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Environmental gradients shaping Mediterranean land cover patterns: A statistical and spatial analysis

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ABSTRACT: This study systematically investigated the environmental characteristics defining distinct land cover types across the Mediterranean region of Türkiye. The study used 13,940 spatial units based on GIS layers, which included land cover from CORINE, as well as information about the landscape, like altitude, ruggedness, and slope. It also considered climate factors such as precipitation, temperature, and seasonal variations. A comprehensive statistical analysis was performed using non-parametric Kruskal-Wallis H-tests and pairwise Mann-Whitney U tests. Results revealed statistically significant differences ($p < 0.05$) in all environmental variables across land cover types. Altitude was the main differentiator, with sparsely vegetated areas and grasslands found at high elevations, contrasting with salt marshes located in low-lying, gentle regions. Climatically, salt marshes were characterized by the highest mean annual temperatures and precipitation, strong precipitation seasonality, and notably low thermal variability. Conversely, high-altitude grasslands and sparsely vegetated areas featured cooler climates and significantly greater temperature fluctuation. Isothermality, in contrast, exhibited minimal variation across the study sites, indicating its limited utility as a climate discriminator. These findings highlight transparent environmental partitioning, where a combination of topographic and climatic factors collectively shapes the unique ecological profiles of each land cover type. This detailed understanding of environmental preferences is crucial for effective ecological management, conservation strategies, and predicting ecosystem responses to environmental changes in the region.

Keywords: Mediterranean region, land cover, environmental gradients, statistical analysis, GIS

Akdeniz arazi örtüsünü şekillendiren çevresel gradyenlerin istatistiksel ve mekânsal analizi

ÖZET: Bu çalışma, Türkiye'nin Akdeniz Bölgesi'ndeki belirgin arazi örtüsü tiplerini tanımlayan çevresel karakteristikleri sistematik olarak incelemiştir. CORINE arazi örtüsü (land cover) ile çeşitli topografik (Yükselti, Engebelilik, Eğim) ve iklimsel (örn., Yağış, Sıcaklık, Mevsimsellik) parametreleri içeren CBS katmanlarından elde edilen 13.940 mekânsal birim kullanılarak, parametrik olmayan Kruskal-Wallis H-testleri ve ikili Mann-Whitney U testleri ile kapsamlı bir istatistiksel analiz gerçekleştirilmiştir. Sonuçlar, arazi örtüsü tipleri arasında tüm çevresel değişkenlerde istatistiksel olarak anlamlı farklılıklar ($p < 0.05$) olduğunu ortaya koymuştur. Yükselti, topoğrafya ve buna bağlı mikroiklimsel ve hidromorfolojik süreçlerle birlikte arazi örtüsü desenlerini güçlü biçimde ayrıştıran temel bir çevresel gradyen olarak ortaya çıkmaktadır; bu bağlamda seyrek bitkili alanlar ve doğal otlaklar yüksek ve engebeli alanlarda yayılım gösterirken, tuz bataklıkları (salt marshes) düşük eğimli ve deniz etkisine açık alçak kotlarda yoğunlaşmaktadır. İklimsel gradyenler açısından, tuz bataklıkları denizel etkinin baskın olduğu alanlar olarak yüksek ortalama sıcaklıklar, yüksek yıllık yağış ve belirgin yağış mevsimselliği sergilerken, termal değişkenliğin sınırlı kaldığı koşulları yansıtmaktadır. Buna karşılık, yüksek rakımlı otlaklar ve seyrek bitkili alanlar artan yükselti ve kıtasallığa bağlı olarak daha serin ve daha geniş sıcaklık paternlerine sahiptir. İzotermallik (Isothermality) daha az varyasyon göstermiş, bu da onun ikincil bir ayırt edici faktör olduğunu düşündürmektedir. Bu bulgular, topografik ve iklimsel faktörlerin birleşiminin her bir arazi örtüsü tipinin kendine özgü ekolojik profillerini kolektif olarak şekillendirdiği şeffaf bir çevresel bölümlenmeyi vurgulamaktadır. Bölgedeki farklı arazi örtüsü türlerinin çevresel koşullarla ilişkisine dair elde edilen bu sonuçlar, etkin ekolojik yönetim, koruma stratejilerinin geliştirilmesi ve ekosistemlerin çevresel değişimlere tepkilerinin tahmin edilmesi açısından büyük önem taşımaktadır.

Anahtar kelimeler: Akdeniz Bölgesi, arazi örtüsü, çevresel gradyanlar, istatistiksel analiz, CBS

INTRODUCTION

Land cover plays an essential role in ecosystems. It helps manage many environmental processes and supports various plants and animals. It provides important functions and services, such as storing carbon and regulating water (Bozali, 2021). These services are essential for the health of our ecosystem as well as for human well-being (Bozali, 2021; Saygıner & Nurlu, 2025). The efficiency of vital services such as carbon absorption and water retention is heavily influenced by the type and condition of land cover. Different land cover types are influenced by land shape, climate, and water availability (Hanna et al., 2019; Outhwaite et al., 2022). To create effective conservation and management policies, it is important to figure how different factors change. These factors create habitats for various species and support biodiversity (Leclère et al., 2020). Understanding these relationships is vital for effective ecosystem management, conservation planning, and predicting ecological responses to environmental change (Newbold, 2018). In regions characterized by diverse landscapes and varying ecological pressures—such as Mediterranean forests or mountainous regions—the spatial distribution of land cover types is intricately linked to underlying environmental gradients (Mantyka-Pringle et al., 2015; Babur et al., 2025). Changes in altitude, terrain, slope, and climate, like rainfall and temperature, create unique ecosystems.

Various elements determine plant communities and impact land management, such as agriculture and conservation efforts. Ecosystems demonstrates its creativity through these variations (Du et al., 2019). For example, greater altitudes can result in cooler climates and varying moisture patterns, leading to completely different plant communities in comparison to those found at lower elevations (Michelsen & Lindner, 2015).

Detailed statistical analyses are key to highlighting the complex relationships between environmental factors. These analyses are crucial for understanding how environmental conditions impact different land cover types. To develop effective land management and conservation strategies, it is crucial to understand these dynamics. (Brown et al., 2015). This study examines the environmental characteristics of different land cover types and measures the extent to which they vary from one another (Wan et al., 2023; Oliver et al., 2016). Through the use of strong statistical methods, particularly non-parametric tests like the Kruskal-Wallis H-test, this study seeks to clarify the particular environmental gradients that shape the distinct ecological niches of different land covers (Ekren, 2022).

This research will improve our understanding of how the environment affects land cover. It will focus on important factors, including topography and climate conditions, that impact land cover changes (Martinez & Mollicone, 2012; Titeux et al., 2016; Türker, 2021). These results will support better environmental assessments and land management strategies in the study area. This will help improve conservation efforts and promote the sustainable use of land resources (Paršova et al., 2019; Liang & Liu, 2017). Understanding how different land types interact with their environments will help efforts to reduce the negative impacts of land-use changes and climate change (Williams & Newbold, 2019).

MATERIALS AND METHODS

Study area

The study focuses on a significant portion of the Mediterranean geographical region of Türkiye, and covers eight provinces: Adana, Burdur, Isparta, Hatay, Antalya, Kahramanmaraş, Mersin, and Osmaniye (Figure 1). This region is a vital ecological and climatic zone characterized by its interface with the Mediterranean Sea and the prominent presence of the Taurus Mountains. Geographically, the study area involves a diverse landscape. The dramatic altitude gradient, transitioning from sea level to peaks exceeding 3,500 meters, is responsible for the diverse array of ecosystems found here, from coastal maquis to subalpine forests. Based on the aggregated areas of the included provinces, the total approximate size of the region is 80,066 km². The Mediterranean Sea defines the region's southern boundary. The major coastal provinces in the study area—Antalya, Mersin, and Hatay—have a total coastline of about 1,138 kilometers. Adana province also has a short coastline. Topographically, the area exhibits considerable variation. The average altitude in the area studied is 1,066.72 meters. This shows that there is extensive mountainous terrain, especially the Taurus Mountains, which run along the coast. The unique geological structures and varying aspects of the Taurus slopes create countless microclimates, significantly influencing local hydrology and soil development. The geographic position of this Mediterranean portion of Türkiye generally extends within a latitude range of approximately 36°07'N to 37°29'N and a longitude range of 29°20'E to 32°35'E. The climate in this area is classified as hot-summer Mediterranean (Köppen Csa). However, the altitude leads to differences in conditions, which helps create a rich variety of unique plants and animals. The study area shows a unique climate and diverse wildlife. These make it an appropriate site for studying land cover and environmental dynamics.

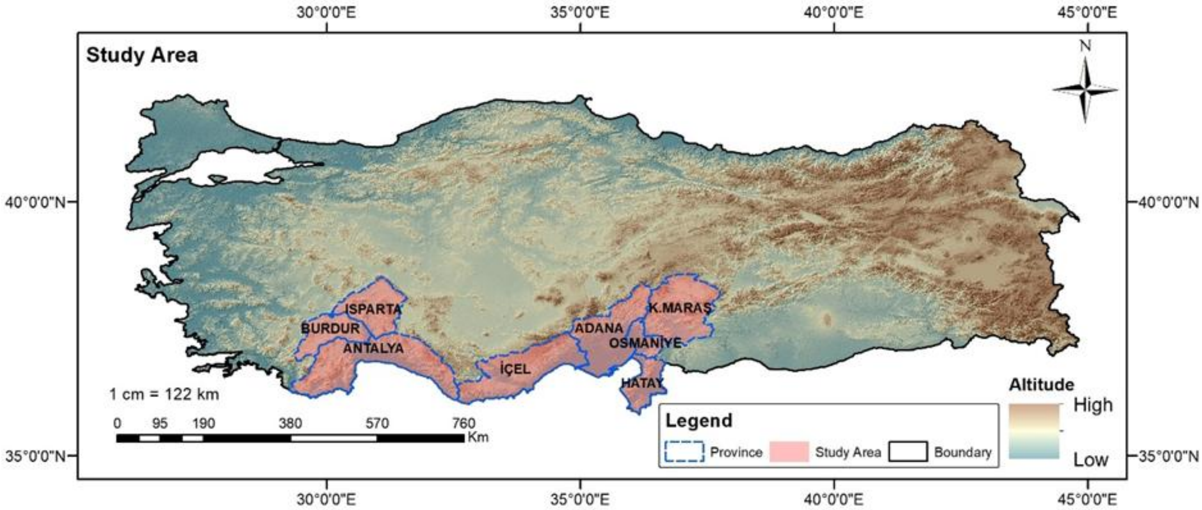

Figure 1. Study Area, Geographical Position, and Topography in the Mediterranean Region of Türkiye

Data

The dataset used in the study includes 13,940 separate working units. Each area had its own land cover type and environmental conditions. This data is mainly prepared using Geographic Information System (GIS) layers. Specifically, these layers incorporated diverse information, ranging from detailed CORINE land cover classifications to various measured topographic and climatic parameters. This full dataset served as the primary input for studying the complex relationships between land cover and environmental conditions in Türkiye's Mediterranean region. It was essential to study the complex connections between different land cover types and environmental conditions in the Mediterranean region. The 13,940 units have high resolution and cover various themes, which allowed for strong statistical analysis. This helps to identify the specific environmental factors that set each land cover type apart.

Land cover types

Land cover information within the dataset is categorized into nine distinct types (Table 1). These layers represent the dominant vegetation and surface characteristics across the study area. These classifications were obtained from the CORINE (Coordination of Information on the Environment) Land Cover program. The land cover data consists of vector-based polygons, providing a standardized thematic representation of the landscape (Figure 2).

Table 1. Distribution of Land Cover Types (by Area)

Land Cover Type	Area (Ha)	Percentage (%)
Transitional woodland-shrub	1,736,796.22	28.98
Coniferous forest	1,462,205.10	24.4
Sparsely vegetated areas	1,455,254.19	24.28
Natural grasslands	507,744.18	8.47
Mixed forest	313,547.00	5.23
Sclerophyllous vegetation	266,959.32	4.45
Broad-leaved forest	182,527.73	3.05
Pastures	52,523.28	0.88
Salt marshes	15,653.91	0.26

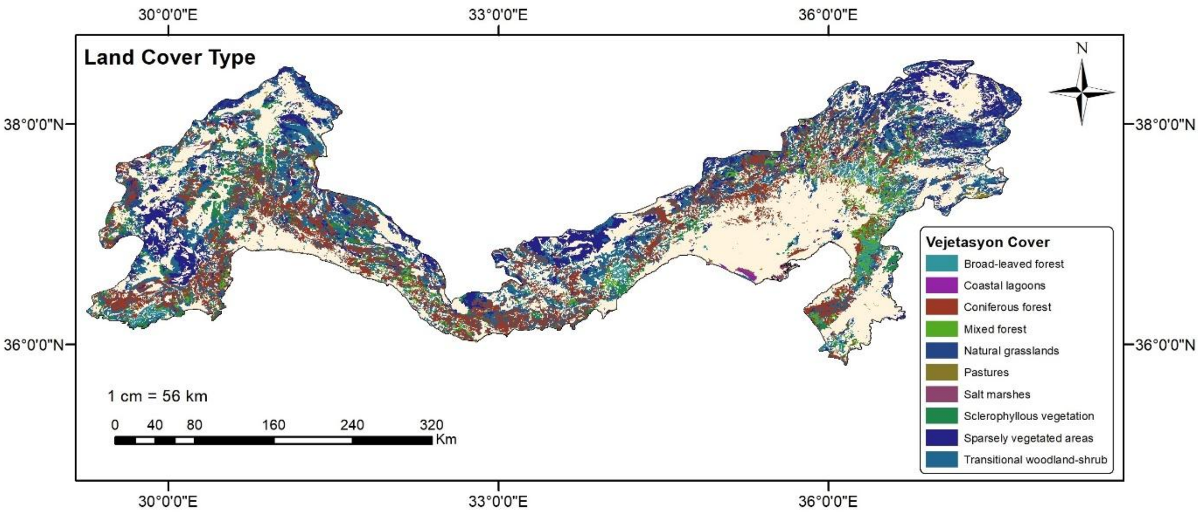

Figure 2. Land Cover Types of the Mediterranean Region

The nine types of land cover show the complexity of the Mediterranean environment, which has three main classes that make up over 77% of the total area. The "Transitional woodland shrub" takes up the largest part of the study area, covering 28.98% or 1.74 million hectares. This shows how common it is in the Mediterranean ecosystem. This is succeeded closely by "Coniferous forest" (24.40%) and "Sparsely vegetated areas" (24.28%), which together emphasize the variety of natural and semi-natural environments present in the eight selected provinces (Table 1). The remainder of the area is distributed among natural grasslands, various forest types (mixed, sclerophyllous, broad-leaved), and pastures. Unlike the dominant classes, the relatively rare but ecologically important "Salt marshes" occupy the smallest proportion of the study area, representing merely 0.26% (15,653.91 Ha) (Table 1). This varied distribution among the various land cover types requires an in-depth examination of the environmental gradients that influence this spatial arrangement.

Environmental conditions

The environmental conditions included in the dataset enable critical information for each spatial unit. This data allows the analysis of how various environmental factors shape land cover distribution. Unlike the vector-based land cover data, the environmental parameters are derived from raster layers. Key environmental variables included in the dataset are topographically related data, such as Altitude, Ruggedness, and Slope, which were produced using a Digital Elevation Model (DEM). It was derived from the Shuttle Radar Topography

Mission (SRTM) with a 90-meter resolution. Climate data were obtained from the WorldClim database, which has a resolution of 30 meters. This data includes Annual Precipitation, Annual Mean Temperature, Mean Diurnal Range, Temperature Seasonality, Precipitation Seasonality, and Isothermality. Table 2 presents the descriptive statistics for these environmental variables, including range, central tendencies, and variability within the study area.

Table 2. Descriptive Statistics for Environmental Conditions

Variable	Mean	Std Dev	Min	Median	Max
Altitude	1066.72	524.78	-0.38	1134.97	2859.52
Ruggedness	0.49	0.04	0	0.49	0.68
Slope	89.89	1.66	0	90	90
Annual Precipitation	681.13	147.53	0	648.37	1417.5
Annual Mean Temperature	124.87	35.38	0	120.95	197.16
Diurnal Range	115.75	10.26	0	116.48	137.01
Temperature Seasonality	7314.48	646.39	0	7273.17	8777.59
Precipitation. Seasonality	65.64	13.95	0	63.01	103
Isothermality	35.47	1.97	0	35.03	42

Data pre-processing and integration

Robust data pre-processing and integration procedures were implemented to ensure the spatial coherence and analytical compatibility of all datasets. All these steps were applied using Arc-GIS Desktop (version 10.0). All GIS layers were initially coordinated and reprojected into a unified spatial reference system: GCS European 1950 (Datum: European 1950). Standardizing the data was important for accurate analysis and mapping. All environmental raster data, including topography and climate layers, were then resampled to a consistent size of 30 × 30 meters using the nearest neighbor method. This phase confirmed that the pixel dimensions of the raster layers conformed to a resolution appropriate for thorough analysis and were consistent with the scale of the land cover information. During the integration process, a careful quality control method was used for the CORINE land cover polygons.

Polygons were removed that did not have a clear vegetation type or included non-vegetated areas. This helped to focus the analysis only on areas that are vegetated. Following this cleaning, the environmental conditions corresponding to each remaining land cover polygon were precisely extracted. This was achieved through the application of zonal statistics, a geospatial operation that summarizes raster cell values within the boundaries of vector polygons. For each environmental raster layer, the mean value of the pixels falling within each land cover polygon was calculated and assigned to that polygon. This process grouped continuous environmental data into specific types based on land cover. After finishing the pre-processing and integration steps, a detailed database was constructed with 13,940 distinct polygons. These spatial polygons include their corresponding land cover type and average environmental characteristics. This database served as the primary source for all subsequent statistical and comparative analyses.

Comparative analysis of land cover types

This study aims to investigate the significance level of key environmental factors throughout various land cover types of the area. In this context, the environmental traits of land cover types were investigated using comparative analytical methods. All the statistical analyses performed throughout the study were applied using RStudio with the R statistical language. At first, basic statistics were calculated for environmental factors like altitude, ruggedness, annual precipitation, and annual mean temperature for each type of land cover (Elhag & Boteva, 2020). These statistics show the average, median, standard deviation, minimum, and maximum values of environmental conditions for every land cover type. They summarize important information about how those conditions vary and what is typical for each type (Herrmann et al., 2020). These initial steps help us understand the environmental characteristics of different types of vegetation. It is important to use both traditional and modern statistical methods in ecological research.

The Kruskal-Wallis test is a non-parametric version of one-way analysis of variance (ANOVA), suitable for comparing three or more independent samples (Leśniewska-Napierała et al., 2019). The null hypothesis (H0) for each test assumed that the medians of the environmental variable were equal across all land cover types. The alternative hypothesis (H1) states that at least one type of land cover had a median value for the environmental variable that was clearly different from the others. A significance level of 0.05 was used for all statistical tests. This choice supports a strong analysis framework (Herrmann et al., 2020). A statistically significant p-value ($p < 0.05$) would thus indicate differences in the distribution of the environmental variable among the compared land cover types, resulting in the rejection of the null hypothesis (Liu et al., 2017). This non-parametric method is crucial for identifying unique environmental characteristics linked with each land cover category, thereby enhancing our overall understanding of their ecological roles.

After the Kruskal-Wallis H-test showed a significant result ($p < 0.05$), the next step was to identify which specific land cover types had different environmental conditions. (Kandari et al., 2024). For this, the Post-Hoc Pairwise Mann-Whitney U Test was used. This test is a suitable non-parametric tool because it compares two independent groups when the data are not normally distributed (Liu et al., 2017). Since we conducted numerous comparisons, the likelihood of a false positive error (Type I error) increased. To ensure the reliability of the results, the p-values were adjusted using the Bonferroni correction (Yang et al., 2021). This step ensures that the overall error rate remains controlled at an alpha level of 0.05. For each pair, we tested the idea that the environmental medians were equal. A p-value of less than 0.05 indicates that a statistically significant difference was found between the two land cover types (Kandari et al., 2024). This analysis explains how environmental factors determine the distribution of each land cover type.

RESULTS

Environmental characteristics of land cover types: a statistical summary

The study shows apparent differences in environmental preferences among the nine types of land cover (Table 1). Altitude is the most important factor that sets them apart. Sparsely vegetated areas and natural grasslands tend to occur at higher altitudes. The average elevations of these areas range from 1365 meters to 1411 meters, with some peaks reaching nearly 2800 meters. At mid to high altitudes, typically between 1000 and 1100 meters, broad-leaved, mixed, and coniferous forests, as well as pastures and transitional woodlands, can be found. Sclerophyllous plants occupy the lower elevations, averaging about 895 meters. Salt marshes grow best at very low elevations, with an average of just 1.45 meters. Some can even be found below sea level (Minimum: -0.38m), indicating that they live in coastal or low-lying areas. This information highlights the differences in elevation among different types of land cover.

While there is a general trend of similar median ruggedness and high median slopes across many land cover types, Salt marshes consistently stand out as preferring the least rugged (Median: 0.45) and gentlest terrains (Median Slope: 85.95°). Sparsely vegetated areas and Natural grasslands tend to occur in the most rugged environments, although their median ruggedness is similar to that of many other types. Most land cover types can be found across all kinds of slopes, from flat to very steep, which shows a common median slope of 90 degrees. However, salt marshes are different; they mostly prefer flatter areas (Table 3). The highest points and roughest terrains in sparsely vegetated areas and natural grasslands highlight the extreme physical features of these high-mountain ecosystems.

Salt marshes get the most rainfall compared to other areas, with an average of 764.41 mm per year. They also show a clear difference between wet and dry seasons, with a precipitation seasonality score of 72.78. This means salt marshes are suited to places that have distinct periods of rain and dryness. Forest types receive high annual precipitation with moderate seasonality. Specifically, all three forest types (Broad-leaved, Coniferous, Mixed) exhibit highly similar precipitation medians (~680-698 mm) and indicate a shared reliance on moderate and consistent rainfall regimes in the mid-altitudes. Natural grasslands, pastures, and areas with sparse vegetation usually receive less rainfall each year compared to other regions. They also have more consistent rainfall throughout the year, which means there are fewer drastic changes in rainfall from season to season (Table 3).

Salt marshes are adapted to the warmest overall temperatures (Median: 189.81) and experience the least temperature seasonality (Median: 6111.27), suggesting a more consistent thermal environment. Sparsely vegetated areas and Natural grasslands are found in cooler climates (Medians ~101-103) and exhibit the most pronounced temperature seasonality (Medians ~7400-7423), indicating wider annual temperature swings. Forest types and pastures generally fall between these two extremes, experiencing moderate annual mean temperatures and moderate to high temperature seasonality (Table 3). This strong inverse relationship between altitude and temperature variables provides a clear thermal gradient driving land cover distribution across the region. Salt marshes exhibit the least daily temperature changes, with an average difference of 92.76 degrees, compared to natural grasslands, pastures, and sparsely vegetated areas, which display the most significant daily temperature variations, with median differences of around 120 degrees (Table 3). Isothermality values are consistent across most land cover types, suggesting it may not be a primary differentiating factor (Table 3).

Statistical Differences in Environmental Conditions Among Land Cover Types

The Kruskal-Wallis test looked for differences in environmental conditions among different land cover groups. The results showed a p-value of about 0.001 for all the environmental variables tested. This value is much lower than the significance level of 0.05 (see Table 4).

Consequently, the null hypothesis (H0) was rejected for all variables. This means there are clear differences in environmental conditions between different types of land cover. All tested variables showed these differences. The H-statistics help us understand how big these differences are. The most significant variable in terms of the largest H-statistic is Altitude (H-statistic = 1191.86), suggesting the most pronounced differences in statistical environmental conditions for this variable across the land cover groups. The least significant variable (among those with rejected H0) in terms of the smallest H-statistic is Ruggedness (H-statistic = 217.07). While still significant, the magnitude of these differences is comparatively smaller than for other variables (Figure 3).

Table 3. Descriptive Statistics of Environmental Conditions by Land Cover Type

	Altitude			**Ruggedness**			**Slope**		
Land Cover Type	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*
Broad-leaved forest	1127.97	5.86	1972.66	0.49	0.31	0.59	90	83.79	90
Coniferous forest	1008.89	0	2038.23	0.49	0.29	0.63	90	0	90
Mixed forest	1025.29	30.91	2003.37	0.49	0.27	0.63	90	86.52	90
Natural grasslands	1365.42	0.45	2830.69	0.49	0.28	0.68	90	78.09	90
Pastures	1082.27	0	2267.77	0.48	0	0.66	89.76	0	90
Salt marshes	1.45	-0.38	850.98	0.45	0.29	0.54	85.95	0	89.01
Sclerophyllous vegetation	894.78	0	1973.61	0.5	0.21	0.63	90	0	90
Sparsely vegetated areas	1411.27	0.76	2859.52	0.5	0.23	0.67	90	70.08	90
Transitional woodland-shrub	1034.3	1.47	2709.4	0.5	0.25	0.66	90	82.17	90
	Annual Precipitation			**Annual Mean Temperature**			**Mean Diurnal Range**		
Land Cover Type	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*
Broad-leaved forest	698.6	0	1365.71	121.9	57.59	195	116.56	86.11	134
Coniferous forest	679.98	0	1340.81	129.04	0	194.07	115.47	0	133.82
Mixed forest	698.1	0	1281.5	128.32	56.51	193.19	117.29	84.32	132.67
Natural grasslands	595.3	0	1301.29	103.53	0	194	120	0	136.79
Pastures	574.51	0	1085.25	120.31	0	197.16	120	0	137.01
Salt marshes	764.41	0	937.33	189.81	0	192.99	92.76	0	128.01
Sclerophyllous vegetation	684.07	0	1353.04	137.78	0	191.06	112.29	0	136
Sparsely vegetated areas	580.74	434.81	1348.5	101.6	26.8	192.68	120.07	81	137
Transitional woodland-shrub	679.13	0	1417.5	129.19	0	196.39	*115.39*	*0*	*135*
	Temperature Seasonality			**Precipitation Seasonality**			**Isothermality**		
Land Cover Type	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*	*Median*	*Min*	*Max*
Broad-leaved forest	7399.84	5585.42	8747.92	66.35	39.82	101.99	35	31	42
Coniferous forest	7238.91	0	8777.4	65.05	0	102	35.38	0	42
Mixed forest	7366.29	5388.59	8706.07	64.62	39.85	98.18	35.02	31.03	40.08
Natural grasslands	7401.82	0	8764.91	57.25	0	102	35	0	42
Pastures	7205.91	0	8753.6	56.14	0	101.99	35.88	0	42
Salt marshes	6111.27	0	7133.95	72.78	0	102.7	35.69	0	41.7
Sclerophyllous vegetation	7048.12	0	8717.36	70.62	0	103	36.54	0	42
Sparsely vegetated areas	7423.12	5701.89	8777.59	56.38	39.73	100.84	35	30.81	41.75
Transitional woodland-shrub	7224.32	0	8774.81	67.29	0	102.4	35.31	0	42

The most important factors that distinguish different land cover types are altitude, slope, temperature variability, and ruggedness. These factors consistently show significant differences in many comparisons (see Table 4). This implies that these environmental characteristics vary significantly across the different vegetation and land-use categories. On the other hand, Isothermality shows fewer significant differences in its pairwise comparisons, suggesting that this particular climate characteristic might be more uniform or less of a distinguishing factor among the various land cover types in the study area compared to other variables (Table 4).

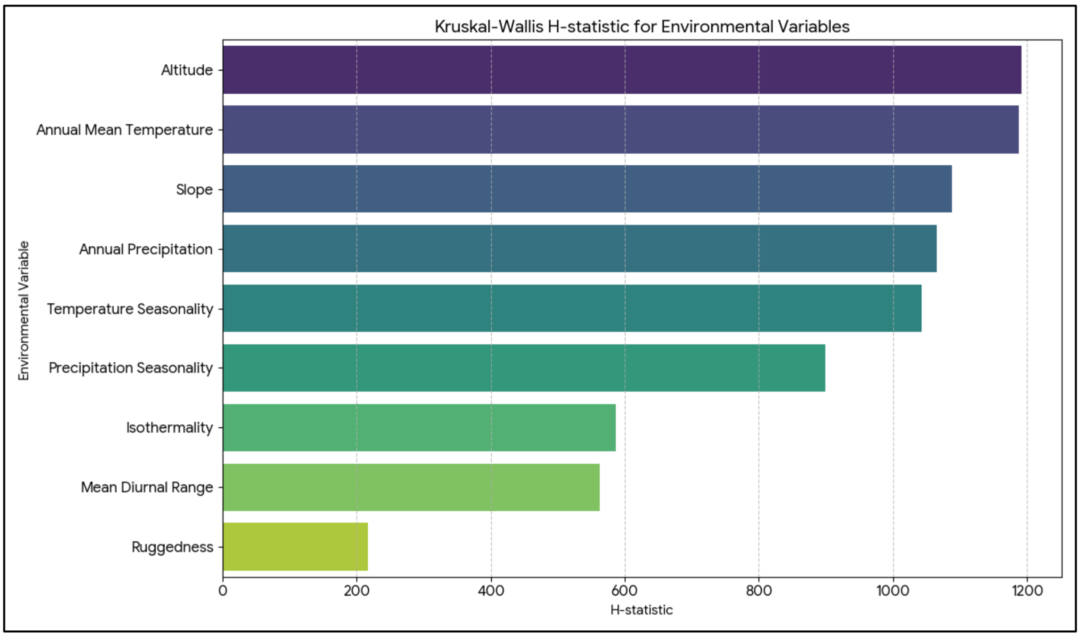

Figure 3. The bar chart visualizes the Kruskal-Wallis H-statistic values, sorted from highest to lowest, for each environmental variable.

Table 4. Results of Kruskal-Wallis H-Test for Environmental Variables across Land Cover Types

Environmental Variable	H-statistic	P-value (approx.)	Conclusion (at alpha=0.05)
Altitude	1191.86	0.001	H0 Rejected
Ruggedness	217.07	0.001	H0 Rejected
Slope	1088.41	0.001	H0 Rejected
Annual Precipitation	1065.41	0.001	H0 Rejected
Annual Mean Temperature	1187.49	0.001	H0 Rejected
Mean Diurnal Range	562.44	0.001	H0 Rejected
Temperature Seasonality	1042.74	0.001	H0 Rejected
Precipitation Seasonality	898.9	0.001	H0 Rejected
Isothermality	586.87	0.001	H0 Rejected

The remaining factors—Annual Precipitation, Annual Mean Temperature, Mean Diurnal Range, and Precipitation Seasonality—show moderate to high differences that help distinguish between land cover types. However, these factors may not be as influential as the top key variables listed in Table 5.

Table 5. Pairwise Mann-Whitney U Test Results for Environmental Variables Across Land Cover Types

Compared Land Cover Pairs	Altitude	Rugg	Slope	Ann Prep	Ann Mean Tm	Diur Rng	Temp Sea	Prep Sea	Isother
Broad-leaved vs Coniferous forest	1.06e−02∗	1	1.12e−08∗	1	1.15e−02∗	0.827	3.10e−11∗	1	1
Broad-leaved vs Mixed forest	4.39e−02∗	0.238	1	1	0.155	1	1	1	1
Broad-leaved vs Natural grasslands	2.62e−26∗	0.598	6.90e−38∗	4.63e−35∗	1.62e−27∗	1.93e−10∗	2.48e−05∗	0.897	3.24e−08∗
Broad-leaved vs Pastures	0.755	1.23e−05∗	4.23e−104∗	1.20e−22∗	1	2.97e−06∗	1	1	1
Broad-leaved vs Salt marshes	8.57e−11∗	4.48e−02∗	2.62e−11∗	1	6.32e−08∗	1.08e−06∗	1.31e−09∗	8.57e−11∗	1
Broad-leaved vs Sclerophyllous veg	5.85e−17∗	1.77e−05∗	1.51e−24∗	1	7.77e−17∗	1.06e−09∗	2.23e−49∗	1	1
Broad-leaved vs Sparsely vegetated	2.27e−48∗	2.86e−03∗	3.22e−09∗	4.80e−55∗	8.87e−49∗	1.45e−13∗	7.06e−06∗	6.58e−77∗	1
Broad-leaved vs Transitional woodland	0.225	1	1.15e−08∗	1	0.057	1	2.22e−09∗	2.84e−17∗	1
Coniferous forest vs Mixed forest	1	3.22e−02∗	1.18e−17∗	0.085	1	1.45e−03∗	1.63e−12∗	1	1
Coniferous forest vs Natural grasslands	4.18e−73∗	2.64e−02∗	4.76e−29∗	3.33e−70∗	6.58e−77∗	2.38e−40∗	1.60e−67∗	1	6.69e−17∗
Coniferous forest vs Pastures	1	1.06e−07∗	4.32e−127∗	1.68e−28∗	1	6.74e−14∗	0.287	1	1
Coniferous forest vs Salt marshes	9.28e−11∗	2.03e−02∗	1.06e−11∗	1	3.18e−07∗	1.16e−06∗	4.21e−09∗	1.69e−16∗	1
Coniferous forest vs Sclerophyllous veg	3.73e−08∗	6.17e−10∗	8.83e−15∗	1	2.88e−08∗	8.05e−09∗	2.80e−45∗	1	1
Coniferous forest vs Sparsely veg areas	3.08e−122∗	1.68e−09∗	1	6.30e−111∗	2.12e−120∗	8.10e−49∗	1.03e−73∗	3.77e−10∗	1
Coniferous forest vs Transitional wood	1	1.01e−04∗	1	1	1	1	1	2.49e−11∗	1
Mixed forest vs Natural grasslands	1.55e−51∗	1	6.71e−64∗	1.01e−63∗	1.40e−48∗	7.20e−14∗	6.49e−13∗	1	4.15e−11∗
Mixed forest vs Pastures	1	1.96e−03∗	1.42e−130∗	1.30e−31∗	1	9.93e−07∗	1	1	1
Mixed forest vs Salt marshes	1.03e−10∗	0.052	1.36e−11∗	1	6.77e−08∗	4.41e−07∗	1.12e−09∗	6.15e−03∗	1
Mixed forest vs Sclerophyllous veg	1.98e−09∗	9.00e−15∗	9.51e−35∗	1	7.15e−10∗	1.54e−14∗	1.50e−60∗	1	1
Mixed forest vs Sparsely veg areas	1.27e−87∗	1.33e−14∗	2.84e−17∗	3.20e−96∗	3.02e−81∗	4.04e−18∗	4.04e−14∗	1.26e−110∗	1
Mixed forest vs Transitional woodland	1	2.22e−10∗	1.11e−18∗	2.04e−03∗	1	4.27e−02∗	1.69e−10∗	3.22e−132∗	1
Natural grasslands vs Pastures	1.00e−21∗	5.27e−03∗	7.02e−88∗	1.58e−02∗	1.69e−16∗	1	1.49e−03∗	1	1
Natural grasslands vs Salt marshes	3.87e−11∗	0.258	1.54e−11∗	0.063	3.84e−08∗	1.86e−07∗	2.45e−07∗	1.36e−11∗	1
Natural grasslands vs Sclerophyllous veg	1.87e−63∗	5.47e−12∗	1	3.74e−22∗	8.25e−67∗	1.73e−37∗	1.26e−17∗	1	5.25e−03∗
Natural grasslands vs Sparsely veg areas	2.33e−04∗	2.96e−13∗	2.20e−16∗	4.04e−03∗	2.51e−02∗	1	1	4.64e−07∗	0.212
Natural grasslands vs Transitional wood	2.38e−75∗	1.48e−10∗	1.12e−34∗	4.49e−70∗	4.91e−82∗	1.81e−39∗	1.42e−06∗	6.15e−03∗	1.26e−04∗
Pastures vs Salt marshes	4.33e−10∗	1	9.68e−09∗	0.071	8.89e−06∗	2.84e−07∗	1	3.77e−96∗	1
Pastures vs Sclerophyllous veg	5.91e−03∗	3.72e−15∗	6.88e−57∗	2.70e−18∗	4.81e−06∗	6.36e−21∗	1.09e−45∗	1	1
Pastures vs Sparsely vegetated areas	1.56e−34∗	6.23e−15∗	1.26e−110∗	1	1.37e−25∗	1	1	6.30e−111∗	1
Pastures vs Transitional woodland-shrub	1	1.21e−12∗	3.22e−132∗	5.79e−27∗	1	1.08e−12∗	1	3.22e−02∗	1
Salt marshes vs Sclerophyllous veg	3.77e−10∗	1.90e−03∗	3.87e−11∗	1	2.21e−07∗	1.16e−05∗	1.17e−08∗	8.25e−67∗	1
Salt marshes vs Sparsely veg areas	2.49e−11∗	6.81e−03∗	1.31e−11∗	6.15e−03∗	1.71e−08∗	1.03e−07∗	1	2.49e−11∗	1

Salt marshes vs Transitional woodland	8.46e−11*	1.05e−02*	1.02e−11*	1	1.02e−07*	1.08e−06*	4.64e−07*	2.15e−15*	1
Sclerophyllous veg vs Sparsely veg areas	8.95e−91*	1	7.78e−10*	4.16e−36*	3.77e−96*	8.83e−43*	1.05e−48*	1.54e−11*	1
Sclerophyllous veg vs Transitional wood	6.04e−12*	2.90e−04*	2.15e−15*	1	2.44e−11*	3.84e−10*	2.83e−45*	8.10e−49*	1
Sparsely veg areas vs Transitional wood	3.07e−130*	4.02e−02*	1	7.44e−114*	4.08e−133*	5.51e−48*	7.95e−07*	1.06e−11*	1

DISCUSSION

Environmental characteristics across different land cover types exhibit distinct patterns. This shows the unique ecological roles of each category. Environmental factors, like altitude, terrain ruggedness, and slope, have a significant impact on different land cover types (Guerra et al., 2019). Sparsely vegetated areas and Natural grasslands consistently occupy the highest elevations and tend to be found in more rugged environments. This pattern suggests an adaptation to high-altitude, potentially harsher conditions, consistent with their reduced vegetation cover (Wu et al., 2015). On the other hand, salt marshes are located at the lowest elevations, in the least rugged and smooth terrains. This reflects their specific adaptation to coastal or low-lying wetland environments (Shen et al., 2016). Forest types (Broad-leaved, Mixed, Coniferous) and Transitional woodland-shrub generally occupy mid-to-high altitudes and exhibit a wide tolerance for steep slopes, indicating their dominance across varied mountainous and hilly landscapes. Climatic variables further refine these environmental preferences. Salt marshes show the highest annual precipitation and the most pronounced seasonality. This pattern suggests they are adapted to environments with distinct wet and dry periods, even though they are low-lying areas (Wang & Ma, 2019). Interestingly, these areas have the highest overall temperatures and the least fluctuation in temperature from one season to the next. This means they enjoy a stable climate throughout the year, likely due to their proximity to large bodies of water (Xu et al., 2022). In contrast, sparsely vegetated areas and Natural grasslands, which are typically found in cooler overall climates, exhibit the most significant temperature seasonality and the most considerable daily temperature fluctuations (high Mean Diurnal Range) (Wu et al., 2016). This supports the notion of their presence in environments with less vegetative cover, leading to more extreme thermal swings. Forest types and pastures generally belong to moderate categories for annual mean temperature and exhibit moderate to high temperature seasonality and diurnal ranges (Chen et al., 2018). The fact that isothermality is similar across most land types shows that this climate factor may not be as important in distinguishing areas in the study compared to other factors. However, the combined influence of altitude, ruggedness, precipitation patterns, and temperature regimes strongly defines the unique environmental fingerprint of each land cover. High-altitude areas have big seasonal changes and large temperature swings between day and night. In contrast, low-lying areas are warmer, get a lot of rain, and have little seasonal change, which is what salt marshes usually need. These differences demonstrate the close link between physical geography, climate, and plant patterns.

The subsequent Kruskal-Wallis test unequivocally demonstrated that the observed environmental differences are statistically significant. With highly significant p-values (consistently 0.001) for all evaluated variables, the null hypothesis—that no significant differences exist among land cover groups—was rejected. This outcome confirms that every measured environmental characteristic distinctly contributes to the unique environmental profiles of the various land cover types. While all variables demonstrated significant differentiation, the magnitude of these differences varied, as indicated by the H-statistics.

Altitude arose as the most significant differentiator, exhibiting the largest H-statistic (1191.86). This highlights that elevation is a primary driver of environmental variation across these land cover types, strongly influencing associated climatic conditions. Ruggedness showed a statistically significant result, but it had the lowest H-statistic (217.07) among the variables that led to rejecting the null hypothesis. This indicates that while there is a significant difference in ruggedness, its capacity to differentiate between the land cover groups is relatively less significant than that of altitude. Further insights from the pairwise Mann-Whitney comparisons (as implicitly referenced by the consistency analysis in the Results section) reinforce these findings. Variables such as Altitude, Slope, Temperature Seasonality, and Ruggedness consistently showed significant differences across a large number of pairwise comparisons. This indicates their strong utility in distinguishing between various land cover categories. Isothermality showed fewer significant differences between land cover types. This suggests a more consistent pattern across these types or that it plays a smaller role in distinguishing them in this ecological context. Other variables like Annual Precipitation, Annual Mean Temperature, Mean Diurnal Range, and Precipitation Seasonality also contribute moderately to highly to the observed environmental differentiation.

These findings suggest that a combination of topographic (Altitude, Slope, Ruggedness) and climatic variables (Annual Precipitation, Temperatures, Seasonality, Isothermality) shape the distribution and environmental characteristics of the diverse land cover types. The clear differences show distinct environmental divisions. This means different land cover types exist in specific environmental conditions, which adds to the region's overall ecological diversity.

CONCLUSION

In summary, this study provides rigorous statistical evidence of significant differences in key environmental parameters across various land cover types within the Mediterranean study area. Through the Kruskal-Wallis test, variables such as altitude, ruggedness, precipitation, and temperature were confirmed to differentiate distinct ecological niches occupied by forests, grasslands, salt marshes, and areas with sparse vegetation. These findings illustrate the critical role of environmental filters, driven by topography and climate, in structuring ecosystem composition. The distinct preferences of sparse vegetation for high, variable climates versus salt marshes for warm, stable conditions highlight how species distributions and community assembly are governed by specific environmental gradients. This enhanced understanding of these environmental dependencies is vital for conceptualizing ecosystem dynamics and can serve as a robust basis for ecosystem management, conservation strategies, restoration planning, and diverse predictive modeling studies aimed at assessing future ecosystem responses to environmental changes in the region.

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AUTHOR CONTRIBUTIONS

Only one author contributed to this study.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

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