LAND SUITABILITY ASSESSMENT USING AGRO-LAND ASSESSMENT (AGLA) MODEL—CASE STUDY: AKRE DISTRICT, DUHOK PROVINCE, IRAQ

PEARIS, M.[1*] – AYDEMIR, S.[2] – BILGILI, A. V.[2]

[1]*Department of Horticulture, Faculty of Agriculture, Akre University for Applied Science, Akre, Duhok, Iraq*

[2]*Department of Soil Science, Faculty of Agriculture, Harran University, Sanliurfa, Turkey*

***Corresponding author**
e-mail: pearis.majeeed@gmail.com; phone: +964-750-451-1181

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Abstract. Land evaluation is essential for developing sustainable agroecological systems, particularly in countries striving to achieve agricultural self-sufficiency. This study focuses on Akre district plain in Iraq, covering approximately 714.87 km^2, which is considered a food basket for a wide range of areas. The aim of this study was to classify the land suitability of the study area and identify the most suitable crops for cultivation. Land suitability was determined based on the interaction of various topographical, physical, chemical and climate analyses from twenty soil profiles collected from different landscapes. These analyses were processed using the AGLA model. The results were compiled into an Excel file (.csv.MS_DOS) that can be integrated into ArcGIS as points. Suitability classes were determined for several crops, including wheat, barley, rice, beans, tomato, lentil, nuts, almond and olive. In total, the results of suitability classes in the study area were class S1 (the suitable lands) were 98.51 km^2 about 13.76%, in class S2 (the moderate suitable lands) were 491.31 km^2 about 68.63%, in class S3 (the low suitable lands) were 111.68 km^2 about 15.6% and in class N (non-suitable or marginal lands) were 14.37 km^2 about 2.01%.
Keywords: *land evaluation, land suitability, agro-ecological, modeling, GIS*

Introduction

Akre district is a newly developing area located in the north of Iraq. The cultivated land is concentrated in almost all areas of good soil quality and suitable water resources.

The rate of population growth and the limited agricultural space calls for increasing the production per unit area (vertical expansion). Land and water resources and the way they are used are vital to the challenge of improving food security across the region. The policy of horizontal expansion represents the cornerstone in the development challenges.

Understanding land suitability is critical to sustainable agricultural development, especially in regions where population growth and food security challenges demand effective land and water resource management. Evaluating the capacity of lands for specific uses enables planners and policymakers to optimize agricultural productivity, guiding both current land management and future development strategies (Alexandratos and Bruinsma, 2012). Land suitability assessments, established by frameworks such as those developed by the Food and Agriculture Organization (FAO, 1976), provide a systematic method for identifying the best uses for land based on its ecological and physical characteristics. These assessments help balance the needs for increased productivity with sustainable resource use.

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Land Suitability assessment is a crucial prerequisite for agricultural production, enabling maximum yield (Nguyen et al., 2020). To obtain soil parameters, farmers depend on soil testing labs; yet, these labs frequently require improvement and provide inaccurate data. Data must be manually collected in order to obtain adequate farming information, which presents serious difficulties for farmers. The strategy entails using sensors that make use of the Internet of Things (IoT) in place of traditional data collection methods (Ali et al., 2023). In order to improve agricultural productivity, sensors are essential for collecting data on a variety of topics, such as soil, water, and climate. In order to help farmers evaluate the current state of their field and increase crop production, LS evaluation is carried out using data gathered from several sensors. To assist farmers in making crop-cultivation decisions that maximize their earnings, a variety of decision-support systems have been developed (Coa and Jiang, 2024).

The progress in the field of data and knowledge engineering has introduced promising prospects for the advancement and utilization of land assessment. Previously, the hands-on aspect of land evaluation processes was manually evaluated. However, contemporary approaches now utilize computer-assisted techniques. This approach encompasses creating interconnected databases, software tools, and specialized resources to construct frameworks that aid in decision-making. The evolution of this process entails moving from experimental regions in the early phases to implementing these systems in novel scenarios (De la Rosa and Van Dieoen, 2002).

Machine Learning (ML) algorithms acquire knowledge from large-scale datasets and effectively integrate diverse data sources (Tripathi et al., 2024). Within digital land mapping systems, ML algorithms have been employed to establish relationships between soil measurements and various influencing factors, thereby enabling a deeper understanding of spatial and temporal variations in soil types and attributes. This study collected agricultural data using multiple IoT sensor devices, including a pH sensor, soil moisture sensor, salinity sensor, and electromagnetic sensor (Rajak et al., 2023). A detector is a device designed to identify and respond to specific inputs from the physical environment. Due to its reduced labor demands and time efficiency, detectors are widely used in various real-time systems (Helo and Shamsuzzoha, 2020). Leveraging the Internet's role as a medium for interactions and information exchange, integrating agricultural data with a cloud-based system is a logical approach. Data collected from various IoT devices is stored on a cloud-based platform, ensuring accessibility and efficient management. The development of IoT in farm data analysis has progressed from concentrating on individual crops to addressing all crop types. This framework offers versatile applications, ranging from crop management and monitoring to product marketing. By employing the interpolation method, a fuzzy approach was utilized to design an irrigation monitoring and management system that produces soil moisture distribution maps (Baradaran and Tavazoei, 2022).

Computer systems have been employed in developing land evaluation methods since the FAO framework was introduced. These computerized models can integrate both socioeconomic and biophysical factors, enabling the storage, manipulation, and analysis of vast amounts of data. They help complete evaluations within a specified timeframe and provide insights for future land appraisals. However, such models can also be costly, time-consuming, and may divert resources from other planning activities. Computer-based land evaluation systems differ based on their purpose, land uses, required data, and model outputs. Examples of these systems include the Agricultural Planning Toolkit (APT), Comprehensive Resource Inventory and Evaluation System

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(CRIES), Land Evaluation Computer System (LECS), Automated Land Evaluation System (ALES), and Microcomputer Land Evaluation Information System. (MicroLEIS) (Kalogirou, 2002; Elaalem, 2010).

Modelling in land evaluation has advanced significantly through the integration of GIS, multicriteria decision analysis (MCDA), and expert systems, leading to more precise and effective assessments. Malczewski (2006) provides a comprehensive overview of GIS-based MCDA, demonstrating its capacity to support complex decision-making by analyzing multiple criteria simultaneously, which is essential for robust land evaluation. Similarly, Additionally, Wulder et al. (2008) underscore the significance of Landsat continuity for consistent, long-term land cover monitoring, highlighting the role of high-quality spatial data in supporting effective land evaluation models. Collectively, these advancements contribute to more accurate land assessments, equipping stakeholders with the information necessary for sustainable land management.

The study will address the ongoing limitations in the land evaluation process. One significant limitation is the insufficient understanding of the functional properties of soil and the environment. Although techniques and methods for evaluating soil and land have advanced considerably over the years, particularly with the expansion of digital data acquisition and processing capabilities, the knowledge of the conditions and processes that influence how plants and soil respond to varying environmental factors and human activities has not kept pace. This gap is largely due to the lack of targeted experimental studies.

The research presented in this article aims to develop an innovative land evaluation model that integrates advanced GIS techniques and computational methods to address the unique agricultural needs many areas. By enhancing the accuracy and efficiency of land suitability assessments, this model offers a significant advancement in the field, particularly valuable for regions striving to optimize agricultural productivity amid limited resources. The model provides a framework for faster and more accurate evaluation of land for agricultural use, facilitating informed decision-making for sustainable land management. This approach not only supports the region’s agricultural sector but also contributes to global efforts in sustainable land use and food security by offering a replicable model adaptable to diverse geographic and environmental conditions.

Study area

Akre district is a new development area that located in the north of Iraq. The cultivated land is concentrated in approximately in all areas because of the good soil quality and suitable water resources. Akre is a district located in the Dohuk governorate in northern Iraq, covering an area of approximately 1835.19 km². It is situated between the longitudes (43°58’58” E) and (43°36’12” E), and the latitudes (36°49’26” N) and (36°30’16” N) (https://earthexplorer.usgs.gov), as shown in *Figure 1a.*

Due to the mountainous nature and topography of the region, the authors focused on the Akre Plain, which contains a large cultivated area considered the food basket for both the district and the Dohuk governorate. The Akre Plain is estimated to cover about 715.87 km², representing 40.49% of the total area of Akre district, as shown in *Figure 1b.*

The climatic conditions of the Akre Plain are characterized by a semi-arid to sub-humid zone, featuring hot rainless summers and cold winters. According to meteorological data from the Kurdistan Region Meteorological Authority (IKRM,

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2024), this study presented the period start from January 1st 2000 to December 31 2023, the maximum temperature recorded in August 2005 was 42.4°C, while the minimum temperature recorded in January was 3.2°C, with average minimum and maximum annual temperatures of 15.3°C and 26.31°C, respectively. Precipitation levels vary from high to medium, with the highest recorded value of 238.69 mm in March and the lowest of 0.02 mm in July as shown in *Table 1*.

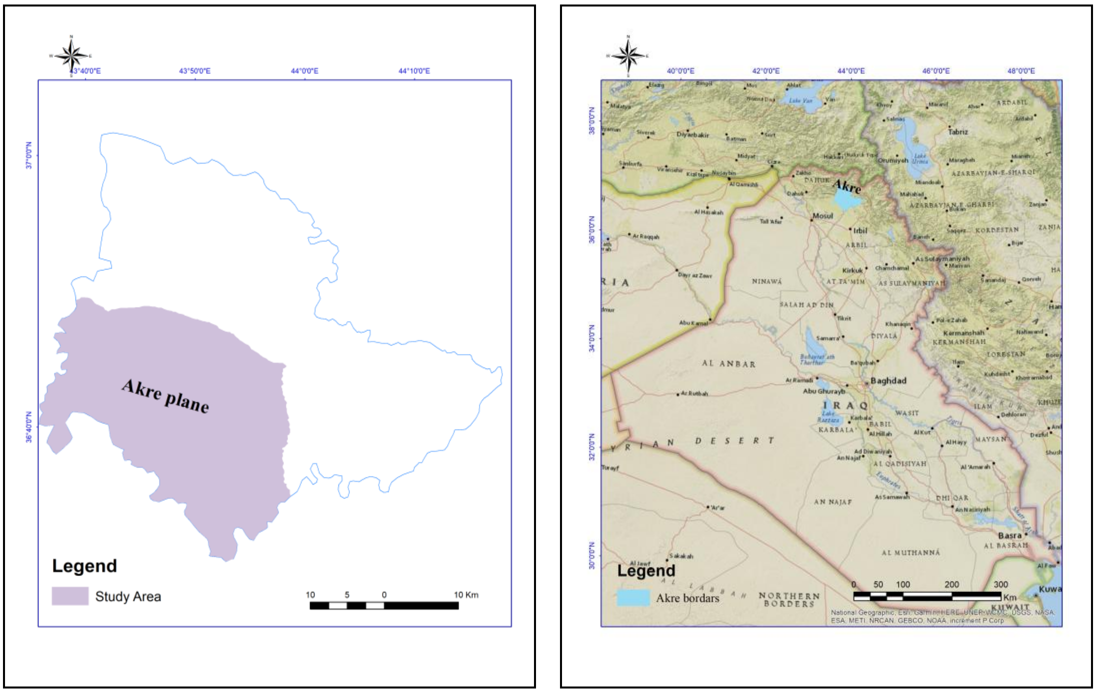

Figure 1. *(a) Map of Iraq showing boundaries of Akre District; (b) map of study area*

Table 1. *The climatological normal of Akre district area (average of 23 years, 2000–2023)*

Months	Temperature °C			Mean total rainfall mm/month	Relative humidity %
	Max.	Min.	Aver.		
January	11.1	3.2	7.15	129.31	66
February	13.3	4.4	8.85	99.38	60
March	17.3	7.8	12.55	238.69	74
April	23.4	12	17.7	69.98	50
May	30.4	17.9	24.15	28.97	43
June	37.2	24.2	30.7	1.24	38
July	41.6	28.1	34.85	0.02	28
August	42.4	29.1	35.75	0.07	29
September	36.8	23.6	30.2	2.49	29
October	28.6	17.4	23	35.16	33
November	19.6	10.7	15.15	94.98	67
December	14	5.2	9.6	121.49	72
Annual mean	26.31	15.30	20.80	811.78	49.08

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The geology of the study area dates back to the Cretaceous epoch through the Holocene epoch, and contain many formation (Qamchugha, Akre-Bekhme, Kolosh, PilaSpi, Upper Fars, Lower Bakhttiari, Upper Bakhttiari, Floodplain Deposits, River Deposits, and Slope deposits) (Maarouf, 1983), the map was prepared by the author using ArcGIS, as shown in *Figure 2*.

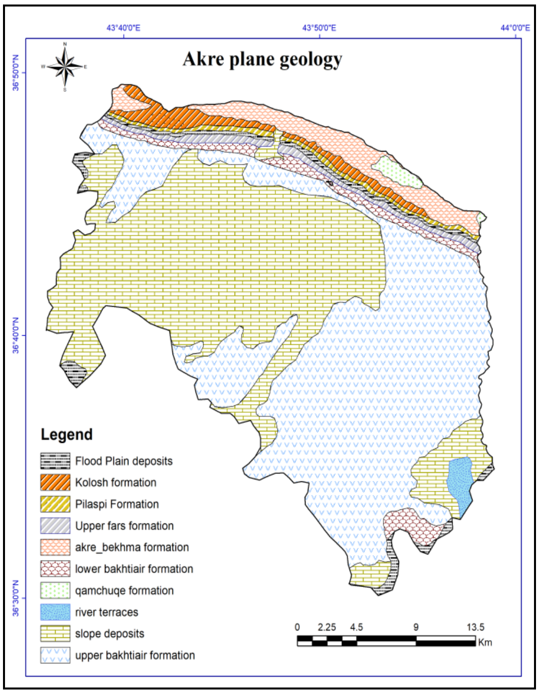

Figure 2. *Geological map of study area after (Maarouf, 1983)*

Great Zab river, one of the Tigris tributaries, is the main sources for the Akre district’s hydrology. It contact with the study area from southeast at a distance 24.6 km, providing the main tributary for Akre plain, and from the west, contact with Khazir tributary at a distance 31.7 km (Aqrawi, 1990).

Zinta tributary is another supplementary source for Akre district, it is twelve km from Akre center and about 30 km in length, bordering the east of study area and supplying the water sources and streams (Ismael, 2006), as shown in *Figure 3*.

Depending on Directorate of Agriculture, Akre District, Irrigation and Ploughed Agricultural report (IKRG, 2023), the study area divided into two groups (mountain and mountain preliminaries part) with 85% being orchards and 15% crops, and Akre plain part with 73% crops and 27% orchards. The main fruits trees are nuts, fig, pomegranate, olive and peaches along with others for purpose uses, while crops are wheat, barley, rice, tomato, beans, cucumber, okra, potato, melon and water melon among others are not widely cultivated.

The hydrology map produced by open the dem with ArcGIS and export the data GRID format the use in in spatial analyst tools > hydrology > fill, then use spatial analyst tools > hydrology > flow direction then use spatial analyst tools > hydrology > flow accumulation them use spatial analyst tools > conditional > con and chose value 500 then change the raster to feature by using spatial analyst tools > hydrology > stream to feature

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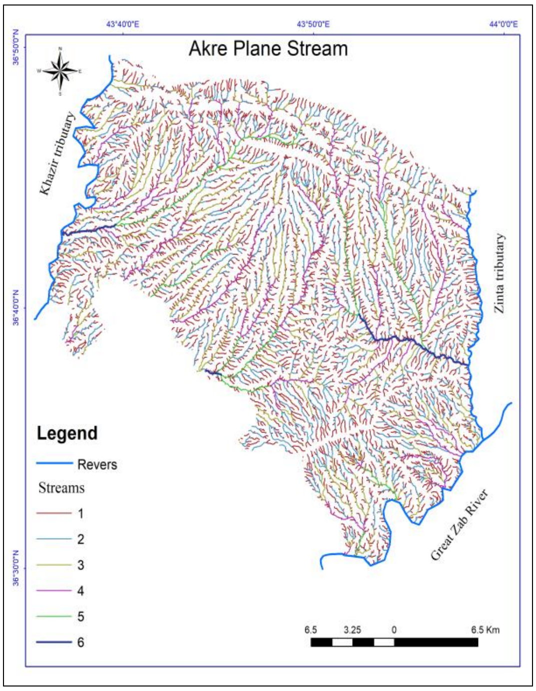

Figure 3. *Streams and rivers of study area*

Materials and methods

Software and dataset

- Arc GIS version 10.8 was used for GIS analyses and mapping.
- Agro-Land Assessment decision support systems (AGLA) DSS is an application model designed by the author.

To prepare the criteria that are fundamental for land suitability, the required database were collected from various resources, including the following:

- FAO framework of land suitability (FAO, 1976). For this study 9 crops and trees were chosen (Wheat, Barley, Rice, Bean, Tomato, Lentil, Almond, Nuts, and Olive).
- Soil observations, which are fundamental steps in obtaining the comprehensive data required to determine land evaluation.
- Climate data for 23 years were collected from 2 metrological stations from Iraq Kurdistan Region Metrological Authority (IKRM, 2024).
- Remote sensing data, including a Landsat 8 Operational Land Imager (OLI) satellite image dated 14 April 2023, and a Digital Elevation Model (DEM) sourced from the Shuttle Radar Topography Mission (SRTM) with a 30 m resolution, were accessed on 15 June 2023, from https://earthexplorer.usgs.gov.

Criteria selection and preparation

Land use and land cover (LU/LC)

The land use and land cover map utilized Landsat 8 OLI satellite images from 2023. The classification method employed a supervised approach with the maximum likelihood algorithm. The image was divided into eight categories: mountain, rocky lands, forest, orchards, barren land, urban areas, cultivated land, and water bodies. To assess classification accuracy, a confusion matrix was used. Additionally, verification involved cross-referencing with an ArcGIS online imagery basemap, random points, and real-world ground observations.

Landscape map and field work

The landscape map was obtained from the digital interpretation of remote sensing images. Five sample areas were selected to represent the different mapping units within areas. All soil profiles were dug within the four sample areas because the fifth one is a mountain, as shown in *Table 2* and *Figure 4*. Soil samplings were done by horizon bases (profile layers) and total of 59 soil samples were collected.

Table 2. *Area landscape with profiles*

No	Landscape	Area (km^2)	Ratio %	Profiles
1	Mountain	25.68	3.59	0
2	Mountains preliminaries	61.78	8.63	1, 14, 15
3	Plain	150.77	21.06	2, 3, 7, 8, 13
4	Undulating plain	224.34	31.34	4, 6, 11, 16, 19, 20
5	Banks collapsed	253.31	35.38	5, 9, 10, 12, 17, 18
Total		715.87	100.00	

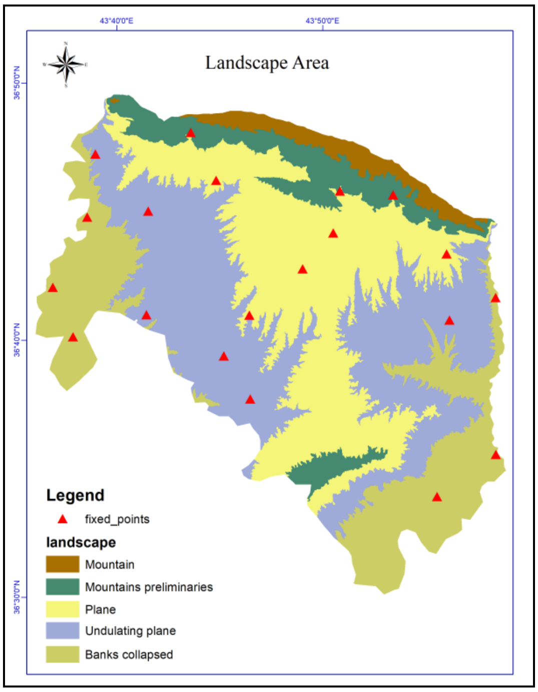

Figure 4. *Landscape map with samples location*

Soil analyses

Soil samples were collected and prepared for the physical and chemical analyses:

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(a) Physical analyses

Particle size distribution and Bulk density were determined according to (Klute, 1986; Piper, 1950; US, 1954).

(b) Chemical analyses

Soil reaction (pH), Electrical Conductivity meter (EC), soluble cations and anions, calcium carbonate content, organic matter content, cation exchange capacity, available nitrogen and available P and K were determined according to (Jackson, 1976; Black, 1982; Soltanpour, 1985).

Land suitability AGLA/RUNAK suitability model

Many models were designed to calculate the land evaluation, but some are too complicated to deal with and some are applied just on arid and semi-arid land and some others need a lot of paperwork, which takes too much time.

Land suitability model was designed by developing the FAO (1976) approach, that divides the suitability into classes (S1, S2 and S3) which are considered suitable lands for cultivation with some limitations, and (N1 and N2) for non-suitable lands.

Agro-Land Assessment (AGLA/RUNAK suitability model) was designed and developed to assist and determining the land suitability.

Land suitability assessment arises from the analysis of multiple elements influenced by the needs of various crops. These elements encompass soil characteristics (both chemical and physical aspects), climatic conditions, topography, and specific types of crops. Each of these elements comprises numerous parameters that influence the overall suitability determination.

The classes were divided into (S1, S2 and S3) which are considered appropriate for supporting crop use, and class N (non-suitable/marginal) which can be used for forestry.

Limitations:

- The soil factors included (depth, stones, texture, drainage, electrical conductivity (EC), ESP and calcium carbonate).
- The topography factor is characterized by slope.
- Climate factors are represented by (precipitation, temperature and humidity) during the crop growing cycle.

The crop types are divided into (annual crops and perennial crops)

AGLA/RUNAK methodology

The land evaluation databases and climate databases were encoded by a computer using C# programming into a machine language system that is readable and creates land suitability model. This model was subsequently transferred to an application that can be used by a PC as it is shown in *Figure 5*.

The programing encoding were produced by using Microsoft visual studio Enterprise 2023 (Microsoft, 2023) as following:

1. The following database was constructed using C# Programming:

- Data Collection: Relevant data regarding soil properties, land characteristics, and climate conditions were collected from various sources.

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- Data Structuring: The collected data are organized and structured that facilitate efficient storage and retrieval. This may involve the creation of a database schema that defines the relationships between different types of data.
- C# Programming: C# is a programming language commonly used for Windows applications. In this context, a C# program was employed to encode the collected data into a format that can be easily processed by a machine.

2. Conversion to Machine Language:
- Compiler Usage: The C# program is then compiled using a compiler, translating human-readable code into a machine language that computers can execute directly.

3. Creation of models:
- Land suitability Model: The compiled program was designed to create a land suitability model. This model assesses the fitness of a particular area for specific land uses based on encoded data. considers factors such as soil type, climate, and terrain.
- Capability Model: Another aspect involves generating a capability model, that considers the land’s inherent capacity to support certain activities or uses.
- Degradation Model: The system may also incorporate a degradation model, predicting how land quality may change over time due to various factors such as erosion or human activities.

4. Model transfer:
- Application Development: The generated models were transferred to an application developed using C# or another suitable programming language. This application serves as a user interface for interactions with land evaluation models.
- PC Compatibility: The application is designed to be compatible with personal computers, allowing users to input specific parameters, view model outputs, and make informed decisions regarding land-use planning.

The integration of C# programming, machine language encoding, and application development facilitates the creation and utilization of sophisticated land evaluation models. These models contribute to informed decision-making in areas such as land suitability, capability, and degradation, supporting sustainable land management practices.

Land suitability model (RUNAK model)

The RUNAK model functions through involves interactive procedures in which the unique attributes of land units are combine with the point coordination and different crops to determine suitability classes. The purpose is to evaluate land by aligning its characteristics with established suitability levels for each specific use class.

The model’s input parameters include (slope, useful depth, stoniness, texture, drainage, $CaCO_3$, EC, ESP, precipitation during grown cycle, mean temperature during grown cycle and relative humidity) as shown in *Figure 6.*

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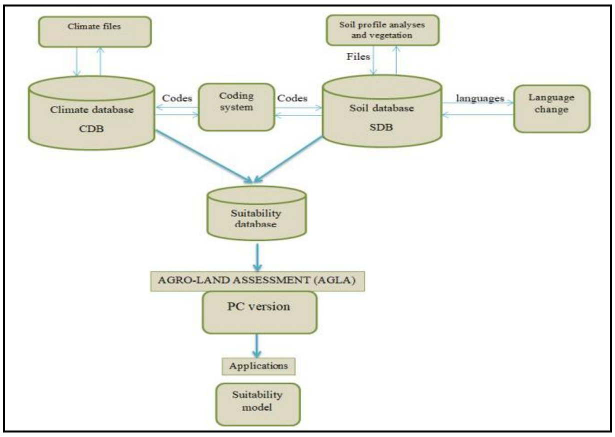

Figure 5. *AGLA model methodology*

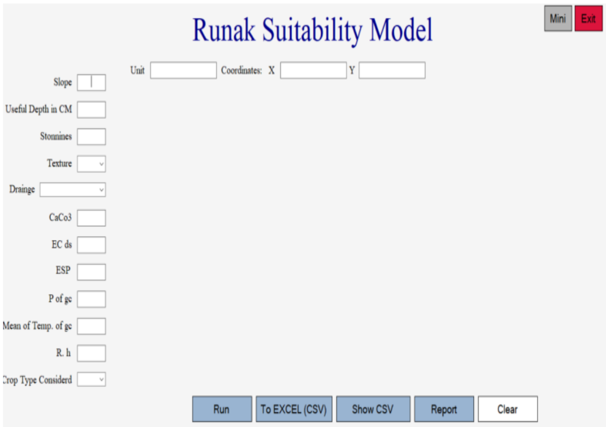

Figure 6. *Runak land suitability parameters input*

RUNAK suitability results

The results of the RUNAK suitability model can be extracted into two formats:

- Portable Document Format (PDF) in *Figure A1* in the *Appendix*.
- Excel sheet Comma Separated Values File (CSV.MS_DOS) that can be directly joined to the ArcGIS program as points. However, each coordination point contain different crop suitability classes.

Inverse distance weighted (IDW) tool

The IDW (Inverse Distance Weighted) interpolation method estimates the values at specific locations based on nearby known data points. It operates under the assumption that points closer to the location have a greater influence on its value than points farther away.

1. Weighting by Distance: The influence of each point is inversely proportional to its distance from the location, meaning that closer points are given more weight in the calculation, while distant points have less influence.
2. Power Parameter: IDW includes a power parameter that controls how quickly the influence of a point diminishes as distance increases. A higher power value

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gives more weight to nearby points and results in a more localized interpolation, while a lower power value gives a more general surface.

3. Interpolation Process:

- The value at each interpolation point is computed as a weighted average of the values of the points.
- The weights are based on the inverse of the distance between each known point and the unknown point.

$$Z(x,y) = \frac{\sum_{i=1}^{n} Zi/d_i^p}{\sum_{i=1}^{n} 1/d_i^p}$$

where: Z(x,y) is the estimated value at the unknown point; Z_i is the value at the known point; d_i is the distance between the known point and the unknown point; p is the power parameter; n is the number of known points.

Results and discussion

Soil of investigated area

The soil mapping unit of the investigation area were analyzed and categorized for each terrains and could be recognized as follows:

(a) Soil of mountain preliminaries: this mapping units was represented by soil profiles nos. 1, 14 and 15. Soil texture is sandy clay loam to clay, soluble cations follow the descending order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, meanwhile the soluble anions ascending order of $HCO_3^- < Cl^- < SO_4^{2-}$, calcium carbonate values are moderate to high where they are ranged between 13.1 and 23.17%. as shown in *Table 3,* and other profile analysis are in the *Appendix*.

Table 3. *Soil profile No. 14 analysis*

Pro No.	Depth (cm)	$CaCO_3$ %	O.M%	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
						N	P	K
14	0 - 30	28.100	1.710	18.040	1.107	112.000	8.770	80.460
	30 - 65	18.750	0.070	13.720	1.170	95.670	6.760	94.230
	65 - 90	22.650	0.030	10.630	1.160	87.530	6.010	95.540

(b) Soil of plain: this mapping units was represented by soil profiles nos. 2, 3, 7, 8 and 13. Soil texture is sandy clay loam to sandy clay, soluble cations follow the descending order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, meanwhile the soluble anions ascending order of $HCO_3^- < Cl^- < SO_4^{2-}$, calcium carbonate values are moderate to high where they are ranged between 6.42 and 22.67%. as shown in *Table 4,* and other profile analysis are in the *Appendix*.

(c) Soil of undulating this mapping units was represented by soil profiles nos. 4, 6, 11, 16, 19 and 20. Soil texture is sandy clay loam to clay loam, soluble cations follow the descending order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, meanwhile the soluble anions ascending order of $HCO_3^- < Cl^- < SO4^{2-}$, calcium carbonate values are moderate to high

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where they are ranged between 14.48 and 22.37%. as shown in *Table 5*, and other profile analysis are in the *Appendix*.

Table 4. *Soil profile No. 7 analysis*

Pro No.	Depth (cm)	$CaCO_3$ %	O.M %	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
						N	P	K
7	0 - 30	22.000	0.720	17.670	1.340	172.140	8.540	54.670
	30 - 85	21.650	0.210	13.650	1.130	166.120	5.550	65.440
	85 - 140	18.270	0.140	13.100	1.120	141.760	5.120	70.080

Table 5. *Soil profile No. 19 analysis*

Pro No.	Depth (cm)	$CaCO_3$ %	O.M %	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
						N	P	K
19	0 - 25	21.45	0.15	22.41	1.45	189.43	12.72	122.75
	25 - 90	19.62	0.02	19.71	0.99	172.64	9.90	131.62
	90 - 150	15.71	0.01	13.63	0.93	155.41	7.31	134.21

(d) Soil of Banks collapsed: this mapping units was represented by soil profiles nos. 5, 9, 10, 12, 17 and 18. Soil texture is sandy clay loam to clay loam, soluble cations follow the descending order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, meanwhile the soluble anions ascending order of $HCO_3^{-} < Cl^{-} < SO_4^{2-}$, calcium carbonate values are moderate to high where they are ranged between 18.50 and 20.64%, as shown in *Table 6*, and other profile analysis are in the *Appendix*.

Table 6. *Soil profile No. 5 analysis*

Pro No.	Depth (cm)	$CaCO_3$ %	O.M %	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
						N	P	K
5	0 - 25	18.52	0.35	18.62	0.94	126.32	8.33	45.63
	25 - 70	18.82	0.17	13.40	0.95	112.14	8.38	49.32
	70 - 90	18.79	0.10	11.52	0.91	91.05	7.72	47.52

Land use land cover (LU/LC)

Landsat 8.0 image was used to identify the land classes and also the image was compared with ArcGIS online imagery basemap, the classes were as shown in *Table 7* and *Figure 7*.

The orchards were separated from cultivated lands because these lands were contour farming or terrace farming and cannot be used for crops because of highly contain of stones and gravels and it is just suitable for trees.

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Table 7. *Land use/land cover classes*

No.	Class	Area (km²)	Ratio %
1	Urban	26.39	3.53
2	Forest	26.97	3.72
3	Orchard	6.78	0.95
4	Mountain	18.21	2.55
5	Barren land	0.78	0.11
6	Water bodies	2.73	0.38
7	Cultivated	519.6	72.74
8	Rocky terrain	114.41	16.02
Total		715.87	100

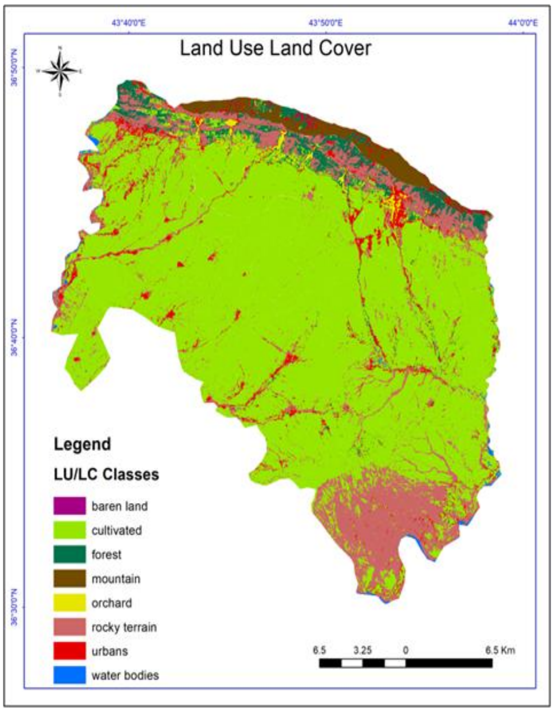

Figure 7. *Land use/land cover classes*

Land suitability

Agro-Land Assessment (AGLA) (RUNAK model for suitability) was used to determined suitability classes for some crops and trees that is widely cultivated in Akre plain i.e. Wheat, Barley, Rice, Beans, Tomato, Lentil, Nuts, Olive and Almond as well. The results of the AGLA model can be saved by the application as Excel sheet Comma Separated Values File (CSV.MS_DOS) that can be joined to the ArcGIS program directly as points as shown in *Table 8.*

The soil characteristics results of the landscape that extracted from AGLA model were matched with crop requirements to extract suitability classes depending on the AGLA (RUNAK suitability) model database for crops and trees as shown in *Table 9.*

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Table 8. *Annual crops extracted from the AGLA model*

ID	Type	Unit	X	Y	Barley	Code	Bean	Code	Tomato	Code	Wheat	Code	Lentil	Code
1	Annual	P1	386508.2	4073742	S3	3	S3	3	S3	3	S3	3	S3	3
2	Annual	P2	394585.4	4063930	S1	1	S1	1	S3	3	S1	1	S3	3
3	Annual	P3	390734.5	4060599	S2	2	S2	2	S3	3	S2	2	S3	3
4	Annual	P4	383425.2	4068087	S2	2	S2	2	S3	3	S2	2	S3	3
5	Annual	P5	376535.5	4062599	S2	2	S2	2	S3	3	S2	2	S3	3
6	Annual	P6	388896.1	4057674	S1	1	S2	2	S3	3	S2	2	S3	3
7	Annual	P7	396785.4	4066506	S1	1	S2	2	S3	3	S1	1	S3	3
8	Annual	P8	388328.2	4070294	S2	2	S2	2	S3	3	S2	2	S3	3
9	Annual	P9	404288.1	4047552	S1	1	S2	2	S3	3	S1	1	S3	3
10	Annual	P10	408532.2	4050592	S2	2	S2	2	S3	3	S2	2	S3	3
11	Annual	P11	405186.4	4060249	S1	1	S2	2	N	4	N	4	N	4
13	Annual	P12	408516.3	4061864	S2	2	S2	2	S3	3	S2	2	S3	3
14	Annual	P13	404987	4065003	S2	2	S2	2	N	4	N	4	N	4
15	Annual	P14	401116.2	4069252	S2	2	S2	2	S3	3	S2	2	S3	3
16	Annual	P15	397277.3	4069522	S3	3	S3	3	N	4	N	4	N	4
17	Annual	P16	379621	4072177	S1	1	S2	2	S3	3	S2	2	S3	3
18	Annual	P17	379019.5	4067654	S2	2	S2	2	S3	3	S2	2	S3	3
19	Annual	P18	378001.5	4059047	S1	1	S2	2	S3	3	S1	1	S3	3
20	Annual	P19	383297.1	4060637	S2	2	S2	2	S3	3	S2	2	S3	3
21	Annual	P20	390805.8	4054575	S2	2	S2	2	S3	3	S2	2	S3	3

Table 9. *Land suitability classes for crops and trees*

Land units	Profiles	Crops and trees								
		Wheat	Barley	Rice	Beans	Tomato	Lentil	Nuts	Olive	Almond
Mountains preliminaries	1	S3	S3	S3	S3	S3	S3	S1	N	S3
	14	S2	S2	S3	S2	S3	S3	S2	S3	S3
	15	N	S3	N	S3	N	N	S2	N	S3
Plain	2	S1	S1	S3	S1	S3	S3	S1	S1	S1
	3	S2	S2	S3	S2	S3	S3	S2	S2	S2
	7	S1	S1	S3	S2	S3	S3	S1	S1	S3
	8	S2	S2	S2	S2	S3	S3	S2	S2	S2
	13	N	S2	N	S2	N	N	S2	N	S3
Undulating plain	4	S2	S2	S2	S2	S3	S3	S3	S2	S3
	6	S2	S1	S2	S2	S3	S3	S1	S2	S2
	11	N	S1	S1	S2	N	N	S2	N	S2
	16	S2	S1	S1	S2	S3	S3	S3	S2	S3
	19	S2	S2	S2	S2	S3	S3	S2	S1	S2
	20	S2	S2	S3	S2	S3	S3	S1	S1	S3
Banks collapsed	5	S2	S2	S1	S2	S3	S3	S2	S3	S2
	9	S1	S1	S1	S2	S3	S3	S3	S1	S3
	10	S2	S2	S1	S2	S3	S3	S3	S3	S2
	12	S2	S2	S1	S2	S3	S3	S3	S2	S2
	17	S2	S2	S1	S2	S3	S3	S2	S2	S3
	18	S1	S1	S2	S2	S3	S3	S2	S1	S2

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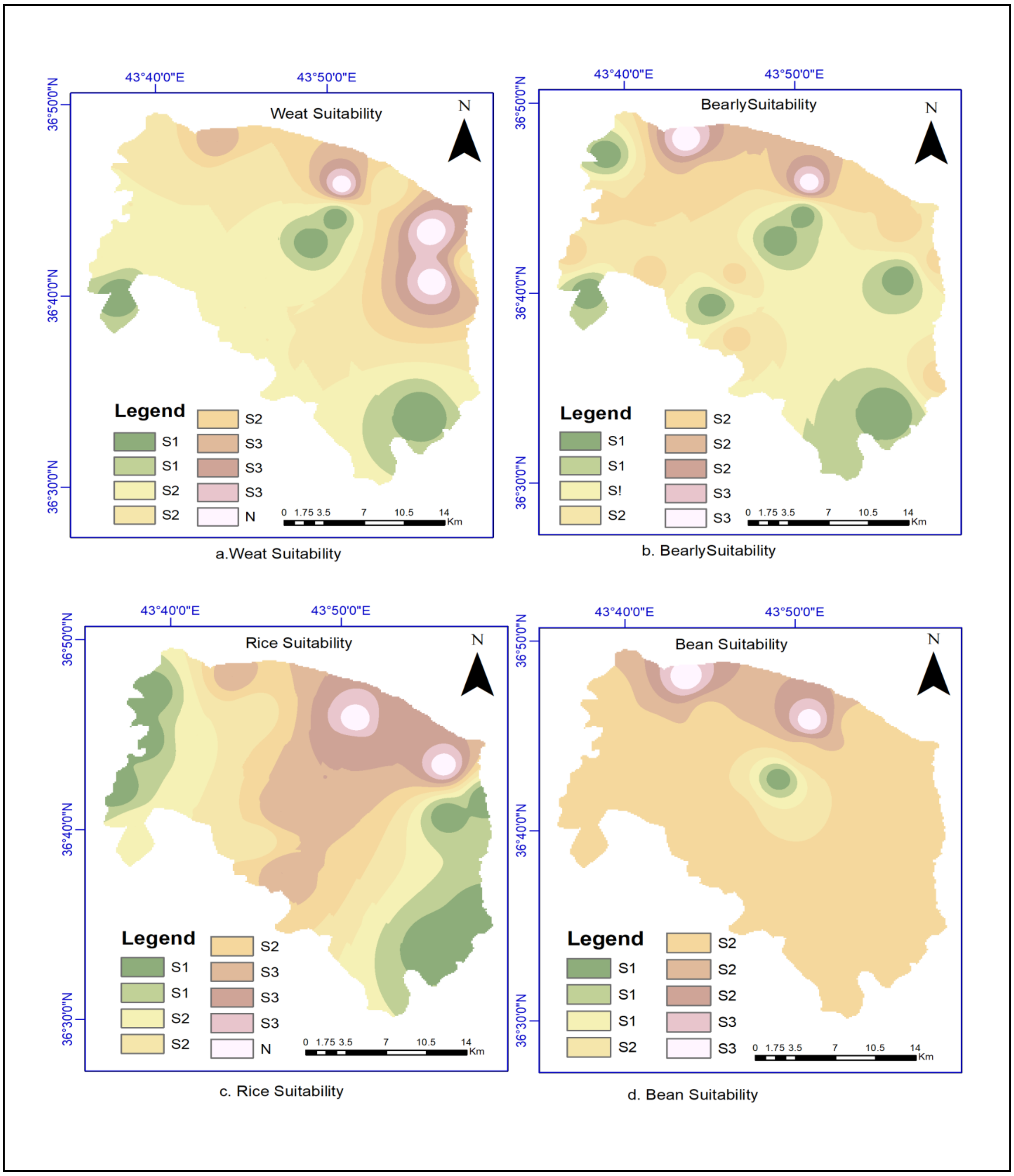
Land suitability maps

Suitability maps were produced by using ArcGIS special tool an inverse distance weighted (IDW) interpolation method to estimate the value of the points that extracted by the AGLA suitability model. The IDW tool deal with the class code of each crop because interpolation deal with numbers not words (S). Different crops and trees were chosen depending on their cultivated density in area as shown in *Figures 8a, b, c, d, e, f, g, h* and *9.*

General land suitability map

A general suitability map was produced for the study area by calculating the mean of the analyses data for each landscape profiles and using the AGLA model to extract the land suitability classes that can help both decision makers and agriculture office to produce one map instead of multi-maps as shown in *Table 10.*



a.Weat Suitability

b. BearlySuitability

c. Rice Suitability

d. Bean Suitability

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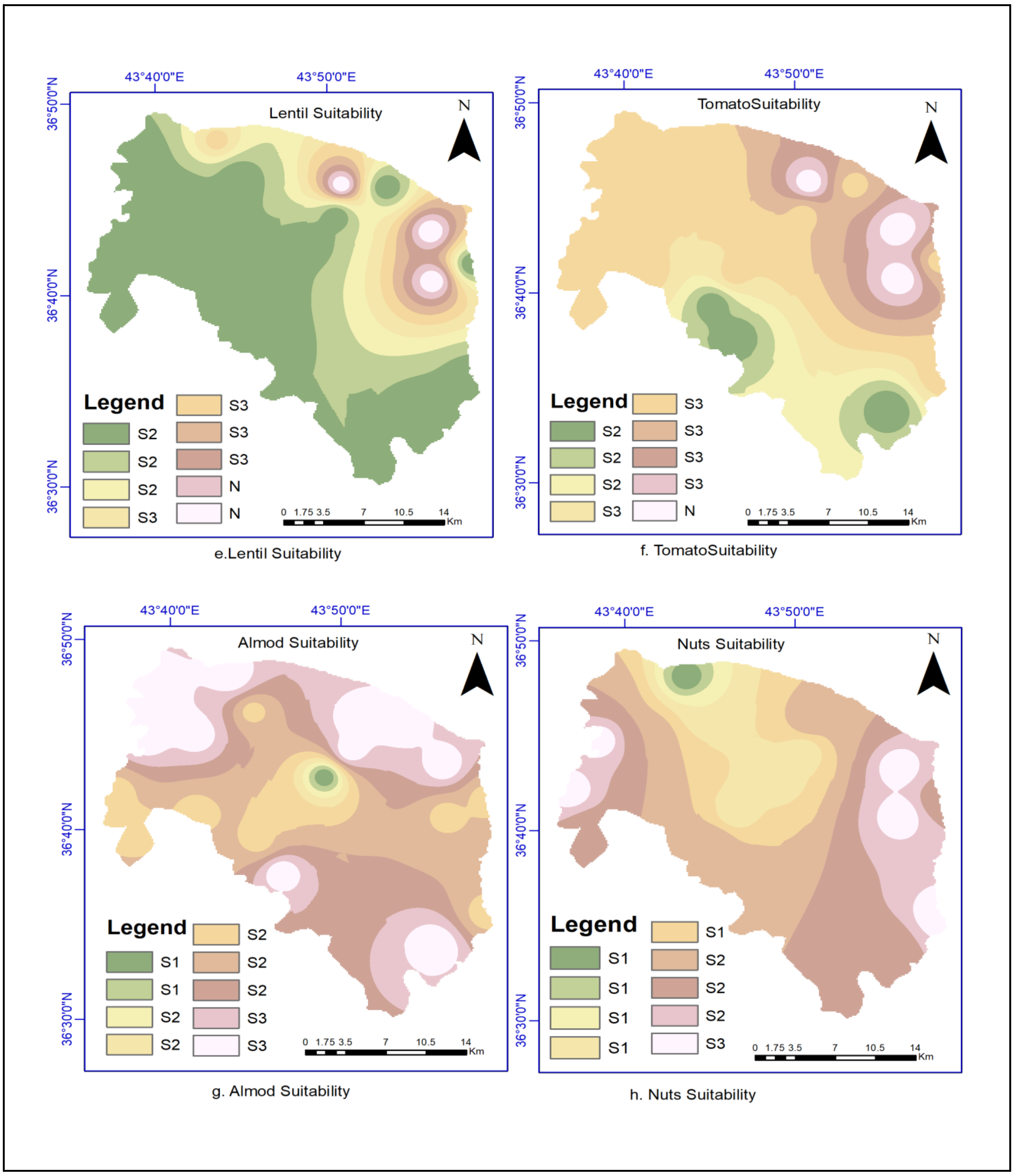

Figure 8. *(a–d) Land suitability classes for wheat, barley, rice and beans; (e–h) land suitability classes for lintel, tomato, almond and nuts*

The Specifying spatial model environment settings and conversion a series of values for input criteria from features to raster resulting in four dataset, reclassifying each derived dataset to a common measurement scale, giving each range a discrete, integer value between 1 and 4. Ascending values were given to attributes within each dataset representing land suitability classes. Using conditional expressions to get land suitability raster classes. Weighted overlay datasets through setting equal influence with different scale values. Converting the land suitability raster classes into land suitability polygons in the geodatabase. Creating land suitability layer. Selecting four land suitability classes by attributes (values) and creating the final layers that represent land suitability classes as shown in *Figure 10.*

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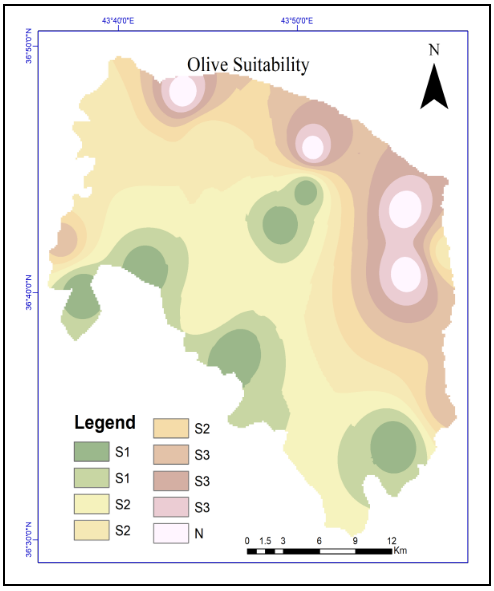

Figure 9. *Land suitability classes for olive*

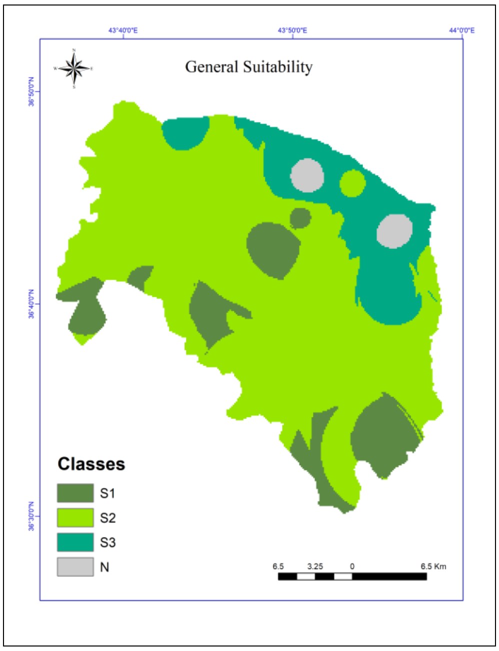

Figure 10. *General land suitability*

Table 10. *General land suitability classes and limitations*

Mapping unit	Wheat	Barley	Rice	Beans	Tomato	Lentil	Nuts	Almond	Olive
Mountain preliminaries	S3 (d)	S3 (d)	S3 (g,u)	S3 (d,a)	S3 (d,a,m,u)	S3 (d,g,a,m)	S3 (u,d,g)	S3 (d,u,a)	S3 (u,d)
Plain	S1	S1	S3(g)	S2 (a)	S3 (a,m)	S3 (g,a,m)	S2 (u)	S2 (a)	S1
Undulating plain	S2 (s)	S1	S2 (s,g,u)	S2 (a)	S3 (a,m,s)	S3 (g,s,a,m)	S2 (s,a)	S2 (a,g)	S2 (s)
Banks collapsed	S2 (d)	S2(d)	S2 (u,g)	S2 (d,a)	S3 (a,m,d)	S3 (g,d,a,m)	S2 (d,a)	S2 (d,a)	S2 (u,d)

S1, S2 and S3 are the suitability classes while d = drainage, s = slope, a = $CaCO_3$, g = rainfall, u = useful depth and m = temperature were the limitations

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The land suitability of study area for collected crops and tree were as following:

1. Class S1 (Highly Suitable): This category covers approximately 98.51 km², which is 13.76% of the total study area. These lands exhibit optimal conditions for crop and tree cultivation, with minimal limitations in terms of soil quality, climate, or water availability. Such lands are expected to provide high productivity and support sustainable agricultural practices with fewer inputs or adjustments.
2. Class S2 (Moderately Suitable): Covering 491.31 km² or 68.63% of the area, these lands are moderately suitable for cultivation. While they can still produce reasonable yields, they come with moderate limitations, such as slight soil fertility issues, water availability concerns, or climatic constraints. These limitations may require some management strategies, such as soil amendments or water conservation techniques, to achieve optimal productivity.
3. Class S3 (Low Suitability): Approximately 111.68 km² or 15.6% of the land falls into this category, which indicates poor suitability for crops and trees. Significant limitations may exist due to factors such as poor soil quality, insufficient water supply, or unfavorable climatic conditions. To make these lands productive, more intensive interventions, such as irrigation systems or soil improvement measures, would be needed, making cultivation less economically viable.
4. Class N (Not Suitable or Marginal): This class represents 14.37 km² or 2.01% of the study area. These lands are considered unsuitable for agricultural purposes due to severe limitations, such as extreme soil degradation, water scarcity, or adverse climate conditions. In such areas, conventional agricultural practices would likely be unfeasible, and alternative land uses, such as conservation efforts or non-agricultural development, might be considered.

This classification provides a critical foundation for determining land use strategies and guiding agricultural planning. It can help prioritize which areas should receive investment in agricultural development and which areas might require alternative strategies for land use to maximize sustainability and productivity.

Testing and comparison AGLA (RUNAK model)

Testing AGLA (RUNAK model)

The AGLA (RUNAK model) was tested by using three points that were chosen by Akreyi (2016). That study used a MicroLEIS model to calculate the land evaluation as it is shown (*Table 11*). The results of suitability of these data combined with climate data were extracted of the study area used in AGLA (RUNAK model) and the results are shown in *Table 12.*

Table 11. *Soil analyses of previous study. Sources: Adopted from Akreyi (2016)*

Sample code	Soil analyses								
	Slope	**Useful depth**	**Stoniness**	**Texture**	**Drainage**	**CaCo3**	**OM**	**EC**	**ESP**
S001	2	> 150	2	SiL	V. good	4	0.3	0.6	5
S034	1	100	1	CL	moderate	3	0.1	0.3	5
S062	4	53	5	SiC	bad	12	0.3	1.1	12

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Table 12. *Land suitability results by AGLA (RUNAK model)*

Sample code	Soil characteristic	Crops								
		Barley	**Bean**	**Cotton**	**Maze**	**Pepper**	**Tomato**	**Wheat**	**Citrus**	**Olive**
S001	Slope	1	1	1	1	1	1	1	1	1
	Useful depth	1	1	1	1	1	1	1	1	1
	Stoniness	1	1	1	1	1	1	1	1	1
	Texture	1	1	1	1	1	1	1	1	1
	Drainage	1	1	1	1	1	1	1	1	1
	CaCo3	1	1	1	1	1	1	1	1	1
	EC	1	1	1	1	1	1	1	1	1
	ESP	1	1	1	1	1	1	1	1	1
	Suitability	S1	S1	S1	S1	S1	S1	S1	S1	S1
S002	Slope	1	1	1	1	1	1	1	1	1
	Useful depth	1	1	1	1	1	1	1	2	2
	Stoniness	1	1	1	1	1	1	1	1	1
	Texture	1	1	1	3	1	1	1	1	1
	Drainage	2	2	2	2	2	2	2	2	2
	CaCo3	1	1	1	1	1	1	1	1	1
	EC	1	1	1	1	1	1	1	1	1
	ESP	1	1	1	1	1	1	1	1	1
	Suitability	S2d	S2d	S2d	S3tdc	S2d	S2d	S2d	S2ud	S2ud
S003	Slope	1	1	2	2	2	2	2	1	2
	Useful depth	1	1	2	2	3	3	1	4	4
	Stoniness	1	1	1	1	1	1	1	1	1
	Texture	3	3	4	1	3	1	4	2	3
	Drainage	3	3	3	3	3	3	3	3	3
	CaCo3	1	1	1	1	3	3	1	3	1
	EC	1	2	1	1	1	1	1	1	1
	ESP	1	3	1	1	1	1	1	2	1
	Suitability	S3td	S3tdep	N	S3sud	S3sutdc	S3sudc	N	N	N

S1, S2 and S3 are the suitability classes while d = drainage, s = slope, a = $CaCO_3$, g = rainfall, u = useful depth and m = temperature were the limitations

Comparison of AGLA model

Many framework approach and toolkit were built to calculate the land evaluation such us (FAO approach, LUSET Tool and MicroLEIS web. version).

Agro-Land Assessment (AGLA) was derived and developed depending FAO framework approach (FAO, 1976).

The data that analyzed by AGLA model were compared with FAO framework data and the results were completely identical. However, there was significant difference in the term of time that used in data analyzed by AGLA as it reduce the time consuming for researchers. In addition, by using AGLA model, an Excel sheet for results can be extracted and join it directly to ArcGIS program. It is worth mentioning, this feature is

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unique to AGLA model that can help the researchers to save time and obtain accurate points shapfile with results in ArcGIS program.

Agro-Land Assessment AGLA (RUNAK model) were also compared with the De la Rosa suitability model in MicroLEIS web version with the points that adopted from Akreyi (2016) from *Table 11*, as shown in *Table 13*.

Table 13. *The comparison in land suitability between AGLA and MicroLEIS*

Sample code	Factor	MicroLEIS					AGLA				
		Wheat	**Maize**	**Cotton**	**Citrus**	**Olive**	**Wheat**	**Maze**	**Cotton**	**Citrus**	**Olive**
S001	Useful depth, p	1	1	1	1	1	1	1	1	1	1
	Texture, t	2	2	1	1	1	1	1	1	1	1
	Drainage, d	1	1	1	1	1	1	1	1	1	1
	Carbonate, c	2	1	1	1	2	1	1	1	1	1
	Salinity, s	1	1	1	1	1	1	1	1	1	1
	ESP, a	1	1	2	1	1	1	1	1	1	1
	Profile development, g	1	1	1	1	1	1	1	1	1	1
	Suitability class	**S2tc**	**S2t**	**S2a**	**S1**	**S2c**	**S1**	**S1**	**S1**	**S1**	**S1**
S034	Useful depth, p	1	1	1	2	2	1	1	1	2	2
	Texture, t	1	1	2	2	2	1	1	1	1	1
	Drainage, d	1	1	1	2	2	2	2	2	2	2
	Carbonate, c	2	1	1	1	2	1	1	1	1	1
	Salinity, s	1	1	1	1	1	1	1	1	1	1
	ESP, a	1	1	2	1	1	1	1	1	1	1
	Profile development, g	1	1	1	1	1	1	1	1	1	1
	Suitability class	**S2c**	**S1**	**S2ta**	**S2ptd**	**S2ptd**	**S2d**	**S2d**	**S2d**	**S2pd**	**S2pd**
S062	Useful depth, p	2	2	3	4	4	1	2	2	4	4
	Texture, t	2	2	2	4	4	4	1	4	2	3
	Drainage, d	3	2	2	4	4	3	1	3	3	3
	Carbonate, c	1	2	2	2	1	1	3	1	3	1
	Salinity, s	1	1	1	1	1	1	1	1	1	1
	ESP, a	2	3	1	2	2	1	1	1	2	1
	Profile development, g	1	1	1	2	1	4	1	2	1	1
	Suitability class	**S3d**	**S3a**	**S3p**	**S4ptd**	**S4ptd**	**N**	**S3cp**	**N**	**N**	**N**

The land suitability comparison between the AGLA DSS and MicroLEIS, there were many significant differences in the results that change the suitability class of the land, which may be related to the criteria used for soil characteristics (chemical and physical) analyses, and the standard ranges between the two models depend on; therefore, the suitability classes show significant differences, and also MicroLEIS model humiliates the climate factors that are the main elements for crop requirements.

Discussion

Twenty profiles were dug in the study area depending on the topographical landscape which are (mountain preliminaries, plain, undulating plain and Banks

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collapsed) and some chemical and physical analyses were determined for land suitability (slope, stoniness, soil depth, texture, drainage, $CaCO_3$, EC and ESP) also some climate data were used (rainfall, temperature and humidity) of crops growing cycle. 5 crops and 3 fruits were chosen in this study depending on their cultivation in the study area

In total the mean of suitability classes for the study area were class S1: the suitable lands were 98.51 km^2 about 13.76%, Class S2: the moderate suitable lands were 491.31 km^2 about 68.63%, Class S3: the low suitable lands were 111.68 km^2 about 15.6% and Class N: non-suitable or marginal lands were 14.37 km^2 about 2.01%. The result show that the suitability class S2 for crops that have been taken in the study area were the largest area and that was mostly related to the highly contain of calcium carbonate in both soil and water, significantly effect on land suitability classes in study area that lead to several agricultural challenges, such as nutrient imbalances and reduced availability of essential nutrients. Addressing high calcium carbonate in soil requires a combination of strategies, including the addition of organic matter, soil acidification, proper fertilization, and regular soil monitoring. Over time, these methods can improve nutrient availability and overall soil health, leading to better crop growth and yield.

Land suitability results provided assessments for wide area ranges (arid, Simi-Arid, and sub-humid) of 9 different crops and trees. The comparison of the results of the Agro-Land Assessment (RUNAK suitability model) has been tested against the Food and Agriculture Organization framework for land evaluation (FAO, 1976) and the comparison were identical, but the time periods of the extracted results were very different because FAO approaches compare each crop with soil and climate analyses and that will take so much time, but using AGLA application will give the results more fast and also the results of AGLA can be joined to ArcGIS program directly as a coordinated points on the shape file.

A comparison was made with the Almagra model (Agricultural soil suitability) in the MicroLEIS DSS web version. The results were significantly different for some crops and were the same for others, and the main difference was in crop environmental requirements which were used by the Almegra model., and the results were identical, however the Runak suitability model was faster and decreased the amount of time, but the number of crops in the AGLA was less.

Conclusion

The agricultural sector in Iraq has faced a complete collapse over the past twenty years due to the events that have occurred in the region. This has significantly paralyzed agriculture, as most arable land has been left neglected and not cultivated regularly. Additionally, the lack of studies and research, along with the weakened performance of agricultural administrations, has led to a widespread reliance on traditional farming methods without an awareness of changing environmental conditions and climate change.

With the emergence of significant scientific advancements, we aimed in this research to keep pace with progress by finding quick and accurate solutions in the field of land evaluation, which is a key entry point for sound and productive agriculture. We developed a new model that meets the requirements for land evaluation, with the goal of helping researchers in this field obtain quick and accurate results. Although there are

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many other models for land evaluation, the researchers sought to distinguish this model by its ability to generate results in Excel format along with coordinates, allowing for direct integration with ArcGIS software, providing researchers with added speed and precision.

Land evaluation prominent consequence of sustainability and agroecological system specially in the new promising countries which seeks to achieve agricultural self-sufficiency. Akre district plain in Iraq is that site that the study focus on about 714.87 km^2 where it considered as a food basket for many areas. Land suitability for agriculture use is the principle base of cultivation in any area.

Twenty profiles were dug in the study area depending on the topographical landscape which are (mountain preliminaries, plain, undulating plain and Banks collapsed) and some chemical and physical analyses were determined for land suitability (slope, stoniness, soil depth, texture, drainage, $CaCO_3$, EC and ESP) also some climate data were used (rainfall, temperature and humidity) of crops growing cycle. 5 crops and 3 fruits were chosen in this study depending on their cultivation in the study area

Agro-Land Assessment (AGLA) is a new designed model that developing depending on FAO framework were built to extract the land suitability facility and accurately. The land evaluation databases and climate database were encoding by a computer C# program to a machine language system that is readable and creates land suitability, capability and degradation models, these models were subsequently transferred to an application that can be used by a PC and the results of the AGLA model (RUNAK suitability model) can be extract as a points with coordinates as Excel sheet file (.csv.MS_DOS)

A geographic information system (ArcGIS) program was used to deal with analyzed data were extract by the AGLA. Suitability classes were determined for (Wheat, Barley, Rice, Beans, Tomato, lentil, Nuts, Almond and Olive). The suitability class of mountain preliminaries: Wheat S3, Barley S3, rice N, Beans S3, Tomato S3, Lentil S3, Nuts S3, Almond S3 and Olive S3. The main problem was the poor drainage of the land, in plain land: Wheat S1, Barley S1, rice S3, Beans S2, Tomato S3, Lentil S3, Nuts S2, Almond S2 and Olive S1, the main problem was $CaCO_3$ high contain, in undulating plain: Wheat S2, Barley S1, rice S2, Beans S2, Tomato S3, Lentil S3, Nuts S2, Almond S2 and Olive S2 also the problem was $CaCO_3$ contain, in Banks collapsed Wheat S2, Barley S2, rice S2, Beans S2, Tomato S3, Lentil S3, Nuts S2, Almond S2 and Olive S2 and the main problem was $CaCO_3$ contain.

In total the mean of suitability classes for the study area were class S1: the suitable lands were 98.51 km^2 about 13.76%, Class S2: the moderate suitable lands were 491.31 km^2 about 68.63%, Class S3: the low suitable lands were 111.68 km^2 about 15.6% and Class N: non-suitable or marginal lands were 14.37 km^2 about 2.01%

Land suitability results provided assessments for wide area ranges (arid, Simi-Arid, and sub-humid) of 12 different crops and trees. The results was identical to those of the FAO, but the time periods of the extracted results were very different. A comparison was made with the Almagra model (Agricultural soil suitability) in the MicroLEIS DSS web version. The results were significantly different for some crops and were the same for others, and the main difference was in crop environmental requirements which were used by the Almegra model. The model has also been tested against the Food and Agriculture Organization framework for land evaluation (FAO, 1976), and the results were identical, however the Runak suitability model was faster and decreased the amount of time, but the number of crops in the AGLA was less.

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Overall, this research is considered the foundation for establishing a land evaluation database and assessing the suitability of agricultural crops within specific regions according to their climatic conditions and soil compatibility. The ultimate goal is to achieve agricultural sustainability and self-sufficiency.

Farther in future land suitability for these promising lands and also for more different crops should be considered to get to the sustainability self-sufficiency using technology in agriculture, and also the authors prepared two other models (land capability and land degradation) that combine to AGLA.

Author contributions. Methodology, Pearis Majeed; data curation, Pearis Majeed; writing, Pearis Majeed; Writing—review and editing, Salih Aydemir; Ali Volkan Bilgili and Pearis Majeed; supervision, Salih Aydemir, Ali Volkan Bilgili. All authors have read and agreed to the published version of the manuscript.

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Data availability statement. The Landsat 8 OLI satellite image is publicly available and can be downloaded from the official websites: https://earthexplorer.usgs.gov / (accessed on 14 April 2023).

Application availability. The program will be available online after the publication of the research to ensure the intellectual property rights of the researchers.

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APPENDIX

Soil chemical and physical properties

Table A1. *$CaCO_3$, O.M, CEC, ESP and available macro nutrients of the studied soil profiles*

Mapping unit	Pro No.	Depth (cm)	$CaCO_3$ %	O.M %	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
							N	P	K
Preliminaries mountain	1	0 - 30	18.72	1.65	20.37	0.98	6.50	7.30	71.80
		30 - 70	21.78	0.16	14.87	0.97	4.60	4.10	67.80
	Water table								
	14	0 - 30	28.10	1.71	18.04	1.11	112.00	8.77	80.46
		30 - 65	18.75	0.07	13.72	1.17	95.67	6.76	94.23
		65 - 90	22.65	0.03	10.63	1.16	87.53	6.01	95.54
	15	0 - 25	11.67	0.42	17.65	1.66	93.23	11.54	93.73
		25 - 70	13.21	0.12	15.52	1.32	73.26	9.93	98.05
		70 - 85	14.14	0.09	12.70	1.18	58.72	6.58	101.57
Plain	2	0 - 30	8.38	0.35	31.53	1.14	140.00	12.67	58.69
		30 - 85	9.54	0.12	18.34	1.10	102.51	9.62	67.83
		85 - 150	9.56	0.10	13.21	1.10	77.27	8.71	81.19
	3	0 - 25	6.47	0.43	17.32	1.13	112.45	7.66	49.63
		25 - 80	6.87	0.18	15.51	0.98	99.14	5.21	52.61
		80 120	5.93	0.10	10.62	1.10	60.34	2.45	73.67
	7	0 - 30	22.00	0.72	17.67	1.34	172.14	8.54	54.67
		30 - 85	21.65	0.21	13.65	1.13	166.12	5.55	65.44
		85 - 140	18.27	0.14	13.10	1.12	141.76	5.12	70.08
	8	0 - 25	17.27	0.42	14.82	0.94	121.52	7.16	39.86
		25 - 75	16.67	0.18	10.46	0.97	100.31	6.82	41.29
		75 - 130	18.32	0.11	8.34	0.89	67.39	6.17	42.07
	13	0 - 30	21.20	0.11	18.32	1.21	189.56	8.06	88.53
		30 - 80	23.41	0.06	16.13	1.16	177.45	7.45	92.76
		80 - 150	23.40	0.02	10.54	1.15	172.32	6.61	99.25
Undulating plains	4	0 - 30	21.61	1.86	21.57	1.01	185.53	9.41	86.74
		30 - 75	24.51	0.62	17.21	0.95	137.24	7.46	99.26
		75 - 110	21.78	0.17	12.56	0.95	111.51	6.63	93.61
	6	0 - 30	16.41	0.19	15.62	1.21	186.31	10.31	77.83
		30 - 80	17.54	0.08	12.76	0.98	165.46	9.83	84.21
		80 - 150	22.23	0.10	9.83	1.03	138.18	7.32	83.41
	11	0 - 30	12.21	0.22	16.47	4.55	89.83	14.17	92.58
		30 - 75	15.63	0.14	11.62	1.67	66.35	10.62	89.61
		75 - 150	15.61	0.10	9.06	1.43	50.04	7.71	97.82
	16	0 - 30	20.00	0.21	23.14	0.82	112.30	10.34	110.65
		30 - 75	21.06	0.11	19.47	0.93	89.65	8.83	121.60
		75 - 135	20.32	0.04	14.53	0.88	68.47	6.03	122.76
	19	0 - 25	21.45	0.15	22.41	1.45	189.43	12.72	122.75
		25 - 90	19.62	0.02	19.71	0.99	172.64	9.90	131.62
		90 - 150	15.71	0.01	13.63	0.93	155.41	7.31	134.21
	20	0 - 30	18.76	0.31	18.86	2.20	194.21	12.56	100.38
		30 - 80	20.29	0.14	14.59	1.87	174.71	10.53	107.64
		80 - 150	22.18	0.10	11.12	1.14	157.38	7.82	111.00

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Mapping unit	Pro No.	Depth (cm)	$CaCO_3$ %	O.M %	CEC (Cmol (c)/kg)	ESP %	Available macro nutrients (mg/kg)		
							N	P	K
Banks collapsed	5	0 - 25	18.52	0.35	18.62	0.94	126.32	8.33	45.63
		25 - 70	18.82	0.17	13.40	0.95	112.14	8.38	49.32
		70 - 90	18.79	0.10	11.52	0.91	91.05	7.72	47.52
	9	0 - 30	19.43	0.47	21.67	0.86	102.10	9.21	102.12
		30 - 90	21.28	0.16	17.51	0.88	88.23	8.14	103.10
		90 - 150	21.21	0.10	12.82	0.80	71.12	6.41	92.54
	10	0 - 25	18.45	0.34	23.43	1.42	89.93	11.62	79.34
		25 - 65	19.34	0.14	18.67	0.96	67.31	9.42	82.14
		65 - 95	21.50	0.06	12.71	0.95	44.17	6.45	88.62
	12	0 - 30	19.45	0.19	21.60	2.12	100.20	11.41	66.82
		30 - 70	18.42	0.07	16.72	1.87	82.76	8.34	74.18
		70 - 100	20.61	0.03	11.36	1.23	52.69	4.07	76.06
	17	0 - 30	21.13	0.16	18.45	0.93	101.60	12.73	87.54
		30 - 75	19.83	0.05	16.41	0.97	92.23	9.65	88.43
		75 - 105	19.80	0.05	12.68	0.89	65.87	6.82	93.31
	18	0 - 30	18.65	0.20	17.48	2.11	95.78	9.43	87.09
		30 - 90	18.54	0.12	12.85	1.87	78.69	6.30	96.00
		90 - 150	18.32	0.10	11.61	1.32	54.19	5.52	101.54

Table A2. *Total soluble salts (ECe), soluble cations and anions and pH of the samples from the soil profiles*

Mapping unit	Pro No.	Depth (cm)	pH	EC	Soluble cations and anions (meq/l)						
				dS/m	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	$SO4^{2-}$
Preliminaries mountain	1	0 - 30	7.43	0.21	28.16	14.51	1.35	8.37	31.12	20.12	1.147
		30 - 70	7.5	0.19	30.167	18.54	1.153	7.642	32.894	23.472	1.138
	Water table										
	14	0 - 30	7.42	0.31	23.869	16.672	2.631	2.946	26.211	18.326	1.582
		30 - 65	8.04	0.23	25.511	14.367	1.744	3.02	23.629	19.18	1.832
		65 - 90	7.12	0.17	23.551	12.428	1.932	3.62	24.147	15.83	1.553
	15	0 - 25	8.14	0.17	36.134	9.015	1.46	5.512	31.462	19.766	0.892
		25 - 70	8.21	0.14	35.156	8.211	1.422	4.58	30.732	17.73	0.921
		70 - 85	8.02	0.13	37.512	9.36	0.838	3.18	34.159	15.735	0.984
Plain	2	0 - 30	7.8	0.33	30.58	16.02	0.681	5.59	28.34	23.25	1.28
		30 - 85	7.83	0.23	35.521	11.234	0.648	4.32	30.374	19.521	1.83
		85 - 150	7.34	0.22	31.322	11.467	0.732	3.178	25.882	19.212	1.603
	3	0 - 25	8.1	0.46	17.41	10.78	1.54	3.64	18.34	14.57	0.46
		25 - 80	8.03	0.25	22.611	9.41	1.021	4.127	21.921	13.258	1.989
		80 120	7.92	0.16	21.653	10.321	0.841	3.722	21.633	12.994	1.91
	7	0 - 30	7.89	0.33	21.663	11.955	1.372	4.541	22.418	16.23	0.883
		30 - 85	7.63	0.24	27.471	13.512	1.12	3.621	26.323	17.83	1.571
		85 - 140	7.33	0.18	32.562	12.5	1.053	5.358	29.865	19.837	1.784
	8	0 - 25	8.23	0.27	19.63	11.152	1.27	3.19	17.31	15.27	2.66
		25 - 75	8.12	0.17	21.423	11.712	1.105	4.643	19.635	17.412	1.834
		75 - 130	8.12	0.16	22.468	12.259	1.043	4.113	20.744	18.146	0.993
	13	0 - 30	8.1	0.16	27.734	10.824	1.742	3.923	23.461	18.62	2.14
		30 - 80	7.98	0.12	27.862	12.521	1.15	4.067	25.932	18.326	1.343
		80 - 150	8	0.13	30.756	11.189	1.145	4.125	26.173	19.832	1.212

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Mapping unit	Pro No.	Depth (cm)	pH	EC	Soluble cations and anions (meq/l)						
				dS/m	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	$SO4^{2-}$
Undulating plains	4	0 - 30	8.16	0.34	33.16	7.046	1.334	3.6	27.31	17.312	0.52
		30 - 75	8.2	0.22	31.642	9.532	1.043	4.671	29.641	16.2	1.05
		75 - 110	8.12	0.13	28.537	9.378	0.931	3.844	30.734	11.015	0.942
	6	0 - 30	8.02	0.22	30.225	15.142	1.46	2.31	27.54	20.175	1.42
		30 - 80	8.1	0.23	30.562	14.371	1.213	4.783	28.371	21.333	1.225
		80 - 150	8	0.16	34.467	16.213	0.953	5.032	29.645	25.328	1.69
	11	0 - 30	8.12	0.34	30.04	9.479	1.521	3.567	25.933	17.22	1.452
		30 - 75	7.94	0.35	33.562	10.603	1.469	4.275	28.267	19.976	1.667
		75 - 150	8.06	0.24	36.188	11.126	1.321	4.683	30.432	21.531	1.355
	16	0 - 30	8.04	0.13	36.134	9.415	1.46	5.552	31.462	19.73	1.371
		30 - 75	7.93	0.14	34.541	11.622	1.621	4.276	32.122	17.821	2.116
		75 - 135	7.91	0.13	37.067	11.452	1.548	4.457	32.752	19.891	1.882
	19	0 - 25	8.12	0.15	41.541	8.842	2.21	4.683	33.582	21.833	1.862
		25 - 90	8.16	0.15	38.366	10.261	2.032	4.261	32.512	20.673	1.734
		90 - 150	8.09	0.12	38.523	9.542	1.943	4.034	33.267	19.112	1.663
	20	0 - 30	7.89	0.17	33.783	10.033	1.351	4.622	28.745	19.411	1.633
		30 - 80	7.94	0.15	35.332	11.681	1.165	4.455	30.032	21.215	1.386
		80 - 150	7.77	0.16	41.667	13.822	1.032	4.321	36.782	23	1.061
Banks collapsed	5	0 - 25	8.24	0.32	26.61	6.56	2.21	1.12	21.53	14.26	0.71
		25 - 70	8.04	0.21	29.234	8.521	1.783	3.511	24.167	17.543	1.338
		70 - 90	7.82	0.2	33.562	9.156	1.342	3.557	27.332	18.784	1.5
	9	0 - 30	8.04	0.14	24.71	12.328	2.132	4.421	22.452	19.21	1.93
		30 - 90	8.1	0.12	28.647	10.476	1.578	4.43	27.574	16.247	1.31
		90 - 150	8.03	0.12	31.358	11.054	1.243	3.865	29.631	15.983	1.904
	10	0 - 25	7.91	0.16	38.213	9.411	1.64	4.752	31.37	20.232	2.414
		25 - 65	7.45	0.16	39.453	11.267	1.107	4.332	34.471	20.002	1.685
		65 - 95	7.51	0.15	43	11.664	1.121	4.121	37.864	21.041	1
	12	0 - 30	7.65	0.21	26.256	8.642	1.17	4.322	18.458	20.71	1.221
		30 - 70	7.43	0.22	28.547	10.611	1.452	4.783	23.731	20.326	1.334
		70 - 100	7.2	0.17	31.622	11.936	1.164	4.009	25.569	22.153	1.01
	17	0 - 30	7.47	0.16	31.842	10.371	1.034	3.633	28.457	17.212	1.21
		30 - 75	7.53	0.15	34.832	10.662	1.111	4.488	28.944	20.843	1.304
		75 - 105	7.6	0.17	34.334	11.051	1.14	4.213	27.675	21.941	1.121
	18	0 - 30	7.74	0.16	27.672	10.849	1.561	4.471	23.642	19.583	1.327
		30 - 90	8	0.14	27.651	11.373	1.256	3.572	26.417	16.251	1.185
		90 - 150	7.65	0.11	29.431	12.362	1.15	4.644	28.482	17.835	1.27

Table A3. *Particle size distribution of the studied soil profiles*

Mapping unit	Pro No.	Depth (cm)	Stoniness %	Gravels %	Sand %	Silt %	Clay %	Texture class	Bulk density
Preliminaries mountain	1	0 - 30	6.00	2.00	45.88	15.68	38.44	SC	1.21
		30 - 70	2.00	1.00	40.52	23.32	36.16	CL	1.26
	70 -		**Water table**						
	14	0 - 30	2.50	4.00	49.55	21.22	29.23	SCL	1.36
		30 - 65	1.00	2.00	39.54	25.28	35.19	CL	1.26
		65 - 90	0.40	1.00	35.45	28.53	36.02	CL	1.25
	15	0 - 25	4.00	2.00	51.00	18.43	30.57	SCL	1.31
		25 - 70	1.00	1.00	39.73	22.72	37.55	CL	1.26
		70 - 85	0.20	0.40	33.32	25.82	40.86	C	1.18

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Mapping unit	Pro No.	Depth (cm)	Stoniness %	Gravels %	Sand %	Silt %	Clay %	Texture class	Bulk density
Plain	2	0 - 30	4.00	4.00	39.68	31.18	29.14	CL	1.23
		30 - 85	1.00	2.00	31.44	36.32	32.24	CL	1.23
		85 - 150	0.20	0.70	30.22	37.42	32.36	CL	1.24
	3	0 - 25	2.00	8.00	42.96	19.44	37.60	CL	1.23
		25 - 80	0.30	3.20	33.29	28.24	38.47	CL	1.24
		80 120	0.10	2.20	34.62	33.21	32.17	CL	1.24
	7	0 - 30	2.20	7.00	46.33	17.82	35.85	SC	1.20
		30 - 85	1.00	3.70	39.75	22.68	37.57	CL	1.25
		85 - 140	0.40	1.25	33.46	27.84	38.70	CL	1.25
	8	0 - 25	1.00	10.00	61.52	14.16	24.32	SCL	1.36
		25 - 75	0.12	6.40	47.26	19.66	33.08	SCL	1.33
		75 - 130	0.00	1.56	39.51	21.68	38.81	CL	1.27
	13	0 - 30	3.00	12.00	59.37	17.69	22.94	SCL	1.37
		30 - 80	0.70	5.72	47.44	20.56	32.00	SCL	1.36
		80 - 150	1.00	2.58	40.26	26.72	33.02	CL	1.31
Undulating plains	4	0 - 30	1.00	5.00	40.24	23.08	36.68	CL	1.23
		30 - 75	0.06	2.00	36.46	26.34	37.20	CL	1.25
		75 - 110	0.00	1.20	32.61	29.52	37.87	CL	1.27
	6	0 - 30	2.00	3.00	52.61	20.22	27.17	SCL	1.34
		30 - 80	0.30	1.40	44.56	26.17	29.27	CL	1.26
		80 - 150	0.06	1.00	37.27	30.52	32.21	CL	1.25
	11	0 - 30	2.00	16.00	50.18	33.26	16.56	L	1.33
		30 - 75	0.60	7.63	42.62	36.67	20.71	L	1.30
		75 - 150	0.20	4.37	38.53	37.05	24.42	L	1.29
	16	0 - 30	2.00	2.00	47.21	22.46	30.33	SCL	1.31
		30 - 75	1.10	1.30	38.46	25.43	36.11	CL	1.27
		75 - 135	0.60	0.70	33.58	30.39	36.03	CL	1.27
	19	0 - 25	1.00	5.00	55.58	20.06	24.36	SCL	1.36
		25 - 90	0.60	2.00	43.27	23.33	33.41	CL	1.32
		90 - 150	0.20	2.10	37.53	25.63	36.84	CL	1.34
	20	0 - 30	0.50	2.00	51.75	19.52	28.73	SCL	1.35
		30 - 80	0.00	1.00	44.52	22.45	33.03	CL	1.28
		80 - 150	0.40	1.00	41.72	27.58	30.70	CL	1.28
Banks collapsed	5	0 - 25	0.50	2.00	33.83	31.77	34.40	CL	1.26
		25 - 70	0.00	1.00	30.41	35.56	34.03	CL	1.25
		70 - 90	0.00	0.40	27.73	38.34	33.93	CL	1.23
	9	0 - 30	0.40	17.00	54.23	18.61	27.16	SCL	1.31
		30 - 90	0.00	9.35	41.67	23.15	35.18	CL	1.26
		90 - 150	1.00	4.35	35.34	28.43	36.24	CL	1.27
	10	0 - 25	0.70	4.00	40.72	23.71	35.57	CL	1.27
		25 - 65	0.20	2.40	32.45	29.53	38.02	CL	1.24
		65 - 95	0.06	1.00	30.51	34.57	34.92	CL	1.27
	12	0 - 30	1.00	2.00	44.78	37.62	17.60	L	1.32
		30 - 70	0.00	1.30	37.62	41.73	20.65	L	1.34
		70 - 100	0.10	1.00	34.62	43.26	22.12	L	1.32
	17	0 - 30	0.60	4.00	55.18	31.62	13.20	SL	1.48
		30 - 75	0.10	2.20	45.35	35.61	19.04	L	1.33
		75 - 105	0.00	1.60	42.15	36.62	21.23	L	1.34
	18	0 - 30	2.00	8.00	51.67	20.38	27.95	SCL	1.34
		30 - 90	1.00	3.30	43.61	26.42	29.97	CL	1.26
		90 - 150	1.00	1.67	37.85	26.82	35.33	CL	1.25

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Report

Runak Suitability Model Result

Soil Unit: P1

Crop Type: Annual

Land suitability classes									
Code	**Barley**	**Bean**	**Cotton**	**Maize**	**Pepper**	**Tobacoo**	**Tomato**	**Wheat**	**Lentil**
Slope ,s	1	1	1	1	1	1	1	1	1
Depth/CM ,u	1	1	1	1	1	1	1	1	1
Stonnines ,o	1	1	1	1	1	1	1	1	1
Texture ,t	1	1	1	1	3	1	1	1	1
Drainge ,d	1	1	1	1	1	1	1	1	1
CaCo3 ,a	1	1	1	1	2	3	2	1	1
EC ds ,e	1	1	1	1	1	1	1	1	1
ESP ,p	1	1	1	1	1	1	1	1	1
P of gc ,g	1	1	3	1	2	2	1	1	3
Temp./gc ,m	1	1	3	1	1	2	1	1	2
Rh ,h	1	1	1	1	2	1	1	1	1
Suitability class	S1	S1	S3={g,m}	S1	S3={t,a,g,h}	S3={a,g,m}	S2={a}	S1	S3={g,m}

Land suitability classes	Subclasses: Limitation factors	
Class S1 = suitable	s = slope	e = EC
Class S2 = moderate suitable	u = useful depth	p = ESP
Class S3 = low suitable	o = stoniness	g = precipitation of growing cycle
Class N = non-suitable (marginal)	t = texture	m = mean temperature of growing cycle
	d = drainage	h = humidity
	a = CaCo3	

***Figure A1.** RUNAK suitability model results*

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