A fuzzy logic-entropy weight method for comprehensive impact evaluations of hydropower stations

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Abstract: The operation and management of hydropower stations significantly influence the hydrodynamic and water quality conditions, which in turn exert large impacts on the

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environment and ecology. In this paper, a novel fuzzy logic-EWM (Entropy Weight Method) approach is proposed to perform comprehensive impact evaluations. Based on the natural and humanistic conditions of the Taizi River Basin, four criterion layers of economy, ecology, society, and management are determined. The fuzzy evaluation method is used to calculate the weight of the criterion layer, and each index under the criterion layer is determined. Further, the entropy weight model is used to calculate the weight of each index, which is compared with the weight of each indicator, as obtained by experts. The results showed that the subjective and objective results were consistent; the method accuracy was also acceptable. The study provided a new promising tool for fast comprehensive evaluations of the impacts of hydropower stations, and the evaluation case studies can provide experience for the comprehensive impact evaluation of hydropower stations in coastal regions.

Keywords: Hydropower station; Ecological evaluation; Fuzzy logic; Entropy weight method; Impact index.

1. Introduction

The operation and management of hydropower stations significantly influence the hydrodynamic and water quality conditions, which in turn exert large impacts on the environment and ecology [1-2]. An unneglectable number of hydropower stations were built in coastal areas due to the relevant abundant water resources. On one hand, these hydropower stations provide an important impetus and guarantees for coastal cities' economic development and flood control [3-4], but on the other hand, they inevitably altered the natural coastal hydrodynamics and water quality, which in turn affect the ecological environment [5-7]. Therefore, the evaluation of the influences of hydropower stations has become an important research topic; it has very important practical significance as a comprehensive and objective evaluation forms the basis and premise of identifying the degree of environmental impact and formulating protection and planning [8]. In addition to the modeling approaches based on numerical methods, evaluating the influences of hydropower stations using evaluation frameworks that consider more aspects is also quite important for decision makers.

The upper reaches of the Taizi River consist of two tributaries: south branch and north branch. The north branch is longer, with its source located in Hongshilazi, Pingdingshan Township, Xinbin Manchu Autonomous County. The source of the southern branch is located in Baishilazi, Huanren Manchu Autonomous County; the north–south branch converges at Xiaweizi, Benxi Manchu Autonomous County, and reaches convergence after the main stream of the Taizi River. The Prince River flows through many important counties and cities, including Xinbin Manchu Autonomous County, Benxi Manchu Autonomous County, Benxi City, Liaoyang County, Liaoyang City, Dengta City, Haicheng, etc. The Taizi River joins the Daliao River after the confluence of the Sancha River and the Hun River. The Taizi River has a total length of 363 km and a drainage area of 13,493 km^2. The Taizi River Basin is located in the temperate semihumid monsoon climate zone, where the northwest monsoon prevails in winter and southeast monsoon prevails in summer. The temperature changes greatly, and the climates are distinct with typical cold and warm and dry and wet seasons [9].

The main stream power stations of the Taizi River are the Guanyinge Reservoir Power Station, Shangbao Power Station, Zhaidong Power Station, Qingshiling Power Station, Songshutai Power Station, Fujia Power Station, Haoyuan Power Station, Weining Power Station, Caitun Power Station, Tuanshanzi Power Station, and the Shenwo Reservoir Power Station. See Table 1 for detailed information.

The impact evaluation refers to obtaining clear evaluation results, thus providing scientific information for hydropower station managers, developers, and the public based on scientific research and monitoring. Generally, it includes screening indicators and establishing an evaluation system, determining index weight and index evaluation, and finally obtaining comprehensive evaluation value. Analytic hierarchy process (AHP) [10], fuzzy evaluation [11-12] and Bayesian method can be used to evaluate the ecological impact of hydropower stations. However, there is no extremely effective method to evaluate the ecological impact of hydropower stations.

The fuzzy logic method can improve the refinement level of conventional methods without increasing the difficulty of operation, so it can become an efficient ecological impact evaluation method for hydropower stations. At present, the fuzzy logic method has been widely used in the fields of environment, engineering, and commerce [13-18], but it is seldom used in the ecological impact evaluation of hydropower stations. The fuzzy logic method has greater subjectivity in the process of determining the index weight value; while the EWM (entropy weight method) is an objective weighting method, which determines the objective weight according to the magnitude of the index variability [19-21], it has the advantages of strong objectivity, simple operation and high credibility, and has been widely used in engineering technology, social economy, and other fields [22-30].

The purpose of this paper is to propose a novel fuzzy logic – EWM approach for comprehensive impact evaluations, and to establish and apply the impact evaluation model of hydropower station based on the proposed approach, which combined the advantages of the fuzzy logic method and the EWM [31]. In this paper, the author determined the environmental impact factors based on expert evaluation and further determined the four indicators of average power efficiency, power grid, employment number, and public satisfaction from the four levels of economy, ecology, society, and management, respectively. It is used as an index layer. According to the fuzzy evaluation/entropy weight method proposed in this study, the weights of each criterion layer and index layer are determined and establishes the impact evaluation model based on fuzzy logic-EWM. According to the data analysis results, the impact index of each model is calculated by using the fuzzy logic-entropy weight model. So, it can provide experience for ecological impact evaluation of hydropower station based on fuzzy logic-EWM, and also provide a basis for ecological environment protection of hydropower station in this basin.

2. Methodology

2.1. Evaluation System

The evaluation system of the comprehensive impact of hydropower stations in the Taizi River Basin is established by the analytic hierarchy process, which divides all evaluation indexes into three levels: target level, criterion level, and index level. In order to ensure the rationality, authority, comprehensiveness, and representativeness of the selection of indicators, the selection process is carried out by means of expert evaluation. There are 15 representatives in total. Through the optimization and screening of various indicators such as basic information of hydropower stations, operating conditions, water ecological conditions of the river basin, people's satisfaction, management level, and economic benefits, the indicators with higher ranking are finally selected as the indicators of the hydropower station's health evaluation system. According to the specific characteristics of the Taizi River Basin and the relevant research results, the "ecological impact index" is selected as the target level indicators, the "economic", "ecological", "social" and "management" are selected as the criterion level indicators, and the "average electricity efficiency", "terrestrials", "employment number" and "public satisfaction" are selected as the indicator level indicators. The fuzzy logic method is used to calculate the index value of multi-criteria layer according to the index value, and then the index of the target layer is calculated based on the results and EWM, finally, the ecological impact index is obtained.

2.2. Fuzzy Logic Evaluation

Based on the fuzzy evaluation method [32-34], the evaluation values of each index in the criterion layer are determined, and the fuzzy logic analysis mainly adopts MATLAB. First, it defines the scope of indicators at the indicator level. Second, the membership curve of fuzzy logic is constructed to determine the membership degree of different values in a set.

Third, input the actual data of each index level in Xichong County. Fourth, to establish calculation rules, that is, to express and replace the process of judgment thinking by means of digitization and programming, this paper chooses the commonly used "IF-THEN" rules. The “if” statement is followed by a command, and the exit status code at the end of the command execution is 0; then, the command in the “then” part is executed. Otherwise, “then” does not execute. The “if” statement signifies the end of the if-then statement. Fifth, the evaluation value of each index in the criterion layer is obtained by operation calculation.

2.3. EWM for Evaluation

Based on the EWM, the weight values of each index in the criterion layer are determined [35-36]. First, x_{ij} was used the evaluation value hydropower station under the j index, and the summation evaluation value of each hydropower station is calculated through $\sum_{i=1}^{n} x_{ij}$, where n represents the number of hydropower stations.

P_{ij} is used to represent the proportion of the evaluation value of the first hydropower station under the j index, and its expression is as follows:

$$Pij = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad i = 1, \cdots, n \quad j = 1, \cdots, m \tag{1}$$

The entropy value of index J is expressed by E_j, and its expression is as follows:

$$Ej = -k \sum_{i=1}^{n} Pij \ln\left(Pij\right), \quad j = 1, \cdots, m \tag{2}$$

in which

$$k = \frac{1}{\ln\left(n\right)} \tag{3}$$

The information entropy redundancy of index j is expressed by D_j, and its expression is as follows:

$$Dj = 1 - Ej \quad j = 1, \cdots, m \tag{4}$$

The objective index weight Wj determined by the EWM can be expressed as:

$$Wj = \frac{Dj}{\sum_{j=1}^{m} Dj}, \quad j = 1, \cdots, m \tag{5}$$

The ecological impact index of each hydropower station is expressed by *S*. The formula is as follows:

$$S = \sum_{j=1}^{m} Wjz \times x_{ij}, \quad i = 1, \cdots, n; \, j = 1, \cdots, m \tag{6}$$

Then the subjective weight value is determined according to the expert scoring method and obtains the ecological impact index, the final evaluation value is obtained on average with the objective index value, in which the higher the evaluation value, the more favorable the impact is.

3. Results and discussion

3.1. Index Layer Index Value

Eleven typical hydropower stations in the Taizi River Basin were selected for the impact evaluation. The official data from the hydropower stations, including those reflecting the opinions of the experts and stakeholders are used to determine the evaluation index. Experts and stakeholders include water management, water research experts, water engineers, and public representatives, a total of 30 to provide the evaluators with water quality, water monitoring data, project construction reports, water resources bulletins and other materials; and ultimately select high ranking indicators. Finally, the economic benefit indicators include the average electricity benefit, net interest rate, asset-liability ratio and ROI rate in the past five years; the ecological indicators include substitution effect, emission reduction effect, terrestrials and aquatics; the social indicators include the number of employees, the number of technicians, the average tax in the past five years, and the input rate of livelihood; the management indicators include the degree of automation, employee satisfaction, mass satisfaction, and equipment utilization. For objective indicators such as "ROI", the original data are used directly, while for objective indicators such as "employee satisfaction" the method of expert scoring is used to determine. Finally, the index values of each index layer are shown in Table 1 of the Appendix.

3.2. Criteria Layer Index

The authors get the evaluation values of the criterion layer by inputting the values of each index layer into the fuzzy logical model, as shown in Table 2. According to Table 2, in economic indicators, the value of S9 is the lowest, 0.369, while that of S1 is the highest, 0.517. In ecological indicators, the value S11 is the lowest (0.394), while that of S2 is the highest (0.672). In social indicators, S2 has the lowest value of 0.328, while S1 has the highest value of 0.672. In the management index, the value of S5 is the lowest, 0.461, while that of S1 is the highest, 0.654. Among the economic indicators, the designed power generation capacity of the S9 power station is the smallest; as such, the value of S9 is the smallest. In the ecological indicators, S11 is located in the lower reaches of the Taizi River, carrying urban wastewater and domestic sewage in Benxi, Liaoyang, Anshan, and other places. The water pollution is relatively serious; thus, the value is the lowest. In the social indicators, Area S1 has perfect industries and population employment; Area S2 is relatively backward due to the impact of the terrain, and the employment rate is relatively low. In terms of management, the public satisfaction in Area S1 is relatively high; as such, the index value is also the highest.

3.3. Final Evaluation Value

Entropy weight method and expert (stakeholder) scoring method are used to determine the weight value of each index at the Criteria Layer. The results show that the objective weights of economy, ecology, society, and management are 0.11, 0.19, 0.58, and 0.13 respectively, and their subjective weights are 0.20, 0.40, 0.30, and 0.10, respectively.

The evaluation values of each criteria layer are obtained by multiplying the index values of the criteria layer and the objective weight values in Table A1. The results are listed in

Table 3. By multiplying the index value of the criteria layer with the subjective weight value, the author gets the index values of the criteria layer of each power station (Table 4).

The subjective and the objective evaluation values of each power station can be obtained with a summary of the weighted evaluation values of the four indicators of each power station, which are listed in Table 5. According to Table 5, in objective indicators, the value of S9 is the lowest, 0.422, while that of S1 is the highest, 0.621. In subjective indicators, the value S9 is the lowest (0.491), while that of S1 is the highest (0.570). In comprehensive indicators, S9 has the lowest value of 0.457, while S1 has the highest value of 0.595. Area S1 is designed with large power generation and high economic indicators; S1 is also located in the upper reaches of Prince Edward, where there is high water quality and rapid economic development. Therefore, in general, the evaluation value of Area S1 is the highest; Area S9 has smaller power generation, smaller storage capacity, and lower economic indicators. Further, because Area S9 is downstream, the water quality is poor. Population employment is also lower due to the economic impact. Therefore, in general, the evaluation value of Area S9 is the lowest. The objective and subjective results tend to match very well. Moreover, the weight of each index is consistent with the natural and economic conditions of the Taizi River Basin, so it follows that this method is feasible and can be used for ecological impact assessment of each scheme.

3.4. Discussion on evaluation results

According to the analyses above, the proposed impact assessment method of hydropower station based on the fuzzy logical entropy weight method only needs to determine the input and operate the fuzzy logic analysis tools, which is simple to operate. A single deterministic value can be obtained by using this method for evaluation, which is better than roughly defining the water quality. Therefore, this research has good value. In this paper, the authors established the model of fuzzy logical-entropy weight analysis for 11 power stations in Taizi River Basin located in coastal areas, which can be applied to the subsequent maintenance and reconstruction projects. The ecological, social, and environmental impacts of each scheme can be evaluated comprehensively by using the model. Compared with the current model, so as to determine the advantages of each scheme. In addition, the model can also be used in new power plant projects, providing a reference for its environmental impact assessment.

4. Conclusions

This study proposes a new hydropower station impact assessment method, i.e., fuzzy-logic entropy weight method. The 11 hydropower stations in the Taizi River Basin are established based on fuzzy logic EWM from four aspects: economy, ecology, society, and management. The impact evaluation model is used to determine the weights of indicators at each level. The results show that the lowest value of Area S9 is 0.457, and the highest value of Area S1 is 0.595. The subjective and the objective results tend to be consistent; hence, the accuracy of this method can be accepted.

The method proposed in this study can better play the role of AHP, reduce the subjective arbitrariness in the process of weight determination, enhance the objectivity of weight calculation, and improve the feasibility, comparability, and practicability of evaluation results. To the best of the authors' knowledge, this method has not yet been applied to comprehensive impact assessments of hydropower stations in coastal areas.

In addition, many indicators and factors affect environmental assessment, and there are certain limitations in the process of data collection and sorting; thus, more objective and comprehensive data support is still needed in future research.

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Table captions:

Table 1 Taizi River cascade hydropower stations

Table 2 Evaluation values of the criterion layer

Table 3 The objective evaluation values of each index in the criteria layer

Table 4 The subjective evaluation values of each index in the criteria layer of each power station

Table 5 The subjective and objective evaluation values of each power station

Table 1. Taizi River cascade hydropower stations

Station	name	Installed capacity（kw）	type	Storage capacity（$\times 10^4$ m^3）	Design power generation（$\times 10^4$ kwh）
S1	Guan Yin Ge	20750	after dam	216800	8015
S2	Shang Pu	960	in river channel	28.35	627
S3	Zhai Dong	4800	diversion type	9	2515
S4	Qing Shi Ling	4800	in river channel	670	572
S5	Song Shu Tai 2	6280	diversion type	69	2297
S6	Fu Jia	3500	diversion type	56	1751
S7	Hao Yuan	2550	diversion type	7.8	1166.8
S8	Wei Ning	3200	in river channel	477	1581
S9	Cai Tun	800	in river channel	105.5	425
S10	Tuan Shan	2200	in river channel	101.7	1108
S11	Shen Wo	44440	after dam	79100	8300

Table 2. Evaluation values of the criterion layer

Station	Name	Economy	Ecology	Society	Management
S1	Guan Yin Ge	0.517	0.500	0.672	0.654
S2	Shang Pu	0.500	0.672	0.328	0.531
S3	Zhai Dong	0.505	0.562	0.534	0.499
S4	Qing Shi Ling	0.500	0.580	0.571	0.641
S5	Song Shu Tai 2	0.471	0.562	0.641	0.461
S6	Fu Jia	0.421	0.617	0.385	0.534
S7	Hao Yuan	0.496	0.617	0.447	0.590
S8	Wei Ning	0.497	0.670	0.429	0.500
S9	Cai Tun	0.369	0.666	0.336	0.500
S10	Tuan Shan	0.380	0.670	0.344	0.508
S11	Shen Wo	0.491	0.394	0.590	0.640

Table 3. The objective evaluation values of each index in the criteria layer

Station	Economy	Ecology	Society	Management
S1	0.056	0.094	0.388	0.082
S2	0.054	0.126	0.190	0.066
S3	0.055	0.105	0.309	0.062
S4	0.054	0.109	0.330	0.080
S5	0.051	0.105	0.371	0.058
S6	0.046	0.116	0.223	0.067
S7	0.054	0.116	0.258	0.074
S8	0.054	0.126	0.248	0.063
S9	0.040	0.125	0.194	0.063
S10	0.041	0.126	0.199	0.064
S11	0.054	0.074	0.341	0.080

Table 4. The subjective evaluation values of each index in the criteria layer of each power station

Station	Economy	Ecology	Society	Management
S1	0.103	0.200	0.202	0.065
S2	0.100	0.269	0.098	0.053
S3	0.101	0.225	0.160	0.050
S4	0.100	0.232	0.171	0.064
S5	0.094	0.225	0.192	0.046
S6	0.084	0.247	0.116	0.053
S7	0.099	0.247	0.134	0.059
S8	0.099	0.268	0.129	0.050
S9	0.074	0.266	0.101	0.050
S10	0.076	0.268	0.103	0.051
S11	0.098	0.158	0.177	0.064

Table 5. The subjective and objective evaluation values of each power station

Station	Objective	Subjective	Final
S1	0.621	0.570	0.595
S2	0.437	0.520	0.479
S3	0.532	0.536	0.534
S4	0.574	0.567	0.571
S5	0.585	0.557	0.571
S6	0.451	0.500	0.476
S7	0.502	0.539	0.521
S8	0.491	0.546	0.518
S9	0.422	0.491	0.457
S10	0.430	0.498	0.464
S11	0.549	0.497	0.523

Table A1. Values of each index layer for each hydropower station.

Station	Economy				Ecology				Society				Management			
	ABE	NIR	ALR	ROI	SE	ERE	TR	AA	EP	TN	AT	LH	AM	ES	MS	EU
S1	0.80	0.19	0.00	0.13	0.98	0.02	0.3	0.3	103.00	47.00	681.00	0.17	0.80	0.98	0.97	0.84
S2	0.59	-0.36	0.01	0.09	1.21	11.08	0.8	0.8	7.00	5.00	3.00	0.08	0.50	0.98	0.95	0.50
S3	0.59	20.00	0.20	0.06	0.97	137.72	0.5	0.3	10.00	8.00	70.00	0.13	0.50	0.98	0.90	0.98
S4	1.46	0.00	0.02	0.02	0.44	0.70	0.8	0.8	16.00	14.00	37.00	0.10	0.80	0.98	0.96	3.48
S5	0.82	-0.06	2.00	0.10	0.95	23.71	0.5	0.3	128.00	36.00	18.00	0.14	0.50	0.90	0.94	0.85
S6	0.53	0.42	0.36	0.02	0.83	14.03	0.8	0.5	7.00	7.00	12.50	0.06	0.50	0.92	0.95	1.00
S7	0.55	0.40	0.06	0.02	0.79	69.98	0.8	0.5	14.00	11.00	15.40	0.07	0.50	0.94	0.94	0.98
S8	0.50	0.23	0.05	0.01	0.78	1.45	0.8	0.8	8.00	4.00	15.00	0.05	0.50	0.78	1.00	1.00
S9	0.44	-0.06	0.90	0.14	0.74	1.49	0.8	0.8	9.00	9.00	4.75	0.03	0.30	1.00	1.00	0.44
S10	0.49	-0.03	0.90	0.12	0.78	4.59	0.8	0.8	9.00	9.00	9.85	0.04	0.30	1.00	1.00	0.36
S11	0.90	0.26	0.16	0.05	0.53	0.08	0.3	0.3	106.00	55.00	1137.00	0.11	0.80	0.98	0.96	0.98

Note: AEB= Average electricity benefit; NIR=Net interest rate; ALR=Asset-liability ratio; SE=Substitution effect; ERE=Emission reduction effect; TR=Terrestrials; AA=Aquatics; EP=Employees; TN=Technicians; AT=Average tax; LH=Livehood; AM=Automation; ES=Employee satisfaction; MS=Mass satisfaction; EU=Equipment utilization.