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Factors Influencing the Spatial Distribution of Regulating Agro-Ecosystem Services in Agriculture Soils: A Case Study of Slovakia

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Abstract: Agro-ecosystem services assessment and mapping are one of the main requirements for implementing the concept of ecosystem services into institutional decision-making within the European Union and worldwide. The aim of this study was to identify the most important regional drivers of the natural potential of regulating ecosystem services with agricultural soil in Slovakia, resulting in an original set of macro-scale spatial stratification criteria for agricultural land, and to estimate typical middle values of its potential in newly defined regions. The non-monetary assessment was based on natural environment parameters and land use factors. For the assessment of individual indicators of agro-ecosystem services, we utilized an expert scoring system. We evaluated ecosystem services on the basis of biophysical indicators that determine the corresponding soil functions and are part of the existing databases available in the Slovak Republic. The new methodological combination enabled us to provide unique mapping and assessment of agro-ecosystem services within Slovakia. Regional climate, land cover, and soil slope were identified as key factors impacting agro-ecosystem services potential within the country, which can be used as data stratification levels for further analyses. Linking the value of individual regulating agro-ecosystem services potential with geographical distribution can help to optimize its potential depending on the needs of the inhabitants living in different regions by introducing appropriate measures and can contribute to effective agricultural policymaking.

Keywords: agro-ecosystem services; soil; natural potential; agriculture land; region

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1. Introduction

Service-providing ecosystems are known as a part of natural capital [1], and only ecosystem processes that contribute to meeting human needs can be defined as ecosystem services (provisioning, regulating, and culture) [2]. Explicit quantification and mapping of ecosystem services is one of the main requirements for implementing the concept of ecosystem services in institutional decision-making, and it belongs to the main targets of the EU Biodiversity Strategy 2030 [3]. Due to food security, agro-ecosystems represent an important research field. Agro-ecosystems contribute to other types of ecosystem services [4,5], such as regulating and cultural services [6–8]. Therefore, the sustainability of agro-ecosystems is also important for their ability to provide a whole group of multiple ecosystem services [9].

Agricultural systems are divided into two groups: (1) soil with its physical, chemical and biological properties and (2) land management, including land use (i.e., cropland or grassland). We consider agro-ecosystems not only as a means of production but also as part of the natural environment where the pedosphere has functions other than food production [10,11]. Soil-based agro-ecosystems are dynamic, complex, and multifunctional

under all conditions, both in terms of processes, functions, and services [12,13]. Soils contribute to the regulation of greenhouse gas emissions, such as carbon dioxide and other gases, and play an important role not only from an agronomical point of view but also from an environmental point of view because the soils filter and clean water and store carbon [14].

Agricultural systems (as genuinely social-ecological systems) have the possibility of producing a wide variety of provisioning ecosystem services, and they provide key ecological processes and regulating services. Recent conceptual work has used an ecosystem services approach to highlight the importance of the pedosphere for human well-being and prosperity [15,16]. The cascade model developed by Haines-Young and Potschin [17] shows how soil functions contribute to ecosystem services. The land is one of the basic production factors, and the study of agro-ecosystem services contributes to understanding sustainable land use. The agricultural sector is often both the producer and beneficiary of the provisioning, regulating, and supporting ecosystem services that enable agricultural production through nutrient cycling and pollination [18]. Regulating ecosystem services, such as climate regulation and stabilization, water flow, and nutrient cycling, have been underappreciated in the past, at least until the time when the natural resilience of the ecosystem becomes disrupted.

Regulating services benefits from the self-sustaining capabilities of ecosystems from the regulation of ecosystem processes [19,20]. In recent decades, agricultural land use systems have been optimized to produce provisioning ecosystem services at the expense of regulating and cultural services. Research has focused mainly on the supply side of ecosystem services and related trade-offs, but the demand side for regulating services, in general, remains ignored [21]. Regulating ecosystem services can impact agro-ecosystems on a global scale (e.g., climate regulation, water regime regulation), as well as from regional and local scale (e.g., microclimate regulation, erosion regulation, filtration services, biological control, pollination [22]).

Modeling and assessment of ecosystem services based on scientific standards is a rather complex task [23–25]. It depends on the spatial association [26], the type of ecosystem [24,27], as well as on the availability of suitable indicators. The most used proxies are land use and land cover data [28,29], which have been useful in regions where soil data are scarce [30]. These data are used as indicators of ecosystem services and properties to estimate the spatial provision of ecosystem services. In the literature, there is a lack of spatially explicit studies of ecosystem services, except for local case studies [31]. Braat and De Groot [32], as well as Crossman et al. [33], emphasize the necessity of spatial quantification of ecosystem services in the socioeconomic evaluation of natural capital stocks from which the flow of ecosystem services proceeds.

Several authors used biophysical spatially quantified data within the assessment of ecosystem services (e.g., [34–36]). At various levels of detail, several studies examined the spatial aspects of ecosystem services [37–40]. The maps have been used at various levels of decision-making and policy support [31,41]. A tiered approach to mapping allows for greater flexibility in the selection of variables, provides decision-makers with relevant information, and contributes to a standardized ecosystem services assessment and monitoring at various scales. The availability of data, their quality, and the selection of mapping and modeling techniques determine the output quality and relevance in the study of spatial dynamics and aspects of ecosystem services. The spatial distribution of ecosystem services is controlled by natural conditions and human activities [29]. Natural factors driving the potential of ecosystem services include soil (soil quality, soil texture), climate (temperature, humidity), and others, such as slope or topography [42,43].

Land use and land cover were identified as important drivers leading to differences in agro-ecosystem services potential [44,45]. Human influences on ecosystem distribution come from land cover type (arable land, grassland), land use (including land management) and land cover and land use changes. It results in a typical spatial distribution of ecosystem services' potential value that changes over the long term across geographic regions and

spatial scales. Linking the assessment of ecosystem services to land cover is one of the conditions for the use of these models within monitoring changes in land use management, in spatial planning, as well as within the implementation of the assessment of the potential of natural capital to provide ecosystem services in socio-economic planning within the region and country [17,46,47].

All the provisioning and regulating ecosystem services were determined by common geographic conditions, climate, and human activities [48]. According to several authors [49–51], climate has a significant impact on the provision of ecosystem services. The climate also affects the management possibilities and land use and, thus, ecosystem services [16]. The results of land management and the effect of tillage on soil properties have been conflicting in different studies, and the effects may be soil-specific and influenced by local pedo-climatic conditions. Identified pressures acting on Mediterranean agroecosystems were: agricultural practices and management, followed by demographic and socioeconomic changes, climate change, habitat loss, and land use change [52]. Demonstrable relationships between the potential value of regulating agro-ecosystem services and soil texture were estimated by [53]. Soil slope belongs to one of the important factors that significantly influence the regulation of erosion and the accumulation of water in the soil [40]. Robinson et al. [54] emphasized the need to assess soil ecosystem services and promote soil-ecosystem connections when developing land-resource policy and management. Knowing these spatial distributions at an adequate level of detail is essential for any practical solution leading to accurate planning of sustainable land management and preservation of soil health at all scales, to which our research should contribute. From previous results of the assessment of individual agro-ecosystem services in the Slovak Republic, statistically significant correlations were detected between some regulating ecosystem services and the climate region (ecosystem services values were lower in colder regions than in warmer climate regions [55,56]).

Based on the literature review and our previous research results, we can assume that the combination of natural factors (climatic region, soil texture, soil slope) with human factors (land cover) can determine the value of the potential of regulating agro-ecosystem services. Local combinations of natural and socio-economic factors at any location can lead to a typical agro-ecosystem services value that varies across different geographic regions and spatial scales. Local assessment of agro-ecosystem services is often limited by the availability of data for their assessment at an appropriate scale. However, knowing those values at an adequate level of detail is essential for a practical solution leading to accurate planning for sustainable land management and the preservation of soil health at all scales. Therefore, we assume that we can divide the agricultural land of Slovakia into a limited number of geographical regions with typical middle values of the agro-ecosystem services potential.

The aim of this study is to identify the most important regional drivers of the natural potential of regulating ecosystem services within agricultural soils of Slovakia based on published research and Slovakian's National Agricultural and Food Centre (NPPC) expert estimations resulting in an original set of macro-scale spatial stratification criteria for the agricultural land and to estimate typical average values of the potential of regulating agro-ecosystem services for newly defined regions created on the basis of macroscale stratification criteria.

2. Materials and Methods

2.1. The Theoretical and Methodological Baselines of the Agro-Ecosystem Services Assessment

Non-monetary assessments express a clear differentiation from monetary methodologies by emphasizing the value that people place on natural capital and ecosystem services [57–59]. At various stages of managing and planning the ecosystems, non-monetary assessment can be applied [60].

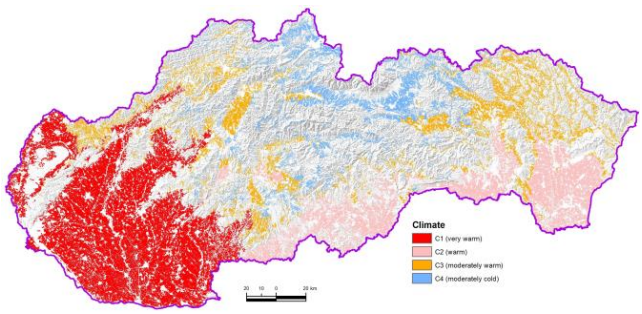
The assessment of the potential of individual ecosystem services is based on natural environmental parameters and land use factors. We modified the methodology of

Makovníková et al. [55,56] based on indicators that determine soil functions of individual agro-ecosystem services. Ecosystem services were evaluated at different scales (e.g., cleaning potential–polygons of soil types and subtypes; climate regulation and erosion regulation–grid at different scales). For a comprehensive assessment and spatial distribution of regulating agro-ecosystem services, it was necessary to unify these data in a regular spatial network. We proceeded from the agro-eco principle [35,61,62], whose aim is to describe and characterize the relationship between agriculture and the environment by means of indicators that determine ecosystem processes and functions (non-monetary model of agro-ecosystem services). This novelty methodological combination enabled us to provide unique mapping and assessment of agro-ecosystem services within Slovakia.

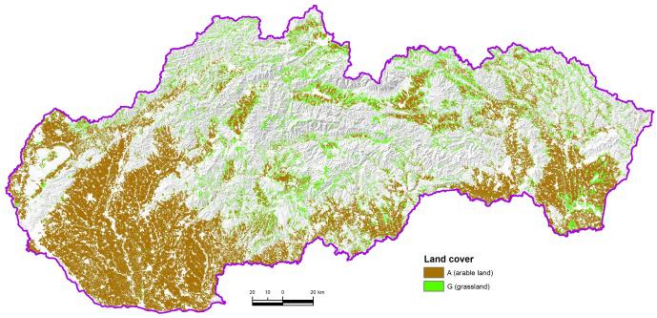
2.2. Study Area

Slovakia is a landlocked country with an area of about 49,000 km^2 located in Central Europe, with respective southern- and northern-most coordinates of N47.78 and N49.60 decimal degrees and respective western- and eastern-most coordinates of E16.85 and E22.57 decimal degree.

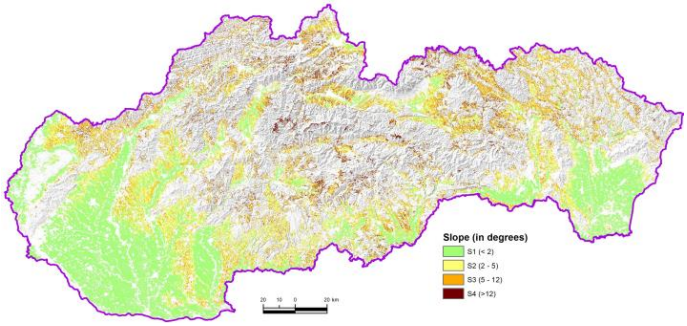
Most of the permanent grasslands occur in the central, north, and northeastern regions. The country's terrain consists primarily of hilly, upland, and mountainous terrain. Slovakia lies in a calm environment zone with four weather seasons, with weather conditions being impacted somewhat by both the gentle and moist Atlantic and cool and sub-muggy mainland environments. The territory of the Slovak Republic consists of agricultural land 49.16%, forests 39.11%, water bodies 1.93%, and non-agricultural and non-forest land 9.8% [63]. The locations of most agricultural areas are in the lower foot-slope and alluvial positions of the Carpathian Mountains, the inner Carpathian basins, and the lowlands of the Danube Basin. Climatic regions, representation of arable land and grassland, soil texture regions, as well as soil slope regions are shown on maps (Figure 1a–d).



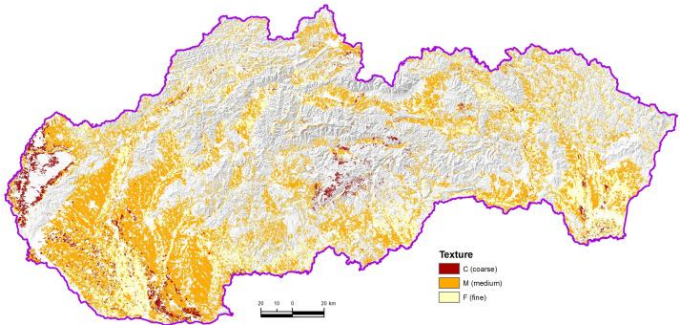
(**a**) Climate regions



(**b**) Land cover



(**c**) Soil slope regions



(**d**) Soil texture regions

Figure 1. (**a**–**d**). Climatic regions, land cover (arable land and grassland), soil slope regions, and soil texture regions.

2.3. Methods of Assessment of the Potential of Agro-Ecosystem Services

We evaluated ecosystem services on the basis of biophysical indicators that determine the corresponding soil functions and are part of the existing databases available in the Slovak Republic. For the assessment of individual indicators of agro-ecosystem services, we used an expert scoring system that is frequently utilized for the evaluation of complex natural systems ([5,64,65]; NPPC expert estimation). Four services are important for Slovakia —water regime regulation, soil erosion regulation, soil pollution regulation (immobilization of hazardous substances), and climate regulation (carbon accumulation in soil)—were evaluated within the group of regulating agro-ecosystem services (type, characteristics, and categorization in Table 1). The methodological assessment scheme of four regulating agro-ecosystem services important for Slovakia is in Figure 2.

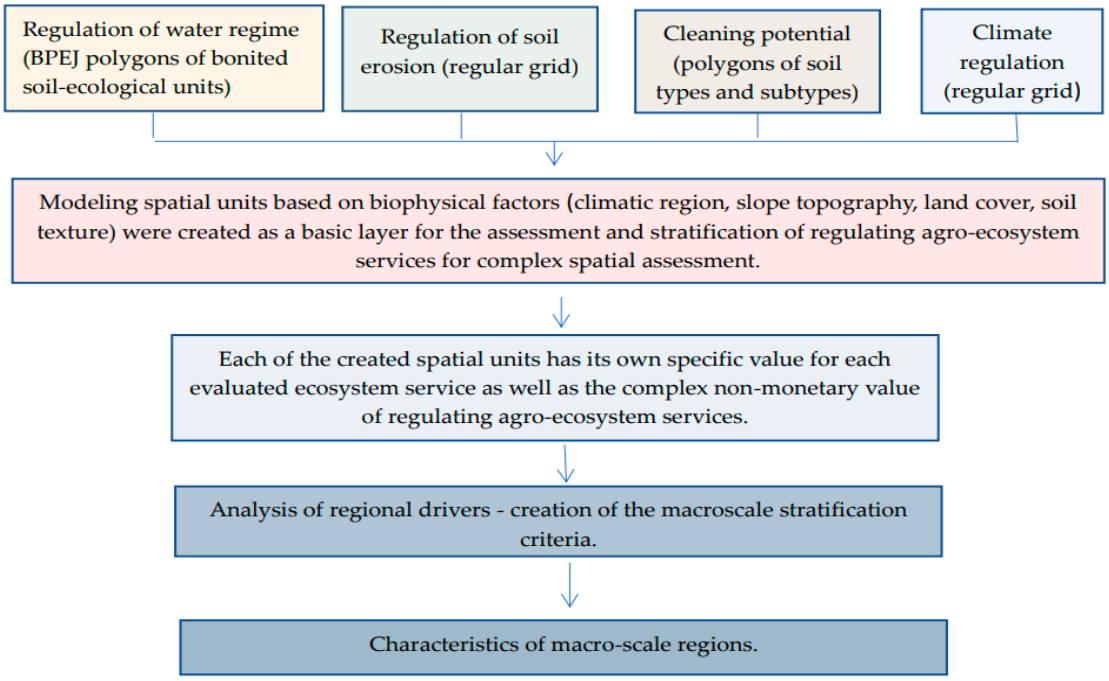


Figure 2. Assessment scheme of regulating agro-ecosystem services stratification (four regulating agro-ecosystems important for Slovakia).

Table 1. Methodological framework–type, characteristics, and categorization of agro-ecosystem services.

Type of Regulation Ecosystem Service	Characteristics	Categorization
Potential of regulation of water regime (soil water storage)	Its values are given in *mm* and are based on the value of retention water capacity recalculated to soil water storage in context with the soil depth. Obtained from maps and databases from a comprehensive soil survey of the Slovak Republic [66].	Values were categorized into five groups: 1 —very low potential (<135 mm), 2 —low potential (135–175 mm), 3 —medium potential (175–215 mm), 4 —high potential (216–275 mm), 5 —very high potential (>275 mm). (Erosion control potential was determined without considering vegetation cover)
Potential of regulation of soil erosion, regulation of water erosion	Values were derived from maps and databases based on empirical model of the universal soil loss equation–USLE [67,68]. The relative ratio of the calculated values of soil loss and acceptable erosion expresses the degree of soil erosion endangerment (SEOP value).	Values were categorized into five groups: 1 —very low potential (more than 2.60), 2 —low potential (2.21–2.60), 3 —medium potential (1.81–2.20), 4 —high potential (1.40–1.80), 5 —very high potential (less than 1.40).

Table 1. *Cont.*

Type of Regulation Ecosystem Service	Characteristics	Categorization
Cleaning potential of agricultural land ecosystem	Cleaning potential of agricultural land ecosystem depends on the actual soil contamination and potential of soil sorbents, and was calculated as accumulative function: Cleaning potential = Sorption potential of soil + Potential of total content of inorganic contaminants (evaluated according to risk elements limits defined in Slovak Law 220/2004 Coll.; [69]. Point evaluation of Sorption potential (SP) of soil was calculated as a sum of quality factors (pH (0–4 points), Q46 (0–1 points) and quantity factors (Cox (0–1 points), H- depth of humus horizon (0–2 points)) according to the function: PS = F(pH) + F(Q46) + F(Cox) × F(H). The overall rating (expert scoring system based on factor analysis of individual indicators) is determined as a sum of the soil contamination and Sorption potential of soil. The high soil contamination was evaluated by the high point value and present high risk (0–5 points). High soil Sorption potential results in low point value and decreases possible risk transport of harmful elements into the soil.	Sum of values was categorized into five groups: 1 —very low potential (more than 6.50 points), 2 —low potential (5.51–6.50), 3 —medium potential (4.51–5.50 points), 4 —high potential (3.50–4.50 points), 5 —very high potential (lower than 3.50 points).
Climate regulation	Within agroecosystems of agricultural land, soil organic matter represents the largest share of total organic carbon found in the soil. Agroecosystems contribute to climate regulation by sequestration of organic carbon in the soil. Soil organic carbon stock (SOCS) was calculated as a function: SOCS (depth 0–30 cm) in t. ha-1 = 10 × (BD (0–10 cm) × SOC (0–10 cm) + BD (10–20 cm) × SOC (10–20 cm) + BD (20–30 cm) × SOC (20–30 cm) BD–soil bulk density in g.cm-3, SOC–soil organic matter content in % [55,56].	Sum of values was categorized into five groups: 1 —very low potential (lower than 58.00 t C.ha-1), 2 —low potential (58.00–62.00 t C.ha-1), 3 —medium potential (62.01–67.00 t C.ha-1), 4 —high potential (67.01–72.00 t SOC.ha-1), 5 —very high potential (more than 72.00 t SOC.ha-1).

The non-monetary model for assessment of agro-ecosystem services was based on the valuation of individual ecosystem services [70]; each category had its point value (five non-monetary units), while the maximum value of one regulating agro-ecosystem service was 25 units (ranging from 1 very low potential = 5 points to category 5 very high potential = 25 points). As a result, agro-ecosystem services could reach a maximum total value of 100 non-monetary units (Figure 3). The assessment system was verified on pilot sites located in different soil-ecological regions of Slovakia [63]. For a comprehensive assessment and spatial distribution of regulating agro-ecosystem services, a regular spatial network was performed (Figure 3) from a combination of agro-ecological indicators (climatic region, slope topography, land cover, soil texture) in accordance with the proposed assessment system as follows:

1. Climatic region (categories: moderately cold, moderately warm, warm, and very warm; according to Kizeková et al. [71]),
2. Slope topography (categories: 0–2°, 2.1°–5°,5.1°–12° and more than 12°),
3. Soil texture (categories: soil particles < 0.01 mm less than 20%, 20–45%, more than 45%) and
4. Land use (arable land, grassland).

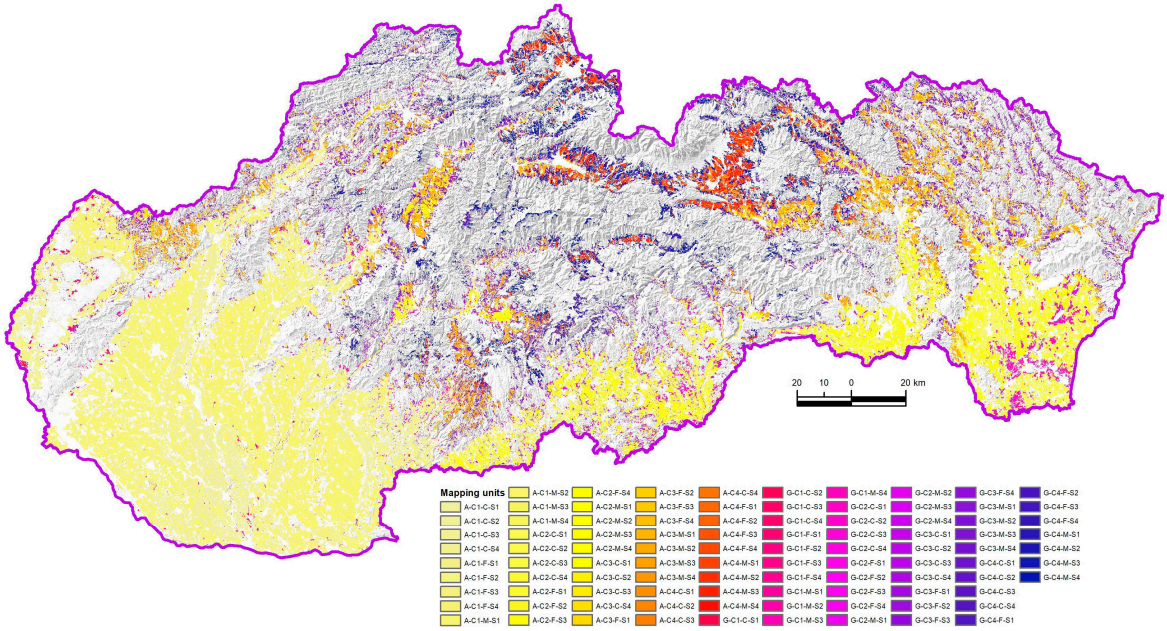


Figure 3. Spatial distribution of combinations of mapping units created from an agro-ecological indicator.

We were able to assess the soil ecosystem with greater precision by combining these agro-ecological indicators, which allowed us to divide the agro-ecosystem layer into 100 distinct combinations of subcategories (spatial raster units with resolution 100 × 100 m), and the evaluated soil parameters determined each subcategory's ecosystem service value for better explanation. These mapping units were also compatible with the spatial units in the international database Corine Land Cover which carries information on the use of land.

Each of the created spatial units has its own specific value for each evaluated ecosystem service, as well as the complex value of the regulating agro-ecosystem services. This layer forms the basis for the subsequent stratification of the agro-ecosystem services according to the selected criteria.

2.4. Geospatial Datasets Used for Specifying the Area Distribution of Individual Agro-Ecosystems

Input layers were used in raster form. Data were concentrated within a unified geodatabase, mainly in raster representation in SHP data format converted to raster with a resolution of 100 m. The land cover layer was used from the LPIS database (Land Parcel Identification System administrated by Agricultural Paying Agency of Slovakia APA; https://data.gov.sk/dataset/4c408849-80e9-41a2-8c93-08a65b7ce4fb; accessed on 20 February 2023) as an important source of agricultural land, and protected areas data. We selected from the LPIS database two types of land use (arable land and grassland). Classification of agro-climatic regions for this study was provided by The Information Service of the National Agricultural and Food Centre—Soil Science and Conservation Research Institute (NAFC-SSCRI). Within this classification, 10 agro-climatic regions were identified according to long-term average temperatures in January, average growing-season temperatures, daily average temperatures sum (T > 10 °C), the length of period with daily temperatures td > 5 °C, and the climatic moisture indicator according to Budyko calculated by Tomlain [72]. The basic database for the geographic information system (ZBGIS) as part of the information system of geodesy, cartography, and cadaster is provided by the Office of Geodesy, Cartography, and the Cadastre of the Slovak Republic (www.skgeodesy.sk; accessed on 23 February 2023). ZBGIS digital terrain model of the Slovak relief at a resolution of 20 m was used for purposeful categorization of the slope of the relief (for assessment of the agro-ecosystems according to their location in a certain altitude area). We used the database of pedo-ecological units provided by NAFC-SSCRI (https://portal.vupop.sk/portal/apps/weba

ppviewer/index.html?id=d89cff7c70424117ae01ddba7499d3ad; accessed on 23 February 2023), from which we selected information about soil texture (% content of particle size fraction < 0.01 mm, a sum of physical clay fr. < 0.001 mm, and fine silt fr. 0.001–0.01 mm); these data were converted to raster layer with resolution 100 m. To obtain the resulting layers, we used geographic information systems methods and tools (GIS, ArcGIS Pro from ESRI).

2.5. Statistical Model Regions Comparison

Databases and measured data were statistically processed by the program Statgraphics Centurion XVI. To compare files in the process of stratification, we used non-parametric tests of agreement because the assumption of the normality of files was not met. (differences between medians; Kruskal-Wallis Test). To compare model regions, we used multivariate methods (cluster analysis, dendrogram, Near and Neighbor Method, Squared Euclidean) and multivariate visualization (sunray plots).

3. Results and Discussion

Specifications of criteria for macro-scale stratification of agricultural land for Slovakia are listed in Table 2.

Tables 3 and 4 display the calculated distributions of the regulating potential of agro-ecosystem services across each individual macro-scale stratification level. Table 5 lists the statistical significance of differences between mid-class values (arithmetic mean, median) separately for each macro-scale stratification level.

Table 2. Criteria for macro-scale stratification of agricultural land for Slovakia—main drivers of regulating AESS.

Stratification Level	Classification Element	Class	Classification Criteria
Climate	Climate region	C1 C2 C3 C4	very warm warm moderately warm moderately cold
Land cover	Land cover class	A G	Arable land Grassland: permanent pastures, meadows, hope gardens, orchards, vineyards other agricultural land other agricultural land
Soil Texture	Content (%) of particle size fraction < 0.01 mm, a sum of physical clay (fr. < 0.001 mm) and fine silt (fr. 0.001–0.01 mm)	C M F	Coarse: <30% Medium: 30–45% Fine: >45%
Slope	Slope (°)	S1 S2 S3 S4	<2.0° 2.0–5.0° 5.1–12.0° >12.0°

Table 3. Non-monetary value of individual regulating agro-ecosystem services potential in climatic regions.

Climatic Region		Potential of Regulation (Point Value)			
		Water	Erosion	Cleaning Potential	Climate
C1	Average	15.40	22.20	22.40	12.80
	Minimum	5.00	5.00	20.00	5.00
	Maximum	25.00	25.00	25.00	25.00
C2	Average	18.91	22.82	11.95	12.82
	Minimum	10.00	15.00	5.00	5.00
	Maximum	25.00	25.00	15.00	25.00

Table 3. *Cont.*

Climatic Region		Potential of Regulation (Point Value)			
		Water	Erosion	Cleaning Potential	Climate
C3	Average	9.80	16.40	9.40	8.20
	Minimum	5.00	5.00	5.00	5.00
	Maximum	20.00	25.00	15.00	25.00
C4	Average	7.29	16.45	10.62	19.37
	Minimum	5.00	5.00	5.00	10.00
	Maximum	15.00	25.00	15.00	25.00

Table 4. Non-monetary value of individual regulating AESS potential for arable land and grassland.

Land Cover		Potential of Regulation (Point Value)			
		Water	Erosion	Cleaning Potential	Climate
A	Average	14.25	20.42	13.29	7.23
	Minimum	5.00	5.00	5.00	5.00
	Maximum	25.00	25.00	25.00	15.00
G	Average	11.40	18.50	14.00	18.90
	Minimum	5.00	5.00	5.00	10.00
	Maximum	25.00	25.00	25.00	25.00

Table 5. Non-monetary value of individual regulating AESS potential for agricultural land in Slovakia with different soil texture.

Soil Texture		Potential of Regulation (Point Value)			
		Water	Erosion	Cleaning Potential	Climate
C	Average	13.03	19.39	13.93	14.09
	Minimum	5.00	5.00	5.00	5.00
	Maximum	25.00	25.00	25.00	25.00
M	Average	11.87	20.00	13.43	12.65
	Minimum	5.00	5.00	5.00	5.00
	Maximum	25.00	25.00	25.00	25.00
F	Average	13.43	18.09	13.59	12.96
	Minimum	5.00	5.00	5.00	5.00
	Maximum	25.00	25.00	25.00	25.00

3.1. Climate Regions

The climate is the primary factor that influences the value of ecosystem services at the regional scale [55,56]. The values of ecosystem services in climatic regions are in Table 3.

The average potential of regulating agro-ecosystem services (Figure 4) of agricultural soils in Slovakia within the four climatic regions C1–C4 was the lowest in moderately warm climatic regions and the highest in very warm climatic regions. Our results indicate the following macro-level gradient of agro-ecosystem services values C2 > C1 > C4 > C3. In climatic regions C3 and C4, we determined the highest dispersion of agro-ecosystem services potential values. Warm, dry lowland regions (C2) had a higher potential for water regime regulation, control of soil erosion, and cleaning potential in comparison to moderately warm and cold regions (C3, C4). The average value of the potential for climate regulation (soil organic carbon stock) was the highest in the cold climatic region (Table 3).

These findings are consistent with Bommarco et al. [73] and Barančíková et al. [74], where regulating service values were also higher in colder climatic areas due to ecosystems of grassland with a high carbon content and, thus, a high value of climate regulation [48]. Climatic conditions, especially temperature and precipitation, are key factors controlling

soil organic carbon stocks at global and regional levels through their influence on soil carbon input and decomposition [43,75–79].

Differences in medians were found statistically significant for all regulating services of the agro-ecosystem services potential between climate regions.

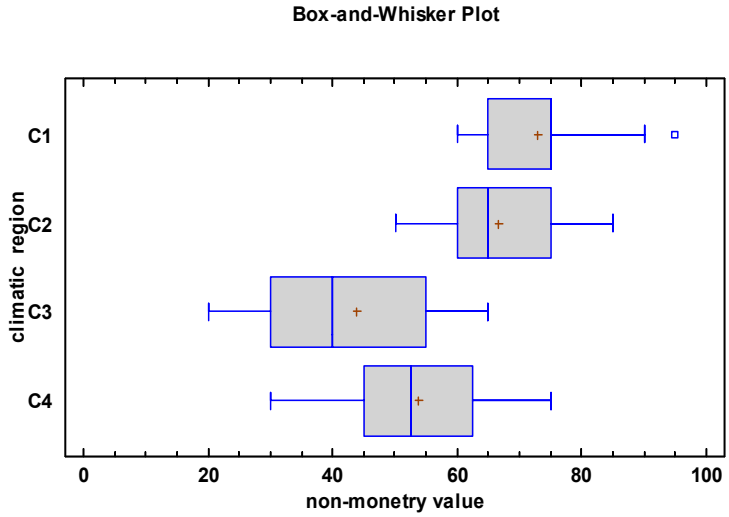


Figure 4. The potential of regulating AESS in climate regions (C1–C4) of Slovakia; + the position of the arithmetic mean.

3.2. Land Cover

The average potential of regulating agro-ecosystem services (AESS) for arable land was 55.21 points, and for grassland, 62.80 points (the maximum value for all individual agro-ecosystem services was not reached in any of the units; Figure 5).

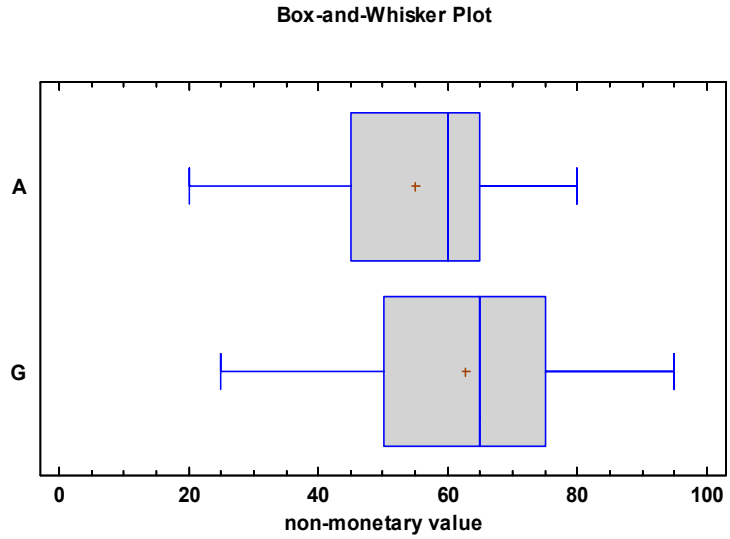


Figure 5. The potential of regulating AESS for arable land (A) and grassland (G) in Slovakia; + the position of the arithmetic mean.

The soil quality, morphological characteristics, and socioeconomic factors all play a role in determining whether arable land has a higher individual ecosystem service value than grassland (Table 4). The Danube basin's high-quality ecosystems of arable land achieve high values (primarily Chernozems). Agro-ecosystem service values are low in heavily skeletal, low-quality soils that are mostly used as grassland and are found at higher altitudes in colder regions. According to Vilček [80], the Danubian lowland has high values

for agricultural lands' ability to perform environmental functions, which are the foundation for providing ecosystem services, while the Košice basin has the lowest values.

The potential for erosion controls was calculated without considering vegetation cover. When considering the total coverage of land (registered as permanent grasslands in LPIS) with permanent grasslands, the potential for soil erosion regulation reaches very high values (100% of agriculturally used grasslands were in the category of very high potential). A very high value of soil erosion control caused by water erosion for grassland agro-ecosystems was reported by Mederly et al. [81]. Grassland agro-ecosystems also had a high value of soil erosion control caused by water erosion. Soil biomass was Involved in the control of soil removal, which reduces the kinetic energy of the incident raindrops, thereby reducing their effect on soil particles on the surface and preventing the formation of a poorly permeable soil layer. Above-ground biomass captures large amounts of water on its surface, reducing the rate of surface runoff and contributing to its reduction. Agro-ecosystems perform climate regulation ecosystem service only in the case that they increase the amount of captured carbon in organic matter from year to year. Grasslands keep the soil under permanent plant cover, which has been considered as the optimal condition for soil quality as it prevents the disturbance of the soil structure, causing less organic carbon mineralization [82].

Human activity has a significant impact on the accumulation of organic carbon mainly through land use in cultivated lands (arable land, grassland), while the effects of human activity are more pronounced in intensively cultivated agricultural lands [15,74,83–87]. From this point of view, pasture meadows have a high potential for organic carbon accumulation, while in intensively used arable soils, the organic carbon content is usually low and arable soil often acts as a source of carbon emissions, not an interceptor [74,88]. The fact that crops do not cover a large portion of arable land almost throughout the entire year, particularly broad-leaved crops and that crops harvest early is a negative factor [89]. As a legacy of intensive agriculture, this phenomenon—large blocks of monocultures and inappropriate management—is typical of Central Europe (primarily the Czech Republic, Slovakia, Poland, and Hungary [90]). Land cover and land use, as one of important factors that affect the value of land capacity to provide regulating agro-ecosystem services, were also mentioned by Mederly et al. [81].

Differences in arithmetic mean, and medians of the ecosystem services potential between arable land and grassland were found statistically significant for climate regulation and complete regulating agro-ecosystem services.

3.3. Soil Texture

Our results indicate the following macro-level gradient of agro-ecosystem services values F (fine soil texture) > M medium soil texture) > C (coarse soil texture; Table 5, Figure 6).

Our results indicate that there is only a slight macro-level gradient of agro-ecosystem services values depending on the soil texture on the agricultural soils of Slovakia. However, the difference in medians was all statistically significant except for climate regulation. This indicates that soil texture is an important supplement to the overall macro-scale agro-ecosystem services assessment in agricultural soils of Slovakia.

From regulatory ecosystem services, soil texture primarily affects water regulation and climate regulation (organic carbon sequestration [42,74,79,91]). Light, aerated sandy soils have a low ability to attract water and nutrients due to the low proportion of clay fraction and humus [15]. Heavy soils can attract more water and nutrients, but the limiting factor is their insufficient aeration. Soil texture (particularly clay content) contributes to the major mechanisms of soil organic carbon stabilization, and numerous studies found a significant correlation between soil organic carbon stocks and clay content [92–94].

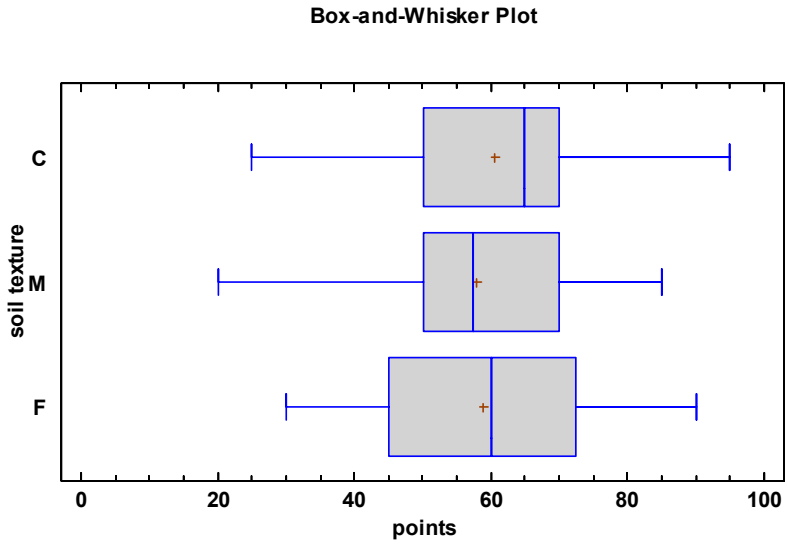


Figure 6. The potential of regulating AESS with different soil textures in Slovakia F (fine soil texture), M medium soil texture), C (coarse soil texture); + the position of the arithmetic mean.

3.4. Soil Slope

Due to a limited number of evaluated units in individual slope categories, we combined: regions S1 and S2 into a region with a slope of up to 5°; and regions S3 and S4 into one region with a slope above 5° (Table 6). The average potential of regulating agro-ecosystem services for soil slope S12 was 64.31 points, and for soil slope S34, 53.36 points (Figure 7).

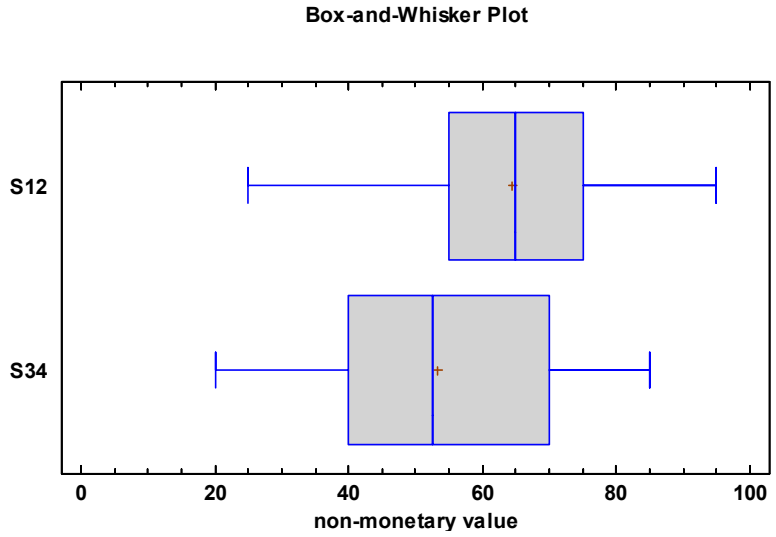


Figure 7. The potential of regulating AESS with different soil slopes in Slovakia; + the position of the arithmetic mean.

The slope significantly affected the natural potential of regulating agro-ecosystem services similar to in Makovníková et al. [55], and correlation analysis determined a significant negative correlation between slope and water regulation r = −0.42, as well as between slope and regulation of soil erosion r = −0.74 [55,56]. Areas with a higher slope had lower values of regulation of water and soil erosion. Differences in arithmetic mean and median were found statistically significant for all regulating services (Table 7) in two classes of soil slope (except climate control).

Table 6. The non–monetary value of individual regulating AESS potential for agricultural land in Slovakia with different soil slopes.

Soil Slope		Potential of Regulation (Point Value)			
		Water	Erosion	Cleaning Potential	Climate
S12	Average	14.21	21.47	15.00	13.26
	Minimum	5.00	5.00	10.00	5.00
	Maximum	25.00	25.00	25.00	25.00
S34	Average	11.20	17.17	12.17	12.82
	Minimum	5.00	5.00	5.00	5.00
	Maximum	25.00	25.00	25.00	25.00

Table 7. Statistical significance of differences between medians of the ecosystem services (Kruskal-Wallis Test) between individual classes within the macro-scale stratification levels.

Measure	Stratification Level	Kruskal-Wallis Test
Regulation of water	Climate region	1
	Land cover	0
	Soil texture	1
	Slope	1
Regulation of soil erosion	Climate region	1
	Land cover	0
	Soil texture	1
	Slope	1
Cleaning potential	Climate region	1
	Land cover	0
	Soil texture	1
	Slope	1
Climate regulation	Climate region	1
	Land cover	1
	Soil texture	0
	Slope	0
Complete regulating ESS	Climate region	1
	Land cover	1
	Soil texture	0
	Slope	1

1—Statistically significant difference at $p < 0.05$, 0—statistically not significant difference (Test statistics and p-values are in Table 1 within Supplementary Materials).

Based on class-definition criteria, the agricultural land of Slovakia was divided into geographical macro-scale regions. We chose three-level stratification because the soil texture had only a slight influence on the values of individual agro-ecosystem services (rows 2, 3, and 4 in Table 8).

The result of the three-level stratification (climatic region, land cover class and slope class) was the creation of 16 original individual regions (Table 8, Figure 8). Due to a limited number of evaluated units, we combined the slope classes S1 and S2 = S12 and S3 and S4 = S34. Typical average values of the individual ecosystem services potential and complete regulating agro-ecosystem services potential in defined regions after macroscale stratification criteria are in Table 8.

The non-monetary value of regulating agro-ecosystem services potential varied across the macro-scale geographical regions of Slovakia in a range of 35.83 points to 81.43 points, with the majority of values being between 50.59 and 69.16 (25-th and 75-th percentile). Arithmetic means of macro-regions located in very warm and warm climate regions were higher than the average values for colder regions of Slovakia.

Table 8. Typical average values of the individual ecosystem services potential and complete regulating agro-ecosystem services potential in newly created regions after macroscale stratification criteria.

Region	Climate	Land Cover	Slope	Water	Erosion	Cleaning Potential	Climate	Ecosystem Services
A	C1	A	S12	17.50	23.33	24.16	5.00	70.00
B	C1	A	S34	18.33	23.33	21.67	5.00	68.33
C	C1	G	S12	14.29	23.57	23.57	20.00	81.43
D	C1	G	S34	11.67	18.33	20.00	20.00	70.00
E	C2	A	S12	23.33	24.17	13.33	5.00	65.83
F	C2	A	S34	17.00	23.00	10.00	5.00	55.00
G	C2	G	S12	18.57	22.14	13.57	20.00	74.29
H	C2	G	S34	16.00	22.00	10.00	20.00	68.00
A1	C3	A	S12	13.33	20.00	10.00	5.00	48.33
B1	C3	A	S34	9.17	15.00	7.50	5.00	36.67
C1	C3	G	S12	10.00	18.57	12.14	10.00	52.86
D1	C3	G	S34	6.67	11.67	7.50	10.00	35.83
E1	C4	A	S12	9.17	23.33	10.00	15.00	57.50
F1	C4	A	S34	6.67	11.67	9.17	12.50	40.00
G1	C4	G	S12	7.50	16.67	12.50	25.00	61.67
H1	C4	G	S34	5.83	14.17	10.83	25.00	55.83

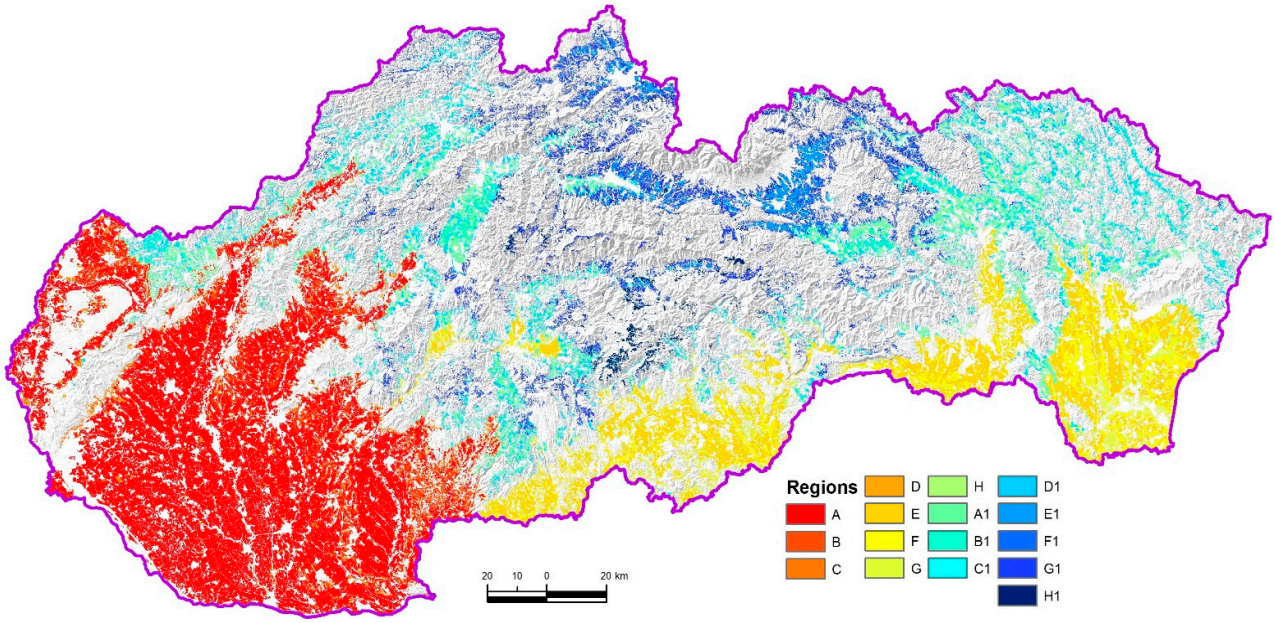


Figure 8. Spatial distribution of newly created regions after macroscale stratification criteria.

Climate region propagates itself as a strong agro-ecosystem services potential driver also if analyzed separately for individual land cover. If we consider two levels of stratification, climate region and land cover, the potential values of grasslands were higher compared to arable land in all climate regions. The influence of soil slope was manifested by a decrease in the value of regulating agro-ecosystem services in regions with a slope above 5°.

The average values of individuals regulating agro-ecosystem services in macro-regions had a different gradient. Water regulation values were slightly higher in the case of arable land in all climatic regions. These were mainly ecosystems on arable land with medium-heavy, loamy to sandy-loamy, deep and boneless soils with a higher humus content or with a deep humus horizon. Predominant soil types of this category are chernozem and fluvisol, with the largest occurrence in the Danube Plain or in floodplains of the middle and lower reaches of rivers. The influence of soil slope was manifested by the reduction of this value within macro-scale geographical regions with a slope above 5°. The average

values of erosion regulation were more significantly determined by the slope, especially in colder climate regions.

The average values of the cleaning potential of macro-regions located in very warm and warm climate regions were higher than the average values for colder regions of Slovakia. The potential cleaning value estimated for macro-regions on grassland was generally slightly higher than for macro-regions on arable land. This trend is visible in all climate regions. The value of cleaning potential was higher in warmer climate regions compared to colder climate regions at all levels of stratification. These are mostly ecosystems with a high carbonate content developed on loess located on the Danubian and East Slovak Lowlands without anthropogenic and geochemical deposition. Lower values of the cleaning potential are characteristic of ecosystems of agriculturally used soils located at higher altitudes with a higher slope on soils with a lower sorption potential and on soils developed on substrates with a higher content of risk elements. These mainly include ecosystems on cambisol.

In addition to the genesis of the soil type and subtype, land use (arable land, permanent grassland) limited the values of the climate regulation potential, which is based on soil organic matter reserves in agro-ecosystems. Campbell and Souster [95] and Schnitzer et al. [96] reported that intensive land management leads to a decrease in the amount of organic matter in the soil. The agroecosystems of arable soils located in the lowlands had a lower potential for climate regulation and a low average stock of soil organic carbon. The low potential of climate regulation for the agro-ecosystem of arable soils was also mentioned by Burghard et al. [97]. At higher altitudes, the average supply of organic carbon and, thus, the potential for climate regulation increases slightly. If we consider two levels of stratification, climate region and land cover, the values of the climate regulation potential of grasslands were higher compared to arable land in all climate regions. The influence of slope as the third level of stratification was insignificant within climate regulation.

Spatially, region A (681 849 ha) was the most represented within Slovakia, followed by region E (193 209 ha), A1 (152 224 ha), G1 (139 155 ha) and D1 (122 579 ha); these are regions with arable land. The smallest areas have regions with colder climates and grasslands on soils with a slope of more than 5° (regions H, H1; Figure 1 within Supplementary Materials). The sun-ray plot compares the similarity of regions between the values of regulating agro-ecosystem services within newly created model regions (Figure 9).

The comparison of the macro-scale geographical regions showed significant differences between regions. Individual regions represent original areas based on stratification criteria (see dendrogram, Figure 10). Only slight similarity is shown by the pairs of regions A-B and D1-F1. In both cases, it is arable land. Regions A-B are located in climatic region C1. Regions D1-F1 are located in two different climate regions (C3 and C4). Knowing the value of the potential of regulating agro-ecosystem services in new model regions can form a basic platform for current users of agricultural land, especially when deciding on a land use change when adopting appropriate management measures to increase the potential of a specific agro-ecosystem service in a given area (for example, the application of anti-erosion measures in areas with a low value of erosion control potential). Such results can also be used as a basis for knowledge about the value of natural capital and agriculturally used land, which does not consist exclusively of the production of food and fodder.

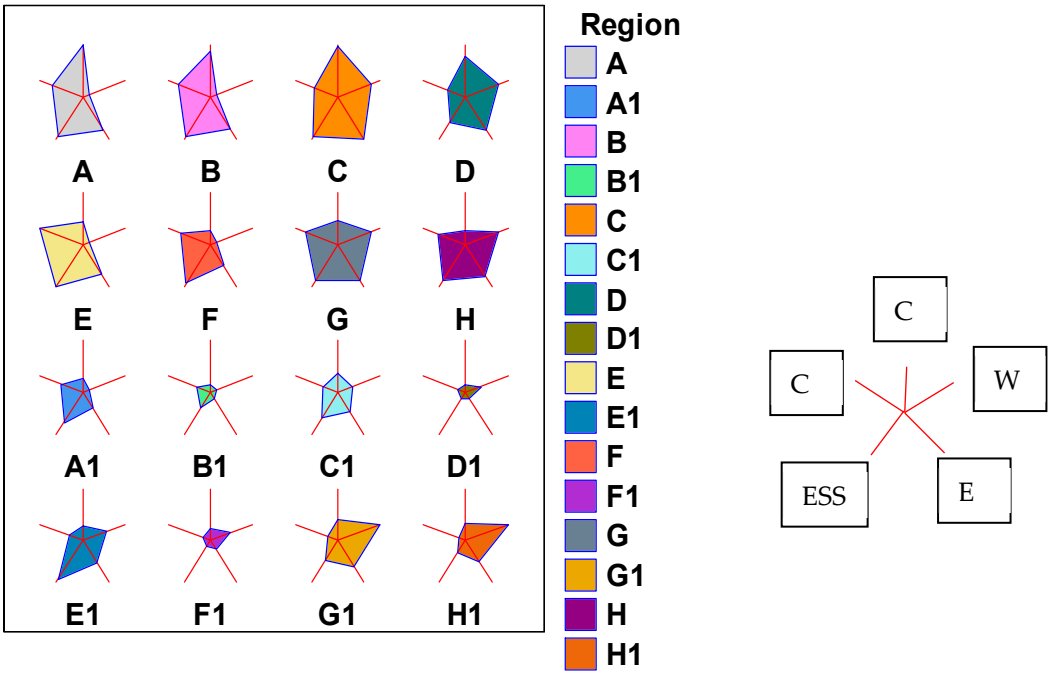


Figure 9. Comparison of the macro-scale geographical region (multivariate visualization; sun ray plot (mean and max). CP–cleaning potential, C–climate regulation, ESS–regulating ecosystem services, E–erosion regulation, W–water regulation.

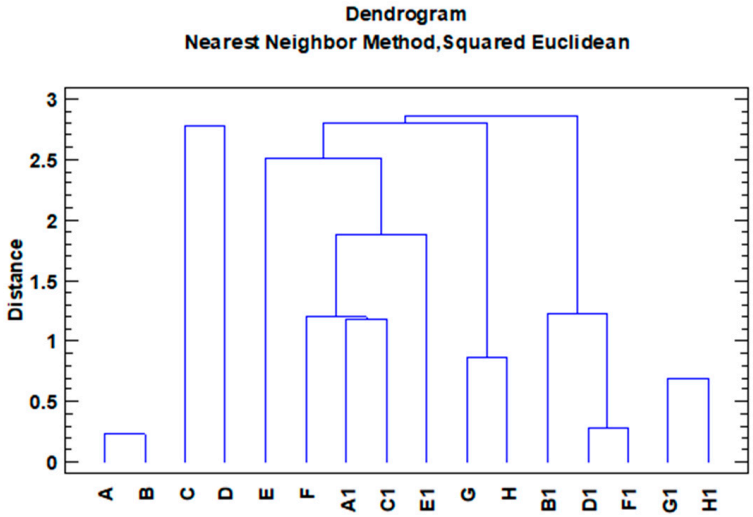


Figure 10. Comparison of the macro-scale geographical region (multivariate visualization; dendrogram).

4. Conclusions

Climate region, land cover, and soil slope were identified as key factors impacting agro-ecosystem services potential within a country which can be used as data stratification levels for further analyses. These main driving forces were used for the original agro-ecosystem services assessment in Slovakia. We identified spatial stratification criteria for the delimitation of the agricultural land of Slovakia into geographical regions homogenous from the perspective of natural and human-driven conditions (useful for national assessments of ecosystem services within the EU Biodiversity Strategy 2030 and updated Slovak biodiversity strategy 2020). Most of the national ecosystem service assessment studies focus on the identification of ecosystems, assessment of their condition and subsequent assignment of a monetary value (e.g., [98]) or investigation of biophysical indicators [99–101]. Usually, map layers are used and created with different precision and

scale for different ecosystem services. Our approach, which combines different landscape parameters into one consolidated scale, is therefore rather unique, it emphasizes the importance of landscape parameters for the provision of agro-ecosystem services, and its strength is the agro-ecosystem services database at the same spatial scale. Our results showed the possibility of using these types of national data for the geospatial stratification of agricultural land in Slovakia along the gradients of climatic regions, land cover, soil texture and soil slope, thereby effectively expanding the interpretive potential of our results towards sub-national estimates of agro-ecosystem services potential. Therefore, we assume that our study contributes to the research gap on spatial distributions of agro-ecosystem services at an adequate level of detail necessary for any practical solution leading to accurate planning of sustainable agricultural land management.

The methodological approach presented in this study is simplified and uses direct assumptions about the relationships between the agro-ecosystem services potential and the analyzed driving forces. However, in the absence of other relevant current data on the value of the potential agro-ecosystem services, this type of assessment can serve as a basic source of official information for the local assessment of agro-ecosystem services in Slovakia, as well as to support the implementation of policies and actions for sustainable land use in the agricultural sector. Our assessment process is clear that we did not attempt to assess a country's capacity to provide regulatory agro-ecosystem services in monetary terms. Instead, we use a relative point scale. The advantage of this method is that these values can be further processed on the basis of available data from relevant research; they can also be replaced by monetary values using advanced analysis or the value transfer method from relevant ecosystem services evaluation studies.

Linking the value of individual regulating agro-ecosystem services potential with geographical distribution can help to optimize its potential depending on the needs of the inhabitants living in different regions by introducing appropriate measures (for example, observing anti-erosion measures in regions with low erosion control potential; or grassing arable soils in high slope regions located in a cold climate; in regions with a low value of water accumulation to include crops that tolerate drier conditions well; in regions with a low value of cleaning potential to consider soil remediation, etc.). In regional development plans, information about the value of agro-ecosystem services potential can contribute to effective, sustainable agriculture policy-making.

According to the definition of sustainable intensification, the EU requires that even with measures to increase the primary production of agriculturally used soils, emphasis is taken on preserving the multifunctionality of the soil and, thus, on the sustainability of the agro-ecosystem's potential to provide regulating ecosystem services as well [102]. Therefore, decision-support tools for evaluating and tracking soil resources in the context of agro-ecosystem services should be the subjects of future research.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13050970/s1, Figure S1: Area representation of model regions in Slovakia (ha); Table S1: Test statistics and *p*-values to Table 7.

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