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Land suitability analysis for rice cultivation using multi criteria evaluation approach and GIS

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ABSTRACT

The main objective of this study was to evaluate the land suitability for cultivation of an economically important crop, which was rice, in Amol District, Iran. To achieve this goal, multi-criteria decision making (MCDM) integrated with the GIS was used to assess suitable areas for growing this crop. Several biophysical, environmental and economical factors were selected based on the FAO framework and experts' opinions. A GIS-based Multi Criteria Decision Making land suitability analysis was performed. An Analytical Hierarchical Process was used to rank the various suitability factors and the resulting weights were used to construct the suitability map layers. In doing so, the derived weights were used, and subsequently land suitability maps for rice cultivation were created. The Study area has been classified into four categories of rice suitability (high suitable, suitable, moderately suitable and unsuitable). Results indicate that the spatial analytical hierarchy process is a powerful support system helps decision makers to defining effective management plan for each part considering its suitability index.

Keywords: land suitability analysis; GIS; analytical hierarchy process; Multi criteria evaluation; rice; Amol District

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INTRODUCTION

Increasing population numbers, particularly in developing countries, intensify the pressure on both natural and agricultural resources. To meet the nutritional demands of the growing world population, an increased food supply is required. Both population increases and the process of urbanization have increased the pressure on agricultural resources [1]. This increased pressure on the available land resources may result in land degradation [2]. Reliable and accurate land evaluation is therefore indispensable to the decision-making processes involved in developing land use policies that will support sustainable rural development. If self-sufficiency in agricultural production is to be achieved in developing and transitional countries, land evaluation techniques will be required to develop models for predicting the land's suitability for different types of agriculture [3].

Multi-criteria evaluation processes are already used in some regional planning processes since they aim at ''estimating the potential of land for alternative land uses, among which agricultural land use may be the most important area where it is applied'' [4]. This method could play a key role in future land-use planning [5].Agricultural land suitability classification based on indigenous knowledge is vital to land use planning. The systematic assessment of land and water potential aims to identify and put into practice future alternative land uses that will best meet the needs of the people, while at the same time safeguarding resources for the future [6]. Selecting the most appropriate land evaluation technique is therefore very important for current and future land use planning in countries such as Iran. There are many different approaches that are widely implemented in land evaluation such as, for example, the United States Department of Agriculture (USDA) USDA land capability classification (1961) or the United Nations Food and Agriculture Organization (FAO) framework for land evaluation (1976). Some of these techniques have been applied in developing countries, often without taking into account local knowledge and local conditions [7].

The land evaluation method is the systematic assessment of land potential to find out the most suitable area for cultivating some specific crop. Theoretically, the potential of land suitability for agricultural use is determined by an evaluation process of the climate, soil, water resources, topographical, and environmental components under the criteria given and the understanding of local biophysical restraints [8]. The use of GIS Multi-Criteria Decision Making (MCDM) methods allows the user to derive knowledge from different sources, in order to support land use planning and management [9,10]. One multi-attribute technique that has been incorporated into the GIS-based land use suitability procedure is the Analytical Hierarchy Process (AHP) [11,10]. MCDM methods such as the AHP method have been successfully applied to land evaluation techniques [12]. These methods, which aim to allow for a transparent decision-making base, are, however, only rarely used in developing and transitional countries such as Iran. We have used a GIS-based MCDM land suitability analysis method to classify the study area (Amol District) with respect to the potential for Rice cultivation. We assumed that this goal could be effectively help agricultural insurance through the Identification and separation of land-based capabilities with regard to environmental, Biophysical and Socio-economical potential.

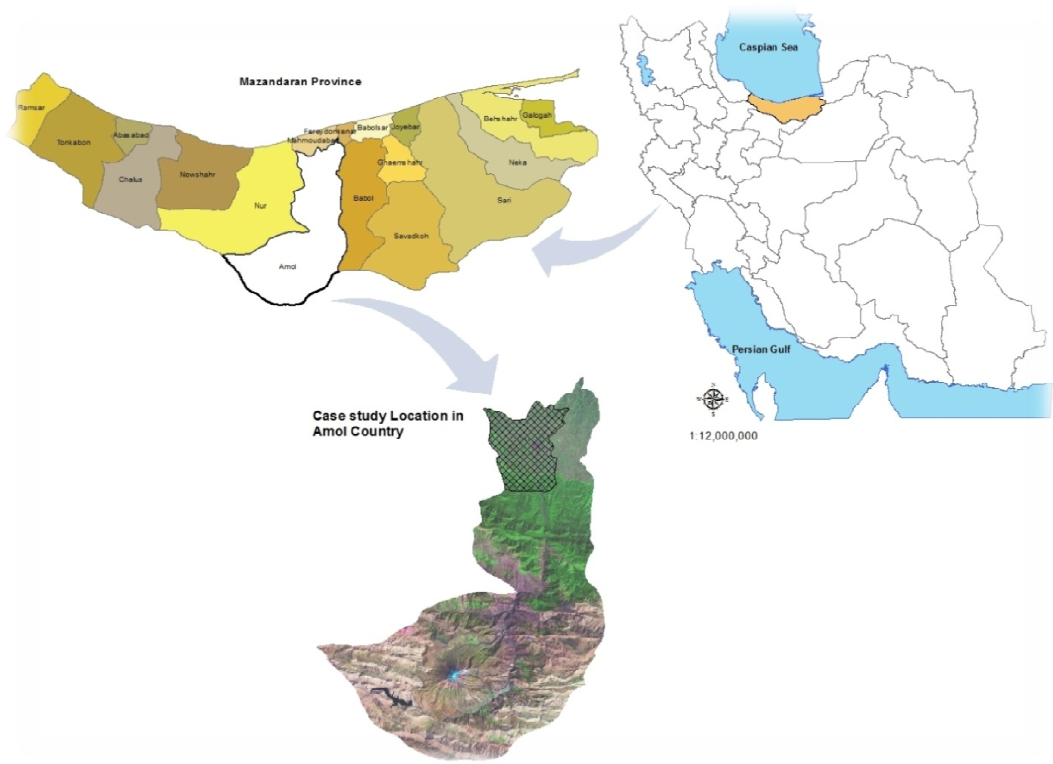

Figure1. Location of case study area in the Mazandaran province, Iran

2. The study area

The studied area was the central part of the Amol District, which is located in the Haraz river plains of Mazandaran province in Iran (Figure 1). This region has an area of 304.83 km2 and is situated in the north part of Iran between 36˚ 34´ 43˝ and 36˚ 22´ 16˝ N latitudes and 52˚ 11´ 34˝ and 52˚ 26´ 54 ˝ E longitudes. Amol city and 135 villages that are in the study area comprise an overall population of approximately 272844 populations (Iranian Census Centre 2011). Elevations range from 20 to 500 metres above sea level. Amol County contains some of the most important human habitations in the Mazandaran province and includes industrial and agricultural centers. Agriculture is one of the main sources of income for the population. Based on weather data the average annual temperature of the region is 17.47° C and the mean annual relative humidity is 78 %. Consequently, the annual average rainfall is recorded to be 800 mm, mostly falling in December.

MATERIALS AND METHODS

Multi-criteria decision making

MCDM approaches were developed in the 1960s in order to assist decision makers in incorporating numerous options, reflecting the opinions of concerned parties, into a potential or retrospective framework. This framework is ‘‘primarily concerned with how to combine the information from several criteria to form a single index of evaluation’’ [5]. They were designed to define the relationship between data input and data output. MCDM methods can be broadly divided into either multi-objective or multi-attribute methods [9, 10]. The integration of GIS and MCDM methods provides powerful spatial analysis functions [13]. In the MCDM approach: GIS are best suited for handling a wide range of criteria data at multi-spatial, multi temporal and multi-scale from different sources for a time-efficient and cost-effective analysis. Therefore, there is growing interest in incorporating GIS capability with MCDM processes [14].

Due to the large number of factors involved in decision making, land suitability analysis can be identified as a multi-criteria evaluation approach [15, 16]. Of the various MCDM methods, the Analytical Hierarchy Process is a well-known multi-criteria technique that has been incorporated into GIS based suitability procedures [17, 18]. For the classification of land suitability within our case study area in northern Iran, we utilized the AHP’s ability to incorporate different types of input data, and the pair wise comparison method for comparing two parameters simultaneously. The application of AHP process involves the following steps [2]. Criteria or factors contributing to the set of suitable are identified: The relative importance of each factor to each other factor, i.e. between pairs of criteria. This is usually done by domain and experts’ opinions: The consistency of the overall set of pairwise comparisons is assessed using its Consistency Ratio (CR).

Constructing decision making tree with evaluation criteria

Evaluation criteria objectives and attributes need to be identified with respect to the particular situation under consideration. The set of criteria selected should adequately represent the decision-making environment and contribute towards the final goal [12]. ‘‘Land suitability assessment is a multiple criteria evaluation process. The attributes of land suitability criteria are to be derived from spatial and non-spatial, qualitative and quantitative information under diverse conditions’’ [19]. Based on the expertise and decision maker views, the factors were categorized into three main criteria including Biophysical, Socio-economic and environmental groups. Next, eight causal factors, including: soil properties, climate, topography, irrigation water, availability, market, Land use compatibility and soil contamination, were selected. One of the most important factors affecting the land suitability classification for cultivation is soil properties. The soil properties criteria were consisted of soil texture, surface stoniness, soil depth, pH, EC, soil phosphorus, Potassium and organic matter. The topography criteria were consisted of slope and aspect. The climate criteria were divided into seven groups according to the climatic requirements for irrigated rice adapted from 1976 FAO framework included the Mean temperature of the growing cycle, Mean temperature of the developing stage, Mean temperature of the ripping stage, Mean minimum temperature of the ripening stage, Mean daily maximum temperature of the warmest month, Relative Humidity after milky stage (2 week before harvest) and Relative Humidity at harvest stage. The distance from surface water and water well were considered as components of irrigation water criteria. The availability criteria were consisted of distance from main road, distance from rice milling plant and distance from population centers. Also the market criteria include the proximity to agricultural service centers and Proximity to the rural cooperative. The environmental criteria were consisted of Land Use Compatibility and Soil contamination (Figure 2).

Data collection and preparation using GIS

Data preparation is the first fundamental step in land suitability analysis. In this research methodology, land suitability is evaluated by applying different GIS analytical techniques, including interpolation and overlay based on multi-criteria analysis and AHP. For this to happen, the following datasets were prepared:

- Digital topographical maps 1:25000 (National Cartographic Centre organization) are used to create TINs, DEM, and derivate layers such as slope and aspect.

- TM satellite images with 30 m spatial resolution were used to derive land use through image classification techniques.
- The available information on wells, springs, streams and river were obtained from Mazandaran water organization and were mapped in a GIS domain.
- Meteorological data for a 10-year period (Iranian Meteorology Organization) were used to create climate maps
- The exact locations of residential areas, agricultural service centers and rural cooperative sites were obtained from the related national agency and were mapped by GIS software.

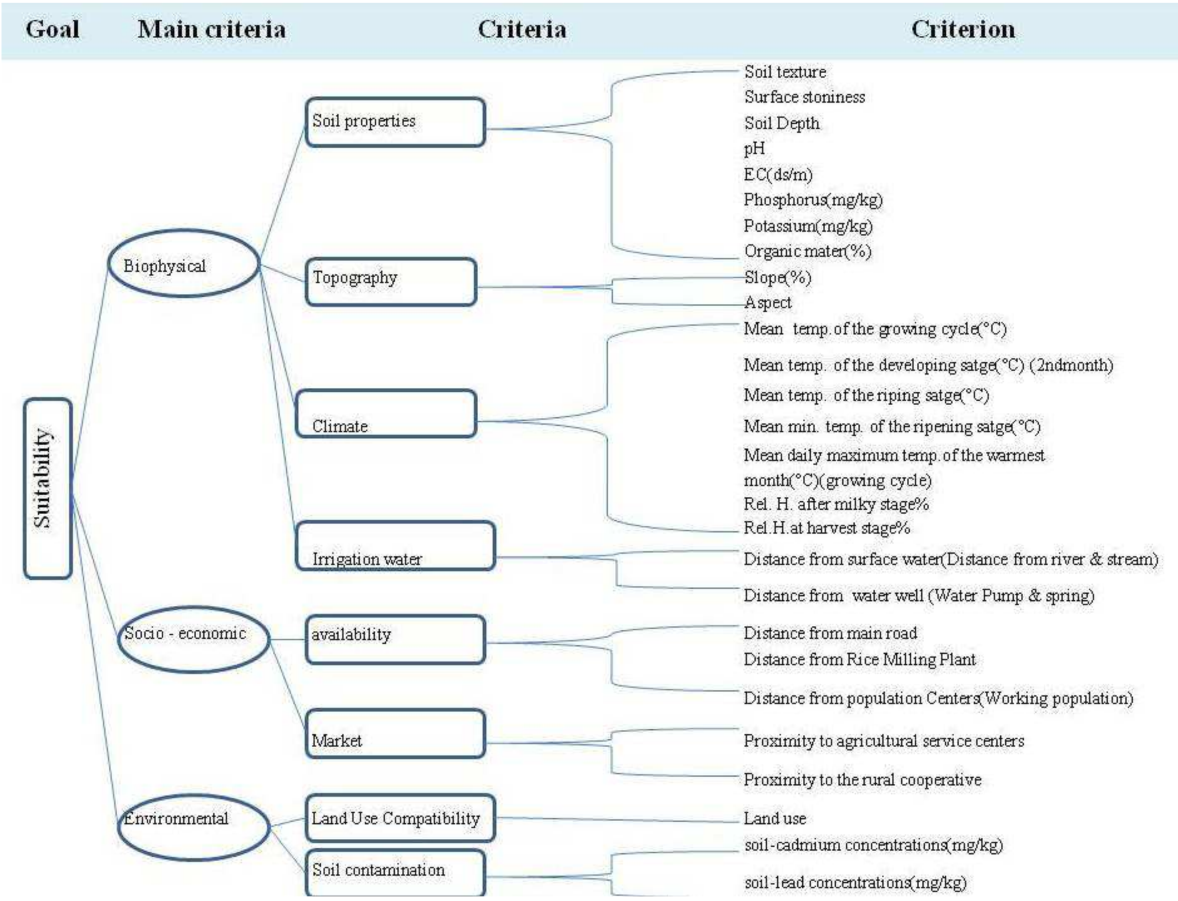

Figure2. The hierarchical structure used in the study area for rice cultivation

- Field operations using GPS for soil sampling were performed and the various physico-chemical experiments were done on samples In order to provide soil maps.

After these spatial datasets were prepared, including all necessary geometric and thematic editing of the original datasets, a topology was created. All vector layers were then converted into raster format with 100 m resolution and the spatial datasets were processed in ArcGIS. The spatial distributions of some of the most important import datasets are shown in Figures3.

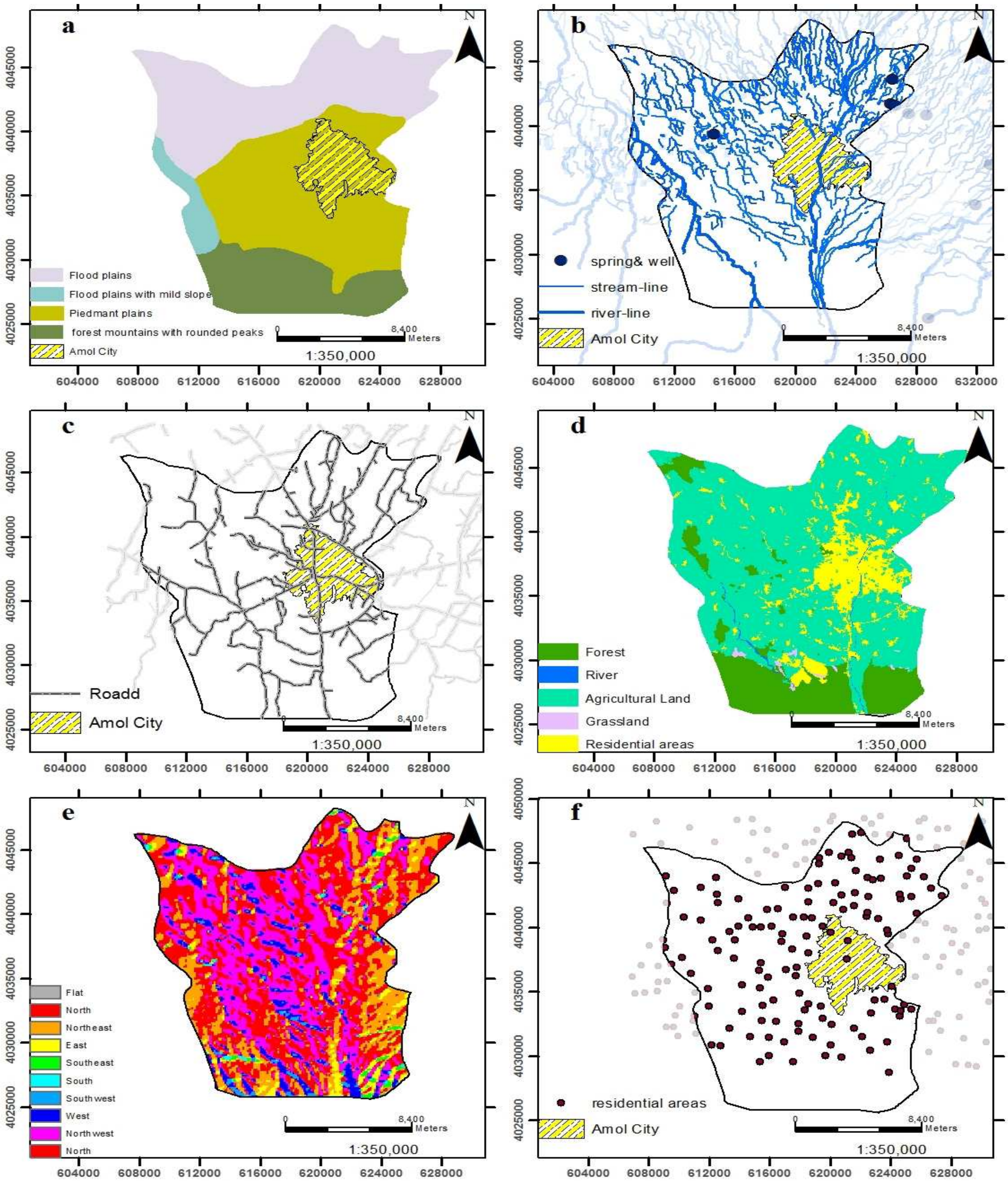

Figure3. (a) Physiographic of the study area (b) rivers and streams; (c) main Roads,(d) Land use, (e) aspect; (f) residential areas

Standardization of criteria

The process of setting the relative importance of each criterion is known as the standardization of criteria [12]. In this process scales of 0 to 1, 0 to 10 or 0 to 100 (etc.) are normally used for criteria standardization. A pair-wise comparison technique is typically used for rating and standardizing the ordinal values [10]. In order to compare criteria with each other, all values need to be transformed to the same unit of measurement scale (from 0 to 1), whereas the various input maps have different measurement units (e.g. distance maps, temperature etc.). In this research two standardization methods were applied as follows:

Spatial AHP: all applied criteria were standardized using AHP method but distance criteria.
Cost- benefit analysis: for standardization of all distance criteria this method was used. For example in population center criterion the Cost- benefit analysis assigns the highest score (suitability degree=1) to the nearest area to the population centers and the lowest one (suitability degree=0) allocates to the furthest. In this way all criteria map were converted to the same scale (0-1).

Weighing of criteria
Criterion weights are the weights assigned to the objective and attribute maps [20]. Deriving weights for the selected map criteria (land characteristics map layers) is a fundamental requirement for applying the AHP method [9, 10].

For determining the relative importance of criteria the pair-wise comparison matrix using Saaty's nine-point weighing scale were applied (Table 1).

Table1. Scales for pair-wise AHP comparisons [33]

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

In the application of the AHP method it is important that the weights derived from a pair-wise comparison matrix are consistent. Therefore, one of the strengths of AHP is that it allows for inconsistent relationships while, at the same time, providing a consistency ratio (CR) as an indicator of the degree of consistency or inconsistency [21, 14]. The CR is used to indicate the likelihood that the matrix judgments were generated randomly [22, 23].

$$CR = \frac{CI}{RI}$$

Hereby the random index (RI) is the average of the resulting consistency index, depending on the order of the matrix given by Saaty (1977), and the consistency index (CI) can be expressed as:

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

In which λ max is the largest or principal Eigen value of the matrix, and n is the order of the matrix. A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency [22, 23]. The determination of the CR value is critical. The CR has been widely used as a measure of the consistency in a set of judgments of AHP applications in literature [19]. If the CR < 0.10, it deems that the pair wise comparison matrix has an acceptable. Otherwise, if the CR ≥ 0.10 it means that the pairwise comparisons are lacking consistency, in other words the matrix needs to be adjusted and the element values should be modified [24, 19]. In this study, the resulting CR for the pair wise comparison matrix for rice suitability was less than 0.10. This indicates that the comparisons of land characteristics were perfectly consistent and that the relative weights were appropriately chosen in this particular land suitability evaluation model. After standardization all criteria and were weighted using pair wise comparison method. Table2 Detailed weights for the main criteria and sub criteria for rice cultivation.

Table2. Weighting matrix for main criteria and sub criteria

Main criteria	weight	Criteria	weight
Biophysical factor=0.276	Soil=0.602 CR=0.06	Soil texture	0.267
		Surface fragmental	0.231
		Soil Depth	0.146
		pH	0.078
		EC	0.079
		Phosphorus	0.049
		Potassium	0.050
		O.M	0.098
	Topography=0.113	Slope	0.676
		Aspect	0.324
	Climate=0.047	Mean temp. of the growing cycle(°C)	0.200
		Mean temp. of the developing stage(°C) (2ndmonth)	0.200
		Mean temp. of the ripping stage(°C)	0.200
		Mean min. temp. of the ripening stage(°C)	0.200
		Mean daily maximum temp. of the warmest month(°C)(growing cycle)	0.200
		Mean temp. of the growing cycle(°C)	0.200
		Mean temp. of the developing stage(°C) (2ndmonth)	0.200
		Rel. H. after milky stage%	0.200
		Rel.H.at harvest stage%	0.200
	Irrigation Water =0.238	Distance from surface water (Distance from river & stream)	0.857
		Distance from water well	0.143
Socio-economic factor=0.128	Availability=0.5	Distance from main road	0.452
		Distance from Rice Milling Plant	0.249
		Distance from population centers Working population	0.299
	Market=0.5	Proximity to the rural cooperative	0.500
		Proximity to agricultural service centers	0.500
Environmental factor=0.595	Land Use Compatibility =0.655	Land use	1.000
	Soil contamination=0.345	soil-cadmium concentrations	0.500
		soil-lead concentrations	0.500

Overlaying map layers

Weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis [25]. After weighing of criteria regarding their importance for land suitability analysis, all criteria maps were overlaid using suitability index.

$$SI = RI.A1 * \sum_{i=1}^{m} RI.Bi * RI.KBi + RI.A2 * \sum_{y=1}^{l} RICy * RI.KCy + \cdots + RIAN * \sum_{z=1}^{j} RIDz * RI.KDz$$

Where, SI is the suitability index of each cells; N is the number of main criteria; RIA1, RIA2 …RIAN are the relative importance of the main criteria A1, A2 …AN, respectively; m, i and j are the number of sub criteria directly connected to the main criteria A1, A2 …AN, respectively; RIB, RIC and RID are the relative importance of sub criteria B, C and D directly connected to the main criteria A1, A2 …AN, respectively; RIKB, RIKC and RIKD are the relative importance of indicators category k of sub criteria B, C and D and main criteria A1, A2 …AN, respectively[26, 27]. After weighting the criteria, as regards the relative importance of each criterion as well as suitability index, all the criterion maps were overlaid and final suitability map was prepared. Suitability maps of study area according to different aspect of biophysical, socio-economical and environmental are demonstrated in Figure4 respectively (a), (b) and (c). The final suitability map resulting from finally weighted overlay, are shown in Figure4 (d).

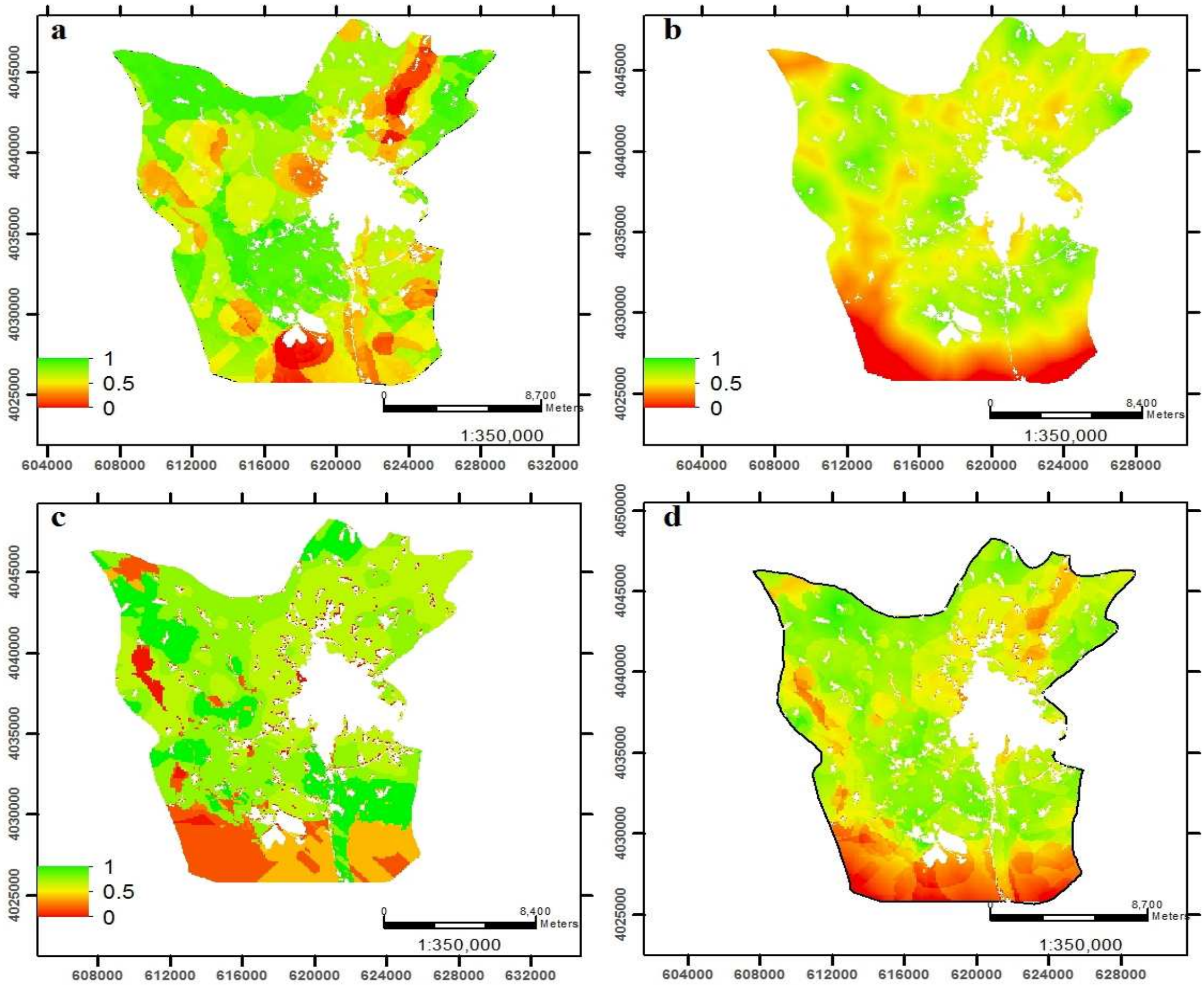

Figure4: suitability maps of (a) Biophysical factor, (b) socio-economic factor, (c) Environmental factor and (d) finally Suitability map

RESULTS AND DISCUSSION

Land suitability has been extracted by weighted overlay techniques based on MCDM using GIS methods, a process that has resulted in information being portrayed on four land suitability maps. Land suitability maps (Figures 4) have been extracted using weighted overlay techniques.

As described in the previous section, this is based on standard weights which were derived from the AHP process. The final land suitability map for rice cultivation (Figure 5) classifies the case study area into four land suitability classes, namely: 'highly suitable', 'suitable', 'moderately suitable' and 'unsuitable'.

This classified map shows that 6.83% (20.77 km^2) of the investigated area is highly suitable, 25.80% (78.65 km^2) is suitable, 36% (109.72 km^2) is moderately suitable, and 16.91% (51.55 km^2) is unsuitable. Together, the two categories 'highly suitable' and 'suitable' make up 32.63% of the total area. Geographically, these areas cover what is already known to be the best agricultural area in Amol County, according to the annual yield.

According to the land use map, 68.78% of the case study area is currently being used for agriculture, bot rice cultivation and orchid. This includes 63.17% being used under rice cultivation and 5.61 %being used for orchid. An additional 14.47% of the area is used for settlements.

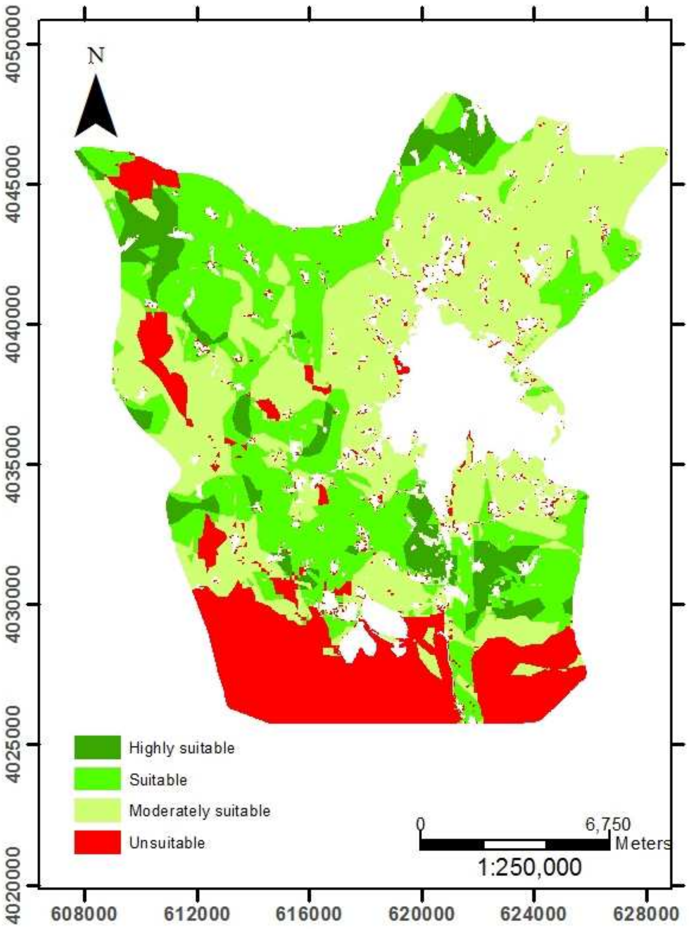

Figure5: the classified final map of Study area for rice cultivation

CONCLUSION

Land suitability maps for Rice cultivation in Amol district were extracted using GIS-assisted MCDM analysis. The results demonstrate that the areas that are classified as ‘highly suitable’ and ‘suitable’ for rice cultivation are already largely under cultivation. This information is of great importance to decision makers and, in particular, to departments of Agriculture for land use management and agricultural insurance for the Mazandaran Province of Iran. Spatial MCDM has thus become one of the most useful methods for land use analysis and environmental planning, as well as for agricultural land suitability classification [28, 29, 8, 30,14]. GIS based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision-making problems [31, 32, 14].

As Figure5 only a small fraction of the total area has a high suitability for rice cultivation. In general, the results obtained from this study indicate that:
- The analytical hierarchy process is a powerful tool for decision making in land suitability issues regarding biophysical, environmental and socio-economic factors. By using this method whole area can be classified in detail about the suitability degrees for considered land use. Specified land suitability helps decision makers for defining effective management plan for each part considering its suitability index.
- High suitability areas for rice cultivation contain only a small proportion (20.77 Km^2) of whole (304.88 km^2) so the implementation of appropriate management plans in this area is essential.
- A wide ranges of area (109.72 km^2) applied as rice cultivation has moderately suitable. It reveals that these areas are endangered to be widespread decreases suitability in near future unless supervised properly.

REFERENCES

[1] Orhan D, llhami B, Mahmut Y, *Turkish journal of agriculture and forestry*, **2003**, 27, 145–153.
[2] Elaalem M, Comberm A, Fisher P, *Transactions in GIS*, **2011**, 15 (3), 329–346.
[3] Elaalem E, Comber A, Fisher P, Land evaluation techniques comparing fuzzy AHP with TOPSIS methods, 13th AGILE international conference on geographic information science, 10–14 May, **2010**, (Guimara˜ es, Portugal).
[4] Chen Y, Khan K, Padar Z, Irrigation intensification or extensification assessment: a GIS-based spatial fuzzy multi-criteria evaluation. In: Proceedings of the 8th international symposium on spatial accuracy assessment in natural resources and environmental sciences, 25–27 June, Shanghai, P.R. China, **2008**, 309–318.
[5] Yu J, Chen Y, Wu J, *International journal of geographical information science*, **2011**, 25 (1), 131–148.
[6] FAO, Guidelines for land-use planning, FAO Development Series, **1993**, No, 1, (Rome: FAO, 96).
[7] Clayton D, Dent D, Surveys, plans and people: a review of land recourse information and its use in developing countries. **1993**, Environmental planning issues, 2, IIED.
[8] Ceballos-Silva A, L´opez-Blanco J, Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico, **2003**, Agr Syst **77**, 117–36.
[9] Malczewski J, GIS and multicriteria decision analysis, Toronto: Wiley, **1999**.
[10] Malczewski J, *Progress in planning*. **2004**, 62 (1), 3–65.
[11] Saaty TL, The analytical hierarchy process, New York: McGraw Hill, **1980**.
[12] Prakash TN, Thesis (MSc), Land suitability analysis for agricultural crops: a fuzzy multicriteria decision making approach. (ITC) International Institute for Geoinformation Science and Earth Observation, Enschede(The Netherlands, **2003**).
[13] Yu J, Chean Y, Wu JP, Cellular automata and GIS based land use suitability simulation for irrigated agriculture, 18th world IMACS/MODSIM Congress, 13–17 July, **2009**, Cairns, Australia.
[14] Chen Y, Yu J, Khan S, *Environmental modelling and software*, **2010**, 25, 1582– 1591.
[15] Reshmidevi TV, Eldho TI, Jana R, *Agricultural systems*, **2009**, 101, 101–109.
[16] Yu J, Chen Y,Wu J, Modeling and implementation of classification rule discovery by ant colony optimisation for spatial land-use suitability assessment, Computers, environment and urban systems, **2011**, 35, 308–319.
[17] Jankowski P, Richard L, *Environment and planning* B, **1994**, 21 (3), 326–339.
[18] Marinoni O, *Computers and geosciences*, **2004**, 30 (6), 637–646.
[19] Chen Y, Khan S and Paydar Z, To retire or expand. *Irrigation and drainage*, **2010**, 59 (2), 17–188.
[20] Meng Y, Malczewski J, Boroushaki S, *Journal of geographic information systems*, **2011**, 3, 50–61.
[21] Forman EH, Selly MA, Decision by objective and how to convince others that you are right, **2001** (World Scientific. Singapore,**2001**)
[22] Saaty TL, *Journal of mathematical psychology*, **1977**, 15 (3), 34–39.
[23] Park S, *Landscape and urban planning*, **2011**, 99, 104–114.
[24] Bodin L, Gass S, *Computer and operations research*. **2003**, 30, 1487–1497.
[25] Kuria D, Ngari D, Withaka E, *Journal of geography and regional planning*, **2011**, 4 (9), 525–532.
[26] Kheirkhah Zarkesh MM, Ghoddusi J, Zaredar N, Jafari MJ, Ghadirpour A, *Journal of Food, Agriculture & Environment*, **2010**, Vol.8 (2), 970-975.
[27] Kheirkhah Zarkesh M, PhD Thesis,Decision support system for floodwater spreading site selection in Iran.(ITC, International Institute for Geo-information Science and Earth observation, Enschede, The Netherlands. **2005**).
[28] Ahamed TRN, Rao KG, Murthy JSR, *Agricultural systems*, **2000**, 63, 75–95.
[29] Joerin F, Theriault M, Musy A, *International journal of geographical information science*, **2001**, 15 (2), 153–174.
[30] Sicat SR, Carranza EJM, Nidumolu UB, *Agricultural systems*, **2005**, 83, 49–75.
[31] Nekhay O, Arriaza M, Guzma´n-A´ lvarez JR, *Computers and electronics in agriculture*, **2008**, 65, 49–64.
[32] Hossain MS, Das NG, *Computers and electronics in agriculture*, **2010**, 70 (1), 172–186.
[33] Satty TL, Vargas LG, Model, Metods, Concepts& Application of Analytical Hierarchy Process, International Series in Operation Research and Management Sciences, **2001**, Boston, Dodrecht, London, Kluwer Academic publishers