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Brownfield to Residential Land Use Change Modeling Using GIS-Based Weights-of Evidence Approach

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Abstract

Fast and unorganized urban development increases the number of abandoned lands and brownfields within the cities. Revitalization of these lands is one of the key factors to achieve urban sustainability. Most researches on this field have mainly considered a single brownfield site for redevelopment on the bases of local neighborhood demand and characteristics. The current paper proposes a brownfields land use change modeling process in a larger scale perspective rather than local aspects. The proposed model is a statistical-based weights-of-evidence (WoE) approach in the GIS environment. The changes probability of brownfield sites of the Qazvin city to residential land use was predicted using several urban development parameters. Next, the predicted map was aggregated with the existing brownfields map in order to evaluate by Master Plan of the Qazvin city. In this manner, existing brownfield sites are project according to planning strategies. Results indicate that according to potential and suitability of the site and neighborhood properties, each brownfield can serve the community as single or mixture of several land use types. It is concluded that the application of land use change modeling techniques in GIS environment can provide a strong tool for brownfields redevelopment planning and strategies.

Keywords*:* Brownfield Redevelopment, Land Use Change Modeling, Residential Land Use, Weights-of-Evidence, Geographic Information System

1. Introduction

Brownfields are abandoned or underused properties that should be redeveloped or reused because of the real or suspected presence of hazardous substances, pollutants, or containment (Collins 2002; Oliver et al. 2005). Redevelopment of existing brownfields is one of the important objectives to enhance the sustainable urban development theory (De Sousa 2008; Nijkamp et al. 2002) and reduce urban sprawl (Nuissl and Schroeter-Schlaack 2009). However, a brownfield redevelopment needs a comprehensive effort to resolve and negotiate among several stakeholders with different interests (P. Bardos 2003; Gross 2010). These complexities have caused many brownfields remain undeveloped, especially in developing countries. According to the literature, there is a variety of approaches for

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various aspects of brownfield redevelopment such as risk assessment, policy analysis, optimization of remediation, remediation cost assessment, general success factors for brownfield redevelopment, infrastructure redevelopment and etc. Hence, strong approaches are required to integrate these aspects and manage complexities of information and results.

Land use change modeling is important for various urban planning and management issues. It is a suitable approach to deal with redevelopment and revitalization of existing brownfields. Proper analysis and prediction of urban growth may prevent many social and environmental problems caused by the urban sprawl, suburbanization process (Helbich and Leitner 2009) and unorganized land developments. The main environmental problems that can be prevented are encroachment on valuable agricultural, forest, and natural areas. The rationale behind this concept is to try redeveloping existing brownfields inside the cities instead of growing built up areas through rural environments. Cho et al. (2011) attempted to solve this problem by evaluating the hypothesis that land value tax contained rural area development and encouraged compact and development closer to and within built up areas. Rall & Haase (2011) assessed the brownfield revitalization program of the City of Leipzig in the context of urban sustainability. The assessment was performed through a triangular integrated evaluation method combined with site surveys and interviews, as well as expert knowledge. However, these assessments and analyses can be improved significantly by modeling the land use changes in order to predict and propose a proper land use types for each brownfield site.

According to the literature, following four core principles are the bases of all land use change simulation models; historical evidence based, suitability bases, neighborhood bases, and actor interaction bases (Verburg et al. 2004). The logic behind historical evidence based is that, "past is the key for future". Therefore, background information can be helpful in predicting future land use change as demonstrated by Kuijpers-Linde et al. (2007). Suitability bases may consist of several factors in a land parcel in order to evaluate for an allocation of specific purpose (Abdullahi et al. 2014). Neighborhood bases deal with neighborhood interaction cells that affect the transition of one land use to another (Li et al. 2008). Actor interaction bases assume that land use change is the result of an interaction of several actors or agents. These core principle are promising research tools for land use change modeling (Jjumba and Dragićević 2012; Matthews et al. 2007).

There are a few main concepts of land use changes such as Markov Chains, Economic-based concept, Agent-Based Systems, Statistical Analysis, Cellular Automata, and Artificial Neural Networks. The Markov Chain concept is based on a continuation of historical trend of development. The main disadvantage of this model is the lack of spatial bases of results (Verburg et al. 2004). The Economic-based concept is also an important reason for land use changes and is mainly based on the suitability of a land. An Agent-Based Systems model of land use change modeling consists of two main components: a map of a study area and a model with agents that represent human decision-making (Parker et al. 2003). Various kinds of statistical computation can be derived from land use maps. For example, logistic regression, frequency ratio, and weights-of-evidence techniques can be used to analyze the probability of occurrence of a dependent variable on each class of independent variables (Verburg et al. 2004). The coefficients of each variable can be calculated from historical land use changes. Furthermore, they can be projected for future land use changes. The Cellular Automata (CA) is the most well-known techniques in modeling of land use changes (White and Engelen 1993). The main logic behind CA modeling for land use changes is the current state of each cell and its interaction with neighborhood cells. The use of Artificial Neural Networks (ANN) has increased significantly due to advances in computing performance and flexibility of software (Skapura 1996).The pattern recognition capability, that makes a relationship between past and future land use and suitability maps are important parameters that can emphasize the strength of ANN models in land use change modeling. Therefore, appropriate knowledge about the land use change modeling based on their concepts allows modelers to select the most appropriate model for area of investigation.

Land use change modeling requires availability of rich spatial data, spatial analysis tools, and displaying capability to illustrate the output maps. Geographic information system (GIS) and remote sensing are the most useful tools to support modeling. GIS can provide a proper environment to store, manage, analyze, manipulate, and display spatial data associated with the models. In addition, GIS can aid modelers to define and create spatial variables for the models, predict land use changes based on several independent spatial variables, and evaluate predicted changes in a spatial pattern. There are numerous studies on land use change modeling using integration of GIS technology (Li and Yeh 2002; Pijanowski et al. 2002; Verburg et al. 2004; Wu 1998). For instance, Thomas (2002) stated that to assess land use modeling performance with respect to the redevelopment of brownfields, accessibility of information such as land capability, environmental concerns, public preferences, etc. for both governmental agencies and decision makers are required. He discussed a GIS-based decision support system to provide access to geospatial data in various scales for better understanding of the brownfields redevelopment issue.

The current study is an attempt to analyze the urban land use changes and spatial patterns of the study area in a quantitative manner. Specifically, it illustrates how statistical-based weights-of-evidence (WoE) approach within GIS aids in the understanding of the process of land use changes. WoE was used to measure the extent and direction of residential land use growth based on several urban related factors and temporal datasets. In addition, the model was utilized to apply and evaluate the driving forces responsible for the change of land use types. One benefit of using the model is the ability to extract and utilize the most effective factors from all the selected factors before evaluating the probability of land use growth. By integrating this process with brownfield redevelopment strategy, one of the environmental objectives of sustainable development can be fulfilled.

Hence, this study initially predicts residential land use changes of Qazvin City using the probability map according to urban development parameters. The created probability maps and the master plan of the study region was used to assess the existing brownfields land use types. It should be mentioned that, due to utilization of the standard and common urban related parameters as well as statistical based methodology, by considering more number of land use types (commercial, industrial, facilities and etc) this process can be easily replicated in other international cities for brownfields redevelopment strategies.

2. Materials and Methods

The proposed modeling was used to predict the residential land use changes for Qazvin City, Iran. The study area is located 150 km from Tehran, the capital city of Iran (Fig. 1). Although there are many abandoned and brownfields sites in the city, most of the new developments in recent years have been constructed towards North direction, which is occupied by agricultural and natural areas. For this reason, the present research attempts to assess the brownfields land use changes to make Qazvin City more environmentally sustainable.

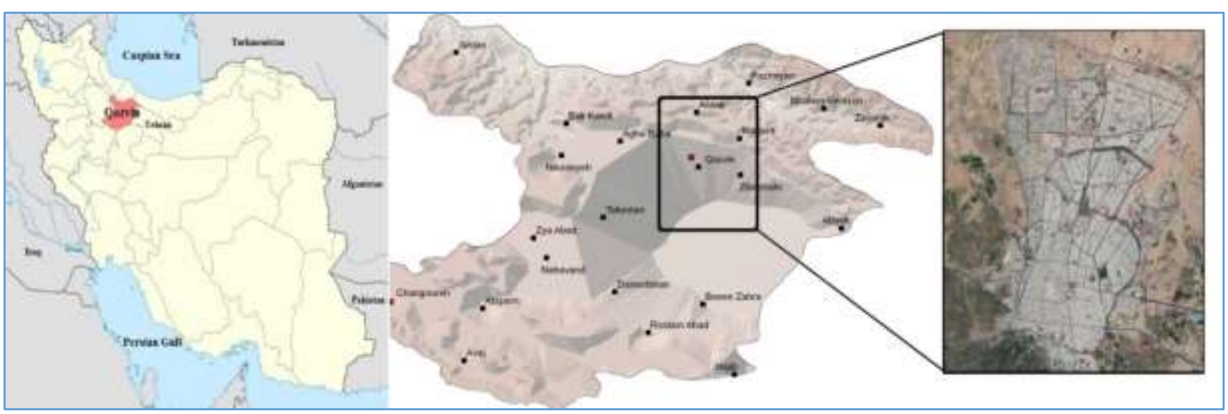


Figure 1. The map of Iran, Qazvin Province and Qazvin city

The overall methodological process is shown in Fig. 2. Most of the data, such as land use map, road network, population map, public transportation, etc., were collected from the local planning authority of Qazvin City. Other layers were extracted or created from the existing layers. It was essential to select the most important parameters among others, which have a significant effect on the land use conversion for the specific study area. Therefore, an optimization process was applied to select the most effective parameters. This process was performed by the frequency ratio (FR) approach, which is the initial step of running the weights-of-evidence technique (Pourghasemi et al. 2013; Pradhan et al. 2010). FR had the ability to examine the existence and changes (the increase or decrease) of land use types with respect to each class of all parameters. In this manner, the effectiveness of each parameter can be assessed by investigating the trend of land use changes based on their classes (Abdullahi et al. 2015). This process also assessed the spatial dependency of the factors.

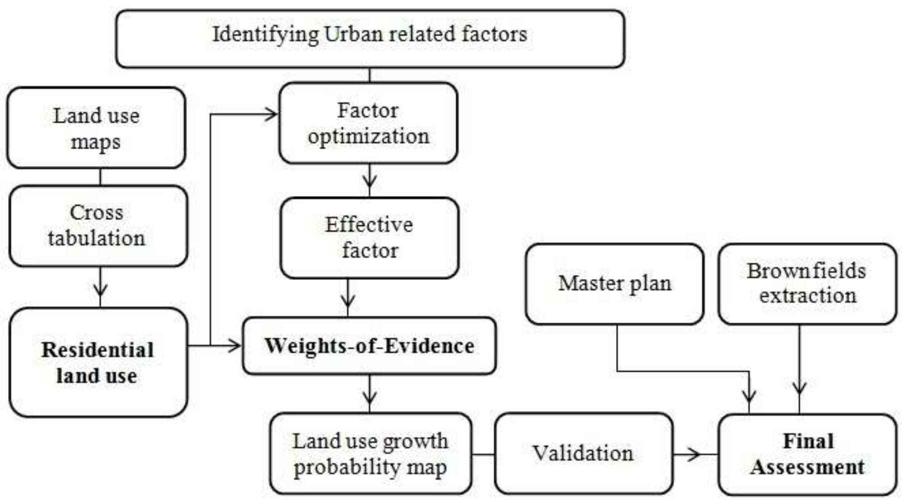


Figure 2. Methodology flowchart of the process

The classification of the parameters was defined according to their types. For instance, a proximity analysis was performed for the distance-based parameters. Then these distances were divided into classes, which include their spatial extent. Every cell is in a distance class: “near” to, “middle”, and “far” from land uses or points of interest. For ordinal parameters, such as urban population, “high”, “moderate”, and “low” density were applied. In the case of nominal parameters such as soil types or geology types, each type was used as one class. The entire base layer of all factors was converted into a grid cell to assess the growth of residential land use type in their classes. For instance, the proximity to industrial land use causes a reduction in existence of residential land use cells. In contrast, in areas near to recreational facilities, a greater number of residential cells can be observed. However, various geological types do not have any significant effect on existence or absence of residential cells. Hence, the proximity to industrial and recreational facilities selected as important parameters. Moreover, geological characteristic assumed as not an effective factor, hence were removed from the process (Table 1).

Table 1. The important parameters for land use change modeling

No.	Selected Parameters
1	Proximity to Road networks
2	Proximity to Public transportation facilities
3	Proximity to Educational facilities
4	Proximity to Recreational facilities
5	Proximity to Health facilities
6	Proximity to Cultural and Religious facilities
7	Proximity to Industrial land use type
8	Distance to Water bodies (Flood zone)
9	Proximity to Green and Natural spaces
10	Population density

For the proposed land use change modeling, Bayesian theorem was applied, with an update of prior probabilities through the weights-of-evidence (WoE) approach (Bonham-Carter 1994; Pradhan et al. 2010). The selected parameters from the optimization process were utilized as evidence in order to evaluate the probability of growth for residential land use. The WoE allowed the ability to assess and combine evidences according to variation of the land use changes. The advantage of this theory is its flexibility to compute uncertainty and to combine evidences from different sources of data (Thiam 2005; Tien Bui et al. 2012). The model created an opportunity to analyze land use changes according to the selected parameters. In general, WoE evaluates the degree to which evidences support the hypothesis, in this case the land use change occurrence, and the degree to which those evidences do not refute the hypothesis (Dempster 1967; Shafer 1976). The WoE has been widely applied in the literature in a variety of applications such as geological mapping (Chen et al. 2013), and natural disaster management (Althuwaynee et al. 2012; Pourghasemi et al. 2013; Tien Bui et al. 2012). However, a few studies have utilized this approach in urban applications such as land use dynamic modeling by Maria de Almeida et al.(2003).

As an example, the WoE of residential land use growth with respect to the proximity to the road is shown in Table 2. The value of C was calculated by subtracting W+ (natural logarithm of occurrence) and W− (natural logarithm of non-occurrence). This value represents the spatial association of each land use pixel and each class of evidence. A positive value represents a higher number of specific land use pixels occurring in this class. In contrast, a negative value represents a lesser number of land use pixels occurring in this class. S2(W+) and S2(W−) are variances of W+ and W−, respectively, and S(C) is the standard deviation of the contrast. Finally, C/S(C) is the standardized value of C which represents the significance of the spatial association and measures the relative certainty of the posterior probability (Bonham-Carter 1994).

The probability value of the land use growth for every cell of the study area is calculated by considering the prior probability of occurrence and non-occurrence of land use types in each class of evidence. The majority of the evidences are distance-based or accessibility. Hence assessing the weights across the different distance ranges is possible. The transitional probability was computed according to the proportion of the observed transition in each predefined class of evidences.

Table 2. Weights-of-evidence for residential land use growth based on "proximity to road" evidence

Factor	Class	Frequency Ratio	W+	W-	C	S2(W+)	S2(W-)	S(C)	C/S(C)
Proximity to Roads	Near	0.89	-0.12	0.10	-0.22	0.000000	0.000000	0.000837	**-261.73**
	Middle	1.42	0.35	-0.16	0.51	0.000000	0.000000	0.000828	**616.57**
	Far	0.78	-0.25	0.07	-0.32	0.000001	0.000000	0.000931	**-340.12**

The output of this process is the residential land use growth probability map which show the probability of residential land use growth according to the selected evidences. It is important to mention that, after evaluation of all evidences the final map was created in two manners. The first manner was to overlay the evidences without weighting consideration shown in Fig.3 (a) and second manner proper weights were assigned to each evidence shown in Fig.3 (b and c). The weights were extracted and calculated from variation and emphasize of C/S(C) value for each evidence. The created map was later classified into three classes: areas with very high, moderate, and low probability of growth.

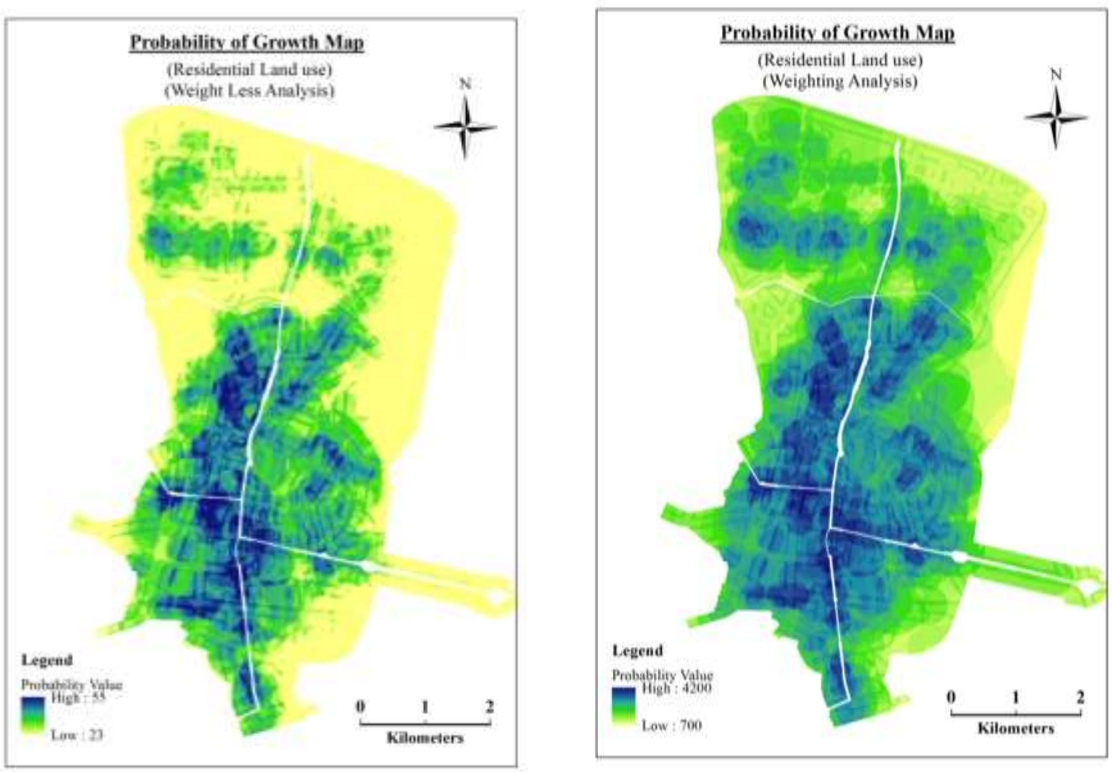
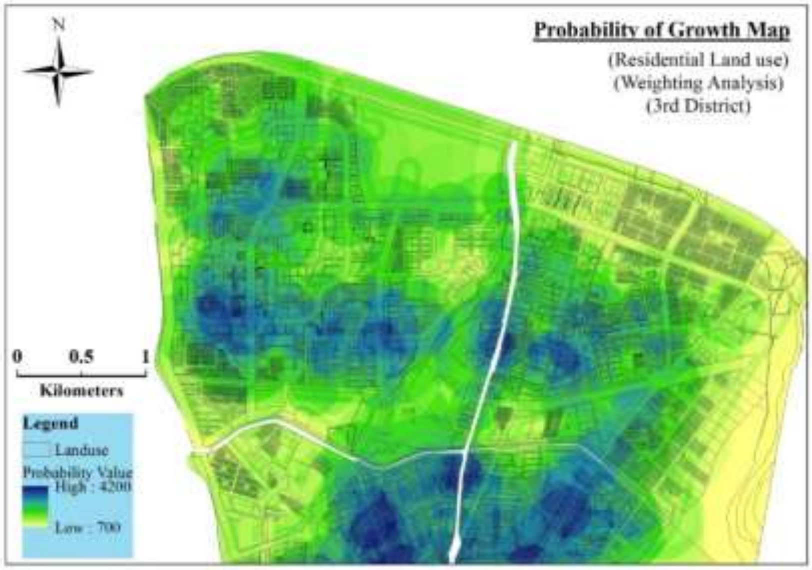


Figure 3. a) Residential probability of growth map (Weight less Analysis) b) Residential probability of growth map (Weighting Analysis)



c) Residential probability of growth map of District 3 (Weighting analysis)

The next step was to extract the existing brownfields of Qazvin City. For this process, the site indicators and criteria as listed in study conducted by Thomas (2002) were tested. All open spaces such as the buffer zone around rivers and highways, recreational play grounds, and natural landscapes were excluded from the analysis. As shown in Fig. 4, most of the small brownfield sites are located in the center and south of the city. They are near dense residential and commercial areas or compact regions. In contrast, brownfields with larger area are located in the east and north of the city near to rural areas, agricultural fields or less compact regions.

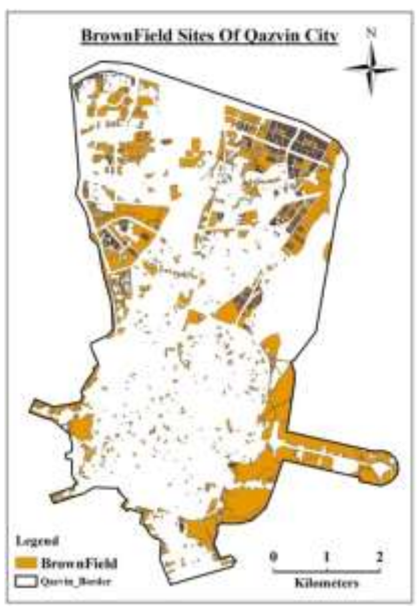


Figure 4. Brownfield sites of Qazvin city

Finally, the map was evaluated according to the master plan of the study area, in order to assign the site potential and suitability, the local demands of the neighborhood and the local planning and development policy. This evaluation can assist to propose a proper land use type for each brownfield sites. For this reason, the probability map was extracted by brownfield site maps in order to have better vision of probability value, Master plan situation and local neighborhood of each site (Fig. 5).

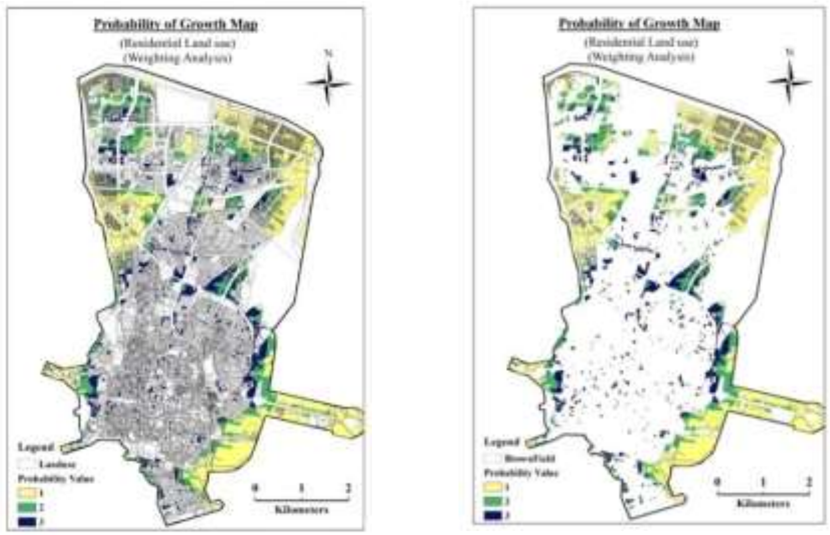


Figure 5. Residential probability of growth map extracted by brownfield site map

3. Results and Discussion

In the first step to understand the current trend of land use change of the study area, a cross tabulation process was run, which revealed that residential land use attempts to capture almost all types of activities. However, this growth is more noticeable through open spaces, agricultural fields and rural areas. In fact, the growth in main land use types through brownfields and abandoned land is desirable. However, loss of natural environments and agricultural fields from residential land use development is an unsustainable problem that should be avoided.

After evaluation of the land use growth with respect to all selected parameters, it was noticed that some of them do not have influence on this growth. Therefore, by running the optimization process, the most effective factors as shown in Table 1 were extracted. The probability value of land use growth (C/S(C) value) for every cell of study area was calculated considering the prior probability of occurrence and non-occurrence of land use type in each class of evidences. A summarized weights-of-evidence calculation for residential land use growth is given in Table 3.

Table 3. Summarized weights of evidence for residential land use growth

	Factors	Class	FR	C/S(C)
			Residential	
1	Proximity to road networks	Near	0.89	**-261.73**
		Middle	1.42	**616.57**
		Far	0.78	**-340.12**
2	Proximity to public transportation facilities	Near	1.68	**968.29**
		Middle	0.86	**-304.19**
		Far	0.62	**-703.03**
3	Proximity to Educational facilities	Near	1.43	**876.99**
		Middle	0.79	**-399.09**
		Far	0.14	**-980.55**
4	Proximity to Recreational facilities	Low	1.41	**628.74**
		Moderate	1.31	**526.68**
		High	0.48	**-1136.54**
5	Proximity to Health facilities	Near	1.69	**924.82**
		Middle	1.40	**584.92**
		Far	0.46	**-1352.68**
6	Proximity to Cultural and Religious facilities	Near	1.68	**1064.11**
		Middle	1.18	**284.03**
		Far	0.41	**-1337.52**
7	Proximity to Industrial land use type	Near	1.06	**80.51**
		Middle	1.43	**522.19**
		Far	0.84	**-291.44**
8	Distance to Water bodies (Flood zone)	Low	0.69	**-521.49**
		Moderate	1.09	**122.94**
		High	1.13	**294.27**
9	Proximity to Green and Natural spaces	Near	1.24	**360.50**
		Middle	1.31	**491.70**
		Far	0.67	**-772.24**
10	Population density	Low	0.46	**-656.71**
		Low	1.16	**159.42**
		Middle	1.38	**361.84**
		Middle	0.77	**-318.76**
		High	1.33	**321.28**
		High	1.09	**128.34**

A majority of evidences were based on distance or accessibility and it was possible to examine the probability of growth of residential land use across the different distance classes. On Table 3 and as shown in Fig. 5 and 6, the probability of growth for residential land use is higher in central, southern and near to old parts of the city. In fact, Qazvin city is divided in to three districts; district one (south and old part of city), district two (centre) and district three (north and new developed area of city). In general, proximity to recreational and community facilities offer advantages for the housing environment. In this study also, this proximity caused positive probability values for residential land use growth. This confirms the inverse relationship of the residential and industrial land uses theory.

Accessibility to main roads and public transportation facilities is another important characteristic of site suitability. Having proper accessibility is a positive factor for most of new developments especially residential buildings. In this case also there is positive value for areas near to public transportations. However, negative value can be seen for near class of road network, which can be due to highly distribution of road network in the city, especially in northern parts that is still not developed properly.

Population density evaluation was in the range of high to low density, which revealed straightforward effects on the land use growth. Higher population resulted positive values of C/S(C) for residential land uses, and negative value for lower density. However, variation of positive and negative values in density domain is high, and hence, not a proper conclusion can be extracted from this evidence.

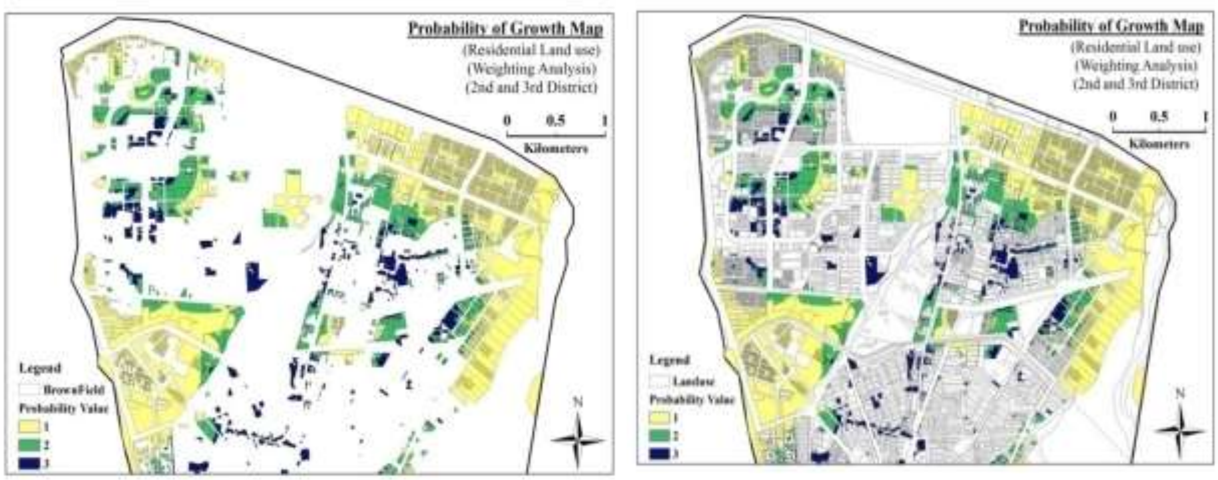


Figure 6. Residential probability of growth map extracted by brownfield site map for northern part of the city

After the aggregation of residential land use growth map with the brownfields map (Fig. 6), it is observed that some brownfield sites are completely assigned as residential land use (polygon sites completely in blow color). According to evaluation of the selected parameters these sites are predicted to change to residential land use. These sites are mainly located in central parts of the city. On the other hand, those with mixture of color can be projected to convert to mixture of uses, either residential-commercial or other land use types. Considering the size, potential, and suitability of these locations, these brownfields can serve the neighborhood as mixed land use development. As getting distance from center of the city these mix sites can be more visible and increase dramatically. The sites with completely yellow color are located in border of the city. It can be concluded that, due to high distance of these sites to center of the city (where most of the community facilities and other evidences are located) these sites are not much suitable to change to residential buildings. However, the local planning authority of the city by providing proper community facilities, can make these areas suitable for living purposes.

4. Conclusion

The present paper illustrates the application of GIS-based WoE for modeling the brownfields land use changes. Using this process especially by considering more number of land use types, the future land use type of each existing brownfield can be identified. This projection can be in single land use or a mixture of two or more land use types depending on brownfield properties, potential, and surrounding environment conditions. The model process was based on the trend and historical land use changes of the study area as well as several urban related factors. However, the results show that one of the main controlling factors for these changes was based on spatial autocorrelation of land use types.

The WoE model is a statistical-based model. Hence, the parameters were evaluated statistically instead of subjective choice of weighing technique by expert knowledge, which is the main source of uncertainty. For this reason, it can be concluded that the model revealed reliable and promising results for brownfields land use change modeling. The final outputs provide valuable land use growth maps and information about the future of existing brownfields of the city. Redeveloping and revitalizing these areas will make Qazvin City environmentally more sustainable. It should be mentioned that, due to utilization of the standard and common urban related parameters as well as statistical based methodology, by considering more number of land use types (commercial, industrial, facilities and etc) this process can be easily replicated in other international cities for brownfields redevelopment strategies.

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