



Determination of suitable lands for rice cultivation in Edirne plain: GIS supported FAO limitation method

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Abstract

Concerns about the future of agricultural production and food security in recent years have increased the importance of agricultural land evaluation assessment studies for different agricultural products. Performing studies using geographical information systems (GIS) techniques provides faster and more reliable results than traditional techniques. Given that, regional studies for land suitability assessment to improve product quality have gained momentum. In this study, we aimed to evaluate the land suitability for paddy cultivation in Edirne Plain, where most rice farming cultivation occur in Turkey. To achieve this, we used GIS-supported Food and Agriculture Organization limitation method. The study model is established based on 5 m high-resolution spatial data and the analysis of land quality indexes that affect paddy cultivation, such as Nutrient Elements Availability Index, Soil Quality Index, Climate Quality Index, Irrigation Quality Index, Socio-economic Quality Index and (Agricultural Mechanization Quality Index). The results indicated that 25.41% of Edirne Plain is highly suitable, 53.85% is moderately suitable, 15.93% marginally suitable, and 4.81% unsuitable for paddy cultivation. It was determined that the current paddy cultivation area is far below its potential. Although 79.26% of the study area is suitable for rice cultivation, only 16.90% of the area is currently used as paddy farming which means 62.36% of potential rice cultivation area is not used as its potential. The findings of the present study are essential particularly for local administrators and policy makers to use the available land resources effectively for sustainable agricultural production. The present study points to an important direction for future research and contributes to regional managers and policymakers to better understand rice cultivation and planning accordingly in the region.

Keywords Land suitability · Land evaluation · Land use classification · FAO framework

Introduction

Agriculture is one of the most important sectors that meet the food needs of the increasing population across the world with limited natural resources (Yao et al. 2017). Global problems such as land and soil degradation caused by improper or excessive use of land has increase the pressure on agricultural areas and threaten the sustainability of agricultural systems (FAO 2019). Furthermore, Global Climate Changes may affect paddy cultivation significantly (Watanabe and Kume 2009). These problems cause low yield in the agricultural products and consequently lead to food scarcity. To minimize such threats, land suitability assessment studies have been increasingly used for agricultural areas (Kahsay et al. 2018). Some of these studies specifically focus on the cultivation of grains such as rice, wheat, and corn, which are considered as the main food sources of the world population (Ujoh et al. 2019).

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Rice (*Oryza sativa* L.) is one of the oldest known cereals in the world and is the main staple food of about half of the population on earth (Amini et al. 2020). The demand for rice, which has the largest cultivation area after wheat (Horuz and Dengiz 2018), is increasing rapidly (Nguyen and Ferrero 2006). For that reason, land suitability assessments are widely used to determine the most suitable areas for paddy cultivation in terms of adequate and quality food supply (Maddahi et al. 2017).

Land suitability assessment is one of the most preferred methods to support land use management as well as an integral part of sustainable land use planning (FAO 2017). Given that, land suitability assessment studies on various agricultural products have gained momentum in recent years (Kong et al. 2016; Jahanshiri et al. 2020). To evaluate the land suitability; geographical information systems (GIS) supported land suitability evaluation method (FAO 1976), Storie index (Storie 1978), Limitation method (FAO 1979), Square root method (Khiddir 1986), Parametric method (Sys et al. 1991) and Multi-criteria analysis (Nguyen et al. 2015) approaches are widely used (El Baroudy 2016; Vasu et al. 2018; El Baroudy et al. 2020). However, the limitation method, which takes account of all the factors necessary for optimum use, is generally preferred worldwide in land suitability assessment studies for paddy cultivation (Bojórquez-Tapia et al. 2001; Elsheikh et al. 2013; Feizizadeh and Blaschke 2013; Ghazanchaai and Fariabi 2014; Appiah et al. 2015). Land suitability assessment studies were conducted for paddy cultivation in important plains such as Lower Namhong Plain (Mongkolsawat et al. 2002), Bafra Plain (Dengiz et al. 2010; Sezer and Dengiz 2014; Özkan et al. 2019), Çankırı-Kızilirmak Plain (Dengiz 2013); Haraz Plains (Maddahi et al. 2014), Hayrabolu Plain (Özşahin 2016), Kumkale Plain (Everest and Özcan 2016), Teesta and Dharla Plains (Islam et al. 2018), Nile delta plain (El Baroudy 2016) and Çarşamba Plain (Dengiz and Özyazıcı 2018; Dengiz 2020). These studies were carried out using GIS-based techniques and obtained successful results (Darwish et al. 2006; Mokarram and Aminzadeh 2010; El Baroudy 2011; Hamzeh et al. 2014; Mishelia and Zirra 2015). The spatial analysis offers advantageous conditions in terms of determining the most suitable areas for paddy cultivation (Dengiz and Özyazıcı 2018) and using natural resources efficiently (Özşahin 2016).

Rice is one of the most cultivated grains in Turkey (Akay 2020). Furthermore, Edirne Plain in the Thrace Peninsula is one of the most important areas in terms of paddy cultivation in Turkey (Surek 1997). Although more than 40% of the country's rice is produced in Edirne Plain, to our best of knowledge, no land suitability assessment in such scale and resolution has been conducted in this area in such scale and resolution. A limited number of studies have examined land suitability assessment for paddy cultivation around the study area have used different methods with low-resolution data

and different scales. In the present study a spatial resolution of 5 m is used to eliminate the resolution-based problems. In this regard, up-to-date data and modern techniques are used depending on the convenience and availability of technological tools and software. In addition, in the previous studies mostly NEAI and SQI quality parameters were used. However, the number of studies using CQI, SEQI, IQI and AMQI quality parameters is very limited. In the present study, all potential parameters identified based on the previous literature are added to increase the reliability of the model.

The present study aims to (1) precisely determine and classify the suitable areas for paddy cultivation and (2) create supportive material and data for agricultural planning by revealing the potentially new paddy cultivation areas of agricultural lands in Edirne Plain. Reaching these aims is critical to generate a universally accepted model that could be applied on areas within similar geographic conditions.

Material and method

Study area

The study area is Edirne Plain located on the Thrace Peninsula. It is located in the Lower Maritsa (Meriç) Basin between 40° 35' 32.492" and 41° 55' 35.612" N latitudes and 26° 02' 15.299"–26° 55' 38.187" E longitudes. The study area is in the northwest corner of Turkey, bordering Greece and Bulgaria. This plain, which has fertile agricultural lands, is often referred to as “the homeland of rice”, “the land of paddy” and “the capital of rice” (Güney et al. 2012).

Geologically, the study area, which consists of Quaternary aged alluvial deposits, is bordered by the Strandja Massif to the north and northeast, the Thrace Tertiary Basin to the east and the Rhodope Massif to the west. The study area was shaped on the Thrace Basin, which started to open under the extensional tectonic regime from the Tertiary period and emerged with the sedimentation process that took place in the Quaternary (MTA 2006).

Erosive activities of the Maritza River and its tributaries eroded and accumulated materials from the surrounding high areas to shape the Edirne Plain. The average elevation is about 100 m and the altitude gradually increases towards the Strandja Mountains (Fig. 1).

Sub-humid Mediterranean climate is observed in the coastal areas and semi-arid and sub-humid continental climate characteristics are observed in the interior areas. The average annual precipitation is 602.8 mm (1950–2020) in the study area and the annual average temperature is 13.6 °C (MGM 2021). The most significant rivers in the area are the Maritza River and the Ergene River. Maritza River is a trans-boundary river of Eastern Europe and the Balkan Peninsula

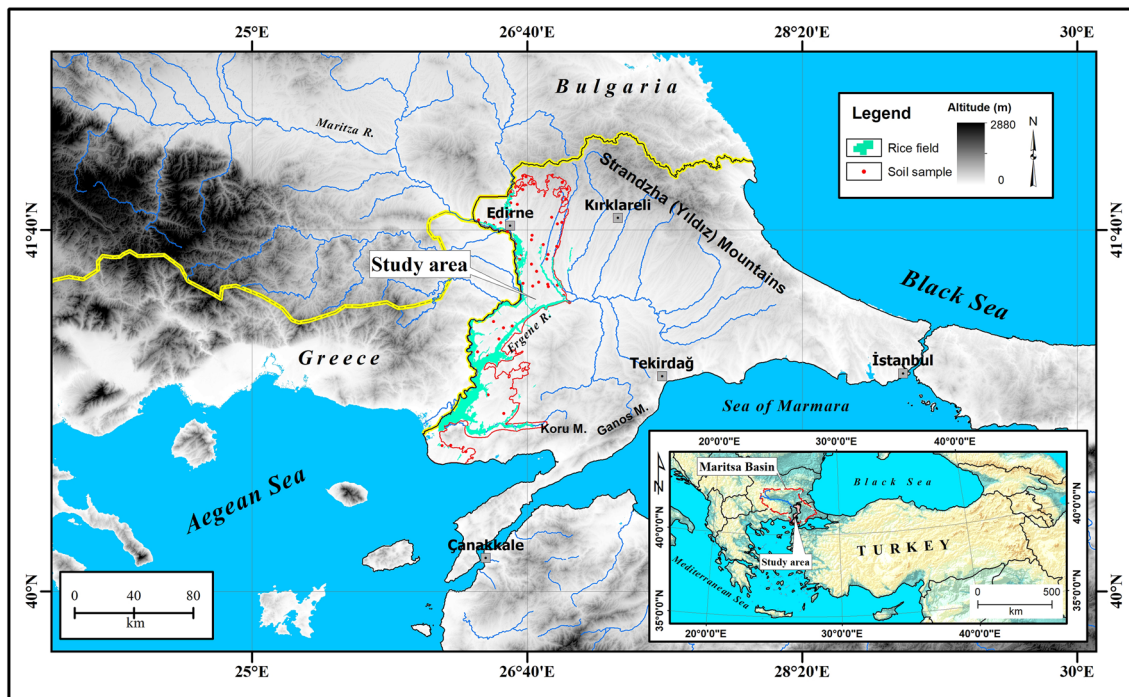


Fig. 1 Location of the study area

while the Ergene River is the most significant tributary of Maritza River (Özşahin et al. 2018).

The soil moisture regime in the study area was determined as Xeric and the soil temperature regime as Thermic. According to the Soil Taxonomy of United States Department of Agriculture (USDA), the soil series are grouped under 5 orders: Entisol, Vertisol, Inceptisol, Alfisol, and Mollisol (Çarpik 1998; Soil Survey Staff 2014).

Materials

Main mapping and modeling analyses were conducted by using high-resolution (5 m) digital elevation model (DEM) data obtained from the Turkey General Directorate of Mapping (HGM 2015). Land quality parameters for rice farming, which constitute the second-degree dataset of the study, were also produced at the same spatial resolution with the scale fixation method (Oh et al. 2017; Pirasteh and Li 2017).

The factor maps of Nutrient Element Availability Index (NEAI) and Soil Quality Index (SQI) parameters were obtained by analyzing 85 soil samples from 0 to 30 cm depth from a randomly selected points that represents the study area. The location and the number of soil samples were determined by considering the local conditions (geology, landforms, land use, and total surface area) affecting the soil properties in the study area and the resolution of

the input dataset (Hazelton and Murphy 2016). The plant nutrients, physical, and chemical properties of these samples were analyzed in the soil laboratory.

Factor maps of the Climate Quality Index (CQI) parameter, data derived by the spatial distribution of the measurement results (Yıldız 2021) using the Inverse Distance Weighting (IDW) interpolation method (MGM 2021). The raw data was obtained from long-term (1950–2020) meteorological observation records of the Ministry of Agriculture and Forestry General Directorate of Meteorology. Factor maps of the Irrigation Quality Index (IQI) parameter were created using the data obtained from the Hydraulic Works and Irrigation Enterprises in Edirne Province (DSI 2020). The Socio-Economic Quality Index (SEQI) and Agricultural Mechanization Quality Index (AMQI) parameters were obtained from the published reports, data, and statistics by Crop Production Statistics of Edirne Province (CKS) and Turkish Statistics Institute (TUIK). Furthermore, a yield map of crops was created by using data obtained from TUIK and CKS (CKS 2021; TUIK 2021) for validation purposes. In addition, land use and land cover (LULC) data were obtained from the CORINE Land Cover (CLC) system to compare and validate the current and potential uses in the land suitability assessment (EEA 2020). Thus, datasets obtained from mentioned sources were processed using GIS techniques on the ArcGIS version 10.8 (Table 1).

Table 1 Datasets and data types used in the study

| Nos. | Data | Derivation | Source |
|------|--|-------------------------------|---------------------------|
| 1 | DEM (5 m) | Main data frame, basemap | HGM (2015) |
| 2 | Soil samples (Total: 85) | NAI | Fieldwork Lab analysis |
| 3 | Soil map (1:25,000) | SQI | Çarpık (1998) |
| 4 | Meteorological observations data (1950–2020) | CQI | MGM (2021) |
| 5 | Agricultural water resources datas | IQI | DSI (2020) |
| 6 | Socio-Economic datas | SEQI | CKS (2021) |
| 7 | Agricultural mechanization datas | AMQI | and TUIK (2021) |
| 8 | Rice yield (kg/decare) | Crop yield map | |
| 9 | Corine Land Cover (CLC) 2018 (Type: Vector, Format: ESRI Geodatabase, Version: v2020_20u1) | Rice fields, LULC classes map | EEA (2020) |

Methods

Scaling

Factor ratios of land quality parameters for paddy farming were determined. For this purpose, weight values between 0 and 1 were assigned to the diagnostic factors and land quality parameters that control land suitability for agriculture (Table 2). Scaling between 0 (least suitable) and 1 (very suitable) was applied according to the degree of importance for paddy cultivation (Montgomery et al. 2016) and the relevant literature (FAO 1983, 1985; Sys et al. 1993; Mongkol-sawat et al. 2002; Dengiz 2013). These factors control the parameters of the land quality for optimum paddy cultivation (Sürek 2002; Kihoro et al. 2013; Özşahin 2016).

Land quality parameters

Land quality parameters and diagnostic factors used in this study were combined according to land suitability characteristics for paddy cultivation (Fig. 2).

Nutrient Element Availability Index (NEAI): The presence of all necessary nutrients in the soil for paddy cultivation is the most important factor in terms of land suitability (Sürek 2002). That is the most suitable areas for paddy cultivation in terms of NEAI diagnostic factors in the study area are the places where the soil is rich in N, P, K, Zn, Fe, Mn and Ca plant nutrients. On the other hand, both land suitability and yield are low in areas where the soil is poor in terms of nutrition (Horuz et al. 2013).

Soil Quality Index (SQI): Paddy is not a very selective plant in terms of soil type and so it can be cultivated in a wide variety of soils (Sürek 2002). However, in areas where the soil is misused and degraded by unsustainable agricultural practices, the soil may not be suitable for rice cultivation either. In the study area, the most suitable areas for paddy cultivation in terms of SQI diagnostic factors are the areas where the hydraulic conductivity, lime, the soil

reaction are low, and the soil is rich in organic matter with deep and heavy texture. Paddy cultivation is generally more productive in poorly drained areas on low-slope or flatlands (Özşahin 2016).

Climate Quality Index (CQI): Rice is a cereal species that typically grown in tropical and subtropical climates (Amini et al. 2020). The study area is predominantly under the influence of Mediterranean climate characteristics and has climatic conditions suitable for paddy cultivation (Eroğlu et al. 2018). In the study area, paddy is typically grown between April and October (Sürek 2002). In this respect, the most suitable areas for rice farming in terms of CQI diagnostic factors are the areas where the temperature is between 15 and 30 °C during the growing period, where solar radiation, precipitation, and humidity conditions are optimal (Peşkirioğlu et al. 2013). Although the study area has suitable conditions for rice cultivation in terms of temperature, it is insufficient in terms of precipitation amount. Therefore, paddy cultivation in the study area is applied via irrigation (Sürek 2002).

Irrigation Quality Index (IQI): Irrigation conditions affect plant physiology and soil properties. Accordingly, efforts to increase the efficiency of existing irrigation systems have attracted much attention recently. As a solution to the irrigation problems, water reuse has been studied in Taiwan and in other countries (Fan et al. 2013). In the study area, IQI has very critical importance in terms of paddy cultivation, as it requires marshy and very humid conditions (Sürek 2002). For this reason, the supply and management of irrigation water have been considered as the main factor limiting paddy cultivation (Meral and Temizel 2006). Paddy cultivation in the study area is generally implemented with a continuous irrigation method, which consumes approximately 1800–2000 mm of water (Sürek 2002). Therefore, in terms of climate conditions, it is very important to provide sufficient irrigation water in the study area in the dry period. In this respect, areas close to surface water, irrigation channels, and dams are the most suitable areas for paddy cultivation.

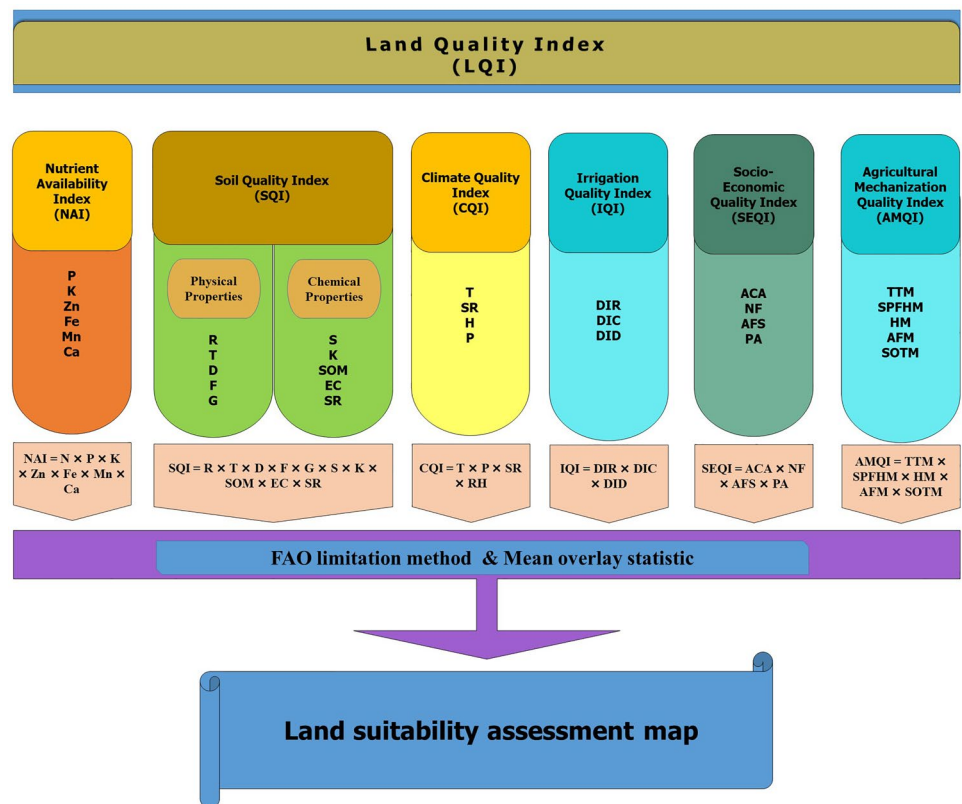
Table 2 Land quality parameters and scaling of diagnostic factors for paddy cultivation

| Land quality parameters (LQI) | | | | | | References | |
|--|---------------------|----------------------|--------------------|--------------------|----------------|--|---|
| Factor rating | | | | | | | |
| Diagnostic factor | Unit | 1.0 | 0.75 | 0.50 | 0.25 | | |
| <i>Nutrient Availability Index (NAI)</i> | | | | | | FAO (1985), Olaleye et al. (2008), Maddahi et al. (2017), Dengiz (2013, 2020) | |
| N | % | >–0.3 | 0.3–0.2 | 0.2–0.1 | 0.1–< | | |
| P | ppm | >–50 | 50–25 | 25–10 | 10–< | | |
| K | ppm | >–60 | 60–45 | 45–30 | 30–< | | |
| Zn | ppm | >–0.7 | 0.7–0.6 | 0.6–0.5 | 0.5–< | | |
| Fe | ppm | >–60 | 60–45 | 45–30 | 30–< | | |
| Mn | ppm | >–60 | 60–45 | 45–30 | 30–< | | |
| Ca | ppm | >–1000 | 1000–750 | 750–500 | 500–< | | |
| <i>Soil Quality Index (SQI)</i> | | | | | | FAO (1985), Ayehu and Besufekad (2015), Maddahi et al. (2017), Ujoh et al. (2019), Dengiz (2013, 2020) | |
| Drainage (R) | | Very poor | Poor | Moderately good | Good/excessive | | |
| Texture (T) | % | CL, SiCL, SiL, C, SC | L, SCL, SiC | Si, SL | S, LS | | |
| Depth (D) | cm | >–50 | 50–25 | 25–15 | 15–< | | |
| Landforms (L) | Major landforms | Plain | Terrace | Plateau | Mountain | | |
| Topographical Slope (TS) | % | 0–2 | 2–4 | 4–6 | 6–> | | |
| Hydraulic Conductivity (G) | % | <–0.5 | 0.5–1.0 | 1.0–2.0 | 2.0–> | | |
| Salinity (S) | % | >–0.3 | 0.2–0.3 | 0.1–0.2 | 0.1–< | | |
| Lime (K) | % | 0–5 | 5–15 | 15–20 | 20–> | | |
| Soil Organic Matter (SOM) | % | >–5 | 5–3 | 3–2 | 2–< | | |
| Electrical Conductivity (EC) | ms cm | >–500 | 500–250 | 250–100 | 100–< | | |
| Soil Reaction (SR) | pH | 5.5–7.3 | 7.4–7.8 5.1–5.4 | 7.9–8.4 4.0–5.0 | 8.4–> 4.0–< | | |
| <i>Climate Quality Index (CQI)</i> | | | | | | | FAO (1985), Samanta et al. (2011), Ayehu and Besufekad (2015) and Maddahi et al. (2017) |
| Temperature (T) | °C | 30–25 | 20–25 | 15–20 | 30–> 15–< | | |
| Precipitation (P) | mm | >–750 | 750–600 | 600–500 | 500–< | | |
| Solar Radiation (SR) | cal/cm ² | 425–500 | 375–425 | 300–375 | 500–> 300–< | | |
| Humidity (H) | % | >–50 | 50–60 | 60–70 | 70–> | | |
| <i>Irrigation Quality Index (IQI)</i> | | | | | | FAO (1985) and Maddahi et al. (2017) | |
| Distance to irrigation rivers (DIR) | km | <–1 | 1–3 | 3–5 | 5–> | | |
| Distance to irrigation channels (DIC) | km | <–1 | 1–3 | 3–5 | 5–> | | |
| Distance to irrigation dams (DID) | km | <–1 | 1–3 | 3–5 | 5–> | | |
| <i>Socio-Economic Quality Index (SEQI)</i> | | | | | | FAO (1985) and Amini et al. (2020) | |
| Average cultivation area (ACA) | decare | >–50.000 | 25.000–50.000 | 10.000–25.000 | 10.000–< | | |
| Number of farmers (NF) | person | >–5000 | 5000–2500 | 2500–1000 | 1000–< | | |
| Average farm size (AFS) | decare | >–50 | 50–25 | 25–10 | 10–< | | |
| Production amount (Pa) | tonnes | >–50.000 | 50.000–25.000 | 25.000–10.000 | 10.000–< | | |

Table 2 (continued)

| Land quality parameters (LQI) | | | | | | References |
|---|--------|-----------|-----------------|----------------|----------|----------------------------------|
| Factor rating | | | | | | |
| Diagnostic factor | Unit | 1.0 | 0.75 | 0.50 | 0.25 | |
| <i>Agricultural Mechanization Quality Index (AMQI)</i> | | | | | | FAO (1985) and Roy et al. (2014) |
| Tillage tools and machines (TTM) | number | >–250.000 | 100.000–250.000 | 50.000–100.000 | 50.000–< | |
| Sowing, planting, fertilizing and hoeing machines (SPFHM) | number | >–50.000 | 25.000–50.000 | 10.000–25.000 | 10.000–< | |
| Harvesting machines (HM) | number | >–5000 | 5000–2500 | 2500–1000 | 1000–< | |
| Agricultural fighting machines (AFM) | number | >–50.000 | 25.000–50.000 | 10.000–25.000 | 10.000–< | |
| Some other tools and machines (SOTM) | number | >–100.000 | 100.000–50.000 | 50.000–25.000 | 25.000–< | |

Fig. 2 Flowchart of land suitability assessment. Expansion of the abbreviations is available in Table 2



Socio-Economic Quality Index (SEQI): Rice yield depends on both socioeconomic factors and natural factors. The socio-economic characteristics of both the producers and the production area affect the land quality in paddy cultivation (Amini et al. 2020). The average cultivation area and the number of farmers per square meter in the study area are directly proportional to the paddy cultivation.

Agricultural Mechanization Quality Index (AMQI): Agricultural mechanization is an important factor that increases productivity and quality by applying new methods and technologies in paddy cultivation (Abdikoğlu 2019). Agricultural tools and machines owned by agricultural enterprises can be grouped as: soil cultivation tools and machines, sowing tools, planting tools, fertilizing and hoeing tools,

harvesting and threshing tools, agricultural pest control tools (Bal and Altuntaş 2019). The most suitable areas for paddy farming in the study area corresponds to the areas where the most advanced technological tools and machines used in paddy farming.

Modeling and analyses

The factor maps were converted to a raster format within the framework of the GIS-supported, grid-based method (Resolution: 5 m) per their weight values (Fig. 3). Then, the model was created, and the model factors were fixed on a common data scale for consistent results.

The factor maps obtained by the transformation process for analysis were combined using Cell Statistics according to the FAO Limitation method (Malczewski 1999; Dengiz and Sarıoğlu 2013; Sezer and Dengiz 2014; Dengiz 2013, 2020). Thus, a single statistical value was calculated from multiple raster layers according to the mean overlay statistical method.

In the analysis phase, the diagnostic factors that formed the land quality parameters and the factor maps of the land quality parameters were produced. Thus, a suitability map for paddy cultivation was created using the FAO limitation method. This map is divided into four classes according to the FAO land suitability classification, which consists of S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N (unsuitable) categories (Table 3) (FAO 1976).

Validation was conducted to test the predictive ability of the model as well as to verify the accuracy of the land suitability assessment map. For this reason, 190 sample points of rice yield were randomly collected from the study area. Accordingly, the accuracy rate decision coefficient (R^2) was calculated. The mapping, modeling, and analysis stages of the study were conducted using Arc GIS version 10.8.

Results

Suitability map

One of the most important results of the study model is the map that created using the land quality parameters. The parameters were categorized into four classes according to the FAO land suitability classification. The suitability assessment map indicated that 53.85% of the study area is consists of moderately suitable, 25.41% is highly suitable, 15.93% marginally suitable, and 4.81% is unsuitable land types (Table 4; Fig. 4).

In terms of land suitability for paddy cultivation in the study area, it was determined that the agricultural lands at the valley floor of the large streams around Uzunköprü, İpsala, Meriç, and Edirne settlements are highly suitable (Fig. 4). A large part of the study area is in the moderately

suitable class. The land is mostly marginally suitable around Enez and Havsa settlements while the Lalapaşa settlement area and its immediate surrounding land are unsuitable.

Validation

Although a universally accepted validation method in land suitability studies does not exist, cross validation method (i.e., “leave-one-out” method) is generally used to select an interpolator from a limited number of candidates in inverse distance weight (IDW) calculations (Tomczak 1998). This method relies on removing one data point at a time, interpolating for the location of the removed point using the remaining samples. That is, pretending that the removed point does not exist, and recalculating the difference between the observed values. This scenario is repeated until each data point is removed sequentially one by one. The overall performance of the interpolator is then evaluated as the root mean of the squared error (RMSE). The result of RMSE of the present study is 0.011, which is considered as low. Low RMSE value of an interpolator indicates that the prediction is likely to give reliable result for areas where the yield rate or suitability value is unknown. Cross-validation is performed with a different parameter set each time, and the set with the lowest RMSE is taken as optimum value. With IDW parameters selected through cross validation, a resampling process are used to reduce the bias of the predicted values and estimate their uncertainty. Validation of the model was calculated using coefficient of determination (R^2), which is a normalized statistic that determines the relative magnitude of the residual variance compared to the observed data variance (Esfahani et al. 2008; Verma et al. 2010; Salehi et al. 2017). R^2 indicates how well the plot of observed versus predicted data fits the 1:1 ratio. $R^2 = 1$ indicates the highest match of the model to the observed data where $R^2 = 0$ indicates the lowest. The result of the land suitability indicated that the R^2 value is 0.89 and the R^2 value for yield data is 0.98 (Fig. 5).

Comparison of current land use and potential land uses

The suitability map was compared with existing paddy fields and other LULC classes to identify differences between current and potential uses for rice farming in the study area (Fig. 4). Accordingly, although 79.26% of the study area is suitable for paddy cultivation, only 16.90% of the area is currently being used as paddy fields. However, rest of the land in the study area is usually used for wheat and sunflower cultivation. This situation stems from the traditional understanding of production shaped by the effects of natural conditions and socio-economic factors. Therefore, the potential area for rice farming is quite high (62.36%) and the agricultural land in the study area is not used by its potential.

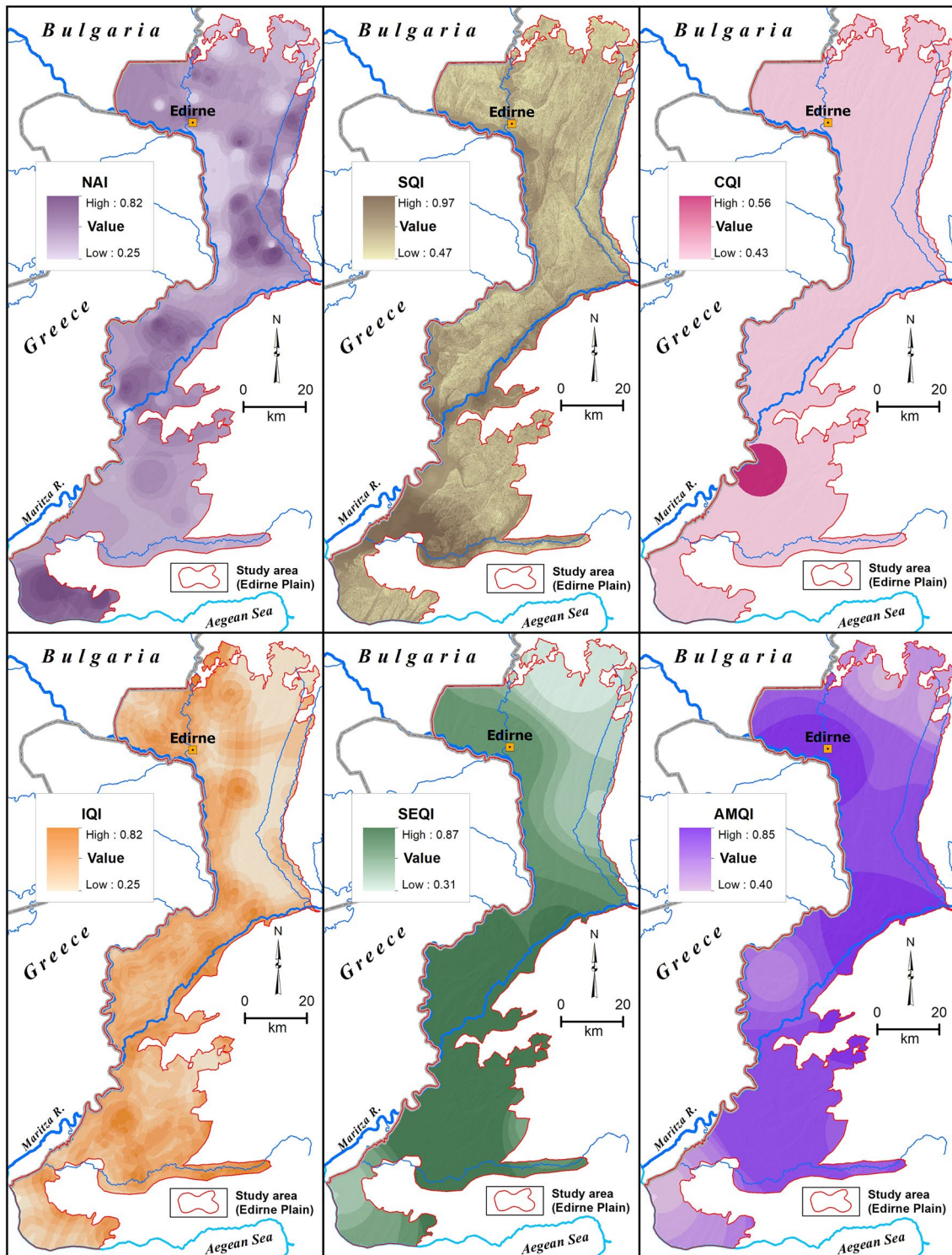


Fig. 3 Suitability maps of land quality parameters evaluated for paddy cultivation in the study area

Table 3 Distribution of land suitability classes for paddy cultivation

| Definition | Suit-ability class | Index value | Area (ha) | Rate (%) |
|---------------------|--------------------|-------------|------------|----------|
| Highly suitable | S1 | 1.00–0.65 | 93,142.86 | 25.41 |
| Moderate suitable | S2 | 0.65–0.55 | 197,411.81 | 53.85 |
| Marginally suitable | S3 | 0.55–0.45 | 58,401.98 | 15.93 |
| Unsuitable | N | <–0.45 | 17,628.23 | 4.81 |
| Total | | | 366,584.88 | 100.00 |

Table 4 Comparison of suitable land, current land use, and potential land use for paddy cultivation in the study area

| Land suitability areas | Area (ha) | Ratio to the study area (%) |
|---------------------------|------------|-----------------------------|
| Suitable area | 348,956.65 | 95.19 |
| Current paddy fields | 61,962.67 | 16.90 |
| Potentially suitable area | 286,993.98 | 78.29 |

Discussion

Land suitability assessment studies help to create realistic models in terms of agricultural planning and management (FAO 2017). In this study, land suitability assessment was used in an area where paddy cultivation is an important economic activity. The present study aimed to determine suitable areas for paddy cultivation. In this regard, the literature on land suitability assessment studies for a wide variety of agricultural products has been enriched recently (Everest 2020). However, studies on land suitability assessment for rice farming mostly have a low spatial resolution, causing some scaling and compatibility problems in the models. The present study uses a spatial resolution of 5 m to eliminate the resolution-related problems in the model. In addition, although NEAI and SQI quality parameters are predominantly used in similar studies, the very limited evaluation of CQI, SEQI, IQI, and AMQI quality parameters (Amini et al. 2020) is another aspect that increases the importance of the study. To increase the reliability and the validity, all parameters that may potentially affect rice farming were added to the model (Abushnaf et al. 2013; Kazemi et al. 2016).

Areas suitable for paddy cultivation differ in terms of soil, climate characteristics, irrigation, socio-economic status, and agricultural mechanization level. Agricultural production and yield increase in proportion to the suitability of these factors (Amini et al. 2020). In the study area, NEAI, SQI, CQI, IQI, SEQI, and AMQI factors were determined to be sufficient for paddy cultivation. However, the current usage for paddy is far below the potential in the study area.

Therefore, it can be concluded that the agricultural lands in the study area were not used by their potential. Ujoh et al. (2019) reported that in the face of such misuses that put serious pressure on the existing arable land, land suitability assessment studies will become increasingly necessary for a better evaluation and maximum use of land resources. On the other hand, Özkan et al. (2019) stated that detecting potential areas will help to increase rice production, reduce imports, and meet domestic demand of rice.

Paddy cultivation in the study area has important advantages over other agricultural products: (1) It can be cultivated on lands where other agricultural products cannot be cultivated. (2) Paddy can be cultivated on high groundwater levels and highly saline soil. (3) It has no marketing problems, contributes to employment, and reducing regional development poverty (Öztürk and Akçay 2010). However, in recent years, these advantageous conditions have become more disadvantageous in the face of problems such as decreased soil fertility, water scarcity, pollution, environmental stresses, and inefficient practices that provide low returns from rice production. Such problems threaten residents and farmers. Land use policy, planning, and management should take a holistic approach where the interests of all resource users, including local farmers and residents, are protected indiscriminately, not just within a specific sector in the region (Tuong et al. 2003). For the solution of these problems, land suitability studies using GIS techniques in agricultural planning are of great importance (Özşahin 2016). Effective use of available land resources for sustainable agricultural practices is a basic requirement to achieve optimum agricultural production (Abach and Ngigi 2016). Therefore, a sustainable management of paddy cultivation is possible with quality determination based on spatial analysis of various parameters affecting the suitability of the land.

While the present study is built on robust foundations, there were some limitations. First, due to high costs of data collection and soil analysis, a limited number of samples were collected and analyzed. In future studies higher number of soil samples should be collected to obtain detailed results in terms of NAI and SQI. Second, the meteorological stations are not evenly distributed in the study area. The only data representing the climate variables in the region is provided from these stations. Third, since no parcel-based yield data was available in the study area, district-based data were converted to point based data using IDW Interpolation method. Using parcel-based yield data could have been more advantageous in terms of validation process.

The distribution of the suitable land for paddy cultivation in the study area varies according to the land quality parameters. Highly suitable areas correspond to the areas where the highest yield per unit area is obtained in paddy cultivation. At the same time, these areas are the most important paddy production centers in the country (Şapaloğlu 2015).

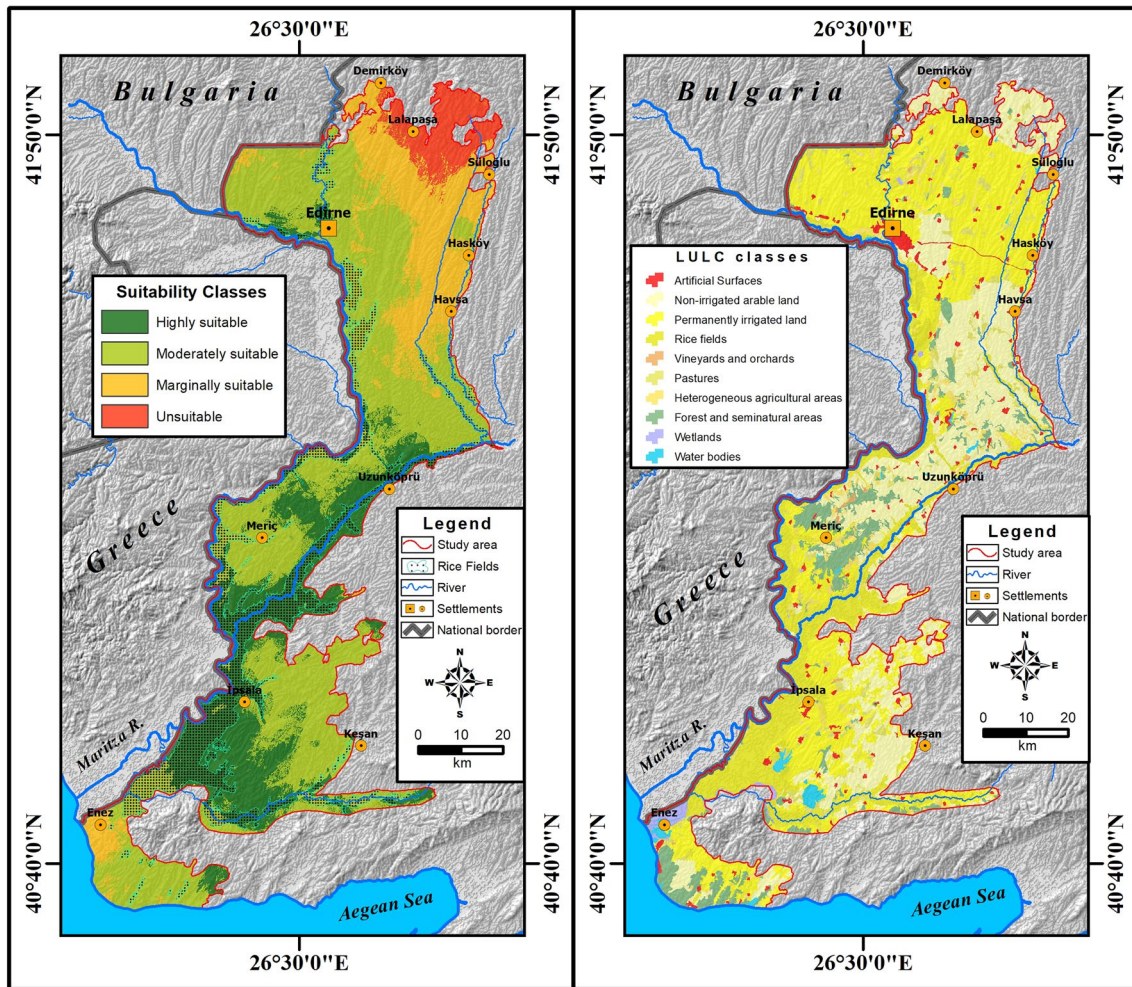


Fig. 4 Land suitability assessment map (left) and land use/land cover (LULC) classification (right) for paddy cultivation in the study area

A significant part of the agricultural lands in the study area is moderately suitable. This is partly due to the significant amount of land with high groundwater level and saline soil structure in the study area (Erdem 2012). Therefore, using these areas in agricultural activities other than paddy cultivation will result in extremely inefficient and low-quality product yields. (Sarı 2005).

In marginally suitable category areas, cost-increasing conditions for agricultural production are dominant. Therefore, it has been reported that both the number of producers, the cultivation area, and the production amount are quite limited in these areas (Ocaklı 2012). On the other hand, the study area is mostly consisting of suitable areas for paddy cultivation. In recent years these areas are mostly used for wheat and sunflower cultivation (Sarı 2005). However, these agricultural productions yield lower crop production compared to paddy cultivation. The average yields of paddy, wheat, and sunflower (2004–2020) in the study area are 826 kg/da, 370 kg/da, and 221 kg/da, respectively (TUIK

2021) in kilograms per decare. Therefore, in terms of paddy cultivation, it is important to allocate the potential areas in the study area, where the crop yield is above average (TKA 2021).

Conclusion

In this study, Edirne Plain, which is the most important paddy cultivation area of Turkey, was chosen to conduct land suitability assessment. The present study fills an important gap in the literature regarding land suitability assessment for rice farming by using high-resolution spatial data and applying many quality parameters on an important paddy cultivation area. The model indicated that the Edirne Plain was determined to consist of lands suitable for paddy cultivation at a rate of 79.26% while 15.93% of the land was in marginal condition. On the other hand, unsuitable areas were found to spread in a very small area (4.81%). The current

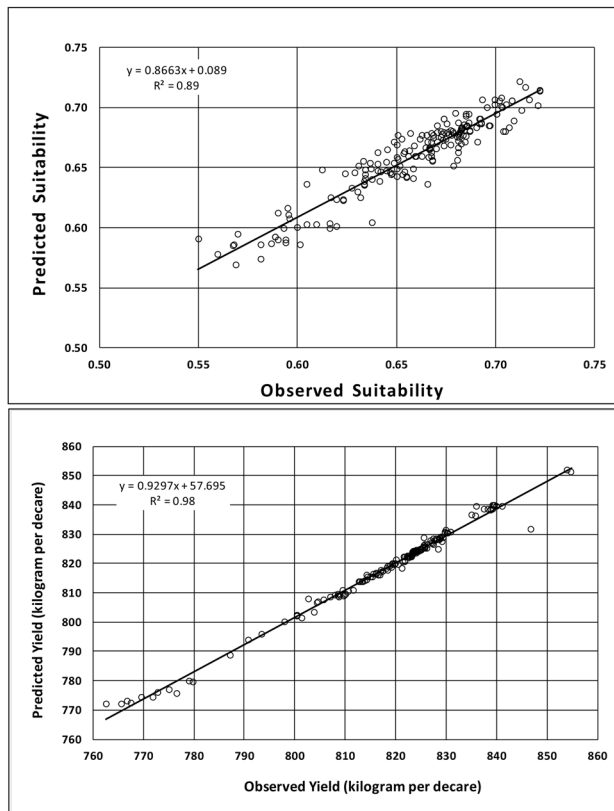


Fig. 5 Predicted versus observed ratio of land suitability (upper) and yield (lower) of the model

paddy fields in the study area were found to be in different suitability classes, however, overlapped with the suitable lands of the result map. In addition, paddy cultivation in the study area is shaped by socio-economic conditions as well as natural conditions.

In sum, effective use of available land resources for sustainable agricultural practices by local administrators and policymakers is a basic requirement to achieve optimum agricultural production. The present study identifies new potential paddy areas and therefore will contribute to increasing rice production, accordingly, reducing imports, contributing to employment, and reducing national and regional poverty. Furthermore, the present findings could provide guidance to local administrators, especially in the planning phase. Considering the food security and the increasing demand in the food supply, it is recommended to use highly productive agricultural land for paddy cultivation instead of other low-yield agricultural products. Therefore, the findings could be used as a guide in determining the new paddy fields in the study area. The techniques used in the present study can be applied in different regions of the world where similar geographical conditions.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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