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ABSTRACT

Rational planning of soil resources based on their capabilities are needed for the sustainable use of agricultural lands. Land suitability classification is an important evaluation tool for the management of soil resources. This study aimed to evaluate the land suitability for wheat (Triticum aestivum) cultivation using an approach that integrates multi-criteria decision making (MCDA) analysis and geographic information systems (GIS). The study area cover 21146 ha land and is located within the land consolidation area in the Çumra Plain, located in Central Anatolia of Turkey, The physical, chemical and fertility properties of the soil samples collected from 342 points in the study area were used as parameters in the wheat suitability assessment. The relative weight values of the soil parameters were determined by the Analytical Hierarchy Process (AHP). Literature and expert opinion were used in the creation of the AHP matrices and the determination of the sub-criteria. The criteria with the highest weight values or which have the highest impact on wheat growth were soil texture (0.30) and pH (0.16), while the lowest weight values were given for micro elements (0.02). Land Suitability Assessment was applied to the maps of soil variables using weighted overlay analysis in the GIS environment by using the relative weights. Thus, the suitability of the study area for wheat cultivation was mapped. The results revealed that 74% of the study area was highly suitable (S1) and 24% was moderately suitable (S2) for wheat cultivation. The coefficient of determination (R2) was 0.81, which indicated a successful prediction of the GIS-MCDA hybrid approach for wheat suitability assessment. Integration of land suitability analyzes specific to plant variety in land consolidation projects can provide a more detailed perspective on the land in the design of planning studies.

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1. Introduction

Agricultural production plays a role in meeting the for food human survival and raw materials for industry as well as delivering several ecosystem services for the economic and socio-cultural development of societies (Viana et al. 2022; Bulbul et al. 2022). Unfavorable conditions that arise with the increasing world population cause deterioration in the quality of agricultural production lands (Sands et al. 2014). Major causes of land degradation are the inappropriate use of agricultural lands, urbanization, industrialization, excessive use of fertilizers and pesticides, salinization and heavy metal pollution (Günal et al. 2015a; Jin et al. 2019; Jiang et al. 2020). These problems not only degrade the quality of agricultural lands but also threaten biodiversity, food security and public health (Dereumeaux et al. 2020; Everest and Gür 2022). For this reason, appropriate and efficient use of agricultural lands have become the most important issues in line with the sustainable development goals of the United Nations (Van Vliet et al. 2015; Musakwa 2018; Song and Zhang 2021).

Rational planning and management of resources are important for the sustainable use of agricultural lands. Therefore, new institutional land use plans that integrate environmental concerns and agricultural policies are needed (Govers et al. 2017; Mohammed et al. 2022). Land suitability assessment has been introduced as one of the scientific planning and management approaches to promote the sustainability of agricultural production (El Baroudy 2016; Ostovari et al. 2019). Land suitability is a land evaluation approach that assesses the suitability of lands for a particular use, and helps decision makers in establishing the optimum crop production system (FAO 1976). The land suitability approach combines qualitative analysis of soil properties, topography, climate and other environmental criteria and quantitative assessments based on yield estimates (Talukdar et al. 2022). Therefore, the use of a land suitability assessment for crop production that covers more than one complex criterion would be more appropriate. In this context, MCDA has been frequently preferred in land suitability studies to choose variables containing more than one criterion and to help determine the optimum outputs (Arabameri et al. 2019). The AHP is one of the MCDA methods used in solving complex decision problems (Kilic et al. 2022). The AHP provides a structure that divides the decision-making criteria into a hierarchical structure, based on their comparison with each other, and allows weights to the criteria according to the opinions of the experts (Saaty 2008). Thus, the land suitability assessment, which will evaluate different land use alternatives and determine the optimum crop rotation, is carried out successfully (Zhang et al. 2015; Budak et al. 2018; Dedeoğlu and Dengiz 2019). In addition, the use of GIS-based MCDA techniques with AHP approach to determine land suitability in different soil and terrain conditions have increased the success of suitability assessment (Jamil et al. 2018; Nabati et al. 2020; Kilic et al. 2022). Integration of GIS-MCDA approach helps to solve the spatial decision problems efficiently by performing the modern preparation, analysis and visualization of comprehensive environmental and spatial geospatial information required in agricultural suitability analysis (Everest 2021; Tashayo et al. 2020).

Demonstrating the suitability of lands for various crops is important in the effective and sustainable use of limited agricultural lands and the economic development of countries (Orhan 2021). Agricultural planning and land suitability reports for the cultivation of strategically important agricultural crops are beneficial for both social and economic development of the countries. Wheat is a strategically important cash crop in Turkey as in other parts of the world (Altuner et al. 2019). The wheat is even more important, especially in Turkey, because wheat and products obtained from wheat are highly important part of the diet in human nutrition (Eser and Soylu 2022). The average wheat yield in

Turkey was 2964 kg ha^{-1} in 2020, but this yield is lower than the average yield (3474 kg ha^{-1}) of the world (FAOSTAT 2021). In addition, a limited increase in wheat production is foreseen in Turkey in the next five years (Aydın 2022). Therefore, the increase in wheat yield is important to be self-sufficient and to ensure social development in Turkey. Wheat yield can be increased by determining the suitability of agricultural lands for wheat production. In addition, the fragmentation of agricultural lands has decreased with the increasing consolidation efforts in Turkey, and the agricultural potential of the lands also increased with the provision of agricultural infrastructure such as irrigation facilities, roads and drainage channels (Küsek 2014). However, the consolidation projects do not include any land suitability studies for the cultivation of important agricultural crops. Determining the suitability of agricultural lands in consolidated lands for wheat cultivation can contribute to the yield increase. For this purpose, the suitability of lands within the Çumra consolidation area for wheat production was determined by the integration of AHP approach into and GIS technique, and appropriate management plans were suggested to the decision makers.

2. Material and methods

2.1. Study area

The study area is located in the Çumra plain, which is an old lake floor in the Konya closed basin and located in the inner southwest of the basin, and the coverage area is 21146 ha (Figure 1). The research area is located at 32°42′-32°51′ E and 37°48′-37°36′ N latitudes and longitudes. The long-term (1975-2010) climate data of the Cumra meteorological station showed that the annual average temperature, precipitation and relative humidity are 11.38 °C, 323.61 mm and 62.42%, respectively. Most of precipitation occurs in the spring (109.84 mm) and winter (108.69 mm) seasons, and the least precipitation occurs in the summer (28.51 mm) season. The entire study area was submerged under the waters of the shallow Konya lake, which existed in the late Pleistocene. Almost all soils were formed on the Quaternary alluvial and lacustrine calcareous clay (marl) parent material. In addition, the terraces of the old Konya Lake are located in the south and southeast of the study area, and there are very few terrace soils formed on soft limestone in this region (Günal et al. 2015). The study area is a part of 46 000 ha Cumra irrigation project, which the first largest irrigation infrastructure project in central Anatolia of Turkey. Land consolidation have been completed recently, drainage has been established and the study area has been opened to agricultural production between 2000-2005. Large production fields are located in the study area and irrigation, surface-underground drainage and road network located in the area are the examples of best infrastructure established within the scope of Konya plain irrigation project. The boundaries of the study area were determined based on the consolidation boundaries.

2.2. Methodological framework

The criteria to be used in the region were primarily determined to determine the land suitability for wheat cultivation in the Çumra plain. Topographic and climatic conditions within the study area were not spatially heterogenous, therefore, soil properties, which varied even within a short distance were selected as the only criteria in land suitability of wheat. Spatial distribution maps of soil properties were produced using geostatistical methods, and soil database to be used in suitability assessment was prepared. Then, the

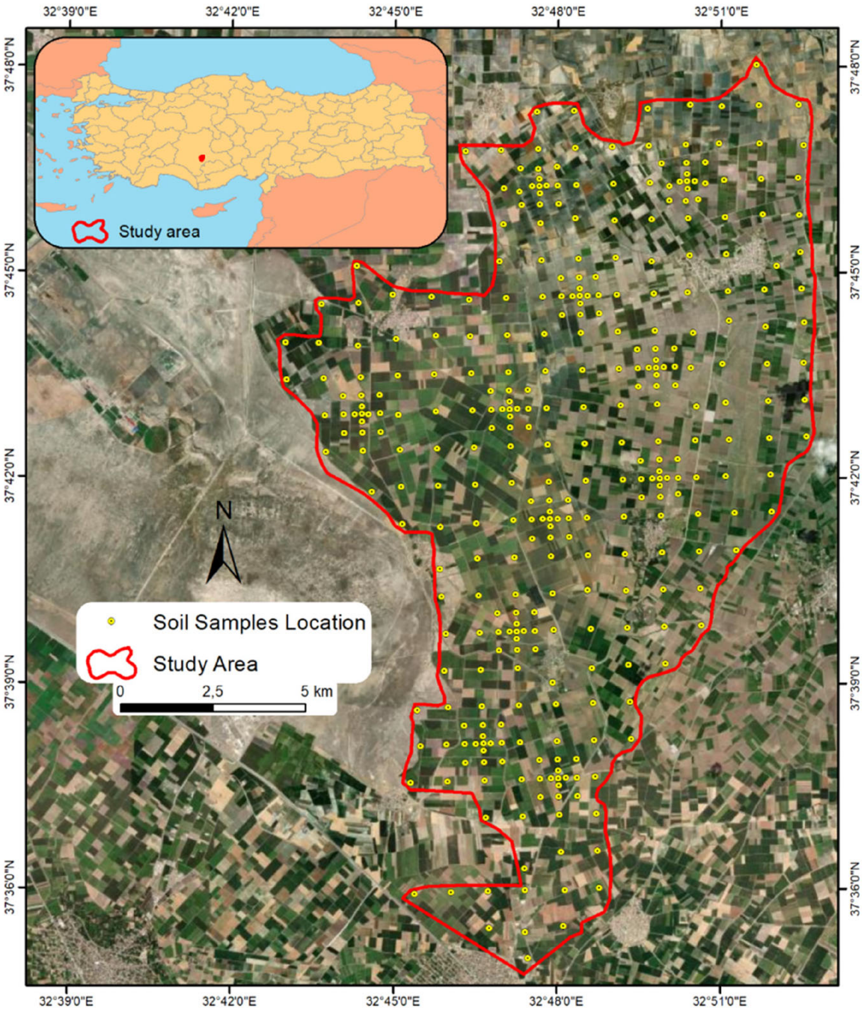

Figure 1. Location of the study area.

12 soil criteria (pH, electrical conductivity (EC), lime (CaCO3), texture, nitrogen (N), phosphorus (P), potassium (K), sum of basics cations (SBC), copper (Cu), iron (Fe), Zinc (Zn), organic matter) were divided into subgroups for wheat production based on the level of importance with expert opinion and literature support. Then, the weights of the main parameters were determined by taking the AHP method into the group hierarchy process (Table 1). Suitability maps were produced by weighted overlay spatial analysis in ArcGIS 10.5 GIS software. The accuracy of the suitability map was tested using the wheat yield values collected from the study area (Figure 2)

2.3. Data used in the study

The soil database prepared by the TOVAG 112 O 039 project, which includes the physical and chemical properties of soil properties and the macro and micro nutrient contents, was used in the land suitability assessment for wheat production. In order to prepare the

Table 1. Methods applied for the analysis of soil physical and chemical properties.

Parameter	Unit	Procedure	Reference
Texture (clay, silt and sand)	%	Hydrometer method	Bouyoucos (1951)
Soil Reaction (pH)	1:2	Soil–water suspension (w:v)	U.S. Salinity Lab. Staff (1954)
Electrical Conductivity	dS m^{-1}	Soil–water suspension (w:v)	U.S. Salinity Lab. Staff (1954)
Organic matter	%	Walkley–Black method	Nelson and Sommers (1982)
Lime ($CaCO_3$)	%	Calcimeter method	Kacar (1994)
Available Phosphorus	mg kg^{-1}	Olsen method	Olsen et al. (1954)
Total Nitrogen	%	Kjeldahl method	Bremner and Mulvaney (1982)
Sum of Basic Cations (SBC) (Ca^{++}, Mg^{++}, Na^{+}, K^{+})	me 100 g^{-1} soil	Ammonium acetate extraction method	Soil Survey Staff (1992)
Microelements (Fe, Cu, Zn)	mg kg^{-1}	DTPA extraction method	Lindsay and Norvell (1978)

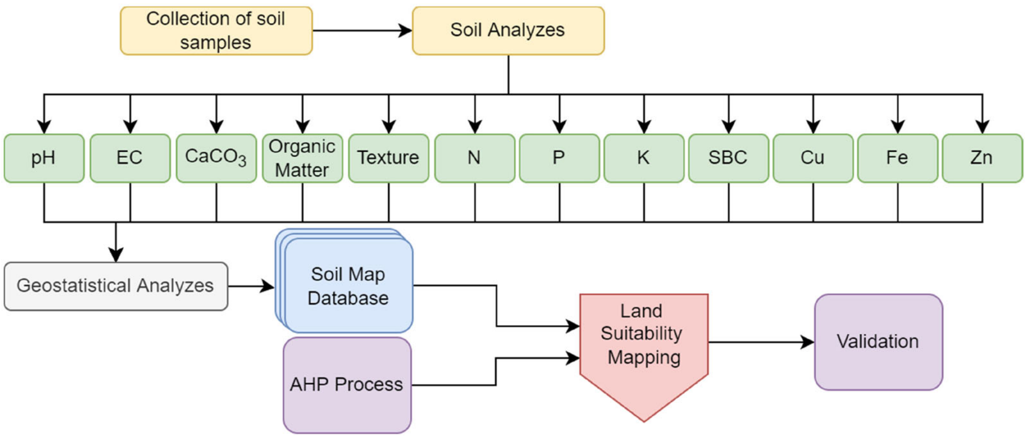

Figure 2. Methodology flow chart of this study.

soil database, a total area of 189.69 km^2 land within the scope of irrigation and consolidation of the Çumra plain was divided into 1000 × 1000 m square grids, and 342 soil samples were collected from approximately the corners of the grids in 2013. The coordinates of each sampling point were recorded using a Global Positioning System (Günal et al. 2015a). The methods used to determine the physical and chemical properties of soil samples are given in Table 1. Spatial distribution maps of the soil properties were prepared using the Ordinary Kriging interpolation method (Webster and Oliver 2001).

$$\hat{Z}(X)_i = \sum_{i=1}^{N} Y_i \hat{Z}(x)_i \qquad \text{Eq. (1)}$$

where; $\gamma_i \hat{z}(x_i)$ and Z(xi) are the weight of points, estimated and observed soil attributes, respectively.

2.4. Land suitability parameters for wheat cultivation

Soil texture, pH, electrical conductivity (EC), organic matter, CaCO3, nitrogen, phosphorus, potassium, exchangeable cations and micronutrients (Cu, Fe and Zn) were selected as the variables based on previous studies to determine the suitability of wheat production in the study area (Sys Ir et al. 1993; El Baroudy 2016; Dedeoğlu and Dengiz 2019; Karimi et al. 2018). Soil texture is the proportional distribution of mineral particles smaller than 2 mm in a soil, and is the most important physical property that controls soil-plant-water relations (Dharumarajan and Hegde 2022). Soil texture has significant effects on other physical properties such as retention of water and nutrients, ease of tillage, bulk density, root penetration and infiltration (Hillel 2013).

Soil pH, which expresses the hydrogen (H+) ion concentration of the soil solution, controls the processes involved in the genesis and development of soils through the weathering of mineral and degradation of organic parent materials, and affects the availability of plant nutrients in soils (Kılıç et al. 1991; Strawn et al. 2020). Aluminum and manganese concentration are very high at low pH (acid soil), while soil aggregates become dispersed and soil properties such as aeration, water movement and resistance to erosion are adversely affected at high pH (alkalinity) and Na concentration (Karimi et al. 2018). Electrical conductivity is a measure of soluble salts in soils. Salts increases osmotic potential in the root zone and cause stress on plants and inhibits plant growth. In addition, high salt content has a direct toxic effect on the cell membrane and protoplasm of the plants, causing severe yield losses (Safdar et al. 2019).

Organic matter acts as a nutrient source in soils, improves the aggregate stability of soils acting as a cementing agent between individual mineral particles and increases soil fertility (FAO 2005). Lime, which expresses free calcium carbonate in soils, is extremely useful for aggregate formation. In addition, lime prevents decrease of pH, while the presence of excess lime constrains the availability of some plant nutrients (Natural Resources Conservation Service (NRCS) 2016).

Nitrogen, one of the macronutrients, affects grain yield and protein content of wheat. Excessive nitrogen accelerates vegetative growth, while decreases grain yield (Kacar and Katkat 2007). Phosphorus is needed for plant root system, and also accelerates flowering and maturation (Malhotra et al. 2018). Potassium increases resistance to diseases and root growth, improves drought and cold resistance, affects harvest time, and increases yield and quality (Pandey and Mahiwal 2020). Iron, one of the micronutrients, plays a fundamental role in the formation of chlorophyll (Havlin 2020), and zinc positively affects grain yield and quality in wheat (Hui et al. 2022). Copper is an essential micronutrient with a very small concentration in biological tissues. Optimum level of Cu is required for normal plant growth, however excess Cu concentration adversely affects plant growth (Adrees et al. 2015). Exchangeable cations such as sodium, potassium, calcium and magnesium are important nutrients for wheat production (Pandey et al. 2020).

The environmental conditions of a region are also important determinants in wheat cultivation. Optimum temperature during a healthy wheat growth and optimum yield should be between 10-25 °C (Sys Ir et al. 1993). Average annual precipitation between 350 and 1250 mm is needed for optimum wheat growth. High humidity causes rust disease in wheat. Humidity in the study area is low enough to prevent such diseases. Irrigation infrastructure has been recently built after the completion of land consolidation carried out in the study area, therefore the annual precipitation is as important as the regions for rainfed wheat cultivation. The temperature of the study area is also within favorable limits for wheat production. The slope, which is one of the environmental conditions, has a negative impact on wheat agriculture due to the erosion risk caused by soil tillage (Karimi et al. 2018). However, flat surface topography ensures that the environmental conditions are at optimum for wheat production. Climatic and topographic conditions of the study area are suitable for wheat production, and both do not vary spatially within the study area. Climatic and topographic parameters would not contribute to the spatial differentiation in determining the areas with high suitability using the GIS-AHP combination; therefore, they were not included in the land suitability model. In contrast, soil properties

Table 2. Land suitability of parameters and parameter classes.

	S1	S2	S3	N1	N2
Significance Range of Classes	100	80	50	20	10
pH	5,5 – 7,0	7,0 – 7,8	7,8 – 8,5	> 8,5	–
EC	0 – 1	1 – 2	2 – 5	5 – 6	> 6
$CaCO_3$	< 20	20 – 30	30 – 50	50 – 60	> 60
OM	> 1,5	0,8 – 1,5	0,4 – 0,8	< 0,4	–
Texture	CL, SiL, SiC, CO	SC, L,C < 60	SCL, C > 60	SL, Lfs	Cm, SiCm, LcS, fS
N	> 3,2	3,2 – 1,7	0,9 – 1,7	0,9 – 0,45	< 0,45
P	> 80	25 – 80	8 – 25	2,5 – 8	< 2,5
K	> 400	400 – 200	200 – 100	< 100	–
SBC	> 5	3,5 – 5,0	2,0 – 3,5	< 2	–
Cu	> 0,2	–	–	–	< 0,2
Fe	2 – 4,5	1 – 2	1 – 0,2	> 4,5	< 0,2
Zn	> 1	1 – 0,5	0,5 – 0,25	< 0,25	–

References: Sys Ir et al. (1993); El Baroudy (2016); Dedeoğlu and Dengiz (2019); Karimi et al. (2018).

in the study area varies even in short distances; thus land suitability assessment for wheat production was carried out based on soil properties.

2.5. Soil requirements of wheat

Wheat can be grown in many soil texture groups ranging from sandy loam to clayey texture. However, soils with clayey loam texture, which have higher water and nutrient holding capacity than sandy loam, are more preferred. The wheat can be grown in soil pH ranges between 5.2-8.5, while the optimum yield is obtained between 6.0-8.2. The wheat is less tolerant to salinity (< 4 ds m-1) during the germination period and no yield loss occurs below 6 dS/m. However, yield losses of 10% are observed at 7.4 dS m-1, 25% at 9.5 dS m-1, 50% at 13 dS m-1, and 100% at 20 dS m-1. Moderate to productive levels of nutrients are sufficient to provide optimal conditions (Sys Ir et al. 1993). In line with this information, Table 2 was prepared considering the data provided in previous studies (Sys Ir et al. 1993; El Baroudy 2016; Dedeoğlu and Dengiz 2019; Karimi et al. 2018) At the stage of determining the land suitability, the suitability values in Table 2 were used for the subclasses of the 12 soil components.

2.6. Multi-criteria assessment: Analytical hierarchy process (AHP)

The MCDA methods are used when variables contain more than one quality and quantity in a problem (Timor 2011). The AHP introduced by Saaty (2008) is a commonly used method in the MCDA processes, and creates a hierarchical structure among the variables depending on the purpose of the study and the experience of the expert. Quantitative weights are obtained that reflect the relative importance of each variable according to the target determined at the end of the process (Srdjevic et al. 2010). Therefore, the AHP has been used in studies with many qualitative and quantitative variables are evaluated together (Budak et al. 2018; Panchal and Shrivastava 2022; Unver and Ergenc 2021). A pairwise comparison matrix, in which all criteria are compared with each other, is created in the AHP method (Saaty 2008). The information in Table 3 is used in the creation of pairwise comparison matrix. The importance of each variable is compared to the other variable using this matrix.

The importance of each variable compared to the other variable is determined with this matrix, which normalized to determine the "relative priorities". The relative priority is

Table 3. AHP pairwise comparison table (Saaty 2008).

Relative importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to objective
3	Weak importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	One activity is strongly favored and demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed between two adjacent judgments

the arithmetic mean of the normalized matrix rows and expresses the weights of the variables used in the study. The consistency of the matrix established at the last stage of the AHP process should be checked. For this control, the "consistency index" is calculated using the following equation (Eq 2.).

$$CI = \frac{\lambda_{max}}{n - 1} \qquad \text{Eq. (2)}$$

In the equation; CI is the consistency index and n is the matrix size. λ_max is calculated as follows: the columns of the first comparison matrix produced are multiplied by the relative priorities, and the weighted total vector is determined. The values obtained for each variable are divided by their relative priorities (significance weights). The arithmetic mean of these values gives the λ_max (Arslan and Khisty 2005; Güngör and İşler 2005). The consistency ratio is obtained by dividing the CI obtained by the Random Index (RI) value. The RI is a constant value and is taken from Table 4. The RI value must be less than 0.10 to obtain a consistent and acceptable matrix (Saaty 2008).

2.7. Land suitability mapping

The AHP has a certain advantage in evaluating many factors and criteria, however, the AHP cannot reveal the spatial distribution of the factors and criteria. This shortcoming of AHP can be compensated by the powerful analysis function of the GIS (Ersayin and Tagil 2017). Thematic maps of soil variables and the weights determined by AHP are used for land suitability assessment. The aforementioned process was carried out using the following equation (Eq 3.).

$$LSI = \sum_{i=1}^{n} (Wi.Xi) \qquad \text{Eq. (3)}$$

In the equation; LSI is the land suitability value; Wi refers to the weight of the soil variable determined by AHP, and Xi refers to the weight for the subclass of the soil variable (Cengiz and Akbulak 2009; Pramanik 2016; Tashayo et al. 2020). The weights of subclasses were attained by considering the subclasses and the weights of subclasses indicated in Table 2. The result obtained from the scoring was also used in the classification of the land suitability map.

Table 4. Random index (Saaty 2008).

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	**1.48**	1.56	1.57	1.58

2.8. Validation of land suitability assessment

The accuracy of the land suitability model, which reveals the suitability of the lands for wheat production, was carried out using the wheat yield of 2013 obtained from the Farmer Registration System of the District Directorate of Agriculture and interviews with the farmers. The accuracy of the land suitability map was tested by a linear regression between the 42 observation yield values and the Land Suitability Index score obtained by AHP and GIS methods. The coefficient of determination (R2) obtained using Equation 4 provides information on the success of the model. The R2 value of 1 or close to 1 indicates perfect prediction of the regression model (Zhang et al. 2019).

$$R^2 = 1 - \frac{\sum_{1=1}^{n} (y_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2} \qquad \text{Eq. (4)}$$

where yi and ŷ shows the observed and predicted soil values of wheat yield, respectively; and ȳ is the mean value of the wheat yield observation values.

3. Results and discussion

3.1. Soil characteristics and soil maps

Descriptive statistics of the soil properties are presented in Table 5. Sand content of the soils in the study area ranged from 6.01 to 77.45% with an average sand content of 15.17%. Clay content of the soils varied between 11.69 and 78.34% with an average value of 63.87%. Organic matter content in intensively tilled fields was as low as 0.20% while it reached 3.66% in the pastures. Lime content of soils ranged from 2.94 to 60.79% with an average lime content of 26.82%. The pH value was between neutral (pH = 7.74) to strongly alkaline (8.56) and the average pH value was slightly alkaline (pH = 8.15). Total nitrogen content ranged from 0.001 to 0.176%, with a mean value of 0.03%. Available phosphorus and potassium contents were 10.77-124.82 mg kg^{-1} and 138.58-2937 mg kg^{-1}, while the average phosphorus and potassium contents were 30.59 and 413.12 mg kg^{-1}, respectively. The SBC contents of soils were between 0.21-10.36 me 100 g^{-1} and mean SBC contents were 0.91 me 100 g^{-1}. The Cu, Fe and Zn contents of soils varied between 0.52-2.03 mg kg^{-1}, 0.62-9.86 mg kg^{-1} and 0.01-1.49 mg kg^{-1}, and the average Cu, Fe and Zn contents were 1.22, 2.29 and 0.36 mg kg^{-1}, respectively.

Coefficient of variation (CV) is an indicator of the variability of a parameter in the study area, and a CV value higher 35% indicates high variability, a CV value between 15-35% indicates moderate variability, and a CV value less than 15% shows low variability (Wilding 1985). Other soil parameters with high variability were sand, EC, CaCO3, OM, P, Kav, Fe and Zn. Clay, silt and Cu had moderate variability, while pH values, SBC and total N content had low variability (Table 5).

Spatial distribution maps of the parameters used to determine the land suitability for wheat cultivation in the study area are given in Figure 3. The coverage area of the subclasses for each parameter is given in Table 6.

Table 5. Descriptive statistics parameters of soil samples (Günal et al. 2015b).

Statistics	N	Min	Max	Mean	Std. Deviation	Cv (%)
Clay	342	11.69	78.34	63.87	9.60	15.03
Silt	342	9.30	42.71	20.96	5.81	27.72
Sand	342	6.01	77.45	15.17	6.67	44.00
Ph	342	7.74	8.56	8.15	0.13	1.61
Ec	342	0.32	5.12	1.03	0.60	58.88
$CaCO_3$	342	2.94	60.79	26.82	13.09	48.81
OM	342	0.20	3.66	1.61	0.60	37.33
N	342	0.001	0.176	0.030	0.001	3.33
P	342	10.77	124.82	30.59	13.40	43.79
K_{av}	342	138.58	2937.55	413.12	275.70	66.74
SBC	342	0.21	10.36	0.91	0.05	5.90
Cu	342	0.52	2.03	1.22	0.24	19.45
Fe	342	0.62	9.86	2.29	1.08	47.04
Zn	342	0.01	1.49	0.36	0.23	63.51

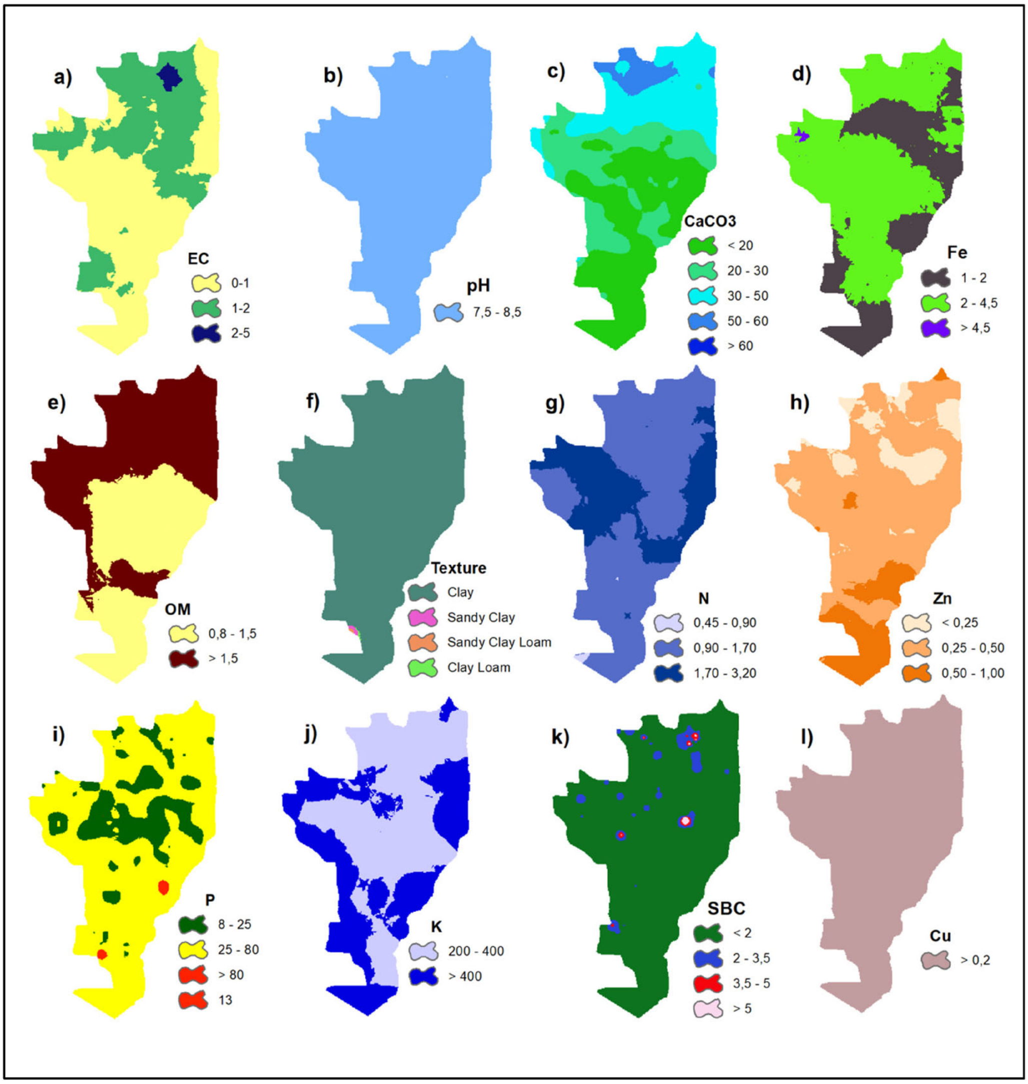

Figure 3. Spatial distribution maps of soil parameters.

Table 6. Land coverage area of subclasses for the parameters.

Sub-criteria classes	Area km^2	Area %	Sub-criteria classes	Area km^2	Area %
pH			**N**		
7.8 – 8.5	189.69	100	> 3.2 %	57.30	30.21
EC			1.7 – 3.2 %	131.78	69.47
0 – 1 dS m^{-1}	110.30	58.15	0.9 – 1.7 %	0.61	0.32
1 – 2 dS m^{-1}	76.99	40.9	**Available P**		
2 – 5 dS m^{-1}	2.40	1.27	> 80 mg kg^{-1}	1.25	0.66
$CaCO_3$			25 – 80 mg kg^{-1}	148.93	78.51
< 20 %	76.57	40.37	8 – 25 mg kg^{-1}	39.51	20.83
20 – 30 %	51.25	27.02	**Available K**		
30 – 50 %	50.76	26.76	> 400 mg kg^{-1}	82.76	43.63
50 – 60%	11.11	5.86	400 – 200 mg kg^{-1}	106.94	56.37
> 60%	0.01	0.00	**Sum of Basic Cations**		
Organic Matter			> 5 me 100 g soil^{-1}	0.33	0.17
0.8 – 1.5%	86.20	45.44	3.5 – 5 me 100 g soil^{-1}	0.85	0.45
> 1.5%	103.49	54.55	2 – 3.5 me 100 g soil^{-1}	7.24	3.82
Texture			< 2 me 100 g soil^{-1}	181.28	95.56
Clay Loam	189.35	99.82	**Cu**		
Sandy Clay	0.26	0.14	> 0.2 mg kg^{-1}	189.69	100
Sandy Clay Loam	0.08	0.4	**Zn**		
Fe			< 0.25 mg kg^{-1}	25.21	13.29
1 – 2 mg kg^{-1}	61.67	32.51	0.25 – 0.50 mg kg^{-1}	134.44	70.87
2 – 4.5 mg kg^{-1}	127.45	67.19	0.50 – 1.00 mg kg^{-1}	30.04	15.84
> 4.5 mg kg^{-1}	0.57	0.30			

Table 7. Pairwise comparison matrix of parameters.

	pH	EC	$CaCO_3$	OM	Texture	N	P	K	SBC	Cu	Fe	Zn
pH	1	3	3	2	1/4	3	3	4	5	6	6	6
EC	1/3	1	2	2	1/4	2	2	2	3	4	4	4
$CaCO_3$	1/3	1/2	1	½	1/5	1/2	1/2	1/2	3	4	4	4
OM	1/2	1/2	2	1	1/4	2	2	2	3	6	6	6
Texture	4	4	5	5	1	6	6	6	7	7	7	7
N	1/3	1/2	1/2	½	1/6	1	2	2	3	4	4	4
P	1/3	1/2	2	1/2	1/6	1/2	1	1	2	3	3	3
K	1/3	1/2	2	1/2	1/6	1/2	1	1	2	3	3	3
SBC	1/5	1/3	1/3	1/3	1/7	1/3	1/2	1/2	1	2	2	2
Cu	1/6	1/4	1/4	1/6	1/7	1/4	1/3	1/3	1/2	1	1	1/2
Fe	1/6	1/4	1/4	1/6	1/7	1/4	1/3	1/3	1/2	1	1	1/2
Zn	1/6	1/4	1/4	1/6	1/7	1/4	1/3	1/3	1/2	2	2	1

Table 8. Normalized comparison matrix.

	pH	EC	$CaCO_3$	OM	Texture	N	P	K	SBC	Cu	Fe	Zn
pH	0.13	0.26	0.16	0.16	0.08	0.18	0.16	0.20	0.16	0.14	0.14	0.15
EC	0.04	0.09	0.11	0.16	0.08	0.12	0.11	0.10	0.10	0.09	0.09	0.10
$CaCO_3$	0.04	0.04	0.05	0.04	0.07	0.03	0.03	0.03	0.10	0.09	0.09	0.10
OM	0.06	0.04	0.11	0.08	0.08	0.12	0.11	0.10	0.10	0.14	0.14	0.15
Texture	0.51	0.35	0.27	0.39	0.33	0.36	0.32	0.30	0.23	0.16	0.16	0.17
N	0.04	0.04	0.03	0.04	0.06	0.06	0.11	0.10	0.10	0.09	0.09	0.10
P	0.04	0.04	0.11	0.04	0.06	0.03	0.05	0.05	0.07	0.07	0.07	0.07
K	0.04	0.04	0.11	0.04	0.06	0.03	0.05	0.05	0.07	0.07	0.07	0.07
SBC	0.03	0.03	0.02	0.03	0.05	0.02	0.03	0.03	0.03	0.05	0.05	0.05
Cu	0.02	0.02	0.01	0.01	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Fe	0.02	0.02	0.01	0.01	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.01
Zn	0.02	0.02	0.01	0.01	0.05	0.02	0.02	0.02	0.02	0.05	0.05	0.02

Table 9. Weights of parameters used in suitability assessment.

Criteria	Weight
pH	0.16
EC	0.10
$CaCO_3$	0.06
OM	0.10
Texture	0.30
N	0.07
P	0.06
K	0.06
SBC	0.03
Cu	0.02
Fe	0.02
Zn	0.02

Table 10. Consistency rate of AHP.

Max. eigenvalue	12.63441
Consistency index (CI)	0.057674
RI (N = 12)	1.48
Consistency Ratio (CR)	0.038969

3.2. Effect of criteria on land suitability

The topographic and climatic characteristics of the study area are homogeneous, therefore, land suitability for wheat cultivation was determined using the evaluation of only 12 soil properties. The AHP method was used to determine the relative weights of the parameters used in the suitability assessment for wheat cultivation. Pairwise comparison matrix (Table 7), normalized matrix (Table 8), and weights of variables (Table 9) were calculated with the AHP method. The CR value indicating the consistency of the established AHP was calculated as 0.038 (Table 10), which showed that the AHP matrix was consistent and acceptable.

Soil particle size distribution (texture) had the highest weight (0.30) for wheat production. The texture is one of the important physical properties that affect soil aeration, water holding capacity and nutrient content, soil aggregation and structure development, bulk density and suitability for tillage (Dharumarajan and Hegde 2022), thus, the weight for soil texture was higher compared to the weight of other parameters (Table 9).

Soil pH affects various processes from the weathering of mineral and organic parent materials to the formation and development of several types of soils (Kılıç et al. 1991). In addition, soil pH significantly affects fertility due to the influence on the solubility of nutrients, the cation exchange capacity, the type and amount of exchangeable ions, the huminization degree of organic matter and microorganism activities and some other properties (Akbas et al. 2009). Due to the aforementioned important effects, soil pH received the second highest weight (0.16) among the criterion. (Table 9).

The electrical conductivity (EC) of soil solution is proportionally dependent on the salt content of soil. The stagnant shallow ground water in arid and semi-arid regions where evaporation is high, rises towards the upper parts of soil profile by capillarity, leaving the salts carried at certain depths or on the surface of the soil profile (Günal et al. 2015a). The increase in salt content adversely affects some physical and chemical properties of the soil and inhibits plant growth (Budak et al. 2020). Soil EC was evaluated as the 3rd most important parameter with soil organic matter by receiving a weight value of 0.10 due to the aforementioned effects on plant growth (Table 9).

Plant and animal wastes added to the soil constitute soil organic matter. Nutrients released by the decomposition of organic matter by microorganisms are used as nutrients

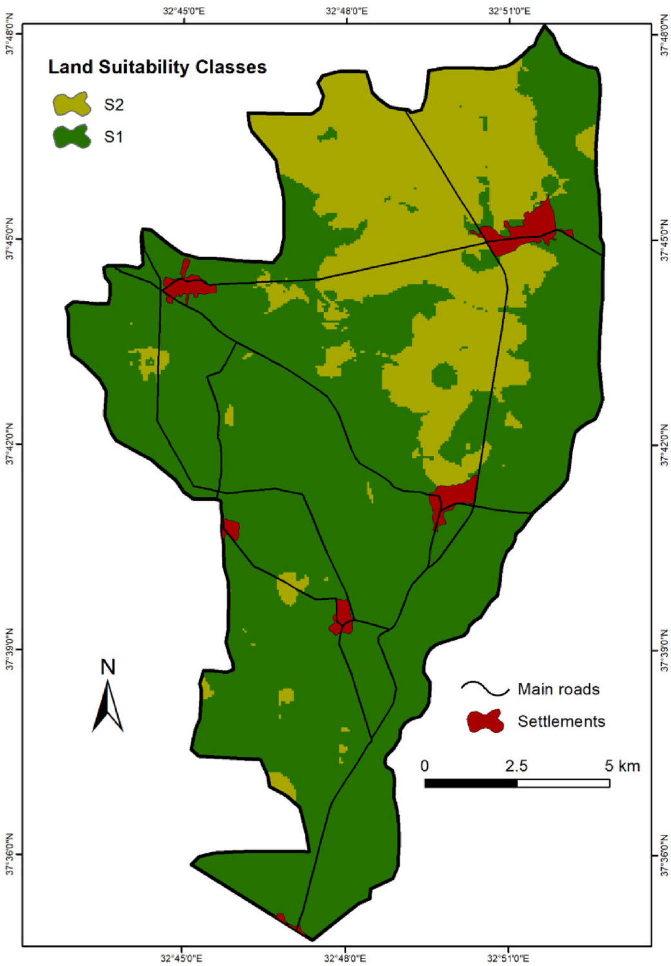

Figure 4. Land suitability map for wheat production.

for plants and as energy sources for microorganisms. Organic matter is an important indicator of soil fertility and is of great importance for agricultural production and food security (Obalum et al. 2017). Therefore, organic matter had the same weight as EC and has been evaluated as the 3rd important criterion for wheat cultivation in the study area (0.10) (Table 9).

The fertility level of agricultural lands for a reasonable wheat yield should be between medium and high. In order to obtain 3 ton wheat ha-1, plants will remove 70 kg of N, 30 kg of P and 60 kg of other nutrients from the soil (Sys Ir et al. 1993). Therefore, N, P and K are important variables that indicate the fertility levels of the agricultural lands for wheat production. Dedeoğlu and Dengiz (2019) used the fertility status of soils in land suitability for wheat cultivation by adapting the N, P and K contents of soils to the Soil Fertility Index. Some researchers have classified N, P and K contents separately in order to reveal soil fertility (El Baroudy 2016; Dadhich et al. 2017). In this study, N, P and K contents were used as an indicator of soil fertility and the relative weight of N was determined as 0.07, P and K were as 0.06 (Table 9).

Table 11. Spatial distribution of classes in the suitability map.

Suitability	Area	
	km^2	%
S1	140,38	%74
S2	49,31	%26

Soils with good buffering capacity and moderate lime content are suitable for wheat cultivation, however, excessive lime content may prevent the uptake of some nutrients (Tugay and Sepetoğlu 1983). In this respect, highly calcareous soils may not be good for wheat cultivation. The amount of CaCO3 between 3-30% may not cause any adverse effect on wheat growth, and a significant decrease in wheat yield (Sys Ir et al. 1993). The weight of lime content for the Çumra soils was determined as 0.06 (Table 9). Hailu et al. (2015) investigated the relationship between exchangeable cations with soil fertility, and used the total amount of cations as a parameter for land suitability in wheat production. The sum of exchangeable Ca, Mg, Na, and K (Sum of Basic Cations) was used as a criterion for suitability and received a weight value of 0.03 (Table 9).

The deficiency or excess of micronutrients in the soil causes negative effects on some physiological properties of many crops. Excess zinc concentration in soil causes a decrease in root and shoot growth, roots become thinner, young leaves curl, and causes chlorosis (Rout and Das 2003). In iron deficiency, yellow color replaces the green color between the veins of young leaves (Aydı n and Turan 2002). Cupper in low concentrations is necessary for plant growth, however, excessive cupper content in soils causes phytotoxic effects (Michaud et al. 2007). Due to the aforementioned importance, micronutrients have been used as a parameter in the classification of suitability for wheat cultivation. All three micronutrients received a weight value of 0.02 (Table 9).

3.3. Land suitability assessment for wheat production

The suitability of lands in the consolidation area of Çumra region for wheat cultivation is presented in Figure 4. The map obtained using AHP-GIS hybrid approach showed that 74% (140.38 km^2) of the area is highly suitable for wheat production (S1) and 26% (49.31 km^2) is moderate suitable (S2) (Table 11). Highly suitable areas are distributed in the edges and southern parts of the study area, excluding the northern parts. The largest share of S1 in the study area is related to the highest relative weight of the soil texture parameter. Almost all the soils of the study area had clay loam texture, which is included in the high-score subclass, causing the majority of the area classified in the highly suitable class. Soil salinity can be expected to be an important problem for agricultural production especially in the closed basins located in arid and semi-arid regions, when irrigated agriculture is carried out (Budak et al. 2020). The construction of drainage channels along with irrigation channels in the consolidation project prevents the rise of the ground water and the salinization of the soils by capillary rise. The parameters related to productivity and quality are in the suitable subclasses; therefore, the majority of the lands in the study area were classified as highly suitable for wheat production. Moderate suitable areas are located in the northern part and in small regional locations of the study area. Sightly high EC and high $CaCO_3$ content (50%) in the northern part, and slightly alkaline soil pH throughout the study area were the main reasons to be classified as moderate suitable. Agricultural production in the study area can be increased by lowering soil pH using ammonium fertilizers as nitrogen sources. Alternative crops other than wheat on S2 class

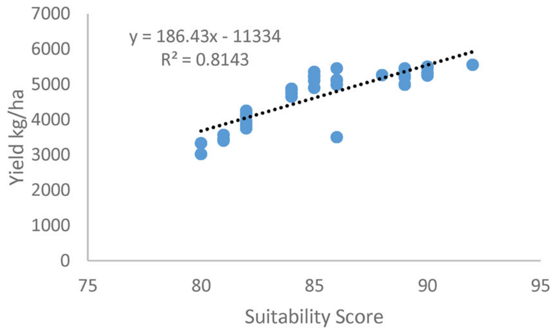

Figure 5. The relationship between the yield and Land Suitability scores.

lands can be grown successfully. Land suitability assessment would help to determine the alternative crops for S2 lands.

3.4. Validation of the land suitability for wheat farming

Wheat yield of the region 2013 ranged from 3021 to 5550 kg ha-1, while the average yield was 4890 kg ha-1 in 2013. The relationship between the wheat yield in Çumra region and the suitability map was evaluated with the linear regression. The coefficient of determination (R2) was 0.81, which indicates a successful prediction of the model (Figure 5). In addition, Sys Ir et al. (1993) emphasized that 2.5-3.5 tons of grain ha-1 in rainfed conditions and 4-6 tons of grain ha-1 in irrigated conditions are good commercial yields. The wheat in the study area is grown completely under irrigated conditions. The average yield of 4890 kg ha-1 under irrigated conditions confirms that the classification obtained in land suitability assessment. The results of validation showed that the land suitability analysis using the integration of AHP and GIS are in good agreement with. Many researchers also reported that the AHP method offers more realistic and rational assessments in analyzing large numbers of hierarchical and complex data. In addition, the AHP is more successful and has many advantageous than other classical parametric methods (Zhang et al. 2015; Yalew et al. 2016; Dedeoğlu and Dengiz 2019; Orhan 2021).

4. Conclusion

This study aimed to evaluate the land suitability of Cumra plain for wheat production. Climate and topography of the study area were homogeneous; thus, suitability assessment was carried out based on the multi-criteria parameters composed of only the soil properties. However, the similar methodology followed in this study can be applied to heterogenous lands including topography, climate and other necessary parameters affecting the crop growth.

Relative importance weights were given to the parameters with expert opinion and literature support using the using the AHP, and the suitability of the study area for wheat cultivation was mapped with overlay analysis in GIS. The results revealed that 74% of the study area is highly suitable and 26% is moderately suitable. High suitability values revealed that wheat production should be prioritized as the main crop in Çumra plain, while other agricultural crops should be considered in rotation.

The results indicated that the GIS-MCDA hybrid approach is an important tool for analyzing, mapping and querying land suitability values. The GIS-MCDA hybrid approach, which yielded reliable suitability assessment for wheat, can be used for other crops. In addition, this study has also revealed that integration of crop specific land suitability assessments to land consolidation efforts would help preparing the sustainable agricultural management plans and increase the efficiency of land consolidation with conserving the natural resources and improving the agricultural production.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

All data generated or analyzed during this study will be provided on request by the corresponding author.

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