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Land-Use Suitability in Northeast Iran: Application of AHP-GIS Hybrid Model

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Abstract: Land-use suitability is the ability of a given type of land to support a defined use. Analysis of land-use suitability requires the consideration of a variety of criteria, not only the natural/physical capacity of a land unit, but also its socioeconomic and environmental impact implications. As land suitability is assessed within a Geographic Information System (GIS) environment, it is formulated as a multi-criteria decision making (MCDM) problem. The study was conducted in the Sangab Plain in northeast Iran. We investigated the study area's suitability for grassland and agricultural uses. A hybrid method of the analytic hierarchy process (AHP) and GIS methodology was applied to evaluate land suitability based on a set of criteria and sub-criteria. Results showed that 20% of the study area had high (rich), 65% had medium (fair), and 15% had low (poor) suitability for agriculture. In terms of grassland use, the comparable amounts were, respectively, about 7%, 23%, and 70%. The lands of the Sangab Plain have medium potential for agricultural use and low potential for grassland use. This paper used both qualitative and quantitative techniques.

Keywords: land suitability; AHP-GIS hybrid method; agricultural land uses; grassland uses; Sangab Plain

1. Introduction

Land as a part of the earth's surface has reasonably stable or predictable cyclic activity. Its suitability for agriculture, settlement and industry [1] depends on its elements. However, these elements have been depleted, especially in the last few centuries. As a result, many lands are facing problems such as soil erosion, water logging, groundwater depletion, heavy run-off and productivity losses [2,3] which are threatening the quality and availability of food, water and energy, and are affecting the security and quality of life of 250 million people and compromising the lives of one billion [4]. For example, FAO has reported that 852 million people in the developing world are suffering from hunger and malnutrition [5]. In addition, land resources are becoming scarce as an increasing population puts pressure on natural resources. As the world population grows, a greater food supply is urgently needed. Additionally, the land use policies in developing countries frequently makes little use of the available technical information and when they do, policy makers require it to be interpreted into brief statements that eliminate technical details [6]. Land suitability assessment is similar to choosing a location for land use and aims to map a suitability index for the entire study area [7]. Selecting the most appropriate algorithm for land suitability assessment is important for current and future land use planning [8]. The creation of suitability maps is one of the most important prerequisites for land-use decisions. Many parameters and criteria on land and its uses must be considered. Social and economic factors are often more manipulated by human interventions than are bio-physical and environmental factors [8]. Thus, determining the weight of each factor that affects land suitability is a key step in land suitability assessment for crop production [9]. Since each factor has its own level of importance or weight for the interest groups involved, weighting them can be difficult. Multi-criteria techniques can be used to solve this complex and multi-dimensional problem. A variety of multi-criteria evaluation methods is available [10]. McHarg and Mumford [11] introduced a planning method of systematic land use by applying the concept of compatibility among multiple land uses. He mentioned that the factors affecting land and its relative value vary, so it is difficult to optimize them for a specific single use. However, it can be optimized for multiple, compatible uses so he introduced a simple matrix system to determine the degree of compatibility. In recent years, the combination use of multi-criteria decision making (MCDM) and Geographical Information Systems has been expanded. This combination has improved the processes of land evaluation, decision-making and the efficiency of data processing [12–14]. The analytic hierarchy process (AHP) is best illustrated by Saaty [15], who described it as a decision support tool that can be used to solve complex decision problems. This process uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and other alternatives. Interest in multi-criteria assessment in agriculture, environmental and rural studies and management has been growing rapidly due to the possibilities it can present [16–21]. Moreover, it can help improve the description of land utilization types that are required for land evaluation [12–23] and provide a powerful spatial decision support system that enables researchers to produce accurate land suitability maps. The combination of AHP with GIS is a new trend in land suitability analysis [14] as previous studies have combined and applied multi-criteria decision making (MCDM) techniques, especially AHP, based on GIS. For example, Gemitzi, Tsihrintzis, and Petalas [24] used these two techniques to integrate the evaluation of environmental problems. Krois and Schulte [25] combined the two evaluation techniques to identify potential sites for soil and water conservation techniques in the Ronquilo watershed, Northern Peru. Al-Adamat, Diabat, and Shatnawi [26] used the combination of the GIS with MCDM to site water harvesting ponds in Northern Jordan; Zhang et al. [8] integrated the fuzzy set model, analytic hierarchy process (AHP) method, and GIS technique to assess land suitability and to create a land suitability map for tobacco production in the tobacco zone of Shandong province, China. They used 20 factors as suitability parameters, including climatic condition, soil type and nutrient characters, and topographical data. Some studies [27–29] have also used multi-criteria and GIS-based methods to analyze the suitability of land for other uses such as waste disposal and management. Ekmekçioĝlu et al. [27] proposed a modified fuzzy TOPSIS methodology for the selection of an appropriate disposal method and site for municipal solid waste (MSW). According to them, the application of fuzzy multiple criteria analysis (MCA) in solid waste management has the advantage of rendering subjective and implicit decision making more objective and analytical, and accommodates both quantitative and qualitative data. Baiocchi et al. [28] used three decision support methods (Boolean logic, index overlay and fuzzy gamma) to perform land suitability analysis for landfill siting. Tavares et al. [29] presented a spatial multi-criteria evaluation methodology to assess land suitability for a plant siting and applied it to Santiago Island of Cape Verde. This study's analysis of land-use suitability focuses on the potential for agricultural and grassland land uses in the Sangab Plain, northeast of the Khorasan-Razavi province (Figure 1). The Sangab Plain has a semi-desert climate, with cold winters and warm and dry summers, with the areas of dry and low rainfall that are components of plains. The people there depend on agriculture, livestock and mining with water from by rivers and from aqueducts. The most important agricultural products of the plain include wheat, barley, corn, and products from orchards. Livestock and poultry are common in the industrial and traditional areas of this plain. The AHP method that was used to evaluate the land has consists of specifying the hierarchical structure, determining the relative importance of criteria and sub-criteria, assigning the preferred weights of each alternative, and calculating the final score [30]. A GIS was then used to calculate soil and the three varying terrains: slopes, elevation, and aspect.

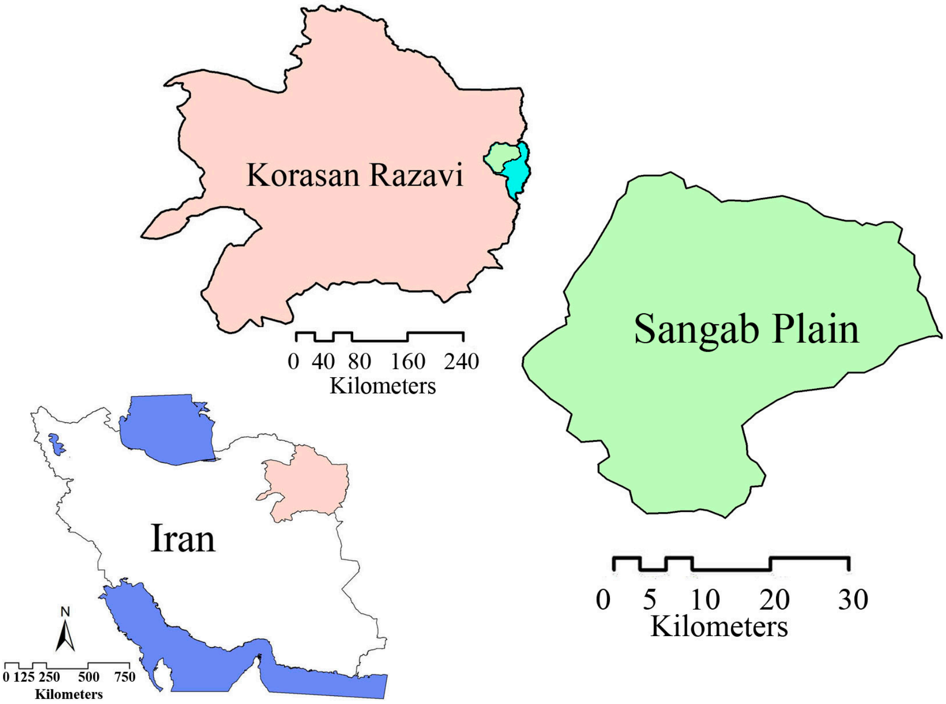

Figure 1. The study site.

2. Methodology

2.1. Data

The data used in this research has bio-physical and socio-economic aspects. The primary data were collected from the field survey through interviews and questionnaires. The questionnaires were filled out by experts to identify factors that are important for evaluating land-use suitability along with statistical data and other GIS datasets. Land and topographic data—slope, slope aspect, elevation, soils, and land use—were taken from the Iranian topographic map at a scale of 1:25,000, produced by Iran National Cartographic Center (INCC).

2.2. Analytic Hierarchy Process (AHP)

AHP was used to weigh the criteria and sub-criteria. It can accurately evaluate land suitability. This method begins by using a hierarchy depicting the criteria, sub-criteria, and decision alternatives (Figure 2), with the goal or mission of the decision-making problem placed at the top. Other criteria and sub-criteria were placed in the remaining levels [31]. The second stage involved the comparison of pairs of criteria, pairs of sub-criteria and pairs of alternatives. The AHP uses a 9-point scale measurement (1 = equal importance, 3 = moderate importance of one over another, 5 = strong or essential importance, 7 = very strong or demonstrated importance, 9 = extreme importance, and 2, 4, 6, 8 = intermediate values) to express individual preferences or judgments [15].

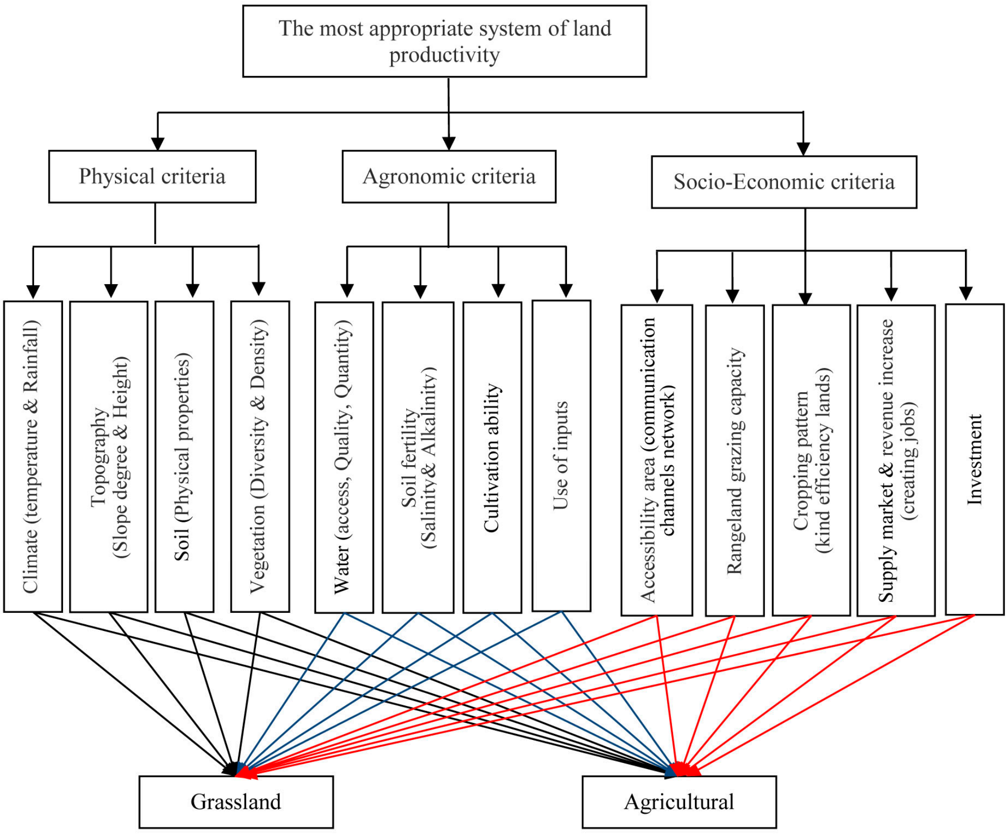

Figure 2. The flowchart of AHP land-use suitability assessment.

2.3. Geographic Information System (GIS)

The weighted sum overlay analysis in the ArcGIS software was used to map the suitability of land. The estimated weights were appointed to the related layers and then the raster maps were overlaid and an agricultural land suitability map was generated [32]. Four steps were followed to produce a site suitability map: (1) finding suitable factors to use in the analysis, (2) assigning factor priority (weight) to the parameters, (3) generating a land suitability map of agriculture and grasslands, and (4) determining the suitability evaluation of the areas [33].

Five important geographical layers were incorporated (slope, slope aspect, elevation, soils, and land use). Data from all of the selected factors were kept, displayed, and managed. These geographical maps were overlaid to create the final suitability classification of the study area for agriculture and grassland. The weighted sum overlay analysis can be performed with ArcGIS software. Finally, to determine the land suitability index, the following formula was used [32,34]:

$$LS \sum_{i=1}^{n} w_i s_i \quad (1)$$

where *LS* is land suitability; w_i is weight of land suitability criteria; s_i is the score of criteria *i*; and *n* is the number of land suitability classes.

2.4. Ecological Models

To survey the situation and the potential of the environmental area and evaluate the land suitability of the study area for agriculture and grassland two models were provided. These models contain Makhdum's [35] ecological model of grassland and agricultural usage, which consists of irrigated cultivation, rain-fed cultivation, working faced, horticulture, animal husbandry, apiculture, beekeeping and grassland uses, which pertains to business sheep fields, dynamic cattle, and wildlife grazing. These models are based on for criteria: current use, height, soil type, slope and floor.

3. Results

3.1. AHP Weights

To determine the preferences of the two elements of the hierarchy in the constraints matrix, a 9-point underlying semantic scale was used. The sum of each column within the matrix was normalized and weights are calculated. Numerical values were assigned to each pair of constraints by using the guidelines (Tables 1–4).

Throughout analysis/decision support/weight, the weights were developed by providing a series of pairwise comparisons of the importance of factors to the suitability of pixels from the activity being evaluated. In fact, a major challenge was the derivation of the weights in light of the decision objective.

Table 1. Paired comparison of first layer criteria in suitability evaluation of the Sangab Plain.

Criteria	(P)	(A)	(E)	Weight
Physical criteria (P)	1	4	5	0.674
Agronomic criteria (A)	0.25	1	3	0.226
Socio-economic criteria (E)	0.20	0.33	1	0.101
Consistency ratio				0.076

Table 2. Paired comparison of sub-criteria, physical criteria in suitability evaluation of the Sangab Plain.

Sub-Criteria	(P1)	(P2)	(P3)	(P4)	Weight
Climate (P1)	1	4	7	8	0.611
Topography (P2)	0.25	1	5	6	0.261
Soil (P3)	0.14	0.20	1	2	0.077
Vegetation (P4)	0.13	0.17	0.50	1	0.05
Consistency ratio					0.068

Table 3. Paired comparison of sub-criteria, agronomic criteria in suitability evaluation of the Sangab Plain.

Sub-Criteria	(A1)	(A2)	(A3)	(A4)	Weight
Water availability (A1)	1	4	7	8	0.611
Soil fertility (A2)	0.25	1	5	6	0.261
Cultivation ability (A3)	0.14	0.2	1	2	0.077
Use of inputs (A4)	0.13	0.17	0.5	1	0.05
Consistency ratio					0.068

Table 4. Paired comparison of sub-criteria, socioeconomic criteria in suitability evaluation of the Sangab Plain.

Sub-Criteria	(E1)	(E2)	(E3)	(E4)	(E5)	Weight
Accessibility area (E1)	1	3	5	6	8	0.496
Rangeland grazing capacity (E2)	0.33	1	4	5	7	0.287
Cropping pattern (E3)	0.2	0.25	1	2	4	0.111
Supply market and revenue increase (E4)	0.17	0.2	0.5	1	2	0.067
Investment (E5)	0.13	0.14	0.25	0.5	1	0.039
Consistency ratio						0.044

When considering lands for future development, much of the suitability depends on developing different abilities and road accessibility. The study area has is reasonably good road accessibility, with all lands not more than 500 m away from a major or a minor road. As a result, when lands are buffered, it always falls outside the area. This indicates that road access is not a constraint in determining developable suitability (Table 4).

Table 5 indicates the partial and overall weight of each criteria and sub-criteria. According to this table, the most important criteria that determines the suitability of land had been physical criteria (0.674). This criterion was respectively, about three and six times more important than agronomic and economic—social criteria. In addition, based on the column "partial weight" within the physical, agronomic and socio-economic criteria, respectively, climate (0.611), water availability (0.611) and accessibility area (0.496) were the most important sub-criteria. However, as the "overall weight" column shows, climate (0.412), topography (0.176), and water availability (0.138) were the key sub-criteria for determining the land suitability.

Table 5. The partial and overall priorities (weights) of criteria and sub-criteria.

Criteria	Weight of Criteria	Sub-Criteria	Partial Weight	Overall Weight
Physical criteria (P)	0.674	Climate (P1)	0.611	0.412
		Topography (P2)	0.261	0.176
		(P3) soil	0.077	0.052
		Vegetation (P4)	0.05	0.034
Agronomic criteria (A)	0.226	Water availability (A1)	0.611	0.138
		Soil fertility (A2)	0.261	0.059
		Cultivation ability (A3)	0.077	0.017
		Use of inputs (A4)	0.05	0.011
Socio-Economic criteria (E)	0.101	Accessibility area (E1)	0.496	0.050
		Rangeland grazing capacity (E2)	0.287	0.029
		Cropping pattern (E3)	0.111	0.011
		Supply market and revenue increase (E4)	0.067	0.007
		Investment (E5)	0.039	0.004

Figure 3 compares the consistency of the criteria and sub-criteria. Socio-economic sub-criteria had the lowest consistency rate of all criteria and sub-criteria. This means that the experts agreed with each other more on this criterion than on the others. Furthermore, the experts disagreed the most about socio-economic criteria.

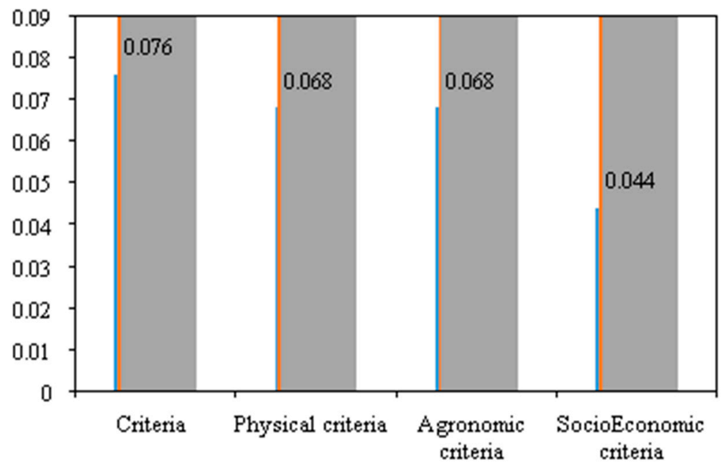

Figure 3. CR comparison for evaluation of ecological potentiality of the Sangab Plain.

3.2. Spatial Analyses

After calculating the results of the hierarchical formation, spatial analyses form the basis of the area's slope, elevation, slope aspects, soil map, and the study area's current land uses. All of these were the same as the agriculture and grassland potential evaluation indexes of the area and are presented in the form of digital maps that are used in the evaluation process (Figures 4–8).

3.2.1. Slope

Soil formation is closely related to geomorphologic properties. Slope degree is the main determinant of erosion control [36]. The slope percent map of the Sangab Plain has five levels; the lowest slope in this area is between 0–2 and the highest is 30–90 m. Low slope areas present flat lands and high slope areas show mountain areas. Figure 4 shows that the northern and southern parts of this area have a steeper slope than the east and center of this plain.

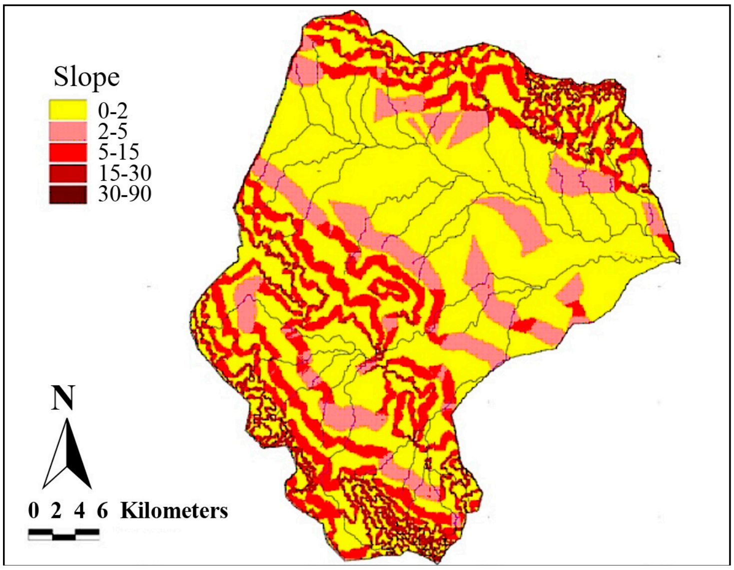

Figure 4. Slope map of the study area.

3.2.2. Slope Aspect

The slope aspect map of the Sangab basin has been presented in nine levels with the slope aspect identified within each area. According to Figure 5, flatlands covered the largest area of the Sangab Plain and the direction of the slopes was seen more in the east and northeast. The rest of slope aspects were equally proportioned within the contained area (Figure 5).

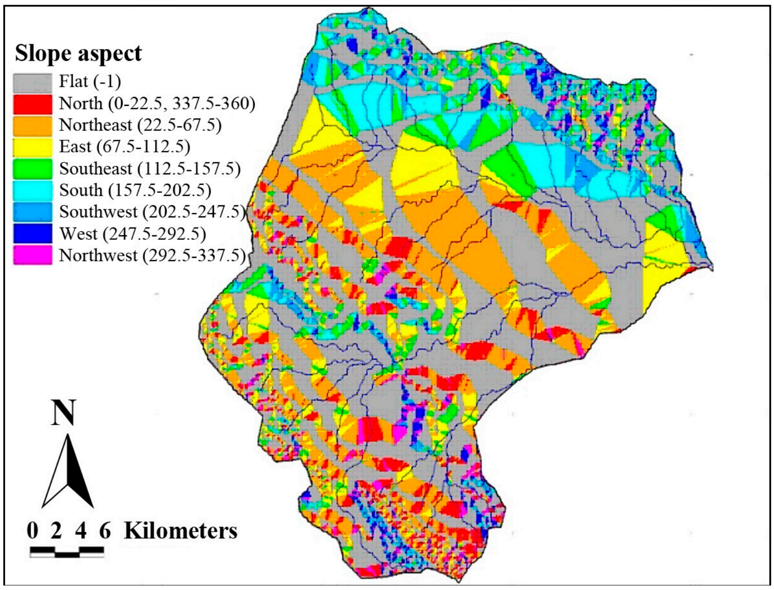

Figure 5. Aspect map of the study area.

3.2.3. Elevation

Elevation affects agricultural land suitability due to its role in temperature changes, and the variations of plant cover. The vegetation and bloom periods are delayed by 4–6 days for every additional 100 m in elevation on the mountains [14]. Figure 6 has eight levels, with a minimum and maximum distance between each level of 175 m. The lowest level of elevation was 600–775 m and the highest level had an elevation of 1825–2000 m. Areas of low elevation are located in the east and the areas of the highest elevation are in the south.

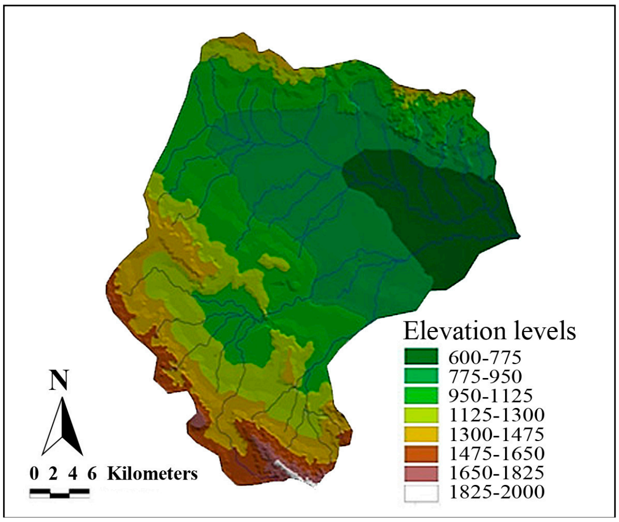

Figure 6. Elevation map of the study area.

3.2.4. Soils

The type of soil in an area of land is one of the most important factors of agricultural land suitability; soil behavior helps estimate the soil performance in agricultural production. Thus, when deciding on the suitability of land for agricultural production, it is necessary to know what types of soil are in the area. According to the topographical map, the soil resources map consists of four levels: mountain area, hill area, piedmont area, prairie and plains region. The soil map shows more mountain areas in the north, south, and southwest side; the center and east of this basin are devoted to mahoori hills, piedmont plains and flood plains (Figure 7).

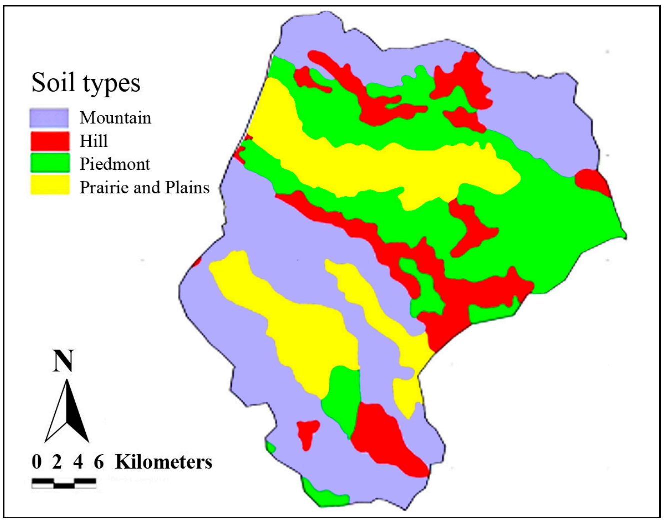

Figure 7. Soil map of the study area.

3.2.5. Land Use

According to the topographical map (Figure 8), the land use map consists of four level; each level explains a type of land use. Based on this map, most of the space in the study area is devoted to rain-fed and grassland uses and with insignificant amounts of irrigated agronomy and no orchards.

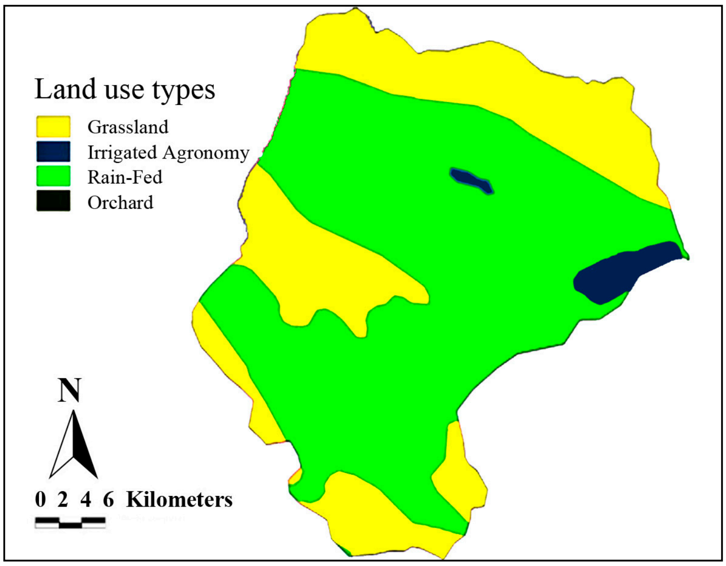

Figure 8. The map of the current land use in the study site.

3.3. Ecological Model of Studied Area Potential Determination

As mentioned in the methods section, to assess the situation and the potential of the environmental area and according to the characteristics of the study area, two models were generated to evaluate the suitability of the Sangab Plain (Tables 6 and 7). The suitability maps for grassland and agricultural land uses were prepared for each model after the ecological models were identified (Figures 9 and 10).

Table 6. Ecological model of agriculture use direction.

Current Use	Height (m)	Soil	Slope (Degree)	Floor
Rain-fed and Irrigated land	600–950	Flood plain	0–2	Lots
Rain-fed	950–1125	Mahoori hill and piedmont plain	2–5	Medium
Grassland	1125–1825	Mountain regosols	5–30	Inappropriate

Table 7. Ecological model of grassland use direction.

Current Use	Height (m)	Soil	Slope (Degree)	Floor
Grassland	1475–1825	Mountain regosols	15–30	Lots
Grassland	950–1475	Mahoori hill and flood plain	5–15	Medium
Rain-fed and Irrigated land	600–950	Piedmont plain and flood plain	0–5	Inappropriate

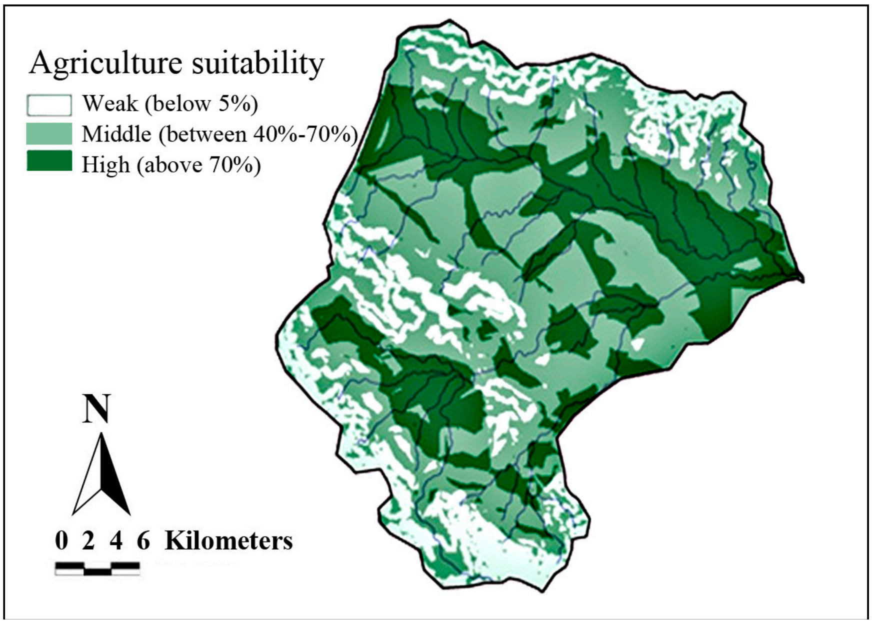

Figure 9. Agriculture suitability map of the Sangab plain.

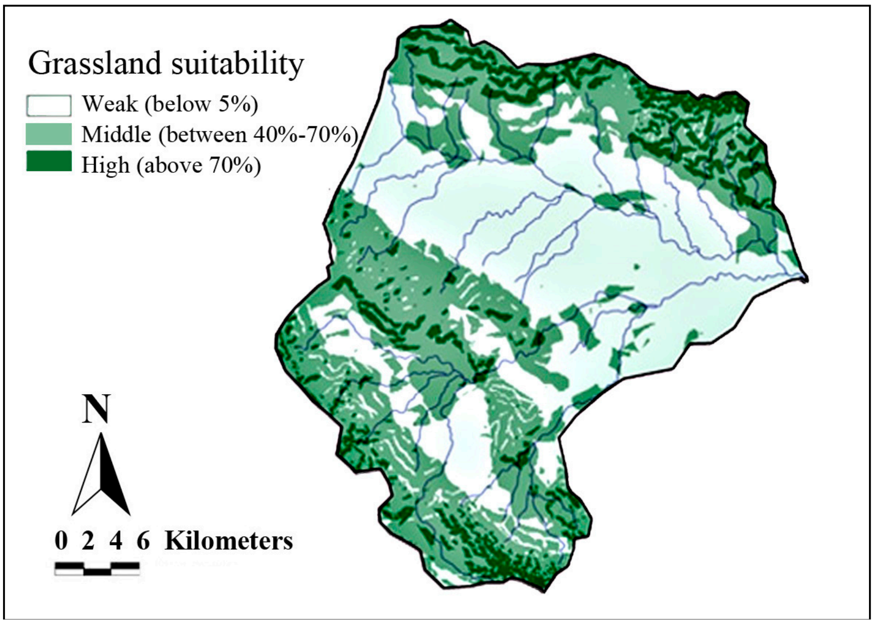

Figure 10. Grassland suitability map of the Sangab Plain.

The results from the evaluation of the Sangab Plain (agriculture and grassland suitability of the studied area) are shown in Figure 11. By using the outcomes of the indexes of weight determination and spatial basis studies, the ecological capability of the studied area was estimated for agriculture and grassland uses (Figures 9 and 10). From the total area of the studied lands, 20% had high (rich), 65% had medium (fair), and 15% had low (poor) potential for "agriculture", whereas about 7% showed high (rich), 23% medium (fair), and 70% had low (poor) potential for "grassland" use (Figure 10). It then seems that most of the land in the study area are more appropriate for agriculture or grassland.

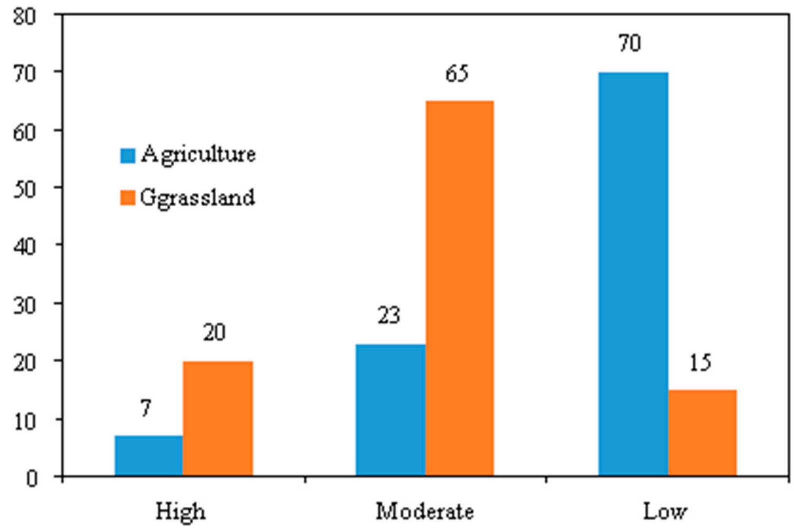

Figure 11. Percentage chart of agriculture and grassland suitability.

4. Conclusions

Determining the appropriate use of land to make the best use of the land in the country and to prevent depletion of resources due to population growth could and would be a useful way to devise strategies for stable expansion [37,38]. This study implemented an integrated GIS and AHP-based method to evaluate the suitability of agricultural land and grassland in the study area. The case study looked at physical, agronomic and socio-economic criteria. These criteria comprised 12 factors, including topography, soil, vegetation, water availability, soil fertility, rangeland grazing capacity, cropping pattern, supply market and revenue increase, and investment. Similar to Zhang et al. [8], Yalew, van Griensven, and van der Zaag [39], Romano et al. [40], Hamzeh et al. [41] and Jankowski [42], in this study, the AHP technique was used to calculated the weights of each factor.

The suitability map of agricultural land and grassland was generated by ArcMap. According to our study, the lands with (a) a slope from 0 to 2 degrees, (b) a flood soil type, and (c) an elevation from 600 to 950 m are the most suitable for agriculture. In addition, the study showed that the site in question is suitable for agriculture and is now being used for irrigated and rain-fed agronomy. It is, therefore, ecologically adaptive. In contrast, areas with (a) a slope from 15 to 30 degrees, (b) mountainous regosol soil, and (c) elevation floors from 1475 to 1825 m, are suitable for use as grassland. Therefore, grassland use is also adaptive in terms of the area's ecological characteristics. Grasslands are also used to control the erosion of highly erodible lands [43,44]. Grasses are used in crop rotations and in strip cropping systems to slow surface water flow [45], to increase infiltration [46,47], and to reduce sediment running off tilled fields [48]. Despite this, it seems that the lands of study area were more suitable for agriculture than for grassland. Moreover, the results displayed that the socio-economic criteria are the least important criteria for investigating the suitability of land use. In other words, the suitability of any land for any use should be determined primarily on physical criteria, secondarily on agronomic criteria, and finally, on socio-economic criteria. However, various studies [49–58] have shown that socio-economic factors and variables have always played an important role in land use change. In that case, although socio-economic factors and variables may not have a direct and important role on determining the suitability of lands for agriculture or other uses, through their impacts on land use and cover changes they do affect it. At the same time, if the type of land use was suitable, future changes in land use are less likely [58–60].

Furthermore, in recent years farmers have been encouraged to convert cornfields into permanent grasslands, whenever soil and economic sustainability become questionable. The priority of land use in some of the units is determined by political needs, and there is no possibility of that changing [61].

In some units where one particular use does not have any advantage over the others and are close in terms of priority, multiple uses may be proposed [35].

Although GIS offers greater flexibility and accuracy in land use planning, some researchers [62–67] have emphasized that combining GIS with tools and methods, such as AHP, will produce better results. In this study, we combined AHP and GIS analyses; we used AHP to weigh the criteria and sub-criteria, as they do not have the same importance in their roles when determining the type of land uses. We also used GIS to survey the situation and the potential of the environmental area and the characteristics of the study area to evaluate the suitability of the lands. Our findings revealed that this combination could improve decision making for policy makers and planners. It can enable them to use more criteria with different weights when making a strategy, policy or decision about whether to preserve or change the use of a land area. It also could combine the experts' views in the process of decision making. Then, we argue that although those land use planners have conducted similar exercises in the past using manual methods, GIS can do the same much faster. Planners can use the present evaluation in their future agricultural and grassland expansions; utilizing information on the least suitable areas for development and practicing conservation is an important part of decision making. Because these combinations are difficult components of the decision-making process, planners will want to judge whether land should be developed or conserved. The combination of the AHP method with GIS is a new trend in land use planning and this study confirms that the findings of other researchers could be powerfully combined and applied in land use planning. This conclusion is consistent with the findings of Weerakoon [67], Duc [64], Al-Shalabi et al. [62], Chen et al. [63] and Thapa and Murayama [66].

Author Contributions: This study presents a team work developed by several authors. Elnaz Memarbashi wrote the main text. Hossein Azadi designed the structure of the paper and enriched the draft from the first to acceptable versions. Ali Akbar Barati and Fatemeh Mohajeri assisted the other authors in enriching the first draft to come up with the final draft. Steven Van Passel and Frank Witlox critically reviewed the paper and helped in addressing the reviewers' comments. With different contributions, all the authors enriched the submitted manuscript and ended it up with the current publication.

Conflicts of Interest: The authors declare no conflict of interest.

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