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Identification of optimal and suitable sites for pistachio orchard replacement using spatial overlaying methods in GIS: A case study in West Azerbaijan, Iran

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ABSTRACT- Replacing regular high-water-consuming crops with tree species tolerant to salinity and drought, such as pistachio, has been suggested to reduce social and economic crises around Urmia Lake in the West Azerbaijan province of Iran, which has been negatively impacted by climate change and water resource mismanagement. In the current study, to determine suitable sites for pistachio production, the climatic requirements of the pistachio tree were determined, and relevant data, including a map of land use, soil type and limiting factors (salinity), average temperature, relative humidity, elevation, slope maps, and layers were collected from local meteorological and agriculture administrations. All data were prepared as grid surfaces and raster layers in GIS to produce digital layers of individual factors. A spatial overlaying analysis was used to assign weights to each variable in each layer cell, and finally, suitable sites were determined with overlay analysis. According to the results, there are potentially about 195 thousand hectares of relatively suitable areas in different regions of the province. However, considering the restricted water sources at the study site, it is recommended that the extension of pistachio orchards be targeted and timed based on maximizing profit and minimizing the use of water resources. Moreover, it should mainly focus on replacing worn-out and non-economical units and high water-demanding crops (approximately 30,000 hectares). To validate the results, all previously cultivated areas were collected and compared with targeted suitable regions, indicating that about 90.42% of pistachio orchards in the province are in suitable areas for pistachio cultivation. Buffer zone areas of Urmia Lake are among the most suitable areas. Eventually, the area under the Receiver Operating Characteristic curve related to observed fields was 0.92, which demonstrates high performance in targeting suitable areas.

INTRODUCTION

West Azerbaijan province, located in the northwest of Iran, plays an important role in the production of different agricultural crops, especially those with high water-demanding crops, and currently suffers from salinity, water shortage, drought, and other environmental crises due to the increasing adverse climate changes as well as the miss manipulation of land and water resources (Anonymous, 2014, 2012; Rezaee and Hessari, 2016). In response to these challenges, the Ministry of Agriculture Jihad has implemented a major policy to enhance resilience against climate change and adapt to water scarcity. This policy involves transitioning from crops requiring a high amount of water to those with lower water demands yet remaining economically viable. According to the comprehensive forecasting models of the World Meteorological Organization, by 2050, the earth's temperature will increase by 2–5 °C, depending on the region, and the production of some products will be decreased by 10–40%, especially at the lower latitudes due to the increased winter temperature, heat waves during the growing season, and increased water shortage and salinity (Sari Saraf et al., 2009, 2014; Rezaee and Taifeh Rezaee, 2013; Shahraki et al., 2023). The unique characteristics of the pistachio (Marino et al., 2018.) tree to adapt to extreme temperatures, water shortages, and soil and water salinity have made it the best alternative in climate change-affected regions in the country (Mehrnejad and Javanshah, 2010). Iran, with 347 thousand hectares of land under pistachio cultivation, currently occupies about 66% of the total land under pistachio cultivation in the world (Shahraki et al., 2023). Most of Iran's pistachio orchards are located at an altitude of 900-1200 meters above sea level and a latitude of 27-38 degrees north (Mehrnejad and Javanshah, 2010). Pistachio trees are frequently found in the southern parts of the West Azerbaijan province. Pistachios grew in some districts unsuitable for common fruit crops, and its cultivation area is increasing (Mostaan et al., 1992). Therefore, suitable site selection by considering factors including climatic parameters (temperature and relative humidity, soil and water resources and quality, market

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access, and the like) is a basic prerequisite in the process of fruit crop orchard establishment (Mehrnejad and Javanshah, 2010). The literature review on the environmental requirements of pistachio trees indicates that pistachio grows and yields well in a relatively wide range of climates, including subtropical and temperate climates. Large-scale pistachio cultivation has developed in regions where the temperature does not fall below -20 ˚C in winter and does not exceed 45 ˚C in summer (Abrishami, 1995). Despite the thermophilic character of the species, proper development and fruiting of popular pistachio cultivars require 750-1400 chilling hours at a temperature below 7 ˚C (Rahemi and Pakkish, 2009). Similar to the most temperate fruit trees, it is sensitive to late-spring cold and freezing temperatures (Mehrnejad and Javanshah, 2010). Heavy rains and the subsequent increase in relative humidity during flowering and/or harvesting time may also disrupt the pollination and development of fungal or bacterial diseases (Mehrnejad and Javanshah, 2010). Pistachio grows in most soils with different textures, so that its endurance and tolerance are better than those of other fruit trees in calcareous and saline soils (Abrishami, 1995). Climatic changes and increased water and soil salinity in all parts of Iran have made it impossible to produce temperate region fruits in large parts of Azerbaijan (Farajnia et al., 2021). Locating areas prone to producing agricultural and horticultural products using the geographic information system (GIS) is a highly efficient way to plan and manage land-use suitability mapping and analysis to prevent losses from trial-and-error problem-solving methods (Makhdoom et al., 2013; Mohammadi et al., 2016). Land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of a given project in wide varieties of urban and agricultural management (Malczewski, 2004; Ghasemi et al., 2011; Deliry and Uygucgil, 2020). GIS was successfully applied to determine suitable lands for different crops by several researchers worldwide (Azarm, 2010; Boonyanuphap et al., 2004; Everest, 2021).

The first step to establish pistachio orchards is to know the climate and soil conditions of the region. Appropriate altitude above sea level and favorable annual average temperature, ambient temperature during the growing season, appropriate ambient temperature at the time of pollination, and appropriate relative humidity at the time of pollination, as well as the availability of deep, loamy, sandy soils with lower water and soil electrical conductivity, and access to the market and services, are important factors for locating pistachio orchards (Mehrnejad and Javanshah, 2010; Martínez-Peña et al., 2023). Considering the high resistance of pistachios to salinity and drought, a huge demand for its growth has increased. Therefore, locating the areas with potential for pistachio production is important to keep pistachio production, create jobs and economic development, and prevent human migration. Spatial overlay methods involve combining multiple spatial layers (climatological grid surfaces) to create a new layer that represents the intersection, union, or other combinations of the original layers. As units of layers differ (e.g., temperature and precipitation, slope, topography, and the like) and some layers may be descriptive (e.g., land use layers), then scoring methods assign scores or weights to different criteria to evaluate suitability. Scoring methods help prioritize criteria and guide decision-making in site selection. Overlay is a powerful technique used in GIS that combines multiple layers of spatial data to create a composite suitability map. The process consists of defining the problem, identifying input layers (criteria) relevant to site selection, reclassifying each criterion into a common preference scale (e.g., 1-10), where 10 represents the most favorable condition, and assigning weights to each criterion based on its importance. Some criteria may be more critical than others. The process further encompasses multiplying the reclassified values by their corresponding weights and summing up the weighted values for each cell to create a composite suitability score. The resulting map demonstrates areas with higher suitability for the desired purpose (e.g., suitable locations for pistachio orchards). In summary, overlay methods with scoring are essential tools in GIS for assessing site suitability. They allow us to consider multiple factors simultaneously and make informed decisions about optimal locations for various purposes. The main aim of this study is to construct a geographical database of land suitability for pistachio and present the final map of suitable lands for local users and decision-makers.

MATERIALS AND METHODS

This study was performed in West Azerbaijan province, in the northwest of Iran. The study area covers approximately 37,400 square kilometers (not including Urmia Lake) and is geographically located at a latitude of 35º 58' to 39º 46' and a longitude of 44º 2' to 47º 24' (Fig. 1). The area mostly has a mean rainfall of 380 mm, and the mean number of rainy days is 15 in April. The average annual temperature in plains varies between 9.4 °C from Mako to 11.6 °C to Mahabad stations and sessional drought period is between May 8 and September 12. The topography consists of mountains in the northern part and flat lowlands with an altitude ranging from 1000 to 2100 m above sea level. The study area shows a different soil property. Among them, clay loam soil is dominant, with a pH value ranging from 7.9 to 8.5. In this research, based on the existing database of climate data and land resources from the province, information layers and their spatial analysis were prepared using the capabilities of the GIS. To collect data related to the theoretical part of the research, documents were reviewed, and relevant statistical information was collected from the databases of related organizations, including Meteorology, Water, Road, and Transportation, Agricultural Jihad Organization, and West Azerbaijan Governorate.

Multifactor spatial analysis by GIS was used to build a geographic database for locating potential areas, as described by Boonyanuphap et al. (2004). Eight factors and variables were selected based on the review literature and experts' opinion. Factors included access to the local market, distance to the road, soil type, height from sea level (altitude), land slope, average relative humidity, and average temperature during the growth season. Data on relative factors and variables were collected from West Azerbaijan agriculture, transportation, metrology stations, and governor administrations. The information was utilized to construct a geographical database using the GIS approach. The general flow chart of the study procedure is shown in Fig. 2. The location of the farms with pistachio cultivation during the study years was identified by using the global positioning system (GPS). Studying the spatial distribution pattern of important variables provides information about the current environmental situation in geographical regions (Ghasemi et al., 2011).

In addition, the weight of factors and variables was determined depending on the importance of each variable in comparison with the others in the same factor group as well as between environmental factors. The more important the factor or variable, the higher the weight. The weight and scores were mostly based on data obtained from previous studies (Hackett and Carolane, 1982; Griffiths, 1994) and discussions with regional officers.

The 2014 land use dataset was used to determine the restricted area for pistachio plantations. The restricted area was recorded as zero and was overlaid with a reclassified suitability dataset using multiple overlay operations to assess land suitability for pistachio plantations.

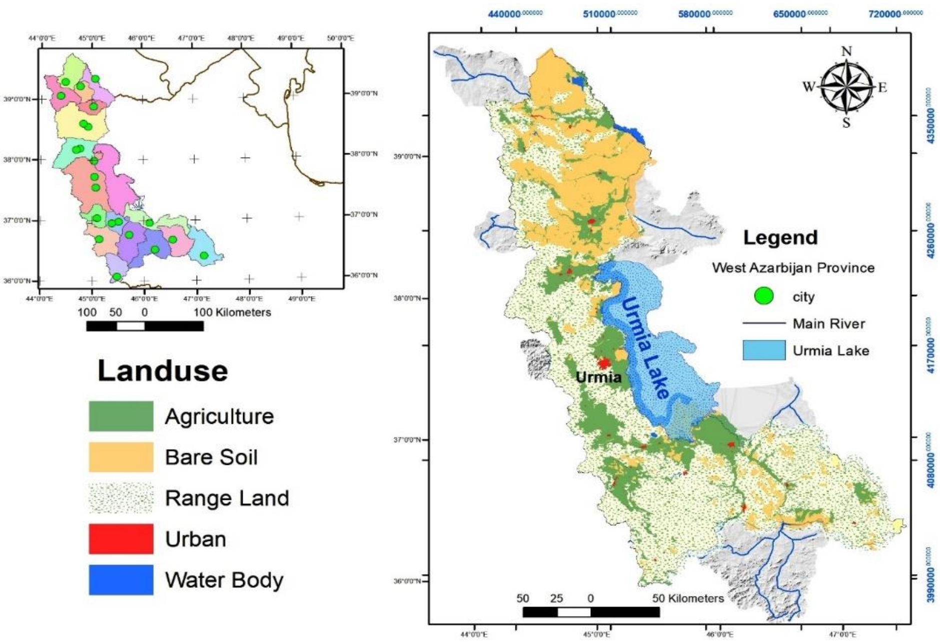

Fig. 1. Map of the study area, West Azerbaijan, northwest of Iran.

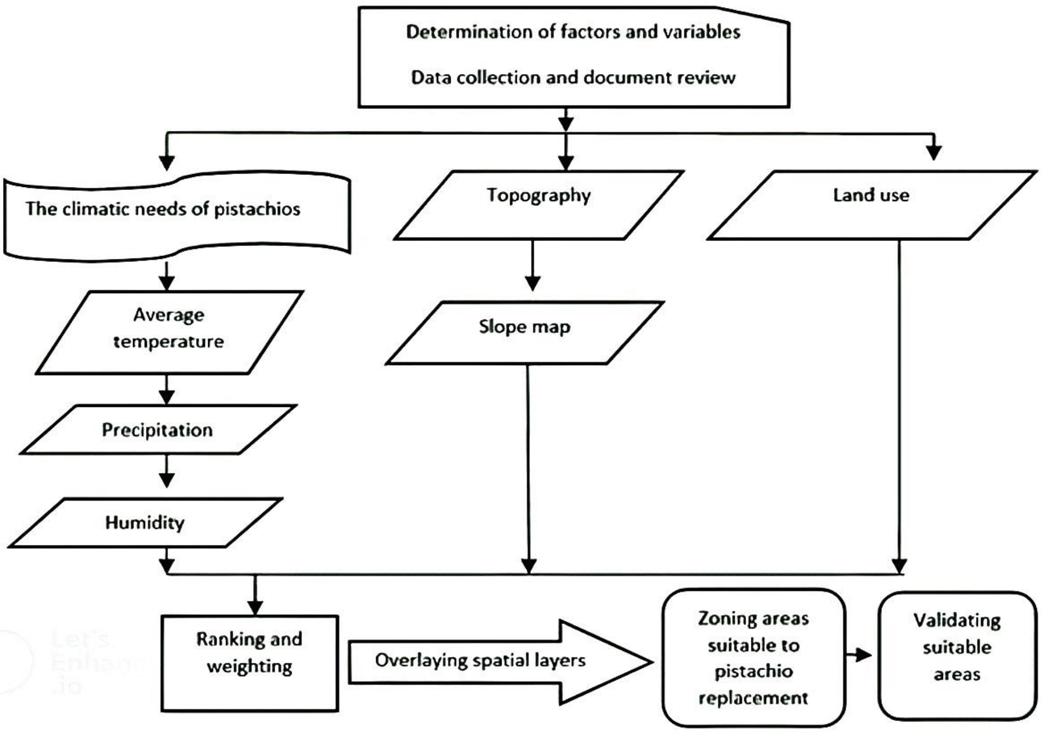

Fig. 2. General flowchart of the study procedure.

In terms of land use capability, information was acquired by the Agricultural Research Center of the province. This information layer specifies the province's lands in terms of their arable ability and soil properties. According to the procedure, rain-fed and irrigated agriculture fields, forests, pastures, bare lands, water surfaces and floodplains, saline lands, sand dunes, and residential areas were weighted and reclassified based on the pistachio requirement and local priorities with a scale of 2-8, as derived by experts' comments, with higher values indicating more suitable locations for pistachio orchards. The weight (score) of factors and variables was determined on the importance of each variable in comparison with the others (Table 1). The highest weight was devoted to the most important factor, and vice versa. All the scored variables were converted to raster-based datasets with a 200-meter grid cell size. The variables in each factor were overlaid together to build new datasets on the environmental suitability of each factor. The grid cell in each dataset contained the suitable value related to the factor, with the higher value being more suitable. Each factor was classified into 4 levels of suitability, including non-suitable (N1), relatively suitable (S3), moderately suitable (S2), and highly suitable (S1). The land use dataset in 2018 was used to determine the restricted area. The restricted area was recorded as zero and was overlaid with a reclassified suitability dataset using multiple overlay operations to assess land suitability for pistachio plantations. For validation of the maps, the current lands under pistachio cultivation were determined by during a field survey in 2018, the global positioning system was compared with targeted, suitable areas. The receiver operating characteristic (ROC) curve was utilized for the validation of location recognition results. The area under the ROC curve (AUC) is a metric that quantifies the overall performance of a binary classification model (Mas et al., 2013). The ROC curve is created by plotting the true positive rate (TPR; observed points) against the false positive rate (FPR) at various threshold settings. The AUC is a metric that quantifies the overall performance of a binary classification model. It represents the probability that the classifier will rank a randomly chosen positive instance higher than a randomly chosen negative instance. The AUC ranges from 0 to 1, where a higher value indicates better performance.

RESULTS AND DISCUSSION

In the first stage, suitability was assessed in terms of temperature since the temperature trends of a given region play an essential role in selection of species for commercial cultivation and/or the planning of protection measures (Hessari, 2013). Several studies have reported that pistachio is a plant resistant to low or high temperatures that can withstand a wide range of temperatures. The absolute minimum temperature of Urmia (-22.8 ˚C) is not much different compared to the pistachio-growing areas of the country, such as Kerman (-30 ˚C) and Birjand (-21.5 ˚C), but the average minimum temperature of the selected sites of the province is somewhat different. The average annual temperature in Iran's main pistachio-producing center is 10-15 ˚C (Mostaan et al., 1992). According to the database, the average annual temperature in the study site demonstrated a significant difference across the region, indicating that about 20% of the studied area has an average-temperature relatively suitable condition for pistachio cultivation, especially in Poldasht, Sardasht, Miandoab, Urmia, and Salmas (Fig. 3). Climatic factors, especially temperature, are decisive for pistachio production and should receive particular attention (Łysiak et al., 2023). The significant temperature difference between the study site and Iran's most important pistachio-producing sites indicates that pistachio cultivation in the study site would suffer from winter and spring frosts, and its cultivation should be accompanied by insurance coverage and all necessary measures to protect young trees (Sari Saraf et al., 2009). Frequent spring frosts were also reported in pistachio orchards, even in the major pistachio-producing sites in Iran and other countries (Hessari, 2013). In terms of chilling requirements, pistachio trees need an average of 700-1400 hours of temperature below 7 ˚C, depending on the pistachio variety (Rahemi and Pakkish, 2009). The analysis of minimum temperature from November to April in different stations of the province (data are not available) implies that the chilling requirement of pistachio could not be a serious problem because of its availability up to 1500-1700 hours throughout the region; therefore, a related map layer was not prepared for the rest of the study. Ambient relative humidity is another important environmental factor that must be considered in pistachio cultivation, as its higher rates may interfere with flowering, pollination, fruit growth, ripening, and harvesting time (Khayatzadeh, 2005). The ambient relative humidity of $< 35\%$ was reported to be favorable for pistachio trees, especially for efficient wind pollination and good fruit set, as well as the nut ripening process (Mostaan et al., 1992). According to the results, the study site's average relative humidity differed throughout the site, and the majority of the region had a humidity range between 40% and 50%. The average relative humidity was favorable in the central and northwestern parts compared to the south of the studied area (Fig. 3). In general, establishing pistachio orchards should be accompanied by applying good orchard practices, orchard floor management, drip irrigation, and on-time orchard monitoring to keep the relative humidity of the orchard at a low level.

The land slope is one of the most essential physiographic aspects effective for selecting the types of crops in any range of the slope. Considering that lands with a slope of more than 8% are prone to temperate fruit trees, in this research, lands with a slope of only 0-8% were selected for pistachio cultivation. The prepared slope map indicates that about 55% of the studied area, especially the parts around the lake, has a slope between 0% and 8% (Fig. 4), which is suitable for pistachio orchards. Altitude is one of the important physiographic factors that affects the cultivation of pistachio. The most important effects of the increase in altitude, including a decrease in temperature, a shortening of the growth season, and an increase in rainfall and humidity, could interfere with the normal process of tree growth and development (Hessari, 2013). The extent of the altitude compatibility of pistachio is relatively wide; it has been cultivated in the altitude range of 100-2500 meters above sea level, depending on the geographical latitude (Farajnia et al., 2021). Considering the higher latitude of the studied area compared to the central part of Iran, an altitude range lower than 1,300 m was considered suitable for this study. Based on the prepared map (Fig. 4), more than 688,000 hectares (green areas on the map) of the lands located in the plains of the province are suitable areas for pistachio cultivation in terms of altitude (less than 1,300 meters above sea level) and slope (Hessari, 2016).

Table 1. Factors and their weight, thresholds, and relevant scores used in this study

Factor	Weight	Threshold	Score
Access to market	4	Km to the city (< 10, 10-25, 25-35, and > 35)	(8, 6, 4, and 2)*
Access to services	4	Km to the roads (< 1, 1-5, 5-10, and > 10	(8, 6, 4, and 2)
Access to irrigation	4	Km to the rivers (< 0.5, 0.5-1, 1-1.5, and > 1.5	(8, 6, 4, and 2)
Mean temperature	3	Degree Celsius (> 15, 10-15, 5-10, and < 5)	(8, 6, 4, and 2)
Mean precipitation	3	mm (< 300, > 500, 400-500, and 300-400)	(8, 6, 4, and 2)
Soil type	3	Soil type series (4.1-5-2, 3.1-3.2, 2.1-2.3, and 1.1-1.3)**	(8, 6, 4, and 2)
Topography	4	m above sea level (< 1100, 1100-1300, 1300-1500, and > 1500	(8, 6, 4, and 2)
Land slope	4	% (0-8, 8-20, 20-30, and > 30)	(8, 6, 4, and 2)

* Numbers 8, 6, 4, and 2 indicate highly, moderately, relatively, and non-suitable classes in each criterion, respectively.

** The 4.1-5.2 series are first-class soils with sufficient depth and loamy texture without any serious restrictions. In addition, the 3.1-3.2 soil series includes medium classed mostly clay, shallow with poor drainage, 2.1-2.2 series is mostly sandy or rocky with shallow depth, and 1.1-1.3 soils are third-class soils with serious restriction in depth, texture, and salinity.

(a) (b)

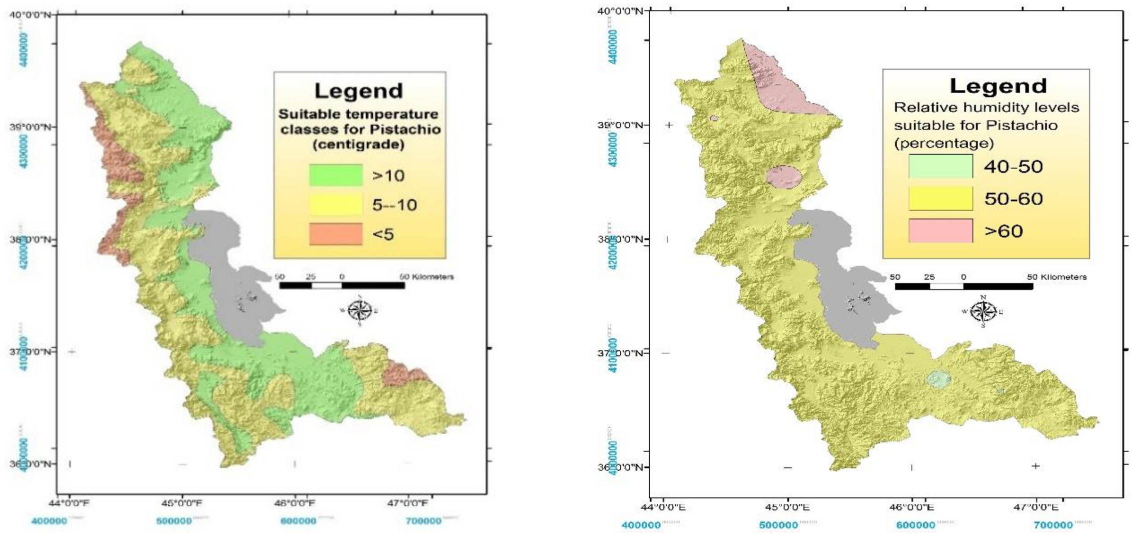

Fig. 3. The suitability map based on a single factor: (a) temperature and (b) relative humidity.

(a) (b)

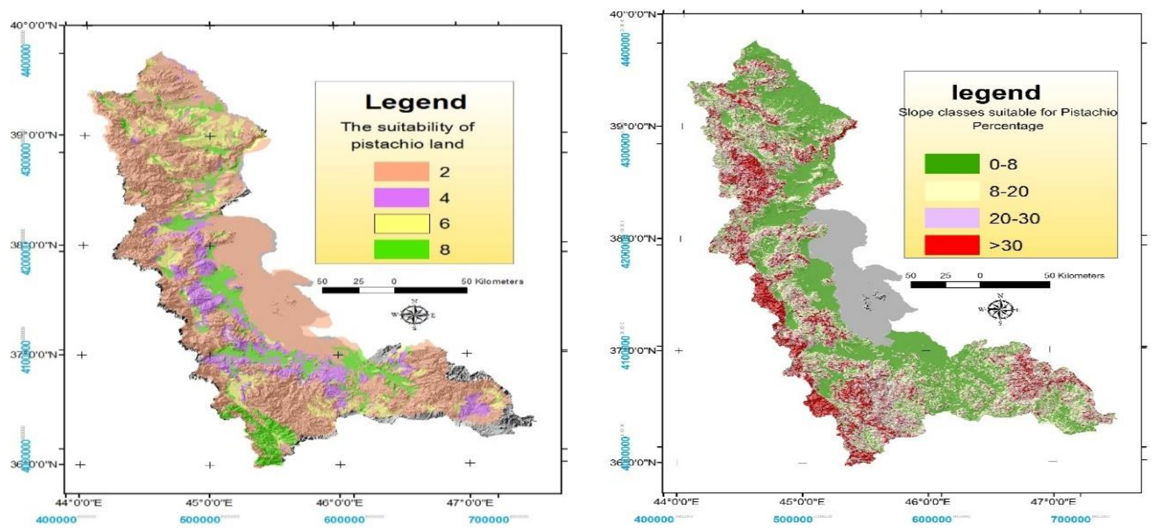

Fig. 4. Suitability map based on a single factor: (a) land capability and (b) land slope.

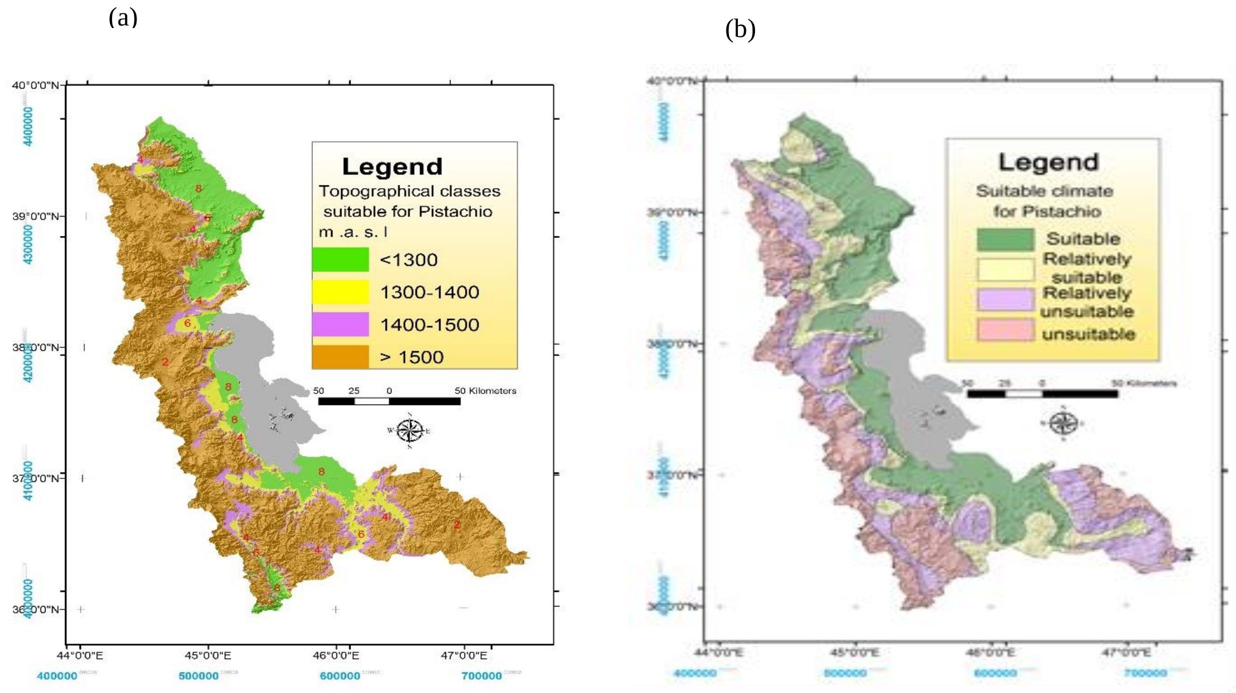

Fig. 5. Suitability map based on single factor: (a) topography and (b) climatic suitability.

Considering the mutual effects of altitude and land slope on the growth of pistachio trees, the integration of altitude and slope data is essential since it can provide more accurate information about the land suitability. These two factors determine the cultivation and mechanization policy of the farm and the degree of accessibility and flooding, and secondary changes in soil conditions and erosion patterns (Hessari, 2013). Climate is one of the most important environmental components that can increase the ability to produce agricultural products in a region. In the present research, average annual temperature, precipitation, and relative humidity were considered the main constituents of climate, and the relevant map was drawn accordingly (Fig. 5).

A map of the land suitable for pistachio cultivation was prepared and drawn based on the land use information and soil capability databases (Fig. 6). According to the prepared map, the northern and northeastern regions, and the central plains of the province are suitable. In addition, the southern areas of the province are medium, and the northern foothills of the province are unsuitable.

Combining climate and land use maps determined that from about 1,100,000 hectares of land in the province, 430,000 gross hectares (in terms of climate) are present for pistachio cultivation at two relatively suitable and moderately suitable classes throughout the province. To prepare the final suitable map for pistachio cultivation, the land use map, including restricted areas such as pastures and residential and urban areas, was overlaid on the climate map (Fig. 6). According to the final map, there are no highly suitable classes for pistachio production in the study area due to the presence of one or more limiting factors; however, there are about 195,000 hectares of relatively suitable land (18% of the province's land) are located in the various domains all around the study area, including Miandoab, Mahabad, Naghadeh, Urmia, Khoi, Salmas, Poldasht, and Chaipareh. These lands are currently under the cultivation of different warn-out farms or garden crops with high and uneconomical water requirements and could be replaced with pistachio. For validation of the results, all previously cultivated areas were collected as observed points and compared with suitable targeted areas (Fig. 6). The ROC curve was used for validation of location recognition results. It is a graphical plot that illustrates the performance of a binary classifier system, as its discrimination threshold is different. The ROC curve is created by plotting the TPR (observed points) against the FPR at various threshold settings. The AUC is a metric that quantifies the overall performance of a binary classification model. It represents the probability that the classifier will rank a randomly chosen positive instance higher than a randomly chosen negative instance. The AUC ranges from 0 to 1, where a higher value indicates better performance. An AUC of 0.5 suggests that the model has no discrimination ability, while an AUC of 1 demonstrates a perfect classifier. In summary, the ROC curve visually represents a classifier's performance, and the AUC provides a single numerical value to evaluate its overall effectiveness. The ROC curve, plots the TPR against the FPR at various threshold settings. However, the TPR and FPR can be calculated using the following equations:

True positive rate = True positives / (True positives + False negatives) Eq. (1)

False positive rate = False positives / (False positives + True negatives) Eq. (2)

This research drew the ROC curve of the observed pistachio against location recognition classes with the ARCSDM toolbox (Mas et al., 2013) (Fig. 6). As shown in Fig. 7, the AUC of the observed fields is 0.92, showing a high level of accuracy in the model's ability to distinguish between positive and negative cases.

(a) (b)

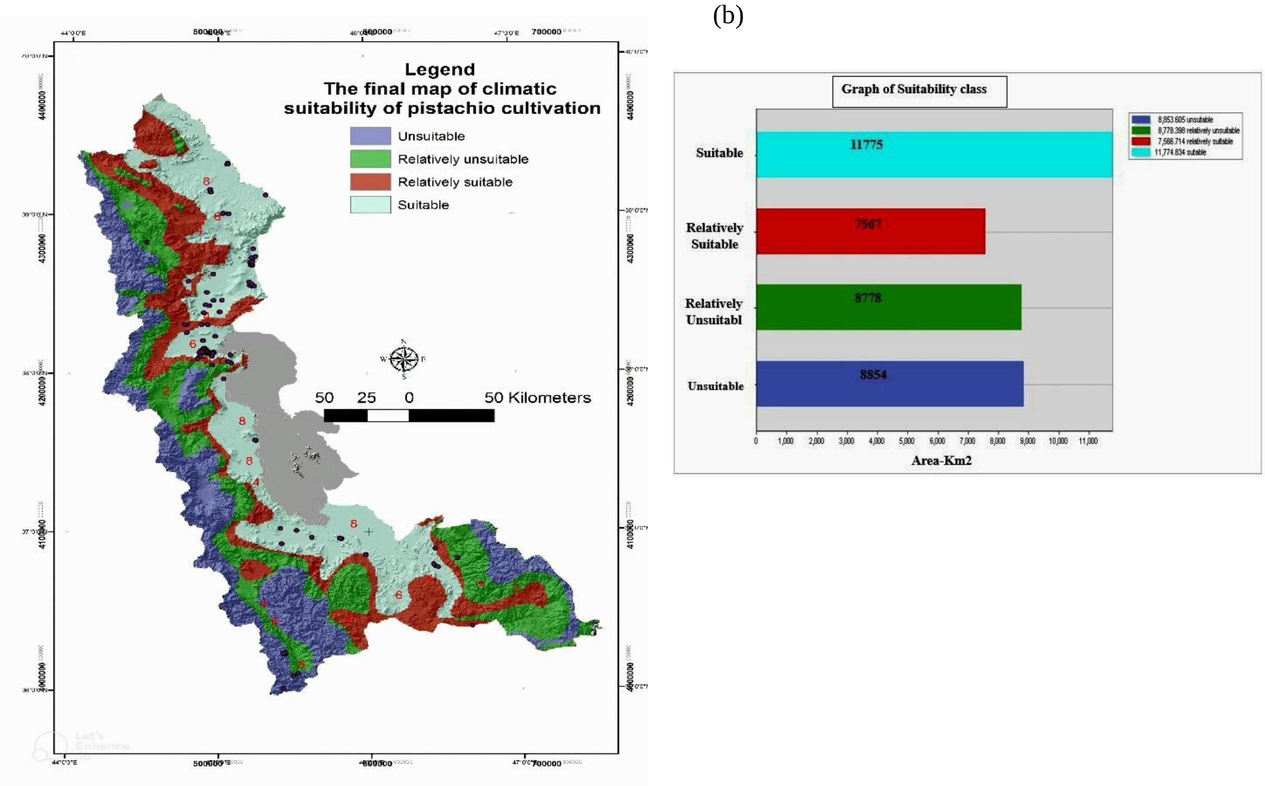

Fig. 6. The final map of (a) the climatic suitability of pistachio cultivation and (b)area histogram of each class in km^2.

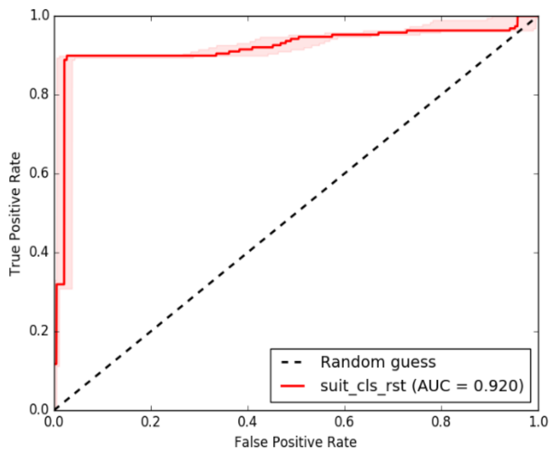

Fig. 7. The Receiver Operating Characteristic (ROC) curve of the observed fields of pistachio.

Mercan and Acibuca (2023) presented a comprehensive, data-driven approach to identify optimal sites for pistachio orchards in the Southeastern Anatolia region of Turkey. Their study contrasts with more traditional site selection methods that tend to be limited in scope, considering only a narrow set of factors. The accuracy of this map is validated through the ROC curve analysis, which yields an AUC value of 0.806, indicating a strong predictive capability. The findings of this study confirm and complement your own research in this area, providing an additional layer of insight and validation for identifying optimal sites for pistachio cultivation in the Southeastern Anatolia region.

This investigation suggested a climatological assessment, which provides information at a regional level that could be valuable for farmers in selecting their crop patterns. The insights from this approach can inform decision-making regarding appropriate crop choices but should be considered alongside other important factors.

Beyond the climatological suitability analysis, farmers and policy-makers should also weigh production supports, marketing opportunities, technological capabilities, and economic feasibility when determining optimal crop patterns. Local customs and traditional practices are also highly relevant and should be factored into decision-making (Ceballos-Silva and Lopez-Blanco, 2003).

This research had some limitations. The lack of rich, detailed maps of land use, local soil profiles, soil quality, and detailed soil texture data limits the pistachio suitability map generated in this study.

CONCLUSION

In general, the agricultural sector of the West Azerbaijan province is expected to be increasingly vulnerable due to the intensifying occurrence and severity of extreme events under climate change conditions. The findings revealed that there are potentially about 195 thousand hectares of relatively suitable area in different regions of the province. However, considering the restricted water sources in the study site, it is recommended that the extension of pistachio orchards be targeted and timed based on maximizing profit and minimizing the use of water resources and should be mainly focused on in order to replace worn-out and non-economical units, especially high water-demanding crops (about 30,000 hectares). Detailed studies on the soil biophysical properties as well as the behavior of different pistachio cultivars/rootstocks, intercropping with other early-return and tolerant crops, such as barberry and jujube, are necessary before starting establishment at each site. Although there is possibly a wide range of suitable areas to extend pistachio orchards in the study site, priorities should be given to the central area, which was adversely affected by climate change. The obtained results can be the basis for a more reliable decision by the planners of the agricultural sector to provide a new cultivation pattern and orchard revitalization programs.

Farmers and regional planners can develop a more holistic and well-informed strategy for crop selection and land use by integrating the climatological evaluation with other agronomic, economic, and social considerations. The climatological data provide a foundational understanding of environmental suitability but should be combined with the analysis of the broader production and market context to arrive at crop choices that are both ecologically suitable and economically viable for local communities.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Reza Rezaee, Behzad Hessari, and Faezeh Jahangiri. All authors read and approved the final manuscript.

DECLARATION OF COMPETING INTEREST

The authors of this paper declared no conflict of interest regarding the authorship or publication of this article.

ETHICAL STATEMENT

Our research was conducted in accordance with ethical standards, ensuring the integrity and confidentiality of all participants.

DATA AVAILABILITY

Data can be sent by email from the corresponding author upon request.

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