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Petrochemical industry site selection using ordered weight averaging with fuzzy logic, A case study of Hamedan province, Iran

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Key words: Geographic information systems (GIS), Petrochemical site selection, Fuzzy logic, Ordered weight averaging (OWA), Fuzzy VIKOR method.

Abstract

Developing in technology and industry can cause so many risks for human health and the environment, but locating a suitable place emphatically on appropriate method can help decision makers to reduce these hazards. It is clear that petrochemical industry with its complication can be so risky and most of these risks are arising mainly from improper site selections. This paper with the aim of reducing risks and hazards, presents geographic information systems-based Multi-Criteria Evaluation of petrochemical industry site selection in Hamedan province, Iran. For this purpose eleven environmental and economic criteria were selected, including: water resources, elevation, slope, faults, flood, soil, protected zone, population centers (city and village) and communication lines (highway and main road) and were standardized by fuzzy membership functions (like: Sigmoidal, J-shaped and Linear). For selecting the best site, the fuzzy kind of VIKOR method was applied to determine the priority ranking of criteria for example rivers were the most important one and at the end all layers were combined by Ordered Weighted Average techniques with five decision alternatives (like: AND, WLC, OR and two MCEMID maps which are middle modes of privies maps). Results of this study demonstrate that the aim of the approach is not to find a single "optimal" solution, but to show other strengths associated with the weighting flexibility of the OWA approach Also the result revealed that integration of fuzzy logic and OWA can give better idea compared with other models like fuzzy logic (individually). Therefore, this model can be applied for petrochemical site selection of other similar places

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Introduction

The major challenge of international community in today complicated world is to protect human health and environment. Hazardous materials which are the result of developing in technology and industry can cause some risks for human life and environment. So it shows the importance of studying about industries like petrochemical industries and paying attention to its site selection (Rezaeimahmoudi *et al.*, 2014). The large and complex petrochemical industry system with more than 8000 different compounds is capital and energy intensive and also structured in an oligopoly (Toledo *et al.*, 2010). So it is clear that petrochemical industry with its complication can be so risky and most of these risks are arising mainly from improper site selections (Pınar Yal and Akgu¨n 2013).

Nowadays, geographic Information Systems is proven to be an effective tool in site selection and many researchers have used it as the best and most powerful spatial analysis tool (Khamehchiyan *et al.*, 2011; Donevska *et al.*, 2012; Nazari *et al.*, 2012; Sahnoun *et al.*, 2012; Khorram *et al.*, 2015). This spatial analyst system needs not only hardware, software and experts but also the spatial data and adequate analytical methods. The presence of set of these factors together can play a vital role to have high quality output data. In contrast, the imperfection in any of these cases will lead to reduced quality of results (Isalou *et al.*, 2013).

Fuzzy logic (Zadeh 1965) is a form of reasoning used in soft computing, specially GIS analysis, to solve complex problems which are difficult to solve by conventional methods. Since its introduction, fuzzy logic has been extensively applied in different ways including mapping landslide hazard, management of complex water resource systems, agriculture, weather prediction and other domains of research activities (Gorsevski *et al.*, 2012; Gorsevski and Jankowski 2010; Ren *et al.*, 2013). Therefore classification of continuous criteria results in waste of valuable spectrum of each of these criteria. On the other hand, using a fuzzy model in site selection will eventuate all of the criteria having a score in the range of 0–1 (Isalou *et al.*, 2013). Thus, fuzzy method is proposed for petrochemical location selection, where the ratings of various alternative locations based on different criteria and weights of all criteria expressed by fuzzy numbers (Safari *et al.*, 2012).

Accordingly, appropriate site selection based on logical and scientific principles and criteria, as environmental consideration priorities is regarded by most countries including developed countries and developing countries (Saidi *et al.*, 2010). Some researchers that have employed fuzzy logic in site selection (Safari *et al.*, 2012; Donevska *et al.*, 2012; Isalou *et al.*, 2013).

The aim of this study with a kind of emphasis on the method was to use fuzzy logic based on Geographical Information System (GIS) and ordered weighted averaging (OWA) regarding all sustainable development measures to locate a petrochemical industry.

Materials and methods

Study area

Hamedan province by mountainous and mild climate and with an area of about 19,232 km2 is located in west part of Iran (34.77°N and 48.58°E). According to the census of 2006, the population of Hamedan province was 1,703,267(Iranian Statistics Center 2006). In recent decade, rapid growth of industrial towns and urban areas in this province has caused series of problems in environmental management (Fig. 1).

Data collection (Criteria selection)

In this study eleven criteria were selected by reviewing human environmental laws, regulation criteria and standards of Iran department of environment (Shaeri and Rahmati, 2011) that were in relation to petrochemical site selection. However the number of criteria could be more, but in this study because of the lack of information or their relation with national security, some of them were ignored (like power lines, gas pipes etc.). With reconciliation of the obtained data, the most effective criteria based on the studying area and its environmental and economic situation were determined (Table 1).

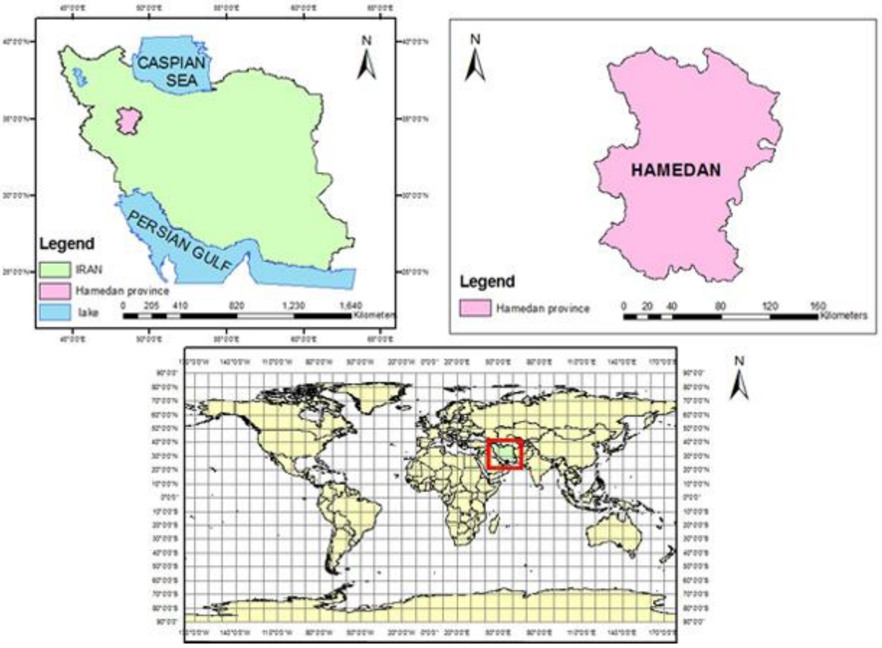

Fig. 1. Geographical position of the studied area.

Table 1. Hierarchical organization of the criteria considered for the petrochemical site suitability.

Goal	Objectives	Criteria		range	constrain
Petrochemical site selection	Environmental	slope		≤10%	-
		elevation		≤ 1800 (m)	-
		water resources (rivers)		1000 (m) ≥≤ 2000 (m)	*
		flood		≥ 4000 (m)	-
		fault		≥ 4000 (m)	-
		protected zones		≥ 3000 (m)	*
		soil		Rock-inseptisoil=1 Rock-entisoil=2 Aridisoil=3 Inseptisoil=4	-
	Economical	population centers	city	2000 (m) ≥≤ 20000 (m)	*
			village	1500 (m) ≥≤ 20000 (m)	*
		communication lines	highway	250 (m) ≥≤ 20000 (m)	*
			main road	150 (m) ≥≤ 20000 (m)	*

Data analysis

The nature of fuzzy logic is spectral study of phenomena, which gives better results hereon in order to match well the criteria with fuzzy models, the variables having spectrum characteristics were classified as continuous data, whereas the variables having discontinuous characteristics were classified into discrete data (Isalou *et al.*, 2013).

Fuzzy logic

Fuzzy logic (Zadeh 1965) is suggested for solving complex and difficult problems which are hard to solve by conventional methods.

The different of fuzzy logic and conventional Boolean logic is because of fuzzy intermediate values. Therefore, the fuzzy set is specified by a membership function, and the function represents any objects on a continuous scale from 1 (full membership) to 0 (full-non-membership).

The central concept of fuzzy set theory lies within the membership function. Membership function maps each element member of the class into a membership value referred as the degree of membership, i.e., represents numerically to which degree an element belongs to a set (Donevska *et al.*, 2012).

Mathematical definition of a fuzzy set (A) is: if (Z) represents a space of objects, then the fuzzy set (A) in (Z) is the set of the ordered pairs.

$A = \{z, MF_A^F(z)\}, \;\; z \in Z$ (1)

Where the membership function $MF_A^F(z)$ is known as degree of membership of (z) in (A) (Donevska *et al.*, 2012). In this study fuzzy membership functions in table 2 were accomplished by IDRISI 17.0 the selva edition software.

Table 2 Fuzzy membership functions with control point use for petrochemical site selection.

Criteria		Control point (a)	Control point (b)	Control point (c)	Control point (d)	Fuzzy function
Slope		-	-	6	10	Sigmoidal, decreasing
Elevation		-	-	1200	1800	Sigmoidal, decreasing
Water resources (Rivers)		1000	2000	3000	20000	Sigmoidal, symmetric
Flood		4000	7000	-	-	Sigmoidal, increasing
Fault		4000	7000	-	-	Sigmoidal, increasing
Protected zones		3000	7000	-	-	Sigmoidal, increasing
Soil		-	-	1	4	J-shaped, decreasing
Population centers	City	2000	7000	10000	84000	Linear, symmetric
	Village	1500	7000	10000	35000	Linear, symmetric
Communication lines	Highway	250	8000	14000	55000	Linear, symmetric
	Main road	150	8000	14000	32000	Linear, symmetric

VIKOR

S. Opricovic had developed the basic idea of VIKOR in his Ph.D dissertation in 1979, and an application was published in 1980 (Duckstein and Opricovic, 1980). The name of VIKOR appeared in 1990 from Serbian: Vlse Kriterijumsk Optimizacija Kompromis nov Resenje that means: Multi-criteria optimization and compromise solution (Opricovic, 1990).

The VIKOR method is a multi-criteria decision making (MCDM) or Multi-criteria decision analysis method. The MCDM problem is stated as follows: Determine the best (compromise) solution in multi-criteria sense from the set of j feasible alternative $A_1, A_2, \ldots, A_j$ evaluated according to the set of n criterion functions. The input data are the elements f_{ij} of the performance (decision) matrix, where f_{ij} is the i-th criterion function for the alternative A_j (Opicovic and Tzeng 2007).

Fuzzy VIKOR

Its focus is on ranking and selecting from a set of variables and determines compatible solutions for a problem according to criteria, which can help decision makers to reach a final decision (Opricovic and Tzeng, 2007). The compatible solution is the possible one and is the closest to the ideal state.

The main profit of the fuzzy VIKOR method is the introduction of the multi-criteria ranking index which is based on the particular closeness to the ideal solution (Opricovic and Tzeng, 2004) and the obtained compatible solution provides a maximum group utility for the "majority" and a minimum individual regret for the "opponent" (Liu *et al.*, 2013).

Fuzzy VIKOR needs a linguistic variable that is a variable whose values are expressed in linguistic terms. The concept of linguistic variable is very useful for too complex situations and described by traditional quantitative expressions (Zadeh, 1975).

The linguistic values can also be represented by fuzzy numbers for example these linguistic variables can be expressed in positive fuzzy numbers as shown in Tables 3. It may be mentioned here that the membership function values can be determined according to the historical data and the detailed questionnaire answered by all domain experts (Liu *et al.*, 2011).

Table 4 shows the weights associated to the criteria. In the table the highest weights were assigned to the water resources (rivers), population centers and communication lines which are the most important factors.

Table 3. Linguistic variables for rating the criteria.

Code	Linguistic terms	Fuzzy numbers
1	Very low (VL)	(0, 0.05, 0.15)
2	Low (L)	(0.1, 0.2, 0.3)
3	Medium low (ML)	(0.2, 0.35, 0.5)
4	Medium (M)	(0.3, 0.5, 0.7)
5	Medium high (MH)	(0.5, 0.65, 0.8)
6	High (H)	(0.7, 0.8, 0.9)
7	Very high (VH)	(0.85, 0.95, 1)

Table 4. Fuzzy VIKOR ranking and criteria weights for the petrochemical site selection.

Criteria		Fuzzy VIKOR rank	Weight (global weights)
Water resources (rivers)		1	0.1670
Population centers	City	2	0.1449
	Village	3	0.1429
Communication lines	Highway	4	0.1146
	Main road	5	0.1126
Soil		6	0.0909
Slope		7	0.0757
Fault		8	0.0540
Flood		9	0.0520
Protected zones		10	0.0303
Elevation		11	0.0151

The OWA operator and its weights estimation

The OWA operator first introduced by Yager (1988) provides the aggregation operators that include the maximum, the minimum and the average criteria. Its significant advantage is that the input data are rearranged in descending order, and the weights associated with the OWA operator are the weights of the ordered positions of the input data rather than the weights of the input data, The OWA operator can be defined as follows (Liu *et al.*, 2014). An OWA operator of dimension n is a mapping OWA: $R^n \rightarrow R$ that has an associated weighting vector.

$\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$, with$\omega_j \in [0,1]and\sum_j^n \omega_j = 1$ such that:

OWA $(a_1, a_2, \ldots, a_n) = \sum_j^n -1\, \omega_j b_j$ (2)

Where $b_j$is the$j-th$largest of the a_i (Yager 1988). As indicated before, OWA, which is a variant of WLC, employs two sets of weights.

The first set of weight is the global weights or the universal weights, which represent the relative importance of the factors and in this case it obtained by fuzzy VIKOR ranking, look up table 4. The second set of weight is the local weights, which are assigned on a pixel basis, where ascending rank order of weighted factors control the aggregation.

By varying the ordered weights, OWA generates continuous aggregation results where the decision rule would fall in a triangular decision.

space between AND operator (a risk aversion) and OR operator (a risk taking) and between of them WLC. For example, ordered weights in a decision making that involves three factors take [1, 0, 0] for the And operator, [0, 0, 1] for the OR operator, and [0.1, 0.1, 0.1] for WLC (an average level of risk).

Table 5. OWA weights used to control levels of trade-off and risk for the criteria.

MCEMIDAND (Low Level of Risk - Some Tradeoff)"											
Order weights	1	0	0	0	0	0	0	0	0	0	0
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
MCEMIDAND (Low Level of Risk - Some Tradeoff)											
Order weights	0.5	0.25	0.125	0.0625	0.0312	0.0156	0.0078	0.0039	0.0019	0.0009	0

MCEMIDAND (Low Level of Risk - Some Tradeoff)"											
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
MCEAVERAGE (Average Level of Risk - Full Tradeoff), WLC AND ness=0.5 OR ness=0.5 TRADE-OFF=1											
Order weights	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909	0.0909
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
MCEMIDOR (High Level of Risk - Some Tradeoff)											
Order weights	0	0.0009	0.0019	0.0039	0.0078	0.0156	0.0312	0.0625	0.125	0.25	0.5
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
MCEMAX (Risk Taking- No Trade off), OR AND ness=0 OR ness=1 TRADE-OFF=0											
Order weights	0	0	0	0	0	0	0	0	0	0	1
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th

In Table 5 the value of 1 for the AND ness suggest that the solution coincides with the AND while the value of 0 for the OR ness suggest that the solution is the most distant from OR.

The trade-off measure of 0 represents no trade-off while 1 represents a full trade-off. Fig. 2 illustrates the flowchart of the proposed site selection process used in this study.

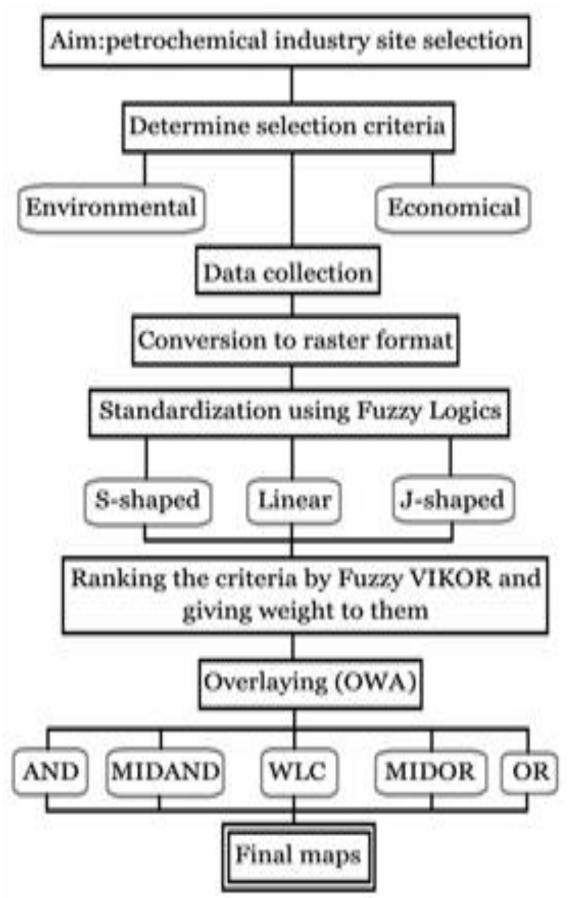

Fig. 2. Flowchart of the proposed site selection model.

Results and discussion

Selection of potential petrochemical sites for the case study of Hamedan province accomplished with eleven criteria that they were standardized using the fuzzy membership functions from Table 1 and 2, and the criteria maps were created. Standardized maps for each of the environmental and economic criteria are shown in Fig. 3.

Fig. 4 shows total of five decision alternatives for petrochemical site suitability associated with the environmental and economic factors. The OWA weights shown in Table 5 were used to generate different patterns to control the levels of trade-off and risk. The decision alternative which is associated with the AND operator have produces a risk averse solution. According to this alternative, the most suitable areas for petrochemical site are located in suitable distance of water resources (rivers) (Fig. 4 MCEMIN (AND)). The decision alternative which is associated with the OR operator have produces a Risk Taking solution. According to this alternative, the most suitable areas for petrochemical site are located near by the protected zone (Fig. 4 MCEMAX (OR)).

The decision alternative which is associated with the WLC operator has produces An Average Level of Risk solution. According to this alternative, the most suitable areas for petrochemical site are located in suitable distance of all criteria equally (Fig. 4 MCEAVG (WLC)). Moreover there are two MCEMID maps which are middle modes of privies maps (Fig. 4 mcenidand and mcemidor).

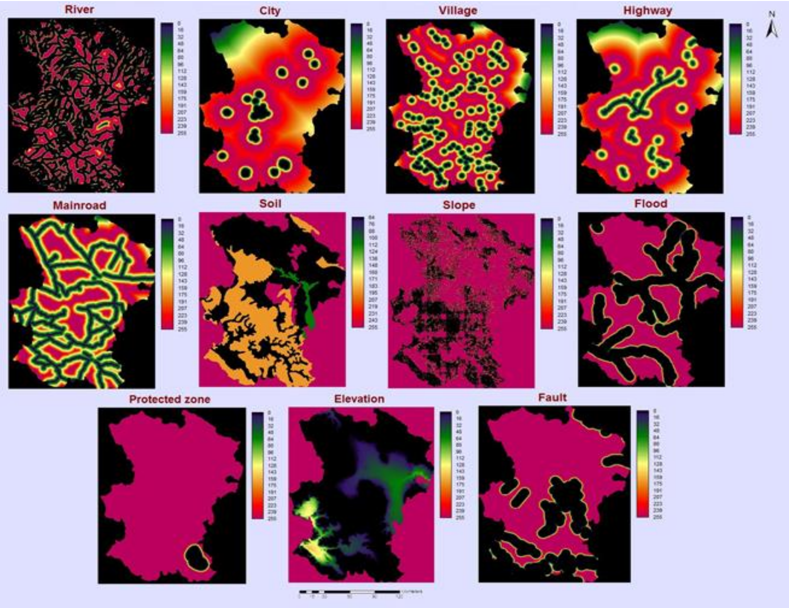

Fig. 3. Fuzzy-based maps.

The legends in the Fig. represent a measure of petrochemical suitability where possibility is expressed on a scale range between 0 and 255. The value of 255 for the AND ness suggest that the solution coincides with the AND while the value of 0 for the OR ness suggest that the solution is the most distant from OR. The trade-off measure of 0 represents no trade-off while 255 represent a full trade-off. The decision alternative MID AND solution which increases the risk in the solution and generates an increased land suitable for landfill siting. This solution pattern allows some trade-off and falls between the AND alternative and the conventional weighted linear combination (WLC) in a triangular decision space. It shows that the suitability for an industry has increased as compared to the previous decision alternative. The solutions with decision alternatives WLC or the AVG fall in the middle of the risk continuum and they are neither risk averse nor risk taking solutions. The next decision alternative set of the continuum produces a risk taking solutions.

The MIDOR solution which falls between the WLC and the OR where some trade-off is allowed and OR is in the opposite extreme from the AND solution. The suitable areas for landfill siting with this alternative has a very large spatial extent and includes all land use types. Finally, at the end of the continuum is the OR solution that recommends the almost entire area as suitable for landfill siting.

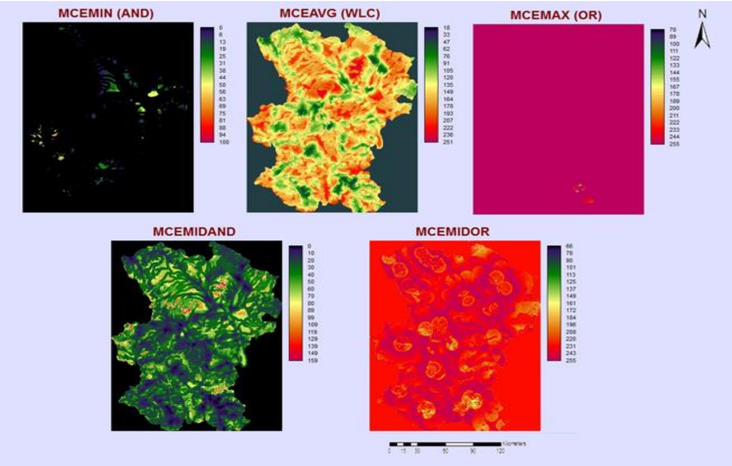

Fig. 4. Suitability maps derived by OWA method using Table 4.

Our results showed that GIS could be used as an analyst in site selecting for petrochemical industry. Furthermore, considering eleven main criteria in this paper and using them in incorporation of VIKOR model and GIS, lead us to understand that selected area in Hamedan Province has limited potential based on environment and economy; therefore, very limited areas of Hamedan surface are completely suitable for petrochemical industry.

Likewise, the results from this study demonstrate that the aim of the approach is not to find a single "optimal" solution, but to show other strengths associated with the weighting flexibility of the OWA approach. For example, the OWA approach provides a robust interactive toolset for adjusting trade-offs and compensation between criteria that allows a rapid assessment and interpretation of possible alternative scenarios and relationships between criteria.

Other strengths of this approach include the ability to integrate heterogeneous datasets such as quantitative and qualitative criteria using expert knowledge, the flexibility to select specific criteria for different study areas or different problems under consideration, to implement a single or a group decision-making, the flexibility to change the importance level of criteria, and the freedom to develop various modeling scenarios for acceptable levels of decision risks. However, since petrochemical industry siting depends on political and public opinion forces in conjunction with scientific analysis, we posit that this methodology holds significant potential to support the complexity of decision-making in real world applications.

Conclusions

Selecting the suitable petrochemical site is a critical activity for establishing an efficient industry management system and is a complicated decision-making problem for local governments, because it requires consideration of multiple alternative solutions and several quantitative and qualitative criteria. In this paper, the fuzzy VIKOR method focuses on ranking and selecting from a set of alternatives in the presence of conflicting criteria and according to the result the first place was given to water resources (river).

This ranking determines a compromise solution which can help the decision makers to reach a final decision. This methodology is used to evaluate the importance of criteria and generates the global weights, which are used in conjunction with the local weights in OWA procedure for producing the decision alternatives.

According to the authors the MCEMID AND map can be more useful because local weights are in harmony with fuzzy VIKOR ranking as well also it considered all the criteria.

These approaches can be generalized within the framework of the ordered weighted averaging (OWA) (ASP Roth *et al.*, 1999; Jiang and Eastman 2000; Markopoulos *et al.*, 2003; Malczewski *et al.* 2003; Malczewski and Rinner, 2005) and for example the result of (Malczewski, 2006) which was about housing development was that suitable areas for housing developments are located away from the wetlands and the result of another study which was about industrial areas site selection (Khavarian and Rezaei, 2015) was given the most weigh to city area.

In any case after ranking and weighting, overlaying is one of the most important steps of this kind of site selection and the benefits that OWA can include in contrast to other methods for example is to have wide range of suitability maps with different levels of risk which can help decision makers to have different choices and make the best decision.

In this paper and for its case study there were used eleven criteria but the presented methodology is flexible; so different evaluation criteria or additional parameters could be added based on site specific problems and requirements. Results of this study demonstrate that the aim of the approach is not to find a single "optimal" solution, but to show other strengths associated with the weighting flexibility of the OWA approach. In addition to this method it have recommended to other researchers to investigate the potential of other analysis methods such as fuzzy DEMATEL, neural network or logistic regression.

Abbreviations

GIS: Geographic information systems
MCE: Multi-criteria evaluation
OWA: Ordered weighted averaging
VIKOR: VI sekriteri jumska optimize cija iK compromise no Resenje (multi-criteria optimization and compromise solution)
MCDM: Multi-criteria decision making
WLC: Weighted linear combination

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