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Analysis of permaculture potential of agro-ecological regions with GIS and RS techniques: An example of Ankara Stream Basin

Agro-ekolojik bölgelerin permakültür potansiyelinin CBS ve UA teknikleri ile analizi: Ankara Çayı Havzası örneği

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Abstract

Conventional agricultural practices have led to widespread environmental degradation, prompting the need for sustainable alternatives like permaculture that offer resilience and ecological harmony. As a holistic approach, permaculture emphasizes the creation of self-sustaining agricultural systems that work in concert with natural ecosystems. This study aims to assess the viability of permaculture practices in the Ankara Stream Basin, located in Central Anatolia, Türkiye, which is known for its challenging agricultural conditions due to poor soil quality and low rainfall, by utilizing Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. The analysis integrates climatic data (precipitation, humidity, average temperature), topographical factors (elevation, slope, aspect), and soil characteristics (texture, fertility, erosion) to identify potential permaculture zones. Analytic Hierarchy Process (AHP) and weighted overlay analysis were used to evaluate these factors. Results indicate that areas around Ova Stream and the northern parts of Çubuk Stream exhibit high suitability for permaculture due to favorable climate, topography, and productivity. Conversely, urban areas, regions with significant erosion, and low soil fertility are deemed unsuitable. The study highlights that permaculture could enhance production and rehabilitate systems damaged by conventional agriculture, providing a sustainable alternative for the region's ecological and economic development.

Keywords: Permaculture, Analytic Hierarchical Process (AHP), Suitability for Site Selection, Agro-Ecological Zones (AEZ), Geographical Information Systems (GIS), Remote Sensing (RS).

Özet

Geleneksel tarım uygulamaları, yaygın çevresel tahribata yol açmış ve bu durum, direnç ve ekolojik uyum sunan sürdürülebilir alternatifler olan permakültür gibi yöntemlerin ihtiyacını doğurmuştur. Bütünsel bir yaklaşım olan permakültür, doğal ekosistemlerle uyum içinde çalışan kendi kendine sürdürülebilir tarım sistemlerinin oluşturulmasını vurgular. Bu çalışma, Türkiye'nin Orta Anadolu bölgesinde yer alan ve zayıf toprak kalitesi ile düşük yağış nedeniyle zorlu tarım koşullarıyla bilinen Ankara Çayı Havzası'nda, Coğrafi Bilgi Sistemleri (CBS) ve Uzaktan Algılama (UA) teknolojileri kullanarak, permakültür uygulamalarının yaşayabilirliğini değerlendirmeyi amaçlamaktadır. Analizde, potansiyel permakültür bölgelerin belirlenmesi için iklim verileri (yağış, nem, ortalama sıcaklık), topografik faktörler (yükseklik, eğim, yön) ve toprak özellikleri (doku, verimlilik, erozyon) entegre edilmiştir. Bu faktörler, Analitik Hiyerarşi Yöntemi (AHP) ve ağırlıklı örtüşme analizi kullanılarak değerlendirilmiştir. Sonuçlar, Ova Deresi çevresindeki alanların ve Çubuk Çayı'nın kuzey kısımlarının, elverişli iklim, topografi ve verimlilik nedeniyle permakültür için yüksek uygunluk gösterdiğini belirtmektedir. Buna karşılık, kentsel alanlar, önemli erozyonu olan bölgeler ve düşük toprak verimliliği olan bölgeler uygun görülmemektedir. Çalışma, permakültürün, geleneksel tarım tarafından zarar görmüş sistemleri iyileştirebileceğini ve bölgenin ekolojik ve ekonomik kalkınması için sürdürülebilir bir alternatif sağlayabileceğini vurgulamaktadır.

Anahtar Kelimeler: Permakültür, Analitik Hiyerarşi Yöntemi (AHP), Yer seçimine uygunluk, Agro-Ekolojik Bölgeler (AEB), Coğrafi Bilgi Sistemleri (CBS), Uzaktan Algılama (UA).

1 Introduction

As the mechanization of agriculture has taken hold, traditional small-scale farming practices inherently facilitating soil and resource rejuvenation have given way to adopting conventional farming techniques. Nevertheless, the widespread embrace of conventional methods raises concerns due to their adverse impact on soil quality and human well-being [1]-[7]. For example, mono-cultivation disrupts the collaborative growth mechanisms and defense strategies that naturally emerge within diverse plant communities, resulting in dependence on pesticides, herbicides, and synthetic fertilizers [8]-[10]. Continuous soil intervention, excessive cultivation, and irrigation impair the soil structure and cause a decline in soil organic matter. This process of soil depletion culminates in reduced crop yields, thus necessitating an increased application of fertilizers and agrochemicals. The ensuing cycle of soil degradation underscores the pressing need for sustainable farming practices [11]-[17].

These problems eventually encouraged researchers and practitioners to find alternative ways to merge agronomy and ecology in the late 1920s and led to the development of the agro-ecology approach [18]. Agro-ecology is based on adapting the principles of nature's functioning to agricultural

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production. It aims to make agriculture and food systems sustainable by optimizing the interaction between living things such as plants, animals, and humans [13],[19]. Permaculture is one of the practices that enable the realization of the agro-ecological approach and is seen as one of its branches. In permacultural implementation, where fields are designed based on ecosystem mimicry and complex system optimization, each system output is used as the input of another element. Permaculture, as a comprehensive agricultural approach, promotes sustainable methodologies addressing a multitude of environmental challenges [20]. With the coexistence of different plants and animals, permaculture areas require very little intervention from outside. Thus, environmental conditions are improved, production efficiency is increased, and the cost of production is reduced [11],[21]-[23].

Permaculture was introduced in the late 1970s by Bill Mollison and David Holmgren, who advocated adapting the laws of nature to agricultural production. The term emerged from the combination of the words permanent and agriculture. Still, the latter is often referred to as culture due to its potential to alter not only agricultural productivity but also the social and economic sectors of society [11],[22]. By watching natural processes and applying them to the form of production, experts including Mollison, Holmgren, and Hemenway created permaculture as a restorative, ecological, and therefore non-destructive form of production to overcome the negative impacts of agriculture [11],[15],[21]-[25].

The three basic principles of permaculture embraced by all permaculture designers are (i) caring for nature, (ii) caring for people, and (iii) sharing surpluses equitably [26]. Permaculture offers a range of significant advantages compared to conventional agriculture. It promotes the reduction of waste through highly efficient resource utilization, ensuring that all resources serve the broader public or nature. It also contributes to air pollution reduction by advocating for sustainable agricultural practices, consequently reducing the use of emission-intensive machinery [27].

Permaculture promotes mutual food supply by emphasizing the cultivation of organic crops in mixed perennial and annual plant communities. Permaculture also supports mimicry in farming and pest control by encouraging the cultivation of a variety of crops rather than relying on monoculture, whether annual or perennial [27],[28]. It facilitates the establishment of self-sustaining systems that fulfill various needs, ultimately decreasing the demand for labor-intensive agricultural practices [27],[29]. Finally, permaculture aligns with principles of climate justice, as it emulates the functioning of healthy natural ecosystems, promoting regenerative methods that maintain nutrient-rich soils, minimize waste, conserve water, and safeguard wildlife habitats. It often results in more nutritious crops compared to industrial farming and, in some cases, yields greater harvests [15],[20],[28].

Today, most permaculture farms are located in Australia, where the first practice is recorded. Over time, these practices have become widespread as ecological food production concerns have increased. Permaculture farms in Türkiye are generally located in the Aegean, Western Mediterranean, and Western Black Sea coastal regions where the soil is fertile, the climate is mild, and rainfall is regular. However, considering the potential of permaculture practices to provide ecological and physical remediation in the geographical context, it is critical to implement it in regions with considerably tougher agricultural characteristics. Due to the impacts of both conventional agricultural practices and climate change, much of Türkiye's soils, especially in Central Anatolia, are nutrient-poor. This situation in Central Anatolia is an obstacle to agriculture in the region without pesticides, herbicides, and artificial fertilizers [30],[31]. Therefore, the presentation of permaculture practices in Central Anatolia is supposed to increase production and productivity while rehabilitating systems damaged by modern agricultural practices. For this reason, the Ankara Stream Basin, located in Central Anatolia, was selected as the study area.

Permaculture sites are selected and designed based on observation of natural systems, the embedded knowledge of traditional agricultural systems, and modern, scientific, and technological knowledge [26]. In this regard, site selection and designs differ according to each region's characteristics; therefore, different climate and soil characteristics require different permaculture site selection and design approaches. Still, specific site selection recommendations exist, especially on certain climatic and soil characteristics that necessitate examining and analyzing land resources and diverse geospatial factors [11],[24]. On the other hand, studies on permaculture generally focus on the assessment, zoning, and design of the selected area rather than analyzing suitability for site selection [32]-[34]. There are also studies on site selection based on agro-ecological zoning, in which the ranges of parameters are not made specifically for permaculture. Instead, it is preferred to select agro-ecologically productive zones [15],[35].

In the studies on permaculture in the literature, different topics such as designing a permaculture farm (with or without GIS) by making spatial analysis for permaculture in a certain area [30],[36], evaluation of permaculture within the scope of tourism [37]-[40], evaluation of practices through permaculture farms [41], permaculture practices in urban planning [42], the place of permaculture in sustainability [23],[43]-[45], and permaculture in agro-ecology studies [15],[33] have been focused. As a result of the extensive literature review, it was seen that no previous study has been conducted on the suitability for permaculture site selection. On the other hand, there are similar studies in terms of agro-ecological zoning in studies on agro-ecological production [46]-[51]. In this context, the authentic side of this study is to develop a novel method for the suitability of site selection by applying agro-ecological zoning methods to permaculture.

The main objective of this study is to provide a scientific basis for suitable site selection analysis of permaculture through agro-ecological zoning method for a specific case study using Geographical Information Systems (GIS) and Remote Sensing (RS) capabilities. In addition to the climate and soil features, topography, hydrology, land use, and biomass data were used to determine the suitability of the Ankara Stream Basin for permaculture establishments. The permaculture suitability map of the study area was developed through weighted overlay analysis according to the impact scores determined by AHP. In addition to determining suitable places for permaculture in the Ankara Stream Basin, a scientific basis for the research that can be used to determine the suitability of permaculture site selection has been established. In line with the scientific basis established within the scope of the study, variables that will provide decision support for permaculture sites planned to be established in other areas have been determined.

2 Material and method

2.1 Study area

In Türkiye, permaculture practices are predominantly found in regions such as the Aegean, Western Mediterranean, and Western Black Sea, all boasting superior soil quality and climatic conditions. However, Central Anatolia lacks permaculture farms, primarily due to its relatively inferior soil quality and lower rainfall. Consequently, given its status as a significant hydrological tributary of the Sakarya River, the Ankara Stream Basin has been identified in this study as a potential site for permaculture practices.

The Ankara Stream Basin (Figure 1) is located within the larger Sakarya River basin. The Ankara Stream itself is strategically situated in Türkiye's Central Anatolian Region. Originating from the eastern parts of Ankara, it flows toward the city center before eventually merging with the Sakarya River. As a significant tributary of the Sakarya River, following the Porsuk Stream, the Ankara Stream stands out as its second-largest branch [52]. The stream, spanning an approximate length of 160 km, passes through the districts of Nallıhan, Beypazarı, and Ayaş before uniting with the Çubuk Stream in the Sincan region.

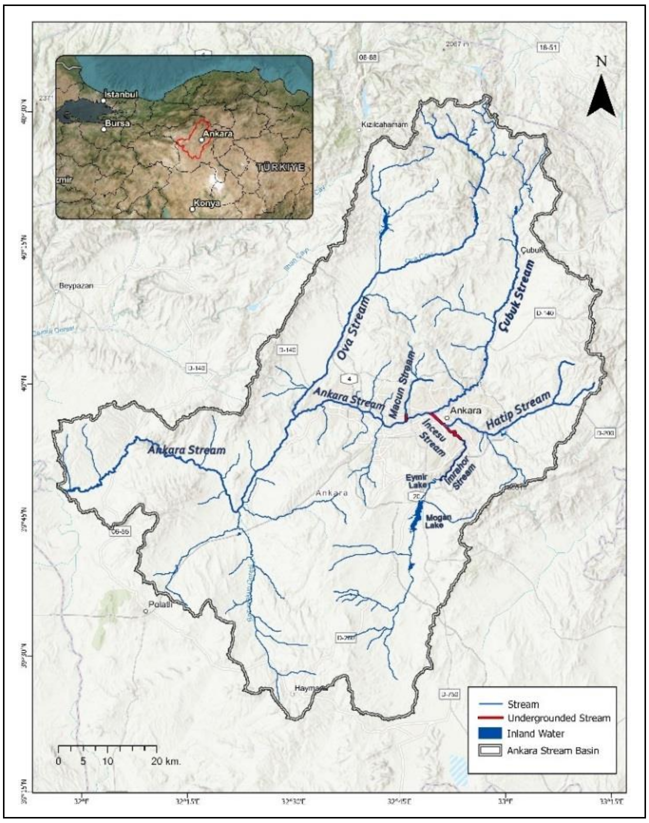


Figure 1. The Ankara Stream Basin.

In the Ankara Stream Basin, approximately 45% of the land area is dedicated to dry farming. This form of agriculture, which relies on seasonal rainfall rather than irrigation, is a testament to the semi-arid nature of the region. Additionally, meadows constitute about 34% of the land cover, offering a rich biodiversity and potential areas for sustainable farming practices. Urban and settled areas account for roughly 7% of the basin, reflecting the ongoing urban development and human presence in the region.

The primary water sources feeding the Ankara Stream are the Hatip Stream from the north and the İncesu Stream from the south. Meteorological data indicate that the stream's flow rate diminishes during the summer months and intensifies during periods of heavy rainfall. Several bridges have been constructed over the stream due to urban development, and certain sections have been covered to cater to urban needs [53]. Climatological analyses highlight that the study area and its surroundings are subject to a semi-arid, sub-Mediterranean climate [54].

In recent years, environmental challenges such as high salinity and increased electrical conductivity have emerged in the Ankara Stream [55]. Additionally, due to industrial activities, water pollution on the stream has become a severe issue in the region [56]-[58]. These environmental problems negatively affect the usability of Ankara Stream as irrigation water. In this context, implementing permaculture practices in the Ankara Stream Basin could protect and improve existing water resources, reducing salinity and pollution issues. Moreover, they could enhance the organic matter content of the soil, control erosion, and thus improve soil fertility in the region while alleviating salinity problems.

2.2 Material

The primary material of this study comprises a diversity of geospatial data. Within this context,

- Climatic factors: precipitation, relative humidity, and average temperature,
- Topographic factors: slope, aspect, and elevation,
- Productivity factors: land use capability classes, land type, soil texture, degree of erosion, hydrological soil groups and land use,
- Biomass factors: Normalized Difference Vegetation Index (NDVI) and dry matter.

were analyzed. The general information on the used materials is given in Table 1.

2.2.1 Climatic factors

In agriculture and permaculture, understanding the interplay of climatic elements is paramount. Three primary climatic parameters underpin this study: precipitation, humidity, and average temperature.

- Precipitation, a vital water cycle component, is critical for soil hydration and nutrient transportation. It governs water availability, an essential resource for plant photosynthesis and transpiration. Additionally, precipitation influences soil fertility, groundwater levels, and the incidence of water-related plant stresses [59]-[63],
- Humidity, representing the concentration of water vapor in the air, impacts both plant transpiration and soil evaporation. It is closely tied to plant hydration, affecting photosynthesis and, indirectly, plant health [61],[64]. For instance, high humidity levels can foster the spread of certain plant diseases and pests,
- The average temperature sets the boundaries for plant growth and survival. Every plant species has specific temperature thresholds for germination, growth, and reproduction. Therefore, average temperature dictates which species can thrive in a given location, shaping the composition of local plant communities. Extreme temperatures can induce stress and affect nutrient availability in the soil [59],[65],[66].

Table 1. Materials and sources.

Material	Source	Type	Spatial Resolution/Scale
Precipitation	Turkish State Meteorological Services	Table for 12 stations	-
Relative Humidity	Turkish State Meteorological Services	Table for 15 stations	-
Average Temperature	Turkish State Meteorological Services	Table for 15 stations	-
Slope	Generated from USGS STRM DEM	Raster	30 m
Aspect	Generated from USGS STRM DEM	Raster	30 m
Elevation	Generated from USGS STRM DEM	Raster	30 m
Land Use Capability Classes	General Directorate of Rural Services	Vector	1:25000
Land Type	General Directorate of Rural Services	Vector	1:25000
Soil Texture	General Directorate of Rural Services	Vector	1:25000
Degree of Erosion	General Directorate of Rural Services	Vector	1:25000
Hydrological Soil Groups	DAAC ORNL	Vector	250 m
Land Use	General Directorate of Rural Services	Vector	1:25000
NDVI	Generated from Landsat 8 OLI Images	GeoTIFF	30 m
Dry Matter	Generated from NDVI analysis	GeoTIFF	30 m

In order to comprehensively analyze the influence of these parameters within the study area, data on monthly precipitation, monthly relative humidity percentages, and monthly mean temperature values were sourced for the period up to February 2021 from the Turkish State Meteorological Services' long-term averages. These datasets were obtained from 15 meteorological stations located in and around the basin, although only 12 provided the necessary precipitation data. The specifics and locations of these stations are provided in Table 2. In the table, precipitation data is supplied as the annual total average, while humidity and temperature data are provided as monthly averages.

2.2.2 Topographical factors

Within the scope of the study, altitude, slope, and aspect data were analyzed as topographical factor indicators for suitability of site selection for permaculture.

- Choosing a proper elevation range with a suitable climate is essential to prevent plants from being exposed to stress due to water and temperature [33],[67],
- The slope data is important both in terms of rainwater collection, in terms of landslides, and in terms of the safety and ease of activities to be carried out in the permaculture area [33],[67],
- The aspect data is significant in Central Anatolia because of the effect of insolation and shading on plant growth. In central-northern Anatolia, insolation positively affects plant growth [68].

The topographic data were generated using ArcGIS 10.8 software from 30 m resolution digital elevation model data from Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global via the United States Geological Survey (USGS) Earth Explorer website.

2.2.3 Productivity factors

Land use capability classes, soil texture, land types, erosion degree, hydrological soil groups, and land use/land cover data were used as productivity factor indicators.

- Land use capability classes include information on whether the soil is suitable for cultivation [69],[70]. One of several interpretive groups created especially for agricultural purposes is the capacity classification. Arable soils are categorized according to their potential and restrictions for sustaining the cultivation of commonly cultivated crops that do not need specialist site conditioning or site treatment. Nonarable soils (soils inadequate for long-term continuous usage for cultivated crops) are divided into groups based on their capacities and constraints for the growth of permanent vegetation as well as their potential for causing soil harm if improperly managed [71],
- Soil texture refers to whether the soil is stony, rocky, saline, or alkaline. Soil texture contains important parameters for optimum plant growth [69],[70],[72]. The root environment and the flow of air and water are affected by the soil's texture [71],
- Land types indicate whether the surface is bare rock, rubble, river floodplain, coastal/land dune, reed marsh, or marsh. These features should be avoided to maximize the benefit of the soil and establish a circular food production system [69],[70],[72],
- The degree of erosion indicates the erosion risk of the soil, with grade 1 representing the highest risk and grade 3 representing the lowest risk. Although permaculture practices will reduce soil erosion over time, it is better to choose a site with a low erosion degree initially,
- Global Hydrological Soil Groups (HSG) express the potential for rainfall-runoff. The classification system consists of four standard classes labeled A, B, C, and D, corresponding to soils with varying degrees of runoff potential. Class A represents soils with low runoff potential, Class B with moderately low, Class C with moderately high, and Class D with high runoff potential [73]-[75],
- Soils with high runoff potential are classified as wet soils, irrespective of their texture. This characteristic arises from a groundwater table within 60 cm of the soil surface. Such wet soils are categorized as having a double HSG classification. However, if these soils have sufficient drainage, they may be assigned to a less restrictive class group based on their texture. Water in the soil at a depth accessible to plant roots is essential for plant growth. Therefore, high runoff potential (except in the riverbed) would be preferable for permaculture [73]-[76],
- Land use/land cover (LU/LC) data is important to observe which parts of the basin are urbanized, used for agriculture and forest, and to identify productive areas suitable for permaculture [33],[77]. LU/LC data includes information on urbanized areas, forest areas, heathland, dry and irrigated agricultural areas, meadows and pastures, and areas with orchards.

Data on soil structure were obtained from the Geographical Soil Database prepared by the General Directorate of Rural Services. HSG data from Oak Ridge National Laboratory Distributed Active Archive Center (DAAC ORNL) was obtained for hydrological soil groups with a spatial resolution of 250 m. Data LU/LC use were also obtained from the Geographical Soil Database prepared by the General Directorate of Rural Services.

Table 2. Meteorology stations and climatic measurements

Station No	Station Name	X (m)	Y (m)	P (mm/year)	M (%/month)	T (C°/month)
17127	Ankara Mürted Havalimanı	462971	4436590	-	63.80	11.70
17128	Ankara Esenboğa Havalimanı	499932	4441520	-	61.90	11.60
17130	Ankara Bölge	488361	4424740	-	58.70	13.40
17137	Elmadağ Radar Sahası	497569	4405390	589.92	71.70	8.20
17715	Elmadağ Barutsan Fabrikası	518160	4418900	451.18	67.10	9.70
17728	Polatlı	428070	4381860	382.95	61.60	13.30
17733	Haymana Tarım	471845	4384860	360.65	65.40	10.80
17759	Sincan/Temelli	446878	4399240	325.78	65.30	12.30
18045	Ayaş	434685	4431370	383.08	67.10	12.50
18242	Çubuk	500918	4459580	520.23	67.00	10.70
18250	Keçiören/9. (Ankara) Bölge	488378	4424710	417.48	60.10	13.40
18257	Haymana	458287	4365230	471.82	64.50	11.20
18594	Haymana/Yenice Beldesi	471682	4347220	308.56	71.70	11.10
19003	Kalecik/Koyunbaba Köyü	526833	4462650	285.37	60.80	12.90
19006	Kızılcahamam/Yıldırım Orman Sahası	477636	4482490	762.50	68.40	8.80

2.2.4 Biomass factors

The selection of biomass factors in this study aims to provide fundamental information regarding critical sustainability dimensions such as ecosystem health, soil fertility, water management, and energy conversion in the Ankara Stream Basin. According to IUPAC [78], biomass represents the mass of living biological organisms in a given area or ecosystem at a given time and can include microorganisms, plants, or animals. Decaying biomass in the ecosystem contains nitrogen, serving as a continuous food source for plants. Biomass can be utilized in various permaculture applications such as compost making and energy production, with trees being recognized as common generators of biomass. In this study, NDVI and dry matter have been employed as biomass factors.

- Among the factors examined in this study, NDVI is an index that provides information about the vegetation density and health of an area [79],[80]. NDVI is calculated as a ratio of the difference between red and near-infrared light reflections to the sum of these reflections and generally takes values between -1 and +1; positive values indicate denser and healthier vegetation, while negative values indicate little to no vegetation. High NDVI values can indicate that the vegetation is alive and healthy, whereas low values may indicate that it is weak or stressed,
- On the other hand, dry matter represents the mass of plant material in a particular area after removing the water content. Dry matter provides significant information about an area's biological productivity and biomass production capacity [46]. Additionally, dry matter values are critical in determining the amount of usable biomass during the planning and management of permaculture applications, such as compost-making or energy production.

NDVI analyses for the Ankara Stream Basin in 2020 were carried out on the Google Earth Engine (GEE) platform, utilizing Landsat 8 OLI images. To calculate dry matter values, we used maximum NDVI values; hence, within the time frame when the NDVI values were at their maximum, two Landsat 8 OLI images were selected and downloaded via the USGS Earth Explorer website.

2.3 Method

The research first involved a comprehensive review of the existing literature to identify the data required to detect suitable permaculture sites. Climatic, topographic, productivity, and biomass data were collected from relevant sources and databases. Under four main headings, subcategories that will be effective on suitability of site selection for permaculture were determined.

Following meticulous data preprocessing, these datasets were categorized into four agro-regions agro-climatic, agro-topographic, agro-productive, and biomass classification. These categories underwent an Analytical Hierarchy Process (AHP) analysis within and between their respective groups. Accompanied by insights from three experts, impact scores for indicators influencing the suitability of site selection for permaculture were ascertained. These established scores were then employed to assign weightings to the indicator layers, a process conducted using ArcGIS, and agro-regions were overlapped with a weighted overlay analysis to create the resulting suitability map. The resulting map was subsequently divided into five distinct classes, forming the basis for evaluation across these categories.

In this context, the following analyses were made for the indicators of the factors determined for AHP:

- Interpolation was made to represent climatic information from station data spatially,
- Basic terrain features such as slope and aspect were obtained from the Digital Elevation Model (DEM). ArcGIS Spatial Analyst tools were used to generate these data,
- NDVI analysis was performed to assess biomass.

The workflow of the study can be seen in Figure 2.

2.3.1 Agro-region analysis

2.3.1.1 Climatic factors

The Inverse Distance Weighting (IDW) technique is utilized in this study for spatial estimation of precipitation, humidity, and temperature data. IDW assigns weights to neighboring points based on their relative distances to determine values at non-sampled locations [81]. This method is particularly effective when there is significant congruence in the values of neighboring points. This technique proves especially effective when values of neighboring points demonstrate substantial congruence.

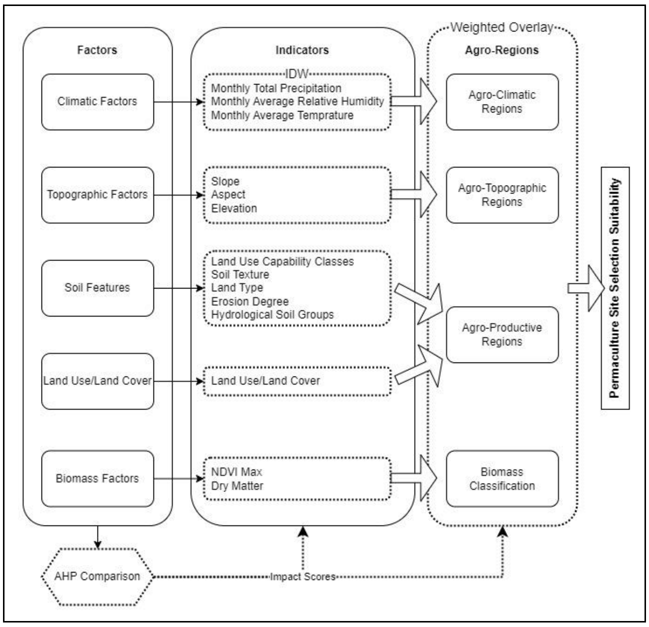


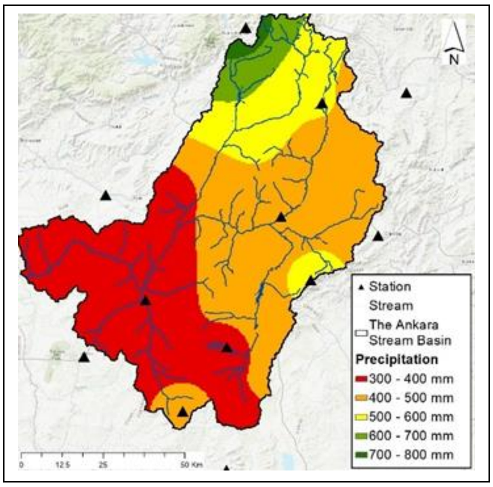
Figure 2. Workflow of the study.

Rainfall patterns are crucial for maintaining plant vitality and constructing water reservoirs in dry periods within the permaculture area. Although literature commonly recommends selecting permaculture sites with rainfall exceeding 800 mm [21],[26],[82], identifying and prioritizing areas within low-rainfall regions that approach this threshold can be crucial for optimizing water resources and ensuring sustainable permaculture practices. While the literature predominantly recommends sites with a rainfall exceeding 800 mm [21],[26],[82], selecting locations in low-rainfall regions can prioritize areas with the most precipitation. The generated indicates an average annual precipitation range of 300-800 mm in the basin. For a more detailed analysis, this data was reclassified into five distinct classes using 100 mm intervals Figure 3(a).

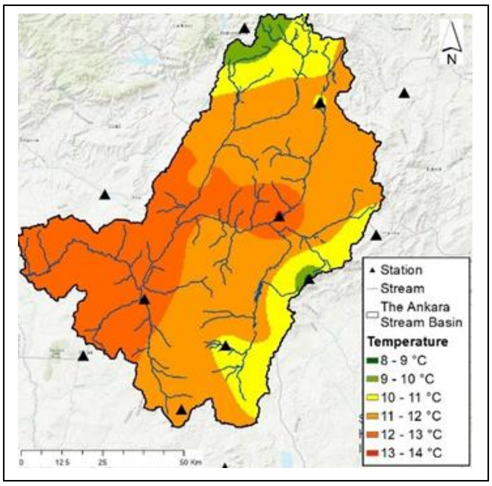
In semi-arid regions like the Ankara Stream Basin, the high temperatures observed during summer months underscore the urgency of effective water management. Temperature undeniably influences ecosystem dynamics, plant growth, and animal behaviors. In agricultural and permaculture contexts, a rigorous evaluation of local temperature conditions is pivotal for informed decision-making regarding plant and animal selection, water resource management, and soil health [21],[83]. The generated IDW map indicates that temperatures in the basin vary between 8°C and 14°C. To facilitate a more detailed analysis, this temperature data was reclassified into six distinct classes, each separated by 1°C intervals Figure 3(b).

In humid tropical climates, meticulous water management planning is necessary. In semi-arid regions such as the Ankara Stream Basin, selecting areas with higher humidity levels is paramount for ecological well-being. The IDW map indicates that relative humidity rates within the basin range from 58% to 72%. For a more detailed perspective, this data was reclassified into seven distinct classes, each separated by 2% intervals, providing insights into the region's humidity dynamics Figure 3(c).

Given the limited dataset, a comprehensive validation of the IDW method's accuracy was not feasible in this study. Nonetheless, IDW remains a commonly used and generally reliable method for spatial interpolation in environmental science and meteorology, trusted for its simplicity and efficiency in various applications.



(a)



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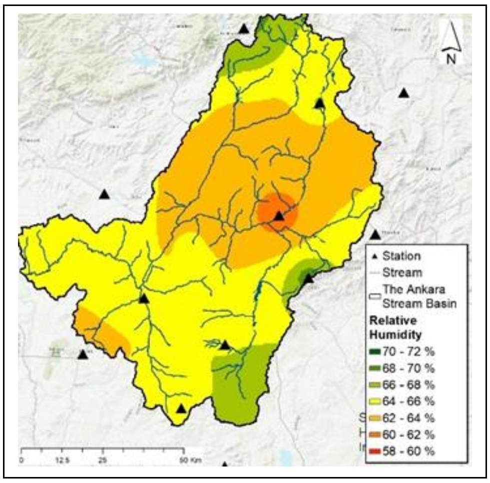

(c)

Figure 3. Interpolated climate data. (a): Precipitation. (b): Temperature. (c): Relative humidity.

It is important to acknowledge that the climate data for this study were gathered from stations located at varying elevations. However, the moderate topography of the region, characterized by a lack of extreme altitudinal variations, made an elevation-based correction for the interpolation process unnecessary. This aspect not only simplifies the analysis but also ensures that the insights derived about the area's climatic conditions remain accurate and meaningful.

2.3.1.2 Topographical factors

According to the literature, a slope of less than 5% indicates areas suitable for water storage and low surface runoff. Water pools can still be constructed on slopes between 5-10%, but precautions should be taken as surface runoff may be high. Areas with slopes above 20% are not recommended in the permaculture site design because of the high surface runoff and the risk of erosion [21],[82]-[84]. The slope values of the Ankara Stream Basin vary between 0% and 87%. The slopes of the basin area are classified as less than 5%, 5-10%, 10-20%, and over 20%. The high slope areas of the area are concentrated in the north, while the slope of the hills along the north-south axis also exceeds 10%. In the vicinity of the Ankara Stream tributaries, slopes are generally less than 5% Figure 4(a).

The aspect of the land is crucial mainly in terms of insolation and evaporation. South-oriented surfaces will have more evaporation than north-oriented ones, whereas sunshine is the most important factor in plant growth and, therefore, more suitable for growing plants [21],[26]. North-facing surfaces cause less evaporation, but in a geographic context like Ankara, where the continental climate is dominant, lack of insolation can negatively affect plant growth. The South-oriented surfaces will have more evaporation than north-oriented ones, whereas sunshine is the most important factor in plant growth and, therefore, more suitable for growing plants [21],[26]. North-facing surfaces cause less evaporation, but in a geographic context like Ankara, where the continental climate is dominant, lack of insolation can negatively affect plant growth. Ankara Stream Basin is classified according to north, south, east, west, and interval directions. Due to the north-south and south-north tributaries of the east-west flowing Ankara Stream, the aspect of the land is divided along the northeast-southwest axis Figure 4(b).

Land elevation is important in two ways. Firstly, if the elevation differences within the permaculture area are high, the changes in the microclimate will be high. Secondly, not all plants grow at all elevations. Therefore, the elevation ranges of the plants grown in the region should be taken into account, and/or the plants to be selected for the permaculture area should be selected according to the elevation of the site [21],[26]. The Ankara Stream Basin shows an elevation change between 640 m and 2050 m. The lowest point is where the Ankara Stream connects to the Sakarya River, while the highest point is located north of the basin, north of Çukurca village Figure 4(c). According to the elevation-area graph, most of the basin varies between 850-1300 meters Figure 4(d)

2.3.1.3 Productivity factors

Soils, already known to be fertile, are used for crop production, thus increasing productivity in permaculture systems [11],[21],[26]. For this reason, land use capability classes I-II-III suitable for crop production are prioritized in the suitability of site selection for permaculture. In this context, in the Ankara Stream Basin, land use capability classes I-II-III are concentrated around the stream and its tributaries Figure 5(a).

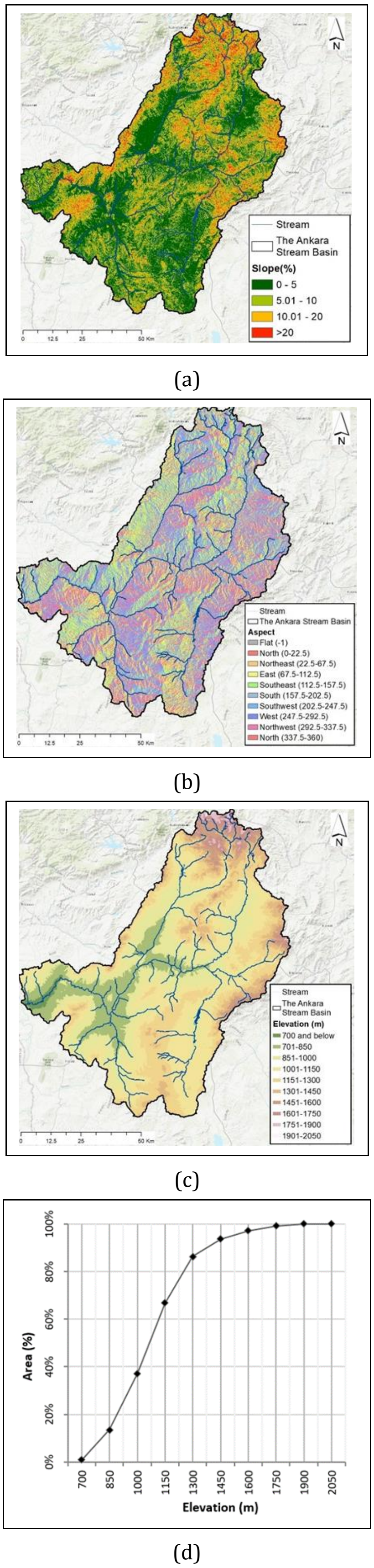

Figure 4. Topographical features of the Ankara Stream Basin. (a): Slope. (b): Aspect. (c): Elevation. (d): Elevation-area graphic.

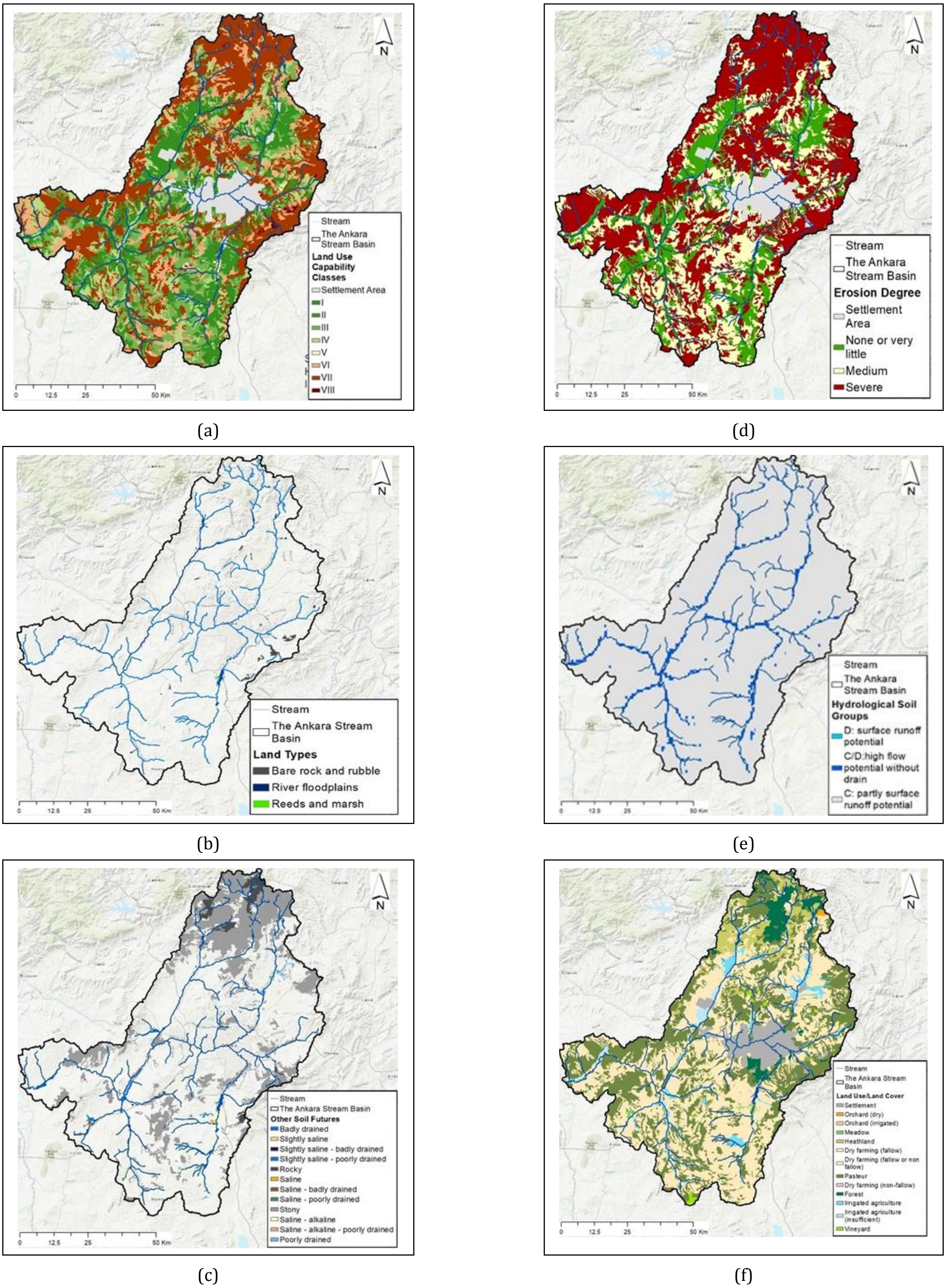

Figure 5. Soil features of the Ankara Stream Basin a) Land use capability classes. (b): Land types. (c): Other soil features. (d): Erosion degree. (e): Hydrological soil groups. (f): Land use/ land cover.

While impermeable soils are suitable for building water ditches, they are unsuitable for growing crops. There is also a risk of liquefaction and landslides in impermeable soils. Permeable soils are preferred for plant growth. In addition, since reeds and swampy areas that are very saturated with water are unsuitable for the development of every plant, it should be avoided to give density to such regions even if they are included in the permaculture area [21],[82],[85]. The area has few reed swamps, river floodplains, and rocky surfaces. Sites other than these are considered relatively permeable in terms of land type Figure 5(b).

If the soil is saline and/or alkaline, the water stored during the dry season will also be salinized or alkalinized. In addition, stony and rocky lands will make it difficult to cultivate the soil for permaculture and root development of plants. Saline, alkaline, stony, and rocky soils should be avoided as much as possible to prevent these situations [21],[82],[85]. Stony, rocky, saline, and alkaline soil structures are observed in the mountainous region north of the study area and in different parts of the area. It is observed that the remaining regions have an unproblematic structure for permaculture site selection suitability in terms of soil properties (Figure 5c).

Areas with low erosion risk are essential for determining a permaculture site without risk. In this context, 1 represents the lowest erosion risk, and 4 represents the highest. It is observed that the areas with low erosion risk are around the tributaries of the Ankara Stream Figure 5(d).

The low surface runoff in the permaculture area indicates it is suitable for constructing ditches for water storage. On the other hand, too much runoff carries the risk of water not passing under the soil. However, runoff can be harvested by slowing the flow [21],[82],[86]. According to the hydrological soil groups showing the surface runoff potential, the areas where the stream and its tributaries pass in the Ankara Stream Basin have a high runoff potential without drainage. The rest of the area has partial runoff potential (Figure 5(e).

Water permeability is low in urban areas, and soil fertility is often lost. Areas with conventional agriculture are generally suitable for plant growth, but the soil is likely to be impoverished in terms of organic agriculture. In forested areas, the soil absorbs more water than in agricultural areas, and forest soils rich in organic matter can enrich the permaculture area with a border effect [21],[22],[24],[26],[82]. For this reason, regions that are currently agricultural and orchard areas and regions with forest borders are preferable, while urban areas are unsuitable for permaculture. In this context, dry and irrigated farming areas and orchards are preferable for permaculture Figure 5(f).

2.3.1.4 Biomass factors

Among the biomass factors, NDVI is a robust measure of vegetation health and density. It captures the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs), offering insight into the photosynthetic capacity based on chlorophyll content. The formula for NDVI is given by:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

Where NIR represents the near-infrared light, NDVI values typically oscillate between -1 and +1. Higher values, closer to +1, denote dense and healthy vegetation, whereas values near -1 often correspond to inanimate objects such as water bodies, barren land, or rocks [87],[88].

2020 NDVI values in the Ankara Stream Basin were analyzed using the GEE platform. Landsat 8 OLI images with a cloudiness rate of less than 10% were selected for this analysis, and any existing clouds in these images were masked. It was discerned that the maximum NDVI values were achieved between May 7th and 20th, 2020 (Figure 6).

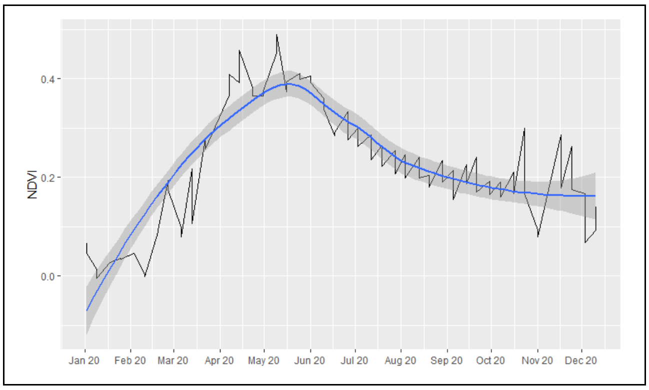

Figure 6. Cloud-masked NDVI over time derived from Landsat 8 for 2020 - Visualized in R

From within this date range, an NDVI analysis for a specific day was executed in ArcGIS 10.8 and is presented in Figure 7(a).

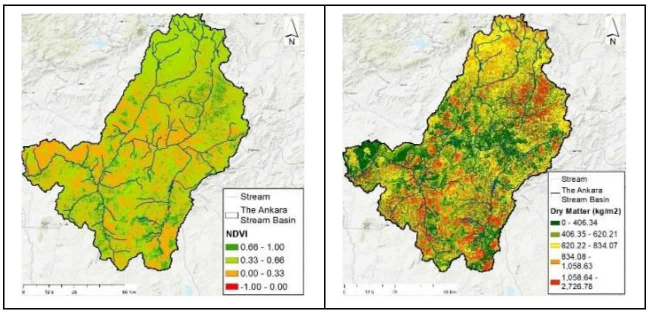

Figure 7. Biomass features of the Ankara Stream Basin. (a): NDVI. (b): Dry matter

Using NDVI to estimate standing green biomass has proven its reliability as a primary source of biomass data [45]. The functional relationship between the monthly harvested green dry matter and the maximum NDVI was established [45],[46].

$$DM = (1.615\ x\ NDVI_{max})^{1.318}\ ;\ R^2 = 0.90 \quad (2)$$

Where DM represents dry matter (kg/m^2) and $NDVI_{max}$ is the maximum NDVI in a year [46].

For this study, NDVI images from Landsat 8 OLI for the year 2020 were analyzed for the Ankara Stream Basin to determine the maximum NDVI. This maximum NDVI was then employed to estimate dry matter as described in Equation 2. The NDVI max value required for the dry matter equation was derived from an aggregation of 2 Landsat 8 images taken on 09.05.2020 and 16.05.2020. These images were specifically selected as they were the clearest (with the least cloud cover) during the peak NDVI period between 07 May 2020 and 20 May 2020.

The May 2020 NDVI analysis of the Ankara Stream Basin (Figure 7a) showed that 14.46% of the area consisted of inanimate surfaces such as water and rocks. At 54.75%, the majority exhibited signs of unhealthy vegetation, while a mere 0.22% demonstrated peak photosynthetic activity. This predominance of unhealthy to moderately healthy vegetation can likely be attributed to monocultural agricultural practices, emphasizing the region's need for diverse permaculture practices.

Five distinct classes were identified using the Natural Breaks method when analyzing dry matter values in the Ankara Stream Basin (Figure 7b). Results indicated that 19.67% of the basin faces challenges suitable for permaculture due to soil or climate conditions. 26.65% showed limited suitability, demanding adaptations, whereas 25.66% were deemed suitable with minor modifications. A considerable 17.27% demonstrated high suitability, favoring productive permaculture, and notably, 10.73% showcased the utmost suitability, characterized by soil rich in organic matter and optimal moisture retention.

2.3.2 Analytic Hierarchy Process (AHP)

In spatial studies involving multi-criteria decision-making, various methodologies can be employed to evaluate different consequences. Among these, the AHP, developed by Thomas Saaty in the 1970s, is a prominent and widely utilized approach [89],[90]. AHP facilitates systematic evaluation and prioritization of options by decomposing complex decisions into a hierarchical structure of criteria and sub-criteria. This methodology involves pairwise comparisons of elements at each hierarchical level to ascertain their relative importance, resulting in numerical values that reflect the weight or priority of each element [91]-[93].

AHP is implemented through a structured sequence of steps designed to facilitate decision-making in complex scenarios. Initially, the decision problem is decomposed into a hierarchy comprising the main goal, criteria, and sub-criteria. Decision-makers begin by identifying the relevant criteria that will influence their choices, which are then organized into a hierarchical structure. Following this, pairwise comparisons are conducted, where each criterion is compared against others to assess their relative importance. This comparison is typically facilitated by a numerical scale ranging from 1 to 9, where a score of 1 indicates equal importance and a score of 9 indicates extreme preference for one criterion over another. Once all pairwise comparisons are completed, a comparison matrix is constructed, and mathematical calculations, including the determination of eigenvalues, are performed to derive the relative weights of each criterion. Furthermore, consistency checks are conducted to ensure that the judgments made during pairwise comparisons are reliable; a consistency ratio of less than 0.1 is generally considered acceptable. The resulting weights are then utilized to evaluate alternatives or make decisions, allowing for a systematic and quantifiable assessment of the factors influencing the decision-making process [92],[94].

GIS is used as a functional tool in the weighting process of the weights obtained as a result of AHP analysis. Ceylan and Yılmaz [95] evaluated the results of AHP analysis for suitability maps to be used in the disaster information system with GIS, while Akyol et al. [96] used GIS after AHP analysis for suitability for settlement. Çeliker et al. [97], on the other hand, performed AHP analysis for landfill site selection and then used GIS for decision making. Additionally, Bostancı et al. [98] applied the AHP method and GIS technology for greenhouse site selection in Aksu district, and Yalçın and Yüce [99] identified suitable areas for solar power plant investments in Burdur using GIS methods.

In the context of this study, AHP was employed to determine the weights of various parameters influencing the suitability of site selection for permaculture in the Ankara Stream Basin. The analysis involved three experts—two hydrogeologists and one urban planner—who utilized AHP-OS, a web-based AHP analysis tool, to conduct the evaluations. The factors were assessed through pairwise comparisons, and a currency analysis was performed using the same tool. Biophysical factors were categorized into five equal breaks, while socio-economic factors were divided based on the data structure identified in the literature review. The hierarchy of factors and the corresponding AHP analysis results are presented in Table 3.

Table 3. AHP hierarchy of the study

Level 0	Level 1 (Factors)	Level 2 (Indicator)
Permaculture suitability	Climate	Precipitation Temperature Humidity
	Topography	Slope Aspect Elevation
	Soil	Capability-Class Erosion Land-use HSG Other features Land-type
	Biomass	NDVI Dry matter

AHP analysis was conducted by three experts. The group consensus of the analysis is 96.5%, and CR value is 0.4%.

2.3.3 Weighted overlay analysis

Weighted overlay analysis is widely used to address multi-criteria challenges, including site selection and suitability modeling. In this approach, input layers are identified, and different weights or importance values are assigned to each based on their relevance to the study area or objective. As the input criteria layers may have different numbering systems and ranges, they are standardized to a common preference scale for cohesive analysis. Preference values must be interpreted consistently across layers. Recognizing that not all criteria are equally important, weights are calibrated to emphasize the more important ones. The input criteria are then multiplied by their respective weights and aggregated to produce a final suitability score [100].

Using this method, we included indicators relevant to the identified factors in the weighted overlay analysis, following the weights identified by the AHP. This allowed the delineation of agro-regions specific to each factor. These agro-regional maps were then subjected to another round of weighted overlay analysis, culminating in the final suitability map. Such a systematic and staged approach ensures that the resulting maps are both comprehensive and nuanced, providing an in-depth view of suitability.

According to the weights obtained after the AHP analysis applied to the factors to determine the permaculture suitability, firstly, the sub-factors were overlapped according to the upper factor categories to create maps of agro-regions. Then, the agro-regions were overlapped according to the weights at their levels, and the result sheet was obtained. The values obtained in the overlapping at the agro-region level were divided into five equal parts out of 100 and classified as 0-20 unsuitable, 20-40 poorly suitable, 40-60 neither suitable nor unsuitable, 60-80 suitable, and 80-100 highly suitable.

3 Results

In this section, the agro-regions and the results of the suitability map for permaculture site selection are presented.

3.1 Agro-regions

According to the results of the AHP analysis, rainfall was the most important indicator in terms of suitability of site selection for permaculture. According to the expert evaluation, climatic conditions, biomass classification, topography, and soil characteristics affect the suitability of site selection for permaculture, respectively. Rainfall is the most effective climate indicator. Both indicators of the biomass factor received equal weight. In topography, the aspect indicator was considered more effective, and in soil properties, land use capability classes were prioritized in terms of suitability of site selection for permaculture (Table 4).

Table 4. Weight results of AHP analysis

Level 0	Level 1 (Factors)	Level 2 (Indicators)	Group Weights	Global Priorities
Permaculture suitability	Climate	Precipitation	0.657	16.4%
		Temperature	0.197	4.9%
		Humidity	0.146	3.6%
	Topography	Slope	0.342	8.6%
		Aspect	0.493	12.3%
		Elevation	0.016	4.1%
	Soil	Capability-Class	0.324	8.1%
		Erosion	0.101	2.5%
		Land-use	0.243	6.1%
		HSG	0.185	4.6%
		Other features	0.073	1.8%
		Land-type	0.074	1.8%
	Biomass	NDVI	0.5	12.5%
		Dry Matter	0.5	12.5%

3.1.1 Agro-climatic regions

Agro-climatic regions were identified through the weighted overlay of climate data, using weights determined by the AHP (Table 4, Figure 8). In this analysis, the northernmost portion of the basin, adjacent to the Kızılcahamam district, emerges as the most agro-climatically suitable zone for permaculture site selection.

A breakdown of the agro-climatic areas relative to the total area reveals that 65% of the site is neutral, neither suitable nor unsuitable for permaculture. Meanwhile, 19% is marginally suitable, 15% is suitable, and a mere 1% is highly suitable. An area close to 0% is deemed unsuitable for permaculture site selection, primarily due to its low relative humidity and temperature values. This region also registers as the basin segment with the least amount of rainfall (Figure 8).

3.1.2 Agro-topographical regions

Agro-topographic regions were obtained by weighted overlay of topographic data using weights determined by AHP (Figure 9). In this context, the regions around the Ova and Çubuk Streams, the north of the region where the Babayakup Stream connects to the Ankara Stream, and the regions where Ankara urban settlement is located are agro-topographically more suitable for permaculture area location selection.

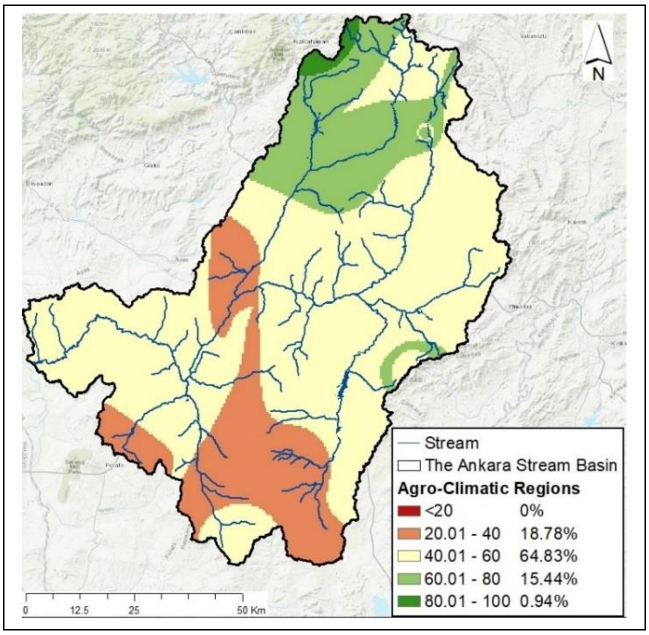

Figure 8. Agro-climatic regions of the Ankara Stream Basin.

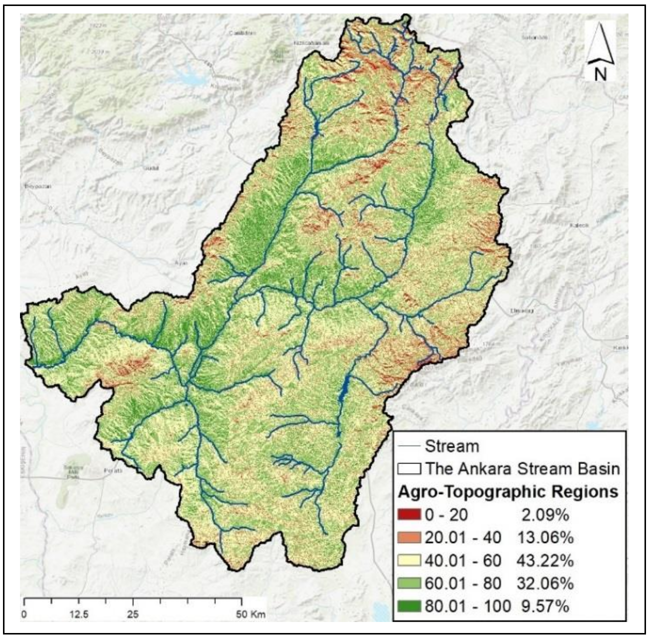

Figure 9. Agro-topographic regions of the Ankara Stream Basin.

The distribution of agro-topographic areas to the total area shows that 43% of the area is neither suitable nor unsuitable for permaculture, 13% is poorly suitable, 11% is suitable, and 10% is highly suitable. Only 2% of the area, highly sloped with north aspect directions, is unsuitable for permaculture (Figure 9).

3.1.3 Agro-productive regions

When the agro-productive regions are analyzed, it is noticeable that the region where urban settlements are located is unsuitable for permaculture in terms of productivity. In addition, stony and rocky areas with high erosion and land use capability class above VI were also found to be poorly suitable.

Although the land use capability is between I-V and is currently used for dry-irrigated agriculture, areas with high erosion are neither suitable nor unsuitable for permaculture site selection in terms of agro-productivity. Areas with land use capability class between I-III and current land use is dry agriculture are found to be suitable, while areas with irrigated agriculture are found to be highly suitable (Figure 10).

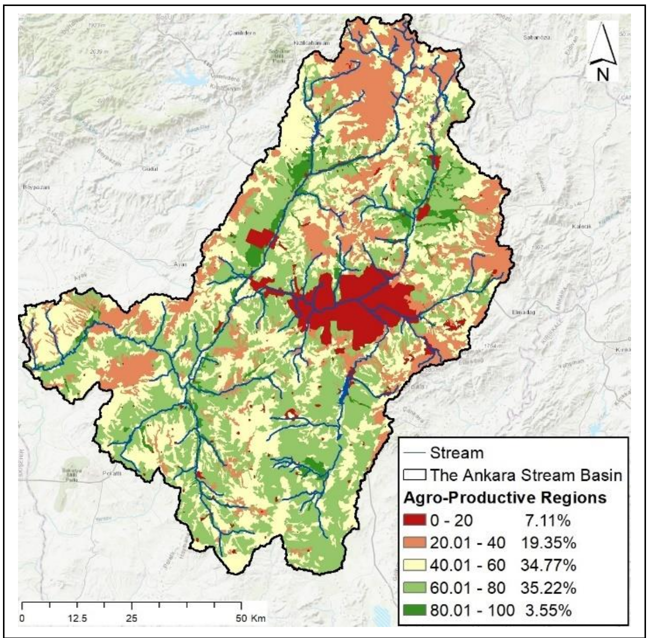

Figure 10. Agro-productive regions of the Ankara Stream Basin.

When the distribution of agro-productive zones according to the Ankara Stream Basin is examined, it is seen that 35% of the area is suitable for permaculture site selection, and these are concentrated around the tributaries of the Ankara Stream, 35% are neither suitable nor unsuitable and these areas are concentrated around the suitable areas. 13% of the area is poorly suitable and corresponds to areas of high erosion with land use capability class VI and above. 10% of the area is agro-productively suitable for permaculture and is located in the area of irrigated agriculture in land use capability class I-III (Figure 10).

3.1.4 Biomass classification

Biomass classification was determined using a weighted overlay of biomass factors, with weights defined by AHP (Table 4, Figure 11). According to the biomass map, 0.22% of the area is deemed entirely unsuitable for permaculture, likely representing areas that are too rocky, wet, or have other challenges. In contrast, 34.71% is marginally suitable, suggesting these regions might support some permaculture activities but would require specific adjustments or enhancements. A significant 37.05% of the area falls into a neutral suitability category. Such regions, possibly influenced by variable topography or soil conditions, could benefit from targeted permaculture interventions.

Additionally, 17.71% of the area is classified as suitable, indicating good potential for permaculture with minimal modifications. Lastly, 10.31% is rated as highly suitable, likely due to favorable conditions like optimal soil quality and sunlight exposure. These areas are prime for permaculture projects. In summary, this analysis provides a detailed guide for the suitability of site selection for permaculture, emphasizing the importance of both optimal and improvable areas.

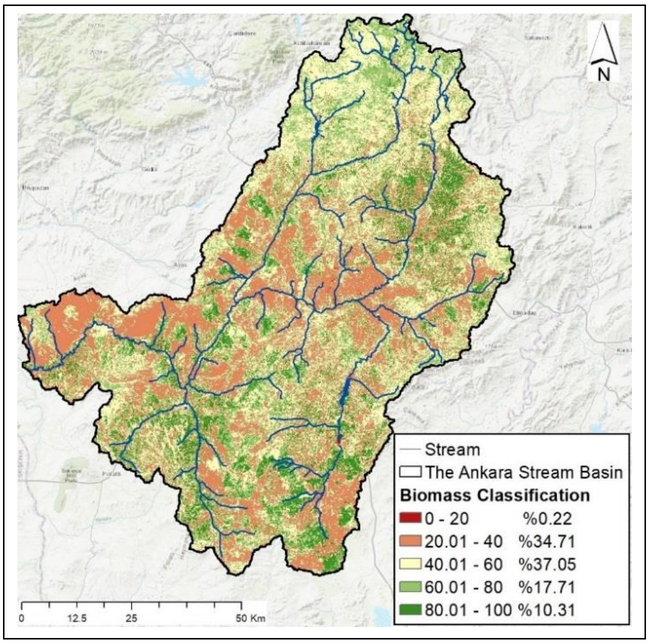

Figure 11. Biomass classification of the Ankara Stream Basin.

3.2 Suitable sites for permaculture

As a result of the AHP analysis carried out for suitability of site selection for permaculture in the Ankara Stream Basin, a permaculture site selection suitability map was obtained by weighted overlaying all agro-regions. When the distribution of the zones created for suitability by basin is analyzed, it is seen that 28% of the catchment is neither suitable nor unsuitable for permaculture site selection. 25% of the area is poorly suitable, and 23% is suitable for permaculture sites. 13% of the area is unsuitable for permaculture, and 11% is highly suitable (Figure 12).

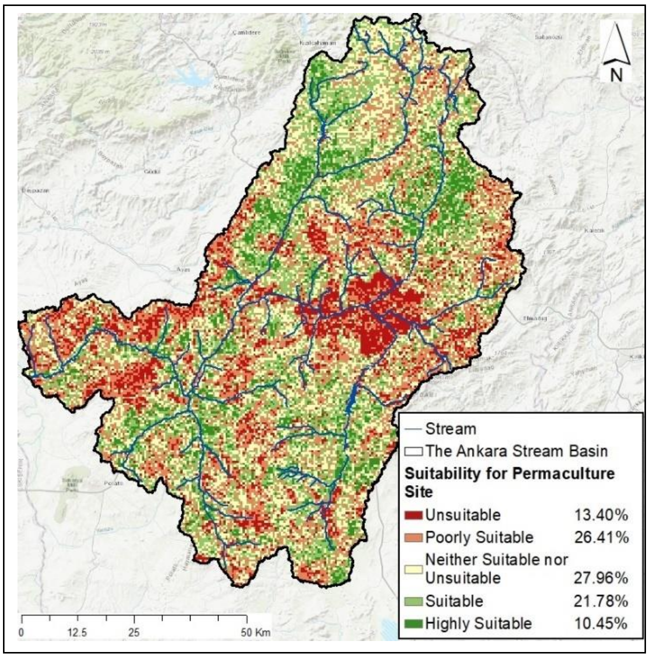

Figure 12. Suitability of permaculture site of the Ankara Stream Basin.

In the region analyzed in terms of climate, topography, productivity, and biomass classification, as seen in Figure 12, it was revealed that the surroundings of Ova Stream and the northern parts of Çubuk Stream are highly suitable for permaculture site selection. On the other hand, it was observed that the regions where urban settlements are located and those with high erosion and low soil fertility are either poorly suitable or unsuitable. Climatologically, areas with abundant rainfall and average temperatures intersect with topographically and productively favorable areas, concluding that these areas are suitable for permaculture (Figure 12).

4 Conclusion and Discussion

The present study, aimed at assessing the suitability of permaculture site selection in the Ankara Stream Basin, represents a pioneering effort in the realm of sustainable land management within Central Anatolia. This research has underscored the absence of prior work specifically addressing permaculture site suitability, thereby marking a significant contribution to the field. By integrating Geographic Information Systems (GIS) and Remote Sensing (RS) technologies, we have developed a novel methodology that leverages agro-ecological zoning techniques to evaluate potential permaculture locations.

Our findings indicate that certain regions within the Ankara Stream Basin, particularly around Ova and Çubuk Streams, exhibit favorable conditions for permaculture. These areas are characterized by adequate precipitation, suitable aspect for sunlight exposure, viable biomass, gentle slopes, and a level of soil fertility conducive to the establishment of permaculture systems. Conversely, urban zones and their vicinities, with their compromised soil quality and less favorable climatic conditions, are deemed unsuitable for permaculture practices.

One of the most striking findings of this study is the identification of a significant research gap in the field of permaculture site selection suitability. Despite the growing interest in permaculture as a sustainable agricultural practice, there needs to be more systematic methodologies for evaluating the suitability of locations for permaculture initiatives. Our research has revealed that while there are numerous studies on agro-ecological zoning and the general principles of permaculture design, none have specifically focused on developing a robust, criteria-based approach for selecting optimal permaculture sites. This gap underscores the necessity for interdisciplinary research that combines agro-ecological knowledge with spatial analysis capabilities to support the expansion of permaculture in diverse environmental contexts.

The inception of this study was rooted in the recognition that while permaculture has been widely adopted in regions with favorable agricultural conditions, such as the Aegean, Western Mediterranean, and Western Black Sea regions of Türkiye [51], its potential in more challenging environments like Central Anatolia remains largely untapped. The prevailing agricultural practices in Central Anatolia, which often rely on chemical inputs, have led to soil degradation and reduced fertility, presenting a barrier to sustainable agriculture in the absence of external inputs [50],[51]. This context provided a compelling case for exploring permaculture as an alternative that could potentially rehabilitate and revitalize these compromised ecosystems.

In contrast to traditional agricultural practices, permaculture emphasizes the harmonious integration of land use with natural processes, aiming to create self-sustaining systems that are resilient to environmental stresses [11]. The principles of permaculture resonate with the goals of agro-ecology, which seeks to optimize the interactions between plants, animals, humans, and the environment within agricultural systems [13]. However, while agro-ecology has been the subject of extensive research, permaculture has not received the same level of scientific scrutiny, particularly in the context of site selection.

Our study bridges this gap by employing GIS and RS tools to evaluate the suitability of the Ankara Stream Basin for permaculture, taking into consideration various environmental factors such as climate, topography, and soil quality. The approach aligns with the principles of agro-ecological zoning, which involves the classification of land based on its potential for agricultural use [45]. By doing so, we have laid the groundwork for a systematic method that can be replicated in other regions, contributing to the broader application of permaculture in areas facing similar environmental challenges.

In conclusion, this study not only provides a methodological framework for permaculture site selection but also encourages further research to refine and expand upon the initial findings. The integration of permaculture with agro-ecological zoning offers a promising direction for future studies, with the potential to enhance the sustainability of agricultural practices and contribute to the resilience of food systems in the face of environmental change.

The application of agro-ecological zoning within this study has provided valuable insights into the interplay between various environmental factors and their collective impact on permaculture viability. This approach mirrors similar methodologies employed in agro-ecological studies, yet our application to permaculture is unique. We have demonstrated that by adopting agro-ecological zoning methods, which consider the complex interactions within agricultural ecosystems, we can more effectively identify areas with the potential for sustainable agricultural practices like permaculture.

A critical aspect of our research has been the utilization of agro-regions as a framework for analysis. Agro-topographical and agro-productive regions have been particularly instrumental in discerning areas of suitability. Our methodology has revealed that while some regions may not initially appear viable for agriculture, their potential for permaculture practices is significant. This is particularly relevant for areas with high erosion and land use capability class VI and above, which can still be transformed into productive permaculture sites with proper design and management.

However, our study faced limitations due to the need for high-resolution climate and soil data, which introduced uncertainties in the evaluation of indicators. This highlights the need for a comprehensive data repository tailored to permaculture site selection. Establishing such a database would facilitate a more precise and informed decision-making process for permaculture practitioners and researchers alike.

In conclusion, this study not only fills a gap in the literature by providing a methodological approach to permaculture site selection but also sets the stage for future research. It emphasizes the importance of creating a more scientific framework for permaculture that can adapt to the unique characteristics of each region. With the growing interest in sustainable agricultural practices, our research offers a roadmap for the application of permaculture in regions that are challenged by modern agricultural practices and climate change. As such, it serves as a call to action for the development of sustainable land management strategies that are both ecologically sound and economically viable.

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6 Author contribution statement

Ceren Özcan Tatar: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing-Original Draft Preparation Bilge Bingül: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation Emrah Pekkan: Data Curation, Formal Analysis, Methodology, Software, Validation, Visualization Saye Nihan Çabuk: Supervision, Writing-Original Draft Preparation, Writing-Review & Editing

7 Ethics committee approval and conflict of interest statement

“There is no need for any permission from the ethics committee for the article prepared”.

“The authors declare that they have no conflict of interest in the article prepared”.

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