



Suitable site selection by using full consistency method (FUCOM): a case study for maize cultivation in northwest Turkey

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Abstract

The agricultural land evaluation procedure is a valuable guide for growing plants where they are best suitable, and it has a critical role in actualizing sustainable plans for providing food security for the growing population. In agricultural land suitability analysis, different multi-criteria decision-making methods are applied. The main objective of this study is to introduce the potential usage of a new multi-criteria decision-making method the Full Consistency Method (FUCOM) in agricultural land suitability analysis. The study was carried out in the northern part of the Karamenderes plain in NW Turkey. Nine land characteristics (soil texture, soil depth, organic matter content, electrical conductivity, pH, slope, drainage, CaCO₃%, and cation exchange capacity) were used for the land evaluation study. The weighting values of the land characteristics were calculated by the FUCOM. According to the results, 223 ha (6.26%) were highly suitable, 2650 ha (74.40%) were moderately suitable, 508 ha (14.26%) were marginally suitable, and 181 ha (5.08%) were not suitable for maize cultivation. The weighted values of the parameters were also tested with Analytic Hierarchy Process (AHP) and the Best-Worst Method (BWM). There is a general compatibility between the methodologies. The data obtained from these methods showed that analysis consists of a very positive relationship with each other. The comparisons of these methodologies showed that FUCOM's prioritization order simplicity in parameter weighting and ability to reduce the processing intensity would provide a significant contribution and advantage to the land evaluation experts and planners. It is recommended that the Full Consistent Method could be reliably used in agricultural land suitability analysis.

Keywords Land suitability · Multi-criteria decision making · Sustainable agriculture · Overlay analysis

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1 Introduction

The rapid increase in the world's population since the industrial revolution has led authorities to seek solutions to issues related to food security, the quality of life of future generations, and increasing land degradation (Beek et al., 1997). The COVID-19 pandemic began at the end of 2019 and rapidly exacerbated, and other pandemics that may occur in future have shown the importance of reaching healthy food. Restricted food mobility and production due to the pandemic have further increased the importance of sustainable use of natural resources.

The reduction of agricultural lands with increasing pressures poses severe threats to producing safe and healthy food. The most important way to reach safe and healthy food can be provided with a sustainable agricultural production model. Only rational planning studies can ensure sustainability in agricultural production and improve soil health. Özkan et al. (2019) mentioned that countries need plans at various scales to meet their nutritional needs and ensure self-sufficiency in primary food products. Land evaluation studies are critical tools for the realization of these plans.

Land evaluation studies ensure using land resources at a sustainable level, and it aids in safeguarding them for future generations' needs. FAO (1976) defined the land evaluation concept as the determination of the capabilities and productivity of the land. Land evaluation is a land use planning tool, and it evaluates the expected benefits, limitations, and environmental impacts that may occur from sustainable land use (Rossiter, 1996).

In agricultural land evaluation studies, complex parameters such as physical and chemical soil characteristics, land morphology, and climatic parameters affect each other. Multi-criteria decision-making (MCDM) methods are often used to evaluate these interrelated parameters (Bilgilioğlu 2021; Zhang et al. 2021). Since the second half of the 20th century, mathematical models have been used in land evaluation studies and valuable results have been obtained with the support of developing computer technologies (Odeh & McBratney, 2005). MCDM is a methodology that allows determining the best alternative among all available options in the presence of more than one criterion. Due to the wide range of data and the complexity of the criteria in land suitability studies, the use of MCDM in these studies has been suggested by different researchers (Sarkar et al., 2021; Makungwe et al., 2021) Several land suitability studies are used different MCDM methods in the literature. Most of these studies were performed using the AHP method. Various researchers have conducted different land suitability and site selection studies using the AHP method (Zolekar, 2018; Dedeoğlu & Dengiz, 2019; Everest, 2021; Özkan et al., 2020; Everest et al., 2021; Bilgilioğlu, 2021; Günal et al., 2022; Everest & Gür, 2022). There are also studies using MCDM methods other than the AHP in the literature. Mendas et al. (2021) conducted an agricultural land-use suitability study in Algeria using the ELECTRE Tri method. Mistri and Sengupta (2019) used Weighted Principal Component Analysis and the AHP method in the agricultural land suitability study. Montgomery et al. (2017) used the Logic Scoring of Preference method to classify land use capability and suitability in Colorado, USA. Jahanpoor et al., (2018) used the PROMOTHEE technique to determine land suitability for pomegranate and pistachio in Iran. Bagherzadeh and Gholizadeh (2017) used the TOPSIS method to assess land suitability for the alfalfa plant in Joveyn Plain in Iran. Everest et al. (2022) determined the land suitability for paddy using the Best-Worst Method (BWM).

MCDMs, used by different disciplines and diversified with the development of new mathematical models, have been increasingly used by land evaluation experts to

determine the suitability of different land-use types. Similarly, the Full Consistency Method (FUCOM) method, recently added to the literature by Pamučar et al. (2018), is discussed by different disciplines. In the literature survey, it was noticed that the FUCOM had been used in many other fields such as; site selection for textile production (Ulutaş & Karakuş 2021), landfill site selection (Badi & Kridish, 2020) determination of groundwater potential (Akbari et al. 2021), site selection for solar panel energy (Cao et al. 2019), wind farm site selection (Ecer, 2021), mapping the mineral potential (Feizi et al. 2021), selection of technologies for municipal wastewater treatment (Srivastava & Singh, 2021). However, agricultural land suitability and suitable site selection studies for different crops are not available in the literature with the use of FUCOM. To the best of our knowledge, this study will be the first agricultural land suitability study to be conducted using the FUCOM. This deficiency in the literature constituted the primary motivation of the study. The main objective of this study is to test the potential use of the FUCOM subjective weighting method for agricultural land suitability. Within the scope of the study, suitable lands for maize cultivation were evaluated by the FUCOM method. Then, the results of FUCOM were compared with other commonly used multi-criteria decision-making methods (AHP and BWM).

2 Materials

2.1 Study area

The study area consists of lands north of the Karamenderes basin in NW Turkey. It is located between 39°57'36"–40°00'18"N latitudes and 26°10'12"–26°18'36"E longitudes and covers an area of 3562 ha (Fig. 1). The main geological units in the study area are the Quaternary aged alluvium deposit carried by the Karamenderes and Dümrek rivers and the Miocene aged Terrigenous clastic and calcareous units in the sloping and high terrain areas. The climate is characterized by the transition between the Marmara and Aegean regions, with cool and rainy winters and hot and dry summers. The annual average temperature is 15 °C, and the total precipitation is 625 mm (MGM, 2021). Soil resources in the study area are Typic Ustifluvents, Typic Fluvaquents, Typic Haplustepts, Typic Calcustepts, Mollic Ustifluvents, Typic Ustorthents, Inceptic Haplustalfs according to Soil Taxonomy (Everest, 2015). The most important economic activity in the region is agricultural production. In addition, the most cultivated crops are wheat, barley, alfalfa, tomato, pepper, maize, and paddy.

3 Methodology

Within the scope of this study, maize was chosen as the target plant due to its strategic importance. Maize is in third place after wheat and paddy in the cultivation area, but it is first in production. Maize is used for food, animal feed, and biofuel. The most maize-producing countries are the USA, China, and Brazil. Turkey ranks 24th in maize production (ZMO, 2016). In 2020, maize was cultivated in $196,982 \times 10^3$ hectares globally and 591,900 hectares in Turkey (TEPGE, 2021). Maize is grown intensively in Turkey's Mediterranean, Southeastern Anatolia, and Aegean regions.

In this study, related studies in the literature were examined to determine the soil requirements of the maize plant (Sys et al., 1993; Jimoh et al. 2016; Tashayo et al. 2020;

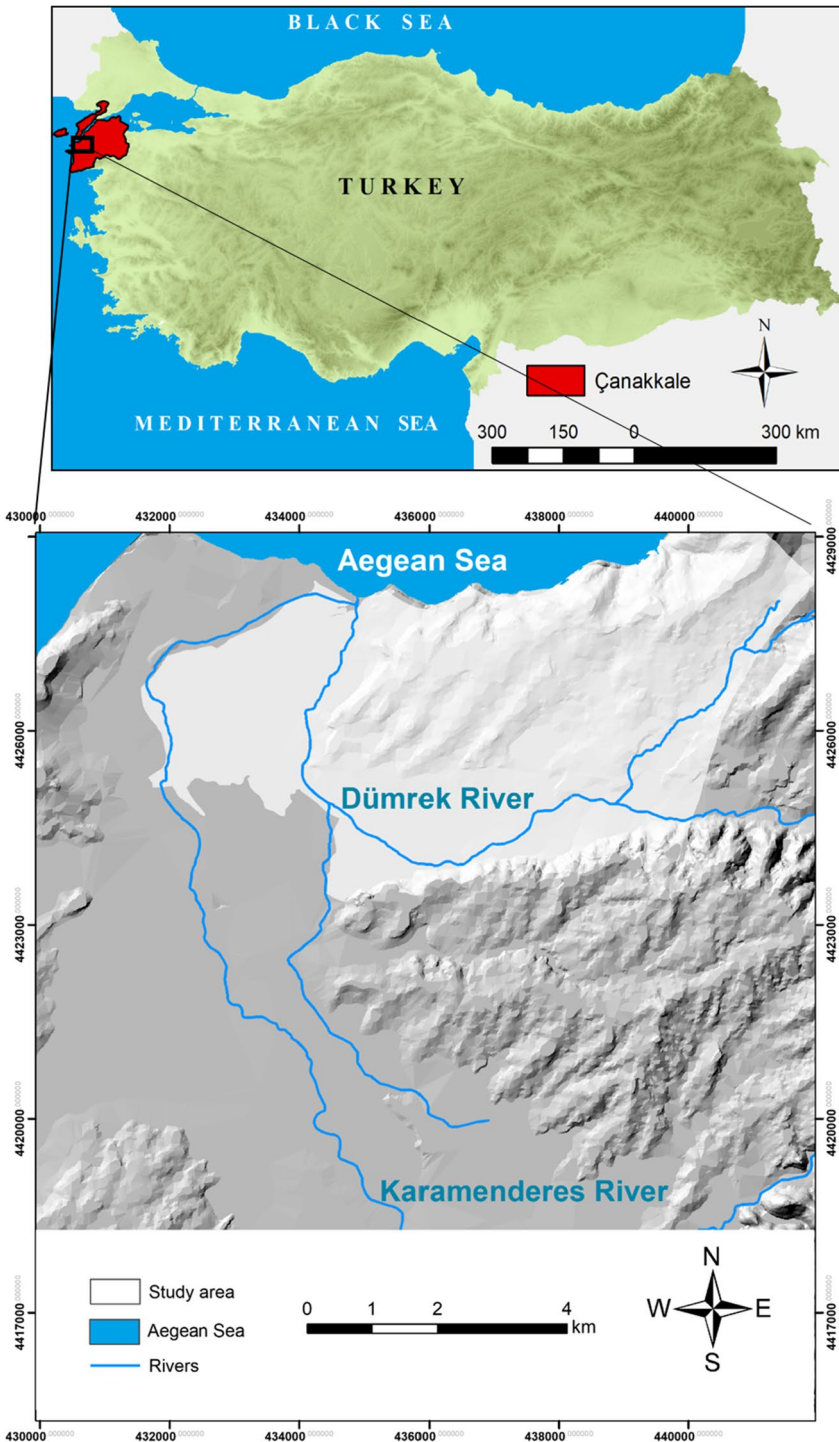


Fig. 1 Study area

Costantini, 2009). Only physical, chemical, and morphological characteristics were evaluated for the suitability analysis. Nine land characteristics (soil texture, depth, organic matter, EC, pH, slope, drainage, CaCO₃%, and Cation Exchange Capacity (CEC)) were used in the model for land evaluation.

The soil properties were taken from the 1/10,000 scale detailed soil survey and mapping report produced by Everest (2015). Spatial information on each physical and chemical characteristic was obtained from land mapping units of the detailed soil survey report. The Digital Elevation Model (DEM) was generated from 30×30 m spatial resolution data downloaded from NASA’s website. The slope map was also derived from the DEM map. An impact scoring was performed to score the sub-parameters. Score 4 was given for optimum conditions for the plant requirements, and score 1 was given for not meeting conditions (Table 1). Middle scores were used among optimal and limiting conditions. The flow-chart of the study (Fig. 2) is also presented.

3.1 FUCOM subjective weighting method

FUCOM is a subjective criterion weighting method introduced to the literature by Pamučar et al. (2018). This method makes it possible to obtain a solution by making significantly fewer pairwise comparisons than other criterion weighting methods. For *n* criteria, this approach performs *n* – 1 comparisons (Pamučar et al., 2018; Ayçin et al., 2021). Furthermore, one of the other outstanding features of this method is that it is not complicated and can be used in the group decision-making process.

The application steps of the FUCOM, which include all the formulas, are explained in three stages (Pamucar et al., 2018; Ayçin et al., 2021).

Step 1. Ranking according to the significance of criteria

Firstly, the decision-maker(s) rank the criteria from most important to least important (Table 2). Thus, criteria rankings are obtained according to the expected values of the weight coefficients as in the expression (1).

$$C_{j(1)} > C_{j(2)} > \dots > C_{j(k)} \tag{1}$$

where *k* represents the rank of considered criteria. In the case of criteria considered to be of equal importance by the decision-maker “=” sign can be used instead of “>”.

Step 2. Determination of comparative priorities of criteria

Secondly, comparing the ranking criteria is performed, and the comparative priority of the evaluation criteria ($\phi_{k/(k+1)}$) is defined. As a result, the vector of the comparative priority is obtained, as shown in expression (2).

$$\phi = (\phi_{1/2}, \phi_{2/3}, \phi_{3/4}, \dots, \phi_{k/(k+1)}) \tag{2}$$

where the value $\phi_{k/(k+1)}$ represents a superiority of $C_{j(k)}$ rank criterion over $C_{j(k+1)}$ rank.

In the FUCOM, the decision-maker(s) can use integers, decimals, or values of certain scales to compare criteria. This provides flexibility to decision-makers in the evaluation of criteria.

Step 3. Calculation of the weights of criteria

The final weight coefficients $\omega_1, \omega_2, \dots, \omega_T$ are obtained in the last step. These values should provide the two requirements:

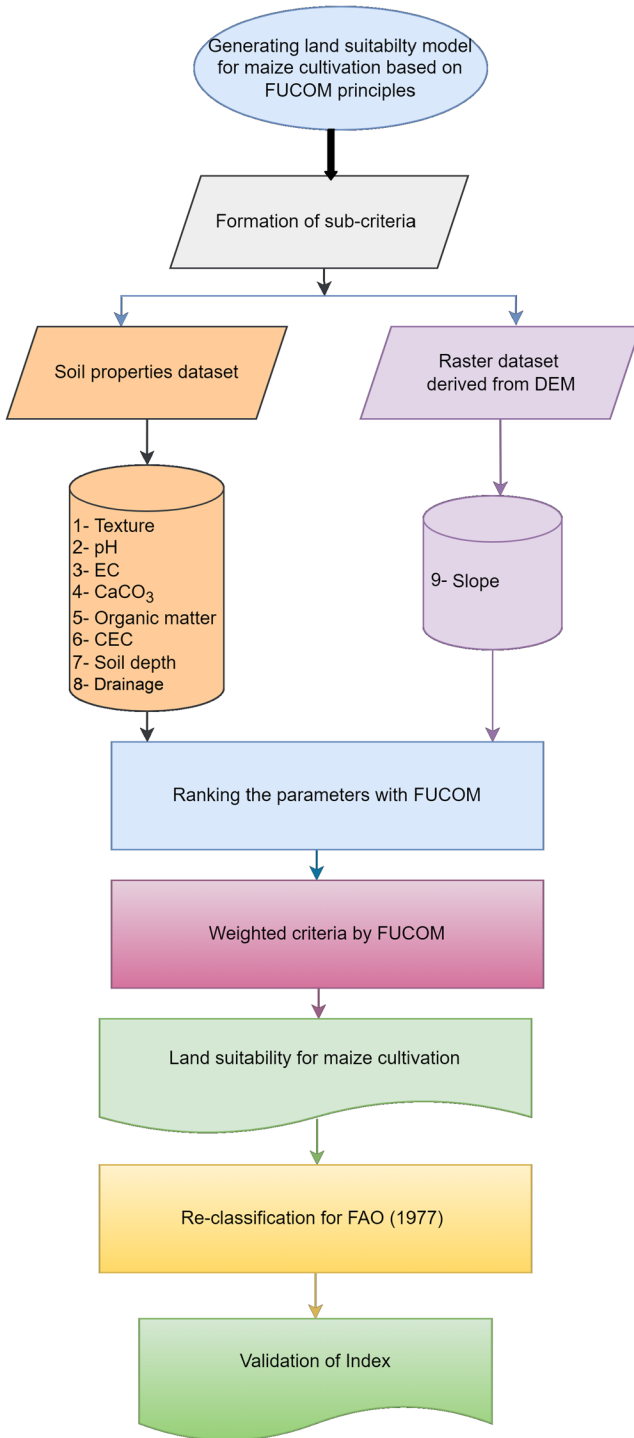


Fig. 2 Flowchart of the study

Table 2 Ranking criteria for FUCOM

Criteria no.	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Criteria	Texture	EC	Drainage	Depth	Slope	CaCO ₃	pH	OM	CEC
Rank	1	2	3	4	5	6	7	8	9

- (1) The proportion of the weight coefficients given in expression (3) is equal to the comparative priority of the criteria determined in Step 2.

$$\frac{\omega_k}{\omega_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

- (2) The final values of the weight coefficients should satisfy the condition of mathematical transitivity; that is.

$\varphi_{k/(k+1)} \times \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{\omega_k}{\omega_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{\omega_{k+1}}{\omega_{k+2}}$, that $\frac{\omega_k}{\omega_{k+1}} \times \frac{\omega_{k+1}}{\omega_{k+2}} = \frac{\omega_k}{\omega_{k+2}}$ is obtained. Therefore, another requirement that the final values of the weight coefficients of the evaluation criteria need to satisfy is obtained as shown in expression (4).

$$\frac{\omega_k}{\omega_{k+2}} = \varphi_{k/(k+1)} \times \varphi_{(k+1)/(k+2)} \tag{4}$$

Full consistency is validated when the conditions in the expression (3) and (4) are satisfied. Namely, a deviation from full consistency (DFC) is minimum in this case. In this way, the criterion for maximum consistency is satisfied, and DFC is $\chi = 0$ for the calculated values of the weight coefficients.

The linear programming model shown in expression (5) should be solved for calculating the final values of the weight coefficients of the evaluation criteria.

$$\begin{aligned} & \text{Min } \chi \\ & \left| \frac{\omega_{j(k)}}{\omega_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq \chi, \forall j \\ & \left| \frac{\omega_{j(k)}}{\omega_{j(k+2)}} - \varphi_{k/(k+1)} \times \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j \\ & \sum_{j=1}^n \omega_j = 1 \\ & \omega_j \geq 0, \forall j \end{aligned} \tag{5}$$

By solving the linear programming model (5), the final values of the evaluation criteria $(\omega_1, \omega_2, \dots, \omega_n)^T$ and DFC(χ) are calculated.

3.2 FUCOM: a case study for maize cultivation

In this study, FUCOM was applied to determine the relative weighted value of criteria required for maize farming. Firstly, criteria and sub-criteria were determined. In the

suitability analysis, nine selected parameters were used. Secondly, pairwise comparisons were made. The comparisons are presented in Table 3. The relative significance of parameters in the same hierarchical level was considered for binary comparisons. Saaty (1980)'s 1–9 scale was used in binary comparisons. Finally, the resultant values of the weighted coefficients were calculated.

By using evaluations in Table 3, all the priorities of the evaluation criteria are calculated as follows:

$$\varphi_{C1/C2} = 2/1 = 2 \quad \varphi_{C2/C3} = 3/2 = 1,5 \quad \varphi_{C3/C4} = 3/3 = 1 \quad \varphi_{C4/C5} = 4/3 = 1,33$$

$$\varphi_{C5/C6} = 5/4 = 1,25 \quad \varphi_{C6/C7} = 6/5 = 1,2 \quad \varphi_{C7/C8} = 6/6 = 1 \quad \varphi_{C8/C9} = 7/6 = 1,16$$

Although the ratio of the weight coefficients given in expression (3) is equal to the comparative priority of the criteria, the ratio of the weight coefficients is obtained as follows:

$$\omega_{C1/C2} = 2 \quad \omega_{C2/C3} = 1,5 \quad \omega_{C3/C4} = 1 \quad \omega_{C4/C5} = 1,33$$

$$\omega_{C5/C6} = 1,25 \quad \omega_{C6/C7} = 1,2 \quad \omega_{C7/C8} = 1 \quad \omega_{C8/C9} = 1,16$$

Furthermore, the final values of the weight coefficients should provide the condition of mathematical transitivity as follows:

$$\frac{\omega_1}{\omega_3} = \omega_{C1/C2} \times \omega_{C2/C3} = 2 \times \frac{3}{2} = 3$$

$$\vdots$$

$$\frac{\omega_7}{\omega_9} = \omega_{C7/C8} \times \omega_{C8/C9} = 1 \times 1,16 = 1,16$$

Finally, the linear programming model for determining the final values of the weight coefficients can be stated in expression (6):

$$\begin{aligned} & \text{Min } \chi \\ & \left| \frac{\omega_1}{\omega_2} - 2 \right| \leq \chi, \left| \frac{\omega_2}{\omega_3} - 1,5 \right| \leq \chi, \dots, \left| \frac{\omega_8}{\omega_9} - 1,16 \right| \leq \chi \\ & \left| \frac{\omega_{j(k)}}{\omega_{j(k+2)}} - \varphi_{k/(k+1)} \times \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j \\ & \sum_{j=1}^9 \omega_j = 1 \\ & \omega_j \geq 0, \forall j \end{aligned} \tag{6}$$

When Excel Solver solves a model (6), the final values of the weight coefficient are calculated (Table 4).

ArcGIS 10.3 was used for overlay analysis and mapping procedure. According to FAO (1977) criteria, the suitability was reclassified, and the final suitability map was obtained.

Table 3 Comparisons in FUCOM

Criteria according to rank	Texture	EC	Drainage	Depth	Slope	CaCO ₃	pH	OM	CEC
Comparisons	1	2	3	3	4	5	6	6	7

Table 4 Weighted values obtained from FUCOM calculations

Parameters	Weighted values
Texture	0.323
EC	0.162
Drainage	0.108
Depth	0.108
Slope	0.081
CaCO ₃	0.065
pH	0.054
OM	0.054
CEC	0.046

3.3 Comparison of FUCOM results with AHP and BWM

The weighted values obtained by the FUCOM were also calculated using the BWM method (Rezaei, 2015) and the AHP (Saaty, 1980).

3.4 BWM methodology

BWM was introduced to the literature by Rezaei (2015). BWM is a pairwise comparison-based multi-criteria decision-making method. Initially, the best and the worst criteria were determined by the decision-maker. Then, the best criterion is compared with the other criteria. In the BWM methodology, a 1–9 scale was used to determine the relative preference levels of the criteria.

The BWM calculations are provided below step by step (Rezaei, 2015; Rezaei, 2016):

Step 1 A set of decision criteria are built.

Step 2 The best and the worst criteria are determined.

Step 3 The best criterion is compared to all the other criteria by using numbers 1–9 with $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$ and $a_{BB} = 1$;

Step 4 The worst criterion is compared to other criteria by using numbers 1–9 with $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})$ and $a_{WW} = 1$;

Step 5 Optimal weighted values for each criterion are obtained. For each pairwise comparison, among the best criterion and the others ($\frac{W_B}{W_j}$) and the worst criterion and the others ($\frac{W_j}{W_W}$) should be satisfied. For this $\left| \frac{w_B}{w_j} - a_{Bj} \right|$ and $\left| \frac{w_j}{w_W} - a_{jW} \right|$ for all j , should be minimized. In the methodology consistency ratio is checked with formulation (7) below:

$$\text{Consistency Ratio (CR)} = \frac{\xi^*}{\text{Consistency index(CI)}} \tag{7}$$

Here ξ^* is the optimal value of the method.

CI value was obtained from Rezaei (2015). The BWM comparisons are presented in Table 5.

Table 5 Pairwise comparisons based on BWM

Best to others	Texture	EC	Drainage	Depth	Slope	CaCO ₃	pH	OM	CEC
Texture	1	2	3	4	4	4	5	5	5
Others to worst	CEC								
Texture	5								
EC	4								
Drainage	3								
Depth	3								
Slope	2								
CaCO ₃	2								
pH	1								
OM	1								
CEC	1								

3.5 AHP

AHP (Saaty, 1980) is a widely used multi-criterion decision-making method. AHP is an MCDM, that can solve complex problems (Moreno-Jiménez et al., 2008). AHP provides to solve problems in a realistic facilitates. In AHP, problems are broken into different hierarchical levels (Badi et al., 2019). AHP enables evaluating qualitative and quantitative factors. With binary comparisons, priority values are obtained. With the AHP, decision-makers can prefer the best alternative. AHP methodology is described in three stages below:

Stage 1: Hierarchical model is structured.

Stage 2: Pairwise comparisons are realized.

Stage 3: Priority values are obtained.

In the first stage, the problem is separated into subsections. In this stage, the determination of criteria, sub-criteria, and alternatives are performed. In the second stage, binary comparisons are structured, and, in this way, a decision matrix is built. The binary comparisons determine the relative significance of parameters that belong to the same hierarchy. In comparison, Saaty (1980)'s 1–9 scale is used. Matrix calculation is carried out in the third stage. With the resultant information of matrix calculations, eigenvector values are obtained. These values are used for assigning weighted values to the criteria and sub-criteria. Finally, the consistency check is controlled. If the consistency is <10% the model is accepted as validated. Otherwise, the binary comparison should be restructured (Saaty, 1980). The AHP comparisons are presented in Table 6.

4 Results and discussions

In this study, suitability analyses for maize farming were carried out. The maize plant was chosen because of its strategic importance. Maize, the feed source for humans and animals, is the most important grain in the world after wheat and paddy (Preedy & Watson, 2019; Tashayo et al., 2020). In addition, maize is used as an industrial raw material source

Table 6 Pairwise comparisons based on AHP

	Texture	EC	Drainage	Depth	Slope	CaCO ₃	pH	OM	CEC
Texture	1	2	3	4	4	5	6	6	7
EC	1/2	1	2	3	3	4	6	6	6
Drainage	1/3	1/2	1	3	3	4	5	5	5
Depth	1/4	1/3	1/3	1	2	3	4	4	4
Slope	1/4	1/3	1/3	1/2	1	2	3	3	3
CaCO ₃	1/5	1/4	1/4	1/3	1/2	1	3	2	2
pH	1/5	1/6	1/5	1/4	1/3	1/3	1	1	2
OM	1/6	1/6	1/5	1/4	1/3	1/2	1	1	2
CEC	1/7	1/6	1/5	1/4	1/3	1/2	1/2	1	1

$\lambda = 9.60$, $n = 9$, CI (consistency index) = 0.074, CR (consistency ratio) = 0.051

(Ramamurthy et al., 2020). Different researchers have conducted suitability studies for maize cultivation in various parts of the world (Braimoh et al., 2004; Tashayo et al., 2020; Pilevar et al., 2020; Wanyama et al., 2019; Ramamurthy et al. 2020). Researchers also suggested that it is essential to determine suitable areas for maize cultivation and that studies should be increased. In addition, Sharma et al. (2018) stated that the literature should be supported, especially with crop-based studies.

The FUCOM was used for assigning weighted values for the selected land characteristics and then suitability analyses for maize cultivation were performed. As a result of the calculations, Texture (0.323) was the most effective factor, and EC (0.162) was evaluated as the second effective factor. The lowest weighted value was assigned to the CEC (0.046) criterion (Table 4). Soil texture is an important parameter affecting the soil's biophysical properties, soil fertility, and quality in the long term (Upadhyay & Raghubanshi, 2020). Leclerc et al. (2001) defined soil texture as the most critical component in soil fertility. In addition, Ziadi (2013) mentioned that soil texture is a very effective parameter in maize cultivation and have an essential role in the uptake of nitrogen element. For these reasons, texture has been considered this study's most critical land characteristic. The weighted value of the EC parameter was determined as (0.162). Soil salinity is an important limiting factor that reduces the quality and productivity of crops. Although maize can tolerate moderate salinity, it is a salinity-sensitive crop in the early stages of growth (Sabagh et al., 2021). Salinity adversely affects maize crops' vegetative and generative development, so plant growth and yield decrease (Iqbal et al., 2020). The weighted value of the drainage parameter was determined as (0.108). Saturated soil conditions in poor drainage restrict the rooting and plant growth of the maize and significantly limit its production (Nielsen, 2012; Nash et al., 2015). The weighted value of the soil depth parameter was determined as (0.108). Shallowness is an important limiting factor for land use, land management, and crop production. In shallow soils, the water holding capacity of the soil and the availability of nutrients are reduced, and crop yields decrease due to the limitation of root elongation (Peralta et al., 2021). Moreover, Sadras and Calvino (2001) reported that maize cultivation in shallow soils significantly reduced crop yield. The weighted value of the slope parameter was determined as (0.081). As the slope increases, the severity of the erosion rises, and using agricultural machinery becomes more problematic. Changere and Lal (1997) reported that sloping lands have disadvantages while flatlands are more suitable for maize growth. On the other hand, Fujisao et al. (2020), reported that plant nutrients decreased

in sloping lands where maize cultivation was carried out, and as a result, this limited the yield. The weighted value of the CaCO_3 parameter was determined as (0.065). El-Tilib (2005) reported that increasing CaCO_3 values in the soil decreased maize's dry matter weight and grain yield. Similarly, Elamin et al. (2005) also reported that high levels of CaCO_3 adversely affect the N, P, and Mg contents in maize cultivated soils. The weighted value of the soil pH parameter was determined as (0.054). The solubility of plant nutrients is associated with soil pH. It has been reported that the ideal pH range for maize cultivation is neutral or near-neutral conditions (The et al., 2006). Tandzi et al. (2018) stated that low pH conditions reduce maize grain yield. Rahman et al. (2011) noted that high pH conditions adversely affect maize growth, especially in calcareous environments. The weighted value of the soil organic matter was determined as (0.054). Soil organic matter improves the soil's physical, chemical, and biological processes and influences soil fertility. It has been reported that increasing soil organic matter increases maize yield (Kane et al., 2021). Low soil organic matter has also been reported to reduce maize yield (Mendez et al., 2019). The weighted value of the cation exchange capacity was determined as (0.046). Cation exchange capacity indicates soil nutrient holding capacity (Fugger, 1999; Braimoh et al., 2004). High amounts of CEC in the soil indicate that plant nutrients are sufficient, and low amounts indicate that the soil needs fertilization (Arunrat et al. 2020).

Figure 3 presents the land suitability map obtained by the FUCOM. The analyses showed that 223 ha (6.26%) were highly suitable, 2650 ha (74.40%) were moderately suitable, 508 ha (14.26%) were marginally suitable, and 181 ha (5.08%) were not suitable for maize cultivation (Table 7). Highly suitable lands have optimum conditions in terms of all land characteristics, where there are no or very few limiting factors in the study area. Moderately suitable lands are the most common lands in the study area. These lands consist of coarser textured, slightly alkaline soils with medium organic matter content. Marginally suitable lands contain coarser textured, sloping, shallow, low organic matter content, moderately alkaline, moderately limy soils. Although not suitable lands have similar characteristics with marginally suitable lands, these lands also consist of sections with severe saline soils in the delta plain and very steep lands in higher altitudes.

Validating the result of MCDA analysis is essential for testing the reliability of the data (Chen et al., 2010; Ghorbanzadeh et al., 2018). For accuracy assessment, interviews were conducted with the experts in Çanakkale Agriculture Directorate. The comparison was easily performed since maize production (forage crop, maize grain, and seed production) was recorded very sensitively. The data produced from this study and the land records showed a significant similarity. Also, it was seen that the farmers chose especially highly and moderately suitable lands for maize cultivation. The results were also compared with AHP and BWM methods. The statistical evaluation showed general compatibility between the three methodologies. The data obtained from FUCOM, BWM, and AHP analysis consist of very closer values. In the correlation analysis ($p < .05$), it was determined that there

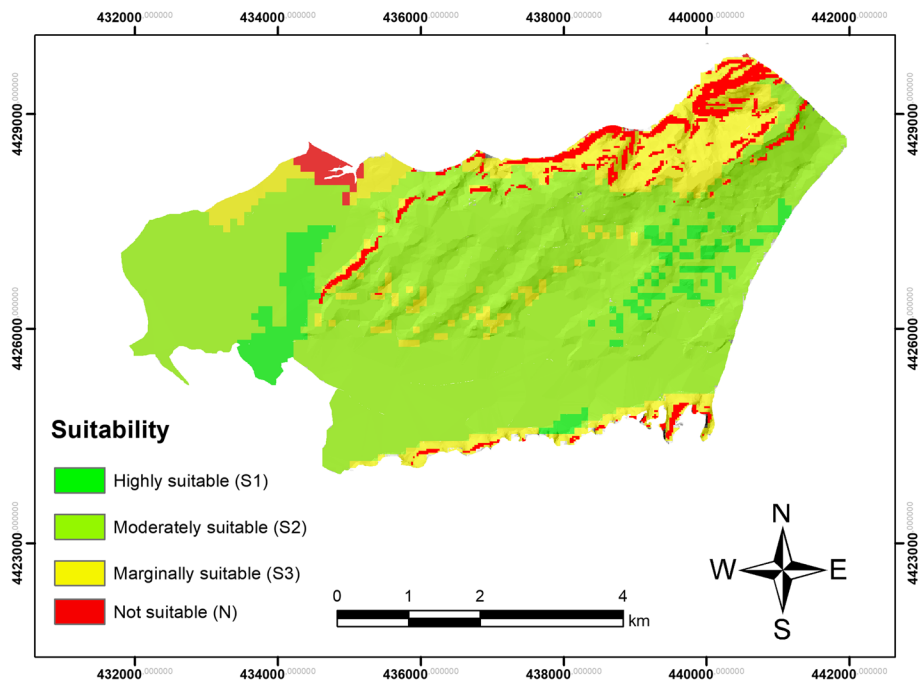
Table 7 Land suitability for maize cultivation based on FUCOM

Suitability classification	Class	Area (ha)	Area (%)
Highly suitable	S1	223	6.26
Moderately suitable	S2	2650	74.40
Marginally suitable	S3	508	14.26
Not suitable	N	181	5.08
Total		3562	100

Table 8 Comparisons of the weighted values according to methodologies

Parameters	FUCOM	BWM	AHP	Mean	Std. dev.	CV
Texture	0.323	0.292	0.290	0.30	0.015	5.01
EC	0.162	0.173	0.209	0.18	0.020	11.07
Drainage	0.108	0.115	0.165	0.13	0.025	19.62
Depth	0.108	0.115	0.107	0.11	0.004	3.24
Slope	0.081	0.086	0.078	0.08	0.003	4.04
CaCO ₃	0.065	0.069	0.055	0.06	0.006	9.35
pH	0.054	0.058	0.034	0.05	0.010	21.57
OM	0.054	0.058	0.035	0.05	0.010	20.48
CEC	0.046	0.034	0.027	0.04	0.008	22.00

Std. Dev.—standard deviation, *CV*—coefficient of variation

**Fig. 3** Land suitability for maize cultivation based on FUCOM

was a positive ($r = .992$) relationship between FUCOM and BWM and a positive relationship ($r = .941$) between FUCOM and AHP method (Table 8). The statistical evaluation supported that there was consistency among the methods. Similarly, Ecer (2021) reported a strong correlation between FUCOM, BWM, and AHP methods in his study. For this reason, it can be concluded that the values obtained by the study are acceptable and reliable.

Different researchers have used the multi-criteria approach for decision support in land suitability studies. Zhang et al. (2015) used the AHP method to determine suitable lands for tobacco farming. They reported that one of their study's challenges was determining the weighting values of the factors in the multi-criteria decision-making process. Flynn

(2019) used AHP in his research and reported that the most critical step in the study is the determination of weights. Zabihi et al. (2015) determined suitable lands for citrus cultivation with AHP in their research. They reported that prioritization of all alternatives and criteria to each other have complex relationships. Seyedmohammadi et al. (2019) emphasized that there are a lot of studies on land suitability evaluation and they suggest more research should be conducted. Therefore, they suggest applying new interactive methodologies for land evaluation. Recently, new methodologies were used in land evaluation studies in the literature. Everest et al. (2022) and Tercan & Dengiz (2022) used the BWM in site selection for rice cultivation. Kheybari et al. (2021) used BWM for land suitability for corn cultivation. Researchers performed fewer pairwise comparisons to AHP and they obtained acceptable results. Although the AHP method is used effectively to solve many decision-making problems, it is criticized in some aspects. These can be listed as the problems experienced in pairwise comparisons, inability to deal with uncertainty and indecision situations, and being too dependent on the expert’s knowledge (Deng, 1999; Özkan et al., 2019). The BWM, on the other hand, makes fewer comparisons compared to AHP.

In our study, fewer comparisons were made with the FUCOM compared to the AHP and the BWM. It is one of the most important results of this study, and it is especially useful in preventing confusion arising from pairwise comparisons in multi-criteria decision-making. These results are supported by different researchers. Puška et al. (2021) reported that the FUCOM method performed fewer binary comparisons than AHP. Biswas et al. (2021) stated that making $(n - 1)$ number comparisons in FUCOM decreases the inconsistency due to judgment. Akbari et al. (2021) reported that the FUCOM methodology removed the redundancy of comparisons in criteria pairs. Required pairwise comparisons for FUCOM, AHP, and BMW methods are given in Table 9. According to Table 9, it was observed that the most comparison was in the AHP (36) method, and the fewer comparison was in the FUCOM (8). These calculations support our results. The approach put forward in this study reveals that the FUCOM can be easily applied in agricultural land evaluation studies. It contributes to reducing the inconsistency of the judgments of the decision-makers. The method offers users a more flexible and comfortable mathematical model, and the results produced by the model are more optimistic. These results are in compliance with other studies. Pamučar et al. (2021) reported that FUCOM used a simple algorithm in the calculation and made fewer binary comparisons in deciding the criterion weights. Multi-criteria land suitability assessments are expressed with mathematical formulas. Each parameter evaluated with these methods is used in the mathematical model and land suitability classes are determined according to these calculated index values (Dengiz & Sarıoğlu, 2013). For this reason, the widespread use of different mathematical methods and practical options for land evaluation experts may produce more effective land evaluation studies. The currently unplanned use of the lands increases the problems of limited

Table 9 The required number of comparisons in AHP, BWM, and the FUCOM

MCDM method	The number of criteria (n) and the required number of pairwise comparisons							
	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$	$n=8$	$n=9$
AHP $(n(n - 1)/2)$	1	3	6	10	15	21	28	36
BWM $(2n - 3)$	1	3	5	7	9	11	13	15
FUCOM $(n - 1)$	1	2	3	4	5	6	7	8

Bold indicates the study’s numbers of pairwise comparison

resources (Chaudhary et al. 2008). As a solution to this problem, planning studies should be expanded. Increasing land evaluation studies can be achieved by developing easy-to-use methods. For this reason, we recommend that the FUCOM can be used in land evaluation studies due to its flexibility, ability to reduce the processing intensity, and only assigning values to parameters by prioritizing.

5 Conclusion

Selection of suitable lands is critical for the sustainable and rational use of resources in agricultural production. The unplanned use of agricultural lands increases the importance of land suitability studies day by day. In this study, suitable lands for maize cultivation were determined using the FUCOM. This study is the first to integrate the FUCOM into agricultural land suitability studies. In this study, nine land characteristics were used and weighted coefficients were calculated with the FUCOM. The weighted values calculated with the FUCOM were compared with the AHP and the BWM, and it was revealed that the results have a strong relationship with each other. It is concluded that the FUCOM's prioritization order provides a significant advantage and contribution to land evaluation processes. It uses a much simpler algorithm than other methods and removes the redundancy of comparisons in pairs of criteria. The FUCOM can be easily applied to land suitability studies due to these positive advantages. Since the agricultural lands have reached the uppermost limits, macro plans for large areas must have been upgraded with crop-based micro plans. Widespread applications of FUCOM and other techniques could support decision-makers, users, and policymakers in managing natural resources. Because finding the best place for a plant to grow is the most fundamental factor for sustainable and rational planning for food security. For this reason, using different multi-criteria decision-making methods in land evaluation studies and determining which methods are most suitable and easily useable for this area may be the subject of detailed studies in future. Comparing FUCOM results using fuzzy & gray methodologies in future and in-depth studies may add a different dimension to the studies.

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Data availability All data included in this study are available upon request by contact with the corresponding author.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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