KPU International Journal of Engineering & Technology
Volume 2, Issue2, Dec. 2022
e-ISSN:2790-0819, p-ISSN:2790-0800
Date Received: 2022-10-03
Date Accepted: 2022-12-22
Date Published: 2022-12-30

Mapping and Evaluating Land Suitability Using a GIS-Based Model: A Case Study in the Abyek Area, Qazvin, Iran

MARHABA SAHBANI[1], FEREYDOON SARMADIAN[2*], MOHAMMAD DAUD HAIDARI[3]

[1]Department of Soil Science and Irrigation, Kabul University, Kabul, Afghanistan, Email: sahbani50400@gmail.com

[2*]Department of Soil Science, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran, E-mail: fsarmad@ut.ac.ir

[3]Department of Soil Science and Irrigation, Kabul University, Kabul, Afghanistan, Email: m.daud.haidari@gmail.com

Abstract

Land suitability is an important strategy for optimal and sustainable use of land and stabilization of its performance. The area covers 5,215 hectares and consists mostly of cultivated land. The objective of this study was to evaluate the available land resources and produce a land suitability map for irrigated wheat. For an assessment of the study area, a total of 32 representative soil profiles were used for collecting soil samples. They were also used as input to the model. The conditioned Latin Hypercube Sampling (cLHS) method was used for determining sampling points. Covariates for running the model were elaborated from remote sensing data. The suitability classification for irrigated wheat crops was determined using a parametric method. The random forest model of SAGA GIS software was used to predict suitability classes. For preparing the final map of land suitability, firstly the raster map related to the parameters affecting land suitability was prepared in the ArcGIS environment, and secondly, this raster file was stacked in the random forest model with auxiliary variable layers and the final map was obtained. The results showed that about 52.68% (2747.5 ha) of the studied area was found to be highly suitable (S1), 44.1% (2295.4 ha) was moderately suitable (S2), and 2.96% (154.8 ha) was marginally suitable (S3). In addition, 0.33% (17.4 ha) of the total area was classified as currently unsuitable. The main limiting factors for land suitability were texture, depth, alkalinity, and the presence of coarse fragments in the soil. It was also found that with the help of environmental variables and GIS, making the framework for the optimum use of land become very easy and provided significant advantages in terms of time and economic aspects.

Keywords: Land suitability, Wheat, Variables, Parametric method, Random forest model

* Corresponding Author

1. Introduction

Land evaluation is the process of relating the specific type of land use to the features of land resources, using scientific standards and techniques. Users and planners can use the findings as a reference to find alternatives to other land uses [1]. Land can be utilized for a variety of purposes, such as entertainment, agriculture, industry, housing, fishing, and the preservation of nature. An adequate framework for land management and appropriate land use is provided by the evaluation of a specific area. Any choice about land use in the initial step requires land evaluation of resources and technology available. The efficient utilization of available land resources for sustainable agricultural crop production necessitates land evaluation. Farmers and policymakers will be able to identify the most suitable places for different plant production and management options and establish sustainable agriculture using the results produced from the creation of a geographical soil map and land assessment [2]. Land suitability analysis is a method of land evaluation that identifies the main limiting factors of a particular plant. In addition, it assists in the creation of a suitable crop management system to increase land productivity through options. Land suitability evaluation is a method that can be used for growing plants resistant to unfavorable environmental conditions [3-4].

GIS is a very useful tool for preparing thematic maps. The integration of geological and topographical maps with digital elevation models is done much more accurately and quickly by GIS. It also greatly reduces the time required for data entry and output [5]. Different machine learning models are used to discover patterns in data and to make predictions and have a great potential to improve land suitability evaluation [6]. The random forest model, which use to predict soil classes, was introduced by Breiman in 2001 as an extension of the CART model to improve the efficiency of the model estimation [7] and it has been mainly used in remote sensing studies; random forest model can consider several environmental variables simultaneously [8].

According to several recent studies, the availability of remotely sensed data and Geographic Information Systems (GIS) allows the combining knowledge from various sources to improve land suitability evaluation [3-4-6-9-10-11-12-13] and the current study was conceptualized using these research findings.

Cereals are an important part of dietaries; they are a significant source of energy, protein, vitamins (vitamins A and C), and minerals (potassium and calcium) [14]. Wheat (*Triticum aestivum* L) is the most widely grown cereal crop in the world - an estimated, wheat covering about 237 million hectares annually [15]. The main objective of this research was to perform the land suitability evaluation and carry out suitability mapping for the wheat crops by integrating different information using GIS tools for areas in the eastern

part of the Qazvin province of Iran. In addition, the main factors limiting the proper growth of wheat in the study area will also be identified.

2. Methods and Materials

2.1. Study area

The study area is approximately 5215 ha and is located between latitudes 36° 2′-36° 8′ N and longitudes 50° 20′-50° 20′ E in Abyik County of Qazvin province of Iran (fig. 1). Its altitude extends between 1163 -1379 m.a.s.l and its temperature and moisture regimes are thermic and xeric. According to the Bagh-e-Kowsar Meteorological Station, The amount of annual rainfall is 278.43 mm and the annual average temperature is 13.88 °C. The month with the most rain was March, with 52.2 mm of rainfall, and the month with the least rain was September, with 0.18 mm of rainfall. Temperatures averaged 21.47 °C for the highest and 6.07 °C for the lowest. In terms of topography, the area is mainly flat, and the majority area has fertile farmland for cultivation.

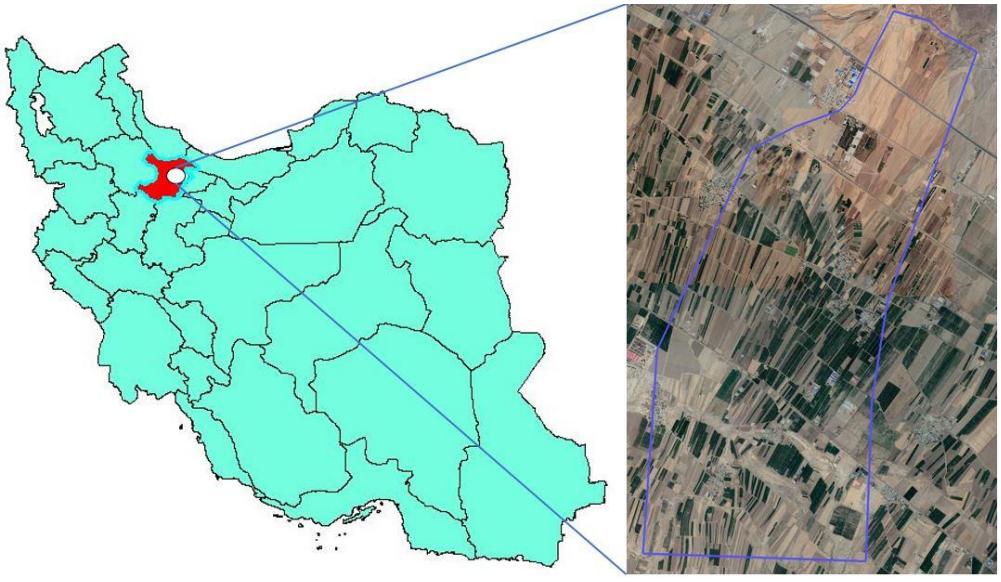


Figure 1. Study area

2.2. Soil sampling and analysis

The soil sampling scheme was performed by applying the conditioned Latin Hypercube Sampling algorithm (cLHS) [16]. The distribution of 32 locations acquired by cLHS is illustrated in Figure 2. The method presented is a stratified randomized design that with the help of multivariate distribution causes effective sampling of the study area. Regarding environmental variables and the geological map of the study area, R Software was used to perform the conditioned Latin Hypercube Sampling (cLHS) approach. The

geological map of the study area has been obtained from the geological Survey and mineral exploration of Iran. Digital elevation model ASTER GDEM with the 30-meter spatial resolution was obtained from Aster Global Digital Elevation Map (http://gdex.cr.usgs.gov/gdex/) and a satellite image of the study area belonging to Sentinel-2 was downloaded from Copernicus Open Access Hub. Variables such as Slope, Slope length, Wetness Index (WI), Multi-resolution Valley Bottom Flatness Index (MrVBF), and Multi-resolution Ridge Top Flatness Index (MrRTF), were extracted from DEM using SAGA GIS and ArcMap software. Normalized Difference Vegetation Index (NDVI) was extracted from satellite images using ERDAS IMAGINE and SNAP software. The selected variables were entered into the conditioned Latin Hypercube Sampling technique, and the algorithm divided the data into n values with the same probability, after applying the Latin square condition (one sample in each dimension a and b) the layers are combined and the algorithm starts it repeats the process until the objective evolution function reaches stability. 50 thousand iterations were used to run the model and obtain the objective function (Figure 3).

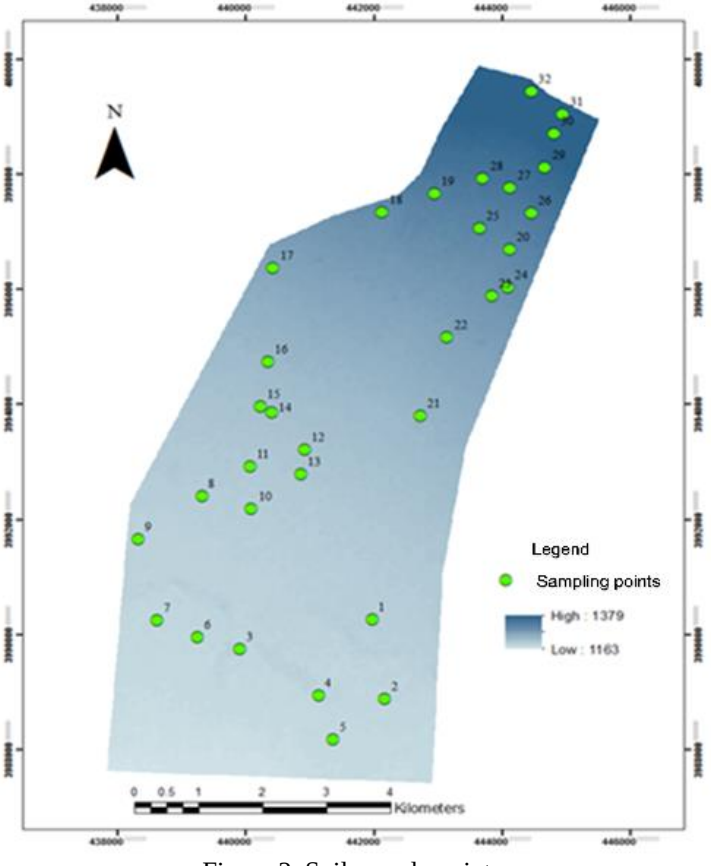


Figure 2. Soil sample point

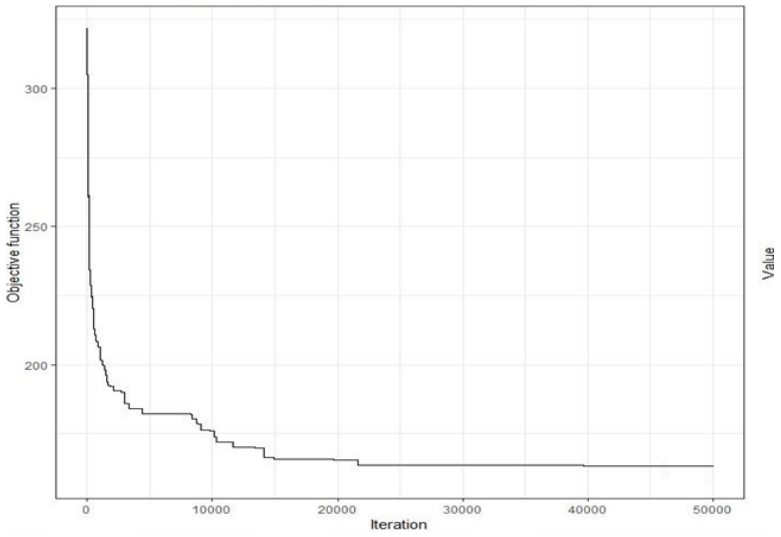


Figure 3. Evolution of the objective function

The Global Positioning System (GPS) was used to determine the geographical locations of all sampling points (profiles) and then profiles were excavated. Profiles were defined using the Field book for describing and sampling soils [17], and samples were collected from all of their genetic horizons and sent to the laboratory for regular physicochemical analyses. Soil samples were air dried and then crushed with mortar and pestle and passed through a 2-mm sieve for separating the coarse fragments (<2mm). The fine particles were stored in separate containers and used for physicochemical analysis. The calcium carbonate contents of the soil were determined using back-titration methods [18]. The organic carbon content was determined by the modified Walkley and Black method described by Jackson [19]. The amount of gypsum was measured using the Acetone method [20]. The soil pH and Electrical conductivity (EC) were measured in extracted saturated soil. The soil texture was determined using the hydrometer method [21].

2.3. Land Suitability evaluation

A parametric approach (Square Root method) [22] was utilized for 32 profiles to assess land suitability for irrigated wheat. The most important factors in land evaluation are topography, soil, and climate. These factors, particularly topography (including relief/ slope and elevation) and soil, have a considerable impact on the land unit determination. Relief and elevation are closely related to plant requirements as relief effect land management and erosion risk, while elevation affects heat and sunlight.

In this study, firstly, important information about the research area's land features was collected. Some of the data were obtained from the results of soil studies (laboratory

analyses and field observation) and climatic data (minimum and maximum temperatures, number of sunshine hours, amount of rainfall, relative humidity, and wind speed) used in land evaluation for various purposes (specifying plant growth period, cultivation date, and so on) were obtained from the Bagh-e-Kowsar meteorological station.

Eight parameters have been used in this work to study land suitability for irrigated wheat. These parameters are soil calcium carbonate, depth, EC, pH, organic carbon, texture, coarse fragments, and gypsum. The average weight of these parameters, including climate (criteria used to determine land suitability), for each profile up to the root depth, was calculated. As our targeted plant is irrigated wheat, an annual crop, of up to 100 cm was calculated. Then, the land limitation (in terms of soil and topography) of each map unit was determined by matching the characteristics of each soil profile with the criteria of the plant demands table [23-24].

The parametric approach (Square root method) uses the following formula to calculate the final land index:

$$I = Rmin \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \ldots}$$

Where I is the index, Rmin is the minimum rating, and A, B, C, … are other ratings besides the minimum rating [25].

Rainfall was eliminated using data from the Bagh-e-Kowsar meteorological station to determine climatic appropriateness, considering the assumption that irrigated wheat water requirements are met by irrigation. Other environmental parameters for the growth cycle [23] were determined using 22-year meteorological data from the Bagh-e-Kowsar synoptic station.

After identifying the climatic parameters needed to assess the climate of the study area, the values were compared with the table of wheat climatic requirements, and the final climatic class for wheat was obtained by using the parametric approach (Square Root method).

The land index was then calculated using the parametric method based on the degree of suitability of the climate elements. After that, considering soil [24] and climatic [23] limitations, the final class of land suitability was determined according to the numerical values of the land index for different classes of land suitability. Finally, the map of land suitability for irrigated wheat production was prepared.

2.4 Modeling to create a digital map of land suitability assessment

To model the land suitability assessment, all land suitability classes were recognized and coded based on the parameters such as soil organic carbon, texture, pH, EC, calcium carbonate, depth, gypsum, and coarse fragments.

Google Earth was used to detect all soil profiles by knowing their geographical coordinates and then saving them as a single KMZ layer. After that, ArcMap software was used to convert the specified layer to a shape file. In the next step, the prepared shape file along with the layer related to the digital elevation model for sampling from land suitability classes and preparing the latest file related to the land suitability classes to introduce it for the desired model was entered into ArcMap software. This method was used to prepare and store the final shape files of land suitability classes.

The digital elevation model (one of the primary indicators of land characteristics) was used to determine the terrain components, which were derived from the ALOS satellite with a spatial resolution of 12.5 meters. After digital elevation model derivation and changing the coordinate system to the UTM coordinate system, five indexes: Wetness (humidity) Index (WI), Multi-resolution Valley Bottom Flatness Index (MrVBF), Multi-resolution Ridge Top Flatness Index (MrRTF), land shapes, and morphometric Features) were calculated and derived using SAGA software. Sentinel-2 images with a spatial resolution of 10 meters from 2017, 2018, and 2019 were utilized to derive the Normalized Difference Vegetation Index (NDVI). Finally, a shape file of land suitability classes along with prepared environmental variables was provided to the random forest model in SAGA software. The model is implemented using 500 trees, with each node containing five different features (mtry).

3. Results and Discussion

The land suitability evaluation procedure was set based on Food and Agriculture Organization's (FAO) 1976 general framework in terms of land suitability [26]. According to the findings of the climate assessment in the study area, the climate does not impose any restrictions on its cultivation and therefore the climate class was obtained as S1. Table 1 shows the land suitability classes for irrigated wheat in each land unit. Figure 4 displays the digital map of the land suitability classes for irrigated wheat, and Table 2 shows the area devoted to the land suitability classes for irrigated wheat. The soils of these regions have mainly less than 2% slope. Generally, cereal crops require slightly sloping land for smooth and easy tillage practices. In addition, the soils have suitable depth; root penetration will stop with soil depth limitation because of a physical barrier or unsuitable chemical properties [27]. The results of the land suitability analysis showed that the large parts of the studied area were classified as highly suitable 52.68% (2, 2747.5

ha) (Table 2) and is located mostly in the central part of the studied area (Figure 4). Because of a physical barrier such as coarse fragments and soil texture, 23.58% of the studied area was classified as S2s (Table 2), The S2s land units are located in the north and south parts of the studied area (Figure 4). Due to the soil alkalinity, 20.43% and 2.65% of the studied area were classified as S2n and S3n (Table 2); these are low lands, located in the south part of the studied area with gypsum-containing soils (Figure 4). However, 0.31% and 0.33% of the studied area (Table 2), located in the north part of the studied area (Figure 4) were classified as N1s and S3s, due to soil texture limitations and the presence of coarse fragments.

The findings show that the accuracy of the results obtained with the square root method is high and revealed to be more realistic in comparison with other methods' results. Bagherzadeh and Mansouri Daneshvar (2011) used different methods, including the square root method, to evaluate land suitability for wheat cultivation in Iran [28]. He fined that texture/structure, coarse fragments, OC, CEC, and pH are the most significant limiting factors for irrigated wheat. Zeinodini (2003) evaluated the land suitability for wheat crops in Iran. The land suitability classification results based on the parametric method show that the land suitability classes are various from S1 to S3. This author found that the dominant limiting factors for wheat cultivation are gypsum, texture, and soil structure [29]. Baqer Zadeh et al. (2012) reported that the Storie method's results were very strict and far from reality, whereas the square root represented more balanced results for the determination of land suitability classes [30].

Table 1: Land suitability classes in each land unit using a parametric approach (square root method) for irrigated wheat

Land suitability unit	Land index	suitability class	Land suitability unit	Land index	suitability class
1	60	S2n*	17	16	N1s
2	61	S2n	18	40	S3s
3	65	S2s*	19	62	S2s
4	58	S2s	20	61	S2s
5	83	S1	21	83	S1
6	66	S2n	22	59	S2s
7	88	S1	23	79	S1
8	41	S3n	24	55	S2s
9	56	S2n	25	77	S1
10	81	S1	26	63	S2s
11	94	S1	27	37	S3s
12	89	S1	28	58	S2s
13	91	S1	29	58	S2s
14	83	S1	30	57	S2s
15	89	S1	31	55	S2s
16	88	S1	32	58	S2s

*n and s show soil alkalinity and soil physical (properties) limitations

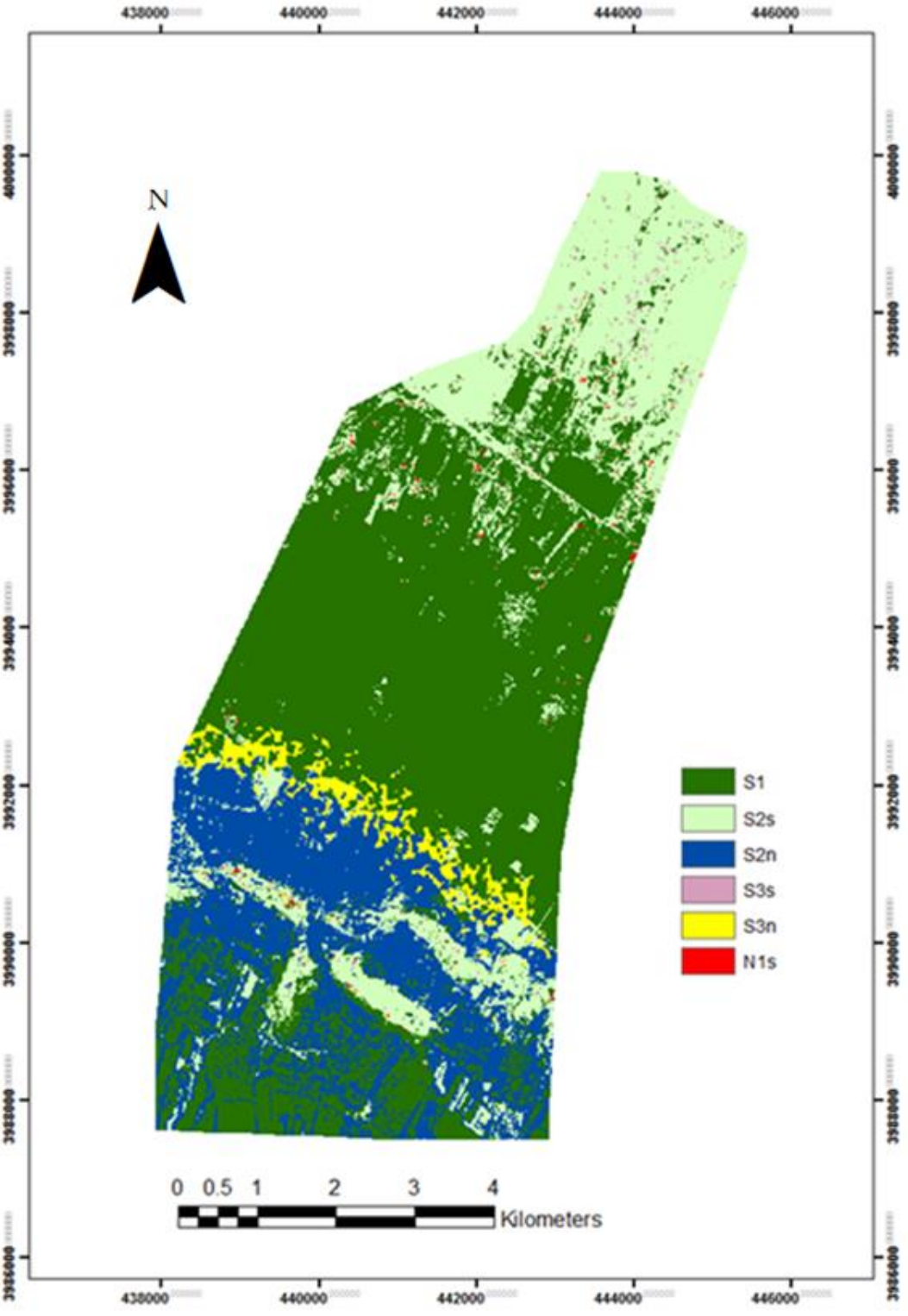


Figure 4. Digital map of land suitability classes for irrigated wheat

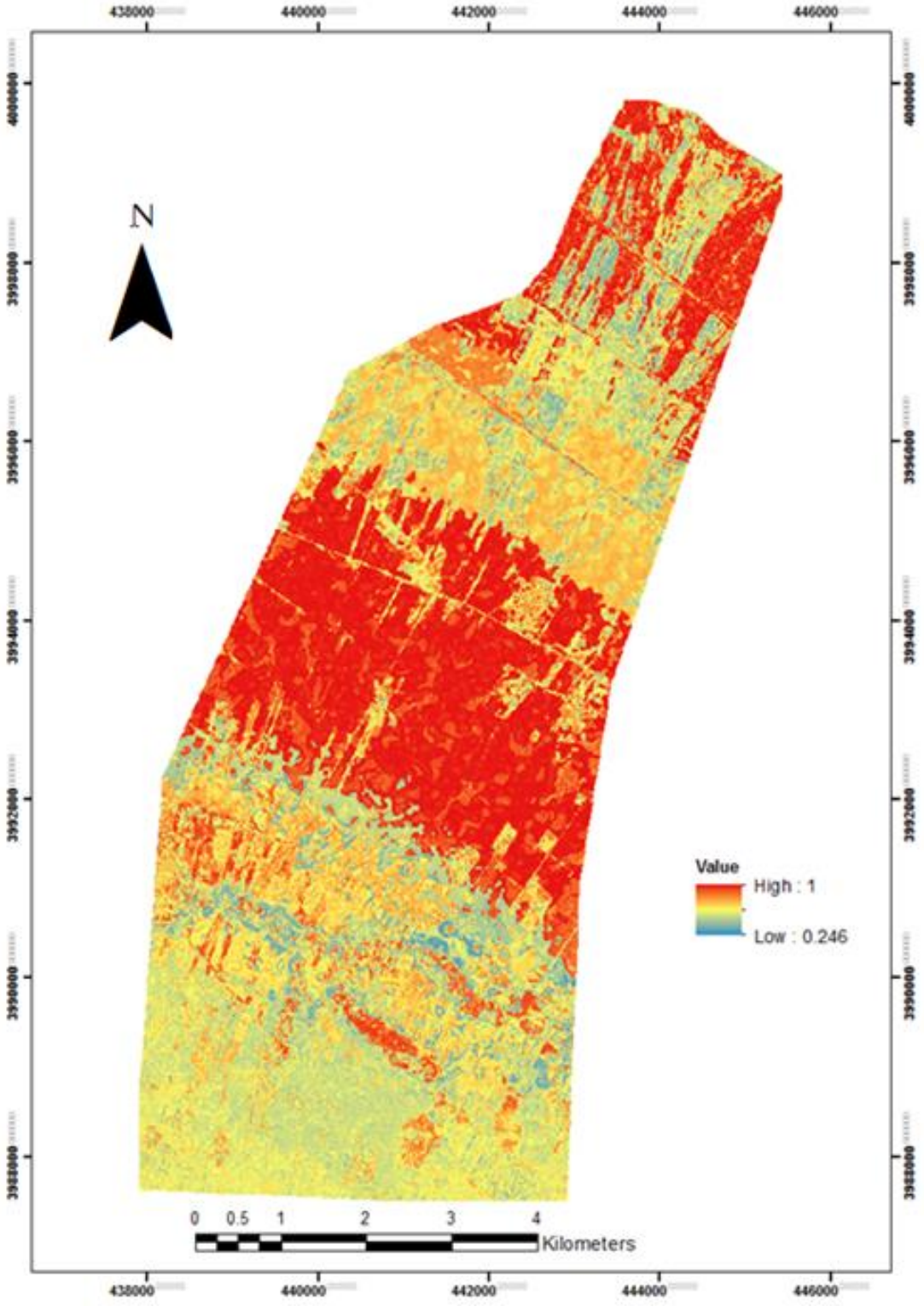


Figure 5. Probability map of land suitability classes for irrigated wheat

According to the probability map of land suitability, the central and northern parts of the study area have the highest accuracy. The estimation accuracy was low in some parts, such as those between the northern and central parts, and it was very low in the southern parts of the study area. Obtaining a probability map, which helps to interpret the map, is a good achievement. The probability map was obtained based on a digital map of land suitability.

Table 2: Area related to land suitability classes for irrigated wheat

land suitability class	Area (ha)	Area (%)
S1	2747.5	52.68
S2s	1229.8	23.58
S2n	1065.6	20.43
S3s	16.3	0.32
S3n	138.5	2.65
N1s	17.4	0.34

4. Conclusions

The purpose of this study was to perform the land suitability evaluation and carry out suitability mapping for the irrigated wheat crops by integrating environmental auxiliary variables, using GIS tools. The parametric method (square root formula) was used to evaluate the suitability. Land suitability analysis of the studied area indicated that 2747.5 ha (52.68%) had no restrictions for wheat cultivation and were classified as highly suitable S1. About 2294.4 ha (44.01%) of the studied area was classified as moderately suitable (S2) due to the soil alkalinity and soil physical properties restrictions, for irrigated wheat cultivation. Due to the soil alkalinity and soil physical properties restrictions, the remaining 3.31% were classified as marginally suitable (S3) and currently not suitable (N1). In preparing a land suitability map for irrigated wheat, variables such as the Normalized Difference Vegetation Index, Inverted-red Edge Chlorophyll Index, Digital Elevation Model, Multi-resolution Valley Bottom Flatness Index, and Multi-resolution Ridge Top Flatness Index, all of these variables had the greatest influence on soil changes and the creation of a digital map of land suitability classes for irrigated wheat.

Acknowledgments

The authors would like to thank all members of the soil science laboratory, Department of Soil Science, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, for providing the facilities to carry out this work and for their suggestions.

References

[1] S. Ritung, F. Agus, and H. Hidayat, “Land suitability evaluation with a case map of Aceh Barat District,” 2007.

[2] B. H. J. Massawe, “Digital soil mapping and GIS-based land evaluation for rice suitability in Kilombero Valley, Tanzania,” The Ohio State University., 2015.

[3] A. A. El Baroudy, “Mapping and evaluating land suitability using a GIS-based model,” Catena., vol. 140, pp. 96-104, 2016.

[4] B. Harms, D. Brough, S. Philip, R. Bartley, D. Clifford, M. Thomas, and L. Gregory, “Digital soil assessment for regional agricultural land evaluation,” Global Food Security., vol. 5, pp. 25-36, 2015.

[5] M. Liengsakul, S. Mekpaiboonwatana, P. Pramojanee, K. Bronsveld, and H Huizing, “Use of GIS and remote sensing for soil mapping and for locating new sites for the permanent cropland-A case study in the highlands of northern Thailand,” Geoderma., vol. 60, pp. 293-307, 1993.

[6] Y. Ostovari, A. Honarbakhsh, H. Sangoony, F. Zolfaghari, K. Maleki, and B. Ingram, “GIS and multi-criteria decision-making analysis assessment of land suitability for rapeseed farming in calcareous soils of semi-arid regions,” Ecological Indicators., vol. 103, pp. 479-487, 2019.

[7] M. Wiesmeier, F. Barthold, B. Blank, and I. Kögel-Knabner, “Digital mapping of soil organic matter stocks using Random Forest modeling in a semi-arid steppe ecosystem,” Plant and soil., vol. 340, no. 1, pp. 7-24, 2011.

[8] Y. Zhang, B. Sui, H. Shen, and L Ouyang, “Mapping stocks of soil total nitrogen using remote sensing data: A comparison of random forest models with different predictors,” Computers and Electronics in Agriculture., vol. 160, pp. 23-30, 2019.

[9] S. Hamzeh, M. Mokarram, and S. K. Alavipanah, “Combination of Fuzzy and AHP methods to assess land suitability for barley: Case Study of semi-arid lands in the southwest of Iran,” Desert., vol. 19, no. 2, pp. 173-181, 2014.

[10] A. Mishelia, and E. M. Zirra, “Application of Geographic Information System (GIS) in evaluating suitable areas for wheat cultivation in Adamawa State Nigeria,” Int. J. Sci. Knowl., vol. 6, pp. 14-22, 2015.

[11] R. B. Zolekar, and V. S. Bhagat, “Multi-criteria land suitability analysis for agriculture in the hilly zone: Remote sensing and GIS approach,” Computers and Electronics in Agriculture., vol. 118, pp. 300-321, 2015.

[12] G. Ayalew, and Y. G. Selassie, “Land suitability evaluation for cereal and pulse crops using geographical information system in East Amhara region, Ethiopia,” Research Journal of Agriculture and Environmental Management, vol. 4, no. 3, pp. 141-148, 2015.

[13] A. H. Rabia, "A GIS-based land suitability assessment for agricultural planning in Kilte Awulaelo district, Ethiopia," In The 4th International Congress of ECSSS, EUROSOIL., p. 1257, 2012.

[14] U. G. A. S. SIsmaila, A. S. Gana, N. M. Tswanya, and D. Dogara, "Cereals production in Nigeria: Problems, constraints, and opportunities for betterment," African Journal of Agricultural Research., vol. 5, no. 12, pp. 1341-1350, 2010.

[15] O.G. Olabanji, M. U. Omeje, I. Mohammed, W. Ndahi, and I. Nkama, "Wheat: In Cereal Crops of Nigeria: Cereals: Principles of production and utilization," NU., vol. 4, pp. 230-249, 2004.

[16] B. Minasny, and A. B. McBratney, "A conditioned Latin hypercube method for sampling in the presence of ancillary information," Computers & geosciences., vol. 32, no. 9, pp. 1378-1388, 2006.

[17] P. J. Schoeneberger, D.A. Wysocki, and E. C. Benham, E, "Field book for describing and sampling soils," Government Printing Office., 2012.

[18] D. W. Nelson, and L. P. Sommers, "Total carbon, organic carbon, and organic matter. Methods of Soil Analysis: Part 2 chemical and microbiological properties," vol. 9, pp. 539-579, 1983.

[19] M. L. Jackson, "Soil Chemical Analysis," Constable and Co. Ltd. Prentice Hall of India Pvt. Ltd., New Delhi., pp. 10–114, 1973.

[20] L. A. Richards, "Diagnosis and improvement of saline and alkali soils," vol. 78, No. 2, p. 154, 1954.

[21] G. W. Gee, and J. W. Bauder, "Particle size analysis. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods," Soil Science Society of America. Inc., Madison, WIS, USA, 1986.

[22] Ir. C. Sys, E. Van Ranst, and J. Debaveye, "Principles in land evaluation and crop production calculations," Land Evaluation Part I, Agricultural publication., 1991.

[23] Ir. C. Sys, E. Van Ranst, J. Debaveye, and F. Beernaert, "Crop requirements," Land Evaluation Part III, Agricultural publication., 1993.

[24] J. Seyedmohammadi, F. Sarmadian, A. A. Jafarzadeh, M. A. Ghorbani, and F. Shahbazi, "Application of SAW, TOPSIS and fuzzy TOPSIS models in cultivation priority planning for maize, rapeseed and soybean crops," Geoderma., vol. 310, pp. 178-190, 2018.

[25] S. M. Khiddir, "A Statistical Approach in the Use of Parametric Systems Applied to FAO Framework for Land Evaluation," Doctoral dissertation, Ghent University., 1986.

[26] Framework, FAO. “A Framework for Land Evaluation. Food and Agriculture Organization of the United Nations,” Rome, Soils Bulletin., No. 32, 1976.

[27] G. Debesa, S. L. Gebre, A. Melese, A, Regassa, and S. Teka, “GIS and remote sensing-based physical land suitability analysis for major cereal crops in Dabo Hana district, South-West Ethiopia,” Cogent Food & Agriculture., vol. 6, pp. 1-19, 2020.

[28] A. Bagherzadeh, and M. R. Mansouri Daneshvar, “Physical land suitability evaluation for specific cereal crops using GIS at Mashhad Plain, Northeast of Iran,” Frontiers of Agriculture in China., vol. 5, pp. 504-513, 2011.

[29] A. Zeinodini, “Land suitability evaluation for wheat in Kerman provinces,” In Proceeding of the 8th Iranian Soil Science Congress., vol. 26, p. 29, 2003.

[30] R. BaqerZadeh, A. BagherZadeh, and J. Moinrad, “Analysis of parametric methods for assessing the quality of Nishabur plain land suitability for wheat (*Triticum aestivum* L),” Journal of Agricultural Ecology., vol. 4, no. 2, pp. 121-130, 2012.

Authors Profile:



Marhaba Sahbani received his BSc degree from plant science Department of Alberoni University in 2010. He got his MSc degree in soil science from College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran in 2019. Presently he is working as assistant professor in Soil science and Irrigation Department, Kabul University, Kabul Afghanistan. His area of research includes Pedology and Land Evaluation.



Fereydoon Sarmadian received his PhD in soil science from College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran in 1992. From 1989 up to present, he is working as professor in Soil science Department, University of Tehran, Karaj, Iran. His area of research includes Pedology and Land Evaluation.



Mohammad Daud Haidari received his BSc degree from Agronomy Department of Kabul University in 2006. He got his MSc in soil science and agricultural chemistry from University of Agricultural Sciences (UAS), Bangalore, India in 2011. In 2012, he obtained his PhD in soil science and plant nutrition from Tokyo University of Agriculture and Technology (TUAT), Tokyo, Japan in 2017. Presently he is working as assistant professor in Soil science and Irrigation Department, Kabul University, Kabul Afghanistan. His area of research includes Soil chemistry and plant nutrition.