-gleizat, weak, moderate, strongly gleizat

Table 2. *Cont.*

Pseudogenization				<0.50		>3.01		0.51–3.00; coastal springs		
Soil texture	sand, coarse sand, medium sand, fine sand			silty sand, coarse silty sand, medium silty sand, fine silty sand		medium clay, fine clay		medium textures, sandy loam, coarse sandy loam, medium sandy loam, fine sandy loam, fine sandy loam, dusty sandy loam, dust	sandy loam, medium loam, medium loam, dusty loam, fine textures, clay loam, sandy loam, medium loam, medium clay loam, clay loam, clay, clay loam, clay clay, clay loam, dusty clay, medium clay, fine clay	
Soil edaphic value				<0.10		0.11–0.20		0.21–0.50	>0.51	
Soil reaction				<3.5		3.6–4.3	4.4–5.8	5.5–5.8	>5.9	
Landslides				shallow landslides						
Soil pollution	excessively polluted	very heavily polluted				heavily polluted		moderately polluted	unpolluted, slightly polluted	
Temperature	<–2.0 °C	–1.9–0.0 °C		0.1–2.0 °C		2.1–4.0 °C		4.1–5.0 °C	5.1–6.0; >12.0 °C	6.1–12.0 °C
Precipitation (mm/year)				<300; >1401		301–450; 1201–1400	451–500; 501–550; 1001–1200	551–600; 600–1000		
Favorability to pasture										
Very Low		Low		Medium		High		Very High		
Score/Factors	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Slope			>100.0	50.1–100.0	35.1–50.0		25.1–35.0	20.1–25.0	15.0–20.0	<15.0
Gleization				complete		excessive		very powerful	non-gleizat, weak, moderate, strongly gleizat	
Pseudogenization				<0.50		>3.01		0.51–3.00; coastal springs		
Soil texture	sand, coarse sand, medium sand, fine sand			silty sand, coarse silty sand, medium silty sand, fine silty sand		medium clay, fine clay		medium textures, sandy loam, coarse sandy loam, medium sandy loam, fine sandy loam, fine sandy loam, dusty sandy loam, dust	sandy loam, medium loam, medium loam, dusty loam, fine textures, clay loam, sandy loam, medium loam, medium clay loam, clay loam, clay, clay loam, clay clay, clay loam, dusty clay, medium clay, fine clay	
Soil edaphic value				<0.10		0.11–0.20		0.21–0.50	>0.51	
Soil reaction				<3.5		3.6–4.3	4.4–5.8	5.5–5.8	>5.9	
Landslides				shallow landslides						
Soil pollution	excessively polluted	very heavily polluted				heavily polluted		moderately polluted	unpolluted, slightly polluted	
Temperature	<–2.0		–1.9–0.0		0.1–2.0		2.1–4.0		4.1–6.0; >12.0 °C	6.1–12.0 °C
Precipitation				<300		301–450; >1401		451–550; 1001–1400	551–1000;	

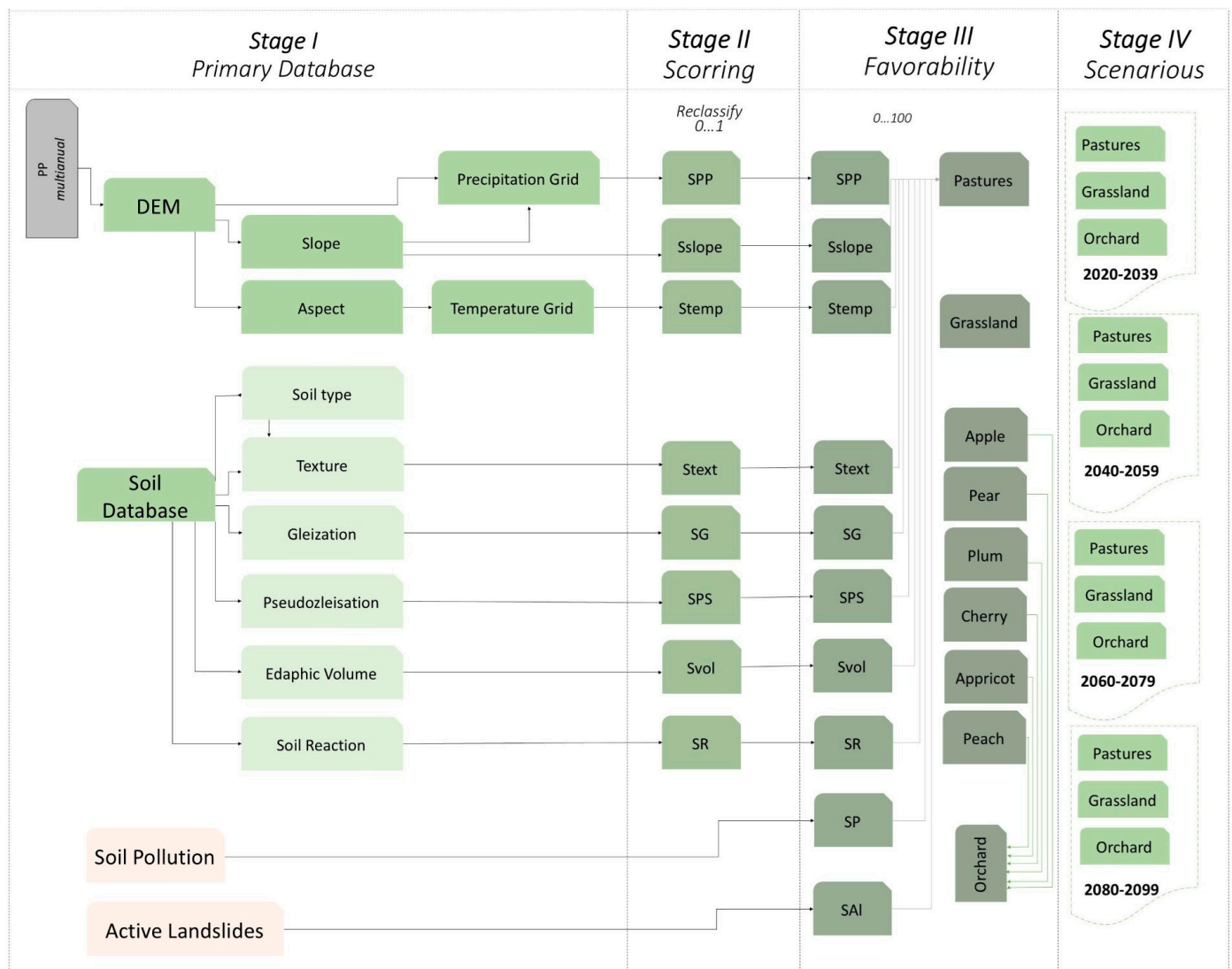


Figure 2. Methodological framework.

Land evaluation was conducted using scoring under environmental conditions, which takes into account 8 factors: slope, mean annual temperatures, mean annual precipitation, gleiss, pseudogleiss, soil texture, soil edaphic volume, and soil reaction with a value from 0 to 1 according to the national methodology used in Romania [79,80]. The land rating by crop and land use is determined by multiplying the sum of the coefficients of the 8 indicators, as indicated by the following formula:

$$FI = (S_{\text{slope}} + S_{\text{temp}} + S_{\text{PP}} + S_{\text{G}} + S_{\text{PS}} + S_{\text{text}} + S_{\text{Vol}} + S_{\text{R}}) \times 100,$$

where

FI—Favorability index;

S_{slope} —scoring value for slope;

S_{temp} —scoring value for average annual temperature;

S_{PP} —scoring value for average annual precipitation;

S_{G} —scoring value for soil gleiss;

S_{PS} —scoring value for pseudogleiss;

S_{text} —scoring value for soil texture;

S_{Vol} —scoring value for soil edaphic value;

S_{R} —scoring value for soil reaction.

Stage III consists of using Raster Calculator and ArcMap software (version 10.8) to calculate the favorability index, with values from 0–100 according to the methodological norms used in Romania [43]. The favorability results for the utilization of orchards (as a mean favorability for apple, pear, plum, cherry, cherry, apricot, and peach), pasture, and grassland are categorized into five favorability classes: class I (very high, 81–100 favorability points), class II (high, 61–80 favorability points), class III (medium, 41–60 favorability points), class IV (low, 21–40 favorability points), and class V (very low, 1–20 favorability points).

Within the category of limitations on production, even in regions with moderate to high favorability, there are locations affected by landslides or contamination of the soil. These have been employed to reduce the frequency of favorable categories. In the study region, there are a total of 113 mapped landslides, which include both shallow and deep-seated landslides. These landslides can be either active or stable, but they have resulted in limitations on land use. The methodology for classifying land in Romania by favorability classes [79–81] adapted the score of areas affected by soil pollution and landslides by 10% [82]. This adjustment allowed parcels of land affected by these natural and anthropogenic processes to be dropped from a higher-suitability class to a lower one in some instances, caused by their adverse impacts.

Stage IV consists of replacing the temperature and precipitation rasters with the SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios for the time period of 2020–2099 [77]. The prediction models are then executed to assess the variations in favorability and restrictiveness inside the analyzed area over time, based on the expected climate condition changes. For the validation stage of the favorability model for the different land uses, the APIA 2023 utilization parcels will be used, which include parcels currently used as hay pasture, grassland, and fruit orchards. This type of validation is semi-quantitative, because it is not necessarily the case that a plot of land that has the highest favorability for orchards will be used as such, some areas being left unused even if the productivity would be good (Figure 2).

3. Results and Discussion

Principally, the conventional method of evaluating agricultural land suitability depends on the biophysical properties of the soil. This approach often adheres to two primary methodologies: qualitative and quantitative. Qualitative approaches classify land suitability into predetermined categories, such as “very highly suitable”, “moderately suitable”, or “not suitable”, according to diagnostic criteria [83]. By contrast, quantitative approaches involve mathematical formulae to calculate an index, therefore providing a more accurate assessment of land capacity [84]. Modern technologies combine expert knowledge, machine learning, and customized models to improve the ability to assess crop suitability in different scenarios with more precision and adaptability [85]. In our case, the results belong to the category of studies that use a quantitative model to categorize all land parcels into suitability classes, taking into account current and future conditions.

The implementation of the suggested model yields findings which allow the classification of the study’s area into distinct favorability categories for grassland, orchards, and pasture. For grassland use, the favorability value ranges from 2.1 to 100 (Figure 3). Favorability class IV (low) occupies nearly 42% of the study area, while the medium favorability class (III) occupies 20.54%, the high favorability class (II) occupies 11%, and the very high favorability class (I) occupies 14.77%. This supports an average favorability for this area considering the topography, soil, and climatic characteristics.

According to the results of the GIS model, the favorability for pasture ranges from 11.7 to 100, being classified according to the methodology into five favorability classes. The 11 administrative territorial units are covered with 30.65% favorability class III (medium), 25.65% favorability class II (high), and 20.36% favorability class (very high). This fact supports the favorable suitability of this use in the study area (Figure 4).

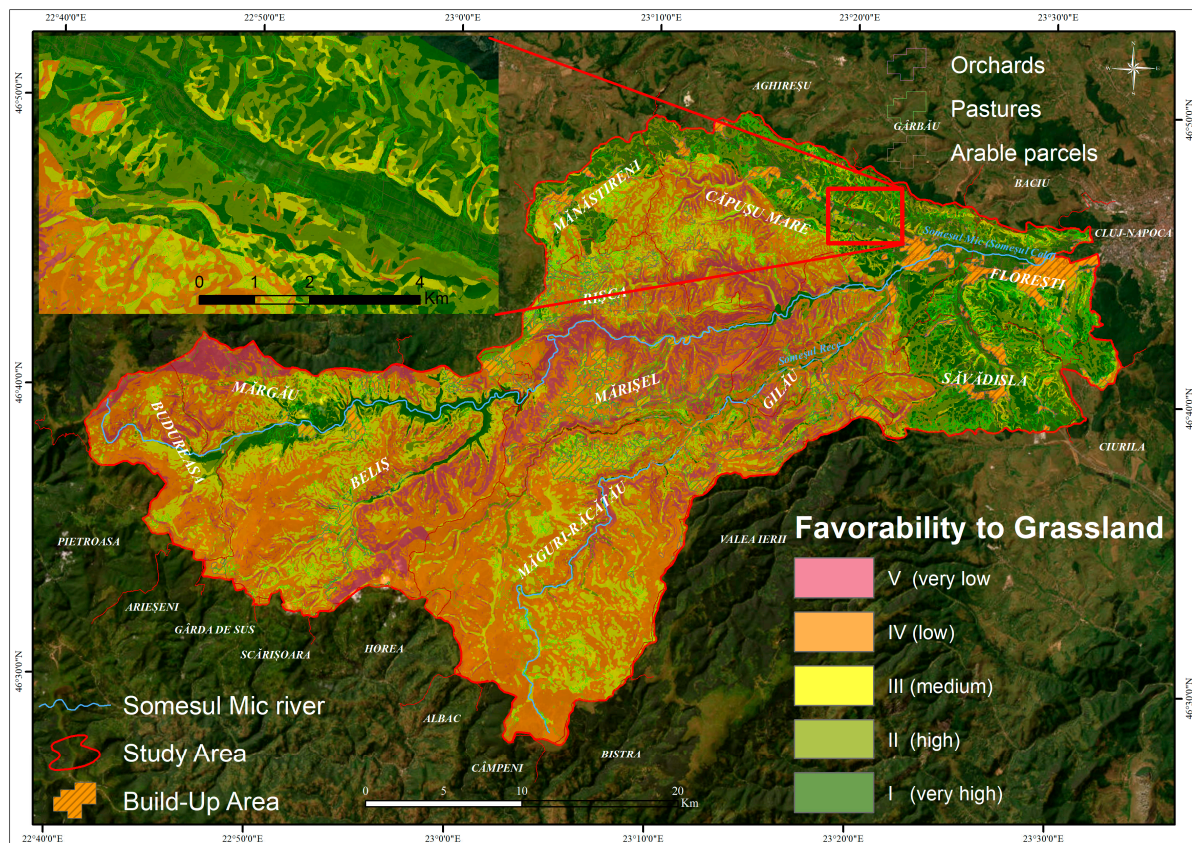


Figure 3. Map of actual favorability classes for grassland.

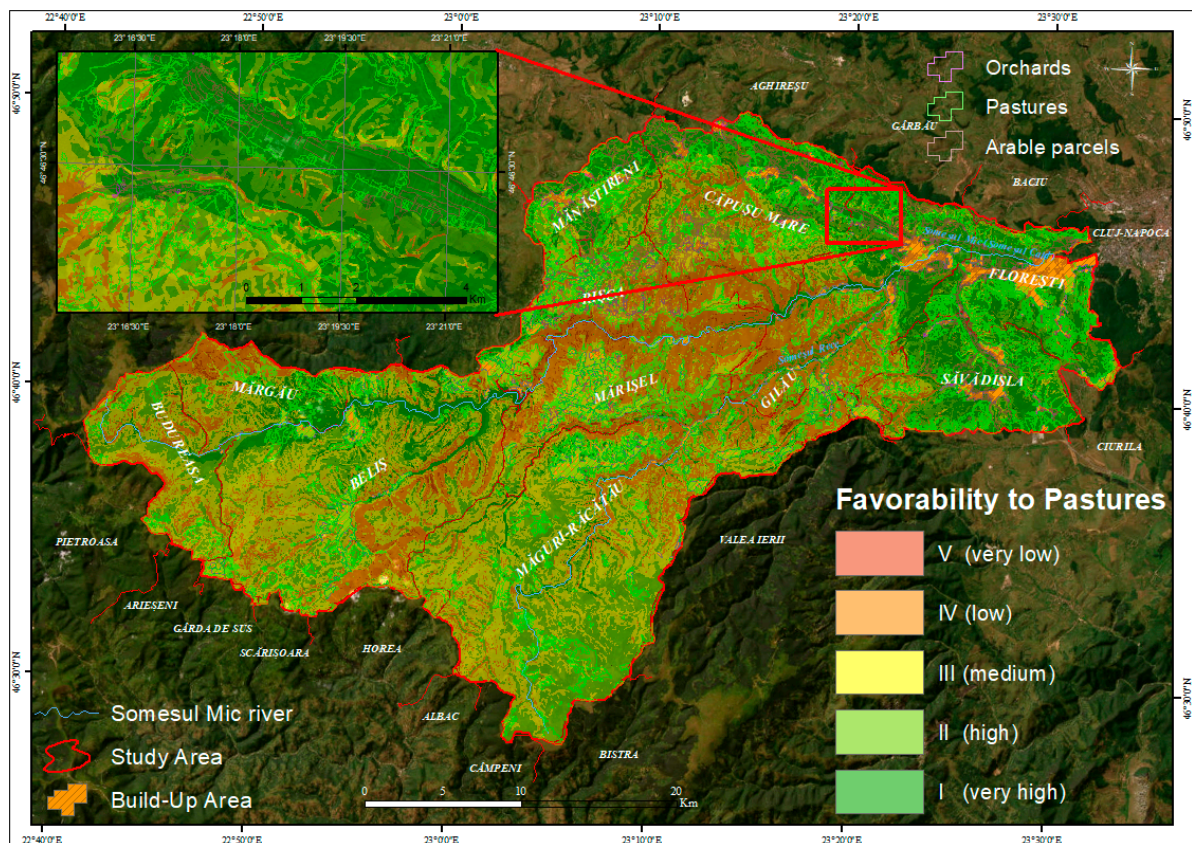


Figure 4. Map of actual favorability classes for pastures.

The use of fruit trees is obtained by arithmetic average of the maximum value of the six crops: apple, pear, plum, cherry, apricot, and peach s.a. This operation results in the above map showing the low to very low favorability of this use. The scores given to the use of fruit trees, as a result of the calculation, range from 0 to 50.1, which classifies the use of fruit trees into three favorability classes. Very poor favorability (class V) covers 82.48% of the study area, followed by poor favorability (class IV) with 14.78%, while medium favorability (class III) occupies 3%. This emphasizes that the study area is not suitable for orchard use (Figure 5).

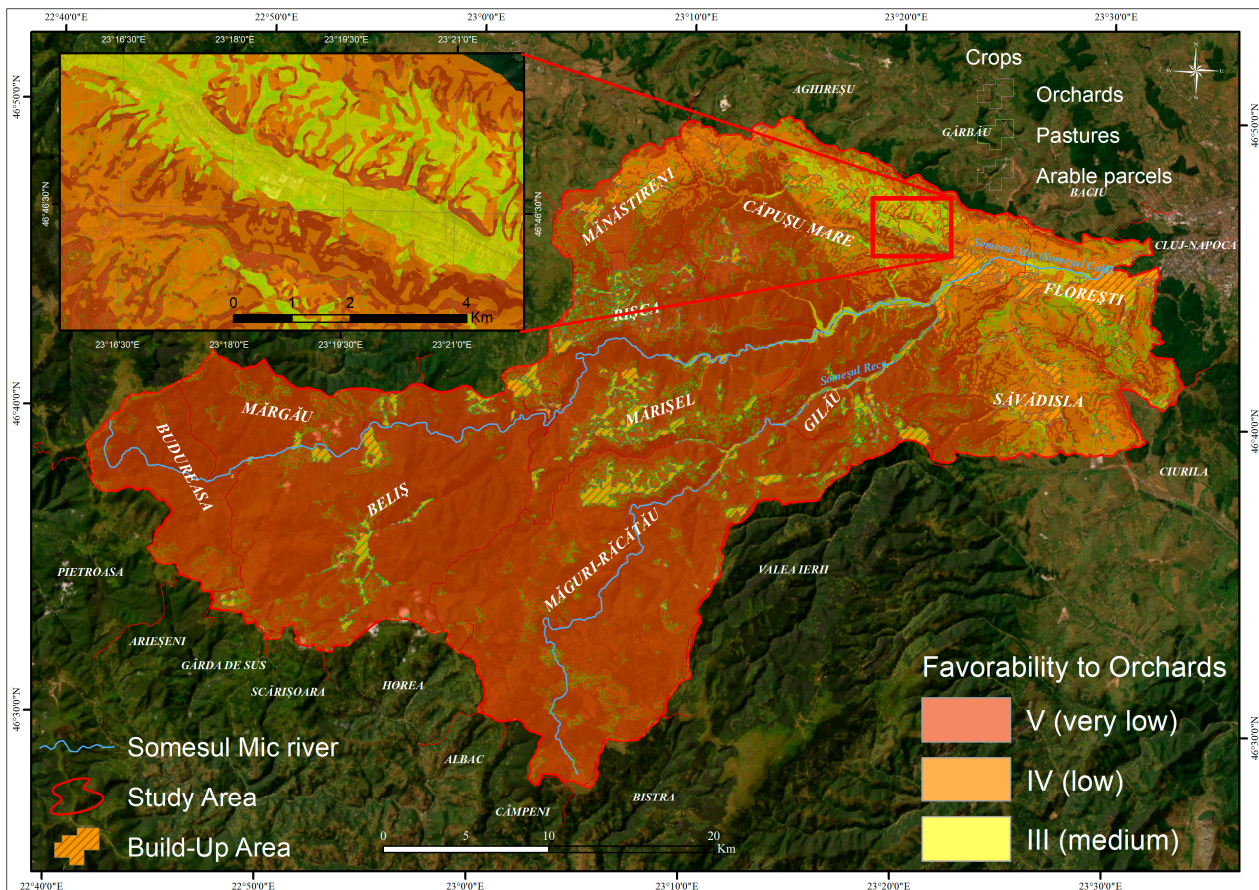


Figure 5. Map of actual favorability classes for orchards.

The effective identification of suitable agro-ecological zones and the mitigation of climate change effects on land suitability are essential for improving crop yields and promoting the financial stability of small-scale farmers. By precisely identifying these zones, farmers can maximize resource utilization and adjust to evolving environmental conditions, resulting in healthier crop production [86,87].

A statistical analysis of the fit of the 6385 pasture, grassland, and orchard plots in the study area to the five favorability classes indicates a Receiver Operating Characteristic (ROC) curve value (which is a tool used to evaluate the performance of a model) of 0.823 for orchards, 0.708 for pastures, and 0.806 for grassland (Figure 6).

The results obtained from the application of the GIS model for the study area were validated using the ROC curve. The values obtained were 0.823 for orchards, 0.708 for pastures, and 0.806 for grasslands. These values indicate that there is an 83% chance that the model correctly identifies a favorable and unfavorable location for an orchard, a 70.8% chance for pastures, and an 80.6% chance for grasslands. This result signifies a robust model that is highly likely to be effective for making practical decisions in determining the favorability of land use using the provided GIS model [88].

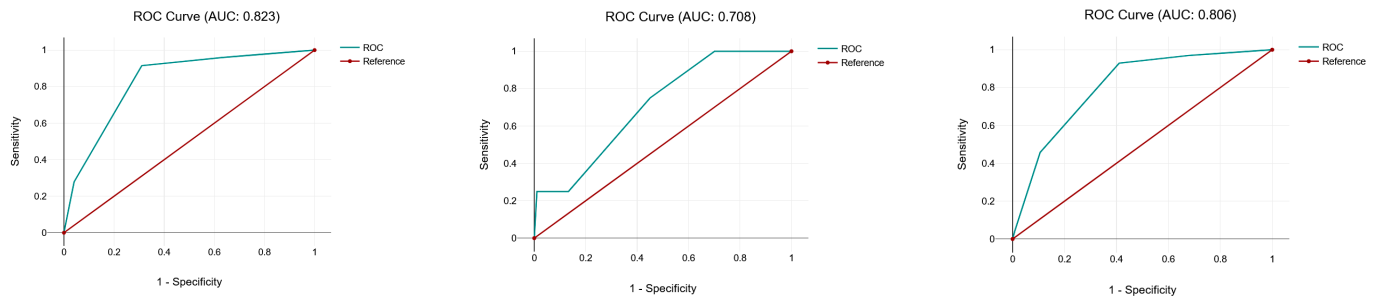


Figure 6. ROC curves for orchards (left), pastures (middle), and grassland (right).

The box plot graphs provide an overview of the distribution of favorability of land parcels across different favorability classes. From the data provided, we can deduce that the distribution has a slight tendency towards higher favorability classes for grassland use (mean > median), with the dispersion of plots being the highest for this land use type. In the case of favorability for orchards, the dispersion is the lowest, the mean being slightly higher than the median, indicating a slight presence of values above 1, but in general the data remain highly concentrated around class 1. The distribution is strongly asymmetric and does not show a large variation, suggesting that most of the land parcels are considered unfavorable for peach and apricot (due to the restrictiveness induced by the mean temperature values being too low in the study area than the species needs). This is supported by the low mean (1.32) and relatively low maximum (3) (Figure 7).

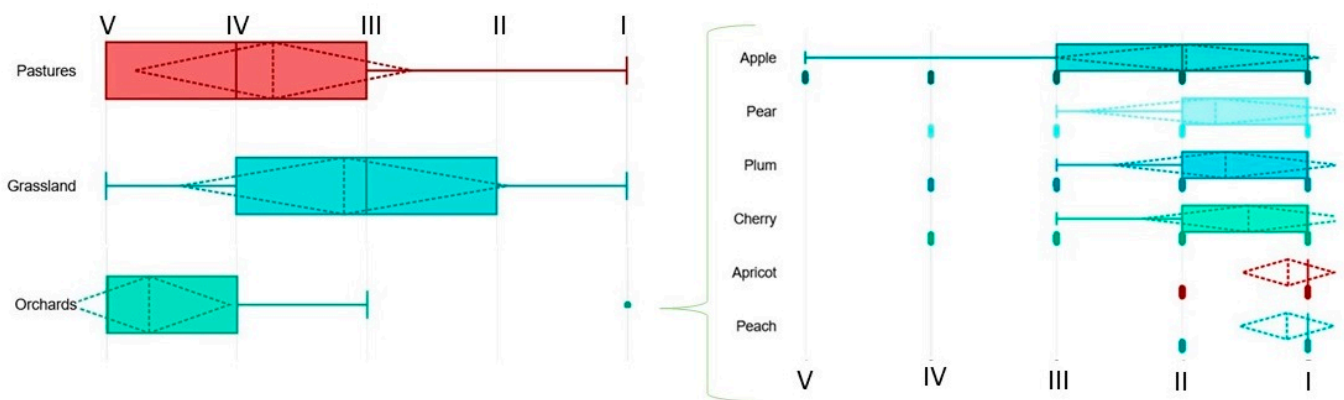


Figure 7. Blox pot diagrams for actual orchards, pastures, and grassland. V—very low, IV—low, III—medium, II—High, I—Very High Favourability (corresponding with the maps).

In order to achieve the second objective of the study, that is to identify the future favorability classes, the temperature and precipitation values from climate models for the time frames 2020–2040, 2040–2060, 2060–2080, and 2080–2100 were used, and the future favorability classes were assigned based on current conditions (Table 3).

The mean annual precipitation for the study area is currently 967 mm/year, but according to the climate scenarios, it can vary from 936.95 mm/year in the period 2020–2039, according to SSP1-2.6, to 821.94 mm/year in the period 2070–2099 mm/year, according to SSP5-8.5 [77] (Table 4).

Table 3. Favorability classes for different land uses according to actual and future variations in temperature and precipitation.

Score/ Temperature	Favorability									
	Very Low		Low		Medium		High		Very High	
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Pasture Actual			<−2.0		−1.9–0.0	0.1–2.0		2.1–4.0	4.1–5.0 5.1–6.0; >12.0 °C	6.1–12.0 °C 6.1–12.0;
Grassland		<−2.0	−1.9–0.0	0.1–2.0		2.1–4.0		4.1–5.0	5.1–6.0; >12.0	6.1–12.0;
Apple trees	<−2.0	2.1–4.0	4.1–5.0		5.1–6.0	6.1–7.0			7.1–8.0; 11.1–12.0	9.1–11.0
Brush trees	<−2.0; 4.1–5.0		5.1–6.0		6.1–7.0			7.1–8.0; >11.1	8.1–9.0	9.1–11.0
Plum trees	<−2.0; 4.1–5.0		5.1–6.0		6.1–7.0		7.1–8.0; >12.0	8.1–9.0; 11.1–12.0		9.1–11.0
Cherry trees	<−2.0; 4.1–5.0		5.1–6.0		6.1–7.0	7.1–8.0	>12.0	8.1–9.0; >12.0	11.1–12.0	9.1–11.0
Apricot trees	<−2.0; 6.1–7.0			7.1–8.0			8.1–9.0			>9.1
Peach trees	<−2.0; 5.1–7.0;			7.1–8.0		8.1–9.0			9.1–10.0	>10.1
Precipitation (mm/year)										
Pasture							<300	301–400; 401–500; >1401	451–550; 1001–1400	551–1000
Grassland						<300; >1401	301–400; 401–450; 1201–1400	451–550; 1001–1200		551–1000
Apple trees		>1401	1201–1400		<300	301–400;	401–450	451–500; 1001–1200	501–550; 801–1000	551–800
Brush trees	>1401	1201–1400			<300; 1001–1200	301–400	801–1000	401–450	451–500; 701–800	451–700
Plum trees	>1401	1201–1400			1001–1200	<300	301–400; 801–1000	701–800	401–500	501–700
Cherry trees	>1401	1201–1400	1001–1200	801–1000	<300	301–400		401–450; 701–800	451–500; 601–700	501–600
Apricot trees	>1401	1001–1200	801–1000			<300; 701–800	301–400	601–700	401–450	451–600
Peach trees	>1401	1001–1200	801–1000		<300	301–400; 701–800		401–450; 601–700	451–500	501–600
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

Table 4. Change in annual precipitation between 2020 and 2099 according to climate scenarios.

Period	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
PP/Y 2020–2039	915.96	936.95	918.78	913.83	896.5
PP/Y 2040–2059	899.96	907.79	896.93	896.91	872.03
PP/Y 2060–2079	900.91	919.22	907.7	864.65	829.7
PP/Y 2070–2099	901.06	912.06	895.02	844.22	821.94

The average temperature for the study area has a value for the present time of 5.51 °C; according to the climate scenarios, it can vary from 10.98 °C in the period 2070–2099, according to SSP1-1.9, to 15.40 °C in the period 2070–2099, according to SSP5-8.5 [41] (Table 5).

A statistical analysis of the classification of parcels for grassland use reveals significant variations by favorability class, both at present and in the medium and long term. In the long term, comparing the current situation with the climate projections for the period 2070–2099, a decrease in the high favorability of the land is observed. Under the SSP5-8.5

scenario, which anticipates an increase in average temperature to 15.4 °C and an annual precipitation of 821 mm, the areas in the high favorability class are projected to decrease by 4.7%. Similarly, under SSP3-7.0, which predicts an average temperature of 14.05 °C and annual precipitation of 844 mm, the estimated decrease is 4.4%. Under the SSP2-4.5 scenario, which projects an average temperature of 12.7 °C and annual precipitation of 895 mm, the reduction is more modest at 1.6%. These results underline the significant impact of climate change on the suitability of land for grassland use, indicating a progressive decrease in the areas optimal for grassland use under increasing temperatures and variations in the projected precipitation regime.

Table 5. Annual mean temperature change from 2020 to 2099 according to climate scenarios.

Period	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
AvgT 2020–2039	10.987	11.073	11.135	10.993	11.311
AvgT 2040–2059	11.272	11.588	11.757	11.977	12.443
AvgT 2060–2079	11.134	11.748	12.341	12.995	13.808
AvgT 2070–2099	10.983	11.679	12.750	14.057	15.408

In the context of climate change, land use for grassland pasture will change significantly between 2020 and 2039 according to climate projections. The modeling based on the SSP1-2.6 scenario, which predicts an increase in precipitation to 936 mm and average temperature to 11 °C, indicates a reduction in the area in the very low favorability class by 23.3%. Similarly, under the SSP2-4.5 scenario, which predicts an average temperature of 12.75 °C and annual precipitation of 895 mm, the decrease in this category is 18.8%. At the same time, for the high and very high favorability classes, the SSP2-4.5 modeling shows an increase of 2.2%. These changes suggest a redistribution of favorable land for pasture use according to climatic developments, with the potential for improved grassland conditions in areas where the climate becomes more favorable at the expense of others. This study highlights the need to adapt land use strategies to new climatic conditions in order to optimize natural resource management in the context of projected climate change.

In the case of orchards, the analysis shows a fluctuating variation in land favorability in the context of climate change (Figure 8). According to the SSP1-1.9 scenario, in the immediate future, the areas in the very low favorability class are expected to decrease by 3.4%. This decrease is even more pronounced under the SSP2-4.5 scenario, where a reduction of up to 6.4% is projected, given an average temperature of 12.7 °C and an annual precipitation of 895 mm. The low favorability class also shows a decrease of 5.1%. In contrast, for the high and very high favorability classes, there is a slight increase of up to 0.7% in the areas falling into these categories.

This increase in favorability is particularly relevant in the context of the expected increase in temperature, given that the favorability assessment for orchards is made by averaging the favorability for species such as apple, pear, plum, and cherry (Figures 9–20). In particular, for the cherry, peach, and apricot species, which require higher temperature limits for optimal development and acceptable yields, the increase in the multiannual mean temperature has a beneficial impact. Thus, some plots that were previously classified in the high favorability class could move to the very high favorability class. This qualitative leap will also be reflected in the statistical analysis of the suitability of plots for orchard use, underlining the importance of adapting orchard management strategies to the new climatic conditions forecast.

Period	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2020-2039	Grassland				
V	147	147	146	145	558
IV	2034	2034	2031	2030	2028
III	2039	2039	2186	2417	2011
II	733	733	728	682	664
I	1417	1417	1279	1096	1109
2040-2059					
V	159	164	143	144	260
IV	2029	2035	2028	2028	2013
III	2037	2028	2176	2415	2413
II	729	728	722	672	678
I	1416	1415	1301	1111	1006
2060-2079					
V	169	158	137	138	182
IV	2026	2029	2024	2021	2017
III	2035	2052	2169	2408	2028
II	727	722	717	362	725
I	1413	1409	1323	1441	1418
2070-2099					
V	185	233	247	217	181
IV	2024	2021	2018	2022	2013
III	2028	2024	2021	2035	2037
II	724	709	706	717	728
I	1409	1383	1378	1379	1411

Period	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2020-2039	Pastures				
V	1	49	156	191	150
IV	621	599	581	578	593
III	2488	2472	2464	2453	2468
II	1485	1478	1474	1467	1476
I	1775	1772	1695	1681	1683
2040-2059					
V	69	169	208	217	332
IV	596	493	577	569	590
III	2472	2468	2439	2451	2461
II	1476	1462	1456	1458	1416
I	1757	1778	1690	1675	1571
2060-2079					
V	56	220	260	-780	333
IV	592	482	568	578	592
III	2463	2463	2437	2449	2460
II	1478	1437	1451	2452	1427
I	1781	1768	1654	1671	1558
2070-2099					
V	27	1532	1344	355	334
IV	615	217	609	588	587
III	2476	1462	1449	2453	2457
II	1479	1472	1415	1417	1430
I	1773	1687	1553	1557	1562

Period	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2020-2039	Orchards				
V	4417	4407	4385	4632	4917
IV	826	813	765	510	211
III	723	728	721	718	721
II	230	235	247	252	258
I	174	187	252	258	263
2040-2059					
V	4434	4455	4726	4658	4929
IV	818	808	461	497	180
III	718	711	708	708	711
II	228	228	231	247	272
I	172	168	244	260	278
2060-2079					
V	4551	4494	4778	4660	4903
IV	721	792	451	495	178
III	713	706	692	695	709
II	217	222	218	252	298
I	168	156	231	268	282
2070-2099					
V	4635	4545	4790	4666	4934
IV	692	783	441	487	153
III	680	687	686	691	685
II	211	201	201	247	296
I	152	154	252	279	302

Figure 8. Variation in crops by favorability classes between 2020–2100 (the increase is indicated with green arrow, the decrease with red arrow and the maintenance with yellow arrow).

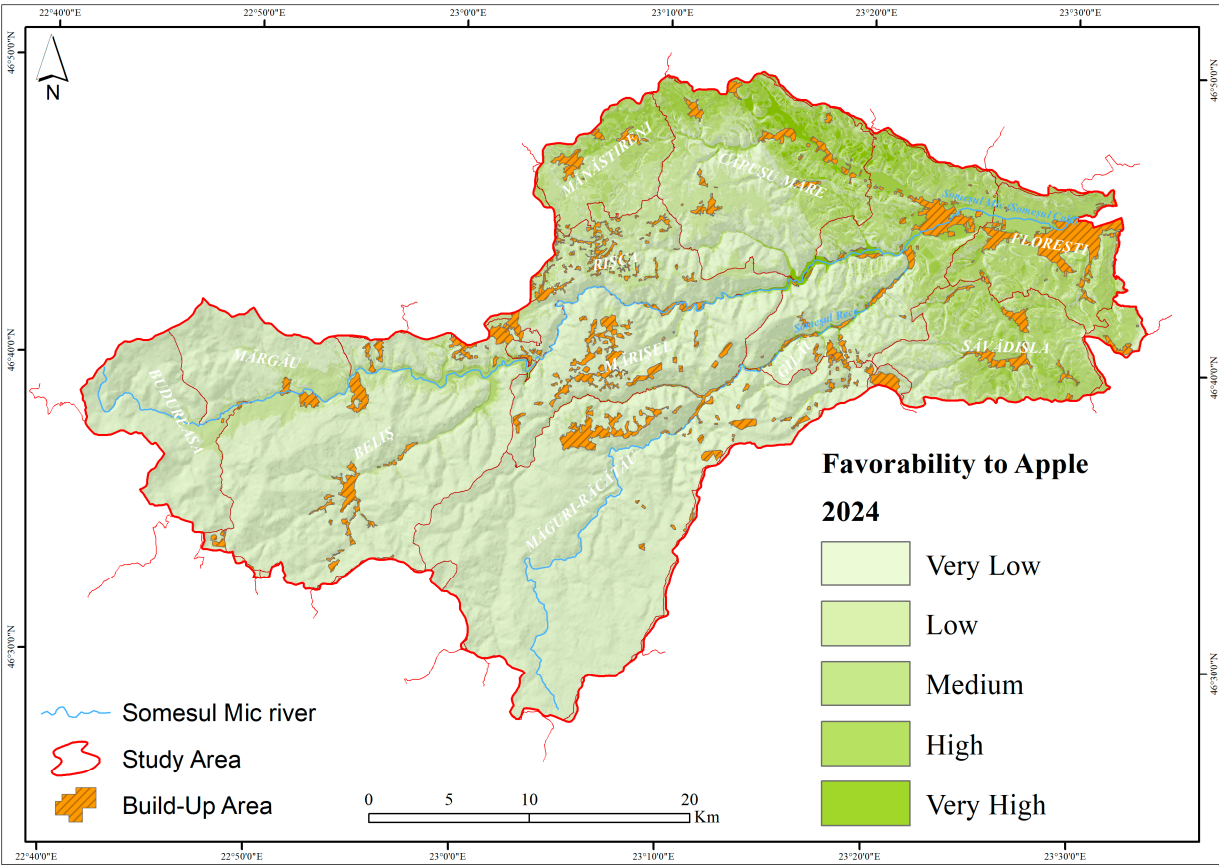


Figure 9. Favorability for apple in 2024.

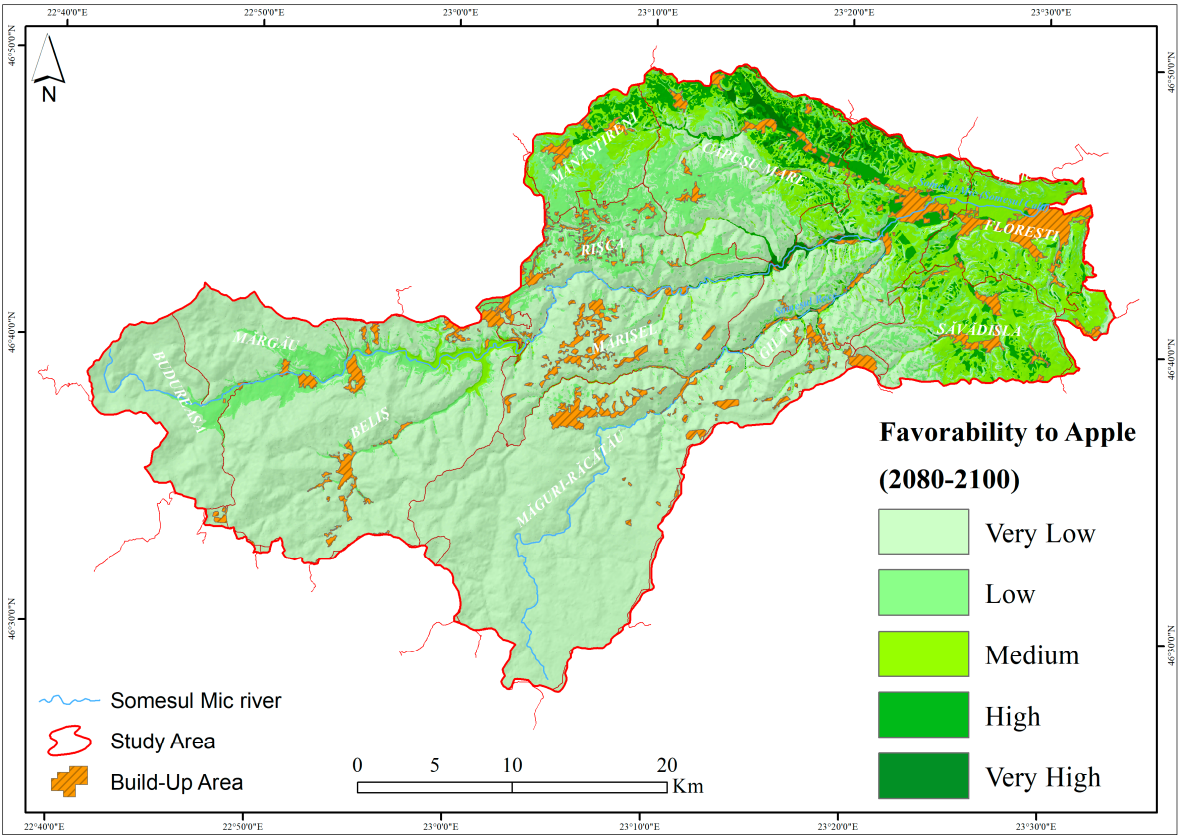


Figure 10. Favorability for apple in 2100.

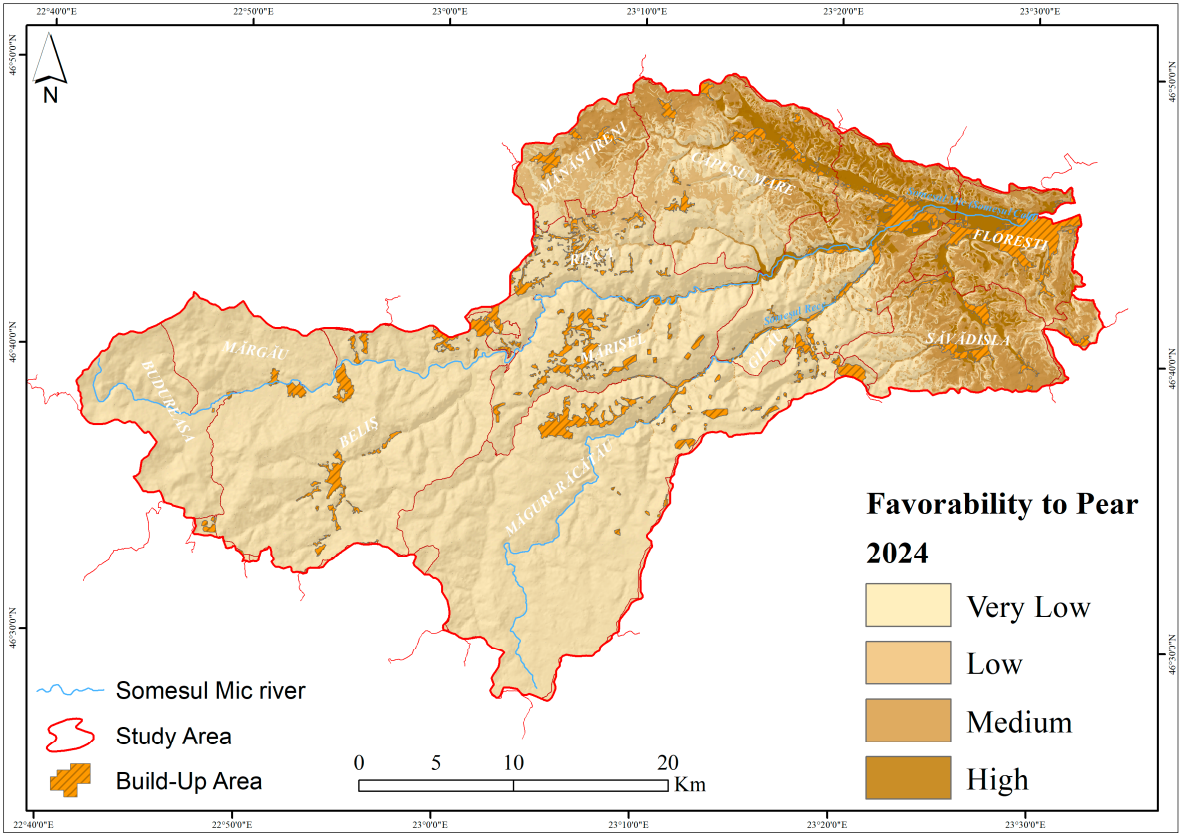


Figure 11. Favorability for pear in 2024.

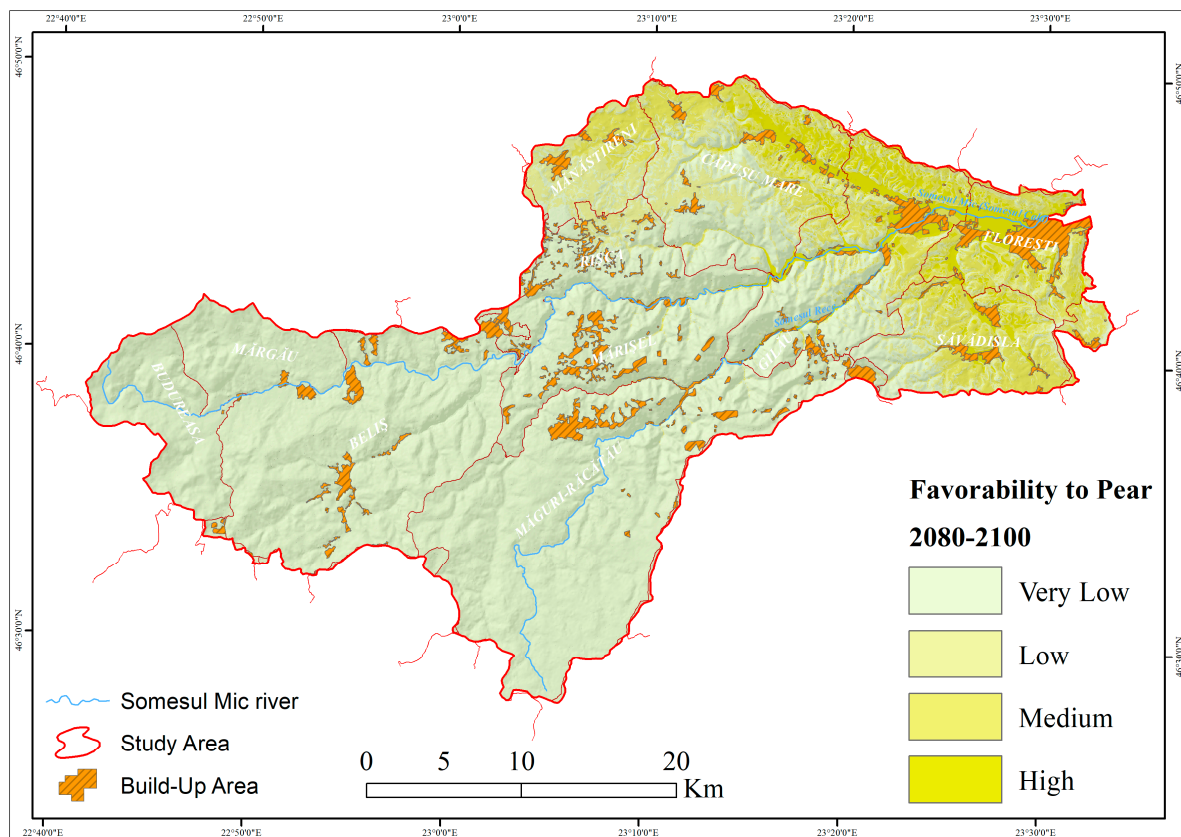


Figure 12. Favorability for pear in 2100.

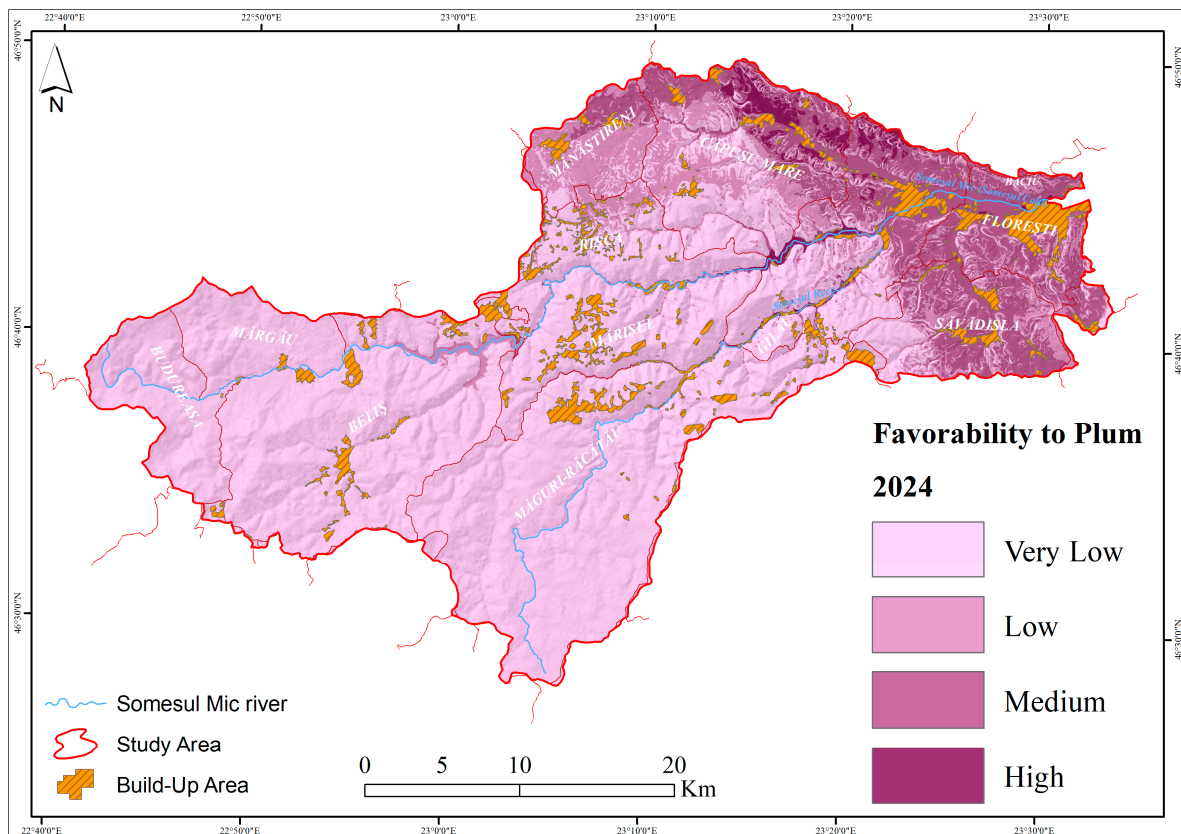


Figure 13. Favorability for plum in 2024.

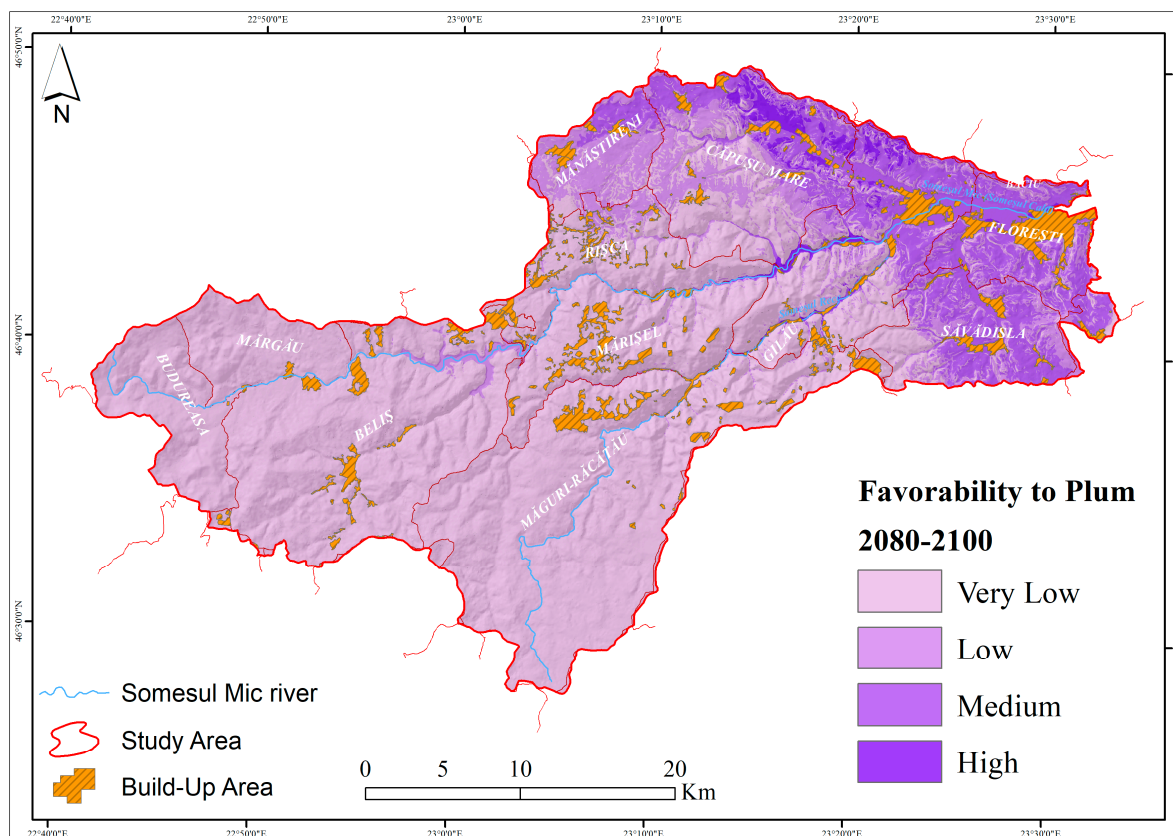


Figure 14. Favorability for plum in 2020–2100.

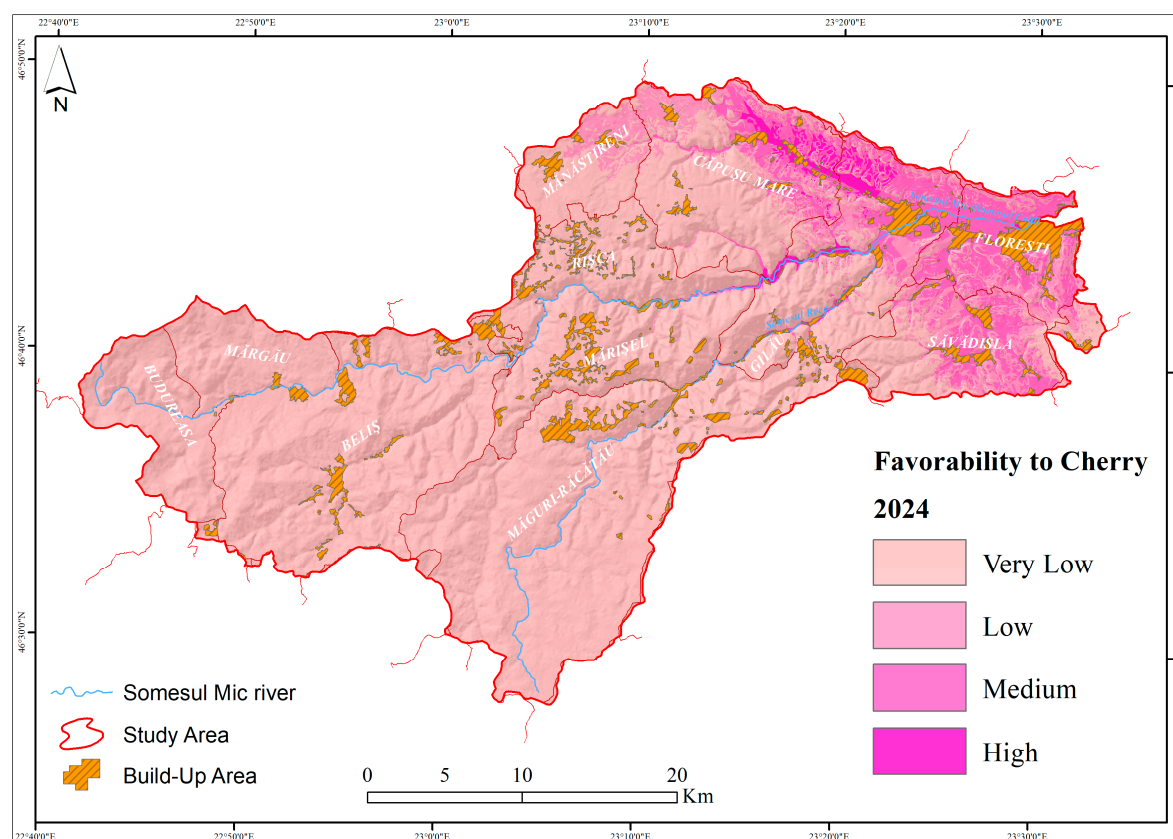


Figure 15. Favorability for cherry in 2024.

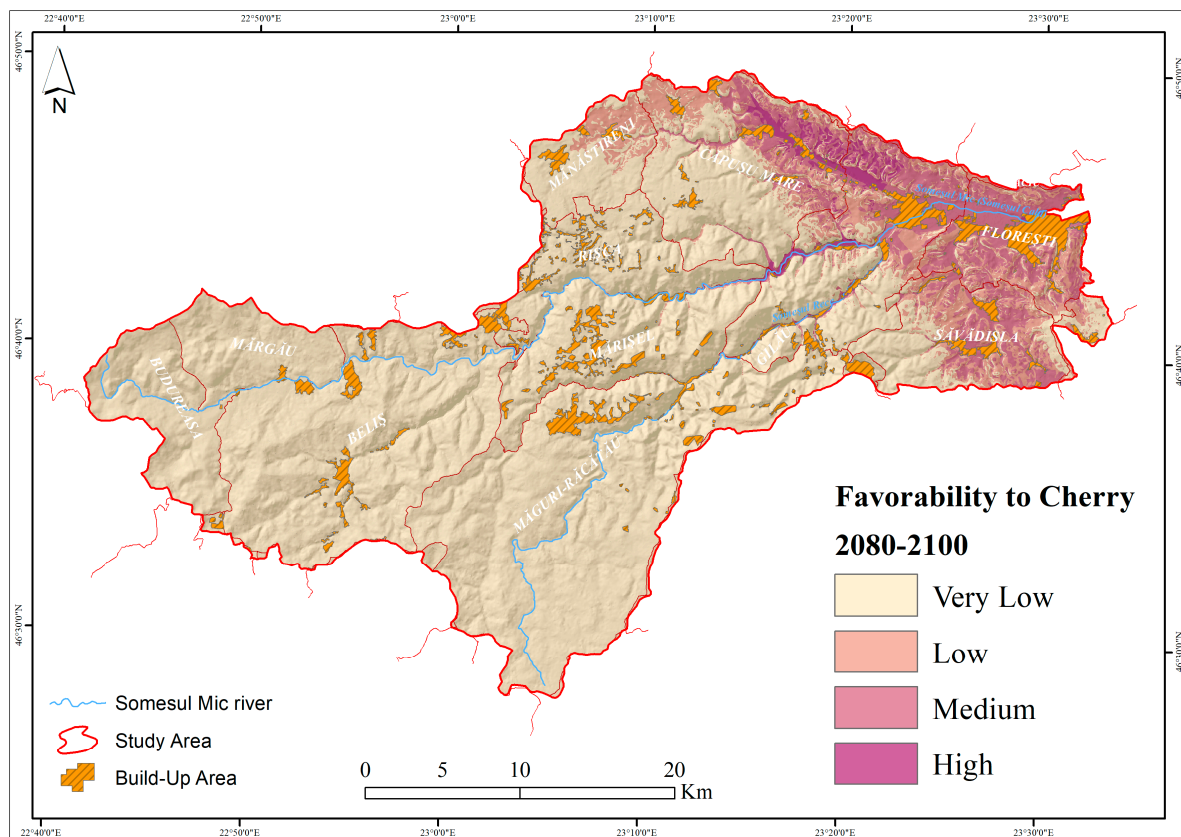


Figure 16. Favorability for cherry in 2100.

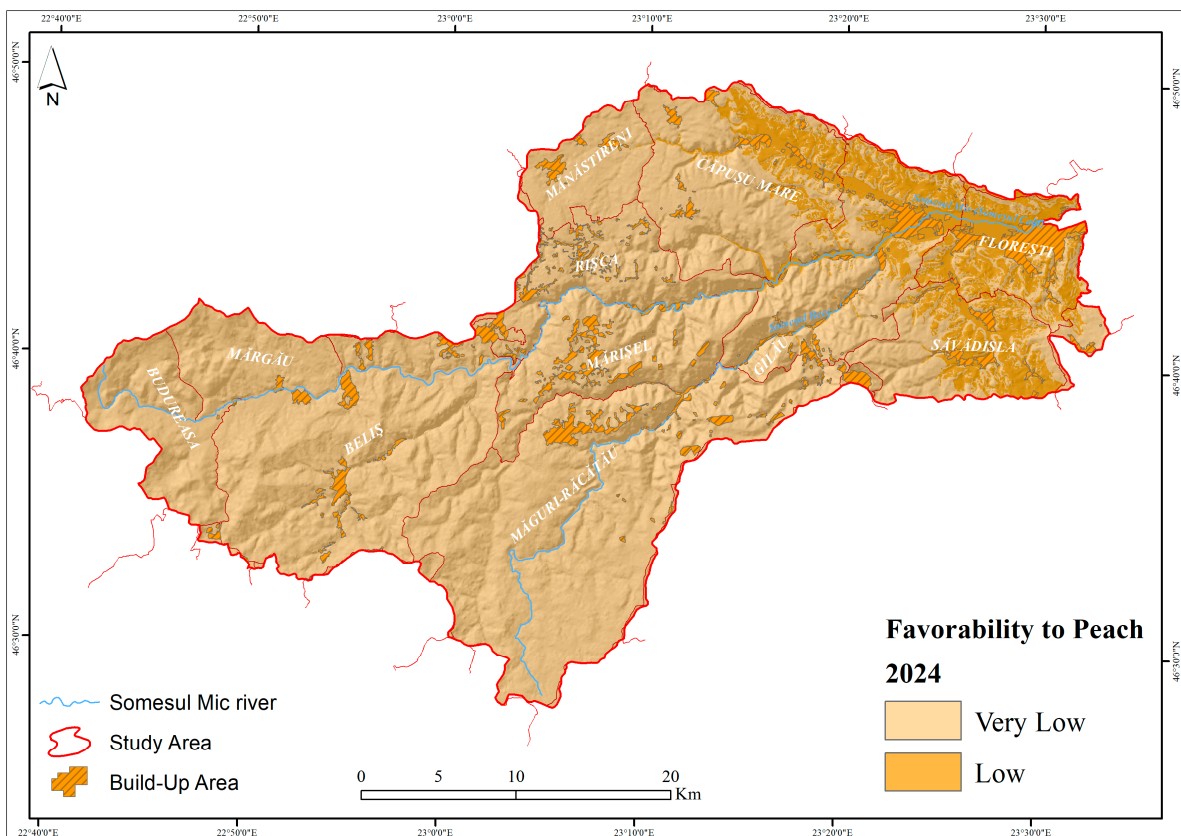


Figure 17. Favorability for peach in 2024.

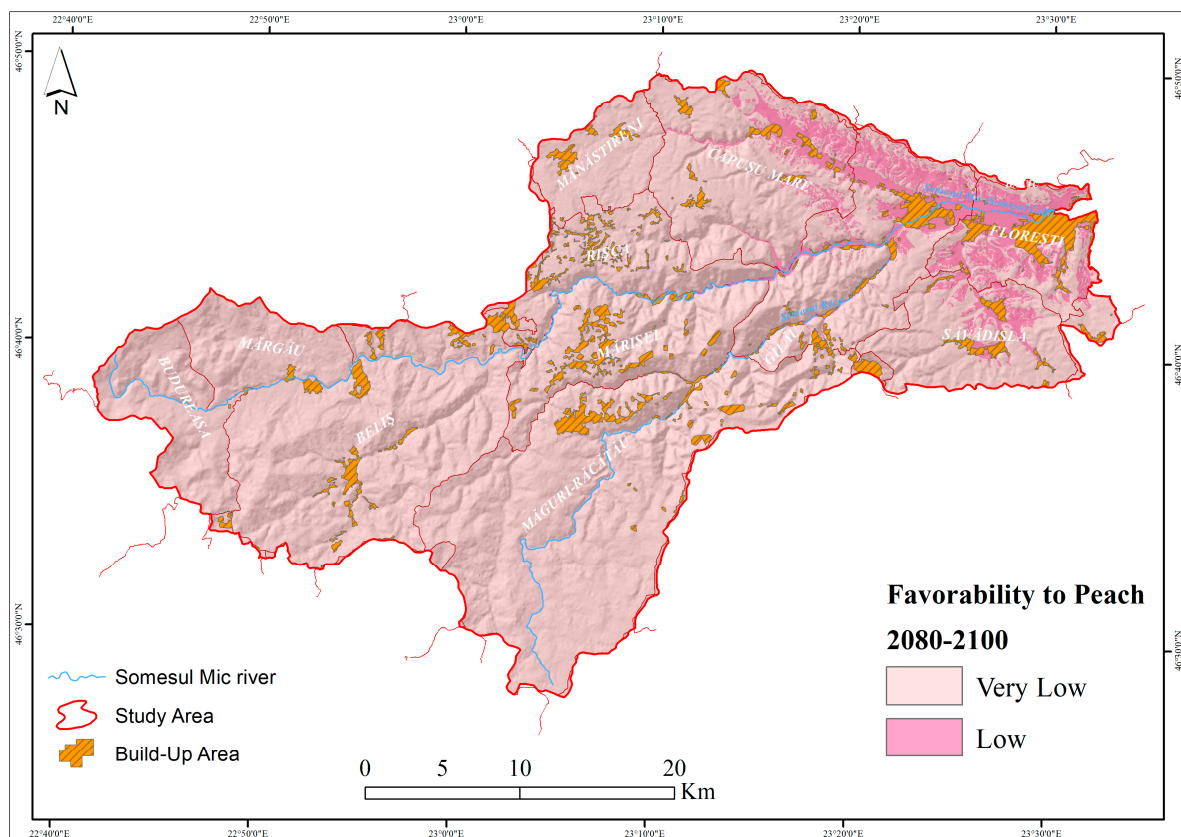


Figure 18. Favorability for peach in 2100.

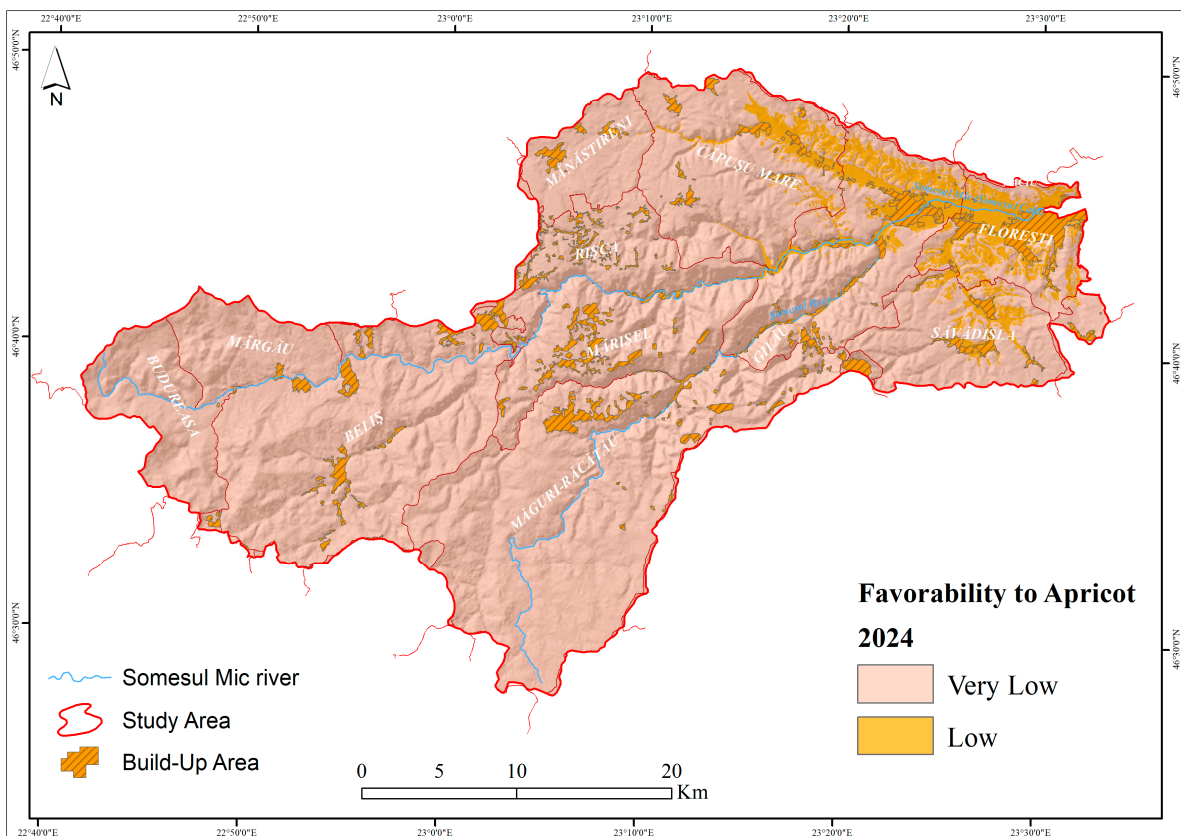


Figure 19. Favorability for apricot in 2024.

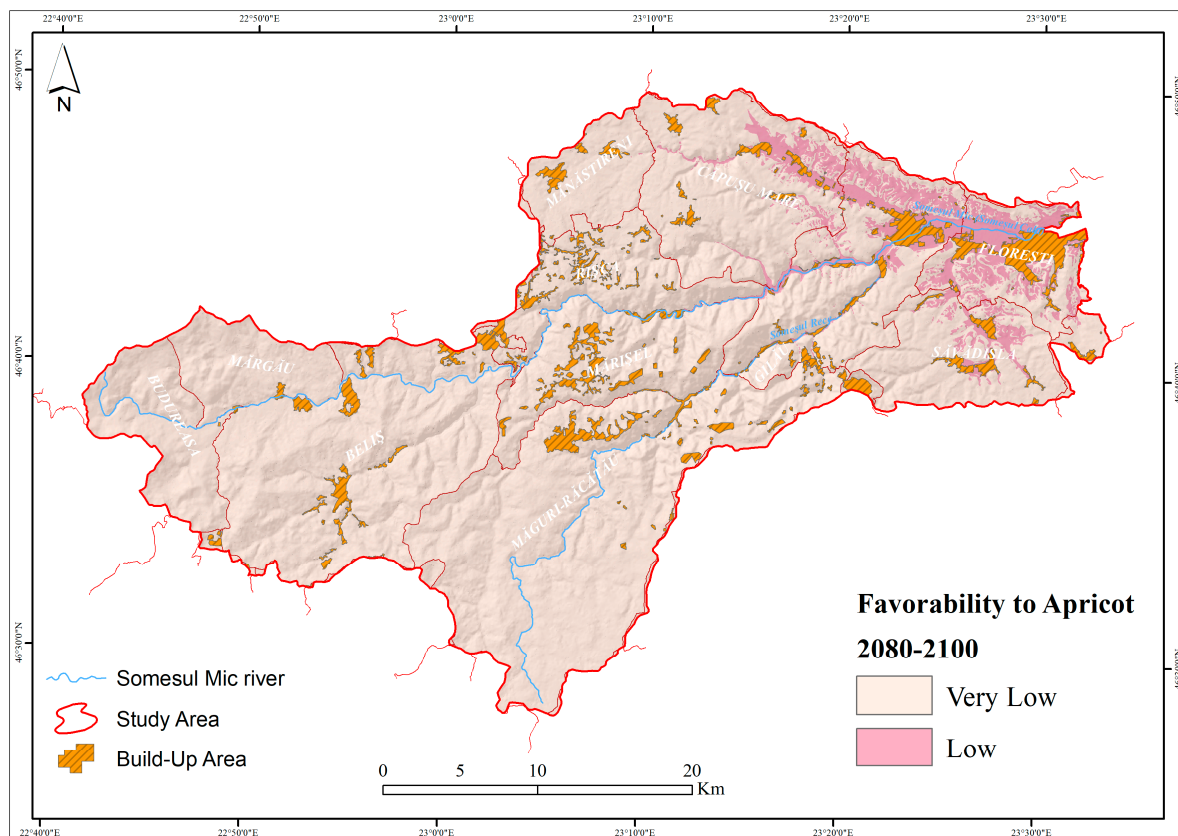


Figure 20. Favorability for apricot in 2100.

Considering the above variables, landowners with existing fruit tree orchards might strategically choose to cultivate new species and types based on the expected future conditions in the medium term.

Anthropogenic activities are exerting a growing impact on land resources in the context of climate change, consequently increasing ecosystem degradation and reducing land productivity. Various anthropogenic activities, including deforestation, urban growth, and unsustainable agricultural methods, are responsible for soil erosion [89], the loss of biodiversity, and the depletion of nutrients. Furthermore, climate change increases these effects by imposing extra pressure on already delicate land systems through changes in temperature and precipitation patterns. The combined impact of human pressures and climate unpredictability reduces the adaptive capacity of land resources, therefore presenting substantial threats to the long-term viability of agriculture and the availability of food. The resolution of these issues requires the implementation of comprehensive land management approaches that tackle both human-induced and climate-related elements.

The population density fluctuations in the study area make it difficult to model due to the lengthy duration of the modeling and the reliance on climate scenarios. However, there has been a general trend in the study area throughout the past period of population migration from neighboring urban areas (Cluj Napoca, Huedin, Turda) to this territory [90]. This migration is driven by the attractive landscape, rich soil resources, and high tourism potential of the mountainous area in the upper basin of the Somesului Mic, as indicated by the increase in the number of buildings that have appeared, especially after the COVID-19 pandemic.

The main goals in land use planning and policy development in relation to climate change involve the promotion of climate-smart agricultural practices that improve food security, reduce environmental consequences, and protect farmland against climate-related issues such as acidification of the soil. In addition, successful land use planning should include collaboration across local, regional, and national stakeholders to provide an integrated

governance framework that promotes active participation and responsibility in climate adaptation initiatives. Moreover, it is important to prioritize biodiversity conservation by implementing policies that seek to preserve natural ecosystems, encourage reforestation, and include biodiversity protection in both urban and rural development systems.

4. Conclusions

The present case study aims to improve the overall comprehension of how Geographic Information System (GIS) capabilities can be utilized to facilitate sustainable land management in mountainous areas that are confronted with the combined challenges of climate change and development. The findings of this study will provide important information for land use planners, environmental managers, and policy makers operating in the Apuseni Mountains (the Somesul Mic watershed) and similar areas.

Having knowledge regarding the interaction between climate factors and human activities is essential for predicting future changes in land use and effectively monitoring landscapes in a sustainable manner. The ongoing evolution of climate change and human activities will have a progressively major impact on land usage, creating issues for environmental conservation and resource management.

The results reveal significant shifts in land use favorability patterns under future climate scenarios, with certain areas becoming more suitable for agriculture, while others may face increased risks of land degradation or reduced agricultural potential. This GIS-based approach offers valuable insights for regional planning and sustainable land management, helping stakeholders adapt to changing environmental conditions. The findings underscore the need for proactive strategies to mitigate climate change impacts on land use and support the resilience of the Apuseni Mountains' ecosystems and communities.

This study incorporates a quantitative Geographic Information System (GIS) model to evaluate the suitability of land for important agricultural purposes, such as grasslands, pastures, and orchards. The assessment is based on environmental criteria, including soil properties, climatic variables, and topographic characteristics. An analysis of SSP climate scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) from 2020 to 2099 shows variations in land suitability, with decreases in high favorability for pastures and grasslands and a little increase in favorability for orchards under specific circumstances. The GIS classification of land favorability offers a reliable and data-driven approach to assess current suitability and predict future changes, essential for well-informed land management and agricultural planning.

While GIS-based land suitability models offer meaningful insights into agricultural potential in the context of climate change scenarios, they are subject to several limitations. The presence of uncertainty in the climate projections might lead to diverse results, therefore introducing complexity to the dependability of the forecasts. In addition, the reliance on existing spatial data, which may be lacking in completeness or generalization, restricts the accuracy of the model, especially at small scales. The models often failed to consider intricate interactions between natural forces and socio-economic variables that are essential for making land use decisions. Moreover, the level of detail in GIS data may not consistently include slight variations at a small scale, therefore diminishing the success of the models in directing specific agricultural adaptation measures.

The potential future research will integrate Geographic Information Systems (GISs) with computer-based machine learning algorithms to improve land suitability evaluations in the context of climate change scenarios. The integration of Geographic Information Systems (GISs) with machine learning facilitates the generation of more advanced and data-oriented insights, therefore enabling the real-time monitoring of land use and climatic effects.

The results of this study have substantial consequences for practical implementations. The capacity to forecast the anticipated changes in land suitability under various climatic scenarios enables policy makers, farmers, and local authorities to actively adjust their policies regarding agriculture. For instance, comprehending the changing suitability of land for

different crops helps guide choices for crop rotation, diversity, and resource distribution, thus enhancing agricultural resilience. Moreover, the emphasis of this publication on the financial consequences of climate change, notably in areas heavily reliant on agriculture, underscores the wider implications of decreased agricultural output, including market instability and the inflation in food prices. This research provides a comprehensive assessment of future agricultural viability, which in turn facilitates the formulation of adaptive measures aimed at reducing the economic vulnerabilities associated with climate change. Within this particular framework, the incorporation of GIS modeling and climatic scenarios offers vital instruments for the purpose of sustainable land use planning, therefore guaranteeing the continued viability of agriculture despite the present environmental and economic obstacles.

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