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Research Article

PARKING STRUCTURE SITE SELECTION THROUGH INTEGRATION OF AHP AND OWA AND SEVEN-RISK MAPS (CASE STUDY: DISTRICT 6 IN REGION 3 OF TEHRAN)

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ABSTRACT
Unbalanced and unprincipled urban growth has brought about some problems in the region studied here in the present study. These problems originate from lack of harmony and consistency among different urban uses and failure in urban units management. In this region, developing sufficient parking sites has not kept pace with development of streets, highways, and urban uses. This, in turn, has caused many problems in urban traffic and transportation system. The present study aims at determining optimal and appropriate places for developing parking lots in the concerned region using GIS and through applying criteria such as distance from attracting excursion centers, distance from streets, and appropriate uses for developing parking sites and constraints like distance from faults and inappropriate uses for developing parking sites. To this aim, certain weights were first prescribed to effective criteria in parking structures site selection using analytic hierarchical process. Given the resulting weights, the best place for developing the parking lot was determined using integration of AHP and OWA methods, or Fuzzy AHP-OWA. Finally, it was observed that Fuzzy AHP-OWA provides more flexible results. Also, the method of all=minimum risk and maximum sensitivity showed the best result among the seven risks.

Keywords: *Parking Structures, Geographic Information System (GIS), OWA Fuzzy Decision Making, Analytic Hierarchy Process (AHP)*

INTRODUCTION
Stationary traffic is one of the major problems in transportation, particularly in some large cities (Hensher, 2001). Nowadays, finding a parking place is one of the main problems in big cities with large population (Benson, 2008). Using new technologies such as developing parking structures can be an answer to the above problem. Using this kind of parking lots, an optimal management can be employed to increase serving large number of vehicles (Nakhaeipour, 2010).

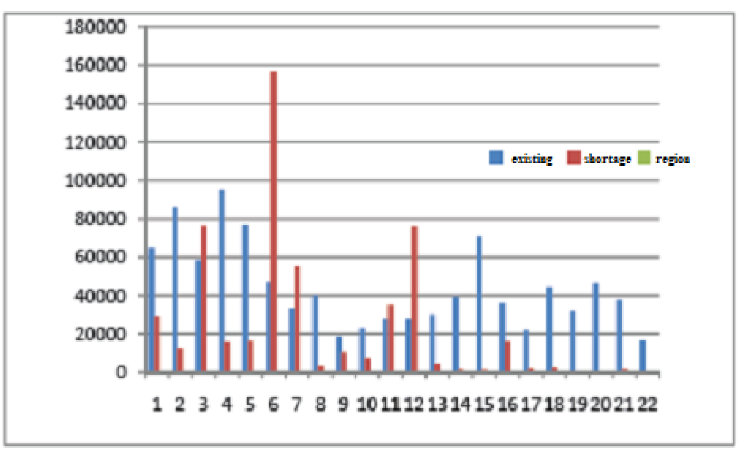
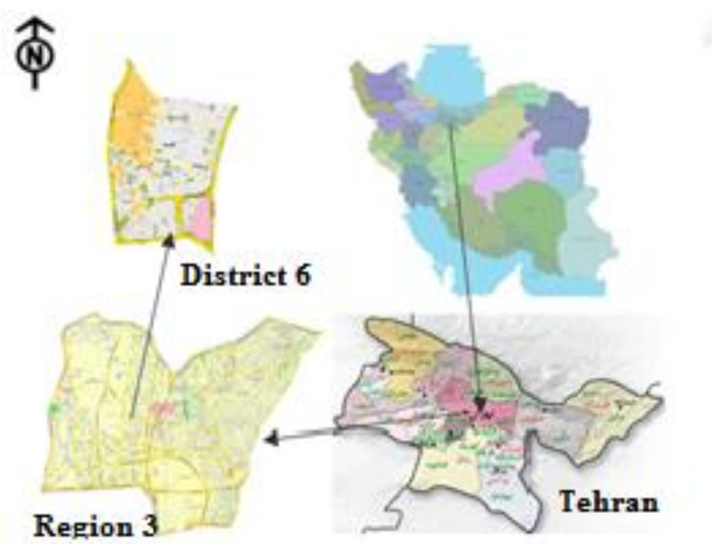


Figure 1: The extent of existing parking lots and parking demand (shortage) in 22 regions of Tehran. Reference: Tehran Traffic and Transportation Studies Center, 2010

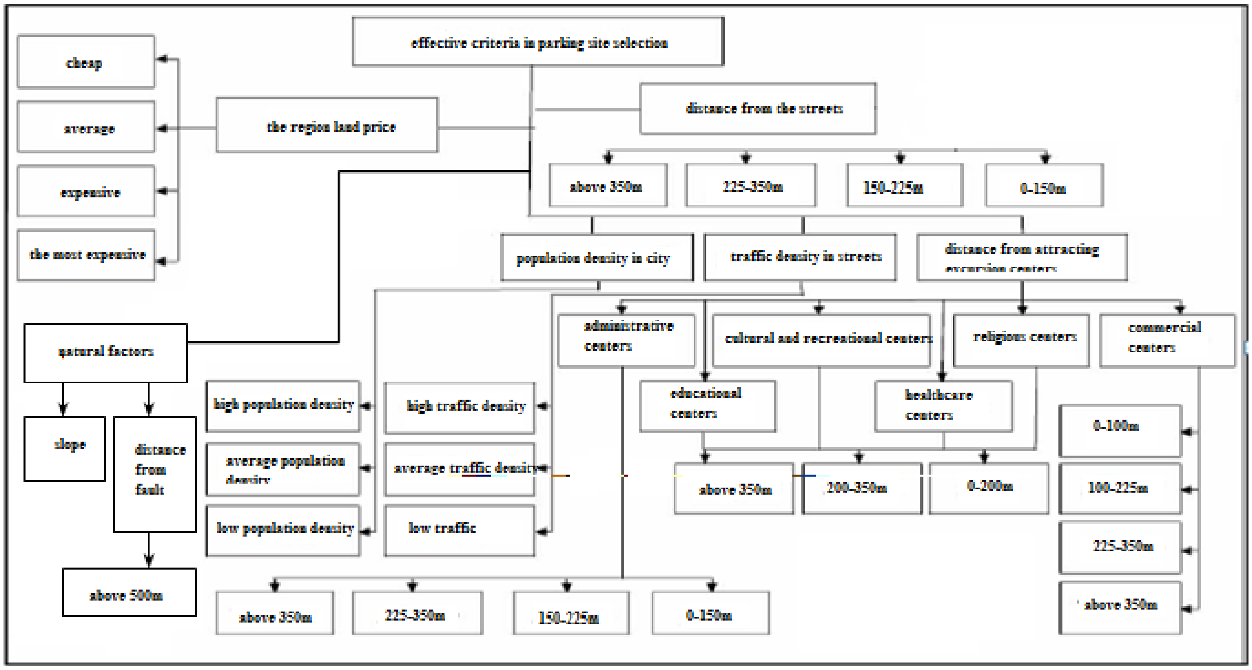
Selecting suitable sites and developing parking structures is one of the main needs of modern cities, especially largeones. If this is performed without considering mutual effects and interactions among uses, it will not solve the problems, but will add to them (Naeeni, 2004). As most of the works on site selections have been carried out according to traditional methods considering limited criteria, the present research aims at combining qualitative and quantitative criteria using fuzzy model and selecting the best spatial-local area for developing parking structures in the concerned region. In this study, the researchers try to locate and select the suitable places for parking structures in the region under study involving effective and important criteria and factors in parking site selection using analytic hierarchy process (AHP) and ordered weighted average (OWA) in order to take a step toward solving the parking problem in this region.
According to Figure 1, the region under study has the highest shortage, after region 6, among other Tehran regions in terms of parking lots. So, selecting optimal places for developing parking structures in this region is necessary.

MATERIALS AND METHODS
With an area of 18,909 square kilometers consisting 1.2% of the whole area of Iran, Tehran Province is distinguished from other provinces in this country in this way that political center of Islamic republic of Iran is located there. Tehran is a province with 13 counties including Tehran, Shahryar, Karaj, RobatKarim, Savojbolagh, Nazarabad, Varamin, Eslamshahr, Shemiranat, Rey, Damavand, Firoozkooh, and Pakdasht and 43 cities and 1358 residential villages. Region 3 is one of the 22 regions of Tehran located in its north-east. This region's area is 31.208 square kilometers consisting 4.3% of the whole area of Tehran and has the 10^{th} rank regarding the area in this province. This region has 6 districts and 12 localities. District 6 is located in south-west with an area of 373ha.



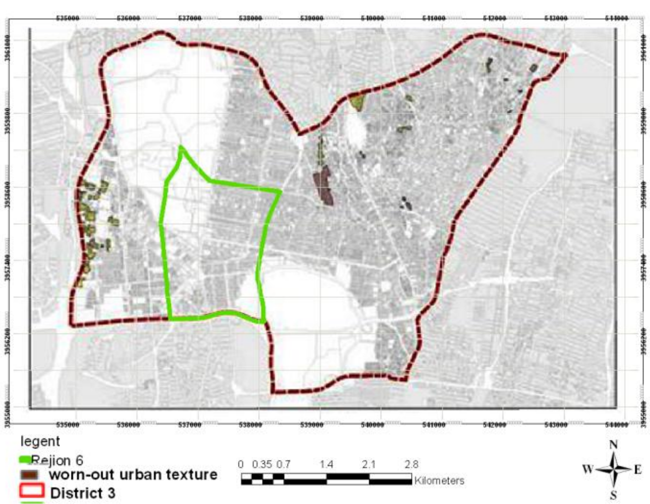
Map 1: Geographical situation of the region under study

Effective Criteria in Parking Site Selection
Different and various criteria are involved in parking structures site selection. In Vanet's research in 1987, it has been stated that capacity of the existing parking lot, parking target and time, and distance on foot from parking lot to destination have important roles in determining future parking sites. Due to variety of criteria in modeling, the criteria were divided into 6 main classes as seen in Table 1 and Flowchart 1.



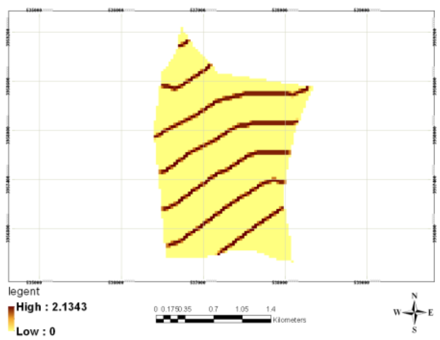
Flowchart 1: Hierarchy of effective criteria and sub-criteria in parking site selection (HosseiniLaghab *et al.*, 2012)

Main criteria in this study are accessibility, neighborhood, and environmental ones.
Accessibility Criterion
1-Highways and freeways
Neighborhood Criterion
1-Residential use
2-Parks and green areas
3-Research, sport, and recreational centers
4-Hygiene facilities
5-Commercial centers
Worn-out urban texture is another layer of neighborhood criterion and according to Figure 2, there is no building with worn-out texture in the region under study.



Map 2: Areas with worn-out urban texture in region 3 of Tehran

Environmental Criterion
1-Fault
2-Slope: Slope layer of the region has been prepared from the 2-meter DEM layer and according to Figure 3, the highest slope of the region is 2 degrees which is ignored in calculations as it is too small.



Map 3: Slope map of the district 6 of region 3 of Tehran

Analysis
Analysis method in the present study includes three methods of AHP, OWA, and fuzzy AHP-OWA which are described as follows.
AHP Method
Selecting effective criteria and sub-criteria in site selection, their weights should be determined with respect to their importance using one of the weighting methods in order to combine them as information layers. Criteria used in site selection are not usually of the same importance and some criteria are more important than others and have a determinant role in site selection.
Weighting through AHP
AHP model, first introduced by Prof. Saaty in 1980, shows how to determine the relative importance of several actions, options, etc. AHP allows for combining qualitative intangible and criteria with tangible and quantitative ones at the same time. This process uses pairwise comparisons of alternatives and decision making criteria (David, 1983). Pairwise comparison method (AHP) is one of the most valid and widely used methods due to its robust theoretical base, high accuracy, simplicity of use, and results' validity and accuracy (Malczewski, 1999).

Table 1: Criteria preferences in AHP weighting method

Value	Preferences
9	Entirely preferred
7	Very strongly preferred
5	Strongly preferred
3	Moderately preferred
1	Equally preferred
2,4,6,8	Weights between breaks up

Comparisons in this method are based on theoretical judgments and the proportions are expressed qualitatively. According to Table 1, the criteria are expressed by quantitative values between 1 and 9 as coefficient matrix.
For site selection using AHP method, the coefficient matrix is first prepared which is seen below.
In the coefficient matrix in AHP, numbers are determined according to pairwise comparison in this way that each of the criteria written in the first column is compared with the criteria written in the first row in

a pairwise manner and takes a number based on its importance (completely desirable: 9, very strong desirability: 7, strong desirability: 5, a little more desirable: 3, identical desirability: 1, and preferences are between strong intervals of 2, 4, 6, and 8). The numbers on the main diagonal are always 1.

OWA Method

To combine fuzzy sets, there are three basic operations:
1-Intersection of fuzzy sets
2-Union of fuzzy sets
3-Averaging

Yager (1988) proposed a combining technique based on OWA operation which is a combination of the three above combinatory functions. This model provides a continuous fuzzy combination operation between fuzzy intersection (AND) and union (OR) combining the weighted averaging between them (Malczewski, 1999). This operator is of balanced fuzzy operators and provides a suitable condition of AND and OR degree (Khan and Alnuweiri, 2004).

In this method, controlling risk level and balance is made possible through a set of ordered weights for different rank-order positions of criteria in every pixel (Eastman, 1997). Ordered weight allows the decision maker to apply those criteria he sees more important in site selection with the same degree of importance in actual site selection. Using these weights, one can manage the total balance level of criteria as well as risk levels (Ghazi, 2004).

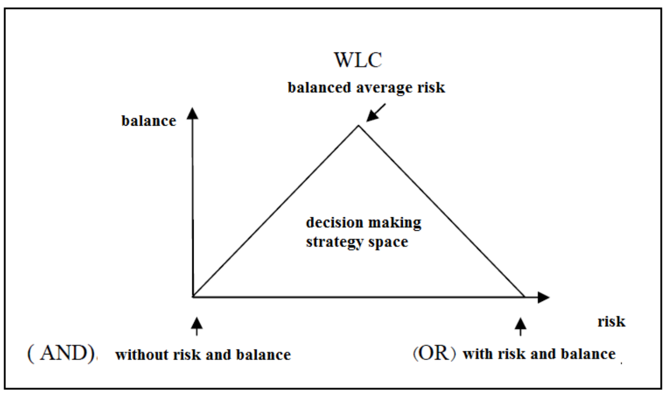


Figure 2: Decision making strategy space in OWA method (Eastman, 1997)

Weighting Using Fuzzy AHP-OWA Combinatory Model

In conventional AHP method, thinking and decision making procedure is not considered accurately and certainty degree of decision makers and the risk in decision making process is not taken into consideration. Therefore, combination of AHP methods with fuzzy logic allows uncertainty and lack of accuracy in problems to be taken into account for more compatibility with reality.

Applying Fuzzy AHP-OWA method, different views and tastes can be used and resultant opinions can be introduced in urban activities and solving its problems along with inherent uncertainty in opinions. The result of combining is fuzzy AHP-OWA and the layers in the next pages have been obtained after calculating values of v and determining LQ through Delphi method and seeking comments from experts and final revising through geometry average as well as applying parking site selection standards in IDRISI software.

The general scheme of fuzzy AHP-OWA method is:

$$v_j = \left(\sum_{k=1}^{j} W_k\right)^{\alpha} - \left(\sum_{k=1}^{j-1} W_k\right)^{\alpha}$$

Equation (1)

From the Equation (1), weights of the main criteria and sub-criteria in the present study are applied according to the following conceptual model.

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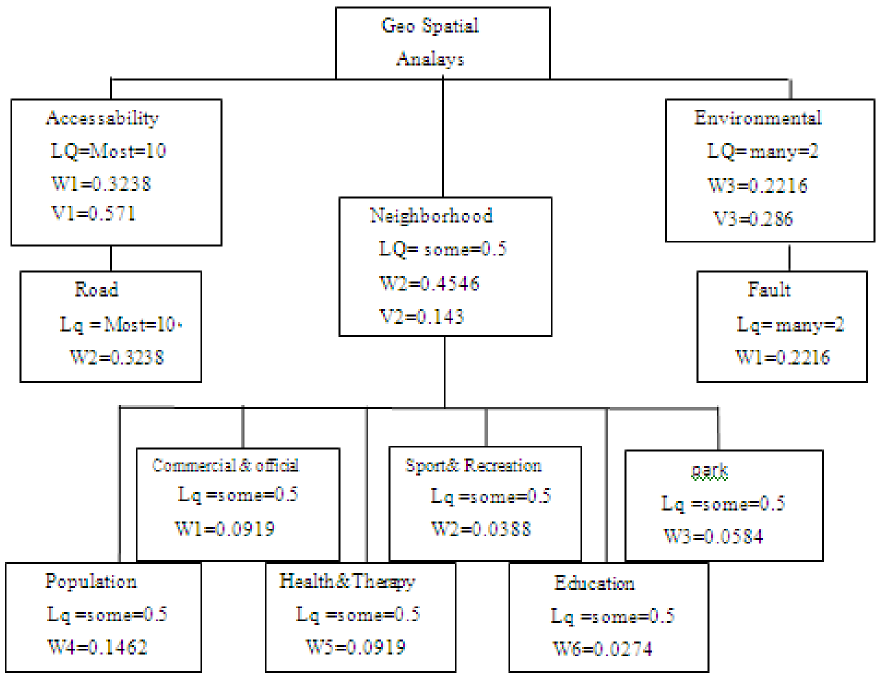
Conceptual Model of FUZZY AHP-OWA



Flowchart 2: Conceptual model of FUZZY AHP-OWA

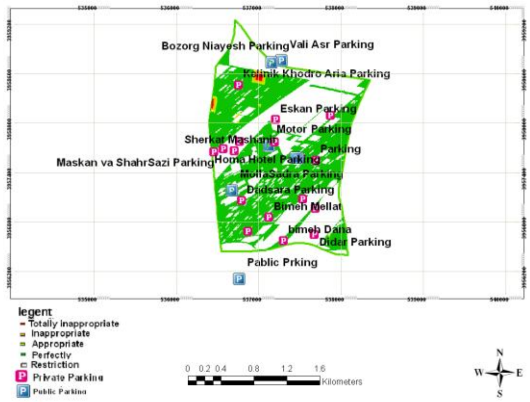
RESULTS AND DISCUSSION

Results

Weights obtained byAHP model

Table 2: Weighting the main criteria and sub-criteria of the study and weights obtained by AHP model

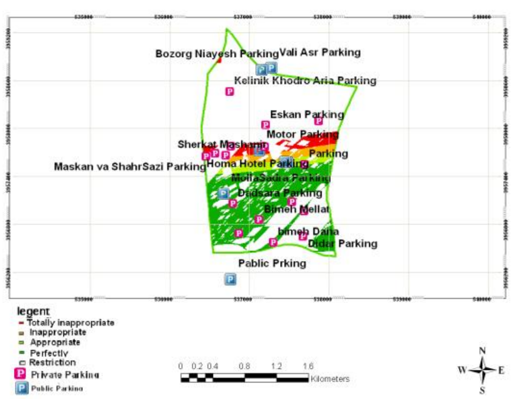
Description	**Criterion**	**Final weight**
Main sub-criteria	Accessibility	0.3238
	Neighborhood	0.4546
	Environmental	0.2216
Environmental sub-criterion	Fault	0.2216
Neighborhood sub-criteria	Commercial centers	0.0919
	Health and medical centers	0.0919
	Research and educational centers	0.0274
	Sport and recreational centers	0.0388
	Population	0.1462
	Green area	0.0584
Accessibility sub-criterion	Distance from road	0.3238



Map 4: Effects of accessibility criteria in the concerned region and locations of existing parking sites by OWA method

Given the map of the effect of accessibility criterion whit the minimum distance from highways as150 meters, it is observed that other than the applied bound area, almost the whole region is inside the green-colored area (completely suitable) and there are only 22 parking sites in the studied region out of which, only 4 parking sited are automobile public parking lots and 1 is a motorcycle public parking lot. Two other parking lots are also near the study area but they are considered out of it.

Map 5: The effects of neighborhood criteria in the concerned region of Tehran and locations of existing parking lots by OWA method



Map 6: The effects of environmental criteria in the study region and locations of existing parking lots by OWA method

As in Map 5, it is observed that neighborhood criteria have the largest effect on the studied region as unsuitable and completely unsuitable areas (orange and red colors) have enlarged remarkably in this map. As it is observed, 4 parking lots out of 5 public parking lots existing in the study region are in the suitable and completely suitable area and 1 parking lot in the bound area.

According to Map 6, red color continues in the north of the region due to existence of fault layer; so the region is completely unsuitable. According to the map of the effect of environmental criteria, 2 parking lots out of 5 public parking lots are in the completely unsuitable and bound area, 2 parking lots in suitable area and 1 parking lot in completely suitable area.

Now the main layers are combined through fuzzy AHP-OWA method and using seven-risk maps (including all=minimum risk and maximum sensitivity, most=very low risk and very high sensitivity, many=low risk and high sensitivity, half=average risk and average sensitivity, dome=high risk and low sensitivity, few= very high risk and very low sensitivity, at least one=maximum risk and minimum sensitivity). According to the following table, risk ability range is obtained with characteristic changes in α.

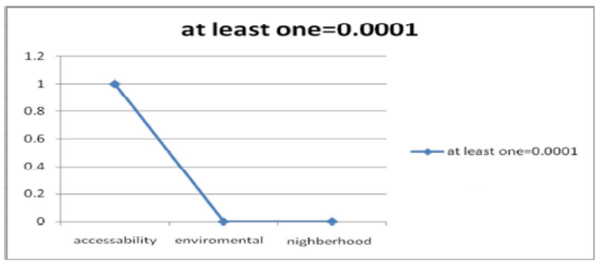
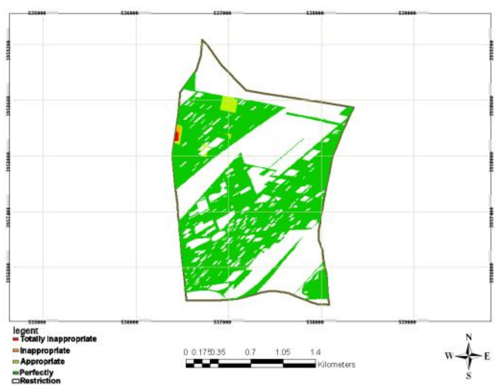


Figure 3: The effect of risk-taking LQ=at least one on all study criteria



Map 7: The effects of all study criteria with LQ=at least one in district 6 of region 3 of Tehran

According to Figure 3, as weights of neighborhood and environmental criteria effects are zero and that of accessibility criterion effect is 1, the minimum weight of the criteria effect has been applied on the study area with LQ=at least one; so, the region is completely suitable and only negligible parts in north-west of the region are observed as unsuitable or completely unsuitable.

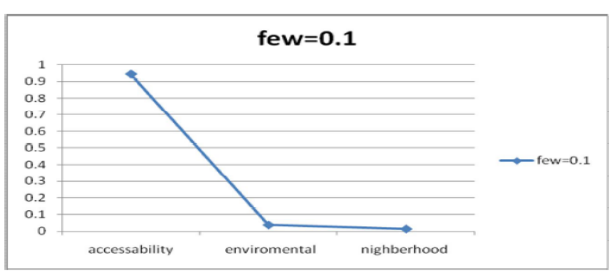


Figure 4: The effect of risk-taking LQ=few on all study criteria

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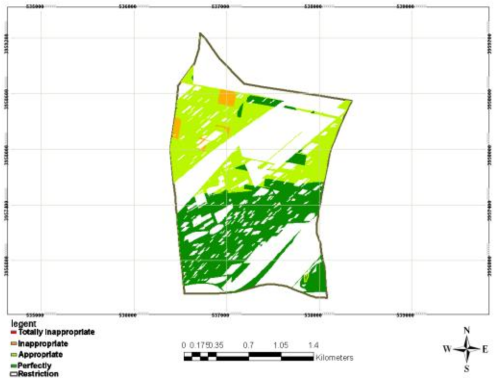


Map 8: The effects of all study criteria with LQ=few in district 6 of region 3 of Tehran

Weight of neighborhood criterion effect is zero and that of accessibility criterion is less than 1, but weight of environmental criterion effect is only a little more than zero and this little coefficient has a large effect on the region map so that it decreases completely suitable area and increases the suitable area to the same degree.

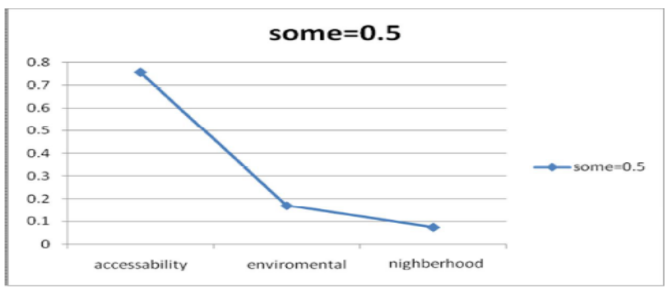
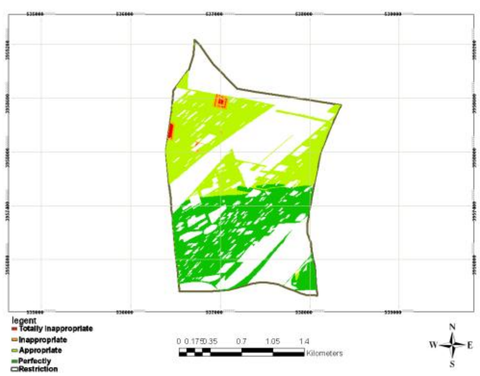


Figure 5: The effect of risk-taking LQ=some on all study criteria



Map 9: The effects of all study criteria with LQ=some in district 6 of region 3 of Tehran

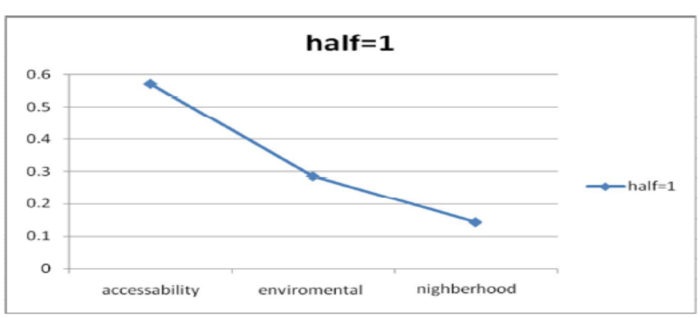
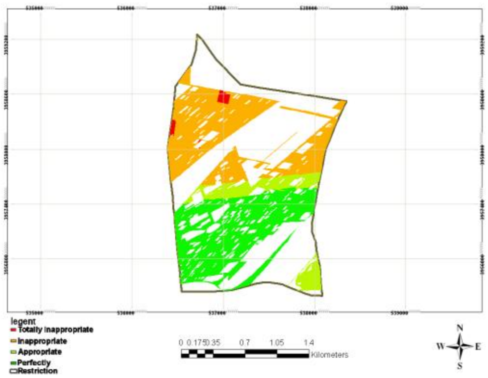


Figure 6: The effect of risk-taking LQ=half on all study criteria

In the above map 9, weight of accessibility criterion effect decreases and those of neighborhood and environmental criteria are gradually increasing to the same degree compared to the previous page map. So, light green-colored areas, i.e. suitable areas, are added to the study area.



Map 10: The effects of all study criteria with LQ=half in district 6 of region 3 of Tehran

In this map, weights of all study criteria effects have been considered with LQ=half, that is without the effect of the linguistic term table which is equal to *wi*. Here, weight of accessibility criterion effect has decreased and weights of neighborhood and environmental criteria effects have increased to the same degree. Decreasing completely suitable areas in the central area and increasing unsuitable areas in northern lines of the region is evident compared to the maps in previous pages.

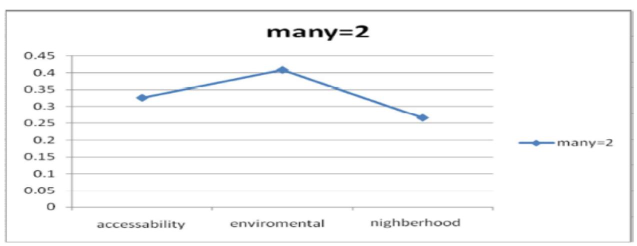
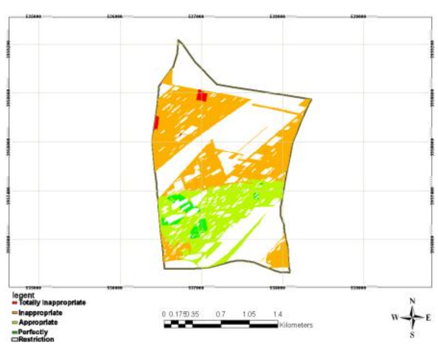


Figure 7: The effect of risk-taking LQ=many on all study criteria



Map 11: The effects of all study criteria withLQ=many in district 6 of region 3 of Tehran

As it is observed, weight of environmental criterion effect is more than those of accessibility criteria effect and weight of neighborhood criterion effect has increased as well. According to the above map, completely suitable and suitable areas are tending toward unsuitable and completely unsuitable areas and the northern patch of the region is unsuitable and in some small parts completely unsuitable.

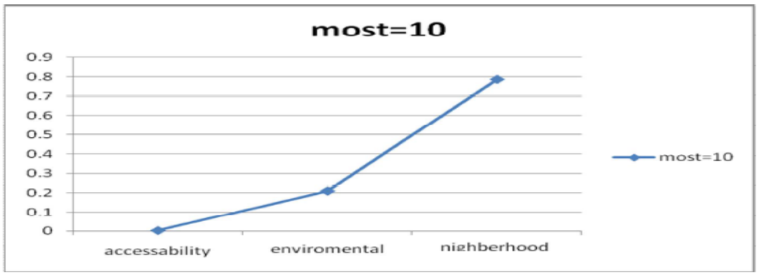
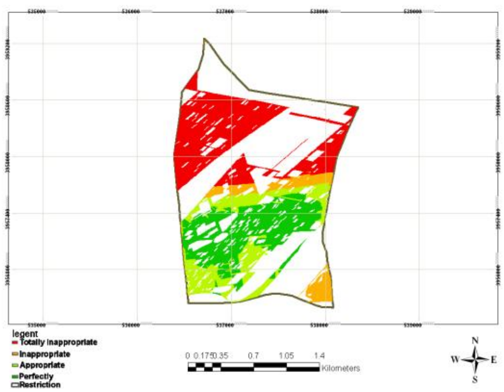


Figure 8: The effect of risk-taking of LQ=most on all study criteria



Map 12: The effects of all study criteria with LQ=most in district 6 of region 3 of Tehran

In this map, weight of environmental criterion effect has increased compared to other criteria; so, the northern patch of the region has become a completely unsuitable area due to the existence of fault.

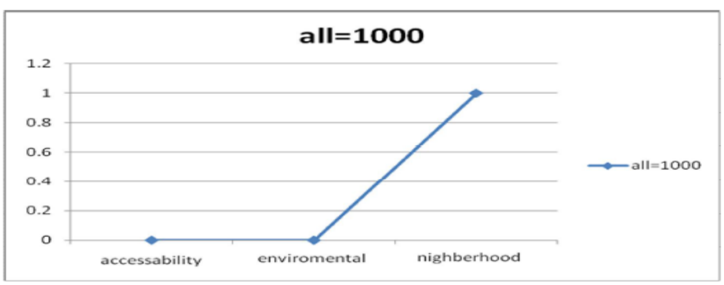
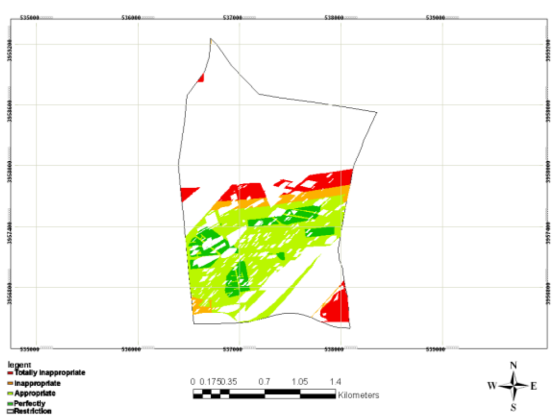


Figure 9: The effect of risk-taking of LQ=all on all study criteria

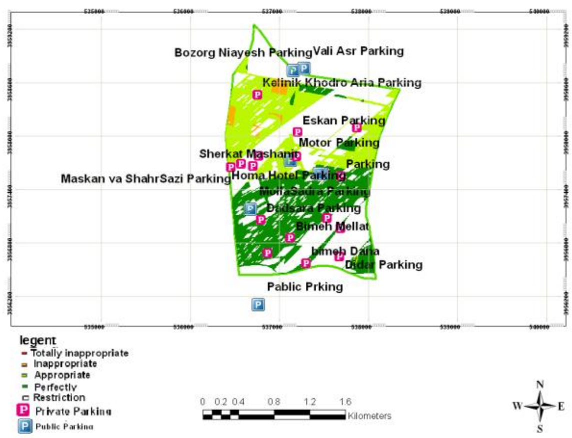


Map 13: The effects of all study criteria with LQ=all in district 6 of region 3 of Tehran

According to the above Figure, weight of environmental criterion effect is 1 and those of neighborhood and accessibility criteria are zero. So, increase in completely unsuitable areas is evident in northern areas due to existence of fault. Comparing this map with the previous maps, it is observed that very suitable places have become less and accuracy of site selection has increased to the same degree.

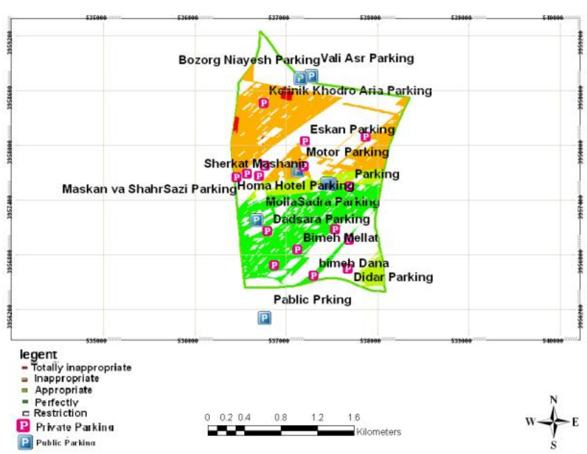
Discussion

Preparing seven-risk maps according to Maps 7 to 13, it is observed that as we move from the map of at least one=maximum risk and minimum sensitivity to map of all= minimum risk and maximum sensitivity, completely suitable and suitable places decrease and completely unsuitable and unsuitable places increase to the same degree. This shows that maps are gaining more accuracy. Regarding the place of public parking lots in the region, three maps with high, average, and low risk-taking have been also considered which are explained as follows.



Map 14: The effects of all study criteria in municipality area of district 6 of region 3 of Tehran and locations of existing parking lots with high risk-taking and low sensitivity

As seen in Map 14, in high risk-taking, 3 parking lots out of 5 public parking lots in the study region are in completely suitable area, 1 parking lot is in suitable area and 1 in bound area.



Map 15: The effects of all study criteria in municipality area of district 6 of region 3 of Tehran and locations of existing parking lots with average risk-taking and average sensitivity

As seen in Map 15, in average risk-taking, northern patch of the study region and some parts of the center are in unsuitable areas. So, 1 parking lot out of 5 existing public parking lots in the study region are in completely suitable area, 2 parking lots in suitable area, 1 in unsuitable and 1 in bound area.

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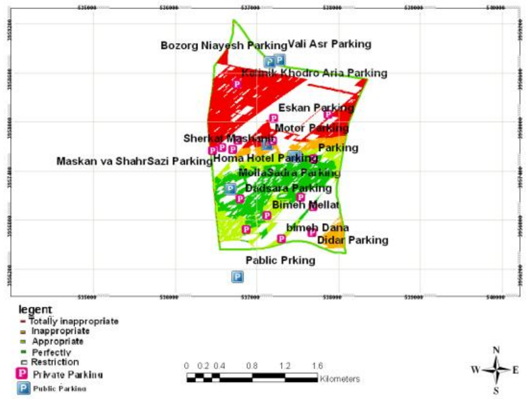

Map 16: The effects of all study criteria in municipality area of district 6 of region 3 of Tehran and locations of existing parking lots with low risk-taking and low sensitivity

As seen in Map 16, in low risk-taking, northern patch of the study region and some parts of the center and north of the region are in completely unsuitable and unsuitable areas and completely suitable parts have become limited and more accurate. So, 1 parking lot out of 5 public parking lots existing in the study region are in completely suitable area, 2 in suitable area, 1 in completely unsuitable and 1 parking lot in bound area.

Conclusion

From the most of research on public parking structure site selection and the present study as well, it is concluded that AHP model allows for investigating quantitative and qualitative data at the same time. Due to lack of robust theoretical structure, ranked weighting methods have less accuracy compared to AHP methods. This superiority is rather due to simplicity of weighting and operation speed of this method. Among AHP methods, fuzzy method has the highest accuracy and flexibility. However, pair wise comparisons increase quickly and accuracy is decreased by increasing parameters.

It can be said that using geographical information system (GIS) with multiple options and large number of criteria, one can select final options with accuracy. This is important as an accurate and logical weighting among criteria and options can be performed so that to select the final place and parking places priority accurately. This helps the plan makers to decide based on spatial and local data. In addition, GIS allows for investigating the qualitative and quantitative data at the same time. Implementing this system, the best place for developing a parking lot can be determined. As fuzzy AHP-OWA is used for selecting the sited for different uses from low to high range of risk-taking, it can determine the places for developing concerned uses in the regions in which we confront limitations through increasing risk-taking, as in Maps 14, 15, and 16.

Recommendations for Further Study

Developing proper, accurate, and comprehensive databases in governmental organizations and institutes can increase efficiency of manager's performances in correct decision making. Therefore, it is suggested that these institutes try to develop accurate and correct databases or complete and correct the existing databanks in order to increase their efficiencies and at the same time set the ground for more accurate planning for future.

Trip demand control through correct urban uses site selection, investment for developing parking facilities along with developing urban roads and spaces, controlling marginal parking lots in the region are among the methods that can be employed in marginal parking lots control and management as well as:

a) parking inhibition for all or part of the day in streets with heavy traffic in the city; b) limiting the allowed parking time; c) issuing parking permissions for local residents; d) determining costs for using parking lots, providing and selecting the optimal sites for parking guide signs, investment in developing parking structures, optimal use of parking facilities by people and avoiding traffics related to parking, using modern and efficient systems like a) using credit cards or cellphones; b) using focused and limited-

time parkometers in streets with heavy traffic; c) using novel information systems and encouraging policies for using parking structures.
Using FUZZY AHP-OWA is suggested because of more flexible results.

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