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Multi-criteria approach with linear combination technique and analytical hierarchy process in land evaluation studies

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Abstract

Land evaluation analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of yields has contributed to the low production. The aim of this study was to determine the most suitable areas for agricultural uses. For that reasons, in order to determine land suitability classes of the study area, multi-criteria approach was used with linear combination technique and analytical hierarchy process by taking into consideration of some land and soil physico-chemical characteristic such as slope, texture, depth, derange, stoniness, erosion, pH, EC, $CaCO_3$ and organic matter. These data and land mapping unites were taken from digital detailed soil map scaled as 1:5.000. In addition, in order to was produce land suitability map GIS was program used for the study area. This study was carried out at Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages in Yenişehir district of Bursa province. Total study area is 7059 ha. 6890 ha of total study area has been used as irrigated agriculture, dry farming agriculture, pasture while, 169 ha has been used for non-agricultural activities such as settlement, road water body etc. Average annual temperature and precipitation of the study area are 16.1°C and 1039.5 mm, respectively. Finally after determination of land suitability distribution classes for the study area, it was found that 15.0% of the study area has highly (S1) and moderately (S2) while, 85% of the study area has marginally suitable and unsuitable coded as S3 and N. It was also determined some relation as compared results of linear combination technique with other hierarchy approaches such as Land Use Capability Classification and Suitability Class for Agricultural Use methods.

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Introduction

Land evaluation analysis is a prerequisite to achieving optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of yields has contributed to the low production. The term "Land suitability assessment" refers to assessment of land performance to derive maximum benefits with minimum degradation when used for a specific purpose. This assessment involves many biophysical factors that directly or indirectly control the ability of this part of land to host the land use under investigation. Performing land suitability evaluation and generating maps of land suitability for agricultural or non-agricultural uses will facilitate to reach sustainable agriculture (FAO, 1976; Vargahan et al., 2011; Rabia and Terribile, 2013).

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Studies of land evaluation are of great importance in guiding decision on land uses in terms of their potential and conserving natural resources for feature generations (Dengiz et. al., 2003). Moreover, the concept of sustainable land use involves producing quality products in an environmentally benign, socially acceptable and economically efficient way (Addeo et al., 2001), ensuring optimum utilization of the available natural resource for efficient agricultural production.

Land evaluation is the process of assessing the performance of land when used for a given purpose. Different types of soils present widely different properties, and therefore the response to each use differs. Land evaluation is based on the idea that this response is a function of these properties. In order to comply with these principles of sustainable agriculture, one has to grow the crops where they suit best and for which first and the foremost requirement is to carry out land evaluation and suitability analysis (Nisar Ahamed et al., 2000). Suitability is a function of land use requirements and land characteristics (Mustafa et al., 2011). Therefore, suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use (FAO, 1976).

Land evaluation methods can be divided into two categories which are parametric and hierarchical approaches. Parametric systems have one category and mathematical formulae are applied so that the final result is expressed in numerical terms. It is generally accepted that the parametric methods are, according to McRae and Burnham (1981) simple, objective, quantitative, reliable, easy to understand and apply, even by the non-specialist, and easy to modify and adapt to new uses. Three main kinds of manipulation can be recognized and these are additive, multiplicative and complex functions such as Storie (1938), Square root (Sys et al., 1991), Productivity index (Delgado and Lopez, 1998), and so on. Categorical systems group the classes into a series of levels of importance (order, class, subclass, type, etc.). In other words, hierarchic systems group land into categories with a different land use potential such as Analytical Hierarchy Process (AHP) (Saaty, 1980), Land Capability Class (Klingebiel and Montgomery, 1966), Suitability Class for Agricultural Use (Şenol and Tekes, 1995) and FAO (1976) systems. In order to overcome the management and analysis of large volumes of spatial data for land evaluation of heterogonous natural land system, the Geographic Information System (GIS) and Multi-Criteria Assessment (MCA) approaches which can be used for solving complex geographical problems associated with AHP are useful because various soil and land characteristics can be evaluated and each weighted according to their relative importance on the optimal land use (Dengiz et. al., 2015).

In this study, AHP was applied in integrating MCA with GIS in order to generate map of land suitability classes for agricultural and non agricultural uses. The main objectives of the current study were to identify the most suitable areas for agricultural land based on physic-chemical properties of various soils in the Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages located in Yenişehir district of Bursa province in the Marmara Region of Turkey. In addition to that, after determination of land suitability distribution classes for the study area, it was also detected some relation as compared results of linear combination technique with other hierarchical approaches such as Land Capability Classification and Suitability Class for Agricultural Use.

Material and Methods

Field description

This study was performed at Mahmudiye, Karaamca, Yazılı, Çiçeközü, Orhaniye and Akbıyık villages in Yenişehir district of Bursa province in the Marmara Region of Turkey (Figure 1). Total study area is 7059 ha. 6890 ha of total study area has been used as irrigated agriculture, dry farming agriculture, pasture, bare land while, 169 ha has been used for non-agricultural activities such as settlement, road, water body etc. Average annual temperature and precipitation of the study area are 16.1^{o}C and 1039.5 mm, respectively. The majority of soils on the study area is Entisol and Inceptisol. Clay content can reach high amount but ranging from 25% to 51% in surface layers. Moreover, these soils include slightly basic to basic (pH 7.05-8.15), non-saline and low and poor organic matter content, which is slightly higher in the surface horizon. From the bedrock point of view, the study area is predominantly located on limestone, marl and alluvial deposit. Topography and slope show great variations and hilly and rolling physiographic units are particularly common in the study area. The research area lies at an elevation from sea level 220-692 m. Besides, slope groups derived from DEM are presented in Table 1 and Figure 2. It can be seen that 54.4 % of the study area has less than 12 % slope whereas, 45.6 % has more than 12 % slope varying from steep to very steep.

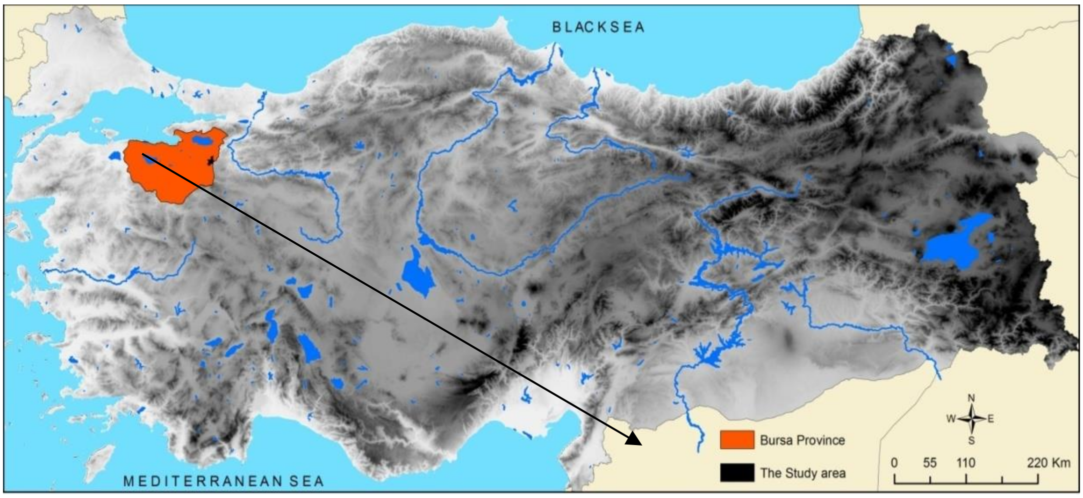

Figure 1. Location map of the study area

Table 1. Distribution of slope degree for the study area

Slope %	Description	Area (ha)	Ratio (%)
0-2	Very gentle	176.1	2.6
2-6	Gentle	1384.3	20.1
6-12	Moderate	2184.6	31.7
12-20	High	1604.7	23.3
20-30	Steep	564.4	8.2
30+	Very steep	975	13.7
Total		6890.0	100.0

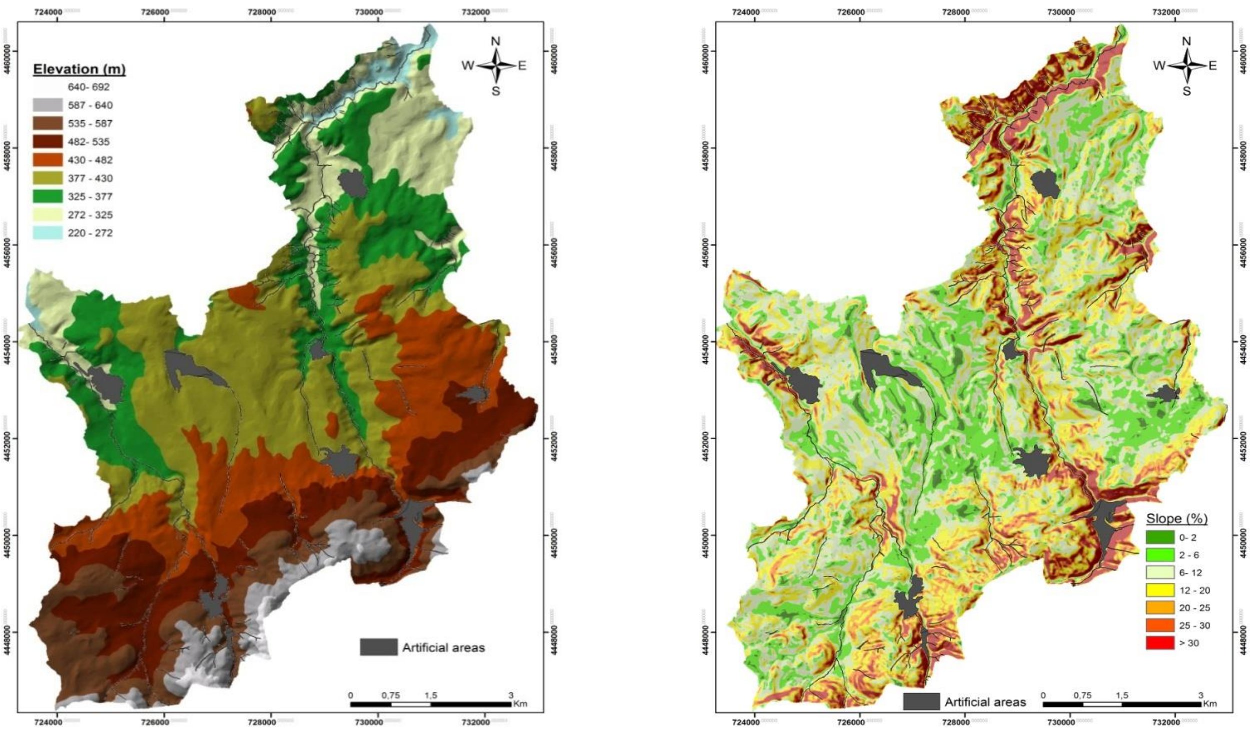

Figure 2. Elevation and slope maps of the study area

Multi criteria assessment approach

The objective of using MCA models is to find solutions to decision-making problems characterized by multiple alternatives, which can be evaluated by means of decision criteria.

Soil and land characteristics criteria taken from digital soil database can be separated into the two categories. First criteria are physical parameters such as texture, soil depth, slope, drainage, and erosion. Another category is chemical criteria which are pH, EC, organic matter, $CaCO_3$ content, and soil fertility (according to macro and micro plant nutrition elements content), their sub-criterion and weighting rates normally employed in land suitability evaluation for agricultural uses were used to compile information on the study area. To analyse MCA, weighted linear combination technique was applied using following formula;

$$\mathrm{LSI} = \sum_{i=1}^{n} (\mathrm{Wi.Xi})$$

Where; abbreviations are: LSI: suitability index, Wi: weighting of parameter i, Xi: Sub-criterion score of parameter i. The above formula is applied to each soil sample. In the overall result, the higher LSI value is the higher suitability of land-use for agricultural activities (Table 2).

Table 2. Land suitability index classes

Definition	Class	Index value
Highly suitable	S1	> 3.500
Moderately suitable	S2	3.000 - 3.500
Marginally suitable	S3	2.000 - 3.000
Unsuitable	N	0.000 - 2.000

In this study, weighting rate takes value between 0 and 4. The least favour value of sub-criteria is 0 and the most beneficial value of sub-criteria is 4 for agricultural land suitability. In other words, the limiting nature of each sub-criterion is taken into account by its effect in reducing productivity (Table 3).

In order to determine which criteria (and at what levels or weights) affect to land evaluation for agriculture; experts are consulted to provide judgments on important of criteria. Using Analytical Hierarchy Process technique these judgments on important of criteria are converted to criteria weights (Wi). Score for each criterion (Xi) on each sample point is then determined. The AHP is developed by Saaty (1980). The principles utilized in AHP to solve problems are to construct hierarchies. The hierarchy allows for the assessment of the contribution individual criterion at lower levels make to criterion at higher levels of the hierarchy.

Using Pair Wise Comparison Matrix, factor weights were calculated by comparing two factors together. The PWCM were applied using a scale with values from 9 to 1/9 or 0.111 introduced by (Saaty, 1980). The comparison can be made using a nine point scale or real data, if available (Saaty and Vargas, 2001). The nine point scale includes: [9, 8, 7, . . ., 1/7, 1/8, 1/9], where 9 means extreme preference, 7 means very strong preference, 5 means strong preference, and so on down to 1, which means no preference (Table 4). This pair-wise comparison allowed for an independent evaluation of the contribution of each factor, thereby simplifying the decision making process (Rezaei-Moghaddam and Karami, 2008).

The pair-wise comparisons of various criteria were organized into a square matrix. The diagonal elements of the matrix were 1. The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted with respect to the criteria or sub-criteria and rated with respect to the alternatives (Bhushan and Rai, 2004). The consistency of the matrix of order n was then evaluated. If this consistency index failed to reach a threshold level, then the answers to comparisons were re-examined. The consistency index, CI, was calculated as:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1}$$

Where; CI is the consistency index (1), λmax is the largest or principal eigenvalue of the matrix, and n is the order of the matrix. This CI can be compared to that of a random matrix, RI (Table 5), such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, CR ≤ 0.1 should be maintained for the matrix to be consistent. Homogeneity of factors within each group, a smaller number of factors in the group, and better a understanding of the decision problem improve the consistency index (Saaty, 1993).

Table 3. Site Selection Criteria and their weighting factor rates for land suitability sites

Physical parameters									
Slope (%)		Texture		Drainage		Depth (cm)		Erosion	
Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate
Flat 0-2	4	Very fine (C->%45)	2	Good	4	0-20	1	1-Low	4
Gently 2-6	3	Moderately fine (C-<%45, CL, SiL, SCL	3	Moderate	3	20-50	2	2-Moderate	3
Moderate 6-12	2	Moderate (L, Si, SiL, fSL)	4	In Sufficient	2	50-90	3	3-High	2
High 12-20	1	Coarse (S, SL, LS)	0	Poor	1	90+	4	4-Severy	1
Very high 20+	0								
Chemical Parameters									
pH		EC (dS/m)		$CaCO_3$ (%)		Organic Matter (%)		Fertility	
Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate	Sub-criterion	Weighting Rate
>8.2-<6.5	1	0-2	4	0-5	2	>3	4	Very poor	1
5.5-6.5	2	2-4	4	5-10	4	2-3	3	Poor	2
6.5-7.5	4	4-8	1	10-20	3	1-2	2	Moderate	3
7.5-8.2	3	8-10	0	20-30	1	<1	1	Fertile	4
		10+	0	30+	0				

Table 4. The comparison scale in AHP

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 5. Values of Random index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Results and Discussion

In order to determine the suitable score for each land mapping unit (LMU), it is composed of two main steps. Firstly, AHP was used to assess and evaluate scores or eigenvector based on suitable criteria. Secondly, after determination of eigenvector for each criteria, weighted linear combination technique was used to determine LSI for each LMU. In first step, AHP requires evaluation of the pair-wise comparison matrices. The pair-wise comparisons of various criteria were organized into a square matrix that was given in Table 6 and normalized pair-wise comparison matrix was also calculated and given in the same table. A standardized eigenvector is extracted from each comparison matrix, allowing us to assign weights to criteria, sub-criteria. It was found the highest value (0.2614) for slope whereas, the lowest value (0.0208) was determined for calcium carbonate content. In order to apply mechanical cultivation in field without taking any measurements, slope degree of the area should not be more than about 10-12% (Sönmez, 1994; Dengiz and Sarioglu, 2013). For that reason, slope is the most important factor in selected criteria to fulfill mechanical agricultural activities. Moreover, slope degree is not only necessary for field traffic applications but also has important role in terms of soil erosion which occurs when slope exceeds a critical angels under absence of vegetation cover and determined second the highest eigenvector value. In addition to that process, for each level in the hierarchy it is necessary to know whether the pair-wise comparison has been consistent in order to accept the results of the weighting. The parameter that is used to check this is called the Consistency Ratio. For this study, consistency ratio was found almost less than 0.1. This indicates that the comparisons of criteria were perfectly consistent, and the relative weights were suitable for use in the suitability evaluation analysis. In second step, weighted linear combination formula was used to assemble a land suitability index for each LMU.

The distribution map of land suitability site for agricultural uses in the study area is illustrated in Figure 3 and classified as four levels according to Table 2. As seen from the land suitability map for agricultural activities, the number of hectares available to each suitability class is as follows: 15.0% of the study area has highly (S1) and moderately (S2) while, 85% of the study area has marginally suitable and unsuitable or non arable lands coded as S3 and N where soils have some main cultivation limitations factors such as high slope (slope degree value > 20%), high soil erosion, low soil depth, low plant nutrient elements, high sand and coarse fragment content, high calcium carbonate content and low drainage condition.

On the other hand, highly and moderately suitable areas (S1 and S2) are only small part of the study area have been mostly used under current crop growing. These S1 and S2 areas were characterized by: slope level of 0-2%, soil pH level between 7.1 to 7.5, soil drainage good and moderate drained, texture class clay loam, these values are in agreement with those considered in the literature such as FAO (1976, 1983, 1985). Unsuitable areas (N) were generally located at north and sought parts in the study areas and covers about 1019.1 ha.

Table 6. Pair wise comparison matrix and eigenvector of criteria in AHP

Pair Wise Comparison Matrix										
	Slope	Texture	Depth	Drainage	Erosion	pH	EC	$CaCO_3$	OM	FR
Slope	1.000	3.000	3.000	5.000	3.000	3.000	5.000	9.000	5.000	7.000
Texture	0.333	1.000	0.333	3.000	0.333	3.000	5.000	5.000	3.000	7.000
Depth	0.333	3.000	1.000	3.000	0.500	5.000	5.000	5.000	7.000	7.000
Drainage	0.200	0.333	0.333	1.000	0.200	1.000	5.000	3.000	5.000	7.000
Erosion	0.333	3.000	2.000	5.000	1.000	3.000	3.000	5.000	5.000	7.000
pH	0.333	0.333	0.200	1.000	0.333	1.000	2.000	3.000	0.500	0.500
EC	0.200	0.200	0.200	0.200	0.333	0.500	1.000	2.000	2.000	3.000
$CaCO_3$	0.111	0.200	0.200	0.333	0.200	0.333	0.500	1.000	0.333	0.333
OM	0.200	0.333	0.142	0.200	0.200	2.000	0.500	3.000	1.000	1.000
FR	0.142	0.142	0.142	0.142	0.142	2.000	0.333	3.000	1.000	1.000
Total	3.185	11.541	7.550	18.875	6.241	20.833	27.333	39.000	29.833	40.833
Normalized Pair Wise Comparison Matrix										
	Slope	Texture	Depth	Drainage	Erosion	pH	EC	CaCO3	OM	FR
Slope	0.314	0.260	0.397	0.265	0.481	0.144	0.183	0.231	0.168	0.171
Texture	0.105	0.087	0.044	0.159	0.053	0.144	0.183	0.128	0.101	0.171
Depth	0.105	0.260	0.132	0.159	0.080	0.240	0.183	0.128	0.235	0.171
Drainage	0.063	0.029	0.044	0.053	0.032	0.048	0.183	0.077	0.168	0.171
Erosion	0.105	0.260	0.265	0.265	0.160	0.144	0.110	0.128	0.168	0.171
pH	0.105	0.029	0.026	0.053	0.053	0.048	0.073	0.077	0.017	0.012
EC	0.063	0.017	0.026	0.011	0.053	0.024	0.037	0.051	0.067	0.073
CaCO3	0.035	0.017	0.026	0.018	0.032	0.016	0.018	0.026	0.011	0.008
OM	0.063	0.029	0.019	0.011	0.032	0.096	0.018	0.077	0.034	0.024
FR	0.045	0.012	0.019	0.008	0.023	0.096	0.012	0.077	0.034	0.024

Eigenvector			
Criteria	Normalized Sum of Rows	Normalized Average Rows	Eigenvector
Slope	2.6136	2.6136/10	0.2614
Texture	1.1744	1.1744/10	0.1174
Depth	1.6926	1.6926/10	0.1693
Drainage	0.8673	0.8673/10	0.0867
Erosion	1.7753	1.7753/10	0.1775
pH	0.4812	0.4812/10	0.0481
EC	0.4229	0.4229/10	0.0423
$CaCO_3$	0.2076	0.2076/10	0.0208
OM	0.4020	0.4020/10	0.0402
FR	0.3492	0.3492/10	0.0349

FR: Fertility, OM: Organic Matter, EC: electrical conductivity , λ_{max} = 11.443, CI: 0.160, CR: 0.1

The results of this investigation were adequate in terms of the evaluation criteria set used here because, in a particular project, only a limited number of land qualities need be selected for use in evaluation (FAO, 1993). In this investigation, the evaluation criteria were selected taking into considering the crop requirements regarding local conditions. In this MCA, the factors were selected based on agronomic knowledge of local experts and reviews of existing literatures. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful precedent for future studies of agricultural cultivation.

It was also determined some relation as compared results of linear combination technique with other hierarchy approaches which are Suitability Class for Agricultural Use (SCAU) and Land Use Capability Classification (LUCC) in this research and their results were given in Table 7 and Figure 3. SCAU values were produced using ILSEN software program created by Şenol and Tekes (1995) based on FAO' principles (FAO, 1976) while, LUCC information was derived from soil database (Anonymous, 1970) prepared by the Rural Affairs General Directory of Agricultural Ministry. SCAU has five classes from best (C1) to non-agriculture

(C5) while, LUCC includes eight classes divided two categories. The first four classes showed as roman number are suitable for agricultural actives whereas, rest of four classes are not suitable for arable lands. In addition, each method class was matched to make interpretation among models. As it can be seen from Table 6, 21.5 % of the total area is coincident with best and relatively good class in SCAU. In the same model, 19.3% of the territory also shows C5 class described as non arable lands. As far LUCC, results of suitability classes for this method were found significantly different from other two methods except for I. class (0.8%) which shows almost parallel with highly suitable (0.5%-LSI) and with best suitable (0.6%-SCAU) values. On the other hand, when compared each methods amount of areas for all other classes in LUCC were determined much higher than others. 42.7 % of the total area was classified as I and II class for agricultural uses whereas, 34.5% area were described as non arable land.

Table 7. Distribution of LSI, SCAU and LCC classes

Land Suitability Index (LSI)			Suitability Class for Agricultural Use (SCAU)			Land Use Capability Class (LUCC)		
Class and description	ha	%	Class and description	ha	%	Class	ha	%
S1: Highly suitable	34.8	0.5	C1: Best	40.9	0.6	I	58.5	0.8
S2: Moderately suitable	997.2	14.5	C2: Relatively good	1440.4	20.9	II	2887	41.9
S3: Marginally suitable	4838.9	70.2	C3: Problematic	2482.2	36.0	III	416.9	6.1
			C4: Restricted	1598.2	23.2	IV	1150.1	16.7
N: Unsuitable	1019.1	14.8	C5: Non-agriculture	1328.3	19.3	VI	668	9.7
						VII	1709.5	24.8
Total	6890.0	100.0	Total	6890.0	100.0	Total	6890.0	100.0

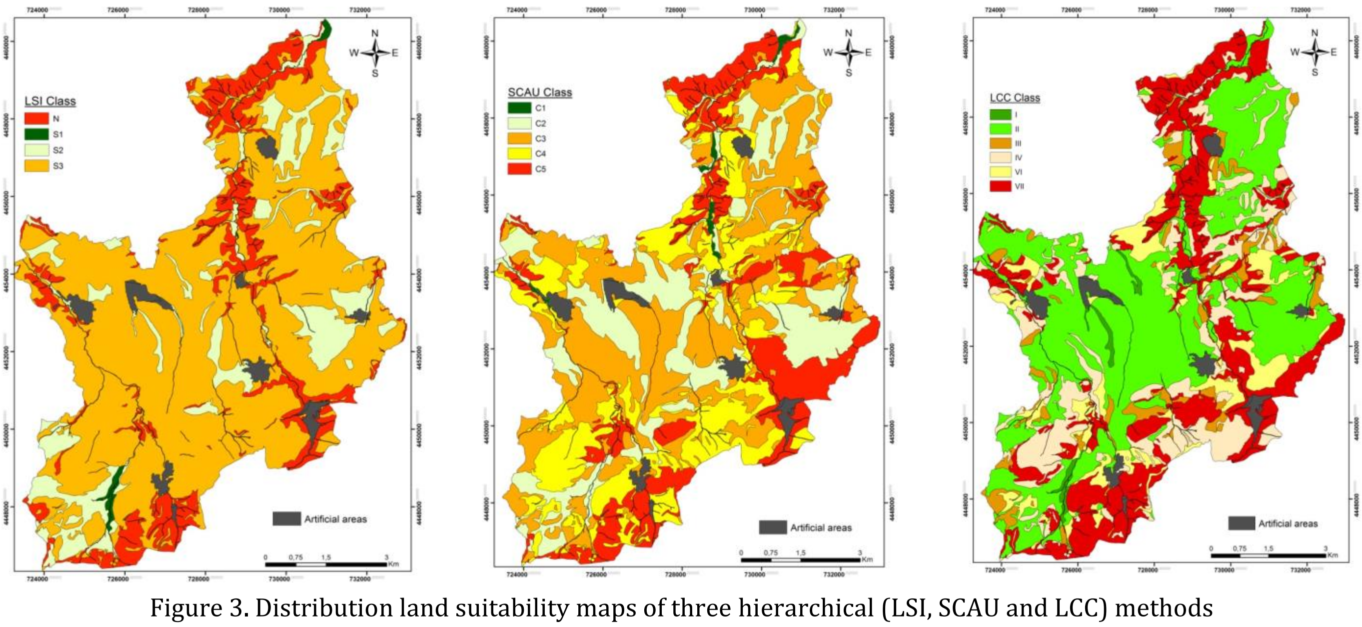

Figure 3. Distribution land suitability maps of three hierarchical (LSI, SCAU and LCC) methods

Conclusion

Land suitability analysis is a vital operation for assessing the value and proficiency of the land and provides great contribution in planning for future sustainable land resources. There are many land evaluation approaches which were given under two main categories that are parametric and hierarchic methods. Accurate assessment methods give better results and consequently facilitate establishment of improved management plans. In this study, multi-criteria approach was used with analytical hierarchy process associated with GIS technique by taking into consideration of some land and soil physico-chemical characteristic in order to generate map of land suitability classes for agricultural and for nonagricultural uses. In this method, the final suitability index value of the equation was based principally on the factor that has the maximum influence on land use suitability with regard to the other factors. As well, results have shown that the limiting factors for agricultural uses in the study area are slope, soil erosion and depth. Moreover, this approach was also compared with SCAU and LUCC methods. According to three methods' results, it was detected high correlation between LSI and SCAU, whereas values of land suitability classes of LUCC were higher especially for its second class (41.9%) includes many some factors that restrict land use in present condition. Although LUCC is of great importance in guiding on land uses in terms of their potential and conserving land resources, this result can be explained that LUCC data have been not upgraded and soil map unit contains one or more soil components (typically great soil groups) with soil properties that are defined by not enough precise definitions.

In present study, it can be strongly recommended that the first 2 suitability classes must be considered simultaneously for land allocation for cultivation areas, using GIS techniques and taking into consideration land-use information, including the results obtained from the MCA model. This study confirms the capability of GIS to integrate spatial and attribute data and to offer a quick and reliable method of land suitability assessment with high accuracy. On the other hand, while GIS has been a powerful tool to handle spatial data in land-use analysis, application of this tool alone could not overcome the issue of inconsistency in expert opinion when trying to judge and assign relative importance to each of many criteria considered in a suitability analysis. To address this issue, the Analytical Hierarchy Process, and Weighted Linear Combination methods are also used in combination with the GIS tool.

This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, the results of this study could be useful for other investigators who could use these results for diverse studies. For further study, we propose to select more number of factors like topography, climate, irrigation facilities and socio-economic factors which influence the sustainable use of the large scale land.

Consequently, the results obtained from this study indicate that the use of GIS and application of Multi-Criteria Assessment using AHP could provide a superior database and guide map for decision makers.

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