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Environmental impact assessment modeling in an urban man-made lake using fuzzy logic

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Abstract

Environmental impact assessment essentially depends on diverse closely connected components and variables. For this purpose, identification of the whole components is fundamentally required. This study aims to investigate environmental impact assessment of an urban man-made lake in the western part of Tehran, based on recognition of affecting components and their reciprocal effects. Since the components are not constant during the time, thus throughout the environmental impact assessment modeling study, dynamism of the relation between the components should be considered. Regarding insufficiency and uncertainty of information, an analytical method, based on expert's opinion can be applied. For this purpose, fuzzy group poll will be carried out throughout model structure design. In fact, in order to solve the lack of historical data in the environmental impact assessment modeling required data will be received based on group poll along with fuzzy logic and then expertise's opinion will be methodically studied. In this research, fuzzy logic is applied to environmental impact assessment modeling of a man-made lake in western Tehran. Firstly, affecting and affected components have been studied using impacts matrix, then using fuzzy logic, related data are required to be determined by experts on the basis of three indices such as influence rate, influence time and influence frequency. Also, all the collected responses are based on fuzzy logic as the components of transformation function. Finally, the total results will be totalized and fuzzy quantities related to expert's opinion calculated.

Key words: Fuzzy quantity, affecting components, affected components, reciprocal effects, group poll.

Introduction

Over the years, people believed that system's modeling is not practically possible by means of uncertain information. Consistently, people used to apply verbal quantities such as very, few, etc [11] to present their real sense or special conditions whereas in mathematical world certain quantity was attempted to be used due to Aristotle' logic which was investigated in 1965 and 1968. Finally all these attempts resulted in a new pattern in mathematic namely "fuzzy logic" which is highly applicable, worldwide [17]. Since there are different kinds of components in environmental impact assessment and also the EIA modeling process is carried out based on historical data, therefore, the relation between the components and dynamic models are identified on the basis of this data [24]. Thus, in the case of decision-making according to available information, modeling based on historical data can be considered as a suitable procedure [12], whereas, in the case of lack of sufficient information about components and their relations; such as environment impact assessment of a man-made lake [18, 20], historical data are not suggested to be applied [22, 23]. Decision-making will not be practical by unstable model structure and unknown components. Therefore, with respect to dynamic model, the EIA requires special procedures to identify the affecting and affected components and their relation. According to experts, this model cannot be exerted as a suitable one due to the following reasons[13]:
1) It is not possible to collect accurate data about experts' opinions, which are basically uncertain and on the basis of verbal quantity.
2) Since entire consensus among experts is not possible, therefore, any special object cannot be achieved.

Methodology

Identification of reciprocal effects between components: In order to indicate the model's structure, dynamic modeling throughout environmental assessment requires considerable information about the relation between the components. Different available methodologies such as Delphi model, Nominal Group Technique, system's analysis procedures, etc. can be applied to identify the affecting components, whereas they have not any effect on modeling and only can be considered as system components identification tools [16, 21].

To indicate the relation between the components, firstly it should be specified that which components have dynamic relation? Table 1 shows the reciprocal effects of the model's components [2]. In Table 1, I_{ij} can be equal to 0 and 1, representing lack and presence of relation between components, respectively.

Results

Application of fuzzy logic in data reception: Due to lack of accurate information, fuzzy logic is basically applied in modeling, in order to receive required data [1]. In the next step, fuzzy logic is used to identify the impact of affecting components (Ei) on affected components (Ej) [12]. For this purpose, it is essentially required to

Table 1. Identification of reciprocal effects among components.

	E_1	E_2	…	E_j	…	E_n
E_1	---					
E_2		---				
.			---			
.						
.						
E_i				I_{ij}		
.					---	
.						
.						
E_n						---

I_{ij} {0,1} E_i = affecting component, E_j = affected component, I_{ij} = relation between E_i and E_j.

collect data related to influence rate, influence time and influence frequency from experts by means of the following questions [8]:

1) How much is the influence rate of E_i on E_j?
2) How much is the influence time of E_i on E_j?
3) How much is the influence frequency of E_i on E_j?

Throughout uncertain condition, it is suggested to collect the opinion as verbal quantities and inaccurate data, in which the related responses are based on fuzzy logic used as transformation function in modeling [9]. In fact, the relation between the components will be asked from all the experts and the received responses are shown in Table 2 [4].

Integration of received data: For modeling, expert's opinion is required to be integrated and totalized as a unit opinion [15]. Table 3 depicts the reciprocal effects of the system's components as a group [3]. Calculating the total experts' opinions, in fact respondent column can be removed, and then a fuzzy quantity due to total calculation of expert opinion's verbal quantity will be recorded in k, a and b columns [4].

Fuzzy quantity calculation: In order to calculate the experts' opinion in the case of inaccurate information, it is recommended to apply the fuzzy logic. For this purpose, the following source is applicable [5]:

$$U=\{x_1, x_2, \ldots\ldots, x_n\}$$

In this study, in order to identify the relation between I and j components, shown in Fig. 1, a group of experts will be asked about this relation.

Figure 1. Relation between two components.

If based on hypothesis, m experts have stated their personal opinions as fuzzy quantity about one parameter of G(S) [7]:

$$V_1=\{\mu_{11}/x_1, \mu_{12}/x_2, \ldots, \mu_n/x_{1n}\}$$

$$V_2=\{\mu_{21}/x_1, \mu_{22}/x_2, \ldots, \mu_{2n}/x_n\}$$

Total member function of each components of U can be calculated as below [24]:

$$\mu_{Fj} = 1/m \sum_{i=1}^{m} \mu_{ij}$$

Then, fuzzy total quantity of parameter is defined as follows [25]:

$$V_F=\{\mu_{F1}/x_1, \mu_{F2}/x_2, \ldots, \mu_{Fn}/x_n\}$$

where, μ_{Fj} is the expert's total opinion about X_j membership in V_F fuzzy quantity of the relation among two components.

Defuzzification: After using the fuzzy group decision-making system, it should change the above complex to defuzzification quantity by the following equation namely center of gravity [26]:

$$Z^* = \frac{\sum \mu_A(x) \times x}{\sum \mu_A(x)}$$

where, Z^* is a defuzzification quantity.

Identification of reciprocal effects throughout environmental impact assessment of man-made lake: Firstly using 0 and 1 matrix, reciprocal effects among components are shown throughout both construction and exploitation phases of man-made lake in western Tehran [19]. The entire components classified in two affecting and affected groups, can be equal to 0 and 1 for the case of with and without effect on each other, respectively. Matrix 1 shows a portion of components effect matrix throughout construction of a man-made lake.

Discussion and Conclusions

Application of fuzzy logic to receive EIA components data: According to dynamic aspect of modeling, proper data about influence rate, influence time and influence frequency should be collected from environmental experts. Following questions have been posed based on above-mentioned reciprocal effects matrix. How is the influence rate of hemisphere on vegetation cover? How is the influence time of hemisphere on vegetation time? How is the influence frequency of hemisphere on vegetation cover?

Expert's opinions about the relation between two components are recorded in Table 4. As shown in Table 4, all the responses are on the basis of verbal data, in order to receive the opinion even in uncertain condition. Therefore, total expert's opinions are presented based on the impact of affecting component (hemisphere) on affected components (vegetation cover, wildlife,...) which results in total transformation function (Table 5).

Calculating the total experts opinions, in fact, respondent column can be removed, and then a fuzzy quantity due to total calculation of expert opinion's verbal quantity will be recorded in k, a and b columns. Fuzzy quantities of k, a and b are shown in Table 6.

As shown in Table 7, by indicating the relation between system's components and using fuzzy quantities, transform function of the impact of affecting components on affected components (vegetation cover, wildlife traffic, wildlife,…) can be characterized.

Regarding to frequency of components throughout the environmental impact assessment which results in considerable limits in dynamic modeling, and also because of lack of sufficient information about the relation between components, it is highly required to apply a proper tool in order to identify the affecting and affected components and their relation [14]. Thus, fuzzy logic can be used by experts to present their opinions verbally throughout the EIA dynamic modeling. For this purpose, finally, a man-made lake has been selected to show the entire results of EIA dynamic modeling using expert's opinions and fuzzy group decision-making.

Table 2. Reciprocal effects between the triple components.

	Respondent	Affecting component	Affected component	Affecting rate	Affecting time	Affecting frequency
n_i	P_i	E_i	E_j	K_i	a_i	b_i

P_i= respondent (expert) code, E_i = affecting component, E_j = affected component, K_i, a_i, b_i are the triple affecting components (influence rate, influence time and influence frequency), respectively.

Table 3. Matrix for the identification of reciprocal effects among components.

Effects matrix	Vegetation cover	Wildlife traffic	Wildlife	Ecologies	Ecosystems	Protected area
Hemisphere	1	1	1	1	1	1
Surface water quantity	1	1	1	1	1	1
Subsurface water quantity	0	0	0	0	0	0
Soil	1	0	1	1	1	1
Soil erosion	1	0	1	1	1	1
Earth shape	-	-	-	-	-	-
Geology and earthquake tendency	-	-	-	-	-	-

Table 4. Collected group data about reciprocal effects of triple components in the EIA.

Affected component	Triple effects													
	Influence frequency				Delay					Impact				
	Very	Mean	Low	Zero	High	Very	Mean	Low	Very low	High	Very	Mean	Low	Very low
Vegetation cover	✓					✓				✓				
Wildlife traffic			✓		`		✓					✓		
Wildlife		✓					✓				✓			
Ecologies		✓				✓					✓			
Ecosystems		✓				✓				✓				
Protected areas		✓			✓						✓			

Table 5. Group data about reciprocal effects of system's components.

Respondent	Affecting component	Affected component	Influence rate	Influence time	Influence frequency
1	X_1	x_1	m	M	nv
2	X_2	x_2	m	M	Nv
3	X_3	x_3	m	Nv	Nv
4	X_4	x_4	m	Nv	Nv
5	X_5	x_5	nv	Nv	V0
6	X_6	x_6	nv	Nv	V0

{nnv, nv, m, v, h}= {very few, few, mean, very, h}, x_1 Vegetation cover, x_2 Wildlife traffic, x_3 Wildlife, x_4 Ecologies, x_5 Ecosystem, x_6 Protected area.

Table 6. Fuzzy quantities of k, a and b components.

Affecting component	Affected component	Influence rate	Influence time	Influence frequency
x_1	X_1	0/5	1	0/49
x_1	X_2	0/47	1	0/252
x_1	X_3	0/41	0	0/34
x_1	X_4	0/41	1	0/55
x_1	X_5	0/41	0	0/34
x_1	X_6	0/37	1	0/52

Table 7. Transformation function of assessment components.

	x_1	x_2	x_3	x_4	x_5	x_6
x_1	$\frac{0.5}{s^\wedge 2+0/6957/87}$	$\frac{0.47}{s^\wedge 2+0/82+9/39}$	$\frac{0/41}{0/34s2+1}$	$\frac{0/41}{s^\wedge 2+0/506+7/87}$	$\frac{0/41}{0/34s+1}$	$\frac{0/37}{s^\wedge 2+0/82+90/72}$

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