

Article

Digital Mapping of Land Suitability for Main Agricultural Crops in Romania

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Abstract: The scientific evaluation of land potential for different uses is essential for sustainable land development. Our study attempts to quantify this potential for agricultural purposes at a national scale, using GIS techniques, high-resolution spatial data, and recent climate data. The land evaluation methodology we applied in our study was developed in the 1980s by soil scientists from the National Institute of Research and Development for Pedology, Agrochemistry and Environmental Protection (ICPA) and it is still the official approach for the assessment of land suitability for crops in Romania. In our study, the application of the methodology is based on high-resolution spatial data including the 25 × 25 m resolution EU-DEM, the CHESLA climate database from which mean annual temperatures and precipitations were extracted for the 1990–2019 period, the digital soil map of Romania, the European LUCAS soil database. Firstly, we compared the evolution of mean annual temperatures and precipitations for 1961–1990 and 1990–2019 periods and found that there is a significant warming trend (an overall increase of 1.27 °C for the entire country, ranging from 0.9 °C to 1.6 °C) among the major landform units and a slight precipitation increase throughout the country (68.8 mm yr^{−1} for the whole country, ranging from 9.3 to 118.8 mm yr^{−1}). Then, we applied the land evaluation methodology for the recent period (1990–2019), starting with the digital mapping of 15 land suitability factors, which were further aggregated to achieve the land suitability index and classes for the main agricultural crops of Romania (winter wheat, maize, sunflower, potato, and vine for wine). The results show that the most suitable landform units for wheat, maize, and sunflower are the plain areas (Romanian Plain, Western Plain) with LSI average values over 60. For potato, the suitable areas (LSI over 50–60) are less extended, being found especially in the intra-mountainous depressions and cooler plateau areas, while vines find very suitable conditions (LSI over 70) at the contact of the Romanian Plain and the Subcarpathians. To assess the model performance, we determined the shares of land suitability classes within the areas occupied by the specific crops. A second validation was carried out by correlating the total crop production at the county level with the cumulated LSI values. We found that, apart from potatoes, the model performs well for the analyzed crops. However, a methodological revision is necessary to accommodate temperature and precipitation values, which did not manifest in the reference climate period (1961–1990), but which are now part of the current climate of Romania.

Keywords: agricultural land evaluation; GIS; Romania



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1. Introduction

Land evaluation for agricultural purposes constitutes the basis for the rational use of agricultural land. According to the purpose/generalization degree, land evaluation methodologies can be grouped into the following categories: (i) *capability evaluations*,

aiming to assess land suitability for general uses (agriculture in general, forestry, pastoral activities etc.); (ii) *suitability evaluations*, oriented towards specific uses (specific crops). One of the first capability evaluations is the land capability classification system elaborated by the USDA [1], while one of the first land suitability evaluations is the general land evaluation framework proposed by FAO [2] for specific uses. This framework was used to develop the agroecological zoning methodology [3], as well as specific guidelines for rainfed agriculture [4] and irrigated agriculture [5]. In the Netherlands, one of the leading countries in land evaluation, the principles and concepts of FAO [2] were applied to design a specific land evaluation methodology, named WIB-C, for interpreting soil map units at scales from 1:10,000 to 1:50,000 [6]. Other methods have been developed as well, such as the production levels approach, which simulates crop growth in relation to the environment and differentiates between the potential production level and water/nutrient-limited levels [7,8].

According to the specific method used in the quantification/aggregation factors, the land evaluation methodologies can be grouped into the following categories: (i) *qualitative* and (ii) *quantitative* systems. Qualitative systems, like FAO [2], use quality classes to assess factor suitability, defined in terms of the number and intensity of limitations, without any numerical assessment. On the other hand, quantitative systems use numerical assessments of factors suitability, generally on a 0–100 or 0–1 scale, as well as specific mathematical formulas to aggregate them into a final suitability index. One of the first such systems is the Storie System [9,10] designed for land taxation purposes. Another example is the methodology proposed by Riquier et al. [11], designed for land productivity assessment. A qualitative system, such as FAO [2], has the advantage of flexibility because it is more like a set of rules and principles which allow experts to build their own evaluation system and, therefore, integrate their expert knowledge. The shortcoming that comes with this is that the procedure is more time consuming and challenging. On the other hand, quantitative systems may lack flexibility, but are easier to apply, and, therefore less time consuming. Another advantage of their quantitative nature is the possibility to statistically analyze the results and correlate them with other quantitative indices, such as crop production or productivity.

The development of information technology has led to the implementation of land evaluation procedures in computer programs, eventually linked to the GIS environment, allowing more accurate and faster data processing. One example is the ALES (Automated Land Evaluation System) computer program [12] which allows researchers to build expert systems to evaluate land according to FAO [2] methodological framework and which can be linked to IDRISI v4 GIS software for more detailed spatial analysis. Another example is the implementation of the Dutch WIB-C procedure in the BODEGA 2.1 software [13]. Also, WOFOST (World Food Studies) program [14] has been developed by the Wageningen University to implement the crop production levels approach. Land evaluation methodologies have diversified recently. Hence, there are many examples of studies applying GIS techniques for agricultural land evaluation, using various quantitative methodologies [15–19].

In Romania, the USDA capability classification system was the basis for the elaboration of more detailed capability evaluations for arable land, pastures, vineyards, fruit tree plantations, and forests [20]. On the other hand, the National Institute of Research and Development for Pedology, Agrochemistry and Environmental Protection (ICPA) has developed a complex quantitative land evaluation methodology in the 1980s [20,21] which is still currently applied by the County Offices for Pedology and Agrochemistry (OJSPA) for the assessment of land suitability for agricultural crops at local scales (1:5000 and 1:10,000). The main problem is that it is used with old climate data, from the reference climate period (1961–1990), which leads to questionable results in many parts of the country. The methodology has been implemented in a computer program named BDUST [22], but without any GIS capabilities. Dornik et al. [23] attempted to apply the official land evaluation methodology [20] for Central and Eastern Europe, including Romania, using spatial data extracted from global, Eurasian, and European datasets. Other studies in

Romania have focused on GIS applications for agricultural land suitability assessment, conducted generally at local and regional scales [24–26].

Our study aims to apply the ICPA [20,21] land evaluation methodology in GIS environment, using recent climate data (1990–2019) and high-resolution spatial data, hence, we aim to provide more realistic results at the country level. Furthermore, considering that the methodology is quite old, our study also aims to identify potential methodological problems and propose solutions for their improvement.

2. Materials and Methods

2.1. Study Area

Romania is a mid-sized country (238,390 km²) situated in Eastern Europe. The relief is characterized by the presence of the Carpathian arch in the center of the country, surrounding the Transylvanian Depression, and a gradual transition to lower elevation landforms (Subcarpathians, Wester Hills, Moldavian Plateau, Romanian Plain, Wester Plain) towards the exterior. The mountainous areas are made up of a wide variety of hard rock formations of magmatic, metamorphic, volcanic origin, including also limestones, sandstones, and conglomerates. The hilly and plateau areas are made up of more friable sedimentary rocks (gravels, sands, marls, and clays), while the lithology of the plain regions is dominated by loess and loess-like formations. The climate of the country is temperate continental, with a mean annual temperature of 9.95 °C, for 1990–2019 period, ranging from <0 °C, at elevations more than 2000 m, to >12 °C in the southern, south-eastern and south-western parts of the country. The hottest month is July (mean of 21 °C, and range of 2.5–26 °C), while the coldest month is January (mean of −2 °C, range of −12–3 °C). The mean annual precipitations are about 700 mm yr^{−1}, for 1990–2019 period, ranging from < 400 mm yr^{−1}, in the extreme east (Danube Delta) to >1200 mm yr^{−1} in the mountains at high elevations. The wettest month is June (mean of 94 mm, range of 28–216 mm), while the driest is generally March (mean of 41 mm, range of 20–128 mm).

Regarding the land use/land cover, the arable lands are dominating in the lower elevation (plain) areas, the hills and plateaus are generally characterized by a mixture of arable land, vineyards, orchards and pastures, while the mountain areas are dominated by forests and pastures. The agricultural land extends on more than 133,000 km², representing about 56% of the country (Figure 1). Within agricultural land, the arable land has the highest extension (about 94,000 km², 64%), followed by pastures and hayfields (about 48,000 km², 33%), vineyards and fruit tree plantations (about 4000 km², 3%) (National Institute for Statistics, Romania, <https://insse.ro/cms/en>, accessed on 24 November 2024).

The Romanian methodology of land suitability evaluation for agricultural purposes [20,21,27] comprises 17 factors, which can be grouped as follows:

- *climate factors*: corrected mean annual temperatures and precipitations;
- *terrain factors*: slope, landslides, flooding, and surface moisture excess;
- *soil factors*: gleyzation, stagnic properties, salinization/alkalization, texture, pollution, depth of water table, porosity, calcium carbonate content, pH, edaphic volume, and humus reserve.

Each factor (F_i) is classified and suitability scores, ranging from 0 to 1, are assigned to the classes, varying according to the specific crops. Then, the scores are multiplied to obtain the Land Suitability Index (LSI), ranging from 0 to 100:

$$LSI = 100 \times \prod_{i=1}^{17} F_i, \quad (1)$$

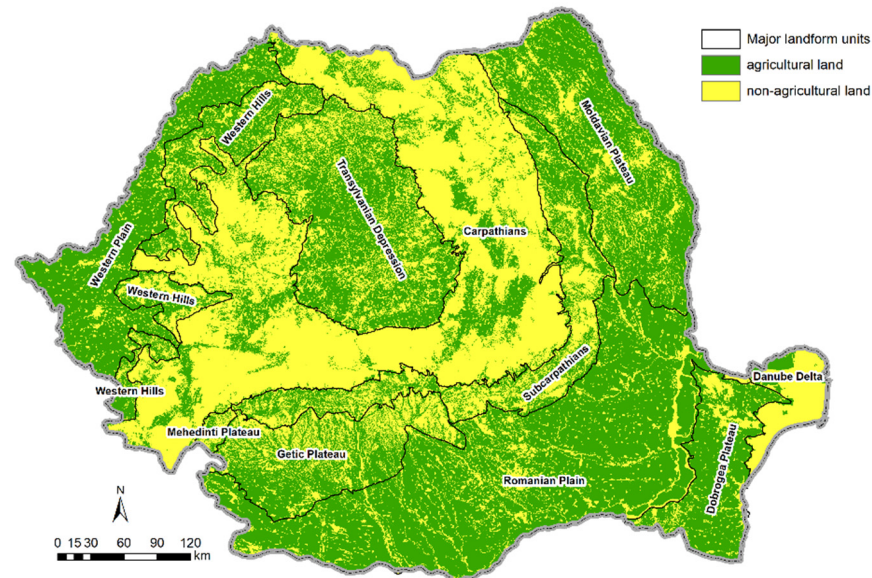


Figure 1. Extent of agricultural land in Romania within the major landform units, according to CLC 2018 (EEA).

2.2. Input Data

To compute the land suitability factors, we used the following input spatial data:

- Climate data:
 - CHELSA database (<https://chelsa-climate.org/> accessed on 24 November 2024) was used to derive the climate factors (mean annual temperatures and precipitations) for 1990–2019 period. This time period was chosen to ensure a 30-year period for land suitability assessment, as it was required by the methodology. The CHELSA database contains raster layers of various climate factors, with a spatial resolution of about 800×800 m [28]. We extracted the mean annual temperatures and precipitations for the Romanian territory, reprojected the maps into the Romanian coordinate reference system (Stereographic 1970) and resampled the data by bilinear interpolation to increase the resolution to 100×100 m.
- Geomorphological data:
 - European Union Digital Elevation Model (EU-DEM, European Environment Agency, <https://ec.europa.eu/eurostat/web/gisco/geodata/digital-elevation-model/eu-dem>, accessed on 24 November 2024), with a resolution of 25×25 m (Figure 2), was used to compute terrain slope and aspect factors, which were further used in the climate factors correction procedures;
 - landslide susceptibility model based on ELSUS methodology [29] was used to derive the landslide factor.
- Soil data:
 - digital soil map of Romania in vector format [30], based on 1:200,000 soil map [31], was used to derive several soil factors (gleyzation, stagnic properties, salinization/alkalization, texture, porosity, edaphic volume);
 - European LUCAS 2015 point database (<https://esdac.jrc.ec.europa.eu/projects/lucas>, accessed on 24 November 2024) [32] spatialized for the Romanian territory by Patriche et al. [33] was used to derive soil reaction, calcium carbonates content and humus reserve;
 - the measured bulk density data were used to achieve a pedotransfer function needed for a continuous mapping of this factor.

- Hydrological data:
 - spatial distribution of wells water depth in over 32,000 points, digitized from 1:50,000 topographic maps (<https://geomil.ro/>, accessed on 24 November 2024), was used to interpolate the water table depth;
 - data regarding the flooding risk, provided by the National Administration of Romanian Waters (<https://inspire-geoportal.ec.europa.eu/>, accessed on 24 November 2024), was used to achieve the flooding factor.

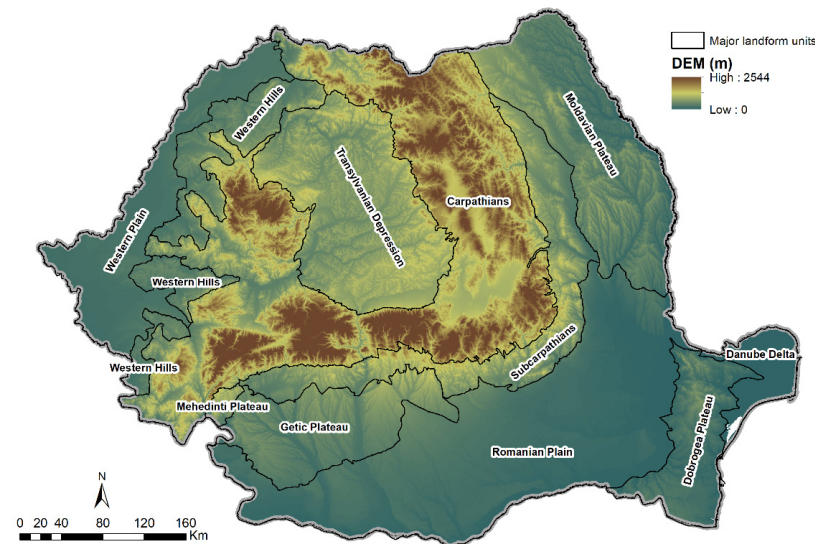


Figure 2. The digital elevation model of Romania (extracted from EU-DEM).

2.3. Computation of Suitability Factors

The *climate factor* group includes the mean annual temperatures and precipitations. These climate variables are corrected to account for the influence of slope and aspect, in the case of temperatures, and slope and soil permeability, in the case of precipitations. In this way, higher temperatures are assigned for southern-facing sloping land, and lower temperatures for northern-facing sloping land, compared to horizontal terrain. In the case of precipitations, the corrected values will be smaller or equal to the uncorrected (horizontal surface) precipitation, because, as the slope becomes steeper, the downslope flow component becomes higher, and less water is useful for plants. But if soil permeability is high, it may compensate for slope influence and allow all rainwater to infiltrate the soil. These corrections were empirically determined by the authors of the original methodology [20,21,27] by measuring the temperature and precipitations under different slope, aspect, and permeability conditions.

To give some examples, slope values under 10% do not influence the temperature; slopes between 10 and 15% will have the same temperature as horizontal surfaces, except the south-facing slopes which will be 1 °C warmer if the horizontal (uncorrected) mean annual temperature is >9 °C. For slopes higher than 15% the temperature differences are more diverse. For instance, if the mean uncorrected annual temperature is 10 °C and the slope is 25–35% then the corrected temperature will be 9 °C for N, NE exposition (shaded terrain), 10 °C for E, NW expositions (semi-shady terrain), 11 °C for S, SW expositions (sunny terrain) and 11 °C also for W, SE expositions (semi-sunny terrain). The temperature differences with respect to the horizontal surfaces can go as high as 3 °C.

In the case of precipitations, corrections begin to be applied for slope values > 2%. For example, if the uncorrected precipitation is 450 mm yr⁻¹, the slope is between 2 and 5%, and soil permeability is very low, then the corrected precipitations will be 400 mm yr⁻¹, which means a 50 mm yr⁻¹ loss of rainwater due mainly to the slow infiltration rate. The differences between uncorrected and corrected precipitation values may go as high as

900 mm yr⁻¹ for uncorrected precipitations > 1400 mm yr⁻¹, slopes >100%, and very low permeable soils.

We applied these corrections by assigning numerical codes of different magnitude to temperature/precipitation, slope, aspect, and permeability classes and by adding them to achieve unique combinations, to which we further assigned the corrected temperature and precipitation values. Figure 3 shows the effect of these corrections compared to the uncorrected (elevation) spatial models.

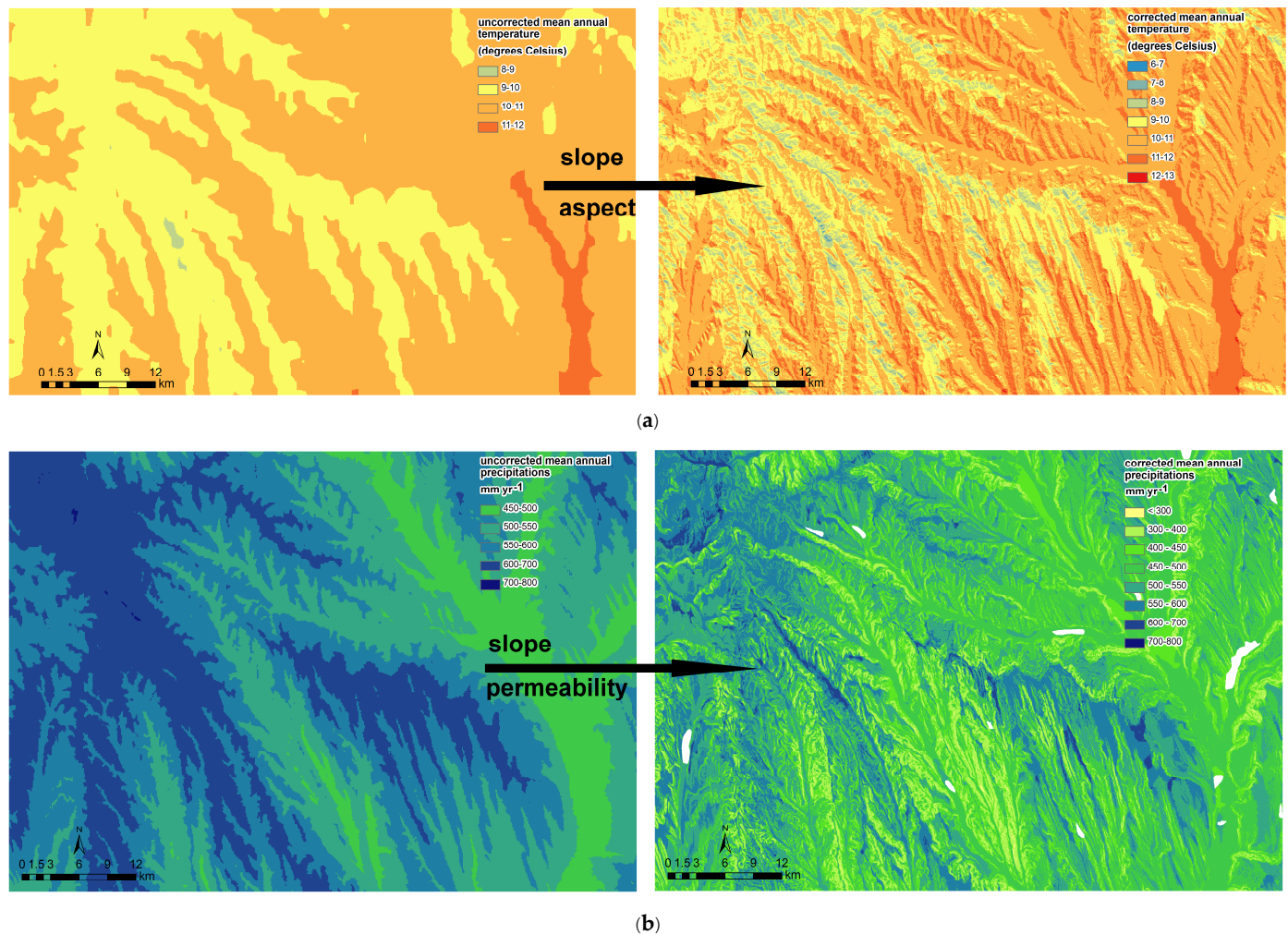


Figure 3. Corrections applied to the mean annual temperature (a) and precipitations (b).

We noticed that the methodology does not include mean annual temperatures over 12 °C, which were not present on the Romanian territory during the 1961–1990 period, but which are quite generalized in the lower plain areas of the country nowadays.

Among the *terrain factors*, the slope was computed from EU-DEM at 25 × 25 m resolution and it was expressed in percentages. The landslide factor was computed based on the landslide susceptibility model proposed by Grozavu and Patriche [29] for the entire Romanian territory. The methodology requires an inventory of active, semi-stabilized, and stabilized landslides for this factor. Since such information was not available at country scale, we substituted the 3 categories with the very high, high, and medium landslide susceptibility classes. This correspondence was suggested by the overlay between landslide susceptibility classes and the landslide polygon database used by the authors [29]. Clearly, the very high and high susceptibility classes were dominated by landslides, either active or inactive. Restrictions for crops should also be applied to land falling into the medium susceptibility class, even though landslides may not manifest at present, because of its potential for landslide activation. The flooding risk was assessed based on the spatial data

provided by the National Administration of Romanian Waters (<https://inspire-geoportal.ec.europa.eu/>, accessed on 24 November 2024). The surface moisture excess was not considered in our study because it was thought to be redundant with the stagnic factor. Moreover, this factor is useful for local scale assessments because it refers mainly to the presence of micro-depressions with excess moisture, which are mappable at fine scale (such as 1:10 k scale usually used in soil studies by Soil Survey Offices from Romania at county level), but not at country scale.

The *soil factor* category includes most of the suitability factors. The attribute table data provided by the soil map of Romania [30] was used to map soil gleization, stagnic properties, salinization/alkalization, and edaphic volume based on soil types.

The LUCAS 2015 database [32] was used to determine pH, CaCO₃ content, and soil humus reserve. We used the spatial models for pH and CaCO₃ achieved by Patriche et al. [33]. The soil humus reserve was computed according to the following formula [27]:

$$HR = Hum \times D \times BD, \quad (2)$$

where

- *HR*—humus reserve (t ha^{−1});
- *Hum*—humus content (%);
- *D*—depth of soil layer (50 cm in our study);
- *BD*—bulk density (g cm^{−3}).

The humus content (*Hum*) was calculated by multiplying the soil organic carbon (SOC) content with the 1.724 factor, while the organic carbon content was taken from Patriche et al. [33], who modeled this parameter based on LUCAS 2015 data [32]. The bulk density was computed by using an exponential type pedotransfer function, based on the humus content, using a database compiled by Vasiliniuc and Patriche [34]:

$$BD = 1.41862 e^{-0.04421 \times Hum} \quad (3)$$

According to the methodology, humus reserve must be assessed in the first 50 cm of soil. Therefore, the *D* factor is 50 in our case.

Soil porosity was computed based on the bulk density, total soil density, and clay content, according to the following formulas [27]:

$$TP = 100 \times (1 - BD/D), \quad (4)$$

$$P_{min} = 45 + 0.163 \times C, \quad (5)$$

$$CD = 100 \times (P_{min} - TP)/P_{min}, \quad (6)$$

where

- *TP*—total soil porosity (%);
- *BD*—bulk density (g cm^{−3});
- *D*—total soil density (g cm^{−3});
- *P_{min}*—minimum necessary porosity (%);
- *C*—clay content (%);
- *CD*—compaction degree (%).

The total soil density, which is that of soil material, was considered constant in our study (2.665 g cm^{−3}, which is the middle of 2.65–2.68 g cm^{−3} interval as specified by Canarache [35] for upper soil horizons).

The water table depth was interpolated from wells water depth, digitized from 1:50,000 topographic maps (<https://geomil.ro/>, accessed on 24 November 2024), using ordinary kriging method.

The pollution was not considered in our study because there were no data available for this factor.

2.4. Computation of Factor Suitability for Agricultural Crops

According to the methodology [20], the suitability of the factors is expressed by means of suitability scores, ranging from 0 (no suitability) to 1 (very suitable, no restrictions). These scores differ according to specific crops. In our study, we considered the 5 main crops of Romania, namely winter wheat, maize, sunflower, potato, and vine for wine. The suitability factors were recorded in the attribute table of classified raster layers representing the suitability factors, and then exported as raster maps. The assessment of the suitability factor is more complicated in the case of several factors because they are evaluated in relation to other factors: precipitations are evaluated in relation to temperature; texture in relation to porosity; water table depth in relation to precipitations and soil texture; porosity in relation to texture; soil reaction in relation to base saturation degree; edaphic volume in relation to precipitations; and humus reserve in relation to texture. In these situations, we had to record multiple suitability scores, export them all as raster layers and integrate them conditionally in order to obtain the factor suitability. For instance, in the case of pH, which is evaluated in relation to base saturation, we recorded two columns of scores in the attribute table of the classified pH map, exported them as two maps, corresponding to base saturations under 55% and over 55%, respectively, then integrated the maps conditionally (if base saturation is <55% take the values from one map, otherwise from the other map) in order to achieve the pH suitability map.

3. Results

3.1. Changes in Temperature and Precipitations

In order to see if there are significant temporal changes in the mean annual temperature and precipitations across Romania, we made a comparison of two time periods, 1961–1990, which is the reference climate period, unaffected or weakly affected by climate change, and the recent 1990–2019 period, significantly affected by climate change. For the reference period, we used the ROCADA database [36], compiled by the National Meteorological Administration and processed by Patriche and Irimia [37], while for the recent period, we used the CHELSA database, as already mentioned.

The temperature maps (Figure 4a,b) show significant differences between the two time periods. Overall, the mean annual temperature has increased in Romania by 1.27 °C, from 8.68 °C to 9.95 °C (Table 1). The climate warming is very clear, especially in the lower elevation areas (hills, plateau, and plain areas): Romanian Plain with the highest temperature increase (1.6 °C); Western Plain and Transylvanian Depression with 1.5 °C increase; and Western Hills, Dobrogea Plateau, and Danube delta with 1.4 °C increase. We noticed that the manifestation of the mean annual temperatures of >12 °C in the recent period (1990–2019) on about a quarter of the Romanian territory, while these temperatures were not present in the reference period (1961–1990).

Table 1. Comparison between means and standard deviations of uncorrected mean annual temperature and precipitations for 1961–1990 and 1990–2019 periods.

Major Landform Unit	Temperatures (°C)					Precipitations (mm yr ^{−1})				
	1961–1990		1990–2019		Difference	1961–1990		1990–2019		Difference
	Mean	Std	Mean	Std		Mean	Std	Mean	Std	
Carpathians	6.1	2.10	7.0	2.30	0.9	785.7	144.5	904.4	210.5	118.8
Subcarpathians	8.8	0.85	9.7	0.94	0.9	648.6	80.3	698.8	100.7	50.2
Transylvanian Depression	8.0	0.83	9.5	0.74	1.5	621.8	61.3	687.2	105.7	65.4
Western Hills	9.6	0.64	10.9	0.69	1.4	672.7	59.3	751.9	111.2	79.2
Mehedinti Plateau	9.2	0.87	10.1	0.86	0.9	767.8	52.1	865.8	106.9	97.9
Getic Plateau	10.1	0.54	11.4	0.87	1.3	651.7	48.1	699.6	68.4	47.9
Moldavian Plateau	8.9	0.70	10.2	0.71	1.3	538.0	33.6	569.8	47.1	31.8
Western Plain	10.3	0.38	11.8	0.35	1.5	596.0	44.4	630.5	54.8	34.5
Romanian Plain	10.7	0.33	12.3	0.55	1.6	525.6	53.8	570.3	53.6	44.7
Dobrogea Plateau	10.7	0.49	12.1	0.50	1.4	423.0	25.3	497.2	41.6	74.2
Danube Delta	11.1	0.07	12.5	0.25	1.4	356.1	22.1	365.3	38.2	9.3
Romania	8.68	2.21	9.95	2.47	1.27	631.8	145.4	700.6	193.4	68.8

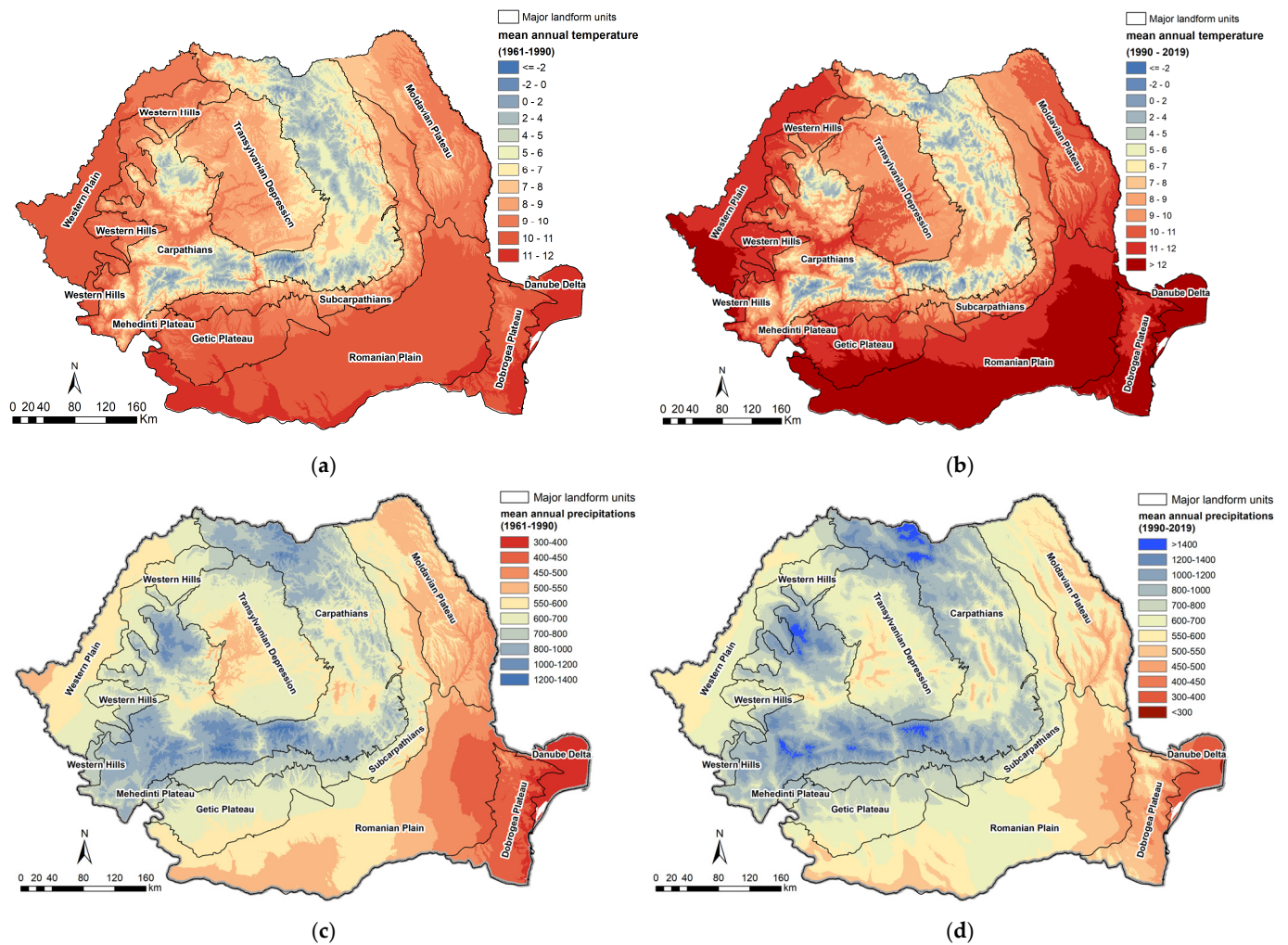


Figure 4. Mean annual temperature (a,b) and precipitation (c,d) maps of Romania for 1961–1990 (a,c), and 1990–2019 (b,d) periods.

In the case of the mean annual precipitations, we noticed a general slight increase in the values across the country (Figure 4c,d), from an average of 631.8 mm yr^{-1} to 700.6 mm yr^{-1} (Table 1), which is the highest in the Carpathians area (118.8 mm yr^{-1}). Among the lower elevation areas, dominated by agricultural lands, the highest precipitation increase is found in the Western Hills (79.2 mm yr^{-1}) and Dobrogea Plateau (74.2 mm yr^{-1}).

These temperature and precipitation changes may have significant impacts on land suitability for agricultural crops, which makes imperative the use of recent climate data for this purpose.

3.2. Suitability Factors

The suitability factors are presented in Figures 5–7, grouped into climate (Figure 5), terrain (Figure 6) and soil factors (Figure 7).

In the case of the mean annual temperatures, we notice that, while the maximum uncorrected values were in the $12\text{--}13^\circ\text{C}$ interval for 1990–2019, the corrected temperature values, according to terrain slope and aspect influences, can increase over 13°C and even 14°C . This situation poses a methodological problem since the current methodology does not consider such high-temperature values. The modal class for the corrected temperatures is $12\text{--}13^\circ\text{C}$ (21.8% for the entire Romania and 29.3% for the agricultural land only). In the case of mean annual precipitations, the modal class is $550\text{--}600 \text{ mm yr}^{-1}$ (25.9% of the country and 32.7% of the agricultural area).

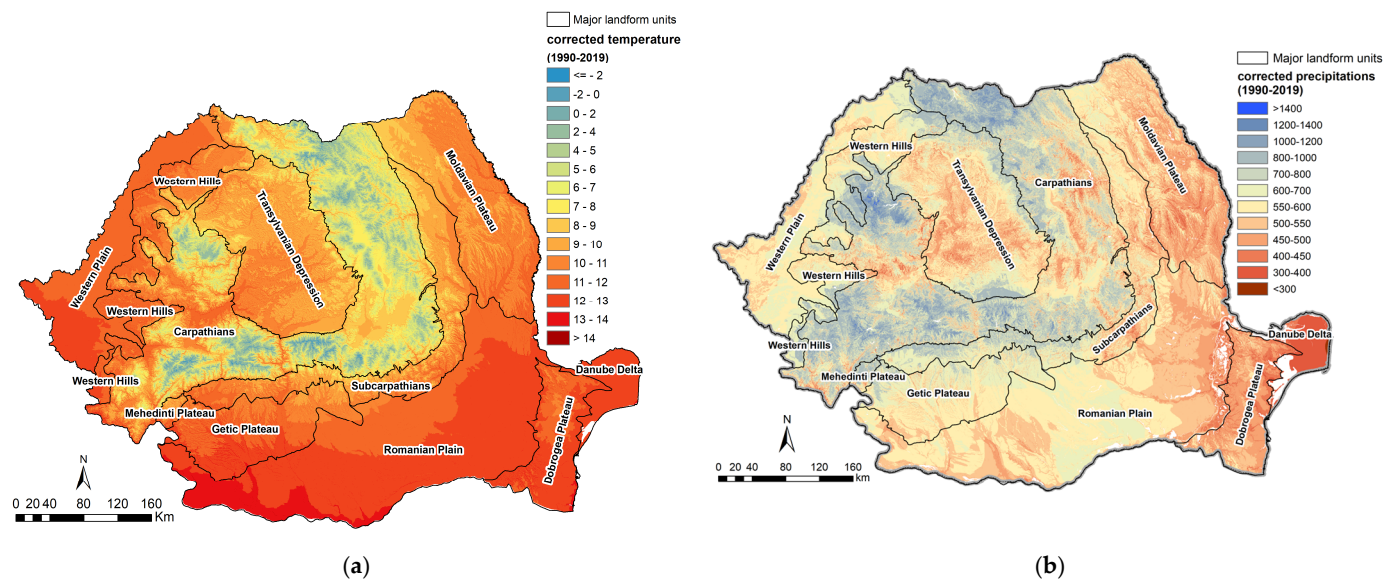


Figure 5. Climate factors: corrected mean annual temperatures (a) and precipitations (b) for 1990–2019 period.

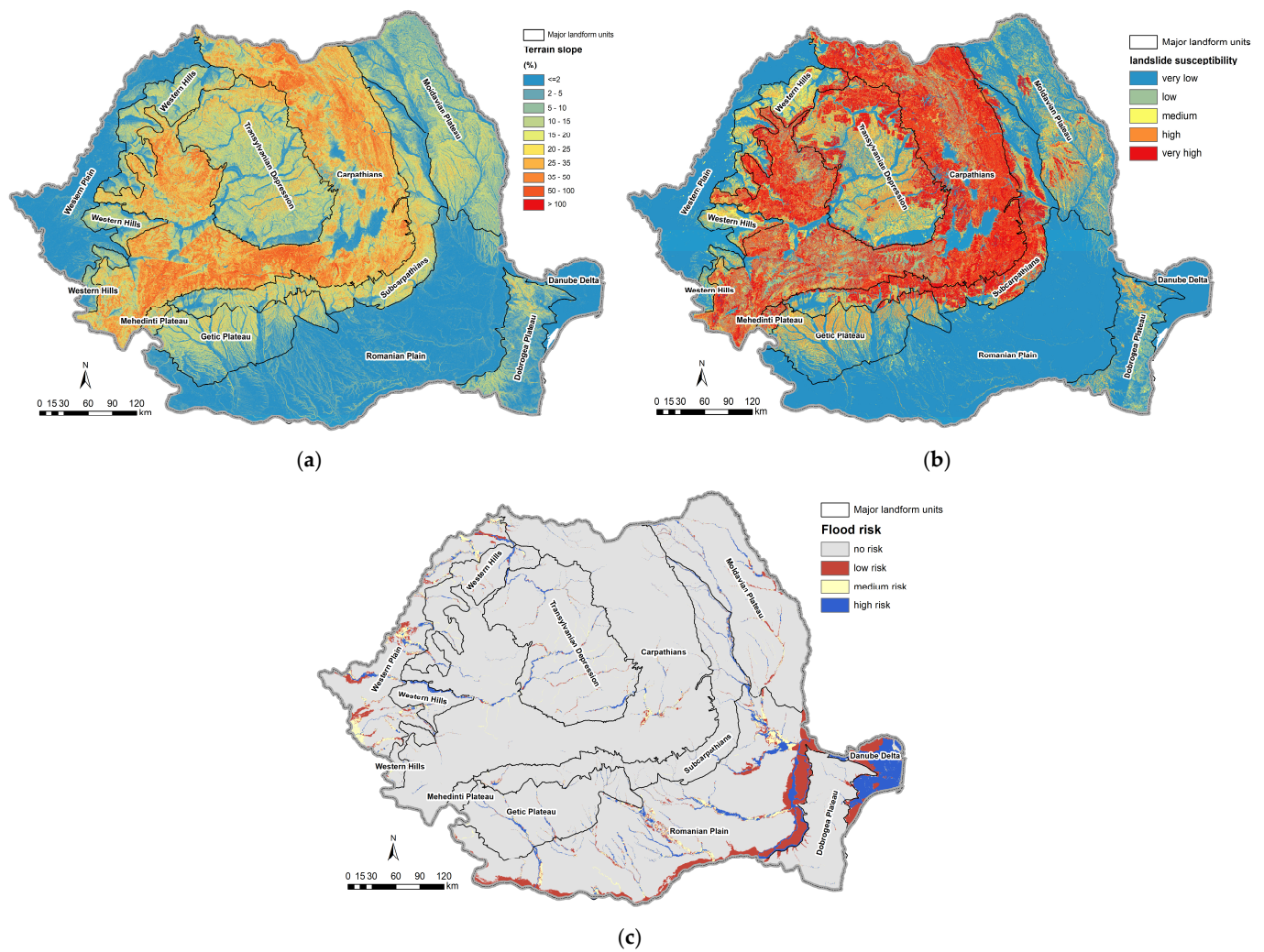


Figure 6. Terrain factors: slope (a), landslide susceptibility (b) and flood risk (c).

The terrain slope is dominated by low values, the modal class being $\leq 2\%$ (30.7% of the country and 43.5% of the agricultural land). Landslide susceptibility is generally low in Romania, with 50.5% of the country and 68.0% of the agricultural land being in the very low susceptibility class. However, 15.6% of the agricultural land falls into the high and very high landslide susceptibility class, mostly corresponding to overgrazed degraded pastures. The flood risk is present along the main river valleys. There is a high flooding risk for 3.6% of the country and on 2.2% of the agricultural land.

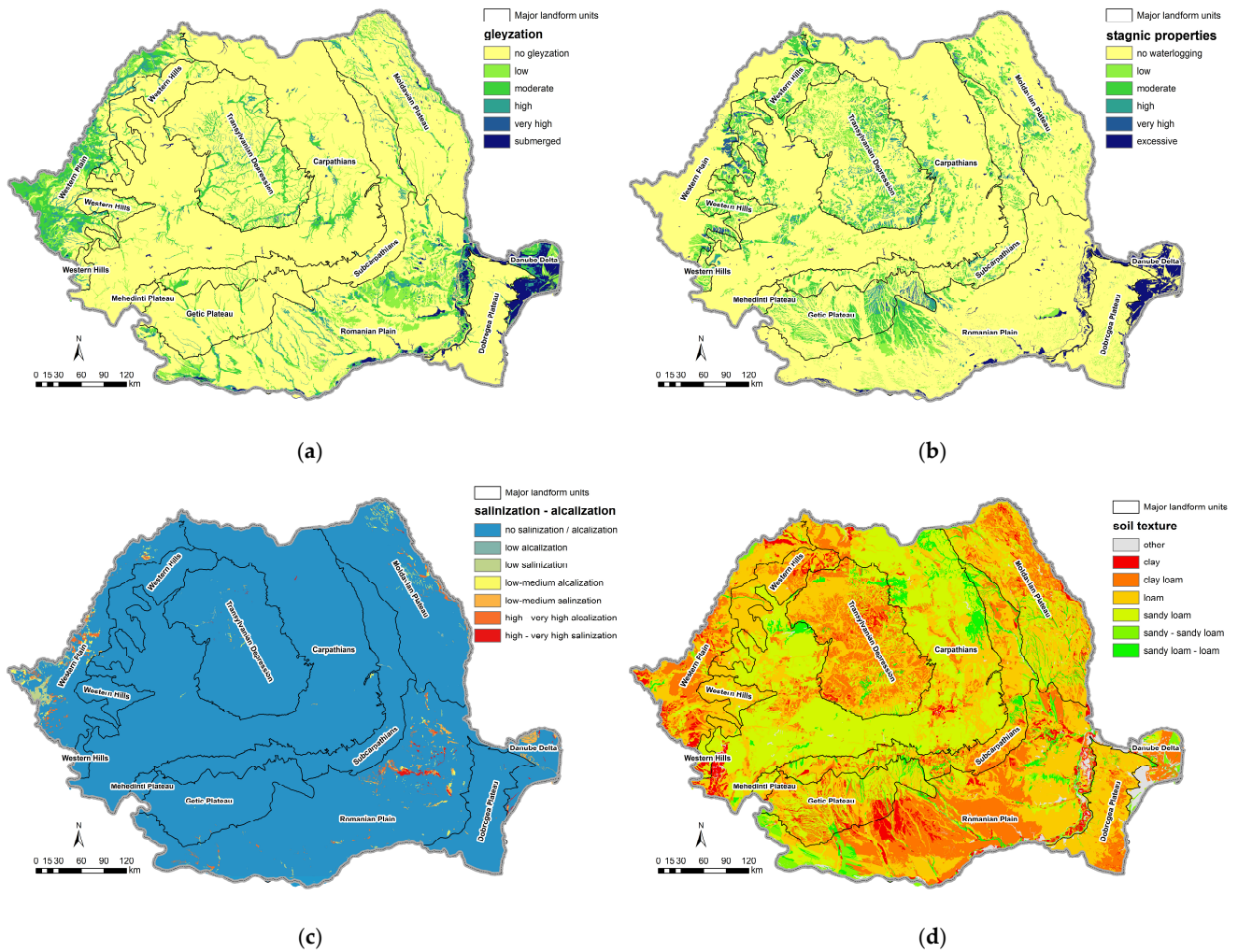


Figure 7. Cont.

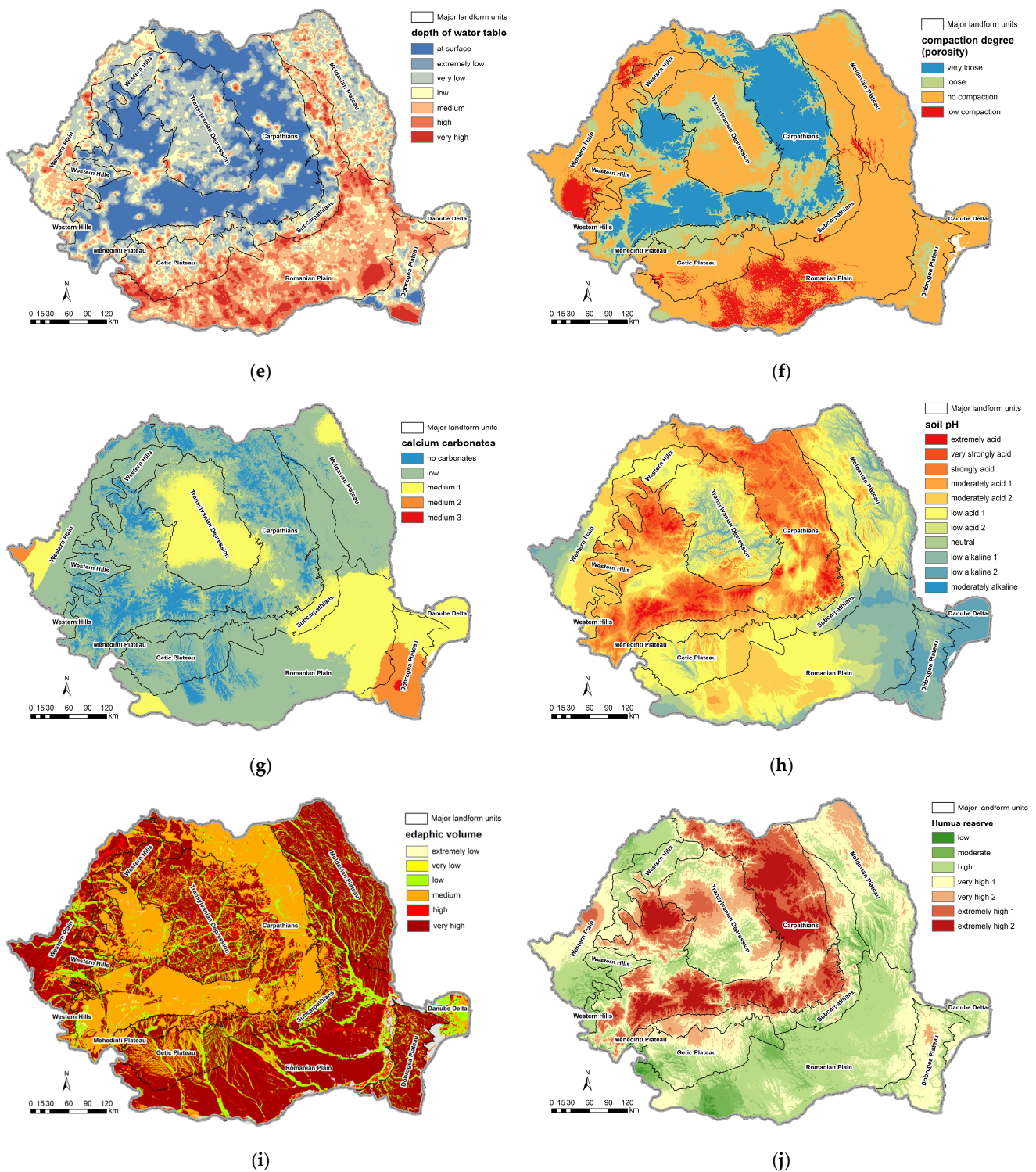


Figure 7. Soil factors: gleization (a), stagnic properties (b), salinization-alkalinization (c), soil texture (d), depth of water table (e), porosity (f), calcium carbonates (g), soil reaction (h), edaphic volume (i), humus reserve (j).

Among the soil factors, water excess is present in 6.4% of the country as gleization and in 4.8% as stagnic properties, while the agricultural areas are affected in 6.6% and 3.9%, respectively, by these restrictive factors. Salinization/alkalinization is a local process which may affect soils along floodplains or situated on slopes intersecting salt deposits. Different degrees of salinization/alkalinization are specific for only in 2.0% of the country and 3.1%

of the agricultural land. Regarding soil texture, the most widespread class is loam (39.0% of the country and 45.7% of the agricultural land), very suitable for crops, followed by sandy loam and clay loam. In the case of water table depth, the modal class is the very low class (1–2 m for loamy and clay textures, 0.75–1 m for sandy texture) which has an overall share of 21.2% of Romania). However, on agricultural lands, the dominant class is the medium one (3–5 m for loamy and clay textures, 2–4 m for sandy texture) with a share of 24.8%. Regarding soil porosity, most of the Romanian soils are not compacted, which is very suitable for agriculture; low compaction affects 6.5% of the country and 9.5% of the agricultural land. Locally, there may be soils affected by higher degrees of compaction, but they are not depictable at the country scale. Calcium carbonates are generally present in low quantities in agricultural soils (57.9% of the country and 60% of the agricultural land). Medium carbonates contents occur in drier climatic conditions like in Dobrogea Plateau or eastern Romanian Plain. Soil reaction is generally weakly acid (24.7% of the country and 29.5% of agricultural land). Soils with strong acidity are present in 15.5% of the country, but only in 2.5% of agricultural land, while soils with moderate or higher alkalinity occur on very small surfaces. The edaphic volume is generally very high (51.8% of the country and 64.5% of agricultural land), and thus, very suitable for agriculture. This factor becomes restrictive mainly along the floodplains or on steep slopes where soils are weakly developed. The soil humus reserve is generally high in Romania; soils with medium and low humus reserves occur in 5.6% of the country (6.9% of the agricultural land), mainly on sandy deposits or steep slopes.

3.3. Land Suitability for the Main Crops

In our study, we analyzed the land suitability for the five main crops in Romania, which dominate the agricultural area: winter wheat, maize, sunflower, potato, and vine for wine. The values of the land suitability index (LSI) were classified into ten suitability classes: from class X (0–10 suitability scores, the lowest suitability class) to class I (90–100 suitability scores, the highest suitability class). We analyzed the distribution of land suitability index (LSI) values for the major landform units of Romania and for the agricultural lands within them (Tables 2–6).

Table 2. Suitability statistics for winter wheat on agricultural land for the major landform units.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Carpathians	13,405.7	21.9	23.8	X (0–10)—47.6%
Subcarpathians	8502.8	46.4	27.3	VII (30–40)—13.9%
Transylvanian Depression	16,797.0	30.2	19.5	VIII (20–30)—20.7%
Western Hills	7791.6	42.8	22.1	VII (30–40)—21.6%
Mehedinți Plateau	332.2	30.7	20.8	VIII (20–30)—23.1%
Getic Plateau	8098.8	52.9	23.5	III (70–80)—15.7%
Moldavian Plateau	16,917.7	56.3	24.6	II (80–90)—22.6%
Western Plain	13,857.6	61.0	24.6	II (80–90)—18.4%
Romanian Plain	39,196.8	64.2	23.6	II (80–90)—28.4%
Dobrogea Plateau	7880.4	57.2	23.5	II (80–90)—20.2%
Danube Delta	514.9	28.4	18.2	VIII (20–30)—26.1%
<i>Romania</i>	<i>133,295.5</i>	<i>50.5</i>	<i>27.8</i>	<i>II (80–90)—16.6%</i>

Table 3. Suitability statistics for maize on agricultural land for the major landform units.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Carpathians	13,405.7	20.0	23.8	X (0–10)—52.4%
Subcarpathians	8502.8	41.4	27.2	IX (10–20)—15.9%
Transylvanian Depression	16,797.0	27.3	19.6	X (0–10)—22.2%
Western Hills	7791.6	42.9	23.6	VII (30–40)—21.8%
Mehedinți Plateau	332.2	27.6	20.1	VIII (20–30)—22.6%

Table 3. Cont.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Getic Plateau	8098.8	53.3	25.7	II (80–90)—15.1%
Moldavian Plateau	16,917.7	52.8	25.2	V (50–60)—15.3%
Western Plain	13,857.6	65.4	26.5	II (80–90)—19.9%
Romanian Plain	39,196.8	69.3	25.4	III (70–80)—28.1%
Dobrogea Plateau	7880.4	58.0	24.1	III (70–80)—37.4%
Danube Delta	514.9	29.9	19.9	IX (10–20)—41.8%
<i>Romania</i>	<i>133,295.5</i>	<i>51.3</i>	<i>30.1</i>	<i>III (70–80)—14.9%</i>

Table 4. Suitability statistics for sunflowers on agricultural land for the major landform units.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Carpathians	13,405.7	18.6	22.6	X (0–10)—54.9%
Subcarpathians	8502.8	40.5	26.5	IX (10–20)—14.8%
Transylvanian Depression	16,797.0	26.8	18.9	X (0–10)—24.0%
Western Hills	7791.6	42.7	22.1	VII (30–40)—21.3%
Mehedinți Plateau	332.2	27.2	20.0	IX (10–20)—22.9%
Getic Plateau	8098.8	52.9	25.0	III (70–80)—18.0%
Moldavian Plateau	16,917.7	52.1	23.1	V (50–60)—17.2%
Western Plain	13,857.6	64.8	23.2	II (80–90)—20.2%
Romanian Plain	39,196.8	67.4	21.7	II (80–90)—30.7%
Dobrogea Plateau	7880.4	55.9	21.8	III (70–80)—31.3%
Danube Delta	514.9	41.4	16.6	VII (30–40)—44.5%
<i>Romania</i>	<i>133,295.5</i>	<i>50.2</i>	<i>28.1</i>	<i>III (70–80)—16.0%</i>

Table 5. Suitability statistics for potato on agricultural land for the major landform units.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Carpathians	13,405.7	17.3	21.8	X (0–10)—57.4%
Subcarpathians	8502.8	33.5	25.2	X (0–10)—23.2%
Transylvanian Depression	16,797.0	19.3	16.4	X (0–10)—37.4%
Western Hills	7791.6	27.7	17.7	IX (10–20)—24.6%
Mehedinți Plateau	332.2	20.6	17.3	X (0–10)—32.2%
Getic Plateau	8098.8	34.8	18.2	VI (40–50)—19.1%
Moldavian Plateau	16,917.7	37.4	20.7	VII (30–40)—20.5%
Western Plain	13,857.6	43.1	17.7	V (50–60)—23.8%
Romanian Plain	39,196.8	41.7	13.9	VI (40–50)—30.9%
Dobrogea Plateau	7880.4	30.6	14.2	VII (30–40)—30.6%
Danube Delta	514.9	15.5	7.3	X (0–10)—37.0%
<i>Romania</i>	<i>133,295.5</i>	<i>33.5</i>	<i>20.1</i>	<i>VII (30–40)—17.1%</i>

Table 6. Suitability statistics for vine for wine on agricultural land for the major landform units.

Landform Unit	Agricultural Area (km ²)	Mean LSI	Standard Deviation	Modal Suitability Class
Carpathians	13,405.7	13.6	20.4	X (0–10)—65.2%
Subcarpathians	8502.8	39.9	29.7	X (0–10)—18.5%
Transylvanian Depression	16,797.0	20.3	18.9	X (0–10)—41.6%
Western Hills	7791.6	33.1	23.3	X (0–10)—19.6%
Mehedinți Plateau	332.2	21.2	21.5	X (0–10)—36.8%
Getic Plateau	8098.8	51.4	25.5	III (70–80)—21.0%
Moldavian Plateau	16,917.7	51.1	26.7	VI (40–50)—21.2%
Western Plain	13,857.6	52.8	26.4	III (70–80)—18.6%
Romanian Plain	39,196.8	66.7	22.7	III (70–80)—39.3%
Dobrogea Plateau	7880.4	54.5	25.4	III (70–80)—23.5%
Danube Delta	514.9	18.6	15.6	X (0–10)—38.4%
<i>Romania</i>	<i>133,295.5</i>	<i>33.4</i>	<i>31.7</i>	<i>III (70–80)—20.2%</i>

According to Corine Land Cover 2018 data [38], the agricultural land of Romania totals 133,295 km², including arable land, permanent crops (vineyards, fruit trees), pastures, and heterogeneous agricultural areas. Most of the agricultural land is found in the lower elevation areas, in the Romanian Plain (39,196.8 km²), the Moldavian Plateau (16,917.7 km²), and the Transylvanian Depression (16,797.0 km²) (Table 2). The non-agricultural area covers a surface of about 99,768 km².

Factor suitability for winter wheat, expressed by scores between zero and one, is given as an example in Figure 8. We notice that the range is not the same for all factors. Some have the entire variation range (0–1), like the mean annual temperature and precipitations, while other factors have a narrower range (e.g., compaction degree, humus reserve). Also, we see that some factors act as restrictive locally (e.g., flood risk, gleyzation, edaphic volume along floodplains), while other factors have more widespread restrictiveness (e.g., temperature, precipitations, soil texture, and water table depth). However, one cannot very accurately say which factor is the most restrictive, because their suitability scores vary in space. So, precipitations may impose restrictions in the eastern part of the country (therefore, irrigation is required here), but not in the western part, temperatures are suitable in the northern half of the country, but less suitable in the south and so forth. The values of suitability scores for all factors and crops are given in Annex S1 in Supplementary Material.

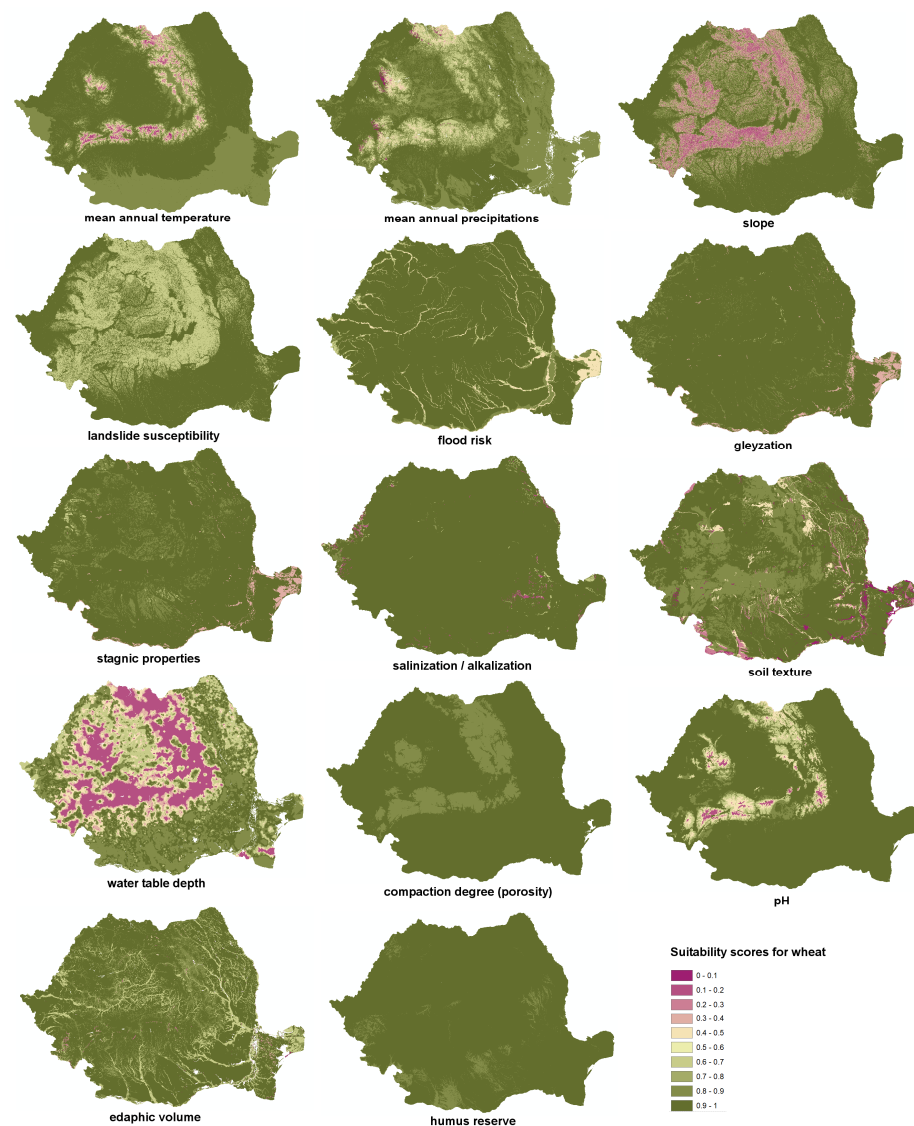


Figure 8. Factor suitability scores for winter wheat (Note: calcium carbonates are not presented because they have a value of one throughout the country).

The integration of all these factors in the LSI formula shows that, for **winter wheat**, the most favorable landform units are the plain areas (Table 2). The Romania Plain and Western Plain have average LSI values over 60, while the modal suitability class is II, with shares of 28.4% and 18.4%, respectively. These are followed by the Moldavian Plateau and Dobrogea Plateau with LSI values over 56 and modal suitability classes also of II, which have shares of 22.6% and 20.2%, respectively. Locally, the most suitable areas for winter wheat are found in the central and eastern parts of the Romanian Plain, in smaller patches in the northern part Moldavian Plateau, and in parts of the Western Plain (Figure 9).

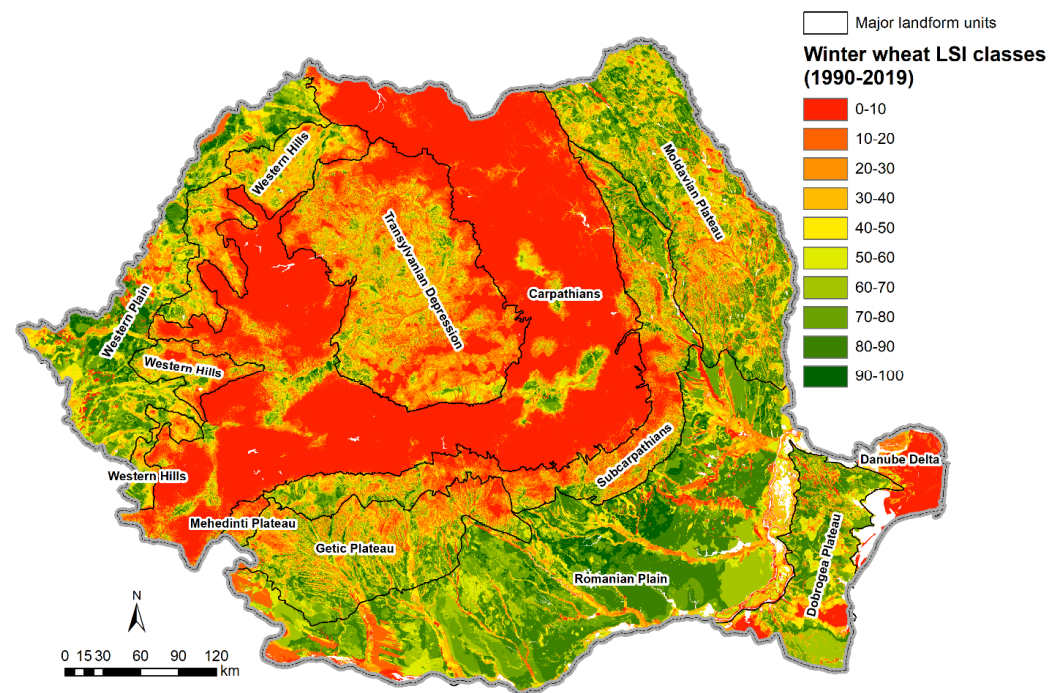


Figure 9. Suitability map for winter wheat.

The least suitable areas for winter wheat are found obviously in the mountain area (mean LSI values is 21.9 and modal class is X, with a share of 47.6%), due mainly to climatic and terrain restrictions, the Danube Delta (mean LSI values is 18.2 and modal class is VIII, with a share of 26.1%), due mainly to water-related problems (gleization, stanic properties, and flooding). Also, less suitable for winter wheat is the Transylvanian Depression, which has a mean LSI value of 30.2 and a modal suitability class of VIII with a share of 20.7%.

In the case of **maize**, our analysis shows that the highest suitability is specific also to the plain areas (Romanian Plain, with a mean LSI of 69.3 and a modal class of III with a share of 28.1%; Western Plain, with a mean LSI of 65.4 and a modal class of II with a share of 19.9%) (Table 3, Figure 10). Also, suitable areas for maize are found within Dobrogea Plateau (mean LSI of 58 and modal class III with 37.4%) and Getic Plateau (mean LSI of 53.3 and modal class II with 15.1%). The least suitable terrains for maize, besides the Carpathians and the Danube Delta, are found in the Transylvanian Depression (mean LSI of 27.3 and modal class X with 22.2%). In the Subcarpathians, the situation is varied. While the Curvature Subcarpathians are generally unsuitable for maize, there are areas suitable in the northern Moldavian Subcarpathians and Getic Subcarpathians, which cause the apparent contradiction between the modal class IX (15.9%) and the higher mean LSI (41.4).

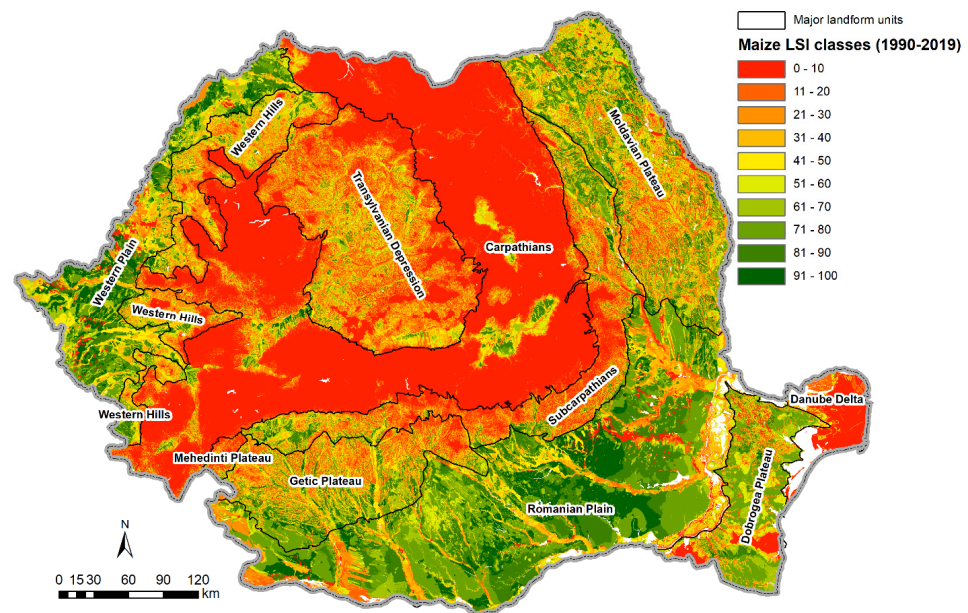


Figure 10. Suitability map for maize.

For **sunflower**, the suitability spatial patterns are similar to those of winter wheat and maize (Table 4, Figure 11). The most suitable areas are found within the plain units (Romanian Plain with a mean LSI of 67.4 and a modal class of II with a share of 30.7%; Western Plain with a mean LSI of 64.8 and a modal class of II with a share of 20.2%). These landform units are followed by the Dobrogea Plateau and Getic Plateau with mean LSI values of 55.9 and 52.9, respectively, and modal classes of III. The lowest suitability characterizes the mountainous areas (mean LSI of 18.6, modal class of X—54.9%) and the Transylvanian Depression (mean LSI of 26.8, modal class of X—24.0%). Again, there is an apparent contradiction in the case of the Subcarpathians, where the modal class is IX (14.8%), indicating the dominance of unsuitable lands, while the mean LSI is higher (40.5). This is due to the presence of suitable areas for sunflowers in some parts of the Subcarpathians, which determines a higher mean LSI value.

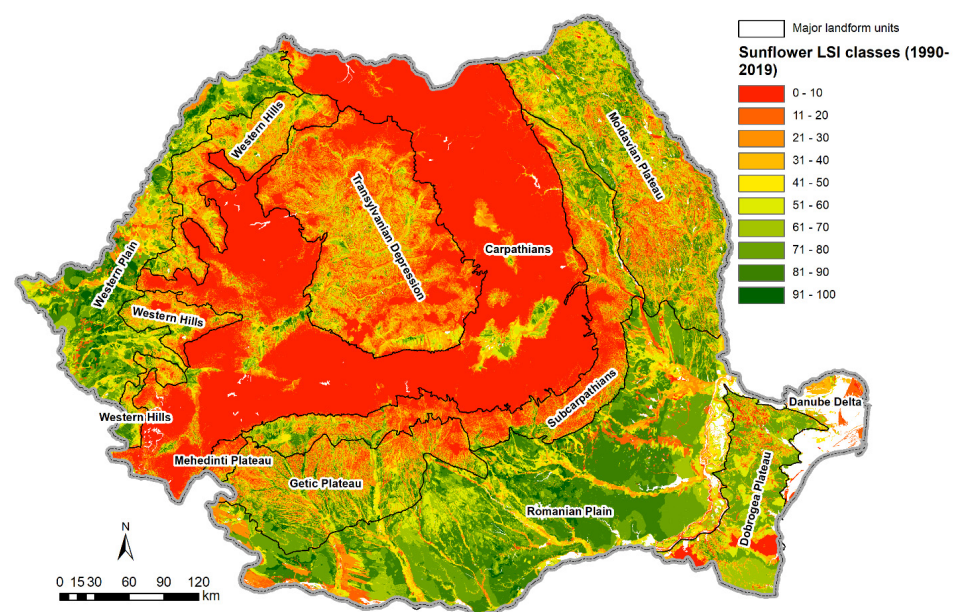


Figure 11. Suitability map for sunflower.

In the case of **potato**, the statistics computed for the major landform units are not so relevant. That is because potatoes are a less widespread crop, with more specific ecological conditions, which means that suitable lands cover quite small areas within the major landform units. As shown in Table 5, the overall land suitability for potatoes is reduced in Romania, which is true at the level of the major landform units, where the modal classes are either unsuitable or marginally suitable. As shown in the map in Figure 12, within these large landform units, there are areas suitable for potatoes, like the northern Subcarpathians, the north-west of the Moldavian Plateau (Suceava Plateau), the intra-mountainous depressions, or parts of the Western Plain.

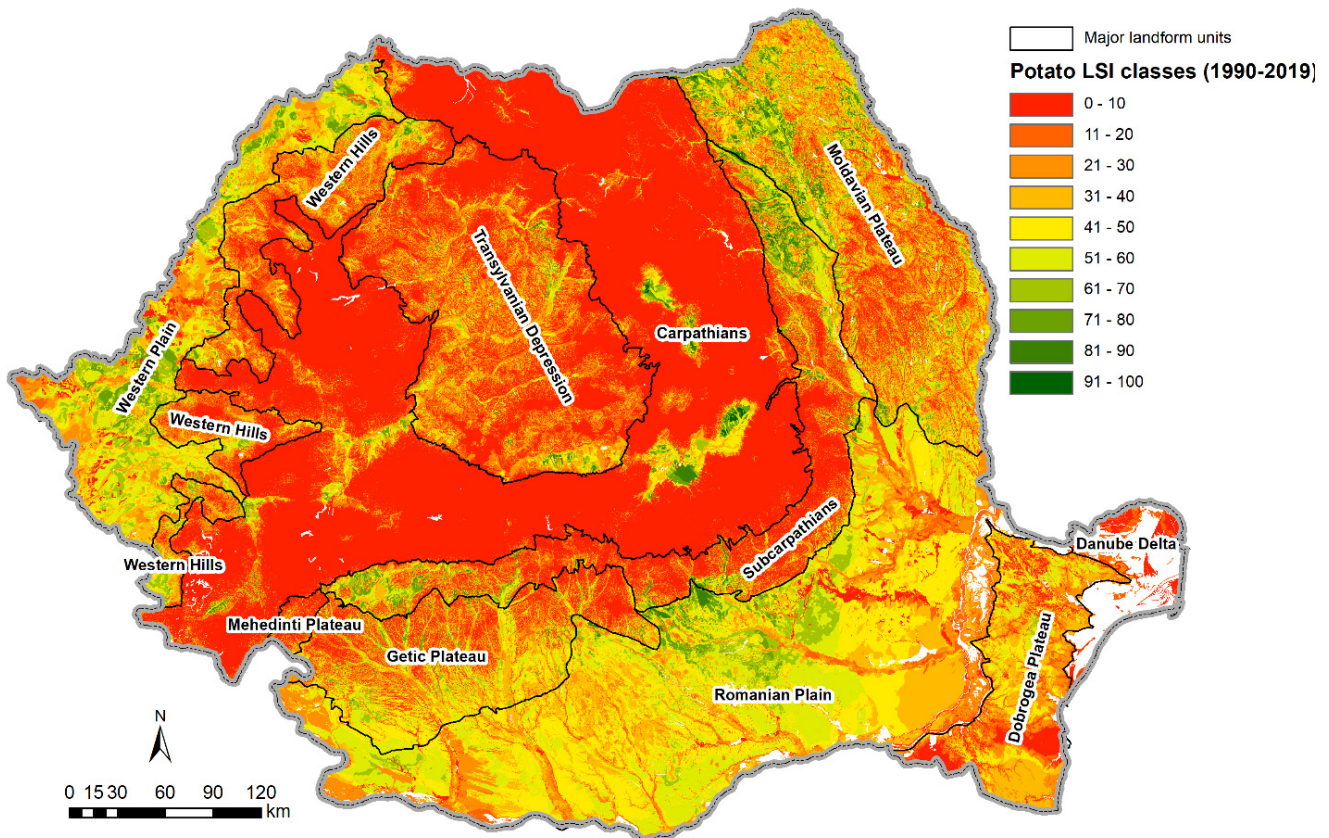


Figure 12. Suitability map for potato.

This interpretation is partially valid for **vine**. Again, the statistics extracted for the major landform units are not so relevant. Table 6 shows that there is higher suitability in plateau areas such as the Getic and the Dobrogea Plateaus, as well as in the Western and Romanian Plains. However, in the plain areas, many suitable lands for vines are situated adjacent the hilly areas (Subcarpathians, Western Hills). For this reason, the plain areas appear more suitable and the hilly areas less suitable, when many suitable lands for vines are found in the Subcarpathians, especially at their curvature sector. The map of vine suitability (Figure 13) shows that the most suitable lands for vines are found at the contact between the Subcarpathians and the Romania Plain, on piedmont deposits. Locally, other suitable areas are found in the Dobrogea Plateau, Moldavian Plateau, and Western Plain.

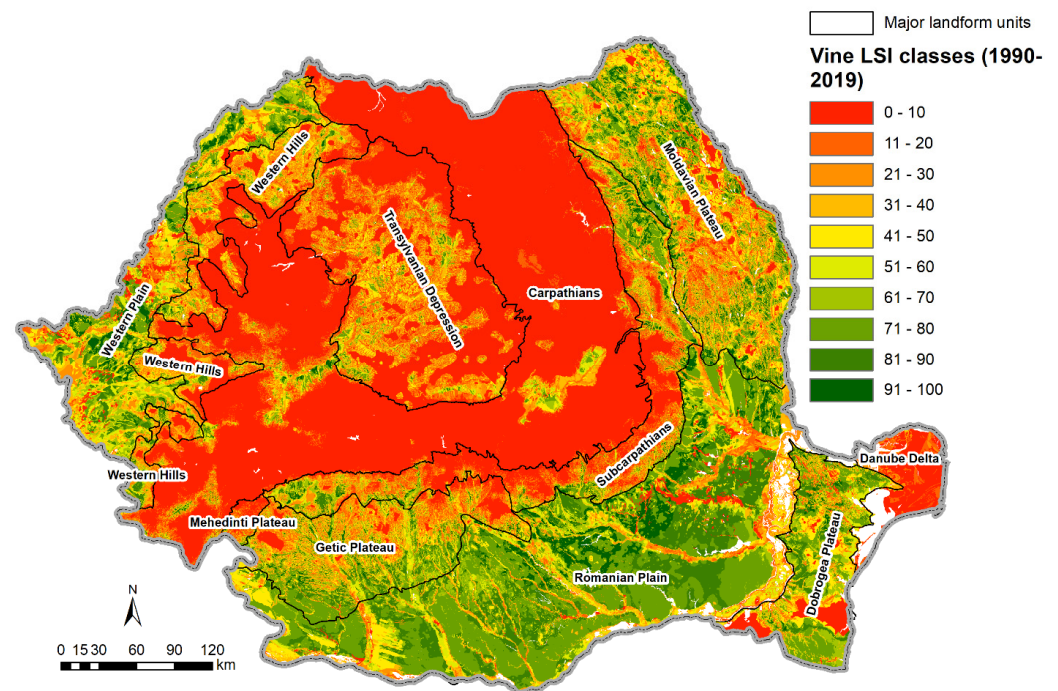


Figure 13. Suitability map for vine for wine.

4. Discussion

Our results seem to be similar to those achieved by Dornik et al. [23] for a much larger area of Central and Eastern Europe when it comes to the spatial distribution of wheat, maize, sunflower, and potato suitability within the Romanian territory. Although the application of the current methodology is operational at NUTS 4 level by OJSPA, other studies at the national scale applying the same methodology in GIS environment are lacking in Romania.

From the structure of the suitability factors, we may see that the ICPA methodology [20,21,27] is mostly soil-oriented, with 11 out of 17 being soil factors. This is why the results reflect better soil suitability and less climate suitability. Therefore, among the possible improvements which could be part of a revised methodology, is the addition of other climate factors (e.g., related to droughts, extreme precipitations, and frosts). Also, the use of average factor values within the growing season would be more meaningful than the use of average annual values. Another necessary methodological revision refers to the need to quantify the influence of high temperatures on crop suitability, such as the mean annual temperatures over 12 °C, which were not considered in the original methodology, because they were not part of the Romanian climate in the 1910–1990 period, but which are now quite widespread in the southern part of the country.

In order to see how the suitability model performs, we calculated the suitability class percentages within the areas occupied by the specific crops (Table 7). In the case of vine, this area was delimited according to Corine Land Cover 2018 [38], while for the other crops we used punctual data of plot centroids provided by APIA (<https://apia.org.ro/>, accessed on 24 November 2024) for the year 2021. If the model performs good, we expect to see that most of the area occupied by a specific crop is suitable for that specific crop. Therefore, we expect that higher suitability classes have higher shares than the low suitability classes. However, this sort of validation has its potential sources of uncertainty: we compare the average suitability of 1990–2019 period with the extent of crops in some specific years (2018 for vine, 2021 for the other crops); our model does not take into account the effect of land improvement works, if they are present.

Table 7. Percentages of suitability classes within the areas occupied by specific crops.

Suitability Intervals	Suitability Class	Winter Wheat	Maize	Sunflower	Potato	Vine
0–10	X	2.17	2.68	0.80	17.39	5.44
10–20	IX	5.43	4.78	2.73	9.06	6.65
20–30	VIII	4.43	9.90	5.95	10.78	8.81
30–40	VII	8.87	13.82	7.15	12.77	9.73
40–50	VI	9.62	10.98	8.10	14.34	14.02
50–60	V	10.62	10.57	12.73	12.21	7.24
60–70	IV	14.46	10.29	14.52	6.97	6.67
70–80	III	18.39	13.58	22.74	8.38	27.23
80–90	II	22.17	16.93	22.91	6.40	7.88
90–100	I	3.85	6.49	2.36	1.70	6.34
40–100	VI—I	79.10	68.83	83.36	50.00	69.37

The data in Table 7 shows that the suitability model performs good in the case of winter wheat, maize, and sunflowers, for which the modal class is II (80–90 suitability scores), with shares of 22.17%, 16.93%, and 22.91%, respectively. Moreover, the cumulated share of classes with medium to high suitability (from class VI to class I) is clearly dominant, being 79.10%, 68.83%, and 83.36% for the respective crops.

For vine, we found that the modal LSI class is class III (70–80 suitability scores), with a share of 27.23%, which indicates high suitability for vine, as it is expected to be within vineyard areas. The cumulative percentage of classes suitable for vine (from VI to I, that is from 40 to 100 suitability scores) is 69.37%.

In the case of potato, the model does not seem to work that well. The modal class is actually the least suitable (class X, 17.39%), while the cumulated percentage of suitable classes is only 50.00%. The explanation for this low performance may reside in the shortcoming we mentioned above, specifically the presence of some land improvement works, or the fact that we compare a 30-year average potential with a single-year extent of the crop. In the case of potato, there may be another possible explanation: as an effect of climate warming, the suitability for potato has declined significantly in the recent period, but the cultivated area has remained roughly the same because of the tradition.

An ideal validation for our study would be to correlate crop production/productivity with LSI values at the fine scale (farm, NUTS 4 scales), using many samples from different parts of the country. However, such data were not available to us; instead, we used the data at the NUTS 3 (county) level made available by the National Institute for Statistics (<https://insse.ro/cms/en>, accessed on 24 November 2024). Figure 14 shows the correlations between the total crop production at the NUTS 3 level and the sum of LSI values for the same areas (which may be seen as an indicator of cumulated land potential for the respective crops). It clearly shows significant positive correlations for winter wheat, maize, and sunflower, which means that the total crop production is in agreement with the cumulated land potential. This is not the case for potato, while for vine the correlation is less strong but still significant. However, we have to bear in mind that this kind of validation is quite general, due to the large size of the counties (from 1500 to 8700 km²).

Every model has a certain degree of uncertainty, and the LSI models achieved in our study do not make an exception. Even though uncertainty cannot be eliminated, it is important to acknowledge it and identify its main sources. In our study, uncertainty is involved in the mapping factor. The factors derived from the digital soil map of Romania (e.g., gleyzation, stagnic properties, and texture) have a certain degree of generalization. The factors derived by statistical interpolation of point data (water table depth, pH, and CaCO₃) include the inherent statistical errors of models. The uncertainty propagates in the case of complex factors (e.g., humus reserve and edaphic volume) from the factors on which their computation is based. Another source of uncertainty comes from the methodology itself. However, the translation of the factor values into suitability values is based on long-term correlations between crop productivity and factor values, making it reliable. On the other hand, the aggregation of factor suitability by multiplication may be another source of uncertainty. There are other methods of factor aggregation (e.g., square root

method, computation of separate climate, soil, terrain suitability indices, and then their integration) which would probably lead to different results.

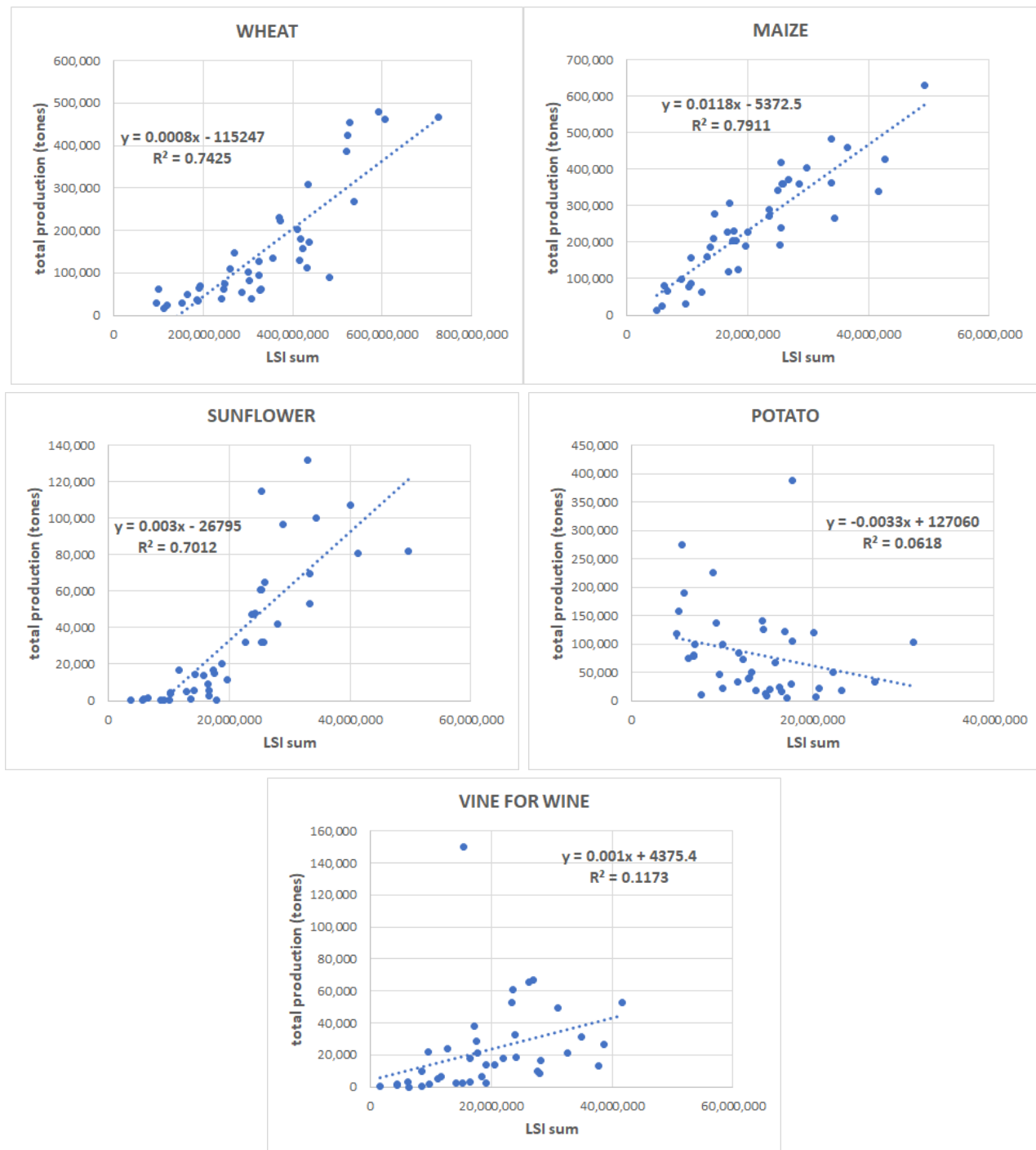


Figure 14. Correlations between the total crop production (1990–2019 averages) and sum of the LSI values extracted for Romanian counties (NUTS 3 level).

5. Conclusions

Our study attempted to quantify the land suitability for the main crops in Romania. We used the official land evaluation methodology, which in spite of being several decades old, is still applied by the County Offices for Pedology and Agrochemistry (OJSPA). The methodology is a quantitative one, resulting from long-term observations and correlations between crop productivity and suitability factors. The main problem is that it is applied

using old, outdated climate data, from the reference period (1960–1990). Our study shows that climate has significantly changed, through warming and higher precipitations, which has certainly induced changes in the land suitability for crops. The mean annual temperatures over 12 °C, which did not exist in the reference climate period (1961–1990), are now common in Romania, affecting more than a quarter of its territory. Therefore, it is necessary for efforts to be made to accommodate these climate changes into the methodology. Also, the climatic evaluation seems insufficient because only two average factors are being used (annual temperature and precipitations). Therefore, a methodological revision is necessary to assess if other factors may be useful and/or if their application should be performed within the growing season. Alternative ways of factor aggregation should be explored like the use of the square root method, or the grouping of factors into climate, soil, and terrain factors and computing separate LSI which will further be integrated into a final LSI, eventually considering different weights for factor groups.

Our study has shown that there is generally a good agreement between the results of the land evaluation model and the extent of the specific crops (winter wheat, maize, sunflower, and vine), except for potato, in which case the model has a rather low performance. This may be due to a more significant decline in land suitability for potatoes, compared to the other crops, which, on the other hand, has kept the traditional cultivation areas.

Given the resolution of the input factors, the generalization degree implied by certain data layers, we consider that our results are relevant for scales ranging from national to the county (NUTS 3) and maybe also for commune (NUTS 4) assessments. However, the fine-scale studies conducted by OJSPA at the NUTS 4 level cannot be replaced by our results, having probably a higher degree of accuracy. Therefore, our approach is useful for regional assessments of land suitability for crops and can be used in the decision-making process by regional and county authorities.

Future research will focus on assessing specifically the differences in land suitability for the main crops in Romania, for the two time periods (1961–1990 and 1990–2019), induced by changes in temperature and precipitations.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy14122828/s1>.

Author Contributions: Conceptualization, C.V.P.; methodology, C.V.P. and B.R.; software, C.V.P. and B.R.; validation, C.V.P., B.R., R.G.P., I.V. and L.M.I.; data curation, C.V.P., B.R., R.G.P. and I.V.; writing—original draft preparation, C.V.P.; writing—review and editing, C.V.P., B.R., R.G.P., I.V. and L.M.I.; visualization, C.V.P., B.R., R.G.P., I.V. and L.M.I.; funding acquisition, C.V.P. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this paper are available on request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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