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 km² (8.61%). The S2 class occupies a minimum area of 85.52 km² (0.59%), while the S3 class occupies a massive area relatively about 4886.75 km² (33.82%). The N1 class occupies the highest area, around 6538.32 km² (45.26%). At the same time, N2 class takes 1693.16 km² (11.72%). Both N1 and N2 have an area of 8,231 km² (56.98%) of the total area while S1, S2, and S3, which takes only 6,216 km² (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 km², 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° 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             | 36.29932958| 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| 44.49069141| 639           | 25             | 36.07792386| 44.64785136| 555           |
| 8              | 36.68163663| 44.51963040| 653           | 26             | 36.06762724| 44.69685836| 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; Akinci 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).

![Hierarchal structure](image)

**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             |
| Very strongly more important    | 8             |
| Strongly more important         | 7             |
| Moderately more important       | 6             |
| Equally important               | 5             |
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).

\[ CI = (\lambda_{\text{MAX}} - n)/(n - 1) \]  \hspace{1cm} (1)

In order to find CI the \( \lambda_{\text{MAX}} \) 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), $\lambda_{MAX}$ is the average of that values which result from this division (Eq. 2). Now, $\lambda_{MAX}$ is calculated, and (n) is the number of factors or criteria; therefore, CI could be calculated using Eq. (1).

$$\lambda_{MAX} = \frac{5.195+5.195+5.172+5.195+5.195}{5} = 5.190$$

(2)

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

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

| 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 $\lambda_{max}$. |
|----------------------------------------|
| Weighted sum value | Criteria weights | $\lambda_{max}$ |
|----------------------|------------------|-----------------|
| 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 |

$\lambda_{MAX} = \frac{5.195+5.195+5.172+5.195+5.195}{5} = 5.190$

$CI = \frac{0.190}{4} = 0.047$
Saaty (2004). The final calculation is to find consistency ratio (CR) by dividing consistency index (CI) by random index (RI) using Eq. (3).

\[
CR = \frac{CI}{RI}
\]  

\[
CR = \frac{0.047}{1.12} = 0.042
\]

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).

\[
LS = \sum_{i=1}^{n} WiXi
\]

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 & Akbuluk, 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.

---

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

| n | RI  |
|---|-----|
| 3 | 0.58|
| 4 | 0.90|
| 5 | 1.12|
| 6 | 1.24|

---

**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.](image-url)
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$^{-1}$) |
|----------------|-------------------------------|-------------------------|-----------|-----------------------------|
| 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 | %    |
|--------------------------|--------------|------|
|                          | Km²          |      |
| S1                       | 1243.94      | 8.61 |
| S2                       | 85.52        | 0.59 |
| S3                       | 4886.75      | 33.82|
| N1                       | 6538.32      | 45.26|
| N2                       | 1693.16      | 11.72|
| **Total**                | **14447.69** | **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

Acknowledgements

The first, last, and all thanks to God, who gave us enough strength and knowledge to conduct this research. We would also like to thank our university, college and department for their continuous support and sponsoring.

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References

Aburas, M., Ho, Y., Ramli, M., & Ashaari, Z. (2017). Land suitability analysis of urban growth in seremban malaysia, using gis based analytical hierarchy process. Procedia Engineering, 198, 1128-1136. https://doi.org/10.1016/j.proeng.2017.07.155

Akinci, H., Özalp, A. Y., & Turgut, B. (2013). Agricultural land use suitability analysis using GIS and AHP technique. Computers and electronics in agriculture, 97, 71-82. https://doi.org/10.1016/j.compag.2013.07.006

Al-Quraishi, A. M. F., Sadiq, H. A., & Messina, J. P. (2019). Characterization and modeling surface soil physicochemical properties using Landsat images: a case study in the Iraqi Kurdistan region. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, XLII-2/W16, 21-28. https://doi.org/10.5194/isprs-archives-XLII-2-W16-21-2019

Baja, S., Nurmiaty, U., & Arif, S. (2014). GIS-based soil erosion modeling for assessing land suitability in the urban watershed of tallo river, South Sulawesi, Indonesia. Modern Applied Science, 8, 50. https://doi.org/10.5539/MAS.V8N4P50

Bandyopadhyay, S., Jaiswal, R., Hegde, V., & Jayaraman, V. (2009). Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. International Journal of Remote Sensing, 30, 879-895. https://doi.org/10.1080/01431160802395235

Bozdağ, A., Yavuz, F., & Günsay, A. S. (2016). AHP and GIS based land suitability analysis for Cihanbeyli (Turkey) County. Environmental Earth Sciences, 75, 813. https://doi.org/10.1007/s12665-016-5558-9

Burrough, P., MacMillan, R., & Van Deursen, W. (1992). Fuzzy classification methods for determining land suitability from soil profile observations and topography. Journal of Soil Science, 43, 193-210. https://doi.org/10.1111/j.1365-2389.1992.tb00129.x

Cengiz, T., & Akbulak, C. (2009). Application of analytical hierarchy process and geographic information systems in land-use suitability
evaluation: a case study of Dimrek village (Çanakkale, Turkey). International Journal of Sustainable Development & World Ecology, 16, 286-294. https://doi.org/10.1080/13504500903106634

Chandio, I. A., Matori, A.-N., Lawal, D. U., & Sabri, S. (2011). GIS-based land suitability analysis using AHP for public parks planning in Larkana City. Modern Applied Science, 5, 177. https://doi.org/10.5539/MAS.V5N4P177

Dedeoğlu, M., & Dengiz, O. (2019). Generating of land suitability index for wheat with hybrid system approach using AHP and GIS. Computers and Electronics in Agriculture, 167, 105062. https://doi.org/10.1016/j.compag.2019.105062

Demir, M., Yildiz, N. D., Bulut, Y., Yilmaz, S., & Serkan, Ô. (2011). Determining the criteria of potential agricultural areas in land use planning with the Geographical Information Systems (GIS) method (Ispir Example). Journal of the Institute of Science and Technology, 1, 77-86. https://dergipark.org.tr/en/pub/jistissue/7926/104247

Effat, H. A., & Hassan, O. A. (2013). Designing and evaluation of three alternatives highway routes using the Analytical Hierarchy Process and the least-cost path analysis, application in Sinai Peninsula, Egypt. The Egyptian Journal of Remote Sensing and Space Science, 16, 141-151. https://doi.org/10.1016/j.ejrs.2013.08.001

FAO, (1976). A framework for land evaluation. Rome: Food and agriculture organization of the United Nations. http://www.fao.org/3/x5310e/x5310e00.htm

Klute, A. (1986). Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 5.1, Second Edition: 383-411 in Gee, G., & Bauder, J. Particle-size analysis. SSSA Book Series. 1188pp. https://doi.org/10.2136/ssassbookser5.1.2ed.c15

Issam, I. B. & Antoine, H. S. (2007). Food and Agriculture Organization of the United Nations, Rome.

Lang, C. Y. (2009). Kriging Interpolation. Department of Computer Science, Cornell University, access on January 2021. Available on https://people.ece.cornell.edu/land/OldStudentProjects/cs490-94to95/clang/kriging.html

Malczewski, J. (1999). GIS and multicriteria decision analysis. John Wiley & Sons. 408pp. https://www.wiley.com/en-us/GIS+and+Multicriteria+Decision+Analysis-p-9780471329442

Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science, 20, 703-726. https://doi.org/10.1080/13658810600661508

Mazahreh, S., Bsoul, M., & Hamoor, D. A. (2019). GIS approach for assessment of land suitability for different land use alternatives in semi arid environment in Jordan: Case study (Al Gadeer Alabyad-Mafraq). Information Processing in Agriculture, 6, 91-108. https://doi.org/10.1016/j.ipa.2018.08.004

Mendas, A., & Delali, A. (2012). Integration of multicriteria decision analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria. Computers and Electronics in Agriculture, 83, 117-126. https://doi.org/10.1016/j.compag.2012.02.003

Mu, E., & Pereyra-Rojas, M. (2017). Practical decision making using super decisions. Vol. 3: An introduction to the analytic hierarchy process. Springer. https://link.springer.com/book/10.1007/978-3-319-68369-0

Muhaimeed, A. S., Saloom, A., Saliem, K., Alani, K., & Mukleef, W. (2014). Classification and distribution of Iraqi soils. International Journal of Agriculture Innovations and Research, 997-1002.

Overmars, K. P., & Verburg, P. H. (2007). Comparison of a deductive and an inductive approach to specify land suitability in a spatially explicit land use model. Land Use Policy, 24, 584-599. https://doi.org/10.1016/j.landusepol.2005.09.008

Park, S., Jeon, S., Kim, S., & Choi, C. (2011). Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea. Landscape and Urban Planning, 99, 104-114. https://doi.org/10.1016/j.landurbplan.2010.09.001

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Razvanchy & Fayyadh/ Basrah J. Agric. Sci., 35(1): 140-157, 2022

Perveen, F., Nagasawa, R., Uddin, M. I., & Delowar, H. K. (2007). Crop-land suitability analysis using a multicriteria evaluation & GIS approach. 5th International Symposium on Digital Earth (ISDE5), June. California, USA.

Pramanik, M. K. (2016). Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. Modeling Earth Systems and Environment, 2, 56. https://doi.org/10.1007/s40808-016-0116-8

Razvanchy, H. A. S. (2014). Modelling Some of the Soil Properties in the Iraqi Kurdistan Region using Landsat Datasets and Spectroradiometer. M. Sc. Thesis, Salahaddin University-Erbil, 145pp.

Roy, J., & Saha, S. (2018). Assessment of land suitability for the paddy cultivation using analytical hierarchical process (AHP): a study on Hinglo river basin, Eastern India. Modeling Earth Systems and Environment, 4, 601-618. https://doi.org/10.1007/s40808-018-0467-4

Saaty, T. L. (2004). Decision making for leaders: the analytic hierarchy process for decisions in a complex world. RWS publications. https://www.goodreads.com/en/book/show/271440.Decision_Making_for_Leaders

Sys, C., Van Ranst, E., & Debaveye, J. (1991). Land Evaluation: Principles in Land Evaluation and Crop Production Calculations. General Administration for Development Cooperation, Brussels.

Tashayo, B., Honarbakhsh, A., Akbari, M., & Eftekhari, M. (2020). Land suitability assessment for maize farming using a GIS-AHP method for a semi-arid region, Iran. Journal of the Saudi Society of Agricultural Sciences, 19, 332-338. https://doi.org/10.1016/j.jssas.2020.03.003

Ullah, K. M., & Mansourian, A. (2016). Evaluation of land suitability for urban land-use planning: case study D haka City. Transactions in GIS, 20, 20-37. https://doi.org/10.1111/tgis.12137

Vasu, D., Srivastava, R., Patil, N. G., Triway, P., Chandran, P., & Singh, S. K. (2018). A comparative assessment of land suitability evaluation methods for agricultural land use planning at village level. Land Use Policy, 79, 146-163. https://doi.org/10.1016/j.landusepol.2018.08.007

Wischmeier, W. H., & Smith, D. D. (1965). Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation. Agricultural Research Service, US Department of Agriculture. https://naldc.nal.usda.gov/catalog/CAT87208342

Yalew, S. G., Van Griensven, A., Mul, M. L., & van der Zaag, P. (2016). Land suitability analysis for agriculture in the Abbay basin using remote sensing, GIS and AHP techniques. Modeling Earth Systems and Environment, 2, 1-14. https://doi.org/10.1007/s40808-016-0167-x

Zhang, J., Su, Y., Wu, J., & Liang, H. (2015). GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China. Computers and Electronics in Agriculture, 114, 202-211. https://doi.org/10.1016/j.compag.2015.04.004

Zolekar, R. B., & Bhagat, V. S. (2015). Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. Computers and Electronics in Agriculture, 118, 300-321. https://doi.org/10.1016/j.compag.2015.09.016
استخدام تقنيتي نظم المعلومات الجغرافية (GIS) والتسلسل الهرمي التحليلي (AHP) في تقييم ملاءمة الأراضي الزراعية في محافظة أربيل، إقليم كردستان، العراق

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الملخص: تتكون منطقة الدراسة من محافظة أربيل، إقليم كردستان، العراق. خمسة وثلاثون عينة من التربة المأخوذة من المناطق المختلفة. تم إجراء العديد من تحليلات التربة من أجل إيجاد تعرفية التربة كمعيار لتقسيم ملاءمة الأراضي. كتلت المعابير الأخرى التي تم استخدامها هي الانحدار، اتجاه الانحدار، نوعية الاستخدام والغطاء للأراضي. تم ترجيح جميع المعابير المستخدمة باستخدام منهجية عملية التسلسل الهرمي التحليلي (AHP) لتحديد الأولويات من أجل استخدامها في منهجية التراكب الموزون (WOM). تم استخدام التكامل بين AHP و GIS بعرض العثور على تقنيات نظم المعلومات الجغرافية (GIS). بناءً على تقنية ملاءمة الأراضي على أساس فئات مناسبة: عالية (S1)، مناسبة بشكل معتدل (S2)، مناسبة قليلاً (S3)، غير مناسبة بشكل دائم (N1)، غير مناسبة بشكل دائم (N2) (WOM). تظهر نتيجة ملاءمة الأراضي أن الفئة الأولى S1 تعقد عموماً في الشمال الغربي في الجزء الأوسط من منطقة الدراسة الممتدة إلى الجنوب الغربي وتحتل مساحة 1243.94 كيلومتر مربع (61.86%). من الساحات الكلية، بينما ساحة الثانية، S2، مساحة شاسعة حوالي 4886.75 كيلومتر مربع (38.20%). بينما تحتل الفئة الثالثة N3 مساحة 1693.16 كيلومتر مربع (11.72%). بينما تحتل الفئة الخامسة N4، مساحة 8231 كيلومتر مربع (56.98%). من الساحات الكلية، بينما تحتل الفئة S1 مساحة 1693.16 كيلومتر مربع (11.72%). من خلال هذه الدراسة وجدنا أن الفئات N1 و N2 يمكن استخدامها في تقييم ملاءمة الأراضي و التحسن في ملاءمة الأراضي (WOM). من خلال هذه الدراسة جدنا أن الفئات N1 و N2 يمكن استخدامها في تقييم ملاءمة الأراضي و التحسن في ملاءمة الأراضي (WOM). من خلال هذه الدراسة جدنا أن الفئات N1 و N2 يمكن استخدامها في تقييم ملاءمة الأراضي و التحسن في ملاءمة الأراضي (WOM). من خلال هذه الدراسة جدنا أن الفئات N1 و N2 يمكن استخدامها في تقييم ملاءمة الأراضي و التحسن في ملاءمة الأراضي (WOM).

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