Integrating Linear Programming and Analytical Hierarchical Processing in Raster-GIS to Optimize Land Use Pattern at Watershed Level

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ABSTRACT: It is very important to develop an optimum land use pattern, in accord with ecological and economic constraints. However, studies indicate capability of linear programming to optimize allocation problems, land use planning is dealing with handling spatial information, and Linear Programming has not been developed for. To handle spatial Data leads to use Geographical Information Systems. Study area is about 28000 ha of Keleibar-Chai Watershed, located in eastern Azerbaijan, Iran. Socio-economic information collected through a two-stage survey of 19 villages, including 300 samples. Thematic maps also have summarized Ecological factors, including physical and economic data. A comprehensive Linear Programming model established, including 106 variables and 43 ecological-socio-economic constraints. Land capability and suitability evaluation accomplished using ecological factors and Comparative Advantages of the uses and the factors, respectively. Analytical Hierarchical Process followed to determine the Comparative Advantages. The allocation process employs a Multi-Criteria Evaluation and a Multi-Objective Land Allocation procedure. Hereby, Linear Programming optimum pattern entered in the process. IDRISIW2.008 Raster-GIS used for doing the spatial analysis. So, 5192, 1019, 94 and 9354 ha of rain-fed barley, walnut orchard, park and rangeland assessed and allocated in the pattern respectively. The model is easily retrievable; however, plenty of data is required. Integrating a non-linear model into GIS is also recommended. @ JASEM
Cereal cultivation and animal husbandry are the main Agricultural activities in the region and all have been done using traditional methods. Fig. 1 indicates the location of the study area in northwestern Iran. Suitability of a certain Land is evaluated according to both natural capability of the land and the economic conditions, which the land has been surrounded by (Riedel, C. (1995). Two group of information have been collected and utilized to develop the allocation model. The First is spatial data collection, which includes thematic maps of physical and natural characteristics of the study area (Forest, Range and Watershed Management Organization of I.R. Iran, 1995) and topographic map of the region in scale 1:50000 (Army Geography Organization of Islamic Republic of IRAN, 1998). The second is attributions, which includes information of production procedures in current land uses. To collect the information, rural residents have been posed an open questionnaire. The information has been collected through a two-stage sampling plan. Type of land use, material and financial input–output among different land uses, transportation costs of Goods, local markets, Land rent, amount of wages; demand for laborer in agricultural activities and potential of investment of the farmers have been extracted from the questionnaires. To allocate scarce resources between competing uses, “Transport Model” has been employed. Hereby, land and the different land uses could be considered as the good and the virtual destinations, respectively. Annual present net value of interest, derived from investment in land is the benefit, which is going to be maximized. Equation (1) indicates a Transport Model, including an objective function and constraints, made compatible to transform into a Linear Programming optimization function (Martinez-Falero and et al., 1995).

\[
\begin{align*}
\text{Max}(\text{Min})C &= \sum_{j=1}^{n} \sum_{i=1}^{m} C_{ij} X_{ij} \\
\text{Subject to:} & \quad \sum_{i=1}^{n} X_{ij} = a_i \\
& \quad \sum_{j=1}^{m} X_{ij} = b_j \\
& \quad X_{ij} \geq 0
\end{align*}
\]

Where, \( C \): The amount of the objective function, \( C_{ij} \); The coefficient of the variable, \( X_{ij} \); The variable, \( a_i \); Available amount of a certain resource, \( b_j \); An expected amount of a certain demand, \( i \) and \( j \); The indices of the variables, \( n \) and \( m \), are Number of Supply and number of demand; respectively.

The objective function is the main part of the model. The first step is to define the variables, which presents amount of annual investment in a corresponding land use. The variables have been labeled, using indices to make an inter-link between land use types and their locations in a mathematical term. In this study, the labeling method is based on a spatial procedure in GIS. A SQL modeling also has been employed to indicate ecological land capability of the region for establishing six major land uses, including irrigated cultivation, rain-fed cultivation, orchard management, rangeland management, recreational park and forest land. So, the study area has been classified into 7 sub-regions, which are ecologically homogeneous. It implies that it is just
possible to establish some certain land uses in a sub-region and some others are not, irreversibly. Economic homogeneity also has been estimated using statistical analysis of the questionnaires in each ecological homogeneous sub-region. So, the variables have been labeled by three-parted indices. The second step is to calculate the corresponding coefficients of the variables. The coefficients indicate Annual Present Net Value of Interest (APNVI). Econometrics techniques and benefit/cost analysis have been employed to calculate it for the land use types. The Constraints are the next part of the model, including expressions to define different types of restrictions, through which the model should be optimized and analyzed. A constraint includes two parts; the first is the variables expression and the second is amount of different resources (Right Hand Side). In this research, 7 groups of constraints have been considered, which present: a) Land resources, b) Land use inter-relationships, c) Technological, d) Economic, e) Environmental, f) Legal, and g) Social restrictions. The model has been established for the study area, including 106 variables and 43 constraints. To evaluate land suitability in GIS, the factor maps were digitized and convert to raster format with resolution of 15m, using Idrisiw3.2. Then, the factor maps have been scaled into 8-bite range of Idrisiw3.2 (0-255). Through interviewing with local farmers supporting with an intensive literature reviews, the relative importance of the factors has been estimated. The weights of the factors have been calculated, using Analytical Hierarchical Processing (AHP) which range between 0 and 1. Then each scaled factor map has been multiplied by its corresponding weight. In each point (cell), the new scores have been compared and ordered among the factor maps. Set of priority weights also have been considered for the orders. So the process is continued with a further multiplication of the scores by the weights of the orders (Order Weighted Averaging). The maps have been ranked into new orders of the points (cell), to be allocated to the uses in turn. Also another AHP process has been used to determine the weight of the relative importance for the uses, by comparing their corresponding APNVI’s. Finally, Land resources have been allocated to the uses according to the ranks. The optimum amount of the land uses, estimated using LP, considered in allocation procedure.

RESULTS AND DISCUSSION
Optimum pattern has been assessed using linear programming Optimization procedure, including 5192, 1019, 94 and 9354 ha of rain-fed barley, walnut orchard, park and rangeland; respectively.

Fig 4. Land use patterns, a) the Economic Optimization, b) the Ecological Land use planning

Then, corresponding optimum land use pattern has been offered for the region, using the Multi-criteria land allocation method as shown in Fig.4 a. It presents the economical place of the land uses in the region. Comparing the optimum pattern with the current one has been demonstrated in tab.5. Table5 also presents the corresponding confusion matrix for (Congalton, et al., 1983, Fallah Shamsi, 2002). The overall agreement of the optimum pattern is about 30% for entering conservation constraints in the LP model. It means more than 70% changes are necessary till the current pattern reaches to the economic optimum one. It means more than 9000 ha of current dry farming and Range management.

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activities should be changed to absolute conservation practices. It is because rural residents don’t consider slope steepness and soil erosion hazards for dry farming and animal grazing. About 1000 ha could be allocated for orchard managements but it has been avoided just because of public ownership on the lands. It means a potential of (illegal) changes in future because of its economic-ecological suitability. More than 5500 ha of lands, suitable for range management are currently under conservation and dry farming practices. It is mostly because of official authority of Department of Environmental Protection in the region to conserve natural lands by law.

Table 5. Comparing the optimum (Column) against Current land use pattern (Row) (ha)

<table>
<thead>
<tr>
<th></th>
<th>D. Farming</th>
<th>Range</th>
<th>Orchard</th>
<th>Recreation</th>
<th>Conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Farming</td>
<td>6.19</td>
<td>83.59</td>
<td>20.36</td>
<td>-</td>
<td>146.99</td>
</tr>
<tr>
<td>D. Farming</td>
<td>744.66</td>
<td>1530.52</td>
<td>164.77</td>
<td>0.05</td>
<td>1089.45</td>
</tr>
<tr>
<td>Range</td>
<td>1674.81</td>
<td>3570.37</td>
<td>306.56</td>
<td>-</td>
<td>7857.97</td>
</tr>
<tr>
<td>Orchard</td>
<td>18.23</td>
<td>92.84</td>
<td>44.84</td>
<td>6.93</td>
<td>168.19</td>
</tr>
<tr>
<td>Recreation</td>
<td>1.51</td>
<td>89.57</td>
<td>0.09</td>
<td>53.91</td>
<td>59.18</td>
</tr>
<tr>
<td>Conservation</td>
<td>2724.37</td>
<td>3968.03</td>
<td>478.76</td>
<td>33.26</td>
<td>2943.09</td>
</tr>
</tbody>
</table>

An overall agreement between the economic optimum and ecological land use plan (Makhdoom, 1993) is about 42 %. It means 58% of expected changes will happen just because of socio-economic factors. It is while both economic and ecological land use planning’s offer extensive changes in current pattern. Tab.6 also presents corresponding amounts of economic (financial) differences, resulted by changing planning method at the watershed level. It indicates about 1475 and 1072 million unit losses because of treating the region like current land use pattern, comparing with economic and ecological planning; respectively.

Table 6. Economic (financial) differences of regional land use patterns, Resulted from current, economic and ecological Land use planning (+/- M.U./yr)

<table>
<thead>
<tr>
<th>Economic Optimization</th>
<th>Current Pattern</th>
<th>Ecological Planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Optimization</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Current Pattern</td>
<td>-1475.19395</td>
<td>0</td>
</tr>
<tr>
<td>Ecological Planning</td>
<td>-1072.76178</td>
<td>+384.43217</td>
</tr>
</tbody>
</table>

Conclusions: The model has a good capability of integrating mathematical programming and decision techniques in GIS. It considers and analyzes more participating Economic and physical factors simultaneously rather than ecological land use planning method. However, establishing the model needs a solid background of Mathematical programming and GIS decision support system, it is easy to use for managers with moderate knowledge of LP and GIS. By changing economic and technological conditions of the region, the model could be employed by mangers to estimate and to map amounts and locations of expected changes as like a warning system. In practice, land resource management is the main objective of the model. So it is very important to consider “irreversibility” in the results. So it is necessary to accomplish an additional risk assessment for the stability of the land uses pattern for economic short, intermediate and long run. Because of non-linear behavior of regional variables and constraints in economic environment, it recommends a non-linear model to be integrated into a GIS.

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