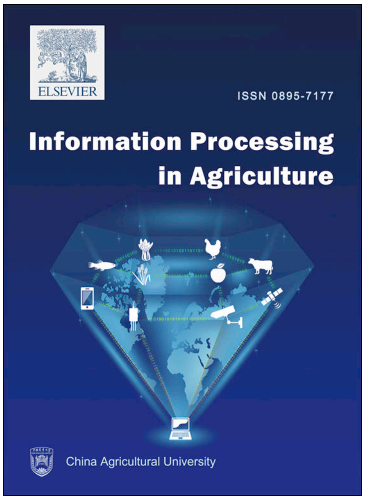


Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran province, Iran

Sherwin Amini, Abbas Rohani, Mohammad Hossein Aghkhani, Mohammad Hossein Abbaspour-Fard, Mohammad Reza Asgharipour

PII: S2214-3173(19)30198-2
DOI: https://doi.org/10.1016/j.inpa.2019.10.001
Reference: INPA 225

To appear in: *Information Processing in Agriculture*

Received Date: 14 July 2019
Revised Date: 30 September 2019
Accepted Date: 8 October 2019

Please cite this article as: S. Amini, A. Rohani, M. Hossein Aghkhani, M. Hossein Abbaspour-Fard, M. Reza Asgharipour, Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran province, Iran, *Information Processing in Agriculture* (2019), doi: https://doi.org/10.1016/j.inpa.2019.10.001

Title

Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran province, Iran

Authors

Sherwin Amini[1], Abbas Rohani [1*], Mohammad Hossein Aghkhani [1], Mohammad Hossein Abbaspour-Fard[1], Mohammad Reza Asgharipour[2]
1. Department of Biosystems Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran
2. Unit of Agroecology, Department of Agronomy, Faculty of Agriculture, University of Zabol, Zabol, Iran

*Corresponding author

Abbas Rohani

Complete Postal Address

Department of Biosystems Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran

E-mail

arohani@um.ac.ir

Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran province, Iran

Abstract

This research was conducted to evaluate the sustainability of rice production using fuzzy logic in Mazandaran province, Iran. The untapped use of modern agricultural technology, such as agricultural machinery, has become a global dilemma, which has forced governments and environmentalists to take a serious stand against the dangers of massive non-standard agricultural practices in the environment. Three types of mechanization, socioeconomic, and economic modeling were used to determine the sustainability and their values were collected through interview method using a 320-item questionnaire from 2016 to 2018. Land evaluation was carried out using soil and climate characteristics, so that about 27.4% of the area was in the perfectly suitable range (S1), 35.2% in the appropriate range (S2), 19.5% in the critical range (S3), and 17.9% in the inappropriate range (N) for rice cultivation. Farmers were selected from two regions (R1 and R2) by the GIS on two lower levels and more than one hectare (A1, A2) according to agricultural methods (mechanical and traditional). The results showed that the highest and lowest means of the product were 4314.44 and 3501.95 kg ha^{-1}, respectively. The sustainability of production was within the range of "sustainability" and "almost sustainable" in terms of mechanistic and economic factors in the fuzzy range of "moderate sustainability" and also with respect to social factors that are in a better position than mechanistic and economic indicators. Results of final sustainability model showed that the average of the lasting sustainability index was in the range of "almost unsustainable" and "moderate sustainability".

Keywords: Sustainable Agriculture, Fuzzy logics, Environmental management, Rice, GIS, AHP

1. Introduction

Rice is one of the most important food products for more than half of the world's population and affects several billion people's livelihood and economics. According to FAO estimates, rice global production has reached 500 million tons, with global consumption of rice rising 1.1% as compared to that of preceding year (2017) [1]. In Iran, rice is also used as the second agricultural crop after wheat, and 75% of protein and 80% of calories are supplied from this food source [2,3]. In order to provide food for a growing population, the world has access to rice as an important objective, so that Asia is dependent on the sustainability of rice production to maintain food security and eradicate poverty [4,5]. The concept of sustainability or sustainable development is clearly the basis for sustainability assessment [6-8]. Sustainability assessment is a tool that can help decision makers and policymakers to decide whether or not actions should be taken in the effort to build a sustainable society [9-11] and to ensure the utility of programs and activities in support of sustainable development [12,13]. Sustainable systems can include systems aimed at the best use of ecological goods and services, while not hurting these assets [14,15]. The measurement of agricultural sustainability is complex and involves complex interactions between technologies, the environment, and society [16,17]. Indicators are an appropriate alternative when direct measurement is not feasible. Explaining any indicator for sustainability assessment should be based on the goals, strategies, tasks, and guidelines developed to achieve sustainability in agricultural activities [18-21].

Models of agricultural sustainability are different in various regions without a single copy. But what is distinct and constant is a model framework based on social, economic, and ecological sustainability [22-26]. In agriculture, sustainability goals include maintaining or increasing the natural resources of the environment, meeting food needs, and social welfare so that if farmers improve the efficiency of their used inputs, they can achieve their economic and environmental goals. Also, the limitation of the production factors can be corrected with proper management and systematic planning [27,28,29].A study on the efficiency and sustainability of fodder corn production showed that optimal consumption of electricity and chemical fertilizers contributed greatly to reducing the climate impact of corn fodder production [30]. The authors recommended to use new irrigation methods to save water and electricity consumption for groundwater pumps, and to increase farmers' awareness for more effective use of chemical fertilizers. Roy and Chan [5] studied the determinants of the sustainability of rainfed and blue rice cultivation and detected that knowledge, skill, and efficiency of rice were the most common factors affecting sustainable production of rice. They also reported that the application of resource conservation technology in irrigated rice had an effective role in increasing the productivity and conservation of natural resources, and that increasing land productivity was a determining factor in the sustainability of rice. The sustainability of agricultural operation units was measured and analyzed in another study and it was concluded that 46.7 percent of the studied systems were highly un` and unsustainable, 43.6 percent were sustainable, and 9.7 percent belonged to the sustainable and very sustainable group [31]. Assessing factors affecting the use of sustainability learning in Iranian agriculture by 120 farmers through random sampling showed that the performance, content validity, use plan, use opportunity, observer support, the years of work experience in agriculture, and age had significant effects on the sustainable use of farmers [32]. A research on the ecological sustainability of small-surface agricultural system in Salahabad area (Hamedan, Iran) showed that the agricultural system of the region was in a critical situation in terms of sustainability, so that 67.7% of small-surface agricultural system was highly unsustainable, 22.9% unsustainable, 7.3% relatively sustainable, and only 2.1% was sustainable [33].

Today, the use of GIS technology in agricultural sciences is increasing to ease the presentation and understanding of information [34]. Sustainability status can be shown in the form of GIS maps. It is easy to determine regions that have less privilege and less sustainability in agriculture, and those that are gaining higher or have high agricultural sustainability [35]. Therefore, the use of GIS technology to scale up areas in terms of agricultural sustainability is a simple and suitable method for understanding sustainability in each region [36]. Next, applying appropriate management for indicators with low scores in each region eliminates the weaknesses of the agricultural system and initiates sustainable cultivation of canoes in that area.

Since the boundary between sustainability and in sustainability is not completely clear and the exact determination of the main values of sustainability is not possible, there should always be a degree of uncertainty in its calculation. In other words, it is difficult to define and measure the complex concept of sustainability due to its obscure nature. For this reason, fuzzy logic is a suitable tool for calculating sustainability due to its ability to model and systematically use vague and imprecise situations as well as the power to use natural language and linguistic values [37]. Considering the ability of fuzzy logic models, social, economic and mechanistic factors are to be considered, these models are used in a multi-stage analysis to eventually reach an indicator that indicates the sustainability of production.

The use of GIS in the field of agricultural science has become widespread in the last few decades. Some studies have also been conducted on agricultural production using fuzzy logics (Table 1).

Most studies that have analyzed the status of sustainability have focused on environmental status and removed the economic, social, and mechanistic aspects that guarantee a comprehensive approach to sustainability assessment given the complexity of agricultural activities. Several researchers around the world have also evaluated land suitability using the GIS technique. This study sought to identify the lands suitable for rice production using GIS/AHP techniques. In this research, it has been attempted to investigate the application of scientific methods of rice sustainability at field level, in the hope that the farmer, as the main user, will get the desired use. In addition, the indicators highlighting the strengths and weaknesses of the rice production system indicate where the agricultural decision makers should focus in order for the rice production system in the region to become more sustainable. Also, the fuzzy method was applied for calculating sustainability with economic, social, and biophysical aspects according to the complex nature of the sustainability (Soil, Climate, and Machinery). Rice production used at the farm level may be used by the farmer as the main user. In addition, the indicators obtained by showing the strengths and weaknesses of the rice production system will show parts of the rice production system on which agricultural decision-makers should focus in the studied area to make it more sustainable.

Table 1. Review of fuzzy and GIS-based papers for sustainability and land suitability evaluation

2. Materials and methods

2.1 Study area

This research was carried out at an area of 580 thousand hectares from Mazandaran province, Iran, in spring and summer 2016-17. With nearly 230 thousand hectares of rice lands, Mazandaran province has been ranked first in rice production in Iran. In the first phase of the study, 950 thousand tons of white rice was produced to evaluate the areas of rice production, along with collection of soil data and maps, and meteorological data [64,65].

2.2 Study area and its suitability assessment for rice production using GIS/AHP

In the first stage, the land suitability of the area with rice production was evaluated from the soil maps of the Jihad Agriculture Organization of Mazandaran province. To this end, data were collected from soil testing (from different parts of rice cultivation areas in Mazandaran province), and meteorological data were obtained from 14 meteorological stations, viz. Alasht, Amol, Babolsar, Baladeh, Bandar-e-Amiradabad, Pulsefid, Ramsar, Sari, Siyah Bisheh, Gharakhil, Kojur, Kayasar, Golghah, and Noshahr. In this study, the soil and climate characteristics were used as follows:

- Soil characteristics: electrical conductivity (ECe, ds/m), acidity (pH), and soil depth (m).
- Climatological characteristics: Annual precipitation (mm/year) and average temperature of growth period (℃).

The fitting range of each attribute was extracted from the food and farming standards of the rice industry, as shown in Table 2 [38,50,66-68]

It is necessary to achieve the final map of the land suitability of the area from the combination of soil and climate characteristics considered in the GIS. Obviously, all soil and climate characteristics in the rice production do not have the same effects, and many studies have shown that the use of multi-criteria decision-making methods, including the hierarchical analysis method, yields more accurate results than conventional numerical methods [69]. In this research, the significance and specificity of the study were obtained by using the hierarchical analysis method and through interviewing agricultural experts and faculty members of agricultural colleges [70]. The schematic view of the research process is presented in Fig. 1.

Using the hierarchical analysis method, soil and climatic characteristics of the first level were considered as criteria and factors related to each other as sub-criteria in the second level (Fig. 2). It should be noted that the purpose of using hierarchical analysis at this stage is to obtain the weight of soil and climatic characteristics, and the ranking of decision options is not desirable [71,72].

Table 2. Range of land suitability in terms of climatic and soil properties for rice cultivation

Fig 2. Hierarchical structure of the soil and climatic factors applied in AHP and GIS

In order to achieve the weight of each factor from the viewpoint of experts, they were asked to complete the matrices of the paired comparisons of each level using questionnaires in the first stage. The final weight of each factor was obtained using Expert Choice v11.0 [73,74].

In the geographical information system, the soil and the climate are separately mapped to obtain the early maps of each characteristic. Thus, three early maps of three soil properties and three maps were obtained for three climatic features. After weighing the factors, these weights were affected in the early maps of each soil and climatic condition of the order. As such, the weight of each property is multiplied using the overlay of the layers in the geographic information system (Eq. 2). Ultimately, a final map was obtained for each soil and climatic group, indicating the land suitability of the soil and climate. In the final stage, these two maps were combined with the same previous trends and with the given weights, yielding the final map of the land suitability of the region. According to the fitting range, the final map outlined two homogeneous regions, each of which has its own land suitability index. Different classes of proportions are shaped such as S1, S2, etc. according to the final index [75].

2.3 Sampling method

Farmers from the two regions were identified at two levels in the GIS. Areas less and more than one hectare were selected according to two agricultural methods (modern and traditional). The sample size needed to perform the probe was obtained using Cochran's formula [76]:

$$n=\frac{N(s\times t)^2}{(N-1)d^2+(s\times t)^2} \qquad (1)$$

where n is required sample size, s is standard deviation, t is the value at 95% confidence limit (1.96), N is the number of holding in target population, and d is the acceptable error (a permissible error of 5%). The sample size was calculated by a criteria of 5% deviation from population mean and 95% confidence level.

A total of two areas were selected based on two levels of cultivation and two cultivation methods, with eight groups of farmers were as listed in Table 3.

Table 3. The number of selected farmers for each amount

2.4 Factors considered in determining the sustainability of rice production

An important step in the sustainability process is the selection of appropriate indicators. The information needed to calculate the sustainability index was obtained by means of a questionnaire and doing interviews, which included mechanistic, social, and economic factors (Fig. 3) [77]. The factors mentioned above were chosen to show the status of production and its sustainability status in terms of agriculture (or in the wider mechanization, economic, and social contexts) and also could be collected and evaluated at the vast area of the study (Table 4).

Fig. 3. Factors considered in determining rice sustainability

Table 4. Analysis of criteria an indicator should match in order to be included in an evaluation

2.5 Fuzzy Models for Rice Sustainability Indexes

In the decision-making process, issues are always encountered in which ambiguity exists that make it complicated and difficult the study and evaluation process. Fuzzy Logic is a method developed to find an appropriate response to such problems. Due to different activities carried out in the agricultural sector, knowledge about the environmental effects of these activities is not yet complete, hence fuzzy logic can be decisively used for making decisions on such uncertain information [78].

2.6 Fuzzy Inference Process

A fuzzy inference system consists of three main input or inputs, a rule base, and output or outputs. The process of inferring a mammalian fuzzy type, regardless of what purpose it is used for, theoretically consists of five steps, including inputs or input fuzzification, logical operators, fuzzy inference rules, clustering or aggregation and non-fuzzy output or outputs (Fig. 4) [79].

Fig. 4. Fuzzy Logic System

The mechanistic and socio-economic factors each have a basic fuzzy model, the constituents of which are listed in Fig. 3. A sustainability index was obtained from the analysis of the cases related to each factor (economic, mechanistic and social factors). These four indicators were introduced into the overall fuzzy model and finally the total sustainability index was extracted, which shows the sustainability of rice production with respect to all the mentioned factors. The schematic diagram of the fuzzy models for the achievement of the total sustainability index is presented in Fig. 5.

Fig. 5. Schematic view of fuzzy models designed to achieve total sustainability index

In the next step, the linguistic variable of each case and its related fuzzy function were determined by the experts. In order to use experts' opinion, questionnaires with similar questions were asked in the first stage, and they were asked to identify the linguistic variable and the fuzzy function range for each factor. After collecting information, it became clear that 98% of the experts tended to define a four-language range called 'low', 'medium', 'high', and 'very large', and therefore, models were defined with these four language variables. All the defined inputs (for example, the mechanization factors in Table 5) have a triangular function for defining a variable whose first (low) and last (very high) variables are defined as trapezoidal functions. For example, the linguistic variables and the range of membership functions in the mechanization model are shown in Table (8).

Table 5. Rating and meanings for diesel fuel *(DF)*, waiting time *(WT)*, farm size *(FS).*

Table 6. Language variables for the mechanistic model

3. Results and discussion

In addition to using Food and Agriculture Organization standards in using experts' opinions, the Analytic Dynamics Analysis was used to determine the weight of each agent in Table 7.

Table 7. Layer weight by AHP method

The electrical conductivity maps, acidity, and depth of the soil, as well as the final map of soil from these three factors are shown in Fig. 7. The final soil map (Fig. 7) was obtained according to the weight of each electrical conductivity, acidity, and soil depth in the geographic information system using Equation 2:

$$\sum\left(grid_i \times weight_i\right) = \left(grid_{Acidity} \times weight_{Acidity}\right) + \left(grid_{EC} \times weight_{EC}\right) + \left(grid_{Depth} \times weight_{Depth}\right)$$

$$= \left(grid_{Acidity} \times 0.335\right) + \left(grid_{EC} \times 0.45\right) + \left(grid_{Depth} \times 0.215\right) \qquad (2)$$

The climatic characteristics and the resulting map are combined with the same relationship (Eq. 2) and by applying the corresponding weight to each characteristic. Each map of the soil characteristics alone (Fig. 7) and the final map (Fig. 7) show that the dominant area of the region (50-70 percent) is located in the "perfectly suitable" (S1) range for rice cultivation. The depth map of the area (Fig. 7) shows that more than 30% of the area is "perfectly suitable (S1)" for rice cultivation. The final soil map in (Fig. 7) shows that 78.59%, 12%, and 38.9% of the area are "perfectly fit" (S1), suitable (S2), and "critical fit" (S3), respectively, for rice production. Even so, there is currently no rice cultivation in the appropriate areas specified in the region.

The climate map of the area shows that rice is cultivated in terms of rainfall, average temperature (Fig. 6), and average minimum temperature during growth (Fig. 5) in the "suitable (S2)" region. However, Fig. 5 shows that the area is not much suitable for rice cultivation in terms of atmospheric irrigation, and the proportion is comparatively higher in areas of "critical fit" (S3) and "inappropriate (N)". This map highlights the risk of emptying the water resources of the area and warns the authorities and farmers that, if steady production of rice is concerned, moving towards proper use of water is not only inevitable, but also imperative.

Fig. 8 combines the final maps of soil and climate (a combination of maps 7 and 6)indicating that the studied area is located in four "perfectly suitable (S1)", "suitable (S2)", "critical fit (S3)" and "inappropriate (N)" rice cultivation areas. Fortunately, most of the area of 159,171 hectares (27.4 percent) is "perfectly" and 204,312 hectares (35.2 percent) is "suitable" for rice cultivation. However, about 112,908 hectares (19.5 percent) fall into within the "critical fit" and 10,396 hectares (17.9 percent) into "inappropriate" areas (Table 8). According to our examination, the two areas are homogeneous in terms of the soil and climate characteristics and are considered titles R1 and R2 in this research.

Land suitability for sorghum production was analyzed in northern semi-arid regions using GIS and AHP, so that the model output was 30.54% in approximately moderately suitable range, 36.16% in marginally suitable range, 18.5% in currently not suitable, and 15.24% in permanently not suitable for sorghum production [45]. The results of a study showed that more than 70 percent of the total area under study was suitable for rice production [38]. Zhang et al. [39] evaluated Tenyako lands in China using GIS and AHP. Their results showed that 29.82% of the land was suitable for tobacco cultivation and 17.77% was not suitable for tobacco cultivation. In another similar research, 23.48% and 26.11% of land were perfectly suitable and unsuitable for bean cultivation [80].

Fig. 6. Climatic suitability map

Fig. 7. Soil suitability map

Fig. 8. Total suitability map from soil and climatic maps

Table 8. Area and percentage of each rice land in Mazandaran province

4.2 Intake rate for rice production

The amounts of inputs and production are presented in Table 9, with reference to the economic, mechanistic, and social factors. The results showed that the highest (4314.44 kg/ha) and lowest (3501.95 kg/ha) means of the product were obtained from the R1A2T and R1A2T values, respectively. The average production distance (about 300 kg/ha) in area 2 is significant compared to that of area 1. Of course, some similar values in areas 1 and 2, such as R1A1T and R2A1T, vary by around 240 kg/ha. The average product at a surface area larger than 1 hectare (A2) is not significantly different from that of less than 1 hectare (A1). However, the average product in modern culture method (M) is more than 500 kg/ha compared to traditional cultivar (T) method.

The largest net income belongs R1A1M with a value of 36,399,610.66 million USD and the lowest cost is related to R1A1M with a value of 37,800,210.76 million USD. However, the highest profit/cost ratio is obtained from the R1A1M and R1A2M values and the lowest is achieved from R2A2T (the profit/cost ratio is not included in the models). The modern cultivation method consumes about 50-60 L/ha more fuel than the traditional one. Farmers who have used modern culture methods are more likely to participate in promotional classes in R1A1M than R1A1T (0.5 years), while they are roughly the same with traditional cultivation in other values, with relatively higher knowledge (37.80 points vs. 29) and a nearly equal rice cultivation history (15.90 to 14.95 years). Also, farmers using modern cropping methods have less R1A1M than R1A1T (18.88 vs. 28.33 days), while they are approximately equal in the other values. The use of the modern method of machinery, therefore, requires much more fuel consumption than traditional cultivation.

3-4 Production sustainability from the aspect of mechanization factors

The results of fuzzy models (mechanical, social, and economic) are presented in Table 10. The fuzzy model of mechanization factors showed that the highest (50.31) and the lowest (43.72) averages of sustainability indicators from the viewpoint of these factors were obtained for the R1A2M and R1A1T, respectively. The sustainability index of 50.31 belongs to membership function (medium or medium sustainability) with 0.985 and to membership function (high or almost sustainable) with 0.016. The index of 43.72 belongs to the membership function (low or almost unsustainable) at 0.314 and to the membership function (average or average sustainability) at 0.686. Thus, it can be estimated that production sustainability in view of the mechanistic factors is in the fuzzy range (moderate or average sustainability) (Fig. 9).

Fig. 9. Mechanical sustainability **degree**

The average mechanization sustainability indices at A2 level with the same agricultural (modern or traditional) method is about 2-4 points higher than that of A1 (by comparing the amount of R1A2M with R1A1M and other values in the same way). Modern agricultural methods also have 2-5 points greater than traditional agricultural methods at similar levels of conservation index (by comparison of R1A1T with R1A1M and other values accordingly). Interestingly, the difference in the average mechanization index with other levels is greater and to about 2-7 points for the values used modern agricultural method (M) at higher levels (A2) (by comparing the A2M values with other levels in each region). This increase is so high that it can move the sustainability level from one function to a higher one (for example, increasing the sustainability from the medium to high function). Therefore, it is expected that the mechanization index status will lead to greater sustainability by increasing the cultivated area towards A2 and using the modern agricultural method (M). Until now, a similar study is not available to measure the sustainability of the mechanical factors.

3-5 Production sustainability from the aspect of social factors

Sustainability indicators resulting from social factors are in a better position than mechanical and economic indicators (Table 9). All the averages achieved are in the range of "moderate sustainability" and "almost sustainable" being very promising in this respect. Maximum index (80) obtained from the fuzzy model of social factors was the highest of all the other models. The index belongs to a sustainable or very high function (0.5) and to nearly sustainable or high function (0.5). This indicator is typically obtained from a farmer with a knowledge score of 45, a history of 2 and 29 years for cultivation and participation in promotion classes, and five dependent individuals. In contrast, the minimum index (17.82) obtained typically belongs to a farmer with a knowledge score of 28, a history of 2 and 0 years for cultivation and participation in the promotion classes, and five dependent individuals (Fig. 10).

Fig. 10. Social sustainability

It is noteworthy that the average of this index in modern agriculture is 12 points higher than that of the traditional agriculture, which can be attributed to higher knowledge and participation in promotion classes compared to farmers who used modern agriculture. The model results show that the two important options, viz. increased participation in promotion classes leading to boosted knowledge of farmers, have had significant effects for increasing this index. It is noteworthy that the values with higher social sustainability indexes also have favorable status in other sustainability indicators, which can explain the positive and beneficial effects of extension classes to educate and improve the knowledge of farmers.

3.6 Production sustainability from the aspect of economic factors

The averages of sustainability indicators derived from economic factors are similar to those of mechanization factors. The highest index (50) belongs to a sample farmer with income and cost values of $ 8396 and $ 10728 per hectare, respectively. In contrast, the lowest index (15.3) is related to a sample farmer with income and cost values of $ 7112 and $ 10916 per hectare, respectively. The average values of economic sustainability index for R2A2M (49.81) and R1A1M (49.01) are in the ranges of "low or almost unsustainable" and "moderate or average sustainability". Even so, the average of this indicator in modern agricultural method was 2-5 points higher than the larger levels and the traditional agricultural method (Table 10). In order to reduce costs, optimal and reasonable consumption of inputs is essential to increase economic sustainability. In spite of the high price of inputs, farmers still prepare them in large numbers by all means and use them on farms at considerable quantities. Although field survey showed that the price factor was the only limitation that reduced consumption among the farmers who consumed less inputs, this factor still did not have much effect. For rational consumption of inputs, therefore, extensional approaches, proper culture-building, and even preventive measures should be utilized among farmers (Fig. 11).

Fig. 11. Economic sustainability

Asadi et al. (2013) developed a structural model for analyzing the effects of climatic, social, and economic factors on sustainable agricultural development in Qazvin province. Their results showed that climatic, social and economic sustainability had positive effects on agricultural sustainability, but climate sustainability (0.642) exerted a higher effect on agricultural sustainability than economic (0.604) and social (0.568) sustainability.

Table 9. Average factors involved in rice production

Table 10. Average, minimum, and maximum sustainability indicators

3-7 Total sustainability index for rice production

The results of average final sustainability index show that all values range within "almost unsustainable" and "average sustainability". However, maximum obtained index (59.66) belongs to the "medium sustainability" function (0.517) and to the "almost sustainable" function (0.483), which is relatively appropriate and promising (see Table 10). This indicator was obtained from a farmer with mechanical, social, and economic sustainability indices of 68.75, 50, and 80, respectively. In contrast, a final index of 35.66 belongs to a farmer with mechanical, social, and economic sustainability indices of 41.58, 17.82, and 15.3, respectively. A study examined total wheat sustainability and showed low and moderate sustainability in the studied area [81].

3.8 Sustainability of rice production from the viewpoint of cultivation methods (modern and traditional)

Due to the importance of agricultural methods and more efforts to promote the region in encouraging farmers to use these methods, the average, minimum and maximum sustainability indicators in both modern and traditional agricultural methods are shown in Fig. 12. The use of modern agricultural methods has led to increases in average values of mechanical, social, and economic sustainability indicators and consequently the final indicator. It is noteworthy that maximum and minimum values of the mechanical sustainability index are significantly different between the two methods of agriculture, with maximum and minimum values being 3-6 points higher in the modern than the traditional agricultural method, suggesting the appropriate use of required machines. However, it should be noted that this is a general analysis in terms of agricultural methodology, which does not consider the area (A) and region (R) factors.

Fig. 12. Sustainability indicators according to agricultural methods (modern and traditional)

4. Conclusion

Most studies that have analyzed sustainability have focused primarily on environmental status and have eliminated the economic, social, and mechanistic aspects that are essential to assess sustainability. In this study, we have attempted to identify suitable land for rice production using GIS, AHP and fuzzy techniques and also to evaluate the sustainability of rice production at farm level by considering economic, social and biophysical aspects. The results show that the average final sustainability index is in the range of "almost unsustainable" and "average sustainability" in all values. However, the maximum indexes (59.66) belong to the 'moderate sustainability' function (0.517) and to the 'almost sustainable' function (0.483), which is relatively favorable and promising. The use of modern agricultural methods has led to increases in average values of mechanical, social, and economic sustainability indicators of and consequently the final indicator. It is noteworthy that maximum and minimum values of the mechanical sustainability index are significantly different between the two methods of agriculture, with 3-6 points higher in the modern than the traditional method, suggesting the appropriate use of required machines. The maximum and minimum sustainability indices in each amount indicate that some farmers act very sustainable and some very unsustainable in each group. The maximum values of the indicators show that there are pioneer farmers operating in the range of medium and higher sustainability in all the investigated factors. Therefore, the homogeneity of the groups in terms of soil, climate, technology (M and T), and cropping area (A) without non-scientific prescription, the imitation of unsustainable farmers from sustainable farmers should also lead to sustainability in their production. As such, introduction of leading farmers as a model in promotion classes (e.g., setting up sample farms for introduction to farmers) can encourage other farmers to comply with them, ultimately leading to optimal use of inputs and sustainable production achievement.

Not Conflict of Interest

Appendix A

See Table A for details.

Table A. Sixty-four rules for fuzzy output (mechanization)

5. REFRENCES

[1] Bernaola L, Cange G, Way MO, Hardke J, Stout M. Natural Colonization of Rice by Arbuscular Mycorrhizal Fungi in Different Production Areas. Rice Sci 2018; 25(3): 169-174.

[2] Mohammadpour Karizaki V. Ethnic and traditional Iranian rice-based foods. J Ethnic Food 2016; 3: 124-134.

[3] Eskandari H, Attar S. Energy comparison of two rice cultivation systems. Renewable and Sustainable Energy Rev 2015; 42: 666-671.

[4] Khush GS. What it will take to feed 5.0 billion rice consumers in 2030. Plant Mol Biol 2005; 59(1): 1-6.

[5] Roy R, Chan NW. Determinants of Sustainable Irrigated and Rainfed Rice Farming in Bangladesh. J Agric Sci Technol 2015; 17(6): 1421-1435.

[6] Partidário MR. Sheate WR, Bina O, Byron H, Augusto B. Sustainability Assessment for Agriculture Scenarios in Europe's Mountain Areas: Lessons from Six Study Areas. Environ Manage 2009; 43(1): 144-165.

[7] Saad M, Nazzal MA, Darras BM. A general framework for sustainability assessment of manufacturing processes. Ecol Indic 2019; 97: 211-224.

[8] He B, Luo T, Huang Sh. Product sustainability assessment for product life cycle, J Cleaner Prod 2019; 206: 238-250.

[9] Sala S, Ciuffo B, Nijkamp PA. systemic framework for sustainability assessment. Ecol Econ 2015; 119: 314–325.

[10] Thi Bui N, kawamura A, Amaguchi H, Du Bui D, Tu Truong N, Nakagawa k. Social sustainability assessment of groundwater resources: A case study of Hanoi, Vietnam. Ecol Indic 2018; 93: 1034-1042.

[11] Zulfiqar F, Thapa GB. Agricultural sustainability assessment at provincial level in Pakistan. Land Use Policy 2017; 68: 492-502.

[12] Borgert T, Donovan JD, Topple Ch, Masli EK. Initiating sustainability assessments: Insights from practice on a procedural perspective. Environ Impact Assess Rev 2018; 72: 99-107.

[13] Mahmoud Sh, Zayed T, Fahmy M. Development of sustainability assessment tool for existing buildings, Sustain Cities Soc 2019; 44: 99-119.

[14] Pretty J. Agricultural sustainability: concepts, principles and evidence, Philosophical Transactions of the Royal Society B: Biol Sci 2008; 363: 447-465.

[15] Rodrigues GS, Martins CR, De Barros I. Sustainability assessment of ecological intensification practices in coconut production. Agric Syst 2018; 165: 71-84.

[16] Rao NH, Rogers PP. Assessment of agricultural sustainability. Curr sci 2006; 91(4- 25): 439- 448.

[17] Asgharipour MR, Shahgholi H, Campbell DE, Khamari I, Ghadiri A. Comparison of the sustainability of bean production systems based on emergy and economic analyses. Environ Monit Assess 2019; 191(1):2.

[18] Madlener R, Robledo C, Muys B, Blanco Freja JT. A sustainability framework for enhancing the long-term success of Lulucf projects. Clim Change 2006; 75: 241-271. https://doi.org/10.1007/s10584-005-9023-0

[19] Papilo P, Marimin M, Hambali E, Sitanggang IS. Sustainability index assessment of palm oil-based bioenergy in Indonesia. J Cleaner Prod 2018; 196: 808-820.

[20] Amiri Z, Asgharipour MR, Campbell DE, Armin M. A sustainability analysis of two rapeseed farming ecosystems in Khorramabad, Iran, based on emergy and economic analyses. J Clean Prod 2019; 226:1051-66.

[21] Jafari M, Asgharipour MR, Ramroudi M, Galavi M, Hadarbadi G. Sustainability assessment of date and pistachio agricultural systems using energy, emergy and economic approaches. J Clean Prod 2018;193:642-51.

[22] Rigby D, Caceres D. Organic farming and the sustainability of agricultural systems. Agric Syst 2001; 68(1): 21-40.

[23] Mofidi Chelan M, Alijanpour A, Barani H, Motamedi J, Azadi H, Van Passel S. Economic sustainability assessment in semi-steppe rangelands. Sci Total Environ 2018; 637-638: 112-119. https://doi.org/10.1016/j.scitotenv.2018.04.428

[24] Quintero-Angel M, González-Acevedo A. Tendencies and challenges for the assessment of agricultural sustainability. Agric Ecosyst Environ 2018; 254: 273-281.

[25] Dantsis Th, Douma C, Giourga Ch, Loumou A, Polychronaki EA. A methodological approach to assess and compare the sustainability level of agricultural plant production systems. Ecol Indic 2010; 10(2): 256-263.

[26] Dempsey N, Bramley G, Power S, Brown C. The social dimension of sustainable development: defining urban social sustainability. Sustain Dev 2011; 19(5): 289–300.

[27] Koeijer T, Wossink G, Struik P, Renkema J. Measuring agricultural sustainability in terms of efficiency the case of Dutch sugar beet growers. J Environ manage 2002; (66): 9-17.

[28] Praneetvatakul S, Janekarnkij P, Potchanasin C, Prayoonwong K. Assessing the sustainability of agriculture: A case of Mae Cheam Catchment, Northern Thailand. Environ Int 2001; 27(2-3): 103–109.

[29] Olakitan Atanda J. Developing a social sustainability assessment framework. Sustain Cities Soc 2019; 44: 237-252.

[30] Esfahani SMJ, Naderi Mahdei K, Saadi H, Dourandish A. Efficiency and Sustainability of Silage Corn Production by Data Envelopment Analysis and Multi-Functional Ecological Footprint: Evidence from Sarayan County, Iran. J Agric Sci Technol 2017; 19(20): 1453-1468.

[31] Iravani H, Darban-Astaneh AR. Measurement, Analysis and Exploitation of the Sustainability of Farming Systems (Case Study: Wheat Production, Tehran Province). Iran J Agric Sci 2004; 35(1): 39-52.

[32] Ataei P, Zamani N. Determinants of the Transfer of Sustainability Learning in Agricultural Sector of Iran. J Agric Sci Technol 2015; 17(6): 1437-1447.

[33] Hosseini SM, Naderi K, Kalantari K. A study of Ecological Sustainability in Farming Systems of Saleh Abad District, Hamadan. Iran J Agric Sci 2005: 2(38): 91-98.

[34] Rao MN, Waits DA, Neilsen ML. A GIS-based modeling approach for implementation of sustainable farm management practices. Environ Modell Soft 2000; 15(8): 745–753.

[35] Mendas A, Delali A. Integration of multi-criteria decision analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. Comput Electron Agric 2012; 83: 117-126.

[36] Belmonte AC, Gonzalez JM, Mayorga AV, Fernandez SC. GIS tools applied to the sustainable management of water resources: Application to the aquifer system 08-29. Agric Water Manage 1999; 40(2-3): 207-220.

[37] Phillis YA, Andriantiatsaholiniaina LA. Sustainability: An Ill-Defined Concept and Its Assessment Using Fuzzy Logic. Ecol Econ 2001; 37(3): 435-456.

[38] Ayehu GT, Besufekad SA. Land Suitability Analysis for Rice Production: A GIS Based Multi-Criteria Decision Approach. American Journal of Geographic Information System (JGIS), 2015; 4(3): 95-104.

[39] Zhang J, Su Y, Wu J, Liang H. GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China. Comput Electron Agric 2015; 114: 202–211.

[40] Raza SMH, Mahmood SA, Khan AA, Liesenberg V. Delineation of potential sites for rice cultivation through multi-criteria evaluation (MCE) using remote sensing and GIS. Int J Plant Prod 2018; 12(1): 1–11.

[41] Maleki F, Kazemi H, Siahmarguee A, Kamkar B. Development of a land use suitability model for saffron (Crocus sativus L.) cultivation by multi-criteria evaluation and spatial analysis. Ecol Eng 2017A; 106: 140–153.

[42] Erbaş M, Kabak M, Özceylan E, Çetinkaya C. Optimal siting of electric vehicle charging stations: A GIS-based fuzzy Multi-Criteria Decision Analysis. Energy 2018; 163: 1017-1031.

[43] Kabak M, Erbaş M, Çetinkaya C. Özceylan E. A GIS-based MCDM approach for the evaluation of bike-share stations. J Cleaner Prod 2018; 201: 49-60.

[44] Houshyar E, Sheikh-Davoodi MJ, Almassi M, Bahrami H, Azadi H, Omidi M, Sayyad Gh, Witlox F. Silage corn production in conventional and conservation tillage systems. Part I: Sustainability analysis using combination of GIS/AHP and multi-fuzzy modeling. Ecol Indic 2014; 39: 102-114.

[45] Kahsay A, Haile M, Gebresamuel G, Mohammed M. Land suitability analysis for sorghum crop production in northern semi-arid Ethiopia: Application of GIS-based fuzzy AHP approach. Cogent Food Agric 2018; 4(1), 1507184.

[46] Peche R, Rodriguez E. Development of environmental quality indexes based on fuzzy logic: A case study. Ecol Indic 2012; 23: 555-565.

[47] Mendoza GA, Prabhu R. Fuzzy methods for assessing criteria and indicators of sustainable forest management. Ecol Indic 2004; 3(4): 227-236.

[48] Pazuki A, Sohani MM. Phenotypic evaluation of scutellum-derived calluses in 'Indica' rice cultivars. acta agric slov 2013; 101(2): 239-247.

[49] Sys C, Van Ranst E, Debaveye J, Beernaert F. Land Evaluation. Part III: crop requirements. General Administration for Development Cooperation Place, Brussels, Belgium, 1993; 191 p.

[50] Sys C, Van Ranst E, Debaveye J. Land Evaluation. Part II. Methods in Land Evaluation. International Training Center for Post Graduate Soil Scientists. Ghent University, Ghent, Belgium, 1991; 247p.

[51] Feizizadeh B, Blaschke T. Land suitability analysis for Tabriz County, Iran: A multi-criteria evaluation approach using GIS. J Environ Plan Manage 2012; 56(1): 1–23.

[52] Müller B, Quaas MF, Frank K, Baumgärtner S. Pitfalls and potential of institutional change: Rain-index insurance and the sustainability of rangeland management. Ecol Econ 2011; 70(11): 2137-2144.

[53] Roy R, Weng Chan N, Rainis R. Rice farming sustainability assessment in Bangladesh. Sustain Sci 2014; 9(1): 31-44.

[54] Roy R, Weng Chan N, Xenarios S. Sustainability of rice production systems: an empirical evaluation to improve policy. Environ Development Sustain 2015; 18(1): 257-278.

[55] Saltiel J, Bander JW, Palchovich S. Adoption of sustainable agricultural practices: Diffusion, Farm stricture and profitability. Rural Soc 1994; 59: 333-342.

[56] Todorova SA, Lulcheva D. Economic and social effects of land fragmentation on Bulgarian agriculture. J Cent Europ Agric 2005; 6(4): 555-562.

[57] Chandre Gowda MJ, Jayaramaiah KM. Comparative evaluation of rice production systems for their sustainability. Agric Ecosyst Environ 1998; 69(1): 1-9.

[58] Zhen L, Routary JK, Zoebisch MA, Chen G, Xie G, Cheng SH. Three dimensions of sustainability of farming practices in the North China Plain: A case study from Ningjin County of Shandong Province, PR China., Agric Ecosyst Environ 2005; 105(3): 507-522.

[59] Pashaei Kamali F, Borges JAR, Meuwissen MPM, De Boer IJM, Oude Lansink AGJM. Sustainability assessment of agricultural systems: The validity of expert opinion and robustness of a multi-criteria analysis. Agric Syst 2017; 157: 118-128.

[60] Rasul G, Thapa GB. Sustainability of ecological and conventional agricultural systems in Bangladesh: an assessment based on environmental, economic and social perspectives. Agric Syst 2004; 79(3): 327–351.

[61] Vav Passel S, Nevens F, Mathijs E, Van Huylenbroeck G. Measuring farm sustainability and explaining differences in sustainable efficiency. Ecol Econ 2007; 62(1): 149-161.

[62] Islam N, Rahman MM. An assessment of crop diversification in Bangladesh: a spatial analysis. Appl Econ Lett 2012; 19(1): 29–33.

[63] Zhang BZ. (2000) Sustainable agricultural development in China. Shandong Press of Sciences and Technology, People’s Republic of China.

[64] Sadeghi-Pouya A, Nouri J, Mansouri N, Kia-Lashaki A. An indexing approach to assess flood vulnerability in the western coastal cities of Mazandaran, Iran. Int J Disaster Risk Reduct 2017; 22: 304-316.

[65] AghaAlikhani M, Kazemi-Poshtmasari H, Habibzadeh F. Energy use pattern in rice production: A case study from Mazandaran province, Iran. Energy Convers Manage 2013; 69: 157-162.

[66] Delsouz Khaki B, Honarjoo N, Davatgar N, Jalalian A, Torabi Golsefidi H. Assessment of Two Soil Fertility Indexes to Evaluate Paddy Fields for Rice Cultivation., Sustainability, 2017; 9(8): 1299.

[67] DENGİZ O. Land suitability assessment for rice cultivation based on GIS modeling, Turk J Agric For, 2013; 37: 326-334.

[68] Isitekhale JHE, Aboh SI, Ekhomen FE. Soil Suitability Evaluation for Rice and Sugarcane in Lowland Soils of Anegbette, Edo State, Nigeria., Int J Eng Sci 2014; 3(5): 54-62.

[69] Kalogirou S. Expert systems and GIS: an application of land suitability evaluation. Comput Environ Urban Syst 2002; 26(2-3): 89-112.

[70] Pramanik MK. Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. Model Earth Syst Environ 2016; 2(2): 56.

[71] Yalew SG, Van Griensven A, Mul ML, Van der Zaag P. Land suitability analysis for agriculture in the Abbay basin using remote sensing, GIS and AHP techniques. Model Earth Syst Environ 2016b; 2(2): 101.

[72] Zolekar RB, Bhagat VS. Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. Comput Electron Agric 2015; 118: 300–321.

[73] Roy J, Saha S. Assessment of land suitability for the paddy cultivation using analytical hierarchical process (AHP): A study on Hinglo river basin, Eastern India. Model Earth Syst Environ 2018; 4(2): 601–618.

[74] Bo L, Feng Z, Li-Wen Z, Jing-Feng H, Zhi-Feng J, Gupta DK. Comprehensive suitability evaluation of tea crops using GIS and a modified land ecological suitability evaluation model. Pedosphere 2012; 22(1): 122-130.

[75] Taheri-Rad A, Khojastehpour M, Rohani A, Khoramdel S, Nikkhah A. Energy flow modeling and predicting the yield of Iranian paddy cultivars using artificial neural networks, Energy, 2017; 135: 405-412.

[76] Tanguay GA, Rajaonson J, Lefebvre JF, Lanoie P. Measuring the sustainability of cities: An analysis of the use of local indicators. Ecol Indic 2010; 10(2): 407-418.

[77] Kumru M, Kumru PY. Fuzzy FMEA application to improve purchasing process in a public hospital. Appl Soft Comput 2013; 13(1): 721–733.

[78] Chanamool N, Naenna Th. Fuzzy FMEA application to improve decision-making process in an emergency department. Appl Soft Comput 2016; 43: 441-453.

[79] Houshyar E, Smith P, Mahmoodi-Eshkaftaki M, Azadi H. Sustainability of wheat production in Southwest Iran: A fuzzy-GIS based evaluation by ANFIS, Cogent Food Agric 2017; 3(1): 1327682. https://doi.org/10.1080/23311932.2017.1327682

[80] Asadi A, Kalantari Kh, Choobchian Sh. Structural Analysis of Factors Affecting Agricultural Sustainability in Qazvin Province, Iran. J Agr Sci Tech 2013; 15: 11-22.

[81] Arabian A, Kalantari Kh, Asadi A, Shabanali fami H. Assessment of sustainability level of wheat cropping system in Fars province and determination of its affective factors. Iranian Journal of Agricultural Extension and Education (IAEEJ), 2009; 5 (2): 29-17.

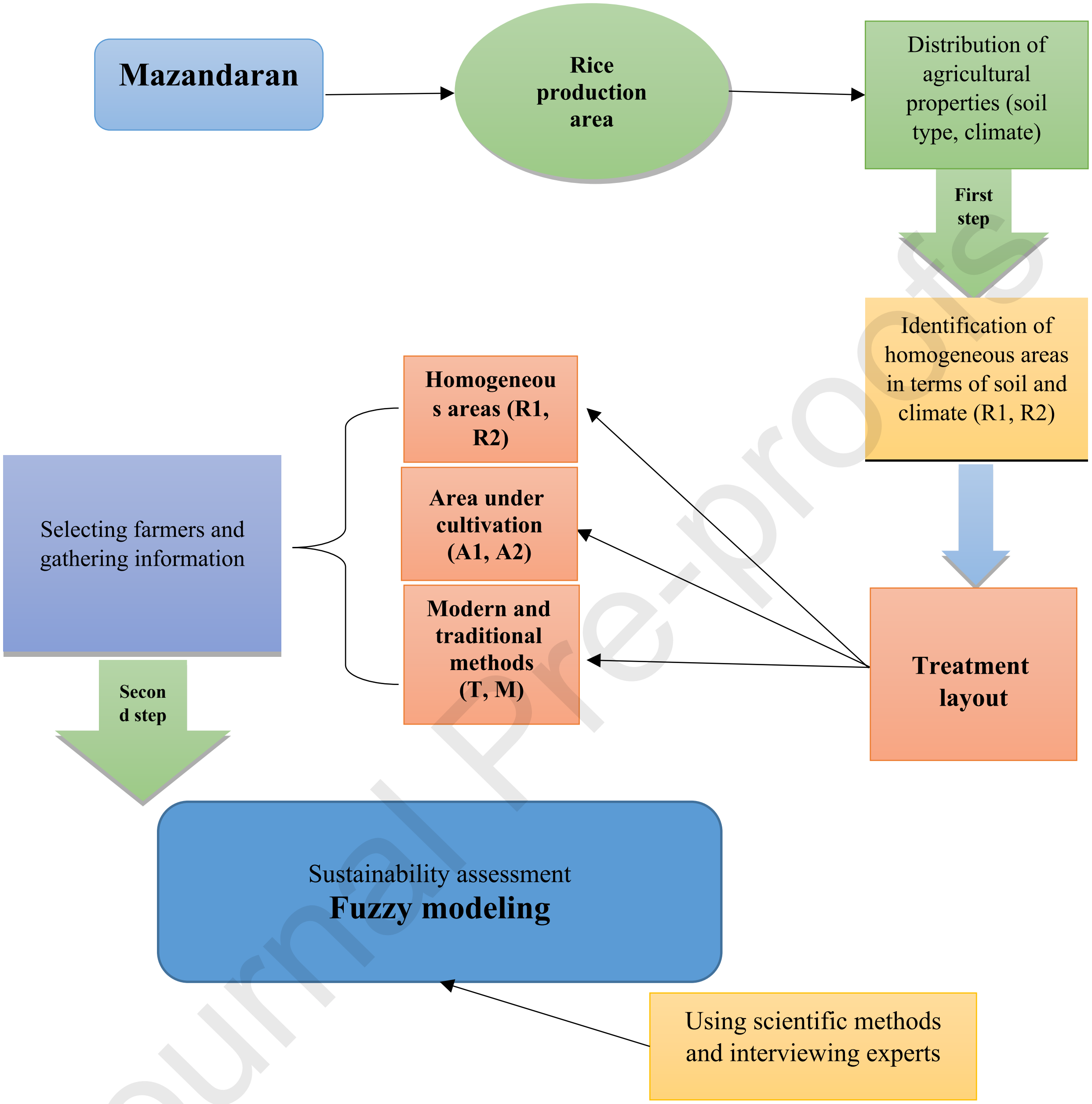


Fig. 1- The schematic view of the research process

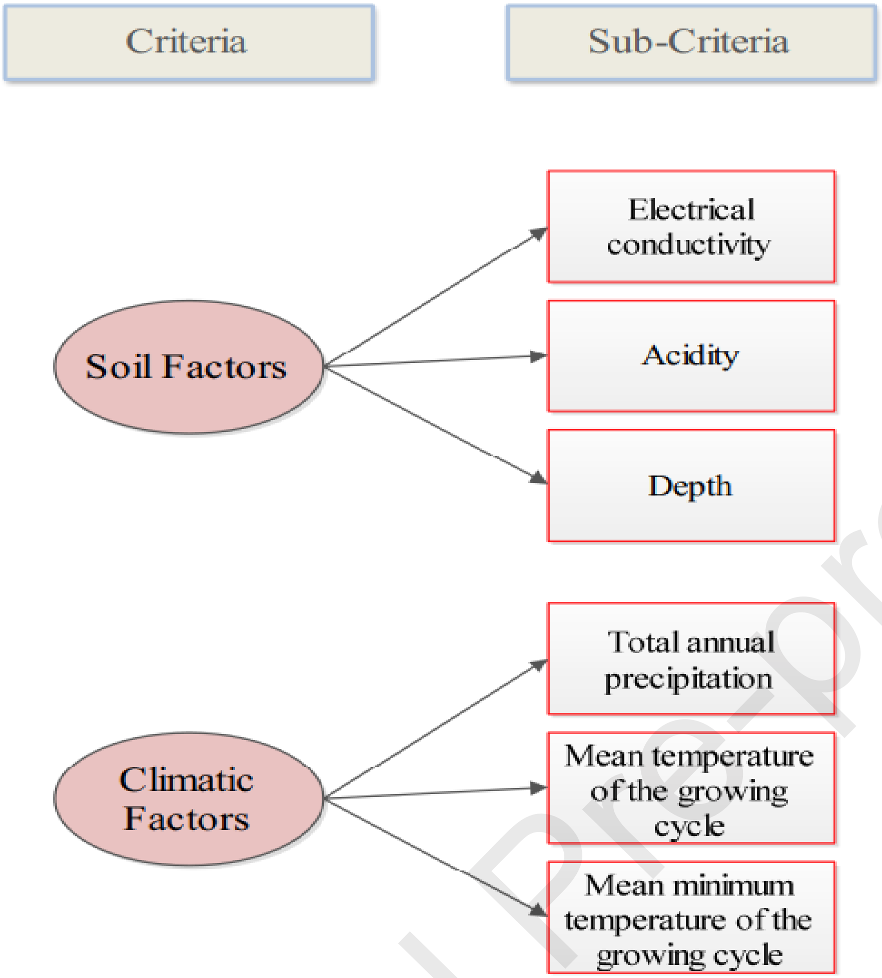


Fig. 2. Hierarchy structure of the soil and climatic factors applied in AHP and GIS

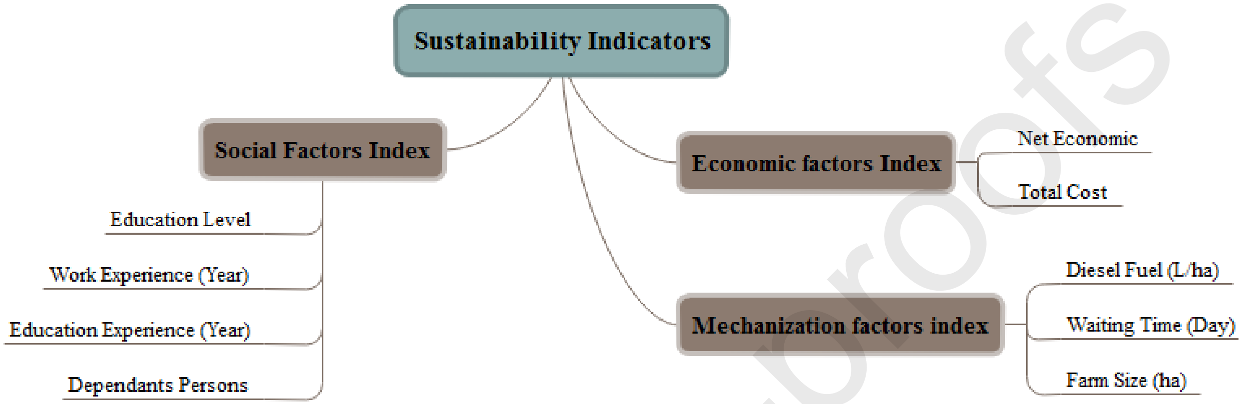


Fig. 3. Factors considered in determining rice stability

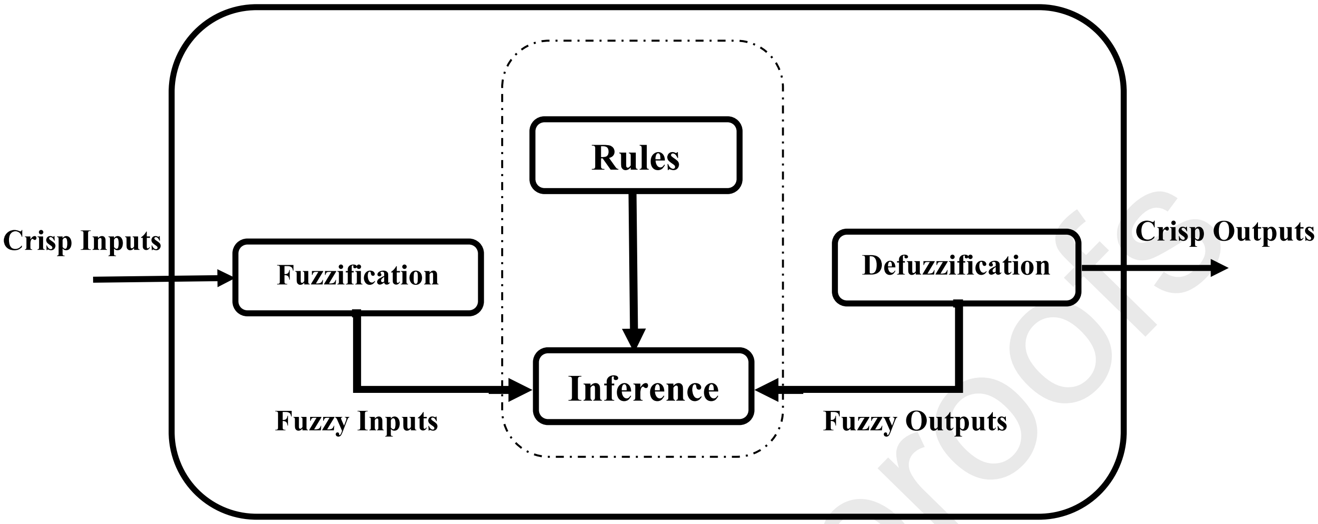


Fig. 4. Fuzzy Logic System

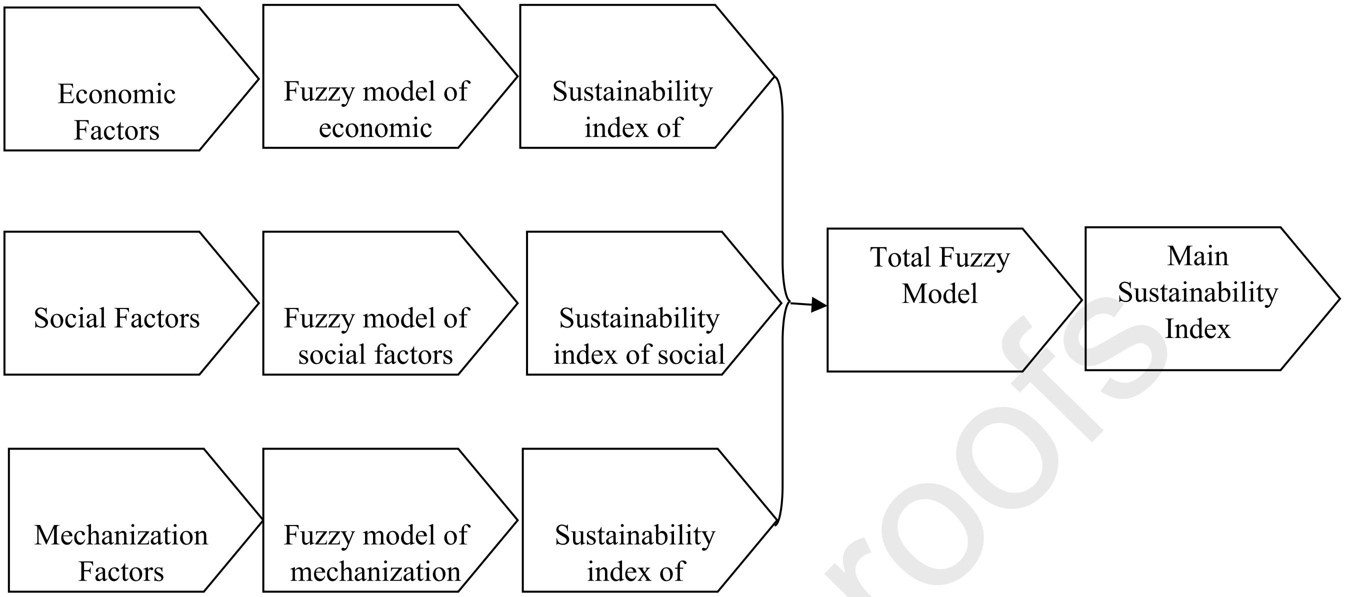


Fig. 5: Schematic view of fuzzy models designed to achieve total sustainability index

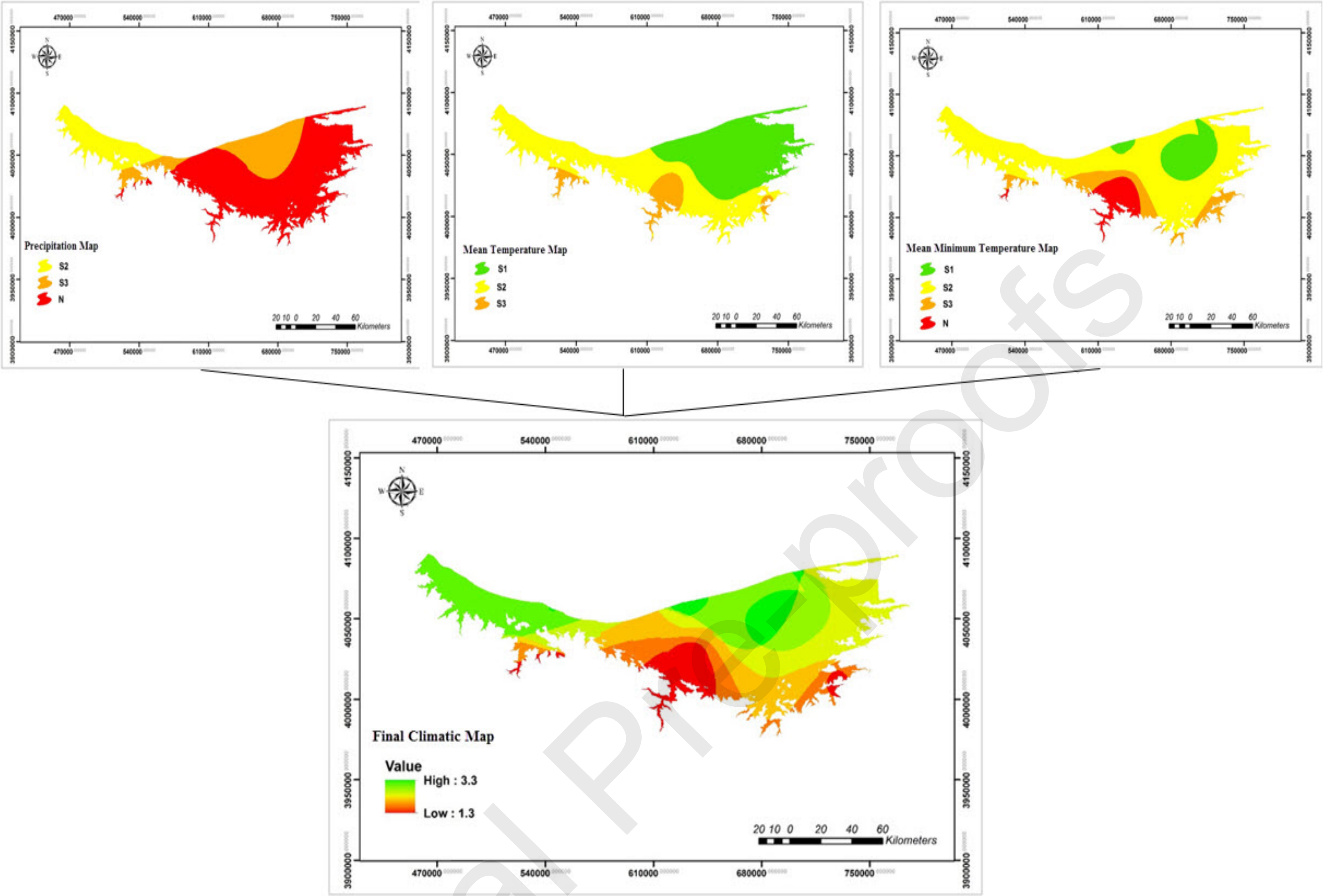


Fig. 6. Climatic suitability map

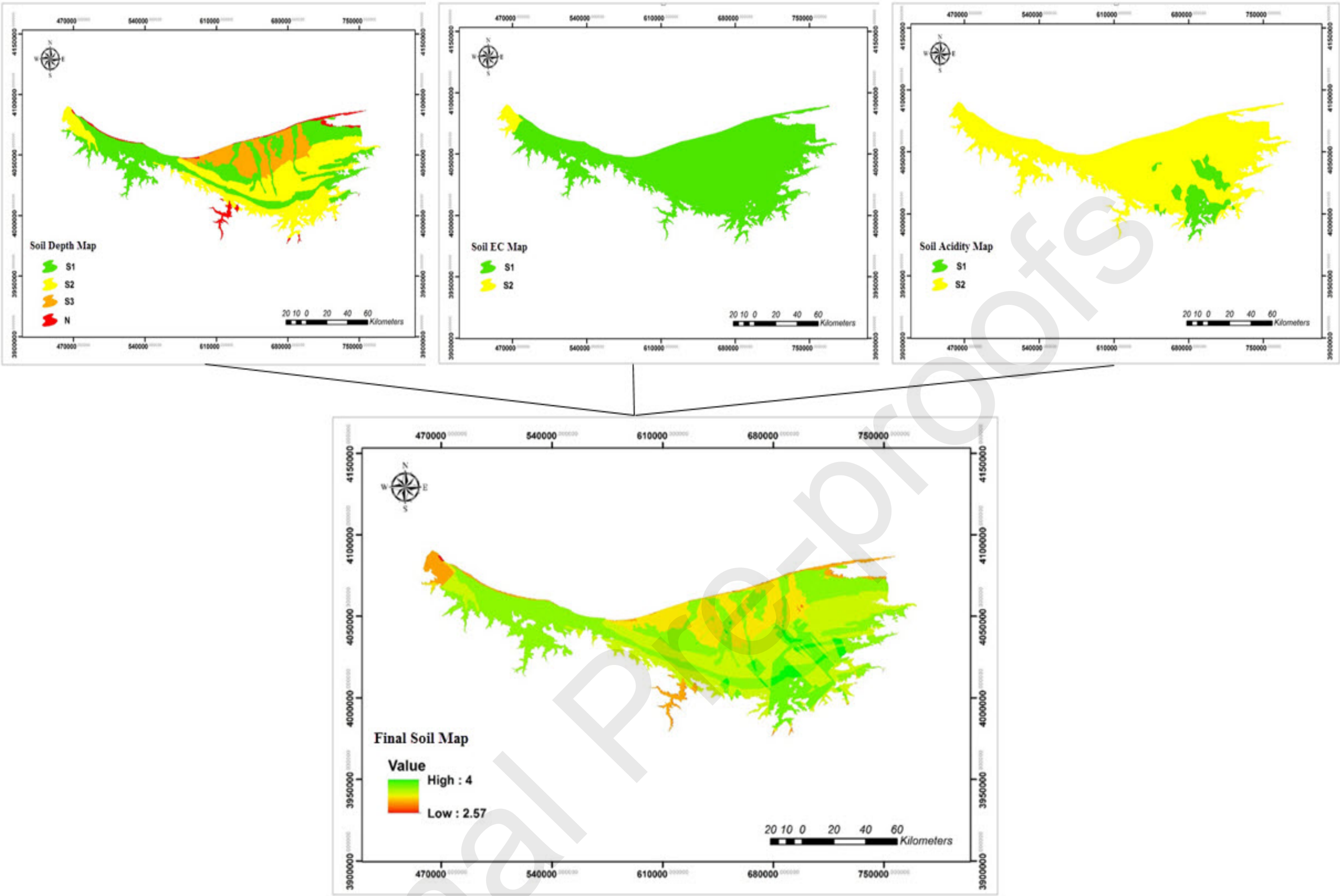


Fig. 7. Soil suitability map

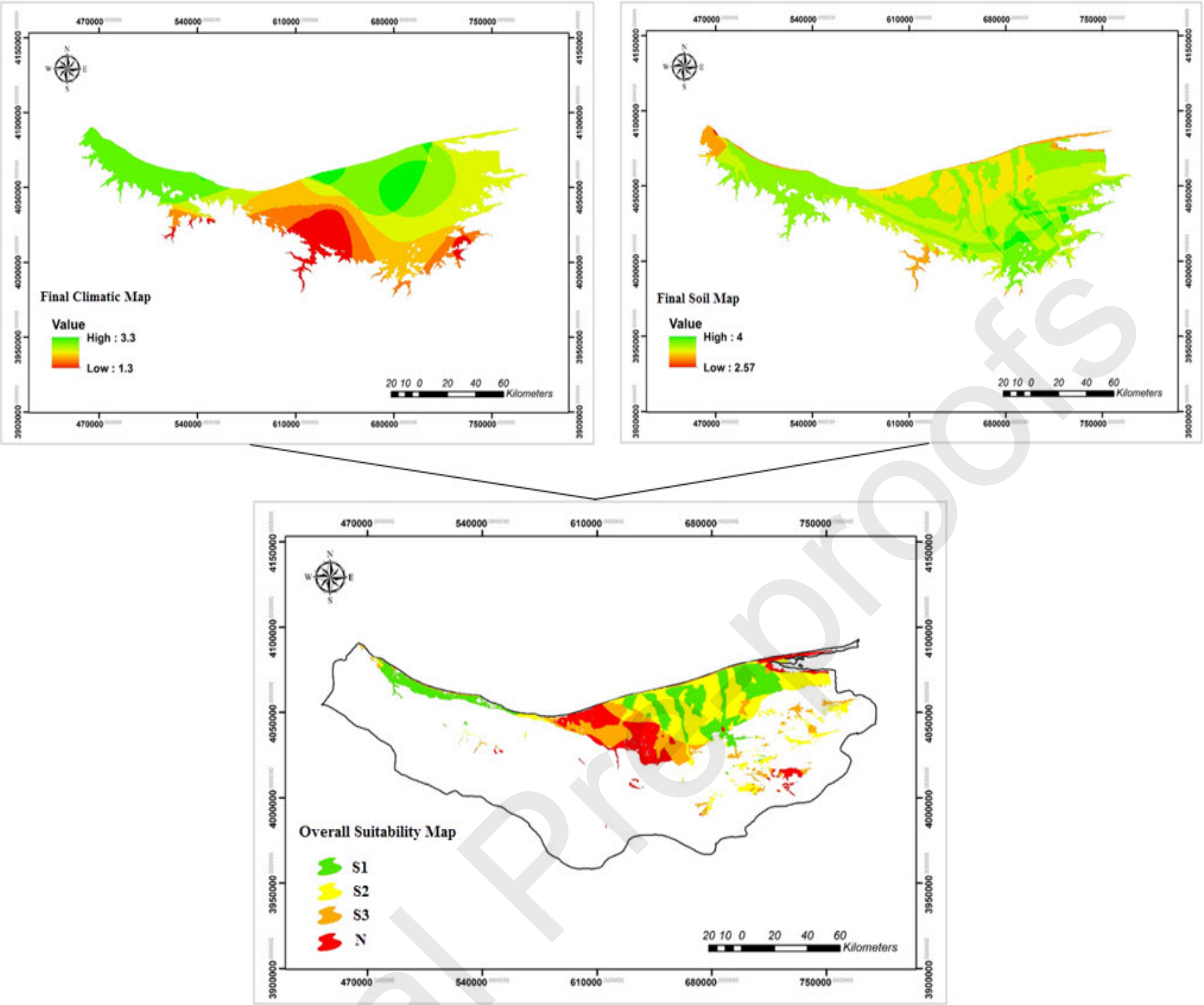


Fig. 8. Overall suitability map from soil and climatic maps

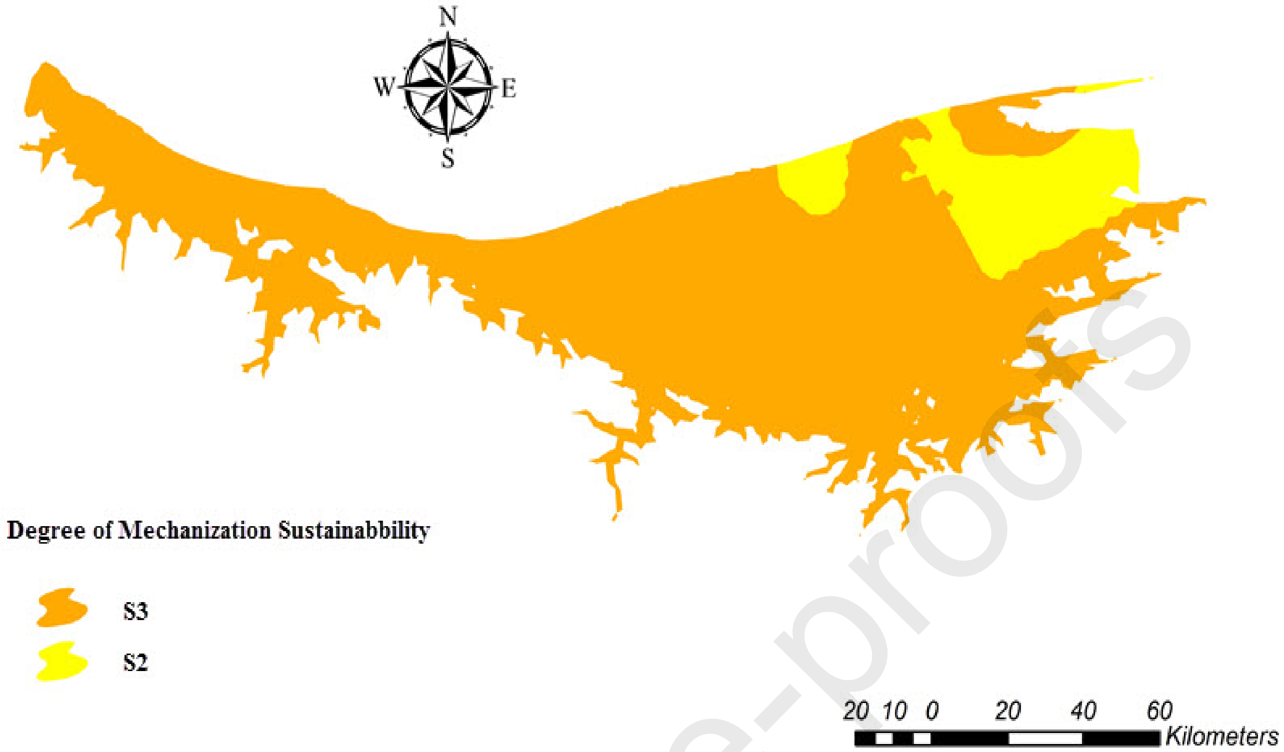


Fig. 9 - Mechanical stabilization degree

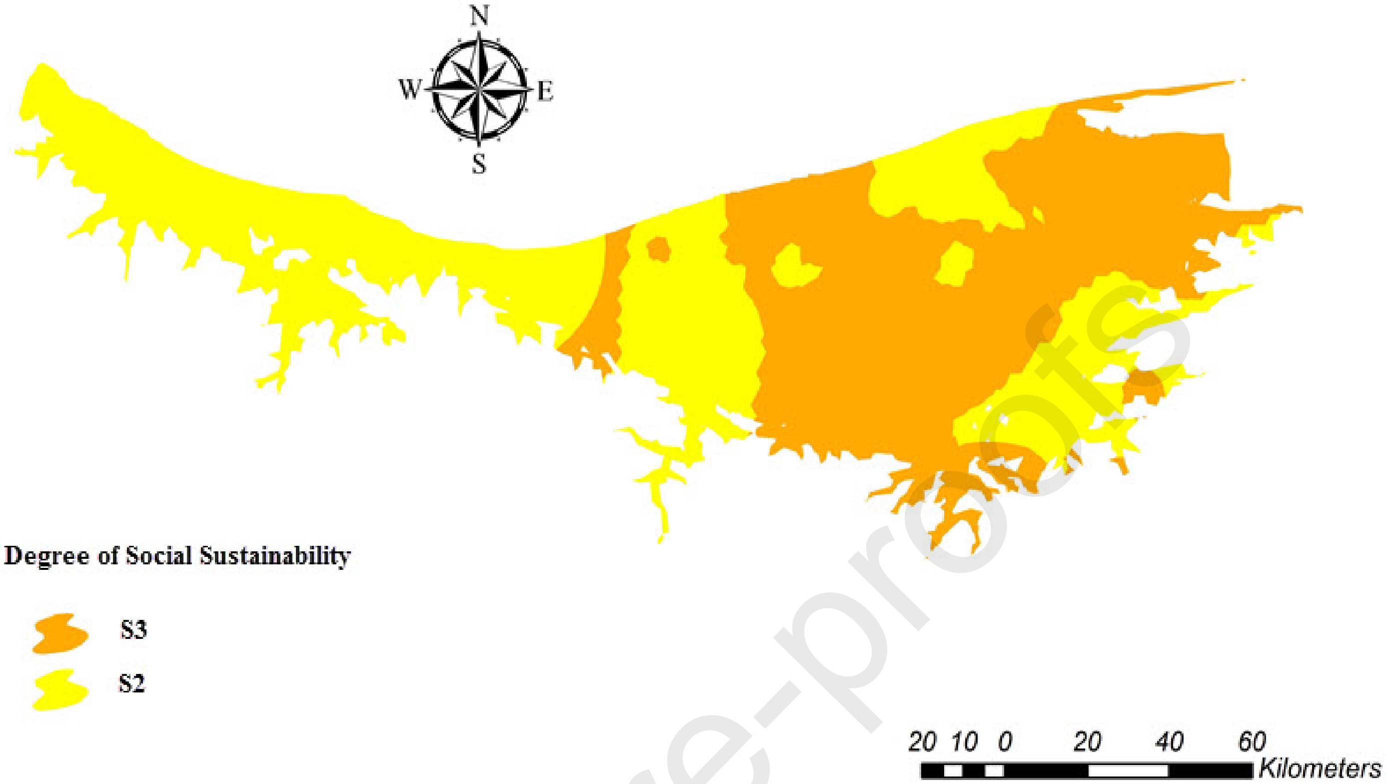


Fig. 10. Social sustainability

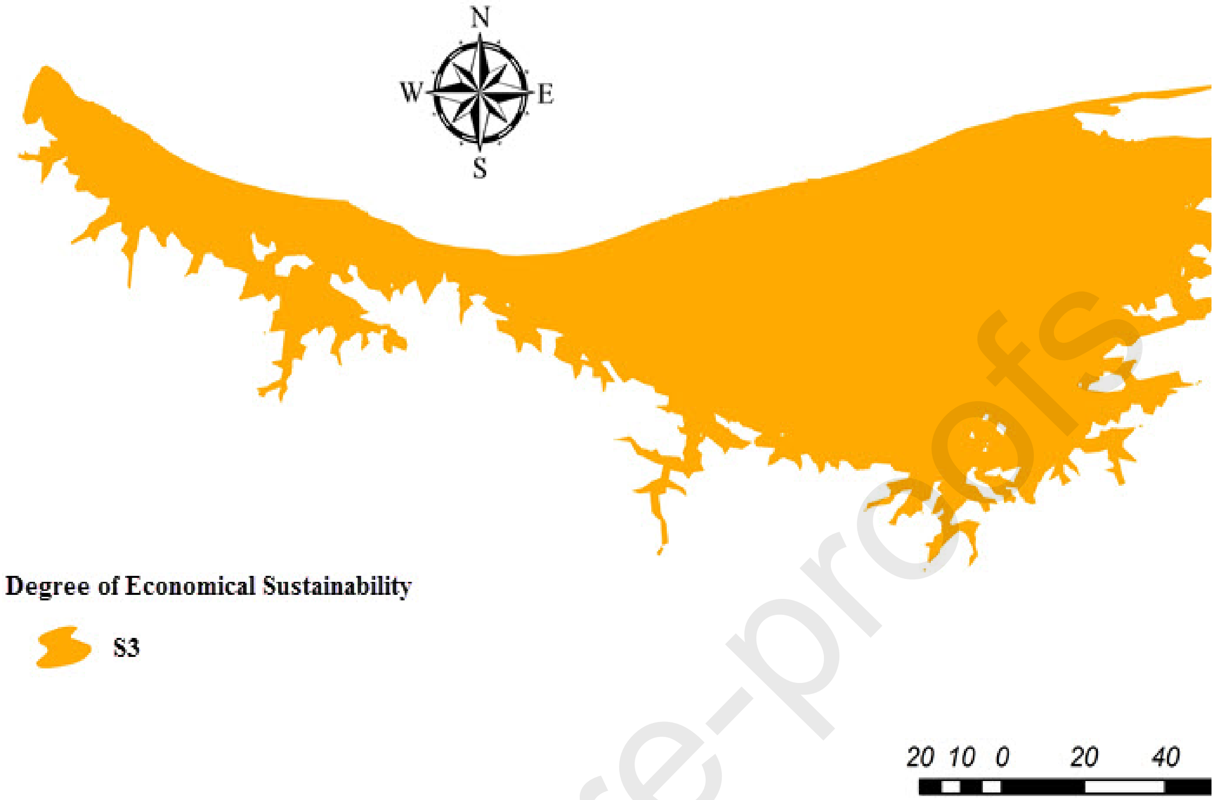
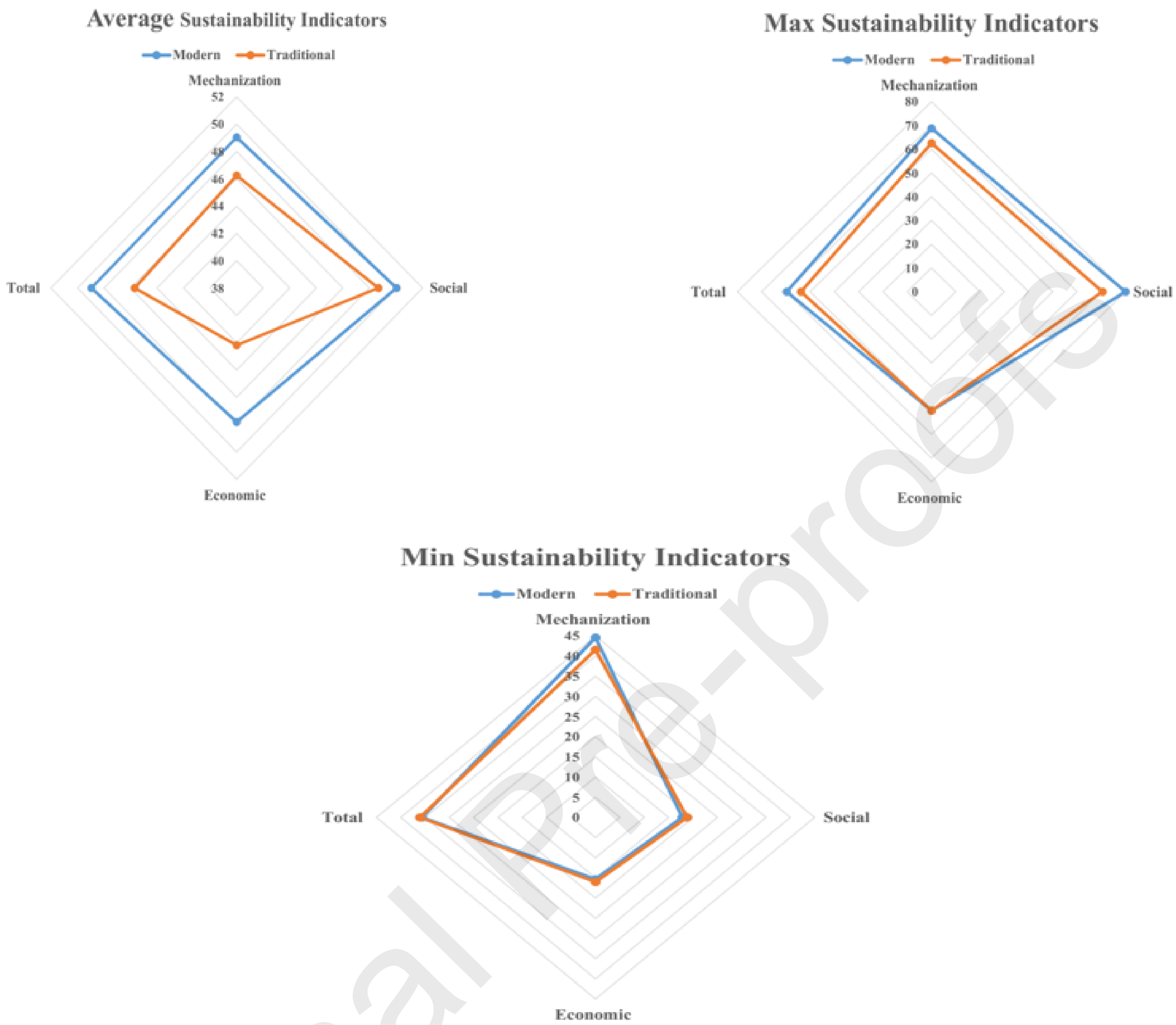


Fig. 11. Economic sustainability



Figu. 12 - Sustainability Indicators According to agricultural methods (modern and traditional)

Table 1
Review of paper that used Fuzzy and GIS-Based for Sustainability and land suitability evaluation

1. GIS-Based			
Author	technique	Criteria used	Suitability or Sustainability Field
[38]	AHP	Slope, soil depth, temperature, precipitation, pH, texture	Rice
[39]	Fuzzy AHP	Precipitation, temperature, sunshine hours, soil soluble chlorine, pH, SOC, AN, AP, AK, calcium, magnesium, molybdenum, relief, elevation, slope, soil types	Tobacco
[40]	AHP	Leaf emergency, tillering, panical primoda, flowering, milky dough, ripening, soil group, drainage, pH, EC	Rice
[41]	AHP	Temperature, precipitation, sunshine hours, frost hazard, RH, permeability, texture, pH, elevation, slope, aspect	Saffron
[42]	fuzzy Multi-Criteria	Environmental Geographical Criteria, Economic Criteria, Urbanity Criteria	Optimal siting of electric vehicle charging stations
[43]	MCDM	Urban Life Dimension, User Oriented Dimension, Transport Network Dimension	bike-share stations
2. fuzzy logic			
[44]	fuzzy logic	Nitrogen fertilizer, phosphate, potash and micro fertilizers, manure fertilizer, chemical pesticides quantity, chemical pesticides toxicity, water, net income, the total cost, farmer's knowledge, farming experience, farm size, seed,	Silage corn
[45]	GIS, fuzzy, AHP	Slope gradient, altitude, temperature, length of growing period, available water capacity, mean weight diameter, total nitrogen, available phosphorus and soil organic carbon contents	sorghum
[46]	fuzzy logic	pH, Compaction, Salinity, Organic matter, Bulk density, Electrical conductivity, Total organic carbon	environmental quality indexes
[47]	fuzzy logic	Vertical structure, Size classes, Canopy openness, Herbs, Deadwood volume, Depth of litter	forest management

Table 2

Range of Land Suitability for Climatic and Soil Properties for Rice Cultivation

Totally inappropriate)N(25-0	Critical fit)S3(25-50	Proportion fit)S2(50-75	Perfect fit)S1(75-100	Parameter	Fitness
Less than 700	700-1000	1000-1500	More than 1500	annual precipitation (mm)	Climatic characteristics
Less than 13 and more than 43	40-43 and 13-19	37-40 and 19-21	20-37	Average temperature of growth period (° C)	
Less than 8 and more than 35	32-35 and 8-10	28-32 and 10-14	14-28	Average temperature of growth period (° C)	
Less than 50	50-75	75-90	More than 90	Soil depth (cm)	Soil Properties
More than 6	4-6	2-4	Less than 2	Electric conductivity (dc / m)	
Less than 4.6 and more than 4/8	4.6-5 8-8.4	5-5.5 and 7.5-8	5.5-7.5	Acidity	

Source: [48-52]

Table 3
The number of the selected farmers of each amount.

Region (R)	Area (A)	Cultivation method (Modern & Traditional)	The size of the statistical society	Specified sample size	Sample size (M and T)	Sample size selected (A)	Sample size selected (R)
R_1	$A_1 \leq$ 1ha	M	645	73	73	105	170
		T	289	32	32		
	$A_2 >$ 1	M	325	50	50	65	
		T	157	15	15		
R_2	$A_1 \leq$ 1	M	530	60	60	80	148
		T	230	20	20		
	$A_2 >$ 1	M	192	50	50	68	
		T	98	18	18		
Total Number			2466	318	318	318	318

Table 4
Analysis of Criteria an indicator should match in order to be included in an evaluation.

Criteria Group	Criterion	Definition and measurement
Social: to enhance the quality of life of society at large. [a][25,32,53,54] [b][32,55] [c][56,57] [d][14,58]	Education Level[a]	Education is a key indicator for sustainable development. Level of education is actual years of schooling of rice grower.
	Work Experience (year)[b]	Agricultural experience is related to the type of production system, farm management, the size of agricultural operations, and the commitment to agricultural occupation.
	Education Experience (year)[c]	The number of years the farmer participated in the promotion classes was to ensure that the farmer's awareness of the farmer's awareness as well as sustainability in agriculture is well understood.
	Dependants Persons[d]	Individuals are referred to people who are either permanently farmed (family, neighbors, friends and acquaintances, or recruited) or temporary workers (workers employed for that season).
Mechanization: to maintain and improve the machinery and the natural resource base. [e][14,59] [f][60] [g][61]	Diesel Fuel (L/ha)[e]	The higher the amount of fuel consumed in machine operation, the more pollution and reduced sustainability.
	Waiting Time (day)[f]	The time spent by the farmer for a number of issues in the field (Tractor failure, lack of worker for planting, Tiller failure to prepare land, lack of combine for harvesting, etc.).
	Farm Size (ha)[g]	The larger size of arable land increases yield and may indicate more potential sustainability of the farm
Economic: to achieve economical viability. [h][62] [i][53,63]	Net Economic[h]	The net income is the profit the farmer gets from selling his product.
	Total Cost[i]	It is said to be the sum of all expenses the farmer has at his stage, planting and harvesting.

Table 5
Rating and meanings for Diesel fuel *(DF)*, Waiting time *(WT)*, Farm size *(FS)*.

Rating	Meaning	Description		
		for Diesel fuel *(DF), (L/ha)*	Waiting time *(WT), (day)*	Farm size *(FS), (ha)*
1	Low	[-inf –inf 100 300]	[-inf –inf 1 3]	[-inf –inf 2 6]
2	Medium	[100 300 500]	[1 3 5]	[2 6 10]
3	High	[300 500 700]	[3 5 7]	[6 10 14]
4	Very High	[500 700 inf inf]	[5 7 inf inf]	[10 14 inf inf]

Table 6 - Language variables for mechanistic model

1.Farm size = Low

		Waiting time			
		Low	Medium	High	Very high
Diesel fuel	Low	Very high	High	Medium	Low
	Medium	High	Medium	Low	Very Low
	High	Medium	Low	Very Low	Very Low
	Very high	Low	Low	Very Low	Very Low

1.Farm size = Medium

		Waiting time			
		Low	Medium	High	Very high
Diesel fuel	Low	High	Medium	Low	Low
	Medium	Medium	Medium	Low	Very Low
	High	Medium	Low	Very Low	Very Low
	Very high	Low	Low	Very Low	Very Low

1.Farm size = High

		Waiting time			
		Low	Medium	High	Very high
Diesel fuel	Low	Medium	Medium	Low	Low
	Medium	Medium	Medium	Low	Very Low
	High	Low	Low	Very Low	Very Low
	Very high	Low	Low	Very Low	Very Low

1.Farm size = Very High

		Waiting time			
		Low	Medium	High	Very high
Diesel fu	Low	Medium	Medium	Low	Low
	Medium	Medium	Low	Low	Very Low
	High	Low	Low	Very Low	Very Low

Very Low	1	□	Sustainable (Fuzzy output)
Low	2	░	
Medium	3	▒	
High	4	▓	
Very High	5	█	

	Very high	Low	Very Low	Very Low	Very Low

Table 7
Layer weight by AHP method

Weight criterion	Weight sub-parameter	parameter	component
0.450	0.400	Precipitation	Climate
	0.300	Average temperature of growth period	
	0.300	Average minimum temperature of growth period	
0.550	0.215	Depth of soil	Soil
	0.45	Electrical conductivity	
	0.335	Acidity	

Table 8
Area and percentage of each area of rice in Mazandaran province

Percentage of area	Area (hectare)	Class
27.4	159171	Perfect fit
35.2	204312	Suitable
19.5	112908	Critical
17.9	103965	Inappropriate

Table 9
Average factors involved in rice production

Mechanistic factors			social factors				Economic factors (toman per hectare)				
Farm size)ha(	Expected time of operation)day(	Fuel consumed)L/ha(	Customers	Participation in the promotion class (Year)	Cultivation history)Year(	Knowledge)0-50(	Ratio of profit to expense	total cost	Net income	Level	
0.82	18.88	382.39	4.75	1.05	16.48	37.80	0.98	37800210.76	36399610.66	R_1A_1M	
0.93	28.33	325.41	4.33	0.67	15.67	29	0.67	39741483.14	26416135.91	R_1A_1T	
3.66	20.33	381.24	4.48	0.97	15.90	37.13	0.98	37906675.82	36357086.08	R_1A_2M	
4.15	20.41	324.65	4.45	1.05	14.95	30.14	0.64	39861163.95	25175134.75	R_1A_2T	
0.84	19.39	454.38	4.77	0.98	15.93	35.66	0.44	55909537.16	24223222.58	R_2A_1M	
0.72	19.91	254.79	4.64	1	12.09	30.45	0.37	51798228.35	18806966.45	R_2A_1T	
3.77	19.05	461.89	4.66	0.95	15.63	35.86	0.41	57074840.82	22722939.8	R_2A_2M	
3.39	18.29	261.53	3.57	0.93	13.50	31	0.40	50579112.71	20147519.94	R_2A_2T	
2.77	20.07	370.31	4.56	1	15.91	35.92	0.92	38260632.29	34116087.71	R_1	R
2.43	19.16	418.58	4.58	0.96	15.18	34.77	0.41	55472790.48	22617986.66	R_2	
0.82	19.51	398.65	4.73	1	15.71	35.74	0.66	47561561.50	28652359.78	A_1	A
3.75	19.68	391.73	4.46	0.97	15.44	35.9	0.67	46418715.92	28183079.19	A_2	
2.50	19.48	420.14	4.65	0.98	15.95	36.59	0.70	47213098.50	29848580.07	M	
2.99	20.18	291.65	4.24	0.98	13.96	30.38	0.51	45481162.93	22440865.65	T	

T: Traditional
M: Modern
A: Area
R: Region

Table 10
Average, Minimum and Maximum Sustainability Indicators

Treatment		Sustainability Indicators											
		Mechanization factors index			Social Factors Index			Economic factors Index			Total Index		
		Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
R_1A_1M		44.90	50.32	48.25	17.82	80	50.1	15.81	50	49.01	39.23	59.66	49.12
R_1A_1T		41.78	45.39	43.72	28.28	60	40.07	37.58	43.93	41.42	38.34	49.77	42.40
R_1A_2M		44.83	63.75	50.31	31.98	66.88	49.95	15.3	50	44.64	35.67	58.33	48.30
R_1A_2T		41.58	62.5	47.84	33.26	70.48	48.97	31.67	44.36	42.64	39.76	53.8	46.48
R_2A_1M		44.54	48.63	46.94	18.53	73.13	50.61	17.92	50	48.44	38.33	56.1	48.66
R_2A_1T		42.04	45.44	43.97	18.77	62.52	50.35	31.55	50	43.74	36.04	50.1	46.02
R_2A_2M		44.56	68.75	49.91	35.13	65	49.65	44.62	50	49.81	44.14	58.95	49.79
R_2A_2T		42.18	59.94	46.08	40	61.27	48.32	15.96	50	40.4	42.03	49.58	44.93
R	R_1	41.58	63.75	49.06	17.82	80	49.64	15.3	50	45.61	35.66	59.66	48.1
	R_2	42.04	68.75	47.91	18.53	73.17	49.90	15.96	50	47.74	36.04	58.95	48.52
A	A_1	41.78	50.32	47.04	17.82	80	50.11	15.81	50	47.93	36.04	59.66	48.36
	A_2	41.58	68.75	49.42	31.98	70.48	49.55	15.3	50	45.87	35.67	58.95	48.28
Modern		44.54	68.75	49.04	17.82	80	50.04	15.3	50	47.8	35.67	59.66	48.96
Traditional		41.58	62.5	46.25	18.77	70.48	48.68	15.96	50	42.18	36.04	53.8	45.7

Table A
64 rules for fuzzy output (Mechanization).

Number	Farm size	Diesel fuel	Waiting time	Sustainability (Fuzzy output)
1	Low	Low	Low	Very high
2	Low	Low	Medium	High
3	Low	Low	High	Medium
4	Low	Low	Very high	Low
5	Low	Medium	Low	High
6	Low	Medium	Medium	Medium
7	Low	Medium	High	Low
8	Low	Medium	Very high	Very Low
9	Low	High	Low	Medium
10	Low	High	Medium	Low
11	Low	High	High	Very Low
12	Low	High	Very high	Very Low
13	Low	Very high	Low	Low
14	Low	Very high	Medium	Low
15	Low	Very high	High	Very Low
16	Low	Very high	Very high	Very Low
17	Medium	Low	Low	High
18	Medium	Low	Medium	Medium
19	Medium	Low	High	Low
20	Medium	Low	Very high	Low
21	Medium	Medium	Low	Medium
22	Medium	Medium	Medium	Medium
23	Medium	Medium	High	Low
24	Medium	Medium	Very high	Very Low
25	Medium	High	Low	Medium
26	Medium	High	Medium	Low
27	Medium	High	High	Very Low
28	Medium	High	Very high	Very Low
29	Medium	Very high	Low	Low
30	Medium	Very high	Medium	Low
31	Medium	Very high	High	Very Low

32	Medium	Very high	Very high	Very Low
33	High	Low	Low	Medium
34	High	Low	Medium	Medium
35	High	Low	High	Low
36	High	Low	Very high	Low
37	High	Medium	Low	Medium
38	High	Medium	Medium	Medium
39	High	Medium	High	Low
40	High	Medium	Very high	Very Low
41	High	High	Low	Low
42	High	High	Medium	Low
43	High	High	High	Very Low
44	High	High	Very high	Very Low
45	High	Very high	Low	Low
46	High	Very high	Medium	Low
47	High	Very high	High	Very Low
48	High	Very high	Very high	Very Low
49	Very high	Low	Low	Medium
50	Very high	Low	Medium	Medium
51	Very high	Low	High	Low
52	Very high	Low	Very high	Low
53	Very high	Medium	Low	Medium
54	Very high	Medium	Medium	Low
55	Very high	Medium	High	Low
56	Very high	Medium	Very high	Very Low
57	Very high	High	Low	Low
58	Very high	High	Medium	Low
59	Very high	High	High	Very Low
60	Very high	High	Very high	Very Low
61	Very high	Very high	Low	Low
62	Very high	Very high	Medium	Very Low
63	Very high	Very high	High	Very Low
64	Very high	Very high	Very high	Very Low

Highlights

- The average of the lasting stability index was in the range of almost unstable.
- The highest and lowest means of the product were 4314.44 and 3501.95 kg ha^{-1}, respectively.
- The use of modern agricultural methods has increased the average sustainability indices.
- The average values of economic sustainability index are in the ranges of low or almost unstable.