Land use Change Modeling Using Multi-Criteria Decision Analysis and GIS

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Introduction

The main goal of this research is to develop a model, based on GIS and MCDA methods, for both the assessment of present land uses and the allocation of future land uses. For this purpose, two models are developed to determine land use suitability and compatibility, using GIS functions and MCDA methods of TOPSIS, ELECTRE and SAW. Finally, a model is developed for the allocation of new land uses, on the basis of parameters such as land use suitability, land use compatibility, difficulty of land use change, and land use demand. In this model, land units with lower levels of suitability and compatibility are considered and evaluated to be changed to more adequate land uses.

Materials and methods

3. Land use Suitability model

The first part of the research is to develop a land use suitability model. A land use suitability model quantitatively calculates the suitability of each land unit for different land use types such as urban and industrial, irrigated farming, dry farming, pasture, forest etc. This model can be developed by combining tools and methods like GIS and Multi-Criteria Decision Making (including TOPSIS, ELECTRE, and SAW).

On the basis of existing studies related to the present land uses and ecological conditions of Iran, carried out by Makhdoum (1999), Keshavarz (1998), Sharifi (2004), Madadi (2003) and Jafari (2005), the criteria for land use suitability were defined, which include slope, elevation, slope direction, climate, erosion level, soil type, and density of vegetation. For each of the determined criteria, a proper map was created, showing the values related to that criterion in the entire study area. To be used properly, the values in the map of each criterion were required to be classified according to the available ecological models for Iran. For example, the real slope values in the slope map were classified into some pre-defined classes of slope ranges. Based on the available studies and the experience and knowledge of the consulted experts, different numerical values are assigned to each map class, for each land use type. Every assigned value to a criterion map class shows the suitability of that criterion class for a defined land use type. For example, in a slope map, the suitability levels of different slope classes for irrigated farming are represented. In every criteria map, the values for different classes are arranged in a way that their summation is one.

As mentioned, different criteria are considered for determining the suitability of lands for any land use type.

Yet, the importance of each criterion varies for different land use types. Here, structured pair wise comparison method was used to weigh the criteria, according to their importance for various land use types. This weighing method is a version of AHP method, a well-known Multi-Criteria Decision-Making method developed by Saaty (1980).

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Afterwards, standardized criteria map is produced according to the criteria classification and the weights assigned to the criteria. In other words, the values of different classes in each criterion map are multiplied by the weight assigned to that criterion. As a result, for each criterion and each land use type, there is a map which shows the suitability of different locations for a land use type, with regard to a specific criterion. Finally, for every land use type, the resulted criteria maps should be integrated in order to calculate the general suitability of all locations, with regard to all criteria. In the final step of land use suitability modeling, standardized criteria maps are integrated by TOPSIS, ELECTRE and SAW methods and the suitability level of each land unit for different land use types are calculated.

1. **Land use Compatibility Model**

Development of a land use compatibility model for the existing land use types in the study area was another milestone of this research. The land use compatibility model determines the level of land use compatibility between each land unit and its surrounding units. According to land use planning rules, the arrangement of land use types in a location should be such that the unwanted and repulsion effects between neighboring land units are minimum. GIS analytical operators, land use compatibility matrix and AHP method are used to develop this model.

In general, a pre-defined compatibility matrix is used to define the compatibility conditions among neighboring land uses. Land use compatibility matrix values are usually determined by experts and are a representation of different levels of consistency among different land uses. Experts usually express their preferences and judgments about the compatibility of different land use types in terms of qualitative levels and values. However, such qualitative judgments cannot be easily integrated with other numeric values in the rest of the research. Therefore, qualitative values in compatibility matrix are needed to be first converted to quantitative values, in a process as described by Taleai et al. (2007).

In the next step, the total compatibility value of each land unit is calculated according to its land use compatibility with all of its neighboring land units. The researchers have provided numerous aggregation methods for the combination of individual land use compatibility values, each of which has different advantages and disadvantages. In this research, according to the nature of modeling and the compatibility levels (values), a method has been provided to determine the level of compatibility for every land unit. Two different concepts of compatibility, called simple and weighted compatibilities, are used in his method.

2. **Recommended Land use Change Model**

The two developed models of land use suitability and land use compatibility are to be used by the land use change model. This model, essentially, tries to first find the land units with the most unacceptable land use, and then allocate the most proper and favorable land use to such land units. The recognition of land units with unacceptable land uses is on the basis of the results from the two models of land use suitability and compatibility. Similarly, for such a land unit, the appropriateness of other land use types are assessed based on the results obtained from the land use suitability and compatibility models, along with other factors such as per capita (land demand) and the difficulty to make the considered land use change. For developing this model, GIS spatial analysis functions, AHP method, change difficulty matrix, land demands and the results from the previous two models were used.

When only suitability and compatibility levels are considered for changing unacceptable land uses, it would be possible to propose a land use change that is practically impossible or very difficult. For example, a residential area could have a low level of acceptability for residential land use, and at the same time, a high potential for irrigated farming. Yet, because it is already developed as a residential area with dense and newly built buildings, it will be very costly and almost impossible to change it to proper irrigated farms. Therefore, another measure should be defined to account for the difficulty and complexity of land use change.

To take this concept into account, the "difficulty of change index" is developed. The method of calculating difficulty of change is similar to the calculation of land use compatibility. First, the values of the difficulty of change matrix are determined in terms of qualitative values.

To carry this out, different experts on land use change were consulted, and their points of view are integrated using AHP method. Finally, the resulted qualitative values are converted into quantitative values, in order to be used in the land use change model.

First, the weighted averages of suitability and compatibility levels are calculated for all land units according to the results of land use suitability model and land use compatibility models. This simple weighted average is used for sorting and classifying land units. Such a classification is used to find lands with inappropriate situations and to consider them as candidates for land use change. Although more advanced methods and concepts can be used for the determination of such candidate lands, here, for the sake of simplicity, only the averages of suitability and compatibility values are used.

Having the above values, the lands that are candidate for land use change were selected and ordered. Now, for every candidate land, the general appropriateness for each demanded land use type was required to be calculated. This general appropriateness was defined based on the results of the land use suitability and land use compatibility models, combined with a measure of the difficulty of change. In other words, for any candidate land, the appropriateness of every land use change from its existing land use to any other land use type is calculated and sorted in a vector. Similar to the selection of candidate lands, here, a simple weighted average of the values related to the land use suitability, land use compatibility and land use change difficulty is considered as the appropriateness of the land use change. The weights are normalized such that their summation equals to one.

Now among all candidate lands and their target land uses for change, the maximum value is selected. In other words, a candidate land along with one of its target land uses that generates the maximum value of appropriateness for change is selected, and for that land the target land use is assigned. An important point is that any land use change will affect the compatibility of other land uses in its surrounding. Therefore, after making any change in the land use of any land unit, all compatibility model values should be recalculated and the new weighted compatibility values should be used in the next steps. In this model, per capita concept is also used, which is simply a measure of the amount of area required for every favorable land use type. Per capita are determined according to the area and population and with the intention of keeping balance between the areas dedicated to different land use types. If the per capita for a land use type is fulfilled, then it would not be assigned to any other land unit. For example, suppose that a candidate land unit is selected to be changed to dry farming according to the calculation of appropriateness for change, when the per capita for dry farming land use has been fulfilled. Thus, the second optimum number (second maximum number of appropriateness) is assigned for that land unit.

Conclusion

The result of this research is the provision of three suitability, compatibility and land use change models. The land use suitability and compatibility models identify the present condition of land uses in the study area. In land use suitability model, the best method for integration of criteria and calculation of land use suitability was the TOPSIS method. This was mainly because of the existing spatial dependency between criteria maps, which affects the results of the methods strongly. Having this model, it is possible to identify land units that are not developed according to the ecological conditions required for their land use. In land use compatibility model, land uses that are incompatible with their surrounding land uses are identified and their weighted compatibilities are calculated. In land use change model, land units of inappropriate land use are identified and the best replacing land uses are suggested for them, using the suitability and compatibility models and considering per capita and difficulty of change parameters. Besides the analysis of the present condition of land uses, these three models provide the possibility of evaluating future land use patterns and scenarios from the land use suitability, compatibility and per capita levels points of view.

Key words

Land Use Change, Suitability, Compatibility, Multi-Criteria Decision-Making Analysis, GIS