MODELLING LAND ALLOCATION PROCESS IN TIME AND SPACE

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ABSTRACT

Modeling land allocation for different land uses at regional level is a multi-dimensional problem, as it is influenced by spatial, temporal and dynamics of environmental and socio-economic factors in the complex process of land use change. It is therefore a challenge to develop a proper model that can handle these complexities. In this context, a new model has been conceptualized and developed. The model is considering the expert knowledge, the heuristics and human decision-making in modeling the process of land use change. This paper briefly presents the conceptual model, which is developed based on cellular automata concept and tested with the Borkhar and Meymeh township datasets in Esfahan, Iran.

1. INTRODUCTION

Land use allocation process is the result of interaction between land suitability and land demand in an environment affected by socio-economic, political and administrative rules and regulations. Therefore, it is a complex, dynamic and non linear process. The assessment of land suitability for land use types is normally carried out by comparisons of the land use requirement with the land use characteristics. This process is mainly implemented at polygon or pixel “micro level”. On the other hand, the demands for different land use types are estimated at administrative “macro level”, considering various scenarios. The interaction of the above two processes “in micro and macro levels” derived by various socio-economic variables of the environment causes the land use change, and can be used for land allocation.

This paper briefly presents a new conceptual model for land allocation process at regional level. The model is based on application of the basic tools and techniques such as geographic information systems, remote sensing, fuzzy logic, cellular automata, analytical hierarchical process, and spatial multi-criteria decision analysis. The developed model is implemented in Borkhar and Meymeh Township, in Esfahan province, Iran, for the periods of 1986-1998 and 1998-2005. The paper first presents the conceptual model, followed by introduction to the study area, some implementation results followed by discussion and conclusions.

2. CONCEPTUAL LAND ALLOCATION MODEL

Land allocation for different land use types at regional level is a multi-dimensional problem, as it is influenced by spatial, temporal and dynamics of environmental and socio-economic factors in the complex process of land use change. In this context, a model has been conceptualized and presented in Figure 1.

The model includes three major processes i) land suitability assessment, ii) land demand assessment, and iii) land allocation. In the land suitability assessment model, suitability of each location for different land use types is assessed by determining and integrating the effects and impacts of environmental and socio-economic factors. In land demand assessment model, using different concepts such as analysis of trends and scenarios, demand for each land uses are estimated. Finally in the allocation model, considering land suitability, land demand, the current land use/cover and land use conversion rules, land use types are assigned to each locations. In the following each of these models are briefly described.

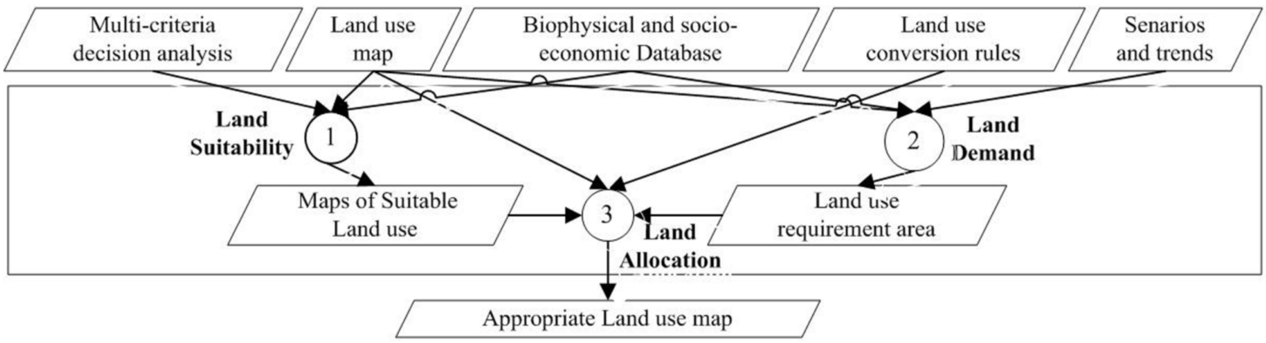

Figure 1. Major components of land allocation model

3. LAND SUITABILITY ASSESSMENT MODEL

Study of land suitability concept in literatures shows consideration of series of environmental and socio-economic criterion. In this research major characteristics of land are considered to determine the land suitability of each piece of land "pixel" for different land use types. These are physical (intrinsic) suitability; accessibility to infrastructure, and major population and industrial centers; neighborhood effects and impacts and land use restrictions (Figure 2).

3.1 Physical suitability

Physical suitability is assessed by comparisons of the ecological land characteristics with the requirements of land use types "LUT" (F.A.O, 1976; Makhdoum, 1999; Ahamed et al., 2000; Kalogirou, 2002; Sante-Riveira et al., 2008, Zucca et.al., 2008). In this model this has been carried out using fuzzy spatial multiple criteria evaluation and applying Makhdoum's ecological capability model (Karimi et al., 2009).

3.2 Assessment of accessibility to infrastructures

In this research, accessibility to relevant infrastructures (road network, electricity transmission, gas pipelines and water canals) and major activity centers (major population and industrial center) are considered. As described by karimi et al., (2010a), accessibility is assessed in the following 3 steps. In the first step, accessibility to relevant infrastructures is estimated based on equation 1 (Engelen et al., 1997):

$$A_{ijk} = \frac{1}{1 + D_{ij} / a_{jk}}, \ j = 1,2,3,4 \quad (1)$$

Where A_{ijk} = the accessibility of pixel i, with land use type k, to the infrastructure j
Dij = the Euclidean distance of pixel i to the nearest pixel of the infrastructure j
a_{jk} = the relative importance of access of land use type k to the infrastructure j.

In the second step, accessibility of population centers to major activity centers is determined using gravity model (Geurs and van Wee, 2004), as presented in equation 2.

$$A_g = (\sum_{k=1}^{K} P_k * e^{-\beta T_{gk}}) \quad (2)$$

Where A_g = the accessibility of population center g to all major activity centers
P_k = the importance of activity center k
T_{gk} = the distance of population center g to activity center k
β = adjustment parameter

In this equation, β plays a similar role as to a_{jk} in equation 1. The importance of population and industrial centers are assumed to be represented by their population and number of employee respectively. In most models, usually accessibility is defined using the concept of Euclidean distance. In this research, time is taken as the basis of calculating accessibility. Using the road networks and corresponding allowed speed, time is estimated and used for the assessment.

The resulted values of accessibility to activity centers are assigned to the population centers "points", in contrast to accessibility to linear infrastructure which is calculated for each pixel. To integrate these two, the point-based values of accessibility to activity centers are needed to be propagated to the regions. Therefore, thiessen Polygon analysis is used to assign the accessibility values to the regions surrounding population centers.

In the third step, overall accessibility is calculated using the Weighted Linear Combination (WLC) of accessibility to infrastructures and activity centers (equation 3).

$$A_{ia} = \sum_j w_{aj} * A_{iaj} + \sum_k w_{ak} * A_{iak} \quad (3)$$

where A_{ia} = the overall accessibility of pixel i with land use type a
A_{iaj} and A_{iak} = the accessibilities of pixel i with land use type a, to infrastructure j and activity center k
w_{aj} and w_{ak} = the relative importance of infrastructures and major activities in relation to land use type a

3.3 Land use interactions and neighborhood impacts

Land use interactions are usually modeled using cellular automata concept. Neighborhood effect for each cell is estimated through agglomeration of land use interactions effects of all adjacent cells, located in the influence region (White and Engelen, 2000; van Delden et al., 2007).

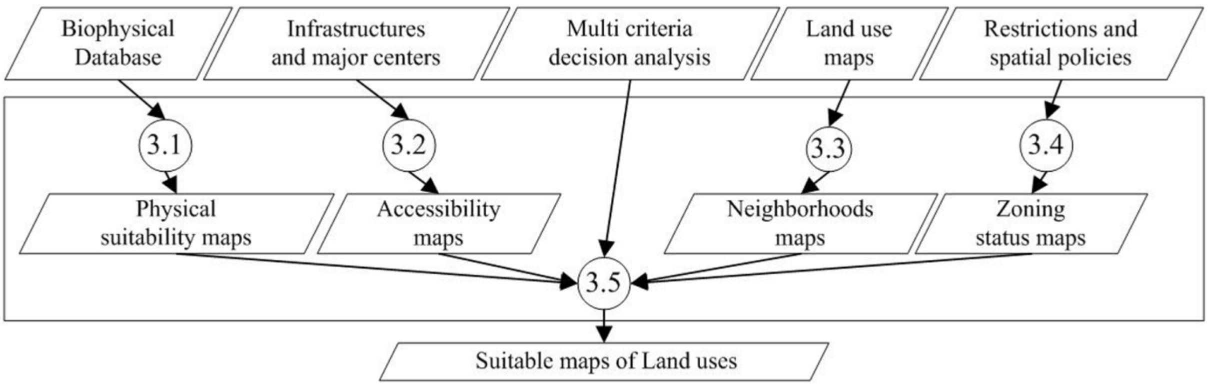

Figure 2. Processes of land suitability assessment

Land use interactions effects are usually represented as transition rules, showing the changes in interactions among land-use categories over distance. These interactions are usually called spatial externality. In generating transition rules, three main elements of influence radius, intensity, and distance decay should be defined (Hagoort et al., 2008). Land use interactions are conceptualized and modeled using linguistic variables, spatial metrics and expert knowledge. Various steps of this model are reported in (karimi et al, 2010b) and described briefly in the followings:

Modeling influence region: Land use interaction is mostly modeled considering eight neighboring cells, as consideration of more cells strongly increase the computation time. To overcome this limitation, hierarchical concept is developed by (van Vliet et al., 2009). As an improvement to that concept, in this research, a structure based on circular radius is proposed as a replacement for the square based structure of the hierarchical concept. This structure is more realistic, regarding the distance-based declining effect of neighborhood. In this representation, space is divided into circular levels, with distances flexible to the requirements of the experts.

Assessment of spatial externalities: The priced and un-priced radiated effects are assumed as a representation of the spatial externality intensity (Hagoort et al., 2008). These effects can be seen in land values. Moreover, often, land value is the main motivation of land use changes. Therefore, here, relative land values are determined using Analytical Hierarchical Process (AHP) (Saaty, 1980) and used as indicator of “intensity”.

The intensity of interaction between land use types usually declines over space. Yet, no mathematical or numerical methods have been developed for representation of these changes. This promotes the usage of expert knowledge. On the other hand, expression of expert knowledge using linguistic variables is easier and more straightforward. Linguistic variables of ‘very high’, ‘high’, ‘medium’, ‘low’ and ‘very low’ are considered for distance-decay. The spatial metrics used in this study is enrichment factor (Verburg et al. 2004), which is derived from land use types, extracted from the land use maps of the past two decades.

Finally, based on interpretation of spatial metrics by expert knowledge, distance decay of spatial externalities is assigned using linguistic variables (Table 1).

Table 1: Assessing the distance decay of spatial externalities

Land use type		Distance				
1	2	D1	D2	D3	D4	D5
U	U	+VH	+H	+M	+L	+L
I	U	-M	-L	-VL	0	+VL
R	U	+M	+M	+L	+L	+0
A	U	-VL	-VL	0	+VL	+VL
U	I	-L	-L	-VL	0	+VL
I	I	+VH	+H	+M	+L	+VL
R	I	-M	-L	-VL	0	0
A	I	-L	-L	-VL	0	0
U	R	-L	-L	+VL	+VL	+VL
I	R	-M	-L	-VL	+VL	+VL
R	R	+VH	+M	+VL	0	0
A	R	+M	+L	+L	+VL	+VL
U	A	-L	-VL	0	0	0
I	A	-M	-L	-VL	+VL	+VL
R	A	+H	+M	+VL	+VL	+VL
A	A	+VH	+H	+M	+VL	0

Spatial externalities of one land use on another in each distance or level of influence regions, is estimated by equation 4:

$$W_{k1,k2,r} = V_k * DD_{k1,k2,r} \quad (4)$$

Where $W_{k1,k2,r}$ = the spatial externalities of a cell with land use *k1*
V_k = the relative land value of neighbor cells with land use *k2*
$DD_{k1,k2,r}$ = the distance decay of neighbor cells, located in the rth level

The quantification of linguistic variables is carried out using structured pair-wise comparison (Sharifi et al., 2006).

Classification of neighborhood effects: Intensity and distance decay for different land use types are different. LUI can be grouped into three classes. Spatial externalities of a land use type on itself, is defined as compactness. Positive and negative spatial externality of a land use type on a different land use type is defined as dependency and incompatibility respectively. Regarding the comparison of these classes, the following points should be mentioned. Distance decay of compactness is steeper than of dependency and incompatibility. Yet, the distance decay of compactness effect is different for various land use types. Some of the negative spatial externalities, decline over distance and finally converts to positive externality.

The classification of the surrounding cells, into the classes of cells with compactness, dependency and incompatibility effects is on the bases of the two land use types involved. The spatial externality of the surrounding cells falling in each class is aggregated separately. Finally, neighborhood effect for each cell is the weighted average of the aggregated effect of three classes, as presented in equation 5.

$$N_{\mathrm{il}} = w_{\mathrm{C}} * C_{\mathrm{il}} + w_{\mathrm{D}} * D_{\mathrm{il}} - w_{\mathrm{I}} * I_{\mathrm{il}} \quad (5)$$

Where N_{il} = Neighborhood effect for pixel *i* with land use *l*
C_{il} = Compactness for pixel *i* with land use *l*
D_{il} = Dependency for pixel *i* with land use *l*
I_{il} = Incompatibility for pixel *i* with land use *l*
w_C, w_D and w_I = the corresponding weights of compactness, dependency and incompatibility

Value of neighborhood effect which is estimated for various land use types does not have absolute meaning and can only be used for comparison. Therefore, these values are normalized.

3.4 Zoning and committed land

Land use restrictions have a deterministic effect on the pattern of land use change. When determining the areas with unchangeable land use, spatial policy regulations, committed land and environmental and socio-economic hazards are needed to be considered. Some spatial policies, such as those regarding environmentally protected areas, restrict all possible land use changes. Others might restrict only a limited set of land use conversions. In addition, status of restriction may be altered during time and even be enforced, more moderately, as a weighted indicator.

3.5 Integrated assessment of land suitability

In order to determine the overall neighborhood effects, various effects should be integrated. In this research, an additive and multiplicative weighted average is used to integrate the above mentioned factors, as presented in equation 6.

$$P_{k,j} = \left(A_{k,j}\right)^{w_a} * \left(S_{k,j}\right)^{w_s} * \left(N'_{k,j}\right)^{w_n} * \left(Z_{k,j}\right) \quad (6)$$

Where P = the overall suitability for cell j with land use k
S = the physical suitability for cell j with land use k
A = the accessibility for cell j with land use k
N = the neighborhood effect for cell j with land use k
w_S, w_A, w_N, and w_Z = the relative importance of those parameters is represented by weights

4. LAND DEMAND ASSESSMENT

Demand for each land use type at each time step is estimated for each Land Demand Unit (LDU). Usually, two policies are considered in deciding on LDU. In the first policy, entire region is assumed as one large LDU, for which, the required land use types areas are estimated. As a result of this policy, the required land use types are mostly allocated around the major activity centers; this can be called agglomerated allocation. According to the second policy, the region is divided into a number of LDUs (small administration units) and the demand for each separate LDU is estimated. In such a distributed approach, the demand and allocation will be distributed over the LDU's. The non-linear historical model based on past trends, as presented in equation 7 is used for calculation of annual demands, in each LDU.

$$A_n = A_0 * (1 + r)^n \quad (7)$$

Where A_n = the required area for the nth year
A_0 = the area in the base year
r = the growth rate of land demand

Using the available land use maps, the A_0 and A_n, which are the land use areas in years 1986 and 1998, for example, and having the time step as 12, the r can be calculated. Later, using r value, the land demands for each year can be calculated.

5. LAND USE ALLOCATION

In land use allocation, beside land suitability and land demand, both the current land use/cover, and land use conversion rules and policies are playing a very important role. Changes of various land use types have diverse environmental and socio-economic effects. Conversion of land use types with high investment into other land uses is often very costly or even impossible. Usually possibility and degree of difficulty of land use conversion are quantified through structure pair-wise comparisons by experts. This concept of land use change difficulty can be integrated with the concept of land suitability. The result of such integration shows the total potential of a pixel with a present land use to change to another specific land use type. Therefore, the potential of each pixel to change to another land use is estimated based on equation 8.

$$TP_{k,j} = P_{k,j} * CM_{e,k} \quad (8)$$

Where $TP_{k,j}$ = total potential of cell j with land use k
$P_{k,j}$ = overall suitability of cell j with land use k
$CM_{e,k}$ = the degree of difficulty regarding change of land use type from e to k.

In present land allocation models, first, initial land uses are allocated using maximum suitability values only. Then, some of the initially allocated land uses are changed to balance land suitability and satisfied land demands. This process is called land demand adjustment (White and Engelen, 2000) or iteration variable (Verburg et al. 2002). In this research, a new pixel-based stepwise procedure for land use allocation is proposed (karimi et al, 2010a), which is shown in Figure 3.

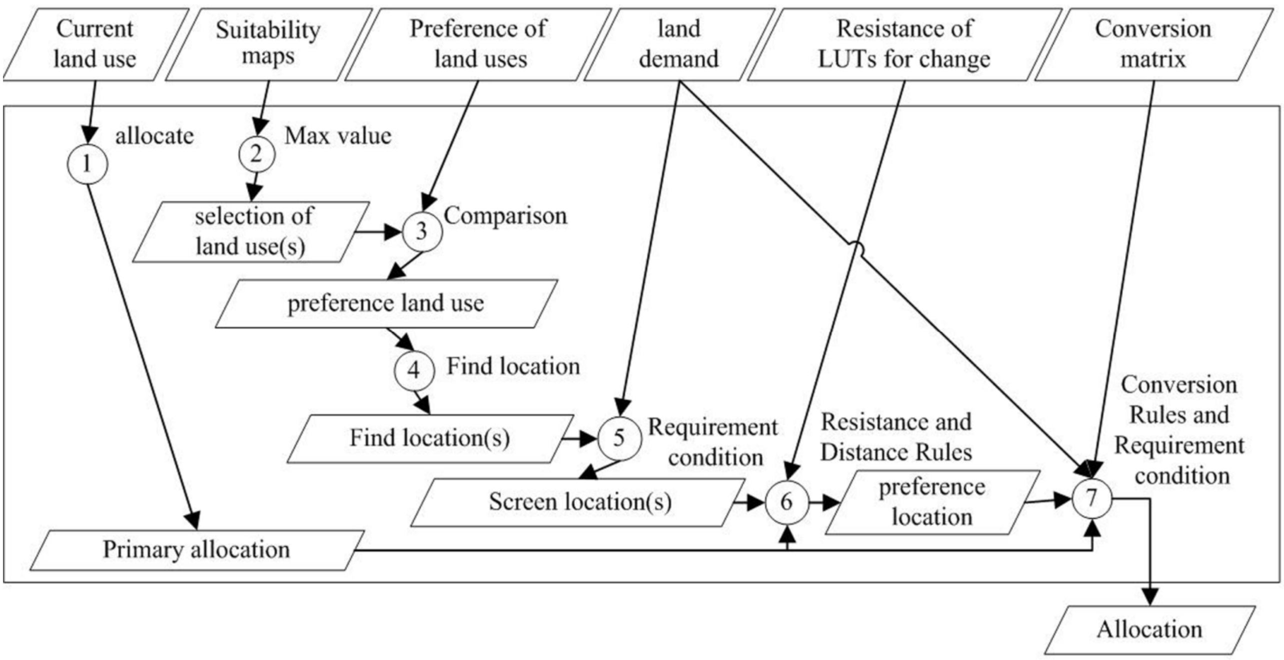

Figure 3. Land allocation process

6. IMPLEMENTATION AND RESULTS

6.1 Case study area

The study area is Borkhar and Meymeh Township located in the center and northwest of Esfahan province, Iran (Figure 4). It consists of 6 districts (Dehestans), 9 cities and 28 residential villages. Approximately 86% of the population lives in urban areas. In this region, mean annual population growth was 2.58% from 1986 until 1996 and 2.39% from 1996 until 2006, which shows high concentration and population growth.

The available date of the study area was studied and the periods of 1986-1998 and 1998-2005 were selected for the implementation and test of the model. There was no suitable land use map for the study area related to those time steps. Therefore, such maps were created by supervised classification of the Landsat images for years 1986 and 1998, and the ASTER images for the year 2005. The resulted land use maps consists of six classes of urban residential, rural residential, industry, agriculture, pasture and others.

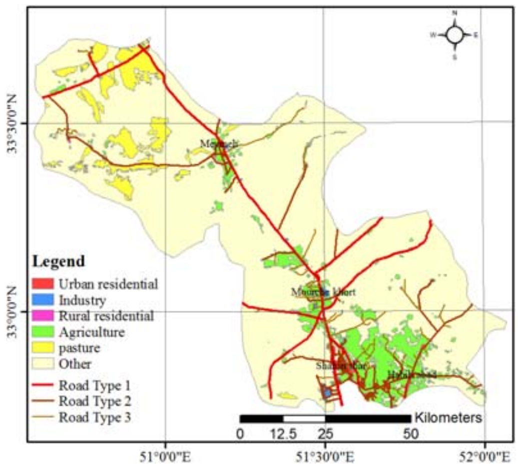

Figure 4: General map of the case study area

6.2 Implementation and results

The conceptual model was implemented in the case study area. In this process, the corresponding maps of physical suitability, accessibility, neighborhood effects, committed lands, demand and current land use map of the area were prepared in 1/250,000 scale. The demands for different land uses, was derived for the periods of 1986-1998 and 1998-2005. Next the simulated land use maps of the years 1998 and 2005 were generated, using the developed allocation algorithm (Figure 5). For evaluation of the results, the real land use maps of these years were also extracted from the relevant satellite images.

In LUC modeling, usually, three processes of calibration, evaluation and prediction are performed. In fact, the processes of calibration and evaluation are to ensure the quality of the prediction. These two processes were carried out using real data and expert knowledge. The calibration parameters extracted from expert knowledge were used in the model to derive the simulated map of future land use (Figure 5). Such map was then evaluated by its comparison with the actual land use map using Kappa coefficient. In addition, the Kappa coefficient for a randomly created land use map, called RCM, was also calculated. Those coefficients are compared in Table 2. This comparison shows the amount of similarity between the simulated map and the real land use map.

Table 2. Comparison of kappa coefficient for 1986-1998 (U: Urban residential, I: Industry, R: Rural residential, A: Agriculture)

	Total	U	I	R	A
RCM map	0.810	0.832	0.641	0.825	0.846
Simulated map	0.902	0.864	0.734	0.863	0.858
Difference	0.092	0.032	0.093	0.038	0.012

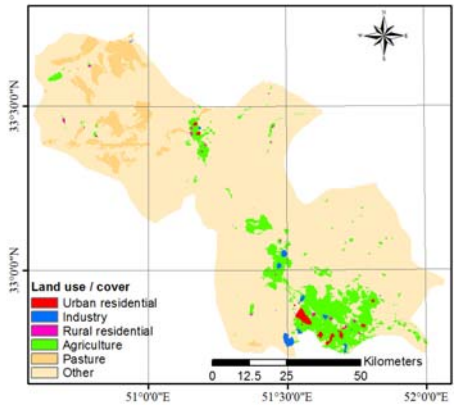

Figure 5: model-extracted land use map in 1998

A general idea about of the potential values of the areas with LUC can be conceived much better using a visual representation. In other words, the occurred LUC can be analyzed spatially, from the point of view of affecting factors. As an example, the total suitability of the areas changed during 1986-1998 to the land use types of agriculture are shown in Figure 6.

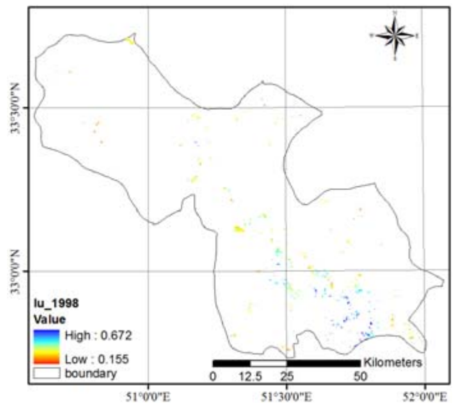

Figure 6: potential of occurred LUCs in 1988 for agriculture

7. CONCLUSIONS AND DISCUSSIONS

As a result of this research, a new method for LUC modeling in regional level is developed, tested and evaluated using the data of Borkhar and Meymeh Township. The presented conceptual model, which is developed based on cellular automata concept, contains the following novelties:

- One of the challenging issues in modeling land allocation is to calculate the land use interaction (neighborhood effect). In this research, neighborhood effect is broken down in to three components namely incompatibility, dependency and compactness. These components are modeled separately and combined in a multi-criteria decision analysis model, which leads to a new method for assessing the land use interaction.

- In the existing land allocation models calibration of parameters related to neighborhood effect are set through a trial & error process, which is considered disadvantage. In this research, attempt is made to estimate simultaneously the spatial interaction of land uses, accessibility to infrastructure, accessibility to major centers and physical suitability parameters based on heuristics of land use change and expert knowledge formulated through linguistic variables.
- In the physical suitability assessment model, fuzzy inference rules is implemented in the process of integrating various environmental layers (spatial multi criteria evaluation)
- In literature, usually accessibility to transportation network alone is considered. In this research, accessibility to all the relevant infrastructures is considered in the process of land suitability assessment. Infrastructure systems include transportation, electric power lines, gas pipelines and water canals.
- In this research, accessibility to major populated and industrial locations are considered and added to infrastructural accessibility.
- Integrated assessment of Land suitability is carried out using multi-criteria decision analysis.
- In this research a new allocation algorithm is developed based on land suitability, land demand, the current land use/cover, land use conversion rules, hubristic rules of land use interactions and land use change.

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