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Research Article

A Hybrid Model for Assessing the Effects of Industrial Complexes on the Environment Using a Fuzzy Expert System

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Abstract

Background: Identifying the effects of industrial complexes on the environmental components is essential in the industrial activities' development planning.

Objectives: The purpose of this study was to evaluate the environmental impact of Khorramabad industrial parks using hybrid modeling.

Methods: In the study, a fuzzy expert system was used to evaluate the environmental impact of industrial parks. In the proposed model, a fuzzy inference system (FIS) was designed based on the Mamdani method and rapid impact assessment matrix (RIAM) model.

Results: The most negative effects are observed in the –E (major negative impacts) and –C (moderately negative impacts) ranges. About 24% of the negative effects of activities of industrial park 1 are in the –E range. In industrial park 3, the most negative effects are observed in the –C range (27%).

Conclusions: Industrial parks cause negative impacts on different parts of the environment. These consequences are a major issue for environmental planners and managers. The proposed approach could increase the accuracy and flexibility of effects in decision-making.

Keywords: Industrial Park, Environmental Impact Assessment, Fuzzy Expert System, Rapid Impact Assessment Matrix

1. Background

Developing industrial complexes is one of the most important parts of economic development strategies in the world (1). Since the 1990s, various industrial complexes have been developed in the Khorramabad area. The industrial parks are a source of pressure on the environment on different scales (2-5). Industrial complexes cause serious problems for the environment, including different kinds of environmental pollution (such as air pollution, water pollution, and soil contamination) (6-9). Environmental impact assessment (EIA) can play an effective role in identifying the effects of industrial development on the environment (10). EIA is defined as a decision-making tool to predict the effects of the environment through a systematic and comprehensive process (11). The purpose of EIA is to improve the project decision-making process, planning, design, and implementation of the project (12). This topic has been considered in different countries. Some countries, such as Canada (13, 14), India (15, 16), Denmark (17, 18), and China (19), try to evaluate environmental impacts through different models. In Iran, 55 large-scale projects, such as industrial parks, must be evaluated before the implementation and in the stage of feasibility studies (20).

In recent years, different methods have been used for the EIA of industrial parks. The most widely used methods developed in the review studies were checklist (21), Leopold matrix (22, 23), Iran matrix (24), rapid impact assessment matrix (RIAM) (25-27), fuzzy logic (28-30), multiple criteria decision making (MCDM) (31, 32), life cycle assessment (LCA) (33), etc. The above methods are inadequate in quickly changing and extremely uncertain conditions, where professional judgments on the environmental effects of industrial areas have a highly complex and imprecise nature. To address these problems in a comprehensive and effective framework, we proposed a fuzzy expert system based on a fuzzy inference system (FIS), which uses a RIAM method to score and standardize criteria in order to evaluate the environmental impacts. The purpose of FIS frameworks is to design an input space by applying fuzzy logic (34). FISs have been used in various fields, including urban planning (34), industrial areas (35, 36), and natural management (37, 38). The RIAM method is a new tool for the execution of EIA (25). The literature review showed that the RIAM method was used in different assessment studies.

Li et al. (39) applied an improved RIAM method to a strategic environmental assessment in China. The results showed that RIAM is a potential resource for overcoming such difficulties. Their analysis of RIAM applications suggested that it could evaluate strategic alternatives because of its applicability in interdisciplinary settings, transparency, and short implementation timeframe. Srivastava and Rawal (40) used the RIAM technique to evaluate environmental impacts in Prayagraj, India. Their results showed that RIAM was beneficial for a detailed study of large projects but less feasible for quick assessments of smaller projects. Cheng (41) designed an evaluation model based on the RIAM model to improve the deviation of the traditional grey comprehensive correlation analysis method and data envelopment analysis method in Sanmenxia, Henan Province, China. The experimental results showed that the design model could effectively reduce the deviation of traditional method analysis, and it was more in line with the actual situation of the Sanmenxia environment. Kumar and Deswal (42) studied the role of RIAM to find out the concerned areas to consider all the different components affecting the environment. The results indicated that RIAM was a proven method to investigate and evaluate the physical, ecological, economic, and social-cultural impacts due to the developmental projects. In Iran, Ghobadi et al. (43) used RIAM for the EIA of petrochemical industries as a decision support system in planning a process and developing the petrochemical industry. Padash (44) assessed the environmental impacts of Masjed Soleyman City's desalination and operating unit project in the south of Iran using RIAM. Shayesteh et al. (26) assessed the environmental impacts of industrial waste by the RIAM method in the Brujen industrial park. A review of the literature shows that a comprehensive study has not been performed using a combination of these methods to compare the impact assessment of industrial parks. The current research applied a fuzzy expert system to predict the environmental impacts of industrial parks in Khorramabad.

2. Objectives

The purpose of this study was to evaluate the environmental impact of Khorramabad industrial parks using hybrid modeling.

3. Methods

The study area is the industrial parks of Khorramabad. Three industrial parks of Khorramabad were chosen to evaluate, including industrial park 1, industrial park 2, and industrial park 3. The elevation of the study area is 1147.8 over the ocean level. Normal yearly precipitation is 511.06 (45). The average daily minimum temperature is -5.5°C in the winter, and the daily maximum temperature is 33°C in the summer (Table 1). Khorramabad has a temperate and semi-humid Mediterranean climate with heavy precipitation. The region is located in a valley and encompassed by mountains. The 2 primary mountains around the zone are Sefidkooh and Makhmalkouh. In a study, a fuzzy hybrid model was applied to evaluate the environmental impacts of Khorramabad industrial parks. Figure 1 presents the process of the used method. In the proposed model, FIS was designed based on the Mamdani method and RIAM model. Designed FIS relies on 2 components: (i) a knowledge base and (ii) an inference engine (34). A knowledge base is an organized table of RIAM about EIA. An inference engine interprets and evaluates the industrial parks in the knowledge base to prepare an answer. Typical tasks for FIS involve a fuzzy input set, knowledge base, inference, and fuzzy output set (35). Input scores for FIS were acquired from the literature review, expert judgments, and engineering opinions.

All variables of EIA were categorized into 4 groups: economical-operational (EO), physical-chemical (PC), sociological-cultural (SC), and biological-ecological (BE) groups. Table 2 presents environmental variables.

Criteria were scored based on 2 groups: groups A and B. Table 3 presents the assessment criteria of the proposed model. The scores of groups were calculated as follows (46):

$$A1 \times A2 = AT \quad (1)$$

$$B1 + B2 + B3 = BT \quad (2)$$

$$AT \times BT = ES \quad (3)$$

Environmental score (ES) is the evaluation score of the RIAM model. For fuzzification of all variables, triangular membership functions were used for inputs. Table 4 indicates fuzzy environmental scores to range bands.

In this study, to design a fuzzy expert system, the fuzzy theory was used to determine the input and output. In the study, a triangular fuzzy number (TFN) was applied due to its computational straightforwardness and capability to improve display and data handling in a fuzzy algorithm. A TFN on R is shown as (s, t, and u), and its function is displayed as follows (37):

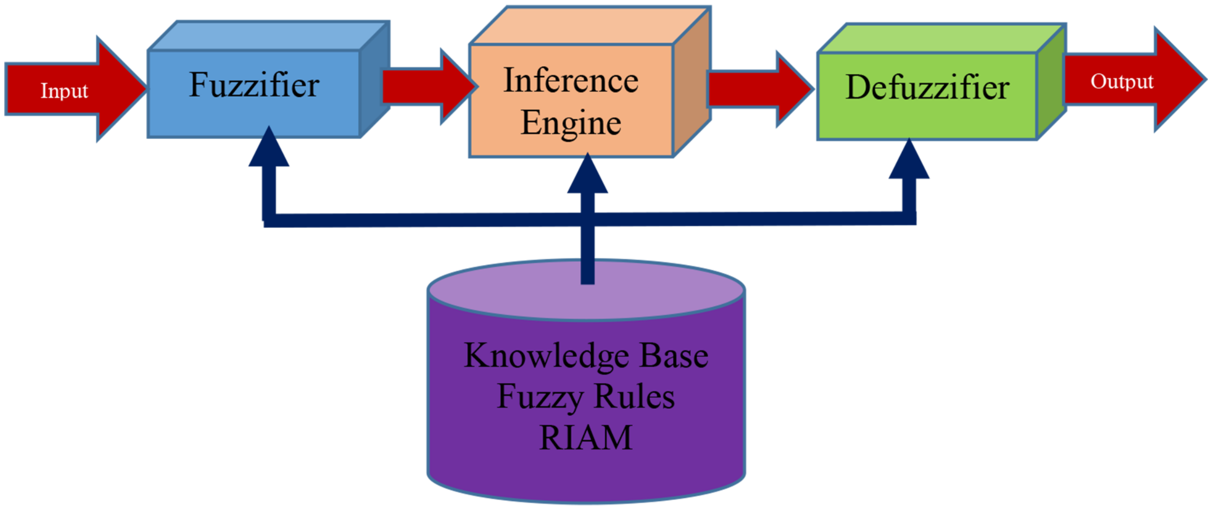

Figure 1. The structure of the proposed model for fuzzy rapid impact assessment matrix

Table 1. The Climate Information of the Study Area

Month	Temperature			Rainfall	Sunshine Days	Snowfall Days	Wind	
	Maximum	Minimum	Average				Speed	Direct
January	11.7	0.5	6.09	127.03	174.6	16	15	230
February	12.0	1.0	6.50	115.21	172.7	13	13	240
March	13.5	1.3	7.42	89.31	217.5	11	14	280
April	23.1	7.3	15.21	103.71	222.7	0	21	130
May	23.6	10.7	17.16	151.74	194.0	0	25	270
June	33.8	15.3	24.57	12.11	318.6	0	20	270
July	41.1	20.6	30.87	0	368.0	0	13	230
August	41.7	20.8	31.28	0	334.7	0	12	220
September	38.2	17.6	27.91	1.9	330.3	0	15	270
October	30.7	13.6	22.15	9.04	243.6	0	12	270
November	19.2	8.4	13.83	139.11	170.5	0	11	250
December	14.1	3.1	8.59	150.8	143.1	5	13	300
Annual	25.2	10.0	17.63	899.96	2890.3	26	25	300

Table 2. The Assessment Criteria of Disposal Scenarios

Components	Criteria	Symbol
Physical/chemical	Air quality	PC1
	Noise for humans	PC2
	Noise for animal species	PC3
	Quantity of surface water	PC4
	Quantity of groundwater	PC5
	Watershed and its physical properties	PC6
	Erosion	PC7
	Soil contamination and its permeability	PC8
	Microclimate	PC9
	Morphology	PC10
	Hydrology and drainage patterns	PC11
Biological/ecological	Land and water ecosystems	BE1
	Species habitats	BE2
	Biodiversity	BE3
	Ecological/biological processes	BE4
	Biosensitive areas	BE5
Economical/operational	Land use	EO1
	Economic conditions	EO2
	Transport	EO3
	Employment	EO4
	Land use patterns	EO5
	Regional development plans	EO6
	Financial income and expenses	EO7
	Tourism plans	EO8
	Future uses	EO9
Social/cultural	Demographic structure and population growth	SC1
	Quality of health and education services	SC2
	Human settlements	SC3
	Landscape	SC4
	Special places such as historical, religious, etc	SC5
	Quality of life	SC6
	Demographic displacement and migration	SC7
	Local participation	SC8

Table 3. The Scores of Fuzzy Rapid Impact Assessment Matrix Algorithm

Category	Indices	Fuzzy Score	Definition
(A)	A1	(3,4,5)	Significance to the international scale (A15)
		(2,3,4)	Significance to the national scale (A14)
		(1,2,3)	Significance to the regional scale (A13)
		(0,1,2)	Significance only to the local scale (A12)
		(0,0,0)	No significance (A11)
	A2	(2,3,4)	Major positive advantage (A23)
		(1,2,3)	Important improvement in the existing state (A22)
		(0,1,2)	Improvement in the existing state (A21)
		(0,0,0)	No alter (A20)
		(0,1,2)	Negative alter in the existing state (A24)
		(1,2,3)	Important negative disadvantage (A25)
		(2,3,4)	Major disadvantage (A26)
(B)	B1; persistence	(0,1,2)	No alter (B11)
		(1,2,3)	Provisional (B12)
		(2,3,4)	Resistant (B13)
	B2; resilience	(0,1,2)	No alter (B21)
		(1,2,3)	Alterable (B22)
		(2,3,4)	Inalterable (B23)
	B3; cumulative	(0,1,2)	No alter (B31)
		(1,2,3)	Non-cumulative (B32
		(2,3,4)	Cumulative (B33)

Table 4. Fuzzy Environmental Scores to Range Bands

Description	Fuzzy Environmental Scores	Range Bands
Major positive impact	(0,0,108)	+E
Significant positive impact	(0,0,71)	+D
Moderately positive impact	(0,0,35)	+C
Positive impact	(0,0,18)	+B
Slightly positive impact	(0,0,9)	+A
No change in the status quo	(0,0,0)	N
Slightly negative impact	(-9,0,0)	-A
Negative impact	(-18,0,0)	-B
Moderately negative impact	(-35,0,0)	-C
Significant negative impact	(-71,0,0)	-D
Major negative impact	(-108,0,0)	-E

$$u\,A(x) = \begin{cases} 0, x < s \\ \frac{x-s}{t-s}, s < x < t \\ \frac{x-u}{t-u}, t < x < u \\ o, otherwise \end{cases} \quad (4)$$

When there are 2 TFNs, = (a1, a2, a3) and = (b1, b2, b3), their functional rules can be as follows (35-37):

$$A \oplus B = (a1,\ a2,\ a3) \oplus (b1,\ b2,\ b3) = (a1+b1,\ a2+b2,\ a3+b3) \quad (5)$$

$$A \otimes B = (a1,\ a2,\ a3) \otimes (b1,\ b2,\ b3) = (a1b1,\ a2b2,\ a3b3) \quad (6)$$

$$A - 1 == (1/a3,\ 1/a2,\ 1/a1) \quad (7)$$

$$\lambda \otimes A = \lambda \otimes (a1,\ a2,\ a3) = (\lambda\,a1,\ \lambda\,a2,\ \lambda\,a3)\ (\lambda > 0,\ \lambda \in R) \quad (8)$$

Figure 2 presents 2 TFNs, A and B, to display the actions of fuzzy scores. The fuzzy score of A can be shown as (1, 2, 3), and the fuzzy score of B can be displayed as (2, 3, 4). The addition of 2 TFNs, A⊕B, creates a new fuzzy score of (3, 5, 7).

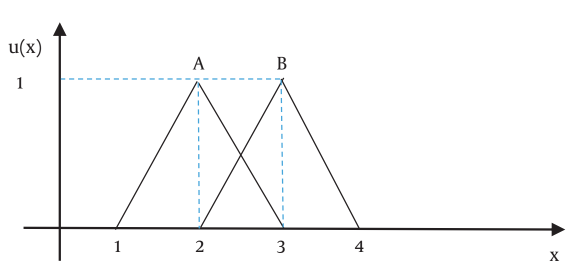

Figure 2. Triangular fuzzy numbers

4. Results

After determining and classifying the types of impacts, EIA was performed for 3 industrial parks of Khorramabad. The results of the evaluation based on the types of environmental impacts classified in the form of defuzzy results are shown in Table 5. The values of the outputs obtained in FIS are fuzzy sets. To simplify the analysis, fuzzy numbers were converted to ordinary numbers. In other words, at this stage, the value of the outputs is non-fuzzy. About 24% of the negative effects of activities of industrial park 1 were in the -E range (Figure 3). Very negative effects of industrial park 1 were related to the effects of PC components (12%) and BE components (9%). About 15% of the very positive effects of this park were related to EC components (15%) and SC components (3%). In industrial park 2 (Figure 4), the most negative effects were observed in the –D and –C ranges, and only about 9% of the negative effects of this park had very negative effects on BE components. Most of the EO effects of the parks belonged to the effects of industrial park 1 (18%). In industrial park 3 (Figure 5), the most negative effects were observed in the –C (27%) and –A ranges (15%). The very negative effects were related to the effects of SC components (3%). Very positive effects of this park were in the +C range and related to EO components (12%).

5. Discussion

The EIA process of industrial parks requires expert modeling, flexibility, and suitable variables for the prediction of environmental impacts. To design an appropriate expert system, one of the decision support tools is FIS. Used together, FIS and RIAM could increase the accuracy and flexibility of effects in decision-making. Also, the uncertainty and complexity of environmental impacts prepare more flexibility for the application of EIA based on fuzzy logic. The research proposed a fuzzy expert system based on RIAM to calculate the fuzzy environmental scores of each variable and obtain the effects of industrial parks by FIS. According to this study, the FIS technique is introduced as an effective assessment tool for the actual assessment of industrial parks and the assessment of complex assessment systems. Using the FIS method in combination with classical methods of impact assessment showed that many effects could be identified by considering uncertainty. Other studies have reported that EIA in combination with fuzzy theory is an effective tool for EIA according to different criteria. Ahmadipari and Hoveidi presented that using fuzzy theory in EIA reduced uncertainty (27). Ghobadi et al. showed that fuzzy RIAM was a flexible tool as a decision support system for the development of industrial areas (29). According to the RIAM process and its properties, one of the most important problems in implementing the RIAM guideline is the determination of environmental scores in weighting the factors and checklist; it is in line with other studies such as Padash (40). According to industrial park conditions, it is necessary to consider a literature review in EIA and expert opinions. It is in line with other studies such as Hoveidi et al. (25), Ijäs et al. (47), and Arani (23). Tashayo et al. (34) highlighted the strangeness of the FIS technique in designing the expert systems and the assessment of different criteria. The basis of the FIS

Table 5. Fuzzy Inference System Outputs of Khorramabad Industrial Parks

Variables	Industrial Parks		
	No. 1	No. 2	No. 3
Physical/chemical			
PC1	-0.892	-0.302	-0.155
PC2	-0.076	-0.082	-0.611
PC3	-0.265	-0.291	-0.233
PC4	-0.784	-0.321	-0.121
PC5	-0.211	-0.621	-0.055
PC6	-0.689	-0.253	-0.277
PC7	-0.564	-0.187	-0.081
PC8	-0.591	-0.642	-0.032
PC9	-0.602	-0.132	-0.214
PC10	-0.061	-0.052	-0.295
PC11	-0.721	-0.578	-0.478
Biological/ecological			
BE1	-0.681	-0.521	-0.294
BE2	-0.432	-0.694	-0.188
BE3	-0.714	-0.721	-0.241
BE4	-0.821	-0.777	-0.429
BE5	-0.489	-0.612	-0.586
Social/cultural			
SC1	+0.561	+0.619	+0.132
SC2	+0.412	+0.487	+0.251
SC3	-0.144	-0.263	-0.692
SC4	-0.321	-0.151	-0.061
SC5	-0.267	-0.125	-0.078
SC6	+0.771	+0.692	+0.881
SC7	+0.611	+0.356	+0.341
SC8	+0.245	+0.192	+0.156
Economical/operational			
EO1	+0.344	+0.669	+0.723
EO2	+0.712	+0.754	+0.311
EO3	+0.642	-0.423	-0.309
EO4	+0.661	+0.793	+0.391
EO5	+0.782	+0.815	+0.203
EO6	+0.721	+0.664	+0.311
EO7	+0.367	+0.366	+0.189
EO8	+0.701	+0.568	+0.555
EO9	-0.642	-0.569	-0.284

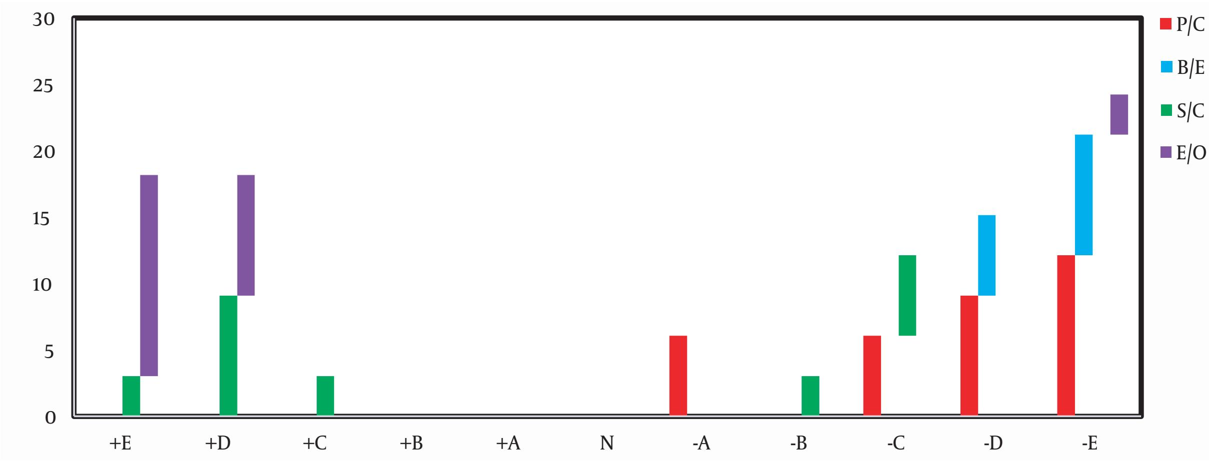

Figure 3. Fuzzy inference system outputs of industrial park 1

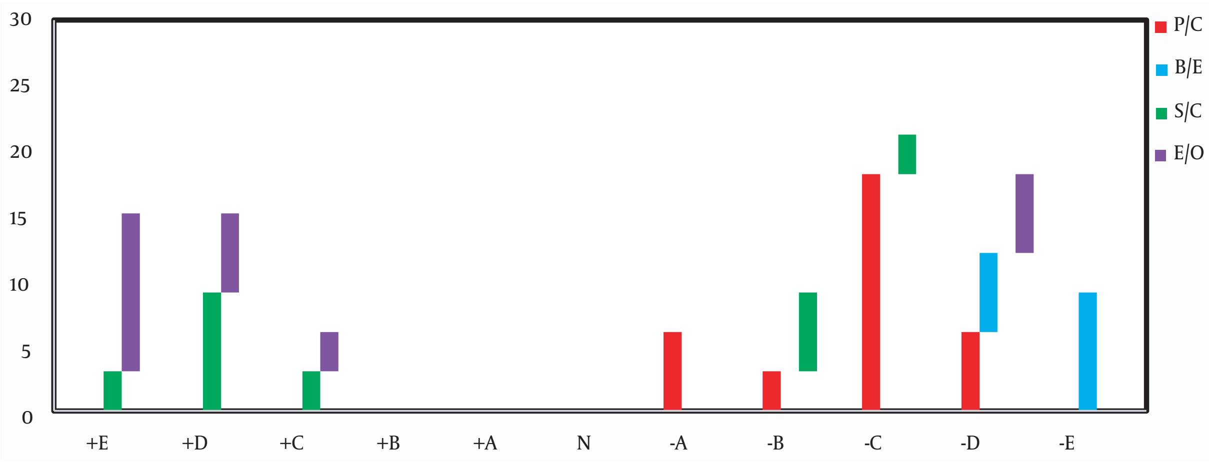

Figure 4. Fuzzy inference system outputs of industrial park 2

technique is characterized by the uncertainty of the environment and the fuzziness of information (36). Sarmah et al. highlighted that fuzzy logic was extensively used to better analyze and design systems for assessment processes (30). It is rooted in its properties and concept in the field of uncertainty. It is necessary to highlight that the current research is the first systematic study conducted in the field of EIA of Khorramabad industrial parks implementing the FIS guideline. Our study has many differences from the other studies: (1) We determined 4 groups of criteria databases for industrial parks; (2) after assessing the impacts of industrial parks, we identified that some of them were not suitable for operation in the region; (3) it was indicated that the tool had a quick calculation process to achieve an impact that makes it an appropriate tool for the actual assessment of industrial parks; and (4) it was observed that FIS could generate all needed fuzzy inputs that are already utilized by RIAM. The sustainability of the Khorramabad environment needs a balance between the natural environment and industrial development. The EIA of Khorramabad industrial parks is also combined with other assessing forms such as the physical assessment, economic assessment, and development assessment. During the preparation of the proposed model for the EIA, it was observed that most of the negative effects on nature were appraised high and long-term with significant impacts. The negative environmental impacts (which will result from the activities of the industrial parks, including increased pressure

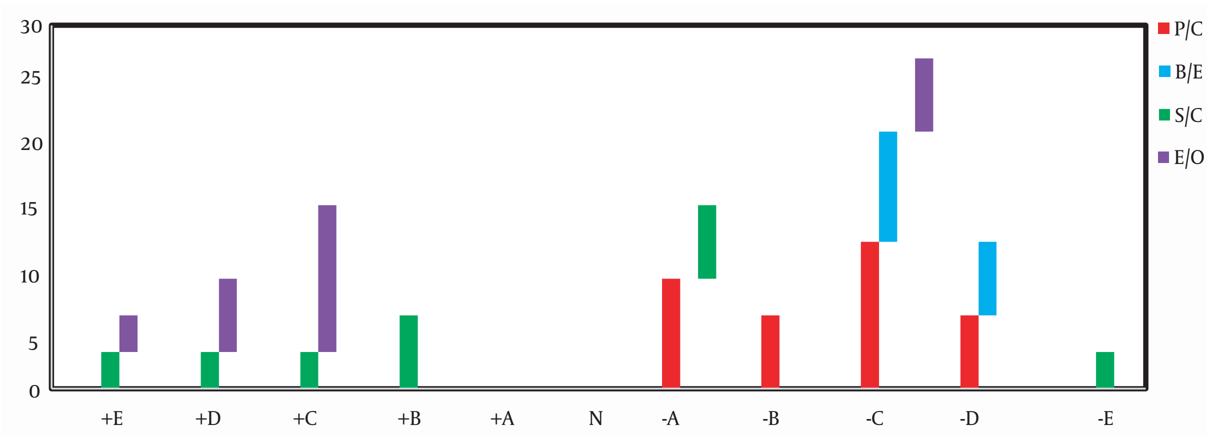

Figure 5. Fuzzy inference system outputs of industrial park 3

on ecosystems, air pollution, water pollution, and waste) can be mitigated.

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Footnotes

Authors' Contribution: Morteza Ghobadi performed the literature review and data collection, analyzed and interpreted the data, and prepared the manuscript text. Masoumeh Ahmadipari performed the literature review and prepared the manuscript text and data collection.

Conflict of Interests: The authors declare that there is no conflict of interest.

Data Reproducibility: The data presented in this study are openly available in one of the repositories or will be available on request from the corresponding author by this journal representative at any time during submission or after publication. Otherwise, all consequences of possible withdrawal or future retraction will be with the corresponding author.

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