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GIS and AHP Based Techniques for Agricultural Land Suitability Assessment in Erbil Province, Kurdistan region, Iraq

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Abstract: The study area comprises Erbil province, Kurdistan region, Iraq. Thirty-five soil samples have been taken from different districts. Several soil analyses have been performed in order to find soil loss as a criterion for land suitability assessment. The other criteria were elevation, slope, aspect ratio, and land use and land cover (LULC). All used criteria have been weighted using Analytic Hierarchy Process (AHP) methodology to find their priorities in order to use them on weighted overlay methodology (WOM) based on the Geographical Information Systems (GIS) technique. Integration of AHP and GIS have been utilized in purpose to find the land suitability based on five classes; high suitable (S1), moderately suitable (S2), marginally suitable (S3), not suitable (N1), and not suitable permanently (N2). The result of land suitability shows that the S1 class is generally located at the northwest of the middle part in the study area extended to the southwest, and it occupies an area of 1243.94 km^2 (8.61%). The S2 class occupies a minimum area of 85.52 km^2 (0.59%), while the S3 class occupies a massive area relatively about 4886.75 km^2 (33.82%). The N1 class occupies the highest area, around 6538.32 km^2 (45.26%). At the same time, N2 class takes 1693.16 km^2 (11.72%). Both N1 and N2 have an area of 8,231 km^2 (56.98%) of the total area while S1, S2, and S3, which takes only 6,216 km^2 (43.02%).In this study we found the possibility of using GIS and AHP in order to find the land suitability assessment.
Keywords: Land suitability, GIS, AHP, Weighted overlay.

Introduction

Due to rapid population increase and urban expansion, land has become a relatively scarce commodity for agricultural and rangeland purposes, the demand for optimal land use is higher than ever. As a result, a growing needs to match land capacities and land uses in the most sensible way feasible. Sustainable agricultural growth is a top priority for every country on the planet. The overall goal of sustainable agriculture is to balance the inherent land resource with crop requirements, with specific emphasis paid to resource optimization in order to ensure long-term production (Ullah & Mansourian, 2016). In land suitability evaluation, a geographic information system (GIS) is a helpful tool for investigating different geographical data with precision and greater flexibility (Mendas & Delali, 2012). GIS is the best, accurate, and flexible approach for investigating geospatial data in land suitability researches, and for land evaluation and proper land use decisions, the multi-criteria decision-making method and GIS have been combined (Malczewski, 2006). Land Suitability Analysis is a GIS-based technique that is using to assess land suitability. In addition, this analysis considers a number of factors, including environmental and socio-economic. By evaluating land's inherent and prospective capabilities for desired purposes (Bandyopadhyay *et al.*, 2009), land suitability analysis may assist create methods to enhance agricultural production (Pramanik, 2016). It can also assist in the diagnosis of priority locations for possible management. The analytical hierarchy process (AHP) technique that developed by Saaty (2004), with the integration of remote sensing (RS) and GIS. These techniques have been utilized for land suitability analysis on different studies around the world for both of general agricultural land suitability analysis and for specific crops as well (Chandio *et al*., 2011; Akıncı *et al*., 2013; Zhang *et al*., 2015; Pramanik, 2016; Yalew *et al*., 2016; Bozdağ *et al*., 2016; Aburas *et al*., 2017; Roy & Saha, 2018; Dedeoğlu & Dengiz, 2019; Tashayo *et al*., 2020).

Iraq has soils that are markedly different from each other because of differences in soil-forming factors. In general, the degree of soil development decreases from northern to southern Iraq (Muhaimeed *et al*., 2014). Iraq has grown to be a major importer and consumer of agricultural products, including wheat and rice, as well as vegetables and fruits. As a result, land use planning is becoming increasingly important in order to support local agricultural sectors (Al-Quraishi *et al.*, 2019). The aim of determining land suitability in this study is to generate a general suitability map for agriculture depending on general criteria without focusing on a specific crop, which is called qualitative classification for land suitability (FAO, 1976).

Materials & Methods

Study area, field work, and soil samples preparation

The study area comprises Erbil province, Kurdistan region, Iraq with an area of 14447.69 km^2, and the geographical position extends from Latitude 35.436151N to 37.319894N and from Longitude 43.374316E to 45.080122E (Fig. 1). Thirty-five surface soil samples have been taken depending on the latitude and longitude, determining their elevation in October and November of 2019 (table 1). All the collected samples were air-dried, crushed, and sieved with a 2 mm sieve after that kept in containers for physical and chemical analyses. The average yearly rainfall amount for 15 years (2006- 2020) was (1390.1, 635.5, 776.4, 740.8, 376.6, 538.6, and 240.6) mm in the districts of Mergasor, Soran, Choman, Shaqlawa, Erbil city, Koya, and Makhmour, respectively. The average yearly temperature for 10 years (2010- 2019) was (15.7, 18.3, 15.3, 17.7, 21.1, 22.1, and 24.1) C^o in the previous locations, respectively (Erbil meteorological station).

Laboratory Analyses

Soil texture was specified depending on the particles size distribution (PSD) analysis by hydrometer method as described by (Gee & Bauder, 1986). Very fine sand was determined depending on (Gee & Bauder, 1986). Soil organic matter (OM) was determined by wet combustion using potassium dichromate as an oxidizing agent (Issam & Antoine, 2007). The results of all these analyses have been used in order to find soil loss magnitude in the study area through the methodology proposed by Wischmeier & Smith (1965).

Table (1): Soil sample locations with their elevations.

Samples number	Latitude	Longitude	Elevation (m)	Samples number	Latitude	Longitude	Elevation (m)
1	36.98104584	44.19267020	967	19	36.29103118	43.94091382	378
2	36.94037328	44.23055869	774	20	36.34679902	43.88573304	364
3	36.94893612	44.27985398	791	21	36.29939258	43.84659516	327
4	36.89350598	44.24739102	976	22	36.02616200	43.93549720	344
5	36.88537887	44.21119003	1172	23	36.07470069	44.04217607	424
6	36.83965676	44.31146279	1053	24	35.95973257	44.06343825	409
7	36.65454774	44.49069914	639	25	36.07792386	44.64785136	555
8	36.68163623	44.51963040	653	26	36.06762724	44.69608536	646
9	36.57323175	44.55186345	798	27	36.05688970	44.63761797	527
10	36.59539415	44.52521242	709	28	36.13127258	44.41250071	687
11	36.64984529	44.86318486	1449	29	36.10281531	44.46813481	640
12	36.62595356	44.89485090	1217	30	36.11783760	44.43695030	681
13	36.58431715	44.81135726	948	31	35.79955380	43.58373845	274
14	36.61873091	44.82319260	1130	32	35.75867203	43.50828672	249
15	36.38267142	44.29594564	971	33	35.79604209	43.50641127	250
16	36.38825171	44.24909792	810	34	36.13009513	43.69103628	271
17	36.46861684	44.21907430	739	35	36.12111787	43.62334132	250
18	36.43560366	44.25221186	850				

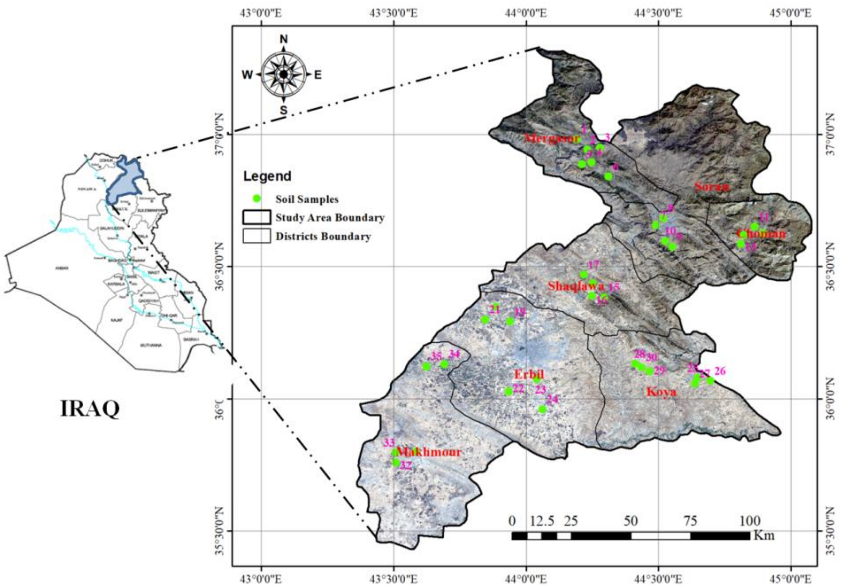

Fig. (1): Map of the study area and the soil samples locations

Remotely Sensed Dataset

A mosaic of two Landsat 8 (Operational Land Imager OLI / Thermal Infrared Sensor TIRS) images have been used for this study (path 169/row 034) and (path 169/row 035), both acquired on 6/10/2019 and they are free of clouds. The images have been downloaded from https://glovis.usgs.gov/. The mosaic of these images has been used to generate land use and land cover (LULC) of the study area using unsupervised classification with supporting field observation information during field works. Geometric correction, which comprises the operations of geo-referencing using a rectification methodology. This is a required step to ensure the exact placing of an image. Moreover, atmospheric correction performed to reduce the impact of earth atmosphere on the satellite image. For this purpose the digital number (DN) should converted to the top of atmosphere (TOA) reflectance, then, finding a correct sun angle.

Additionally, a mosaic of two Shuttle Radar Topography Mission (SRTM) 1 arc-second Digital Elevation Model (DEM) has been used, and these images are downloaded from https://remotepixel.ca/. The DEM raster dataset of the study area was used to confirm the elevations and slopes values that have been taken during field works of each soil samples locations with the DN values. In addition, the values of all generated maps have been extracted, for this purpose, the Extraction function has been utilized using ArcGIS 10.7 version software. The Extraction function is an integrated function in ArcGIS 10.7 version software and it is specifically designed to take the values from maps depending on the selected points that will be defined by users.

Soil Loss Estimation

The GIS technique has been applied on the Revised Universal Soil Loss Equation (RUSLE) which was developed by (Wischmeier & Smith, 1965) to generate the final interpolated map for determines the soil loss and estimate soil erosion intensity in the study area. A Geodatabase has been created using ArcMap environment to obtain and drawing the final map for the soil loss. The interpolated map was produced for soil loss changes as measured interpolated map using the ArcMap environment.

The Geostatistical Analyst has been used based on Kriging/CoKriging method ("Ordinary" type) as a method for generating the interpolated map. A Kriged estimate is a weighted linear combination of the known sample values around the point to be estimated (Lang, 2009). The accuracy of the interpolated map in this study has been determined using Root Mean Square (RMS). The RMS has been extracted from Cross-Validation/Prediction Errors in the final step of interpolation process using ArcMap environment. In order to illustrate the accuracy of the generated interpolated map, the RMS has been written beside the name of interpolated map.

Land Suitability Analysis

A land suitability map has been generated for the study area using elevation, slope, aspect ratio, soil loss, and land use-land cover (LULC) as criteria for determining land suitability classes according to (FAO, 1976).

Elevation

The elevation values have been used depending on the values that taken form the DEM image. All the values picked from the DEM using Extraction function through ArcGIS 10.7 for all the sample locations.

Slope

The slope map has been generated using 3D Analyst Tools through ArcGIS 10.7. Then, all values have been extracted according to the sample locations using ArcGIS 10.7.

Aspect ratio

As one of the variables that can be derived from the DEM image, the aspect ratio map produced using 3D Analyst Tools and all the values of soil samples picked by Extraction function through ArcGIS 10.7.

LULC

The LULC for the study area have been recorded during the field observation for all sample locations. In order to separate the different features in the study area image the Iso Cluster unsupervised classification has been created using a mosaic of two Landsat 8 images using ArcMap 10.7 software. Additionally, for labeling each class in the output of unsupervised image, a side-by-side comparison between original Landsat 8 image and unsupervised image has been done. Focusing on the several different areas with a various land cover to make a better representative classification for unsupervised image. This map has been used to confirm the observations that taken previously for each location. In addition, several locations have been selected as a result validation points to ensure the result of the LULC map.

Soil loss

The soil loss calculated using RUSLE equation, then based on the result of it the final soil loss map has been generated for the entire study area. Many factors or criteria should take into consideration in order to evaluate lands that call quantitative classification. In this study a qualitative classification has been adopted (not quantitative that is usually using for small areas) which is suitable for large areas and for general agricultural idea about an area (FAO, 1976). As well as, Sys *et al.* (1991) mentioned that in order to find land suitability for any area all used criteria with their classes and limits can be utilized in term of specific crop (quantitative) and as a general idea (qualitative). Therefore, based on FAO (1976) and Sys *et al.* (1991) that have been used as a guidelines for selecting the land suitability criteria in this study.

Many researchers have been used topographic variables, soil loss and LULC to calculate the land suitability (Burrough *et al*., 1992; Overmars & Verburg, 2007; Perveen *et al*., 2007; Akıncı *et al*., 2013; Baja *et al*., 2014; Yalew *et al*., 2016; Vasu *et al*., 2018; Mazahreh *et al*., 2019).

All studied criteria have their own importance and effects. Besides it, not all criteria are equally important at the same time. Therefore, the relative priorities (weights) for all criteria should be determined. It is called relative due to the obtained criteria priorities are measured according to each other. The best methodology for decision-making and to determine the weights for the criteria is AHP (Mu & Pereyra-Rojas, 2017). Determination of the weights of each criterion is important because it is necessary for producing suitability map for the study area by using Weighted Overlay Methodology (WOM) in the ArcMap environment.

AHP

The AHP has been used for determining the weights for each criterion. For this purpose, the following steps applied based on the methodology proposed by (Mu & Pereyra-Rojas, 2017):

Developing a Model for AHP

The first step for an AHP analysis is to build a model (Fig. 2), which determines the three levels of the model including GOAL, CRITERIA, and ALTERNATIVES. In the first level (GOAL) which is the land suitability classification for this study, while in the second level (CRITERIA) the factors or criteria that are influencing land suitability. Third level (ALTERNATIVES) including the types of land suitability (S1, S2, S3, N1, and N2).

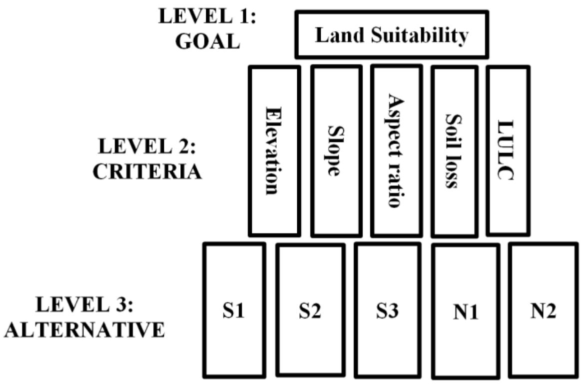

Fig. (2): The analytic hierarchy process (AHP) model.

Deriving Priorities (Weights) for the Criteria

As mentioned in the Land Suitability section, that not all criteria have the same importance. Therefore, in this step of AHP, the relative priorities for each criterion will be calculated. For this purpose, pairwise comparisons will be generated for criteria according to the methodology developed by Saaty (2004). Each criterion should take a value from table (2) when making a pairwise comparison. A pair from criteria takes value to make this comparison of each criterion separately. For instance, elevation is less important than slope or slope is more important for land suitability than elevation. Therefore, elevation takes 6 (Very strongly more important) and slope takes 9 (Extremely important) from table (2). For that reason, the intersection of row and column in table (3) between elevation and slope is 6/9 (elevation/slope = 6/9) that is the ratio of importance between this pair of criteria. It means that elevation is 4.5 times less important than slope or slope is 4.5 times more important than elevation as written in the intersection of slope-elevation, which is 9/6 (slope/elevation = 9/6) which can call the reciprocal comparison. The ratios in table (3) will continue in table (4) with the total of each column.

The next step is to obtain the normalized pairwise values for table (4), which are performed by dividing each value in a single column to the same column summation as shown in table (5). Then, the average of each row is calculated to obtain the priorities or weights of each criterion as shown in table (6). At this step, weights of all factors or criteria have been calculated, ranged between 0 to 1 and their summation is equal to 1 (Malczewski, 1999). Multiplying each of them by 100 to obtain a percentage value of them becomes ready to use for generating the land suitability map.

Table (2): Pairwise comparison scale as Satty (2004).

Verbal judgment	Numeric value
Extremely important	9
	8
Very strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

Table (3): Pairwise comparison matrix of criteria for land suitability.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC
Elevation	1	6/9	6/3	6/9	6/9
Slope	9/6	1	9/3	9/9	9/9
Aspect ratio	3/6	4/9	1	4/9	4/9
Soil loss	9/6	9/9	9/3	1	9/9
LULC	9/6	9/9	9/3	9/9	1

Table (4): Pairwise comparison continued.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC
Elevation	1.000	0.666	2.000	0.666	0.666
Slope	1.500	1.000	3.000	1.000	1.000
Aspect ratio	0.500	0.444	1.000	0.444	0.444
Soil loss	1.500	1.000	3.000	1.000	1.000
LULC	1.500	1.000	3.000	1.000	1.000
SUM	1.000	0.666	2.000	0.666	0.666

Table (5): Normalized pairwise.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC
Elevation	0.189	0.233	0.233	0.233	0.259
Slope	0.243	0.300	0.300	0.300	0.333
Aspect ratio	0.081	0.100	0.100	0.100	0.111
Soil loss	0.243	0.300	0.300	0.300	0.333
LULC	0.243	0.300	0.300	0.300	0.333

Table (6): Calculation of weights.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC	Criteria weights
Elevation	0.189	0.189	0.189	0.189	0.189	0.164
Slope	0.243	0.243	0.243	0.243	0.243	0.246
Aspect ratio	0.081	0.081	0.081	0.081	0.081	0.098
Soil loss	0.243	0.243	0.243	0.243	0.243	0.246
LULC	0.243	0.243	0.243	0.243	0.243	0.246

Check the consistency

The third step is to check the consistency of calculated weight values, because it is necessary to check if they are consistent. For this purpose, the consistency index (CI) should be calculated from Eq. (1).

$$CI = (\lambda_{MAX} - n)/(n - 1) \qquad (1)$$

In order to find CI the λMAX should be calculated by placing criteria weights as factors (table 7), then, multiply each value in table (4) (pairwise comparison matrix) by criteria weights to obtain weighted columns (table 8).

After that, the summation of each row in table (8) will be calculated to obtain a weighted sum as shown in table (9). The weighted sum of each row (table 9) is divided by criterion weight in the same row (table 10), λMAX is the average of that values which result from this division (Eq. 2). Now, λMAX is calculated, and (n) is the number of factors or criteria; therefore, CI could be calculated using Eq. (1).

Table (7): Weights as factors.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC
Criteria weights	0.164	0.246	0.098	0.246	0.246
Elevation	1.000	0.666	2.000	0.666	0.666
Slope	1.500	1.000	3.000	1.000	1.000
Aspect ratio	0.500	0.444	1.000	0.444	0.444
Soil loss	1.500	1.000	3.000	1.000	1.000
LULC	1.500	1.000	3.000	1.000	1.000

Table (8): Calculation of weighted columns.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC
Elevation	0.164	0.163	0.196	0.163	0.163
Slope	0.246	0.246	0.294	0.246	0.246
Aspect ratio	0.082	0.109	0.098	0.109	0.109
Soil loss	0.246	0.246	0.294	0.246	0.246
LULC	0.246	0.246	0.294	0.246	0.246

Table (9): Calculation of weighted sum.

Land suitability	Elevation	Slope	Aspect ratio	Soil loss	LULC	Weighted sum value
Elevation	0.164	0.163	0.196	0.163	0.163	0.851
Slope	0.246	0.246	0.294	0.246	0.246	1.278
Aspect ratio	0.082	0.109	0.098	0.109	0.109	0.507
Soil loss	0.246	0.246	0.294	0.246	0.246	1.278
LULC	0.246	0.246	0.294	0.246	0.246	1.278

Table (10): Calculation of λmax.

Weighted sum value	Criteria weights	λmax
0.851/	0.164=	5.195
1.278/	0.246=	5.195
0.507/	0.098=	5.172
1.278/	0.246=	5.195
1.278/	0.246=	5.195

$$\lambda_{MAX} = \frac{5.195+5.195+5.172+5.195+5.195}{5} = 5.190 \quad (2)$$

$$CI = (\lambda_{MAX} - n)/(n-1)$$

$$CI = (5.190 - 5)/(5-1)$$

$$CI = \frac{0.190}{4} = 0.047$$

Another requirement for the process of checking consistency is determining random index (RI) from table (11) which provides by

Saaty (2004). The final calculation is to find consistency ratio (CR) by dividing consistency index (CI) by random index (RI) using Eq. (3).

Table (11): Random index by Saaty (2004).

n	3	4	5	6
RI	0.58	0.9	1.12	1.24

$$CR = \frac{CI}{RI} \qquad (3)$$

$$CR = \frac{0.047}{1.12} = 0.042$$

Since the value of CR (0.042) is less than 0.10, it is an indicator that the entire methodology is reasonably consistent and can be adopted to the process of decision-making using AHP Saaty (2004). The CR value should be less than 0.10 that demonstrating the general consistency of the pairwise comparison matrix (Park *et al*., 2011; Bozdağ *et al*., 2016).

Because all of the chosen criteria are in different units, they must be transformed into the same units to be suitable for the Weighted Overlay Method (WOM). This process is called standardization, the measurement will be converted using standardization procedures to uniform units (or pixel values) and the unit of measurement for all criteria will lose its original values (Effat & Hassan, 2013).

Based on the results of the AHP analysis, the land suitability map has been generated using RS and GIS techniques. The WOM technique has been used by selecting each factor as an input (thematic layer) with weights of (16.4%, 24.6%, 9.8%, 24.6%, and 24.6%) for elevation, slope, aspect ratio, soil loss, and LULC respectively. This has achieved after dividing each criterion into five sub-criteria, then, each sub-criteria take a value from 1 to 10 that called "score" depending on (FAO, 1976) guidelines as .well as on several kinds of research with the same direction (Akıncı *et al*., 2013; Roy & Saha, 2018).

The WOM has been used for determining land suitability by many researchers (Chandio et al., 2011; Akıncı et al., 2013; Zolekar & Bhagat, 2015; Yalew et al., 2016; Pramanik, 2016). Using all the criteria as thematic layers through GIS environment with their weights and score of each sub-criterion in order to generate the final land suitability map using Eq. (4).

$$LS = \sum_{i=1}^{n} WiXi \qquad (4)$$

Where; LS = land suitability, Wi = weight of a certain land suitability criteria, Xi = sub-criteria score of i (for a certain land suitability criteria), n = total number of land suitability criteria (Cengiz & Akbulak, 2009; Pramanik, 2016; Yalew *et al*., 2016).

The final step is to reclassify the generated map from WOM into five classes according to (FAO, 1976) and (Sys *et al*., 1991). The classes are highly suitable S1, moderately suitable S2, marginally suitable S3, not suitable N1, and not suitable permanently N2.

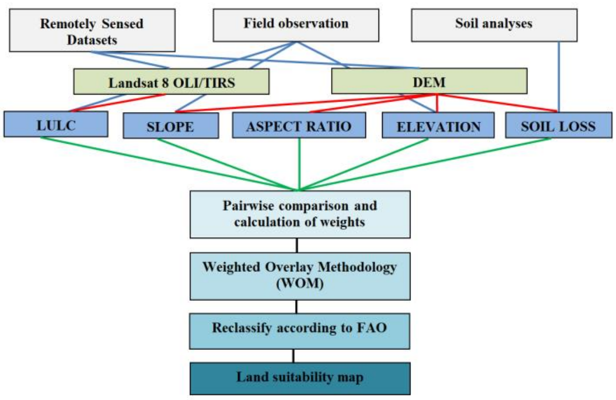

Fig. (3): Flowchart of producing land suitability map.

Results & Discussion

Soil analyses

The results of soil analyses (table 12) reveal that the organic matter has the higher value in the sample (3) with 43.0 $gm.kg^{-1}$, while, the lower value of organic matter was 6.54 $gm.kg^{-1}$ in the sample (30). On the other hand, the higher sand fractions located in the sample (12) and the lower one located at the sample (19) with values of 651 $gm.kg^{-1}$ and 246 $gm.kg^{-1}$ respectively. Silt particles have higher values in sample (24 and 31) with 461 $gm.kg^{-1}$ and the lower value is 172 $gm.kg^{-1}$ for the sample (1). The maximum clay particle value is 457 $gm.kg^{-1}$ in the sample (1), while the minimum value is 103 $gm.kg^{-1}$ in the sample (24). Finally, the very fine sand particle has the higher value of 40.9 $gm.kg^{-1}$ in the sample (17) and the lower value of 4.0 $gm.kg^{-1}$ in the sample (11). For the texture classes the clay loam (CL) was the dominant texture class across the study area.

Used criteria

Elevation

As shown in the elevation map of the study area (Fig. 4), there is magnitude variation in elevation starting from 169 meters for rivers and some water bodies in the south and southwest part, increasing to reach around 500 meters in the middle part of the study area. Continuing to increase with north and northeast direction to become more than 3000 meters in the mountainous area. These variations dramatically affect many aspects such as the amount of precipitation, vegetation cover, temperature, soil spatial variation, and others as indicated by Razvanchy (2014).

Slope

A slope map is one of the most essential derived maps from DEM because it has been used for estimating soil loss and used as one of the criteria for estimating land suitability. The slope of the study area increasing from southwest to northeast direction, and the slope percent in the mountainous area is 35% and more to reach 50% in some places. While in the lower part of the study area slopes of 2% or lower are dominated. Generally, there are fluctuations in slope values across the study area, which lower slope classes have been found in some mountainous areas and vice versa as shown in fig. (5).

Aspect Ratio

Aspect is the direction in which a unit of terrain faces (Fig. 6). It is usually expressed in degrees from the north to the north to completing 360 degrees. The variation of the aspect increasing from southwest direction to northeast direction especially in a mountainous area the complexity of aspect ratio maximized.

Soil loss

The result of soil loss illustrates that it increasing from southwest to north and northeast (Fig. 7). The lowest soil loss was found in samples (31, 32, and 33) because of the slight slope and less amount of rainfall in these locations. Whereas the highest soil loss value was found in samples (1, 2, 3, 4, and 5). This result can be attributed to the high slope and their locations at mountain areas with a very high amount of precipitation and the dominance of gully erosion.

LULC

The result of LULC (Fig. 8) determination indicated that the vegetation and forest cover types are dominated land uses compared to the other uses of land especially in the north part of the study area. The main reason for this is due to the high amount of precipitation in these spots.

Land Suitability result

The result of land suitability analysis was adopted to generate a suitability map for the study area (Fig. 9). The distribution of the land suitability classes is dramatically related to the factor or criteria used to build it. Each elevation, slope, and soil loss is relatively lower in the middle part of the study area toward the southwest (Figs. 4, 5, and 7). Additionally, these areas' land use and land cover (LULC) are mostly agricultural and bare lands (Fig. 8).

The land suitability map shows that the S1 class which is "high suitable" is generally located at the northwest in the middle part of the study area extended to the southwest, and it occupies an area of 1243.94 km^2 (8.61%) as shown in table (13). This distribution because of these areas has relatively low slopes 2-8% (Fig. 5). In addition, soil loss of these areas is relatively low around 30 ton ha^{-1}.year^{-1} (Fig. 7). Besides it, the elevation of this part of the study area is around 500 meters and lower than other areas (Fig. 4). The S2 class, which is "moderately suitable", occupies a minimum area of 85.52 km^2 (0.59%). While the S3 class is "marginally suitable" occupying a massive area relatively about 4886.75 km^2 (33.82%).

The N1 class that represents "not suitable" occupies the highest area around 6538.32 km^2 (45.26%). While N2 class that represents "not suitable permanently" takes 1693.16 km^2 (11.72%). Both N1 and N2 classes including areas of urban, water body, mountains, high slope (>25%), high elevation (>1000 meter), soils with high stone (>10%), high eroded soils (>50 ton ha^{-1} year^{-1}), and wet soils (aspect ratio = north, northeast, and northwest). Both N1 and N2 have an area of 8.231 km^2 (56.98%) of the total area that is plenty with comparison to all S1, S2, and S3, which takes only 6,216 km^2 (43.02%). High slope and soil loss are effective factors resulting decrease in the suitability of agricultural areas (Demir *et al*., 2011).

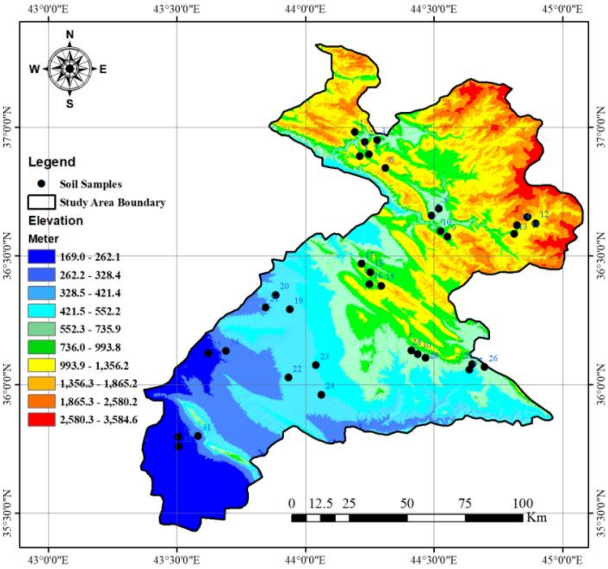

Fig. (4): Spatial distribution of the elevation.

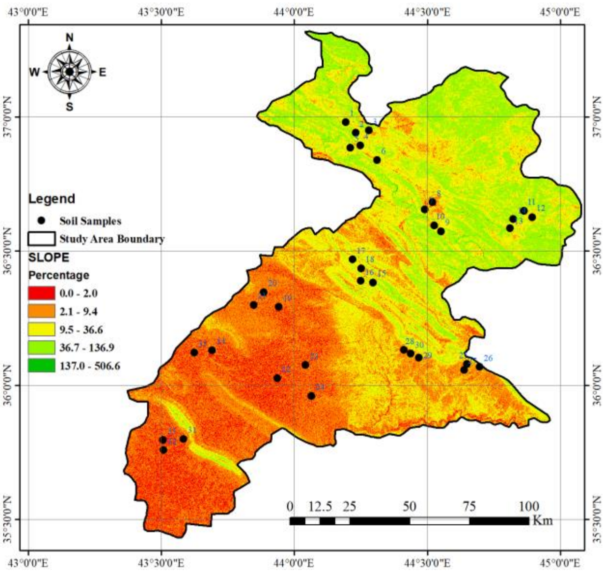

Fig. (5): Spatial distribution of the slope in percentage

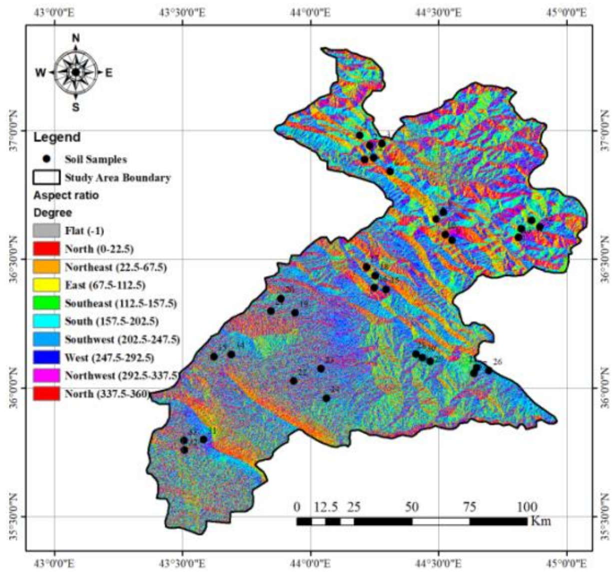

Fig. (6): Spatial distribution of the aspect ratio

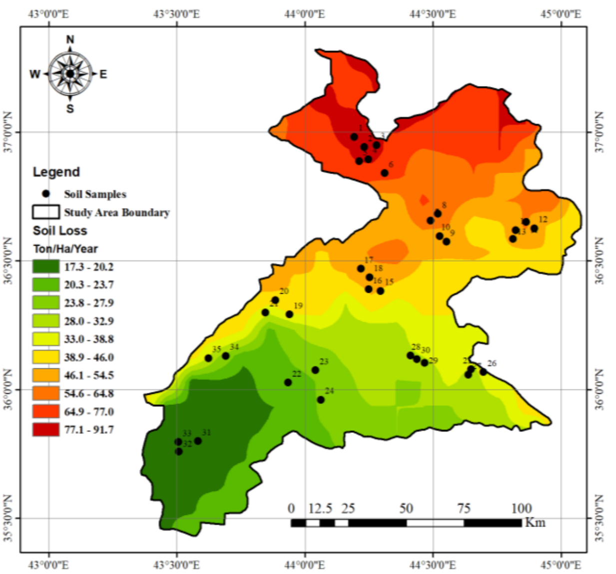

Fig. (7): Spatial distribution of the soil loss for year 2019 (RMS = 11.78).

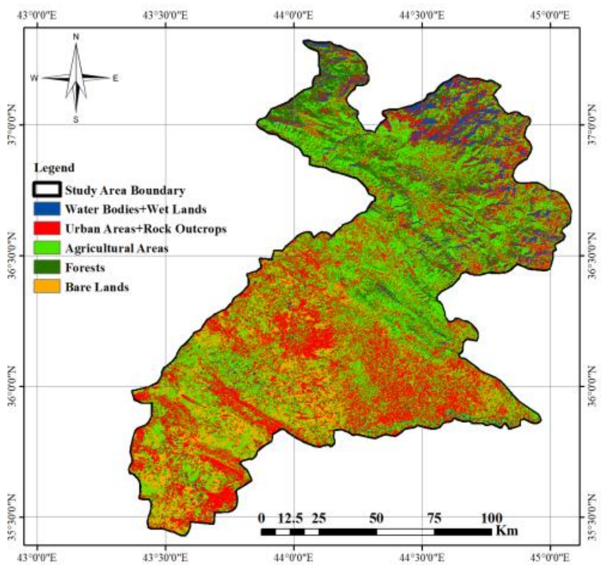

Fig. (8): Unsupervised classification for the study area (LULC).

Table (12): Laboratory analyses for the soil samples.

Samples number	Organic Matter (gm.kg^{-1})	**PSD (gm.kg^{-1})			*Texture	Very Fine Sand (gm.kg^{-1})
		Sand	Silt	Clay		
1	32.68	371	172	457	C	37.8
2	34.40	301	264	435	C	32.0
3	43.00	393	289	318	CL	35.0
4	33.37	358	229	413	C	12.9
5	32.16	370	273	357	CL	15.9
6	24.08	435	216	349	CL	11.4
7	32.34	411	200	389	CL	16.4
8	34.40	425	272	303	CL	14.6
9	25.80	281	318	401	C	23.9
10	20.64	258	245	497	C	16.3
11	25.97	608	208	184	SL	4.0
12	18.92	651	212	137	SL	8.4
13	15.31	582	248	170	SL	14.3
14	25.80	531	210	259	SCL	21.7
15	18.92	492	212	296	SCL	16.5
16	15.82	470	203	327	SCL	20.9
17	18.92	511	335	154	L	40.9
18	29.41	467	285	248	L	25.8
19	12.90	246	384	370	CL	3.8
20	15.65	330	297	373	CL	9.9
21	20.98	370	250	380	CL	13.8
22	25.80	410	374	216	L	15.5
23	16.34	321	389	290	CL	16.6
24	21.84	436	461	103	L	16.0
25	19.44	321	406	273	CL	12.2
26	20.81	387	391	222	L	18.0
27	16.68	282	407	311	CL	13.7
28	13.42	418	299	283	CL	17.1
29	9.98	603	280	117	SL	15.9
30	6.54	560	277	163	SL	23.3
31	21.84	375	461	164	L	22.4
32	16.86	287	408	305	CL	25.1
33	18.40	354	426	220	L	12.0
34	16.34	406	347	247	L	22.5
35	26.32	350	362	288	CL	28.4

*C: Clay, L: Loam, S: Sandy, ** PSD: Particles size distribution.

Table (13): Land suitability analysis results.

Land Suitability Classes	Area Covered		
	Km^2	%	
S1	1243.94	8.61	43.02%
S2	85.52	0.59	
S3	4886.75	33.82	
N1	6538.32	45.26	56.98%
N2	1693.16	11.72	
Total	14447.69	100.00	100.00

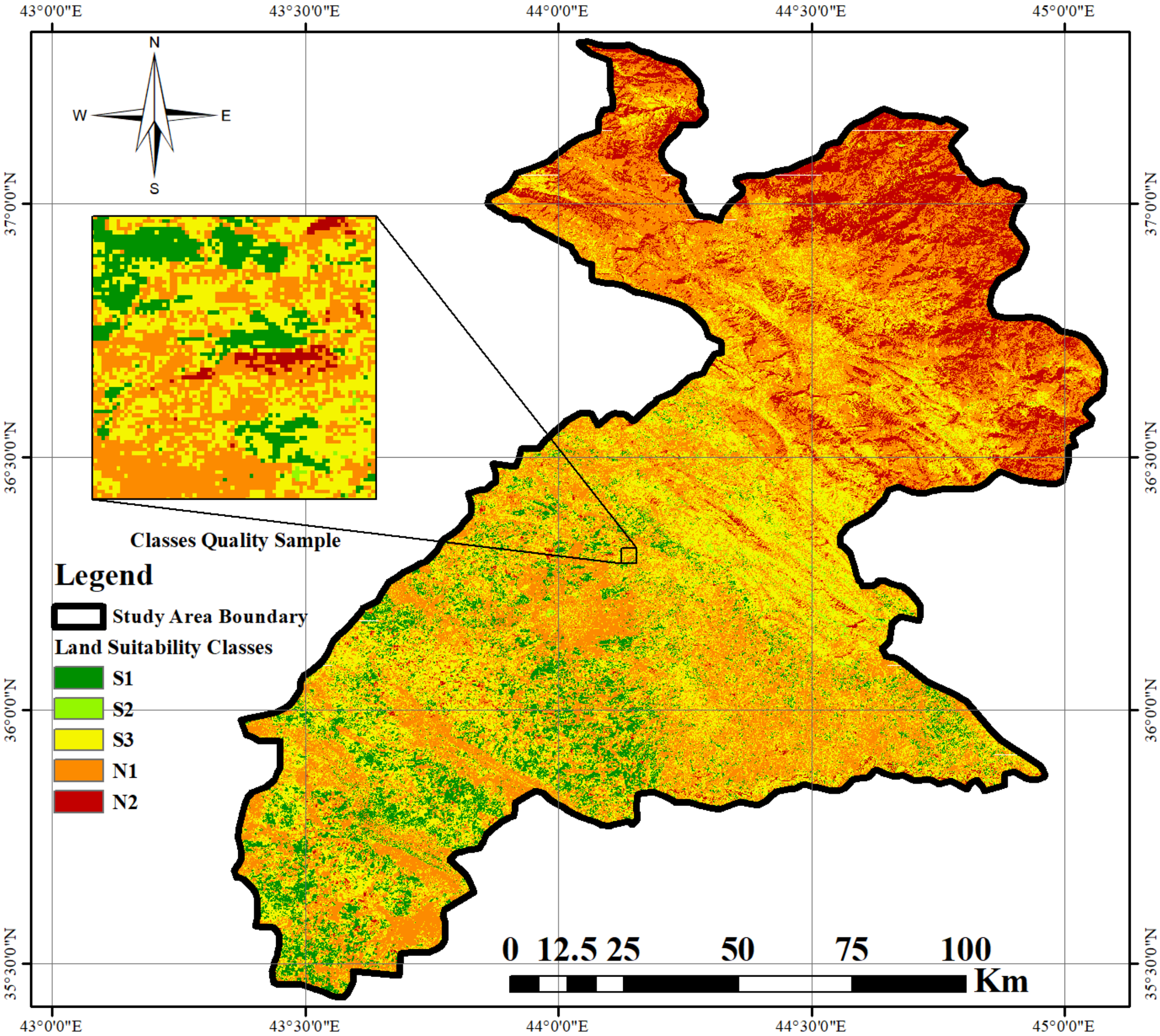

Fig. (9): Land Suitability Classes, with a zoomed area that shows the classes quality.

Conclusions

The purpose of this research was to determine the spatial distribution of land suitability classes with their area. Five criteria have been used in order to find suitable areas for agriculture purpose using qualitative classification. Using the topographic variables (elevation, slope, and aspect ratio) with soil loss and land cover types and land use have been successfully employed. The results reveal that soil loss rates have significant effects on the suitability distribution. The soil loss reaches its peak on the mountainous area of the study specifically the north and northeast parts. Nevertheless, these areas have a great condition for agriculture in terms of the amount of precipitation, natural vegetation covers (forests), source of surface water, and others. Despite the southern part of the study area having low precipitation and low vegetation cover compared to the mountainous area, it is suitable for agricultural activities that it has a relatively lower intensity of soil loss. From the result of this study our recommendation for the other researchers in this field that the integration of GIS and AHP is a powerful tool that can be utilized for determining land suitability

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استخدام تقنيتي نظم المعلومات الجغرافية (GIS) و التسلسل الهرمي التحليلي (AHP) في تقييم ملائمة الأراضي الزراعية في محافظة أربيل، اقليم كردستان، العراق

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المستخلص: تتكون منطقة الدراسة من محافظة أربيل, اقليم كردستان, العراق. خمسة وثلاثون عينة من التربة المأخوذة من المناطق المختلفة. تم إجراء العديد من تحليلات التربة من أجل إيجاد تعرية التربة كمعيار لتقييم ملاءمة الأراضي. كانت المعايير الأخرى التي تم استخدامها هي الارتفاع ، الانحدار ، اتجاه الانحدار، ونوعية الاستخدام والغطاء للأراضي. تم ترجيح جميع المعايير المستخدمة باستخدام منهجية عملية التسلسل الهرمي التحليلي (AHP) للعثور على الأولوية من أجل استخدامها في منهجية التراكب الموزون (WOM) بناءً على تقنية نظم المعلومات الجغرافية (GIS). تم استخدام تكامل مابين AHP و GIS بغرض العثور على ملاءمة الأراضي على أساس خمس فئات ؛ عالية المناسبة (S1) ، مناسبة بشكل معتدل (S2) ، مناسبة قليلا (S3) ، غير مناسبة (N1) ، وغير مناسبة بشكل دائم (N2) تظهر نتيجة ملاءمة الأراضي أن الفئة الاولى S1 تقع عمومًا في الشمال الغربي في الجزء الأوسط من منطقة الدراسة الممتدة إلى الجنوب الغربي وتحتل مساحة 1243.94 كيلومتر مربع (8.61٪) من المساحة الكلية. بينما تغطي الفئة S2 الثانية مساحة لا تقل عن 85.52 كيلومتر مربع (0.59٪). بينما تحتل الفئة الثالثة S3 مساحة شاسعة نسبياً حوالي 4886.75 كيلومتر مربع (33.82٪). من جهة اخرى تحتل الفئة الرابعة N1 أعلى مساحة حوالي 6538.32 كيلومتر مربع (45.26٪). بينما تحتل الفئة الخامسة N2 1693.16 كيلومتر مربع (11.72٪). تبلغ مساحة كل من N1 و N2 8231 كيلومترًا مربعًا (56.98٪) من المساحة الإجمالية ، بينما تبلغ مساحة كل من S1 و S2 و 6216S3 كيلومترًا مربعًا (43.02٪). من خلال هذه الدراسة وجدنا انه من الممكن ان تستخدم و بنجاح كلتا التقنيتين نظم المعلومات الجغرافية (GIS) و التسلسل الهرمي التحليلي (AHP) مع بعضها البعض لتقييم ملائمة الأراضي.

الكلمات المفتاحية: ملائمة الأراضي, نظم المعلومات الجغرافية, التسلسل الهرمي التحليلي, التراكب الموزون