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Agroforestry-Silvopastoral Systems Suitability for the Plateau Landforms: Devrekani Plateau (Northern Turkiye)

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Abstract

The Devrekani Plateau, located in the Kure Mountains massif (Kastamonu-Türkiye), is a geomorphological unit with flat areas ranging between 1000 and 1300 meters in altitude. Agriculture, animal husbandry, and forestry activities are standard on the plateau. Due to environmental constraints, versatile, holistic, and sustainable land use plans are needed in such high areas. This study examines land use patterns compatible with natural environmental conditions for the Plateau Landforms. Agroforestry-silvopastoral systems where agriculture, pasture, forest lands, and recreational functions are applied together have been evaluated in the study area. Criteria that have a high relationship with land use have been identified. Using Geographic Information Systems, weighted overlay analysis was carried out with factor maps regarding Lithology, Slope, Elevation, and Actual Land Use. The model output reveals that the regions between agriculture and forest are the most suitable for the agroforestry-silvopastoral systems (outside urban areas) and recreation. The most suitable areas for mixed land use plans on the plateau are generally karst areas with sparse vegetation, located above 1200 meters, and having a 6-12% slope. The lower border of these areas is agricultural areas with flat or nearly flat slopes, commonly formed by alluviums. The upper limit consists of forest areas with steep slopes surrounded by high hills. Implementing agroforestry-silvopastoral land use models on plateau landforms can be an effective strategy for sustainable environmental management and land use.

1. Introduction

Land use compatible with natural environmental conditions reduces the loss of productivity of soils, socioeconomic problems, and degradation of ecological systems. Natural environmental conditions require different land use types to be intertwined. For example, agriculture, forestry, and animal husbandry in degraded/unproductive forest areas can be combined. Such mixed land use patterns fulfill essential functions for some locations. It provides rehabilitation and biological remediation of soils in areas affected by water and wind erosion. It also contributes to food security and carbon storage. In areas where mixed land use systems are applied, wild fruit plants also enable the production of non-wood products such as plant-derived extracts (such as oils, tannins, and resins), various medicinal drugs, and honey production (Chebli et al., 2021; Jose et al., 2019; Jose & Dollinger, 2019; Nath et al., 2020; Solorio et al., 2017; Yadav et al., 2019).

Non-urban mixed land use forms holistic and managerial land use on suitable lands. The aim of different land use combinations is to increase and diversify the sustainable production of land (Nair et al., 2021). Rural mixed land use systems generally can be grouped as systems where agriculture and forestry are done together

(Agroforestry), animal husbandry and forestry can be done together (Silvopastoral), and agriculture, forestry, and livestock are collected in the same area with management goals (Agrosilvopastoral systems) (Ok, 2019).

Land evaluation is a process that is aimed at the sustainable development of agricultural production in rural areas, especially in developing countries. Therefore, land evaluation involves many aspects of natural conditions, economic, and social issues (Herzberg et al., 2019). Agroforestry can be defined as an integrated land management system in which perennial woody plants (trees, shrubs) and agricultural products are combined. In this system, there are both ecological and economic interactions between different components. Agroforestry is especially important for small farmers and rural communities. It contributes to their food supply and income (FAO, 2022; Puri & Nair, 2004).

Silvopastoral systems are grazing management systems in which livestock activity is met with forest forage plants. In this land use system, animals are fed with feed obtained from forage plants grown in the region close to the farms. Many silvopastoral systems worldwide involve the grazing of free-ranging animals under fertile/unproductive natural stands. Under suitable conditions, as much forage as open pasture systems can be produced. The feeds produced have been determined to have high nutritional quality (Gabriel, 2018). The key design criterion for these complex land use practices is to optimize the use of spatial, temporal, and physical resources by maximizing positive interactions (facilitation) and minimizing negative ones (competition) among the components, for which the principles of sustainable land use systems are relevant (Jose et al. 2019). Research suggests that mixed land-use systems can increase systemwide productivity while providing multiple ecosystem services (Chará et al., 2019; Smith et al., 2022).

Agroforestry-Silvopastoral systems are potential areas where soil fertility is low, erosion potential is high, and the surface soil dries (loses moisture) (Geray & Göreceliouglu, 1993). High plateau landscapes are generally semi-arid regions. Traditional animal husbandry activities are also common in these areas. The livestock-based farming system is the main source of livelihood in the dryland. It is one of the best land use practices for semi-arid conditions and high areas such as plateaus (Solorio et al., 2017; Soni et al., 2016).

Mixed land use systems are humanity's oldest practice. For this reason, the first applications in this field appeared in developing countries, and later, they began to be implemented in developed countries (Joshi, 2023; Nair et al., 2021; Steiner, 2012). There are studies on the applicability of agriculture and animal husbandry along with some forest tree species in Turkiye (Ayberk et al., 1996; Fidan et al., 2007; Filiz & Tolunay, 2003; Geray & Göreceliouglu, 1993; Turna & Ayaz, 2001). Suitability analysis of agroforestry-silvopastoral systems on high plateaus has yet to be conducted in the study area. The region, which includes the Devrekani Plateau and its surroundings, has the characteristics of a Plateau according to its structural and morphological characteristics (Johnson, 2011; Kurter, 1982). The name "Devrekani Plateau" has been suggested for the flats that form integrity in the topography (Duran & Aygun, 2017). However, there is no study on the agroforestry-silvopastoral systems and other land use models of the region.

2. Data and Methods

2.1. The Study Area

The Kure Mountains correspond to the mountainous area of the Province of Kastamonu, in the North of Turkiye. The high peaks and hills of the Kure Mountains surround the Devrekani Plateau. It extends in an E-W direction, compatible with the Kure Mountains. Devrekani Creek is located in the middle part of the plateau (also in the E-W direction). It has an average length of 30 km and a width of 10 km. The average elevation varies from 1000 to 1300 m from the mean sea level. The geographical coordinates of the study area comprise Latitude 41°31'10" N to 41°47'45" N and Longitude 33°31'00" E to 34°08'25" E.

The northern part of central Turkey has a convex appearance towards the Black Sea. The Kure (Isfendiyar) mountain range, which forms a barrier between the sea and the interior, extends behind the coast and parallel to the coast (Kurter, 1971). Daday-Gokirmak, Devrez rivers/valleys, and their plains are located behind the Kure-Ilgaz mountain range. There are Devrekani, Seydiler, and Agli districts of Kastamonu province within the

Plateau (Figure 1). Agriculture and husbandry practices are the primary sources of economic activity for the rural people of the district.

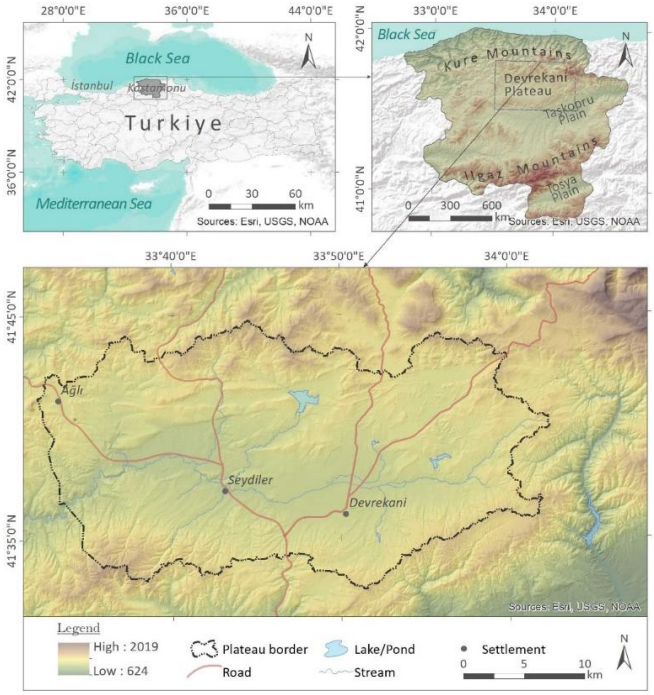


Figure 1. The Location Map of the Study Area

2.2. Methodology

A geographical area may be classified as "extremely suitable" or "completely unsuitable" for a particular land use for various reasons. Rough and sloping terrain is not suitable for agriculture due to reasons such as water and wind erosion. In this study, categorical criteria were determined according to the reasons restricting land use classes in the natural environment. These criteria reflected land characteristics, such as spatial factors such as geology, topography (such as slope and elevation), and actual land use, which were considered in the decision-making process for land suitability evaluation. Field surveys were also carried out to detect differences in topography.

The geological-lithological characteristics of any region can affect the land use pattern. In this context, geological/lithological features of rugged terrains, along with other natural factors, are considered. In addition, the socio-economic-cultural characteristics of the people living in the region are also effective in this use (Gülersoy & Buldan, 2020). Among physiographic factors, slope percent and elevation are important parameters used for land use suitability (Birhanu et al., 2019). Agroforestry land suitability can be assessed through a multi-criteria approach using GIS (Ahmad et al., 2019; Herzberg et al., 2019; Nath et al., 2021). Generation of various thematic layers in order to determine suitability criteria for Agroforestry-Silvopastoral systems in the study area; 1/25000 scale topography maps, digital elevation model (DEM with 10m resolution; (Harita Genel Müdürlüğü, 2010), 1/100000 scale geological maps (MTA, 1990; 2002) and 1/25000 scale actual land use maps were used (Orman Genel Müdürlüğü, 2020).

The Weighted Overlay Method (WO) was used to create the final model and maps of agroforestry-silvopastoral systems suitable for the plateau. This method is one of the most widely used approaches in spatial decision-making processes. The Weighted Overlay approach was applied by assigning appropriate weights to each criterion based on their importance for agroforestry-silvopastoral systems to integrate them into a single output raster where more favorable factors result in higher values, and less favorable ones have lower values. The weight coefficients between the criteria were determined according to the average of the scores by nine different experts. Their suitability degrees/weights were evaluated with Geographic Information Systems. In

scientific research on GIS-based land suitability evaluation, the approach is frequently applied (Dan et al., 2018; El Baroudy, 2016; Herzberg et al., 2019).

Among lithological criteria, alluviums are the most suitable class/variable for agricultural activity. Clasts and carbonates are suitable variables for both agriculture and forest areas. Other lithological units are classified as suitable for the forests. The percentage of slope affects land use. Flat surfaces (slope with an angle less than 6%) are the most suitable class for agricultural activities. The surfaces with a slope between 6-12% are reserved for agriculture and forest (mixed land use forms). The areas with a slope of more than 12% are classified as suitable for forests (steep slopes and rough terrain). The 1000-1100 m altitude of the plateau is the most suitable for agricultural activities. The altitudes between 1100-1200 m in the study area were classified as suitable for the mixed land use forms. Areas where the altitude is lower than 1000 m and higher than 1200 m are classified as suitable for forest. Actual land use classes are agricultural activity areas, which are the most suitable classes for agriculture. Pastures, open/bare area land, and degraded/unproductive forest areas were classified as suitable for agroforestry-silvopastoral systems. Productive forests were deemed suitable for the forest area (Table 1, 2; Figure 2).

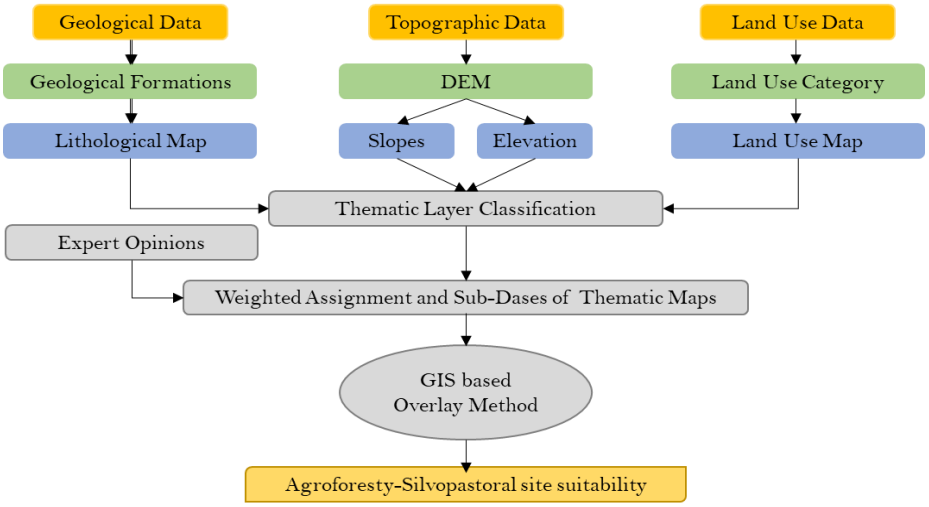


Figure 2. Flow Chart Briefly Explaining the WO Method Applied in This Study

Table 1. List of Criteria and Variables Used for the Suitability Analysis

Suitability criteria	Lithology variables	Slope (%) variables	Elevation (m) variables	Actual Land Use variables
Agriculture	Alluvium	0-6	1000-1100	Agriculture
Agroforestry-Silvopastoral systems	Clastic and carbonate rocks	6-12	1100-1200	Pasture, Unproductive Forest, Bare land
Forest	Other units	>12	<1000 & >1200	Forest

Table 2. Influence Rate for the Criteria

	Lithology	Slope (%)	Elevation (m)	Actual Land Use
Influence rate	0,25	0,35	0,175	0,225

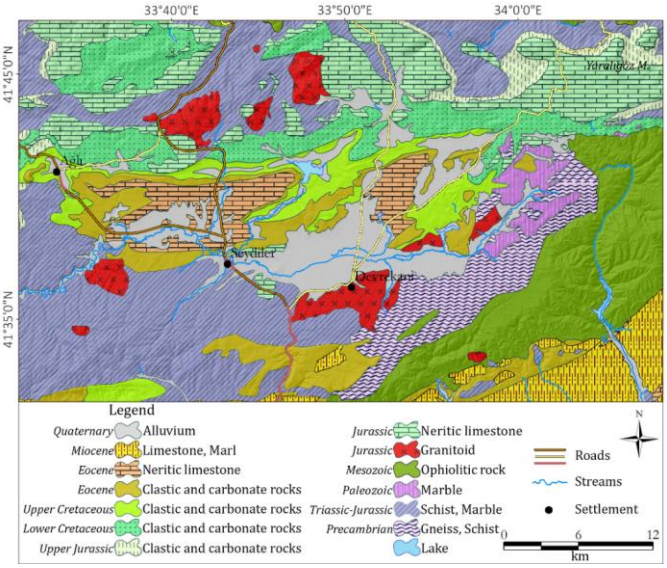
3. Results & Discussion

3.1 The Geological/Lithological Criteria

The geological/lithological condition of a region is one of the factors that shape the ecological environment as well as the fertility of the soil. Regions with different bedrock, landforms, and soil characteristics under the influence of similar climate types show different ecological characteristics (Kantarci, 2005). Because Turkey's mountainous areas are sloping/rugged (erosion), the soils reflect the characteristics of the bedrock (Erinc, 1993). The texture of the soil, formed by the weathering of bedrock with different lithological structures, affects its water-holding capacity (Duran, 2013).

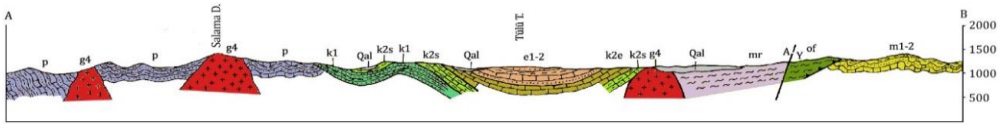
In Kastamonu province and its surroundings, a metamorphic series of crystalline schists, phyllites, crystallized limestones, and marbles spread over vast areas (Kurter, 1982). Besides local granite intrusions, there are metamorphism and submarine sediments of sandy, clayey-calcareous structure. Many Ammonite samples have also been identified in the region (Kennedy et al., 2007; Uzun, 2004). There are also different sedimentary units in the north and east. The ophiolitic series occurs on the south-eastern slopes of the plateau. Granotoid rock groups crop out as sloping hills (Kurter, 1982). The alluviums carried by the Devrekani Creek and its tributaries from the highlands spread along its direction. There are limestones (karstized) around the field. Karstic shapes appear in areas where there is limestone. In addition, clastic and carbonate rocks give the outcrop in large areas on the plateau (Figure 3, 4).

Lithological variables were used to form the lithological suitability map for agroforestry-silvopastoral systems. Alluviums have suitable soil with outstanding potential for agriculture. However, clastic and carbonate rocks mostly have relatively moderate-quality soil that is suitable for agroforestry-silvopastoral systems. The other units (schist, marble, gneiss, ophiolitic rock, and granitoid) are suitable for forest soils. The lithology was reclassified into three groups for WO analysis and were ranked as suitability maps respectively (Figure 9a)



Source: MTA (1990; 2002)

Figure 3. Geology/Lithology Map of the Study Area



Source: MTA (1990; 2002)

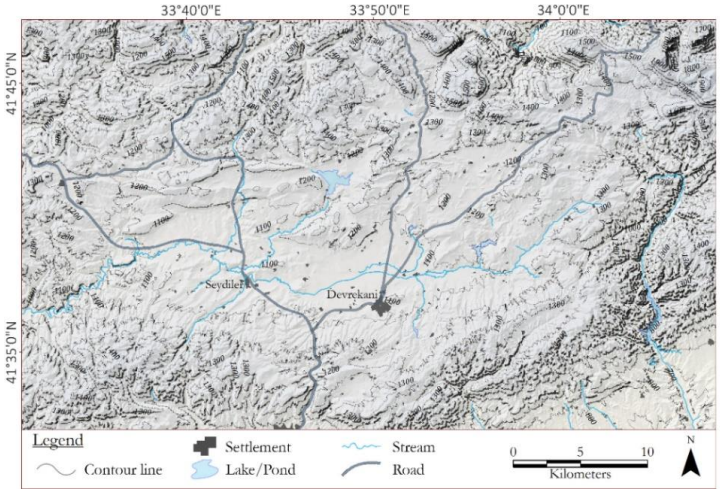
Figure 4. Geological Cross-Section of the Study Area (A-B direction)

3.2 Topographic Criteria

The Kure Mountains massif is a part of the pontine orogenic belt (Ketin, 1966). Layers of geological formations in this zone, faults, and unconformities are intertwined. The mountain range rises in an arc to the Black Sea between the Bartin Stream and the Kizilirmak River (Yücel, 1988). The highest peak is 2019 m (Yaraligoz Mountain) (Figure 5). Topographic conditions have an essential role in the distribution of land use/cover. Many phenomena, such as agriculture, transportation, climate, economic activity, settlement, and erosion, are directly related to topography. Topography also affects the growth and development of forage plants (Nath et al., 2021; Wu et al., 2023). Different topographic factors can be used in multicriteria suitability analyses (Lisso et al., 2024; Nath et al., 2021). However, due to their close relationship with land use, slope and elevation criteria were used in this study.

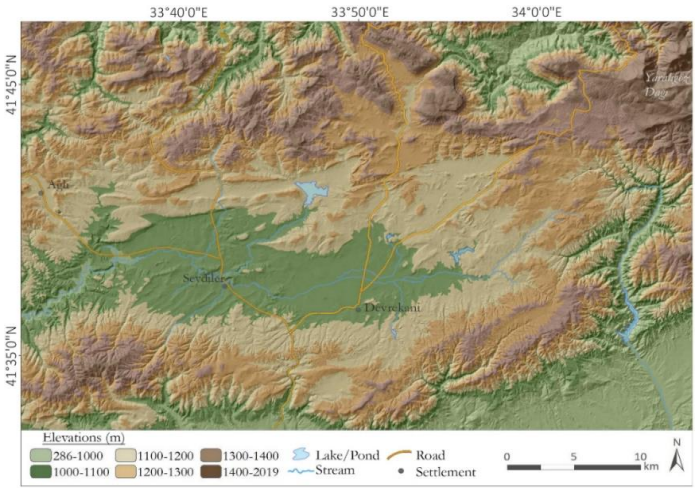
3.2.1 Elevation Levels

Although the difference between altitudes in the study area varies, the general altitude of the plateau is between 1000-1300 m. The elevation increases around the plateau. The peaks in the northeast are located on Yaraligoz Mountain. The relative elevation difference between the plateau and its surroundings reaches 500-600 m (Figures 5, 6).



Source: HGM (2010)

Figure 5. Topographic Map of the Study Area



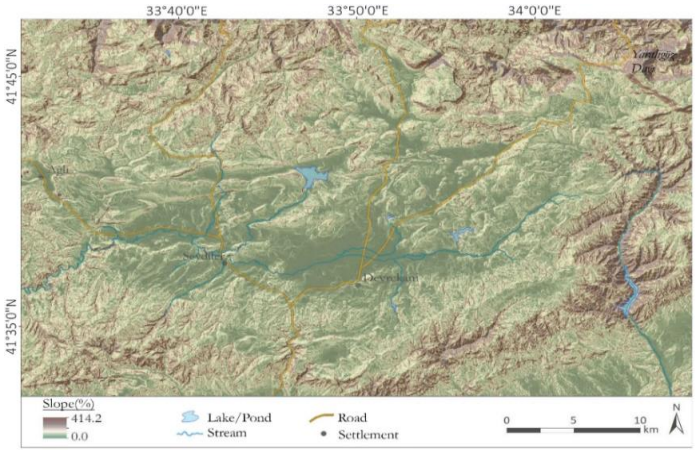
Source: HGM (2010)

Figure 6. Elevation Map of the Study Area

The spatial distribution of elevation is provided in Figure 6. The whole region has mostly mountainous topography with elevation ranging from low (<1000 m) to moderate (1000–1300 m) and high (1300–2019 m). Altitude/elevation is considered an essential parameter in agroforestry suitability mapping, and tree growth declined with high altitude. Temperature and vegetation decrease due to an increase in altitude/elevation. The tree does not grow above the tree line/timberline due to low air pressure and reduced levels of carbon dioxide/oxygen. Carbon dioxide is needed for plant metabolism and growth (Ahmad & Goparaju, 2017; Bijalwan et al., 2015; Coomes & Allen, 2007). The elevation levels were reclassified into three groups for WO analysis and were ranked as suitability maps respectively (Figure 9c).

3.2.2 Slope Percent

The Devrekani Plateau looks like a basin surrounded by the high peaks of the Kure Mountains. Tectonism and river erosion caused this area to slope and steepen towards the west as a result of compression and uplift. Alluviums are in the middle part of the Plateau.



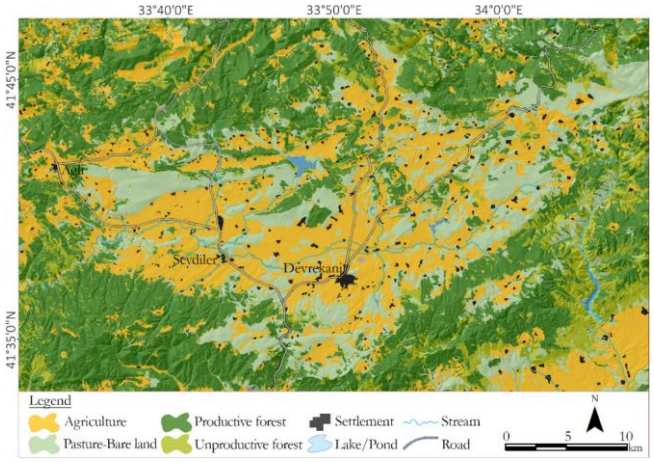
Source: HGM (2010)

Figure 7. Slope Map of the Study Area

In Figure 7, the slope is almost flat, and the soil is more profound. The slope increases around the alluviums. Far from these flat areas, the elevation and ruggedness increase. The region has a topography with a gentle slope (<6%), undulating slopes (6 to 12 %), and hilly to steep (>12%) slopes. The slope was generated from DEM (Figure 7). The regions with moderate elevation (1100-1200m) and undulating slopes have highly suitable topography for agroforestry-silvopastoral systems. The slope percent was reclassified into three groups for suitability analysis, respectively (Figure 9b).

3.3. Actual Land Use Criteria

Land use in the Devrekani Plateau is shaped depending on the topography. The land use was generated from 1:25.000 scale stand types' maps of Kastamonu province (Orman Genel Müdürlüğü, 2020). Alluviums accumulated by streams and irrigable areas are used as agricultural areas. The steeply sloping landforms in the highlands surrounding the plateau are covered with forests between these two main land uses (agriculture and forests), derived as unproductive forest, pasture, bare/open land, settlement, and water surface. The derived unproductive forest, pasture, bare/open area land, and sparse vegetation were evaluated for the agroforestry-silvopastoral systems suitability mapping. The actual land use was reclassified into three groups for analysis (Figure 9d).



Source: OGM (2020)

Figure 8. Current Land Use Map of the Study Area

3.3. Suitability for Agroforestry-Silvopastoral Systems of the Devrekani Plateaus

There are some methods for the suitability analysis of land use classes. The weighted overlay method in GIS was used in this study. The variables under each criterion have an importance level for land use suitability.

Each map was determined based on the relative significance of the four criteria (lithology, slope, elevation, and current land use) (Figure 9).

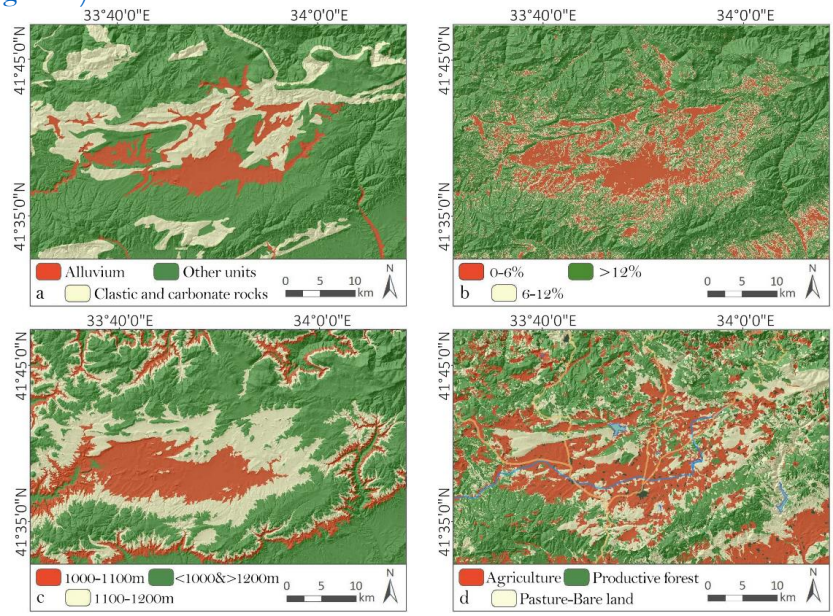


Figure 9. Criteria and Variables for Land Use Suitability based on a) Lithology Criteria b) Slope Criteria c). Elevation Criteria d) Actual Land Use Criteria

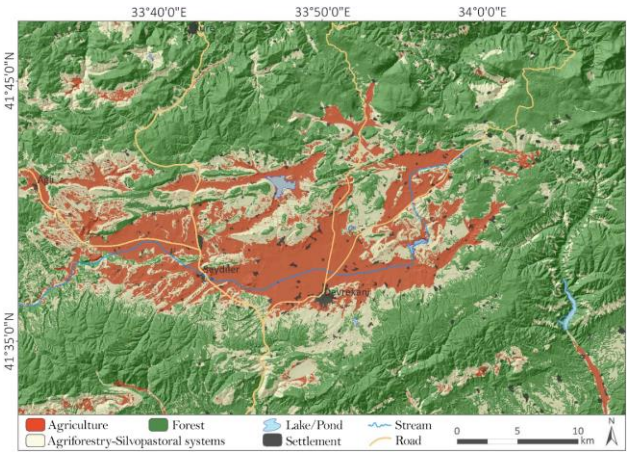


Figure 10. Result of Weighted Overlay Analysis (Land-Use Suitability for Plateau Landform)

While similar weights were assigned to each variable under the lithology and actual land use criteria, higher weights were provided to slope percentage variables and lower weights were provided to elevation variables. The sum of all the weights was 100%. As a result of the suitability analysis, agriculture, forest, and agroforestry-silvopastoral system classes were determined. The final agroforestry-silvopastoral suitability map was validated through field-based location information. Regions suitable for agricultural activity are on the alluviums and flat land in the middle part of the plateau. The high, steep slope-rugged region surrounding the plateau is suitable for forests. The regions between agriculture and forest are suitable for the agroforestry-silvopastoral systems (Figure 10). These areas mostly exhibit karstic bedrock with low to moderate slope and medium elevation, providing an average favorable condition towards potential animal feed crops. These areas can be utilized for agroforestry-silvopastoral systems with good planning.

5. Conclusion

Devrekani Plateau is a part of the Kure Mountains massif (Kastamonu). It is one of the region's main geomorphological units. It is also the upper basin of Devrekani Creek. The peaks of the Kure Mountains are also around the plateau. Land use in the plateau and its immediate surroundings depends on the variability in

topography. The alluvial area formed by the Devrekani Creek and its tributaries is under intense agricultural activity. It is the third largest agricultural activity area of Kastamonu province, after Taskopru and Tosya plains. The steep slopes of the plateau are covered with forest cover. Pastures, sparse vegetation, and bare/open lands formed due to environmental restrictions and degradation are distributed in different parts of the plateau. The water surface and settlements are located on lower land. Agroforestry-silvopasture systems are used to increase the sustainability of land use/cover. However, it is not an extensively used practice in Turkiye. Agriculture and livestock activities can be developed on the plateau landforms.

Therefore, the suitability of agroforestry-silvopastoral system patterns was examined within the aim of this study. Using GIS, areas suitable for mixed land management systems were determined on the Devrekani plateau. The results of this study show that agroforestry-silvopasture systems are suitable for plateau landscapes. The most suitable areas for mixed land use plans on the plateau are generally karst areas with sparse vegetation, located above 1200 meters, and having a slope of 6-12%. Mixed land management models have versatile benefits for similar plateau landscapes. It is more beneficial to practice than open pasture and thin forests in terms of economics. Monocultures and poor farming practices threaten the bulk of the world's landscapes. Due to its soil protection function, sloping and rugged areas are suitable for forests/permanent vegetation. It also keeps sloping and rugged lands away from socioeconomic (agriculture and grazing) pressure. Additionally, the importance of pastoral/recreational features increases. High plateau landforms with communities of low socioeconomic status can be implemented agroforestry-silvopastoral systems in the identified potential sites. Agricultural and animal production can be increased with versatile planning of self-renewable natural resources. In the land use plans of the plateaus, sophisticated mixed land models contribute to productivity and rural development.

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