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Land Suitability Analysis for Vineyard Cultivation in the Izmir Metropolitan Area

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Abstract: The grapevine, so-called Vitis vinifera L., is one of the most diffuse perennial crop plantations in the world due to a flourishing market that shaped the landscape and the societal values. Turkey has been a historical vine producer, counting on an overall vineyard extension of 550,000 hectares. Besides, Turkey has some favorable pre-requisites to be one of the most fertile lands for vineyard production: variegated topography, rich soil diversity, heterogeneous morphology, and several micro-climatic conditions. However, establishing a flourishing and fully productive vineyard requires many years, and therefore, the selection and management of sites should be considered with great attention. Within this work, a first land suitability analysis for vineyard production has been established for the entire metropolitan area of Izmir according to the most scientifically-agreed criteria: elevation, slope, aspect, land capability, and solar radiation. These criteria were superimposed through spatial overlay analysis using Esri ArcGIS (ver.10.8) and evaluated using the Principal Component Analysis technique. The first three bands were then extracted to define the most suitable areas for vineyard production in Izmir. The final layer has been used to define which areas can be considered for future strategic expansion and management. The discussion focuses on the Kozak plateau, where a new policy of vineyard plantation will be promoted with techniques that aim to maintain and revalorize the traditional vineyard landscapes and conserve traditional methods and practices that have evolved with the cultural values of the villagers and producers.

Keywords: land suitability; sustainability; landscape management; vineyard; land use planning

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1. Introduction

The grapevine, so-called Vitis vinifera L., is one of the most diffuse perennial crop plantations globally. The latest report of the world viticulture issued by the Organisation Internationale de la Vigne et du Vin stated that approximately 7.4 million hectares of world surface land are occupied by vineyards, leading to a production of 292 million hL while half of the total world land occupation is concentrated in five countries: Spain, China, France, Italy, and Turkey [1]. According to FAOStat (2021), while Spain has the largest share of area dedicated to grape harvesting (13.53%), Turkey is the fifth country after Spain, France, China, and Italy, with 405,439 hectares of land (5.85%) on the global level [1,2].

Viticulture is a growing agricultural practice due to a flourishing market, but it requires a specific landscape and societal values for its development. Turkey has been a historical vine producer [2], as studies show that vineyard cultivation started around 7000 years ago in Anatolia, and shaped the land's culture, landscape, and economy for centuries [3]. Receiving the benefit of a variegated topography, a rich diversity of soil conditions, a heterogeneous morphology and a combination of several micro-climatic conditions, Turkey has some favorable pre-requisites to be one of the most fertile lands for vineyard production [4,5]. These conditions enable grapevine production approximately 400,000 hectares of land [6]. Besides, among the reasons that support the vineyard production, the monetary value of vine production has been increased constantly, reaching record values in the last period, thus emphasizing the economic, socio-cultural, and environmental dimensions of this farming activity.

However, vine production is a long-term process that only partially relies on vineyard plantation: it requires long land management practices and several on-site procedures for vine production. In addition, the vineyard sites are important landscape elements, which holds traditions and memories; thus, their conservation goes beside the economic aspects and roots on the preservation of culture, memory, tradition and the legacy of rural villages, which is rooted in parts of Turkey where microclimatic conditions and culture enables vine grape production [7]. Moreover, establishing a flourishing and fully productive vineyard requires many years, and therefore the selection of conservation or new vineyard productive sites should be considered with great attention [8]. Besides, vine cultivation should be located in favorable areas to achieve a sustainable water balance, thus, the determination of sites for grape cultivation purposes should be analyzed before deciding on viticulture regulation or promotion [9]. Several European Member States have already built their own national viticulture Geographic Information System (GIS) to support dry vineyard cultivations [10], while in Turkey such efforts are still missing. In addition, such a database could be used in landscape planning and rural planning processes to promote a sustainable use of dryland landscapes, such as in the water-sensitive Mediterranean landscape. Considering the declining rural economy and continuing rural to urban migration in Turkey, it is important to integrate land use planning and diversify economic activities in rural areas to make wine as a lifestyle community. Viticulture could enhance the rural economy and sustainability of the productive landscape through the ecosystem composition it requires and the livelihood opportunities it possesses.

Although vineyards are widespread across the country, they concentrate mostly in the Aegean, Mediterranean, Central Anatolian, and Southeastern regions. Overall, Turkey has 1250 varieties of grapes and, among all, here are at least 34 types of wine grapes that 22 of them are considered local biodiversity [11]. The country is the top global exporter of dry grapes (raisins), which shows the extent of added value production potential from grapes [12]. The share of grapes among all fruit production is 21% and five out of six grapes are used for table and drying purposes, whereas the rest is used for preparing wine and other traditional products (molasses, fruit pulps, etc.) [11]. While all over grape production in tonnes slightly changed since the last 10 years, the wine grape production in tonnes increased by almost 25% due to monetary returns and added value of wine production on the local economy [6]. Having a historical interrelation of Izmir with viticulture dating back to ancient times, Izmir has always been the locus of grapevine production in Turkey. Izmir is the tenth city with the largest land coverage allocated for grapevine production in the country; however, this coverage decreased by half (approximately from 22,000 ha to 11,000 ha), and the overall yield has decreased by 20% since 2004 [6]. Yet, the area dedicated to wine grape production has increased by 49%. This trend is clearly seen from the increasing numbers of initiatives in the form of wineries, local destinations, and wine routes in Selçuk and Urla districts of Izmir. Only in Urla, more than 20 vine boutiques are operative, and half of them are just opened in the last 10 years while demonstrating a new vine demand.

On the other hand, it is seen that there has been a constant decrease in vineyard areas and grape yields in the most productive districts such as Menemen, Kemalpaşa, Menderes, and Bergama since 2004. Whereas only in three districts (Seferihisar, Selcuk, and Dikili) among 30, both the land for vineyard and grape yields increased. This situation poses the main motivation behind this study. Although the Izmir city has a suitable socio-ecological environment for viticulture in terms of soil, climate, and culture, this land practice has an underutilized potential for the rural economy.

Particularly, in the Izmir city, such an information system can support some specific vineyard re-plantation and expansion processes, especially in the tourism corridor between destinations such as Ayvalık and Bergama and in some areas such as the Kozak Plateau of Bergama district (see Figure 1). Bergama, the successor of Pergamon city, represents a unique case for viticulture that has been an agricultural practice since ancient times. On the other hand, due to site-specific circumstances, the productive landscape of the plateau is changing after a process of agricultural diversification, and the area is experiencing a spontaneous reconversion to increase the land for vineyard cultivation.

Figure 1. The location of Bergama district in the Izmir's Province. Source: author's elaboration.

In these areas, a deep analysis of land characteristics can help introduce a water-sensitive vineyard expansion policy in selected sites while accompanying the process with sustainable development of the economy and the safeguard of the original traditions. The Kozak plateau represents an authentic picture of the Aegean Turkish Mediterranean inland, mainly covered with Pineus pinea forest that produces the pine nuts and represents the area's vital economic income. Besides, the rural communities hold a deep local culture and warm hospitality. Suitable areas for vineyard cultivation are located in hugely heterogeneous and topographically variable regions, which can influence the microclimatic and micrometeorological conditions while also influencing grape quality.

Therefore, within this work, firstly, a land suitability analysis for vineyard production has been established for the entire metropolitan area of Izmir according to the most scientifically agreed criteria: elevation, slope, aspect, land capability, and solar radiation [13]. These criteria were evaluated through spatial layers using ESRI (Environmental Systems Research Institute, CA, USA) ArcGIS (ver.10.8) and superimposed by Principal Component Analysis (PCA) technique [14]. Then, the result has been used to determine which areas in the Kozak plateau have favorable characteristics for vineyard cultivation compared with the existing pattern.

1.1. How to Perform Land Suitability for Vineyards?

As agreed by many international publications, vineyard productivity depends on a combination of biophysical and chemical characteristics, which influence the growth, quality, and number of grapes in a vineyard plantation site [15]. There is no unique combination of these parameters to determine the exact localization for vineyard cultivation since grapes often need site-specific conditions. Nevertheless, the integration of land use, climate, soil, and topographic information in GIS can remotely support the definition of the most suitable sites for vineyards.

Topography (traditionally slope, aspect, and elevation) [16], meteorological conditions (quantity of rain, temperature, and period of drought) [17], soil type (land capability classification, organic content, pH, acidity, and texture) [18], and energy (solar radiation) [19] have all considerable impacts on grapevine production and shape the terroir [13]. Therefore, a proper land suitability analysis for vineyard plantations should consider at least some of the abovementioned data and define a method of integrating these spatial layers with multicriteria analysis.

Land suitability [20] is normally built on spatial multicriteria approaches [21,22] based on the simultaneous visualization/evaluation of layers in a defined catchment. Landscape ecology has originally introduced land suitability analysis to recognize and protect the core ecological areas by describing the potential connections between core and hub areas for species migration and vegetation defragmentation [23,24].

Nowadays, the methodologies to produce composite layers [25,26] have consistently expanded, including different approaches that range from simple tabular analysis, where the composite index is the result of a statistical sum of average quantitative indicators associated with a certain land use category [27] to context-specific mapping analysis produced by the spatial interaction of biophysical values [28–30].

Whatever the method, the final "composite" layer is produced by a mathematical combination of an original set of map indexes that represent the different "dimensions/variables" of a spatial phenomenon [26,31]. Unfortunately, the abovementioned aggregation process is often threatened by the spatial autocorrelation among the input layers [32–34]. Spatial autocorrelation is often underestimated by scholars who perform spatial overlay, but it is agreed that composite indicators should be the product of less correlated input data, thus representing all the "dimensions" of the phenomena.

A basic example is represented by the relation between three morphological indicators: elevation, slope, and vegetation. While overlaying these layers, there is a high probability that the final map results are similar to the single input original layers. Specifically, the spatial overlay results are "redundant", since slope and vegetation depend on elevation, and most of the variance within the catchment can be explained just by the elevation.

1.2. Tools and Methods for Land Suitability

To maximize the landform and soil characteristics, land use and land classification for agricultural purposes often address questions such as "where" the land can be used for particular uses, especially when the location is relevant to maximizing a particular crop's growth.

The suitability assessment techniques mostly rely on multi-criteria analysis [35–38], which includes (i) the selection of several (suitable) variables to analyze [22] and (ii) the aggregation method [39].

According to Mugiyo et al. (2020), the variables that can be included span to several different characteristics, including climatic [40], hydrology [41], soil [42], socio-economic [43], and landscape properties [44]. The review counts more than 67 different parameters (layers) that can be employed by superimposition to obtain a final synthetic map, but there is a significant variability on this matter since there is no common method to obtain perfect suitability for each kind of agricultural production [45]. Some basic assessments count three variables, while others include more than twenty layers [46,47]. Besides, there is no direct relation between the number of criteria and the reliability of the assessment: sometimes, a few well-selected and representative variables give better results than assessments that include several more layers [20].

As for the aggregation method, multi-criteria analysis can employ several different approaches, which include the analytical hierarchy process [5,38], fuzzy methods [48], machine learning [49], weighted or unweighted overlay [14], or principal component analysis [25]. Still, there is no consensus on the best aggregation method for crop suitability.

Therefore, the determination of the suitable lands for vineyard plantation by PCA in this work consisted of two crucial steps. The first step has been the selection of the crucial parameters that should be involved in the analysis [14,50], and the second step has been the application of an aggregation method for these parameters [22,51].

Due to the availability of digital layers, in this research, the PCA has been applied using the topographic, soil, and solar radiation information to produce the vineyard plantation suitability map of the Izmir [52]. Particularly, the main objective of this research is to check whether geospatial data can support the current distribution pattern of vineyards to support farmers in selecting new vineyard sub-regions and provide context-specific management policies especially dedicated to sustaining the local farmer's initiatives for vineyard cultivation.

2. Materials and Methods

2.1. The Area of Interest

The Izmir city, defined by the administrative borders of the metropolitan municipality of Izmir, spans 154.181 ha and is inhabited by more than 4 million citizens [6]. The administrative edge extends along the outlying waters of the Izmir Bay and inland to the north across the Gediz River Delta and to the east along an alluvial plain created by several small streams while on the south, the terrain is characterized by mountainous systems [53]. The topography comprises a variegated alternate of plain and hilly areas, ranging from high crests in the mountainous system to the plain costs adjacent to the Aegean sea [54]. The city comprises 30 districts and 1.328 villages at an average altitude of 238 m a.s.l. According to Copernicus sources [55], the mean imperviousness is 21%, and the average tree cover density is 16%.

2.2. Elevation

The elevation is considered one of the basic parameters for potential vineyard allocations. High elevations tend to receive more direct sunlight (ultraviolet rays), but, at the same time, altitude influences temperature, humidity, and air composition [20].

Elevation data were ranked for different levels using the raster reclassification technique. Elevation ranking was performed following the study findings of Alganci et al. (2019), which evaluated the land suitability analysis for vineyards in the Sarkoy region of Turkey [52]. Their study ranked the absolute elevation using twenty intervals according to different coefficients of altitude. Absolute elevations of the study area and their respective ranks were given to the Digital Elevation Model (DEM) of the Izmir province. The original DEM employed is the European Environmental Agency raster layer (Copernicus service) with a 20-m pixel resolution. The layer has been processed with the "fill-sinks" function to correct potential gaps. Some minor adjustments on the ranking were adopted to classify elevations higher than 390 m (which do not exist in the original study area but in the current catchment). Therefore, these elevations were included in certain ranks (4 and 10) according to their suitability for viticulture activity.

2.3. Slope

According to some bibliography [5,8,56], the slope is another key parameter along with the altitude. Indeed, the slope influences the management practices and the potential land erosion due to plant distribution and directly affects the sunlight exposure due to the different range of altitudes to which the grapes are dislocated. It is generally agreed that terrains ranging between 5 and 15% of slopes are highly suitable for vineyard cultivations [57].

The same input of the first layer (DEM) has also been used to produce the slope analysis employing the "slope" tool. Then, the slope gradients were classified according to the guideline published by the Food and Agriculture Organization of the United Nations (FAO) and reported by other authors [13] in classes for grading eligibility in viticulture.

Slope where reclassified in 3 suitability classes ranging from 1 (non-suitable) to 3 (highly suitable) [58].

2.4. Aspect

Among all possible criteria, the aspect is often considered or mentioned in land suitability analysis for vineyard cultivation. Aspect determines the quantity of solar radiation and influences the microclimatic vineyard conditions (wind and humidity) [17,59]. South, southeast, and southwest are always preferred to north directions as they receive more solar radiation and benefit from optimal sunlight conditions.

The DEM has also been used to generate the Aspect layer. Distribution was based on south, north, east, and west directions. Then, all directions were ranked with raster reclassification, giving higher value to south and southeast facing direction, as commonly agreed by bibliography [56].

The reclassification of suitable classes has been executed, assigning values ranging from 1 (non-suitable) to 3 (highly suitable).

2.5. Land Capability Classification

Obviously, the Land Capability Classification (LCC) is extremely important for this analysis [60–62]. It includes all the chemical and physical soil properties that can influence the use of soil for different types of production activities [18]. For vineyard plantations, LCC should be interpreted with relative importance. It is commonly agreed that excellent vine production sometimes comes from grapes planted on soils that have some limitations for agricultural uses. At the same time, it is generally valid that a highly capable soil for agricultural purposes can also be considered suitable for vineyard cultivation. Besides, here it should be considered that the "quality" of the vine depends on several vine-production processes that go largely beyond the basic physical and chemical characteristics of the soil.

Land use capability classes were assigned as attribute information contained in the official soil characteristics map of Izmir Province. According to the LCC attribute in the table of content, the digital map was converted to raster format and ranked according to the land use capability classification, using 1 for the inconvenient lands and 9 for convenient lands [15,63].

2.6. Solar Radiation

The sun is the primary energy source for all biological processes on the earth [64,65]. Solar radiation affects air and soil temperature, transpiration, soil moisture, atmospheric humidity, etc. Thus, growing conditions are determined mainly by the solar radiation received at the site [66]. The growing of the grape requires careful consideration of the microclimate of the selected location.

The amount of solar radiation received at a site varies widely with slope and aspect of the area, especially in hilly and mountainous areas [19]. The accumulated seasonal solar radiation tends to be lower on slopes facing north, northeast, and north-west and higher for the slopes facing south. The solar radiation tool in ArcGIS has been employed to estimate the watt per hour/mq in each pixel of the selected catchment land. According to the following table, it has been ranked in 5 classes [57].

As mentioned earlier, the five output layers were then used as new inputs to perform the PCA (see Figure 2).

2.7. Suitability Map Production

As earlier mentioned, the aggregation method considers a raster band replacement based on the spectral properties of the covariance matrix (eigenvectors and eigenvalues), determining the final aggregate layer [67,68]. This process replaces the original layers with few output bands, which retain the same generalized variance as the original data [69,70]. The digitalization and rendering of the final raster suitability map have been based on the following steps:

1. The reclassification of the suitability raster map into a 3-classes output using Natural Breaks (low suitability, medium suitability, and high suitability);
2. The transformation of the new reclassified raster in a feature polygon shapefile;
3. The extraction of the values with high suitability (class 3);
4. The automatic aggregation of the polygons into a combined network.

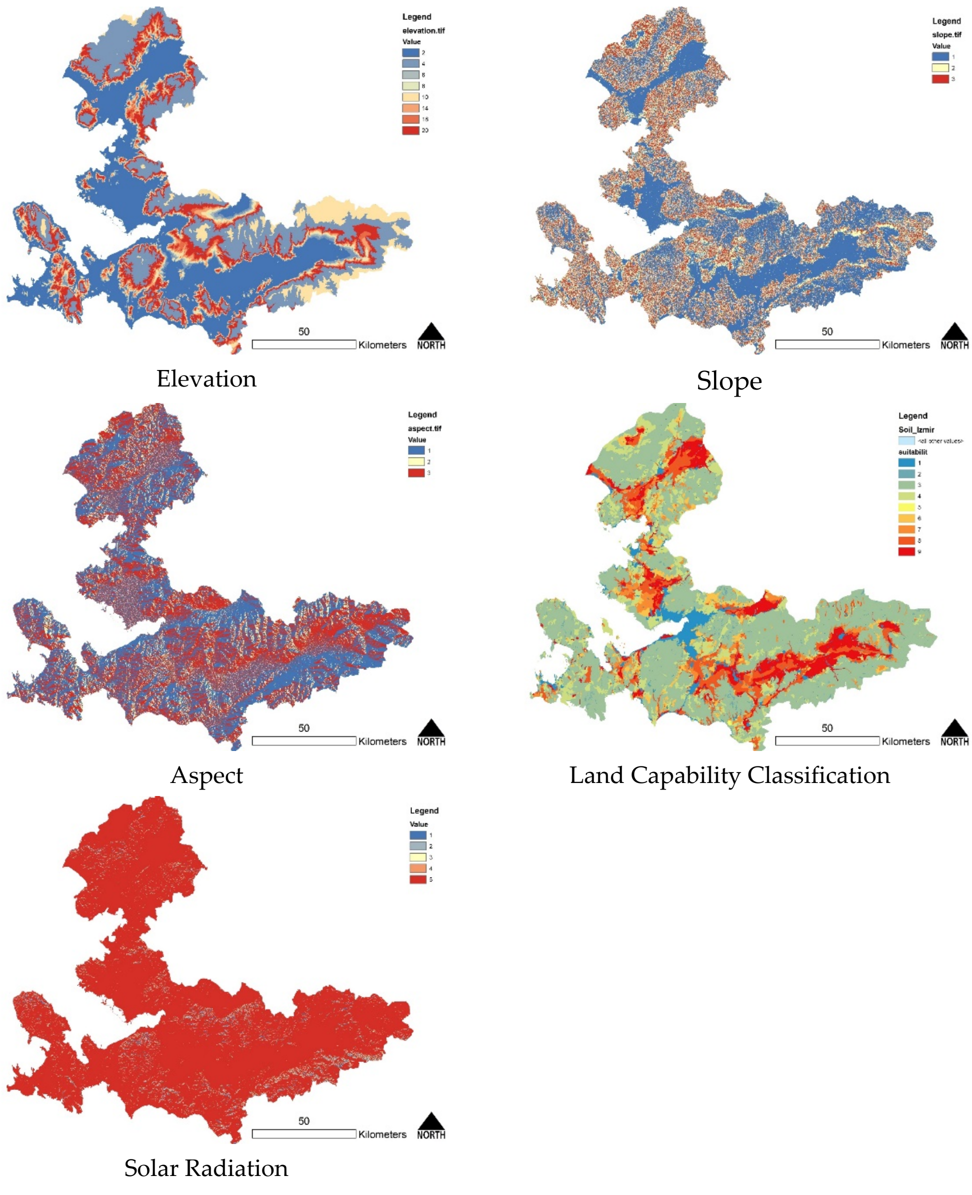

Figure 2. GIS spatial categorization of the five analytical input layers. Source: author's elaboration.

2.8. The Testing Site: Kozak Plateau

As earlier mentioned, we decided to downscale our analysis while including an in-depth assessment of suitability to vineyard cultivation in the Kozak Plateau, as a typical representation of the traditional Mediterranean Aegean landscape. From an agroecological perspective, this part of Turkey still retains some of the most significant sustainable traditional land practices, contrasting the globalized agricultural system dominated by intensive monoculture production.

The Kozak Plateau is located at an altitude of 500–1000 a.s.l. on the foothills of Madra Mountains near the Aegean coast of Turkey and is located along the Ayvalık-Bergama road towards Northern Izmir. This portion of the Bergama district comprises 16 villages, spanning 31.819 hectares (See Figure 3). Kozak villages are located in the far northwestern border of the Bergama District—Izmir along the Kozak plateau. The plateau landscape is characterized by a variegated topography with a rich and typical Mediterranean environment.

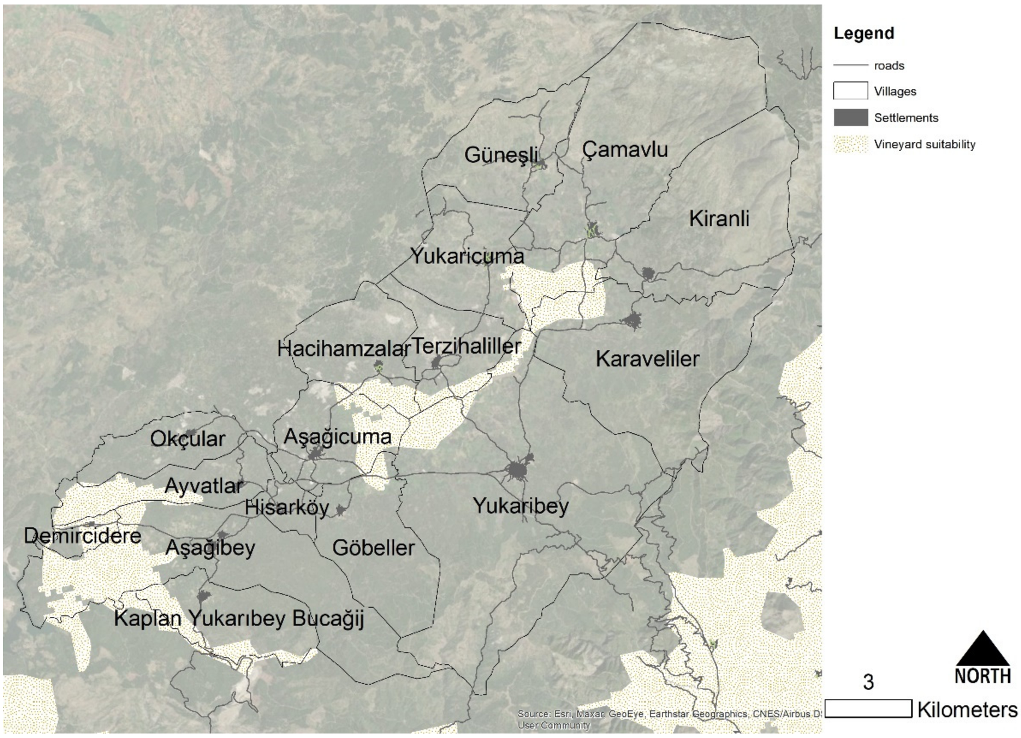

Figure 3. The Kozak Plateau. Source: author's elaboration.

A high forestry index characterizes these villages (the average tree cover density is 40.7–16.4% is the value of the Izmir metropolitan area) and a low presence of roads that fragment the landscape. All these are peculiarities that, associated with the low imperviousness rate (impermeable anthropic surfaces cover less than the 1% of the village—21% is the value of the Izmir metropolitan area), gives to these villages a pronounced rural character (the average land capability class of soils in these villages range between the 3rd and the 4th class) with huge and flourishing biodiversity [71,72].

The stunning pine-clad landscape can be observed and appreciated through the gentle slopes, and the curvy roads that cross the valleys while intercepting sloppy pedestrians that serve to local shepherds reach their sheep or goats in mountain pastures located on uphill prairies and grasslands.

The lush green environment is surrounded by natural springs, while the pine litter is sometimes punctuated by surfacing rocks scattered around the forests.

Kozak, which is the name of the main river that shapes the plateau, is composed of small villages distributed up and down the sides of the hills. In these settlements, the typical and simple Turkish lifestyle is still maintained. The Mediterranean mountain products such as olives and grapes are auto-produced by a slow and purely extensive land management. Good air quality, spring water, and optimal microclimatic conditions with warm winters and long dry summers represent a unique ingredient for healthy and sustainable agricultural production.

The villages' economy is based on rural activities. Land management for crop production and livestock (cattle) grazing represents the main occupation of people [20,73,74]. Pine nuts, olive oil, and grapes are the most reach natural products that usually occupy local communities' lives, mostly in autumn. Furthermore, rock extraction for the building's industry is another important sector that collides with the more sustainable agricultural practices. Unfortunately, the number of mines, quarries, and excavation sites increases and frequently exposes visitors' views in Kozak Plateau. This problem creates local conflicts by clearing productive land cover and livelihood opportunities of villagers and creates landscape degradation, dust, and an ecological threat. This region is famous for granite rocks used for paving not only the roads of neighboring villages, but also used all around Turkey and exported extensively as a paving and construction material. In addition, carpet wool production and dairy farming are other peculiarities of this area as being traditional rural productive activities originating from husbandry.

Traditional productive knowledge still exists, and subsistence farming continues in these high altitude villages. Local villagers cultivate in their land some of the most basic and delicious primary products: the bread, the butter made from hand-milked cows and goats, the olive oil, the vine, the eggs, and all the typical vegetables produced in small rural orts.

Currently, the local economy in the plateau is composed of several agricultural income resources such as pine nut farming, husbandry, agriculture, and viticulture. Bergama is the fourth district in Izmir with the largest vineyard cultivation area. However, the area for grape production has decreased by 32%, whereas the production amount in tonnes has decreased by 75% since 2004 [6].

Until recently, pine nuts have been the driver of the rural economy in the plateau due to the high added value and export rates of pine nuts and having almost half of Pinus pinea tree coverage in Turkey. Yet, the gradual decreases in pine nut yields have resulted in the abandonment of pine nut farming and intentions for transition to other alternatives value-added production, viticulture. As a result, the region is experiencing a spontaneous reconversion process to increase the land for vineyard cultivation.

Within these premises, the analysis of the local characteristics of land for vineyard cultivation can be helpful to define some active conservation and expansion policies aimed at maintaining and subsidizing the local cultivation of vineyards.

The spatial overlay between the optimal potential for vineyard production and the existing grape cultivation areas can determine if the modelled scenario fits and aligns with the actual distribution of these specific cultivation patterns. Potential management practices by allowing an expansion of vineyard production in the suitably modelled areas can increase the farmer's output, thus preventing the use of the same land for alternative and less efficient/sustainable uses. In this perspective, it has to be mentioned the Izmir Metropolitan Municipality's efforts to sustain the rural heritage in the region: the RURITAGE project goes in this direction having in Bergama one of the most significant locations for new rural management approaches.

3. Results

3.1. Principal Component Analysis Results

As earlier mentioned, the aggregation method considers a raster band replacement based on the spectral properties of the covariance matrix (eigenvectors and eigenvalues), determining the final aggregate layer [67,68]. This process replaces the original layers with few output bands, which retain the same generalized variance as the original data [69,70].

We decided to perform PCA instead of a more traditional weighted overlay for some main reasons:

- The PCA performs better when applying GIS spatial overlay technique while reducing the spatial autocorrelation of the original input layers, thus reducing the data redundancy and obtaining more reliable spatial results;
- According to the literature on suitable vineyard locations, an optimal weighting criterion on a selected group of layers is highly uncertain [75,76]. Despite the bias and the "halo" effect of traditional experts' judgment [77], some authors argue solar radiation is the critical variable, but alternatively, all the other variable appears to be the most important in other works: land capability, slope, aspect, slope, and elevation seems to be all equally important;

- Having all the layers that have some dependencies (the DEM influences aspect, slope and solar radiation as well), the utilization of PCA reduces the unnecessary information while optimizing the spatial autocorrelation between inputs.

The inputted layer order was the following: (1) land capability classification, (2) solar radiation, (3) slope, (4) aspect, and (5) elevation. Correlations, eigenvalues, and vectors among the input layers are shown in Tables 1–3.

Table 1. Correlation matrix.

Layer	1	2	3	4	5
1	1.00000	0.13404	−0.21415	0.05324	−0.23470
2	0.13404	1.00000	0.07208	0.12112	−0.05595
3	−0.21415	0.07208	1.00000	0.00805	0.14861
4	0.05324	0.12112	0.00805	1.00000	0.00986
5	−0.23470	−0.05595	0.14861	0.00986	1.00000

Table 2. Eigenvalues and eigenvectors.

Number of Input Layers			Number of Principal Component Layers		
	5			5	
PC Layer	**1**	**2**	**3**	**4**	**5**
Eigenvalues					
	14.40545	1.72673	0.29913	0.19655	0.11659
Eigenvectors					
Input Layer					
1	−0.09522	0.99188	−0.02857	0.06466	−0.04592
2	−0.00563	0.03517	0.12858	0.19869	0.97094
3	0.01874	−0.06931	0.06543	0.97386	−0.20533
4	0.00116	0.02910	0.98912	−0.08843	−0.11393
5	0.99526	0.09636	−0.00439	−0.01093	0.00509

Table 3. Percent and accumulative eigenvalues.

PC Layer	Eigenvalue	Percent of Eigenvalues	Accumulative of Eigenvalues
1	14.40545	86.0312	86.0312
2	1.72673	10.3123	96.3434
3	0.29913	1.7865	98.1299
4	0.19655	1.1738	99.3037
5	0.11659	0.6963	100.0000

PCA's results (see Table 1) showed that the input reclassified layers were not too correlated, thus revealing a good overall variance and poor spatial autocorrelation among each single suitability map. There are no values with significant positive or negative correlation. The higher negative value is −0.23 between LCC and elevation, which seems reasonable: it means that the land that offers generic suitability for agricultural purposes (normally located in plain fertile areas) is not located where there is a perfect altitude for the vineyard (which instead is on hilly terrains).

As for the eigenvalues and eigenvectors, Table 2 shows how the original values are transformed into the new components. Table 3 shows that only the first principal component host more than 86% of the original variance. The cumulative value, including the second layer, increases at 96% and rises to 98% with the third component. It has been considered enough to use the first three components to post-process the final suitability map for these reasons.

3.2. The Distribution of Suitable Areas for Vineyard Cultivation

The first three components (see Table 3) were extracted, normalized, and recomposed in a new single band raster using the raster overlay technique. The final map had values that ranged from 0 (low suitability) to 3 (high suitability) for vineyard production (see Figure 4).

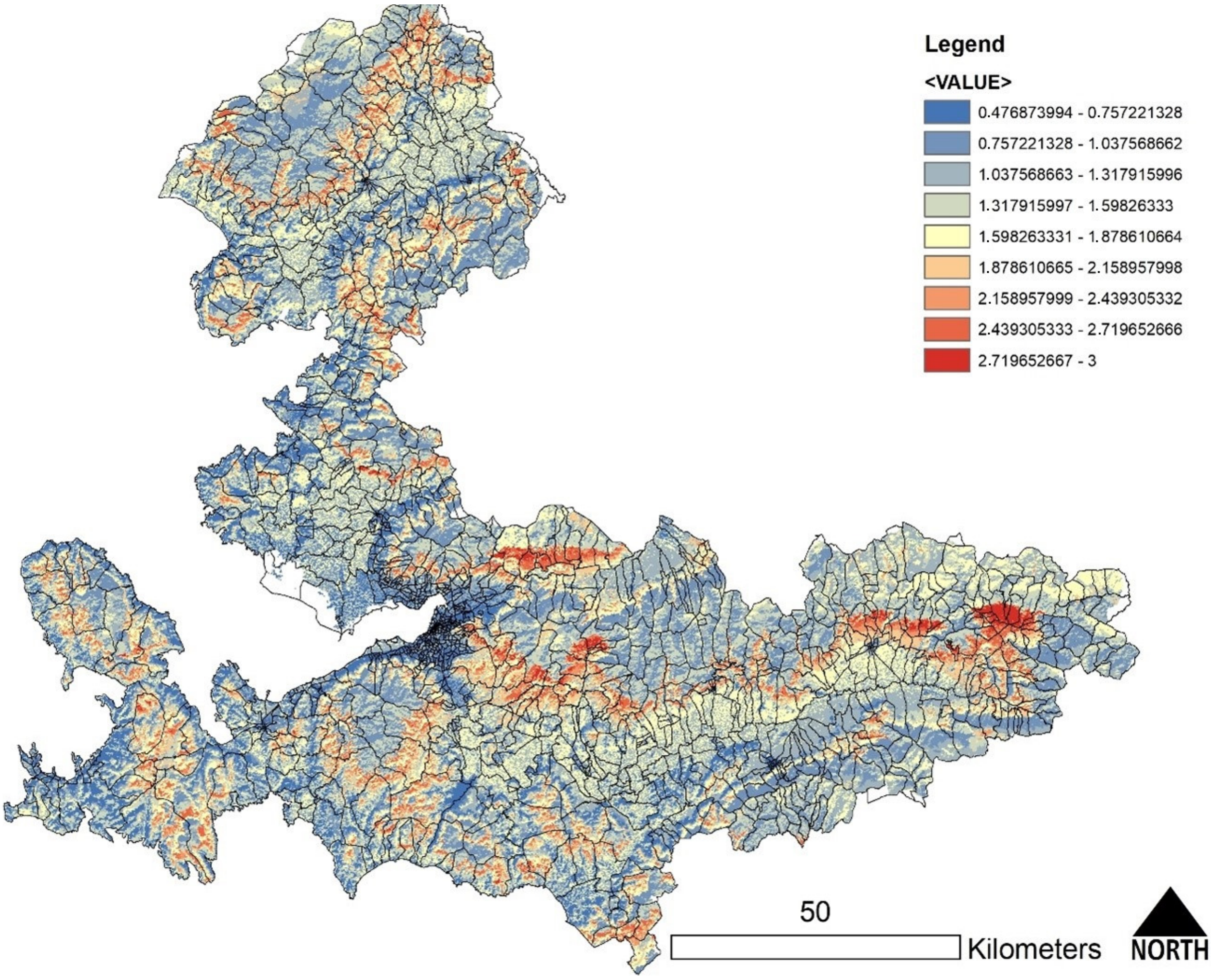

Figure 4. Principal Component Extraction. Source: author's elaboration.

The map of potential vineyard districts in Izmir demonstrates how the suitable conditions are clustered in specific districts of Izmir (see Figure 5), characterized by a simultaneous favorable predisposition of elevation, slope, aspect, land capability, and solar radiation.

A post-processing GIS rendering phase has been employed to better define the areas for vineyard production at the local scale and obtain a map where vector polygons identified each feature of land with high suitability. As already mentioned, the map can be used as a supporting decision-making layer for the metropolitan city to inform spatial planning and decide proper management practices.

Figure 5 shows that the potential suitability for vineyard cultivation only partially matches the official production. Statistically, the top grape producer districts in terms of area are (1) Menemen, (2) Kemalpaşa, (3) Menderes, (4) Bergama, (5) Torbalı, (6) Seferihisar, (7) Selçuk, (8) Karabağlar, (9) Urla, and (10) Bayırdır.

The result of the post-processing phase is represented in the following Figure 6. More than 280 thousand hectares of the metropolitan area present high suitability for vineyard production, representing 23% of the total administrative catchment.

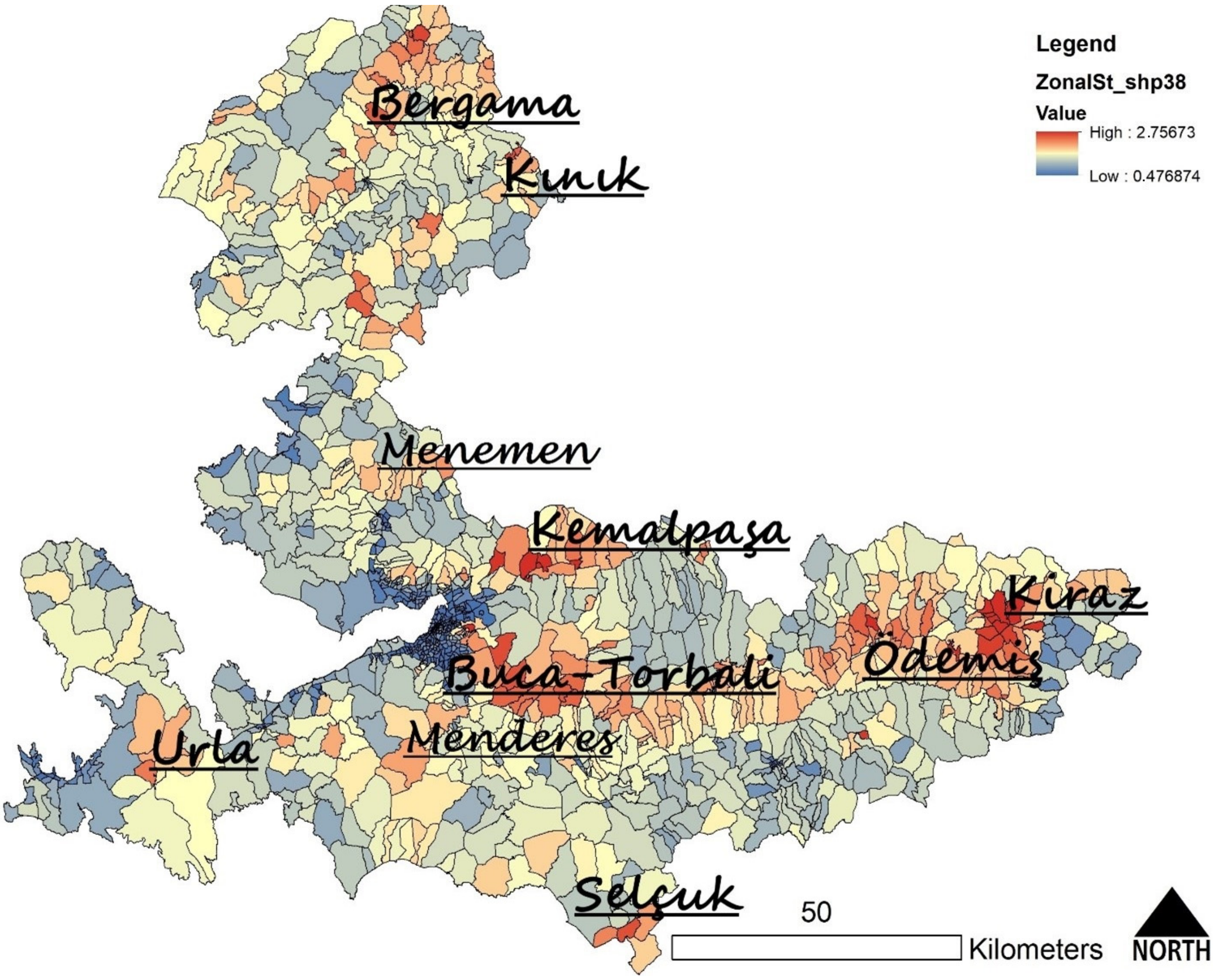

Figure 5. Spatial distribution of the potential vineyard production districts. Source: author's elaboration.

The final map identifies all those parts of the İzmir's Promontory suitable for vineyard cultivation and, in turn, where site-specific policies of vineyard expansion according to the terrain's specificities can be considered. The distribution of the potentially suitable areas for vineyard production seems to confirm that the regions for grape cultivation occupy different types of land uses according to Corine Land Cover: complex cultivation patterns 11.78%, coniferous forest 17.80%, land principally occupied by agriculture, with significant areas of natural vegetation 11.76%, Sclerophyllous vegetation 10.83%, and transitional woodland-shrub 25.09%. Unfortunately, as earlier mentioned, there are no detailed Land Use Land Cover datasets for this part of Turkey to check whether the result of land suitability fits within the real utilization of land for vineyard cultivation purposes. The Copernicus Urban Atlas and the Coastal Zone land-use dataset do not cover the whole Izmir Province. Their geometrical precision is not detailed enough to satisfy the need of this study. Besides, despite the huge intensive vineyard cultures in the lowlands, which are easy to detect by remote images, the remaining regions for vineyard cultivations are characterized by a scattered and discontinuous distribution, especially in remote hilly villages where the grapes are cultivated in small parcels of land and where compresences of pastures, grasslands, and small cultivation patterns are mixed with the Mediterranean maquis and the pine forest.

As announced, to test and evaluate the layer results, we focused our attention on the Kozak plateau, one of the most characteristic and potential vineyard regions of the province, where site-specific policy development is required as the region undergoes a process of reconversion from different agricultural production to the vineyard which is occurring without any real policy orientation or support. In the discussion part, we tried to synthesize how the land suitability analysis can integrate local landscape values and maximize production in the light of a new strategy to support grape cultivation as one of the most qualitative landscape practices for sustainable vineyard farming.

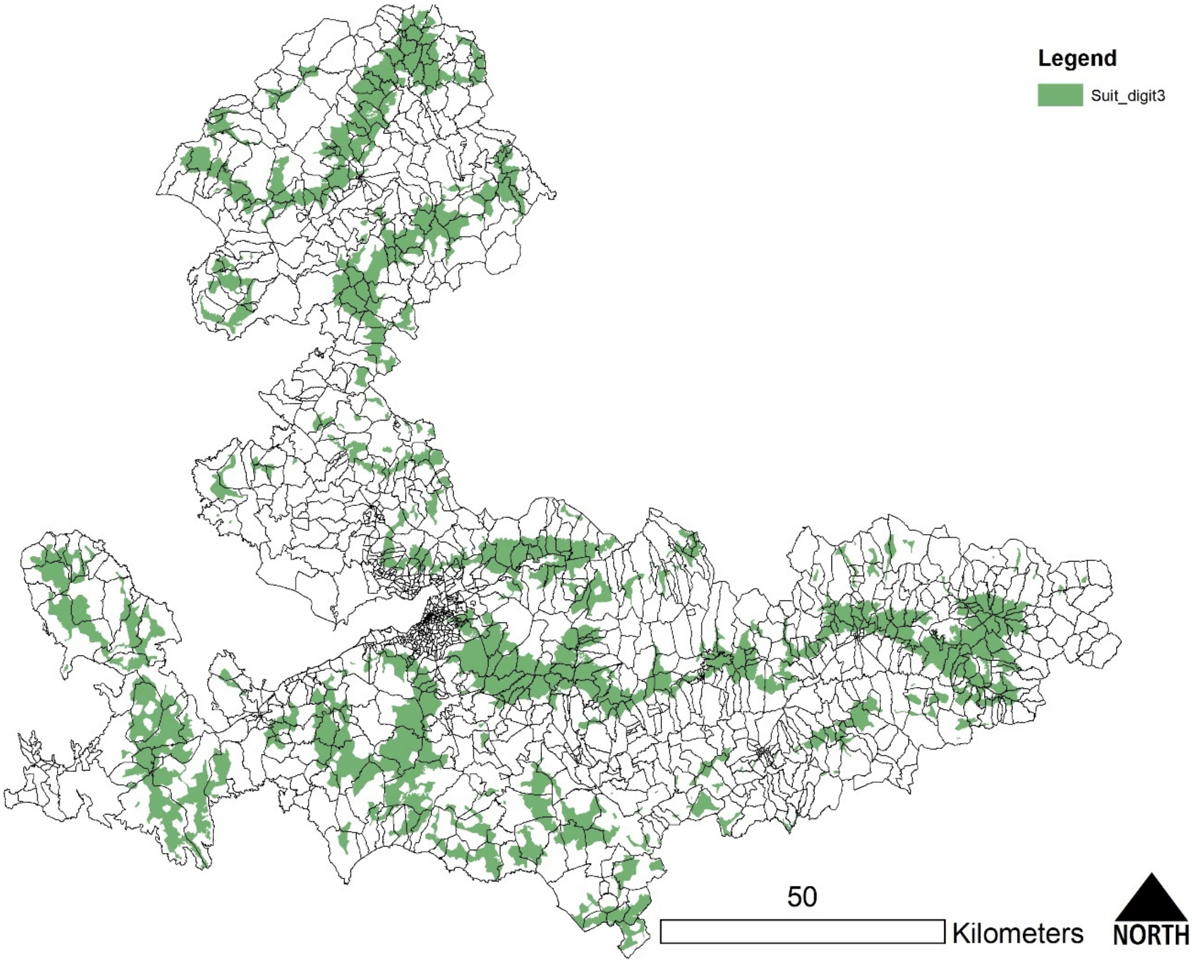

Figure 6. Rendering of the final vector layer. Source: author's elaboration.

4. Discussion

4.1. Vineyard Management for the Kozak Plateau

As shoved in detail by Figure 3, the central part of the plateau and the western border seems to present visible suitability to vineyard cultivation, with a higher suitability value that is concentrated in the southwestern cluster (Ayvatlar, Demircidere, Asagibey, and Kaplan) due to a more pronounced characterization of the slopes that look at the southern and southeastern sides. Because of this morphology of tortuous aspects and a significant slope gradient, vineyard topography varies considerably in this part of the region.

According to the digital analysis (characteristics of the morphology, soil, and solar radiation), more than 3.627 ha of land has a suitable predisposition for vineyard cultivation, demonstrating that the 11% of the Kozak plateau can potentially be employed for grape production.

This assessment confirms that the potential for vineyard cultivation in this part of Turkey is much higher than the land's actual utilization for this purpose. According to local statistics, the number of farmers ranges from 15 to 100 in these villages. Only a limited portion possess small vineyards (from 6 to 10 hectares is the average extension of vineyards per village). The vineyard cultivation decreased due to the priorities of pine nut and olive plantations, but nowadays, vineyard replacement is occurring.

The grape species that are cultivated here are mainly "şıkka", "gemre", and "efes" (see Figure 7), which are sold in the local bazaars for a cheaper price (10 tl/kg). Local farmers adopt common techniques for this local, sustainable dry vineyard production: the harvest ranges between mid-September and continues until mid-November, while the pruning period is between December and January. The soil is tilled by animal fertilizers in the winter, while during the growing seasons, many pesticides are sprayed to protect the vineyard from potential diseases.

Figure 7. The vineyard cultivations in the Kozak Plateau. Source: authors' pictures.

Unfortunately, the increasing water deficits due to climate change affect vineyard yields negatively and decrease the profitability and sustainability of wine production. The slow adaptations to drier seasons are becoming increasingly relevant in worldwide viticulture. Consequently, efforts in applied research have been dedicated to exploring a more water-efficient vineyard cultivation system. Therefore, the process of vineyard expansion in new suitable land should be carefully analyzed, respecting the new terrains' essential characteristics that could host the grape plants.

Therefore, some considerations on vineyard management will be hereafter reported, especially for those plant management strategies that concern the cultivation of grapes in semi-arid regions which experience seasonal drought, such as the typical Mediterranean areas of the Izmir promontory. As previously argued by other authors in these areas, the combination of soil characteristics and atmospheric conditions can cause severe limitations in vineyard production; thus, some important management strategies for these potentially suitable areas should be accounted [2,78]. The increasing demand for irrigation requires several precautions for water use efficiency for new vineyard cultivations [79].

First, as stated by Gaiotti et al. (2017), soil moisture management is crucial to maintain sufficient soil humidity [80] and minimize plant irrigation requirements [81]. All the practices that can improve the chemical and physical structure of the soil should be favored [82], such as the basic reduction of the soil evapotranspiration by organic mulching (even reusing the organic pruning residual biomass) can be an optimal and sustainable measure to reduce the water stress [79]. Mulching has several benefits (soil nutrients and anti-erosion practice) and increases the micro-biodiversity with some ecosystem service-related benefit effects (water holding capacity end other regulative functions). The advantages of this practice are reported in many reports [83,84]. Buesa et al. (2021) reported that mulching practices change the quantity of nutrients that the plants can absorb, the control of the weed, the soil sediment retention, and increased yields [85].

Additionally, the direct effects on evapotranspiration of covering the vineyard land with the vegetal biomass of organic pruning on fully irrigated vineyards have been estimated as reducing between 16 and 18% of the water utilization [2,86]. Green pruning aims to remove excess shoots to balance the grapevine's vegetative growth and yield, which helps manage the grapevine's water use [87]. Agnew et al. (2005) reported that the timing of green pruning could be combined with cover crop management to modulate water dynamics in an intermediate scale between plot planning and irrigation scheduling [88]. However, this practice is costly because experienced personnel must carry it out.

As highlighted by Palliotti et al. (2014), canopy management can also be a fundamental agronomic practice that directly influences the microclimate on the vineyard locations while positively affecting the health of the plants, the quality of grapesand the yields as well [89,90]. Especially in ancient times, vine growers in the Mediterranean basin have used a particular pruning system, the Mediterranean goblet, resistant to drought (vines can be rain-fed with only 350 mm of rainfall per year) high temperatures. The goblet technique can be recognized as it shapes the plant such as an "inverted cone" with many variations (number of arms, opening angle, and branching) [91].

Unfortunately, this training system has been abandoned due to its inadequacy with the mechanization of the harvest; however, goblet pruning was inherited from the Romans and then widely used in Languedoc until the 1970s.

Row orientation is another fundamental basic strategy for water-scarce vineyard plantations: it is demonstrated that water efficiency increases while orienting the plant towards east-west lines, and the efficiency increases even more while adopting leaning canopies to west.

As extensively demonstrated by Hunter et al. (2017), row spacing is, also, an important factor to consider [92,93]. Tight row spaces augment the productivity and relative land utilization but requires more water. At the same time, vineyard resistance to drought can increase considerably, increasing the row spacing and reducing the number of plants per hectare [94,95].

These studies highlight that the vineyard planning before its plantation should consider these issues for solving problems related to water availability that could appear in the future; still, land tenure problems (ownership, use, lease) could conflict with solutions that are based only on the scientifical criteria.

4.2. Limits and Potentialities of This Study

Indeed, the physical evaluation of site examination cannot be entirely replaced by remote-sensed spatial GIS evaluations to address context-specific situations [96] but, at the scale of metropolitan city environmental planning, these remote assessments can support more efficient use of ecological resources according to the natural characteristics of the land thus, in the long term, achieving a less-vulnerable environment by reducing environmental conflict and enforcing the land use synergies. The most performative criteria for vineyard suitability should be extrapolated by comparing technological, analytical approaches to context-specific qualitative analysis. In any case, gathering qualitative data by interviews with local experts can always be a good approach to these analyses since their utilization can be positive, both for evaluating the final maps' reliability or weighting the layers [21]. The spatial detection of topographical suitability for grape plants can constitute an optimal basic knowledge for sustainable management practices, including the preservation and valorization of topographical, vegetational, and vineyard productivity in some selected areas. The general management of agricultural practices should be based on this context-specific knowledge and contribute to the protection of specific environments for qualitative grape productions and, in the long term, reduce the huge effects of the intensive agricultural management that threaten the local economy and impoverish the natural landscape.

Special protection and valorization zones (optimal areas of potential vineyard production) for certain agricultural productions such as the grape should constitute part of a new layer of the regional environmental plan of Izmir Metropolitan City that identifies the primary agricultural production zones for intensive management purposes and the remote peripheral hilly areas for extensive ago rural practices (e.g., definition of intensive plain irrigated farmland and identification of non-irrigated farmland with biodiverse local production). The latter regions are highly relevant for applying resilient strategies to cope with the dramatic effects of climate change, sustain local farmers, and improve remote villages' ecological and landscape quality.

5. Conclusions

The purpose of this study was to define a basic GIS analytical layer that indicates which parts of the Izmir Metropolitan Area present natural conditions that are favorable to sustainable vineyard cultivation. Unfortunately, most of the primary production, including vineyard cultivation, is massively concentrated on plain, fertile soils that are intensively used, fertilized, and irrigated while impoverishing the biodiversity of the Aegean promontory and emarginating the local farmers of peripheral areas to clustered communities with any relationship with local markets.

To better understand the existent predisposition of the landform for vineyard cultivation, this study employed five criteria (elevation, slope, aspect, land capability, and solar radiation) to determine which part of the İzmir Promontory can offer suitable conditions for vineyard cultivation. All the criteria were evaluated through spatial maps elaborated in a GIS environment, using publicly accessible and free databases. As already demonstrated by other similar publications (see Methodology and Discussion), the technical assessment is fully replicable in every part of the world while achieving a basic preliminary spatial knowledge of the land suitability for vineyards.

To avoid any potential bias in the overlay procedure, the layer superimposition has been aggregated by a Principal Component Analysis (PCA), and the extraction of the first three components has been used to define the land suitability. Once extracted, the suitability layer has been deeply analyzed in the Kozak Plateau catchment while adding some relevant considerations regarding the management of vineyards by sustainable practices. Within the research, we want to pave the road for other similar studies in Turkey or in areas where the growing consumption of vine requires some strategies for sustainable vineyard cultivation.

As already mentioned, the suitability assessment presented is fully replicable in another context, as it deals with input layers that can be easily downloaded and reproduced elsewhere. Besides, the final layer can support the decision-making processes that concern the rural management of local farmers in delicate ecosystems characterized by outstanding landscape quality and the presence of local traditions.

The idea is that proper tools should manage vineyard cultivation to avoid uncontrolled, water-dependent, and unsustainable development of the grapes in areas that are not favorable to this kind of cultivation. Land suitability can optimize the sustainable design of rural development strategies by reducing the water demand for new plantations and indicating which areas present natural conditions to host certain nature-positive productions.

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