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Optimal use of Agricultural Land in an Arid Region from Using GIS and Linear Algorithm: Al-Hasaka-SYRIA

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Abstract

This research aims to evaluate the lands of Wadi Khirbet al-Malihah area in Al-Hasaka province (2016-2018) and determine the optimal land use. A geo-pedological soil survey was initiated, and 10 soil profiles representing the physiographic in the study area were collected for some chemical and physical properties analysis. The land evaluation was achieved using LAMIS (Land Management Information System) program under the GIS platform. The evaluation was done applying map-algebra on both crops' requirements with parametric conditions of lands and climate characteristics. The resulting evaluation showed according to the suggested scenario (limited irrigation water), crops with the lowest water requirements were selected: moderate suitable S2 by 41.52%, limit suitable S3 by 28.27% of the study area. Linear programming was used to produce the final optimal land use map according to three criteria: costs, gross margin and water requirements. The results show that there are diversity advantage and the most important challenges for obtaining the highest gain.

Keywords: Optimal land use/land evaluation, GIS, Linear Programming.

Introduction

The optimal use of lands is very important to obtain permanent development that includes economic, social environmental and political diameters under the recent challenges. The optimal planning of land use are a group of chain procedures that made and done to make the best use of land through studying and evaluating the natural economic and social factors (Edrich, 2005). Optimal crop style that lands are assigned to it for different crops through using limited resources has become one of the most important challenges for obtaining the highest gain. Where optimal agricultural planning is an important issue in the gain operation because it increases the income from low-cost operation (Scarpai and Beaclair, 2010). The maximum economical agricultural land use depends on two things, which are land evaluation suitability and analysis of farmer's agricultural commodities that are cultivated (Ülker et al., 2018).

Where stating the proper selection of plants for every type of land is a major issue in an attempt to maximize the overall contribution of land (Sarker et al., 1997). In this study, the Geographic Information System (GIS) with Linear Programming (LP) was used to determine the optimal use of agricultural land. Land area constraints impose a greater need to assess agricultural natural resources. Geographic Information System (GIS) has a strong capacity in data integration and analysis and visualisation, a powerful tool to get a solution to problems and building land use planning. The use of GIS will integrate diverse geospatial data, such as topographic, land and soil suitability, vegetation cover, land use and others in GIS database and their joint analysis, which increases the quantity as well as the quality of derived information (Bojorquez-Tapia et al., 2001; Ball, 2002; Hoobler et al., 2003; Malczewski, 2006; Trung et al., 2006). While Line programming treats different issues where it finds best values (x1, x2, x3… xn) that give the biggest benefits to make a decision to increase gains and reduce costs (Taëi et al., 2009). Linear programming techniques have been widely used by agricultural economists. Despite its limitations, the method has proved very useful in studying the decision-making process in the agricultural sector. Agricultural resource allocation issues can be addressed through potent techniques such as LP and the production of optimal solutions (Alsheikh and Ahmed, 2002) in many studies of land optimization, linear programming model has been used to determine the area to be used for different crops for maximum contribution. Such as (Sarker et al., 1997) which developed a linear programming model to identify areas to be allocated to a variety of crops to maximize total contributions from agricultural activities in Bangladesh. Sarker and Quaddus (2002) studied the problem of crop planning at the state level using a multi-objective improvement model that met different objectives. Zander (2005) used
Hassan et al (2005) used LP to calculate crop area, production, and revenue in the Dera Khan section of Punjab province. Sharma et al (2007) used fuzzy goal programming for agriculture land allocation problems. Kaur et al (2010) also formulated an LP model to propose an optimal crop pattern to maximizing net revenue and ensure significant savings from groundwater in Punjab, Pakistan Mohammed and Sa'id (2011) modelled an LP crop mix for a limited planning horizon. The optimal enterprise combination in the cassava-based farming system in Nigeria was obtained by using LP by Bamiro et al (2012). Antwi (2016) used linear programming in the problem of allocation of agricultural resources to determine the optimal plan for the allocation of crops to women farmers under land, labor and capital constraints. Imamoğlu and Sertel, (2016) in the study, field interpretation and analysis of different Interpolation methods for soil moisture mapping using remote sensed data.

Linear programming was used to enhance the irrigated areas in Egypt (Osama et al., 2017) where different crops contend for a limited amount of land and water resources. In order to evaluate the relationship between land cover and land surface temperatures by using data perceived remotely by Kaya et al (2017), it was studied in Silivri region of Thrace peninsula. The linear programming model was used to make decisions about crop cultivation patterns by farmers and improve land use for agriculture in Sumedang Regency (Zenis et al 2018). Menegto (2019) conducted similar applications in Nigeria.

The linear programming issues can be solved through the prepaid and hard to deal programs or through Excel program by SOLVER in it (Vijay, 2002). SOLVER program is used in Excel to determine the best crops depending on joining the results of evaluating lands with the economic factors to make map for the final suggested uses or study Region when the additional function SOLVER is used to solve the line and non-line programming issues where the function SOLVER can solve all line programming issues (Burton Carrol and Wall, 1999). Buzuzi and Buzuzi (2018) evaluated the economic activity on a small-scale farm in the Mutasa district of Manicaland province of Zimbabwe in which maize, cabbages, potatoes, and tomatoes are cultivated. By applying the linear programming model using Microsoft excel SOLVER, and Hamza and Bellundagi (2018) used a quantitative analytical approach using Microsoft excel SOLVER in optimal crop plan allocation analysis. In this paper GIS was used to determine the suitability of the land for agriculture, then used LP to determine the optimal model for land use. Finally, GIS was applied again to produce the land use map generated by the LP model.

Materials and Methods

Study area

Wadi kherbat ALmliha is a region that belongs to AL-Hasaka province in Syria has an area of 41895 ha at 36’ 78 length line and 34’ 89 width line and 300 m above the sea level. It is surrounded by AL-Shaddada and Jerwan hill at the north Markada at the east. AL- Arysh at the west and Deirezzor at the south. The lands of the studied area are plainly topography with low waving. The climate of the study region is tropical mediterran with humid warm winter and dry hot summer and it is located between semi-arid and arid regions. rainfall rate is 250-300 mm/year (Climate Atlas of Syria,1977). Due to low rainfall during the last few years, the region faced drought, reducing the agricultural lands, and high levels of desertification (Ali, 2010). Vegetation cover and land use: The plant families in the study area showed that Atlantic pine trees, Palestinian pine bushes, white atriplex, oat, salsola and a number of perennials plants are dominants (Sankri,1987). Main cultivation crops are wheat, barley, some medical ornamental plant like cumin. In addition to these, rearing cows, sheep and goats are there (ASG, 2016).

In this study the geographic information system program (ArcGIS 10.3) and Land information management system (LAMIS), under Arc view 3x (Idriss,2011"1") where used.

The study used survey methods; data collected consists of:

a) Primary data, form of the data

Field work: A 121 land points were studied to test the differences on physiographical unit's map and to choose and prepare 10 soil profiles in different sites, the diagnosing characters and classification of soil was done according to USDA soil taxonomy ( Soil Survey Staff,2010), and color index (Munsell soil color charts,2000). the soil profiles were described using mandated form. Soil samples were collected according to the horizons in the soil profile. the samples were air-dried, crushed and sieved at 2 mm.

Soil chemical and physical data, were done in labs by researchers:

- physical analysis
- mechanical analysis Performed on soil texture % using hydrometer method, and general porosity % was calculated.
- chemical analysis
- PH of a saturated paste extracted using PH-meter (Conyers and Davey, 1988), ECe (Desimeise/cm) in a saturated paste extract using ECe-meter (Richards, 1954), total carbonate percentage using calcimeter (Balazs et al., 2005), gypsum percentage using the American method (Rhoades,1990), and organic matter% using wet oxidation method with Di-potassium chromate in a high acidity medium (Walkley and black, 1934) were estimated in labs of General Commission of Scientific Agricultural Research (GCSAR).
b) Secondary data
i. Meteorological Data obtained from the meteorological department and ICARDA water resources data obtained from the GCSAR and statistical agricultural data obtained from the ministry of agriculture (ASG, 2016).

GIS work
Planning important crops requires two kinds of data: Digital maps made by GIS that describe climate, main characteristics of soil, topography, current land uses and land cover and description data including the environmental requirement for crops and fruiting trees in the form of a table. The factors used in the study, number of standers were used in this study relating soil, climate, topography, recent land uses and land cover (Sys et al., 1993). The standards are as follows:

Environmental factors
- Frost length (below 0 c˚) in a day.
- Absolute minimum temperature for the coldest month of the year which is the lowest temperature during the year. this is used to determine the rate of reducing the temperature from plant resistance. When some species growing or die at low temperatures.
- Temperature average for the coldest month of the year (temperature during winter and spring). Considering the dormancy stage for perennial and fruiting trees.
- Absolute maximum temperature for the hottest month of the year. Temperature average the hottest month of the year (temperature during summer growth). This is used in two sides: it's important for the maturity of summer crops and it may lead to stop crop growth at its non-tolerance of temperature.
- Growth length determines humidity the temperature length of the growth period and defined as the period (number of days) that rainfall exceeds half of the evaporation rate when the temperature is above 0 c this is used for rainfall crops.
- Rainfall quantity

Soil factors
- Soil texture
- soil PH
- soil salinity
- soil depth
- soil fertility
- calcium carbonate
- gypsum
- productivity map.

Topographical work
Slope degree: a map of slope degree was made and classified into degree using DEM, though this factor may not directly affect plant growth, reduces using machinery and increases soil removal while irrigating crops. Factors relating of land use and land cover.
- Recent land uses: it describes the present function of land uses in the study region. Though recent land uses may not affect the agricultural plants, but it is taken into consideration to avoid urban lands, forests, and orchards from agricultural planning.
- Land cover: Describes the form of the natural lands that are used by man and it also doesn’t affect the agricultural plan 2.

Fig. 1. Location map of Study area, Wadi kherbat ALmlia, AL-Hasaka province (Syria).
1. costs: (state group of the ministry of agriculture, 2016).
2. gross margin using (state group of the ministry of agriculture, 2016). Based on the wholesale cost average.
3. water requirements for crop irrigation at m3/h.

SOLVER program in Excel was used to obtain a map of land uses: The SOLVER is a part of group orders sometimes called "what-if analysis".

With SOLVER, you can find the maximum or minimum values of one cell called a targeted cell in a working paper through changing other cells.

**Selection of variables**

Max. \[ x_1 + x_2 + x_3 + \ldots = z \] subject to \[ x_1 + x_2 + x_3 + \ldots + x_n \leq L \] (land limitations) \[ g_1 x_1 + g_2 x_2 + g_3 x_3 + \ldots + g_n x_n \leq G \] (gain) \[ w_1 x_1 + w_2 x_2 + w_3 x_3 + \ldots \leq W \] (water requirements) \[ p_1 x_1 + p_2 x_2 + p_3 x_3 + \ldots + p_n x_n \leq P \] (production cost)

To know the economic feasibility of farming can be defined by the Benefit-Cost Ratio.

**Results and discussion**

**Land suitability**

The results of applying LAMIS software on conditions map and requirements table were the following land suitability classes (Idriss,2001”2”).

S1: High land suitability for all crop’s cultivation was not found in the study area.
S2: medium land suitability for cultivation at simple to medium in Caso4 and an area of 17373.11 h. and makes 41.52% of the total area. After removing the determining factors, it becomes suitable in the future.
S3: limited land suitability for cultivation due to the presence of medium to high determines in soil parameters (2 factors) (salinity, Caso4, slope. Max temperature, productivity, LGP) area of 11829.8 h and makes 28.27% of the total area.
S4: limited land suitability for cultivation due to the presence of high determines in soil parameters (3 factors) (Caso4, Caco3 slope, Max temperature, ECE, LGP) area of 5730.911 h and makes 16.47 of the total area. After removing the determining factors in the future by reforming this class, might convert into suitable class S1.

N: non-land suitability for cultivation due to limitation factors (water and urban) with an area of 14.81ha (0.035%) of the total area.
N1: non- land suitability for cultivation due to the presence of high determines in the soil parameter (5 factors) (Caso4, Caco3, organic matter, ECE, min temperature, fertility) with an area of 6893.33% and makes 16.47 of the total area. After removing the determining factors in the future by reforming this class, might convert into suitable class S1.

Data were checked, entered the computer and linked with GIS where spatial data entered and linked with description data that were obtained from the field and lab measurements using ArcGIS 10.3 program, then these data were deal and put on purpose map.

**Procedures**

The theme of used standards of the study was made using the previous map extracting in ArcGIS 10.3

1. Table of standards was made in excel program including ID field and crops field along with the previous standards where names of the standards of the theme must match the names of the previous standards in the table and then keeping the form as dbf.
2. Adding standards theme and standards table to Arc view 3.x program and activating the extension LAMIS V 1.0.
3. using the order: build the parameters table from determined factors which have yes and no and put them in one lest (the determined factors list).
4. Producing suitability map for crops where LAMIS program perform the following operations (Idriss,2001”2”).
5. Check items of parameters table that contained the determined factors which have yes and no and put them in one lest (the determined factors list).
6. Searches in the fields that represent the determined factors and writes against each value of no value (N) and put the cause in the causes field.
7. Reads fields of the rest parameters and look for the values that express crop requirements and then compare it with the theme. if they all matched it writes S1 (best suitability) and leave the cause field empty.
8. Each factor of the undetermined factors that don’t match the crop requirements leads to a change in the value one class. the difference of one factor gives the value S2, two factors S3. Three factors S4 and four factors S5 and more than that gives the value N1 giving the reason.

The same thing repeated in each record of the theme records until finishing the intersected map records. Determining the type of optimal use of crops. Types of uses compete for highly productive lands while appropriate patterns for medium and low land in their productive capacity are limited (Bani et al.2003). Three Variables were used in this study;

1. Water availability factor
   - Availability of irrigation water: agricultural plant must be done according to the optimal conditions but performing is done with water availability.
   - The area suffers from water scarcity due to dryness of the Khabour River, and it has some wells that are used for drinking for human and livestock.

2. gross margin using (state group of the ministry of agriculture, 2016). Based on the wholesale cost average.
3. water requirements for crop irrigation at m3/h.
Table 1. Classification of the studied crops according to the cultivation season and irrigation method

| group          | crop                          | season  | irrigation                                      |
|----------------|-------------------------------|---------|------------------------------------------------|
| Cereals        | Wheat-Quinoa                  | winter  | Rain fed and supplemental irrigation            |
| legumes        | lintel                        | winter  | Rain fed and supplemental irrigation            |
| fruting trees  | Apple-pistachio-almond        | perineal| supplemental irrigation                          |
| Forage crops   | Forage beet-red oat           | winter  | supplemental irrigation                          |

Table 2. Suitability classes according to land use

| Suitability classes | Semi suitability classes                | Land use % | Area H | Percent % of the total area |
|---------------------|----------------------------------------|------------|--------|----------------------------|
|                     |                                        | Agricultural lands | pastures | Barren |                                |
| S2                  | CaSo4                                  | 55.79      | 31.49  | 12.66                       | 17373.11 | 41.52 |
| S3                  | EC, CaSo4, Tmax, slope, lgp productivity | 30.38      | 59.44  | 10.15                       | 11829.8  | 28.27 |
| S4                  | Caco3, EC, CaSo4, Tmax, slope, lgp, CEC | 12.06      | 80.95  | 6.99                        | 5730.911 | 13.70 |
| N                   |                                        | -          | -      | -                           | 14.81    | 0.335  |
| N1                  | CaCo3 CaSo4, Tmin, slope, CEC, stone, om | 1.97       | 93.49  | 4.54                        | 6893.33  | 16.47  |

Fig. 2. Map of the land suitability.

Table 3. Crop distribution areas and percentage of this distribution

| Crop type                  | Area h | Percentage % |
|----------------------------|--------|---------------|
| N                          | 39.15  | 0.09          |
| N1                         | 5968.67 | 14.25        |
| farm structures            | 10185.83 | 24.31        |
| lentil                     | 7436.21 | 17.75        |
| Lentil-almond              | 62.29  | 0.15          |
| Wheat-forage beet-red oat  | 6792.24 | 16.2          |
| Wheat-almond-forage beet-red oat | 4049.82 | 9.67          |
| Wheat-almond-apple-forage beet-red oat | 20.89 | 0.05          |
| Wheat-forage beet          | 1510.69 | 3.61          |
| Wheat-lentil-forage beet-red oat | 1346.2 | 3.21          |
| Wheat-lentil-almond-apple-forage beet-red oat | 249.68 | 0.6           |
| Wheat-lentil-almond-forage beet-red oat | 278.4 | 0.66          |
| almond                     | 165.89 | 0.41          |
| almond-apple               | 1562.64 | 3.73          |
| wheat-Quinoa-forage beet-red oat | 158.346 | 0.378        |
| wheat-Quinoa-almond-apple-forage beet-red oat | 2049.75 | 4.887         |
| wheat-almond-forage beet-red oat | 18.3 | 0.045         |
Optimal crops use

Types of uses compete for highly productive lands while appropriate patterns for medium and low land in their productive capacity are limited (Bani et al.2003). Three Variables were used in this study:

1. Costs: (Agriculture statistical group, 2016).
2. Gross margin using (Agriculture statistical group, 2016). Based on the whole sale cost average.
3. Water requirements for crop irrigation at m3/h.

where:

\[ x_1 + x_2 + x_3 \leq 6792.24 \]
\[ 158283.4x_1 + 203808x_2 + 185160x_3 \leq 210000 \text{ s.p} \]
\[ 202200x_1 + 308800x_2 + 109675x_3 \leq 300000 \text{ s.p} \]
\[ 3220x_1 + 1500x_2 + 2000x_3 \leq 2000 \text{ m}^3 \]
\[ x_1, x_2, x_3 \geq 0 \]

Table 4. Proposed crops and production constraints

| Factors       | Red Oat | Wheat | Forage Beet |
|---------------|---------|-------|-------------|
| area          | 158283.4| 203808| 85160       |
| Cost (s.p)    | 202200  | 308800| 109675      |
| Gain (s.p)    |         |       |             |
| Water requirements m3/h | 3220 | 1500.00 | 2000 |

To resolve the model of optimal crops uses, SOLVER under Excel was used:

Step 1: The target cell and limitations are entered to SOLVER program
Step 2: pressing add Where the option add is to add limitations by pressing it
Step 3: In cell reference, the limited value (constraint) was entered while in the cell of the constraint was filled by the limitation's values.
Step 4: pressing the SOLVER button. at the end, we press the button ok to obtain the output.

The resulting solution indicates that wheat crop cultivation occupied the largest area of 6059.421 while oats occupied 733 hours. Then beet fodder with 0 hours so it is not recommended to plant it here.

Table 5. The resulting solution

| Factors       | Red Oat | Wheat | Forage Beet |
|---------------|---------|-------|-------------|
| area          | 0       | 6059.42| 733         |
| Cost (s.p)    | 158283.4| 203808| 85160       |
| Gain (s.p)    | 202200  | 308800| 109675      |
| Water requirements m3/h | 3220 | 1500.00 | 2000 |
Table 6. The optimal crops distribution and percentage

| crop    | area  | Percentage % |
|---------|-------|--------------|
| N       | 39.21 | 0.094        |
| N1      | 5977.65 | 14.268   |
| farm structures | 10201.15 | 24.349 |
| Apple   | 26.96 | 0.064        |
| Lentil  | 9324.47 | 22.257   |
| Wheat   | 12391.94 | 29.579   |
| Quinoa  | 3888.93 | 9.283     |
| almond  | 44.69 | 0.107        |

Conclusions

This study attempted to obtain a model for optimal land use in the study area. From the results, the study concluded:

1. Models of land use to get the optimization advantages of farming in the study area with a combination of planting: Wheat 12391.94 ha, Lentil 9324.47ha, Quinoa 3888.93ha, almond 44.69 ha, and Apple 26.96ha.
2. GIS is an effective tool for mapping, creating database, spatial description, and land uses requirements mapping.

3. LAMIS was adequate software to evaluate land suitability for single or multiple crops in the study area.

4. Typing and solving of the optimal use of field can be made using SOLVER program in excel that doesn’t need big knowledge of the complicated mathematical concepts.

5. An agricultural plan can guide farmers to produce varieties and crops required in the local and out markets.

6. Good management of land resources to conserve the land, can support the national economy and improve the farmer's income.

7. The study showed that the best crops from the viewpoint of economic are those don’t need more water, high yield, and low cost.

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