Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 17 | No. 1 | pp. 131-138 | 2018

Original Research Paper | Open Access

Evaluation and Eco-regulation of Eco-restoration Engineering on Slopes of Hydropower Projects

Yang Yueshu*(**), Xu Wennian*(**), Liu Daxiang*(**)† and Xia Zhenyao*(**)
*Hubei Key Laboratory of Disaster Prevention and Mitigation, College of Civil Engineering and Architecture, China Three Gorges University, Yichang, 443002, China
** Engineering Research Center of Eco-environment in Three Gorges Reservoir Region, Ministry of Education, College of Civil Engineering and Architecture, China Three Gorges University, Yichang, 443002, China
†Corresponding author: Liu Daxiang

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 14-04-2017
Accepted: 13-07-2017

Key Words:
Eco-regulation
Eco-restoration
Hydropower projects
Slopes

ABSTRACT

Based on the fuzzy AHP method, an evaluation index system for eco-restoration engineering on the slope of a hydropower project is established with twenty indexes, which can combine qualitative analysis and quantitative analysis. It includes four kinds of indexes which are the effect of soil and water conservation, the effect of habitat material improvement, the effect of ecology and the effect of landscape. According to the problems found through the analysis, five targeted regulatory technologies were developed and then applied to eco-restoration engineering on the slopes of the Guangzhao, Nuozu, Xiaowan, Xiangjiaba and Pubugou hydropower stations, respectively. And the eco-regulation measures have effectively solved the existing problems. Through eco-regulation, the evaluation result of each has greatly increased and these measures have clearly improved the current conditions of the five typical engineering cases. This shows that the regulatory technologies are effective and that the evaluation index system is applicable.

INTRODUCTION

Most hydropower projects are in areas with fragile ecological environments in China. A large number of bare slopes are formed along with the large-scale engineering construction, which always has negative effects on the surrounding environment. The common types of disturbance, including rock side-slope, soil side-slope, waste soil and slag, can result in ecosystem degradation, loss of biodiversity and water and soil loss (Fig. 1). For high rock slopes in hydropower engineering, construction will break the force equilibrium of the original natural slope, and improper operation will create slope instability and may lead to geological disaster. Ecological restoration of the degraded ecosystem and vegetation resulting from the disturbance contributes to the sustainable utilization and development of the project and local society (Zeng et al. 2009, Wang et al. 2013). Many kinds of eco-restoration and protection technologies have been widely used in these hydropower project slopes. The ecological system of eco-restoration engineering on a slope can be regarded as the combination of the habitat material, vegetation and environment, the stability and continuity of which is in a state of dynamic change (Hou et al. 2012). Therefore, monitoring and evaluation of eco-restoration engineering on the slope is essential, and can also provide guidance on eco-regulation. At present, research on systems for evaluating eco-restoration engineering on the slopes of hydropower projects is relatively rare.

The analytic hierarchy process (AHP) established by Saaty is a method to solve multiple criteria decision problems by setting their priorities (Saaty 1977, Karahalios et al. 2011, Zhang et al. 2015). The fuzzy AHP method is the organic combination of the analytic hierarchy process and the fuzzy comprehensive evaluation method. Fuzzy AHP is a useful tool to deal with imprecise, uncertain or ambiguous data and the high non-linearity and complexity of ecosystems and ecological and environmental issues (Ardente et al. 2004). Based on the fuzzy AHP method, this paper established an evaluation index system for eco-restoration engineering on the slopes of hydropower projects, which was applied to five typical eco-restoration engineering projects, and satisfactory results were obtained.

METHODS

Principle of the fuzzy AHP method: The fuzzy AHP method has been widely used by various authors and has proved to be one of the best of the various assessment methods (Weck et al. 1997, Calabrese et al. 2013, Taylan et al. 2014, Men et al. 2015, Hsu et al. 2016). This method avoids the one-sidedness of traditional decision-making methods and subjective decision-making errors caused by the differences, and can provide more scientific and reasonable solutions, close to the practical engineering judgment (Tan et al. 2013). The evaluation system and index weight can be determined by using the AHP model. The index weight of the second-level index is:

$$W = \{w_1, w_2, w_3, ..., w_i\} \ (i = 1,2,3,\ldots, N) \quad ...(1)$$

The index weight of the sub-indexes of the *i*-th first-level index is:

$$W_i = \{w_{i1}, w_{i2}, w_{i3}, ..., w_{ij}\} \ (j = 1,2,3,\ldots, n) \quad ...(2)$$

The set of evaluation grading standards: $V = \{v_1, v_2, v_3, ..., v_k\}$, where v_k (k =1,2, ..., m) is the *k*-th evaluation grading standard. The membership degree of B_{ij} to the evaluation grading standard, v_k can be expressed as follows:

$$C_{ijk} = B_{ijk} \Big/ B_{ij1} + B_{ij2} + ... + B_{ijk} \quad ...(3)$$

Where, *i* is the number of first-level indexes; *j* is the number of second-level indexes under the *i*-th first-level index, *k* is the number of elements in the set of evaluation grading standards.

The membership matrix can be calculated as follows:

$$C_{ijk} = \begin{bmatrix} c_{i11} & c_{i12} & \cdots & c_{i1k} \\ c_{i21} & c_{i22} & \cdots & c_{i2k} \\ \cdots & \cdots & \cdots & \cdots \\ c_{ij1} & c_{ij2} & \cdots & c_{ijk} \end{bmatrix} \quad ...(4)$$

The comprehensive evaluation set of the *i*-th first-level index is:

$$R_i = W_i * C_{ijk} = (w_{i1}, w_{i2}, ..., w_{in}) \begin{bmatrix} c_{i11} & c_{i12} & \cdots & c_{i1k} \\ c_{i21} & c_{i22} & \cdots & c_{i2k} \\ \cdots & \cdots & \cdots & \cdots \\ c_{ij1} & c_{ij2} & \cdots & c_{ijk} \end{bmatrix} = (r_{i1} \quad r_{i2} \quad \cdots \quad r_{im}) \quad ...(5)$$

The fuzzy evaluation set of the first-level indexes can be calculated as follows:

$$S = W * (R_1 \quad R_2 \quad \ldots \quad R_N)^T = (w_1 \quad w_2 \quad \ldots \quad w_N) * (R_1 \quad R_2 \quad \ldots \quad R_N)^T \quad ...(6)$$

Adjustment method of eco-regulation for eco-restoration engineering: Based on years of practical experience, we have summarized a method for the dynamic adjustment of eco-regulation for eco-restoration engineering on slopes. This method is mainly divided into the following six steps. These steps can be repeated until the final evaluation result achieves the expected goal.

Step 1: Based on the field monitoring and laboratory test data, the target eco-restoration engineering is evaluated by using the evaluation system established. The evaluation result of each first-level index is recorded as B_{xy} (x, y=1, 2, ..., n) and the final evaluation result is recorded as A_x (x=1, 2, ..., n), which can be obtained according to the grading standard established. Here, x represents the number of times that the target eco-restoration engineering is evaluated and *y* represents the number of first-level indexes.

Step 2: If A_x (x=1, 2, ..., n) does not achieve the expected goal, the real-time problems of the target eco-restoration engineering can be analyzed by combining B_{xy} (x, y=1, 2, ..., n) and the actual conditions of the target eco-restoration engineering.

Step 3: The eco-regulation methods for the target eco-restoration engineering can be determined by the problems identified in step 2. Specifically, if a composition of one or more existing regulatory technologies can solve these problems, these regulatory technologies are chosen. If not, new and suitable regulatory technologies will be developed for these problems.

Step 4: The regulation scheme is made up around the regulation method selected in step 3, which is then applied to the target eco-restoration engineering.

Step 5: Based on the field monitoring and laboratory test data, the target eco-restoration engineering is evaluated again by using the evaluation system established. The evaluation result of each first-level index is recorded as B_{x+1y+1} (x, y=1, 2, ..., n) and the final evaluation result is recorded as A_{x+1} (x=1, 2, ..., n), which can be obtained according to the grading standard established.

Step 6: If A_{x+1} (x=1, 2, ..., n) achieves the expected goal, it is not necessary to carry on with the regulation. If not, A_{x+1}(x=1, 2, ..., n), B_{x+1y+1}(x, y=1, 2, ..., n) and A_x (x=1, 2, ..., n), B_{xy} (x, y=1, 2, ..., n) are analyzed by comparative analysis. The next regulation scheme is optimized and made up based on the comparison and evaluation of the regulation effect of the last.

THE EVALUATION INDEX SYSTEM FOR ECO-RESTORATION ENGINEERING

Establishment of evaluation index system: Designing the index system scientifically is the prerequisite and basis for correctly evaluating the effect of eco-restoration engineering on slopes. Eco-restoration engineering on a slope is a dynamic system project, which requires the selection of evaluation indexes to comprehensively reflect the engineering effects on a multifaceted and multi-level object. The basic principles of the evaluation index system respectively are the principle of scientificity and objectivity, the principle of comprehensive and dominant factors, the principle of

Table 1: Index weight of the evaluation index system.

First-level index	Index weight	Second-level index	Index weight	Total sequencing weight	Order of importance
The effect of soil and water conservation	0.2312	Permeability C1	0.1765	0.0408	14
		Shearing strength of root-soil composite C2	0.2073	0.0479	10
		Soil erosion intensity C3	0.2519	0.0583	6
		Root weight density C4	0.1805	0.0417	13
		Maximum scour depth C5	0.1838	0.0425	12
The effect of habitat material improvement	0.3888	Available N C6	0.1603	0.0623	5
		Available P C7	0.0751	0.0292	17
		Available K C8	0.0714	0.0277	18
		Microbial biomass C C9	0.1117	0.0434	11
		Microbial biomass N C10	0.1348	0.0524	8
		Soil bulk density C11	0.0939	0.0365	15
		Organic matter C12	0.2110	0.0820	2
		pH C13	0.1418	0.0551	7
The effect of ecology	0.2558	Importance value of dominant species C14	0.1956	0.0500	9
		Gleason species richness index C15	0.3061	0.0783	3
		Shannon–Wiener diversity index C16	0.3640	0.0931	1
		Pielou evenness index C17	0.1343	0.0344	16
The effect of landscape	0.1242	Landscape coordination C18	0.2000	0.0248	19
		Landscape visiting capacity C19	0.2000	0.0248	19
		Bareness degree C20	0.6000	0.0745	4

(a) Rock side-slope (b) Soil side-slope (c) Waste soil and slag

Fig. 1: The common types of disturbance.

practicability and operability, and the principle of dynamism and stability. According to these principles, the evaluation index system for eco-restoration engineering on the slope of a hydropower project is established, including four kinds of indexes. These are the effect of soil and water conservation, the effect of habitat material improvement, the effect of ecology and the effect of landscape. The evaluation index system is shown in Fig. 2.

Determination of index weight: Starting from level 2 of this index system model, the importance of factors at the same level is compared. The judgment matrix is constructed according to Satty's 1-9 scale until the lowest level (Xie et al. 2012, Macharis et al. 2004, Kahraman et al. 2009). Through consistency testing, the index weight can be obtained, as given in Table 1.

Determination of grading standard: According to the analysis for monitoring the data of each index, the grading standard system is established. It is suitable for evaluating the indexes of eco-restoration engineering on slopes of hydropower projects. The grading standard is divided into five levels (v_1-Very good, v_2-Good, v_3 -Normal, v_4 -Poor and v_5 -Very poor), as given in Table 2.

APPLICATION CASES OF EVALUATION AND ECO-REGULATION

General situation of engineering cases: The eco-restoration engineering efforts on the slopes of the Guangzhao, Nuozu, Xiaowan, Xiangjiaba and Pubugou hydropower sta-

Table 2: The grading standard system of the evaluation index.

GradeIndex	v_1	v_2	v_3	v_4	v_5
Permeability/(mm·h^{-1})	>30	30~20	20~10	10~5	<5
Shearing strength of root-soil composite/(kPa)	>60	60~50	50~40	40~30	<30
Soil erosion intensity/(g·cm^{-3}·a^{-1})	<5	5~15	15~25	25~35	>35
Root weight density/(kg·m^{-3})	>3.5	3.5~2.5	2.5~1.5	1.5~0.5	<0.5
Maximum scour depth /(cm·a^{-1})	<5	5~10	10~15	15~20	>20
Available N/(mg·kg^{-1})	>75	75~55	55~35	35~15	<15
Available P/(mg·kg^{-1})	>30	30~20	20~10	10~5	<5
Available K/(mg·kg^{-1})	>205	205~150	150~95	95~40	<40
Microbial biomass C/(ug·g^{-1})	>200	200~150	150~100	100~50	<50
Microbial biomass N/(ug·g^{-1})	>25	25~20	20~15	15~10	<10
Soil bulk density/(g·cm^{-3})	<1.5	1.5~2.0	2.0~2.5	2.5~3.0	>3.0
Organic matter/(g·kg^{-1})	>30	30~20	20~10	10~5	<5
pH	>6.5	7.5~8.0	8.0~8.5	8.5~9.0	>9.0
Importance value of dominant species	>20	25~35	35~45	45~55	>55
Gleason species richness index	>19	19~14	14~9	9~6	<6
Shannon-Wiener diversity index	>3.0	3.0~2.5	2.5~2.0	2.0~1.5	<1.5
Pielou evenness index	>1.0	1.0~0.8	0.8~0.6	0.6~0.4	<0.4
Landscape coordination	Very good	Good	Normal	Poor	Very poor
Landscape visiting capacity	Very good	Good	Normal	Poor	Very poor
Bareness degree	<20	20~40	40~60	60~80	>80

Note: Shearing strength of root-soil composite is under the saturated condition and the vertical pressure of 75 kPa .

tions are defined as Case I, Case II, Case III, Case IV and Case V. The general situation of the five engineering cases is as given in Table 3.

Taking Case I, for example, the expected goal of this case was very good or good. Based on field monitoring and laboratory test data, Case I was evaluated by using the evaluation system established. The evaluation results of the first-level indexes were recorded as B_{11}, B_{12}, B_{13}, B_{14}, respectively. The final evaluation result was recorded as A_1 (Normal), as given in Table 4. Obviously, A_1 (Normal) did not achieve the expected goal (very good or good). Combining B_{11}, B_{12}, B_{13}, B_{14} (the value of the effect of habitat material improvement proved to be the minimum) and the actual conditions of this eco-restoration engineering project, we identified the existing problems of Case I (Table 5). Additionally, for Case II, too, the value of the effect of habitat material improvement proved to be the minimum. For Cases III and IV, the value of the effect of ecology proved to be the minimum. For Case V, the value of the effect of soil and water conservation proved to be the minimum.

Eco-regulation technology for eco-restoration engineering: According to the problems identified in Table 5, new and targeted regulatory technologies were developed for Case I, Case II, Case III, Case IV and Case V, respectively.

1. Activation agents (Patent number: ZL200910063087.6, Notified number: CN101608446, China): The activation agent, produced by soaking for two hours and then freeze- drying, may consist of a microbial agent of nitrogen-fixing bacteria, phosphate-solubilizing bacteria and silicate bacteria, etc.
2. A-B microbial fertilizer (Patent number: ZL201310627756.4, Notified number: CN103626584A, China): Mixture A consists of broken pieces of peanut shell, active enzyme agent, corrosion inhibitor, urea, etc. Mixture B consists of honeycomb coal cinder, calcium superphosphate and compound fertilizer, etc. The A-B microbial fertilizer is synthesized from a mixture of A and B.
3. Vegetative bags for shrubs (Patent number: ZL201110377113.X, Notified number: CN102498 915A, China): Vegetative bags are made of biodegradable material and filled with habitat material and shrub seeds, then placed in holes dug in the slope.
4. Shrub seedling protection (Application number: 201510183183.X, China): This device mainly consists of a conical cover, cylindrical tube and several fixed links, and is installed over the shrub seedlings after transplanting.
5. Non-destructive repair for habitat material (Patent number: ZL 201510203274.5, Notified number: CN104805847A, China): Several differently specified pieces of eco-friendly cardboard with multiple grids are produced depending on the damage condition of the habitat material. These can be installed in the bare mesh sheet by means of cutting and splicing.

Evaluation results and eco-regulation effect: Taking Case I as an example, the regulation scheme (application amount:

Table 3: General situation of five engineering cases.

No.	Location	General engineering situation	Conditions after engineering completion
Case I	Guizhou Province	There are two parts to the original excavated rock, one limestone and the other sedimentary sandstone. The entire area of the slope is probably 8500 m^2, with a vertical height of about 20 m and a slope angle of up to 80°.	After 2 years, the available N, P, K content was lower than before in some sections of the habitat material. The plants appeared to be undernourished.
Case II	Yunnan Province	The original excavated rockface is mainly purple sand shale, sandstone and gneiss. This slope covers an area of about 6500 m^2 and the slope angle is up to 67°.	After 3 years, the content of soil sand was high and the nutrient loss was more serious.
Case III	Yunnan Province	This rock slope is located on the highway to the construction encampment. This slope covers an area of about 16000 m^2 and the slope angle is 65°~75°, which is seriously eroded.	After 5 years, the vegetation community consisted mainly of Gramineae and Composite.
Case IV	Yunnan and Sichuan Province	This slope is located on the incoming highway to the hydropower project. The area of the original excavation is 7000 m^2 and the slope angle is about 53°.	*Pennisetum purpureum* was selected as one of the pioneer species in order to achieve the goal of high vegetation coverage. A vegetation survey revealed that shrubs were limited in settlement after 2 years.
Case V	Sichuan Province	This slope is located on the right bank of the highway of the hydropower project. It covers an area of about 2000 m^2 and the slope angle is about 50°.	The anchors were not fixed according to the design specifications, which resulted in partial damage of the habitat material and the exposure of the original mesh.

Table 4: Evaluation results before and after eco-regulation.

No.	Order	Evaluation results				
		Very good v_1	Good v_2	Normal v_3	Poor v_4	Very poor v_5
Case I	Before	0.1147	0.1860	0.3391	0.2483	0.1128
	After	0.7625	0.1757	0.0458	0.0163	0.0000
Case II	Before	0.1763	0.2137	0.1887	0.2928	0.1285
	After	0.5891	0.1396	0.0872	0.1841	0.0000
Case III	Before	0.2061	0.1825	0.1757	0.3392	0.0965
	After	0.1396	0.5391	0.1023	0.1818	0.0372
Case IV	Before	0.0254	0.1015	0.1202	0.5909	0.1620
	After	0.6625	0.2717	0.0392	0.0266	0.0000
Case V	Before	0.0364	0.2221	0.3008	0.3079	0.1329
	After	0.6625	0.2757	0.0458	0.0160	0.0000

2.5 g/m^2) was made up based on the activation agent technology selected, which was then applied to Case I. Based on the latest field monitoring and laboratory test data, Case I was evaluated again by using the evaluation system. The evaluation results of the first-level indexes were recorded as B_{21}, B_{22}, B_{23}, B_{24}, respectively. The final evaluation result was recorded as A_2 (very good), as shown in Table 4. Apparently, A_2 (very good) achieved the expected goal (very good or good), so it was not necessary to continue the regulation. If not, the above steps should be repeated until the final evaluation result achieves the expected goal. The five engineering cases before and after eco-regulation are compared in Table 5.

The experimental results show that the activation agent technology has effectively improved the properties of the habitat material and vegetation growth in the environment. It has also enhanced the fertility of the habitat material. The A-B microbial fertilizer technology has increased the number of beneficial microbes, and it has greatly improved the buffering capacity of the rhizosphere environment and soil aggregate structure. The vegetative bags for shrubs technology have created a suitable environment for germination and the initial growth of shrub seeds, so that the survival rate of the shrubs has now increased from less than 30% to 85%. The shrub seedling protection technology significantly improves the survival rate of shrubs, which can achieve the objective of synchronous planting of herbs and shrubs. The non-destructive repair for habitat material technology can reduce water loss and soil erosion. Moreover, according to the size of the exposed mesh and the concave or convex slope surface, the multi-grid cardboards ensure that the slope remains flat after repair. The effect of the eco-

Table 5: Comparison of engineering cases before and after eco-regulation.

No.	Evaluation results (before)	Existing problems	Eco-regulation method	Evaluation results (after)	Current conditions	Eco-regulation effect
Case I	Normal	Soil fertility of the habitat material was insufficient and the fertility sustainability was poor.	Activation agent ($2.5g/m^2$)	Very good	The microbial biomass of the habitat material has increased about 32 times. The average content of avail able N, P, K has more than doubled in the past 5 years. The excavated slope has been harmonized with the surrounding mountain landscape.	Significant
Case II	Poor	Soil nutrition of the habitat material was not harmonious and the soil structure was bad.	A-B microbial fertilizer	Very good	The microbial biomass level is 30 times higher than before, which has effectively solved the problem of long-term nutrients for the habitat material.	Extremely significant
Case III	Poor	The shrub seed germination rate and growth was not as good as for herbaceous plants.	Vegetative bags for shrubs (10 bags/m^2)	Good	The vegetation coverage has reached more than 80% with a substantial increase in species diversity.	Significant
Case IV	Poor	The shrub survival rate was low and shrubs had the disadvantage of interspecies competition with herbs.	Shrub seedling protection	Very good	The growth of shrubs on the slope is in a good condition and the vegetation community has obvious stratification.	Extremely significant
Case V	Poor	It was difficult to spray again to repair damage to the habitat material without harmful effects on the other areas.	Non-destructive repair for habitat material	Very good	The repair process has not damaged the original vegetation, but realized a smooth coordination between the repaired surface and the original slope.	Extremely significant

regulation of Case IV is shown in Fig. 3.

The eco-regulation measures adopted have effectively solved the existing problems, which shows that each technology is effective. Through eco-regulation, the evaluation result of each has greatly increased compared with the previous situation. The eco-regulation effect for Case I and Case III is significant and the eco-regulation effect for Case II, Case IV and Case V is extremely significant. Correspondingly, these measures have indeed improved the current conditions of the five engineering cases, which shows that the evaluation index system is highly applicable for eco-restoration engineering.

CONCLUSIONS

Twenty indexes that reflect the comprehensive quality for eco-restoration engineering on the slopes of hydropower projects are selected. Based on the fuzzy AHP method, the evaluation index system and the grading standard are established, which has achieved the combination of qualitative and quantitative evaluation for eco-restoration engineering.

By choosing five typical eco-restoration engineering projects as examples, five targeted regulatory technologies were developed according to the existing problems identified. These were the technologies of activation agents, A-B microbial fertilizers, vegetative bags for shrubs, shrub seedling protection and non-destructive repair for habitat material, which were applied in the eco-restoration engineering on the slopes of the Guangzhao, Nuozu, Xiaowan, Xiangjiaba and Pubugou hydropower stations, respectively. These eco-regulation measures effectively solved the existing problems, showing that each technology is effective.

We have summarized a method for the dynamic adjustment of eco-regulation for eco-restoration engineering on slopes. In this method, five eco-restoration engineering cases were evaluated by using the established evaluation system before and after the eco-regulation. The evaluation results have greatly increased and these measures have clearly improved the current conditions of the five engineering cases, which shows that the evaluation index system is highly applicable for eco-restoration engineering.

ACKNOWLEDGEMENTS

The research is supported by National Key R&D Program of China (Program SN: 2017YFC0504902-02), National Natu-

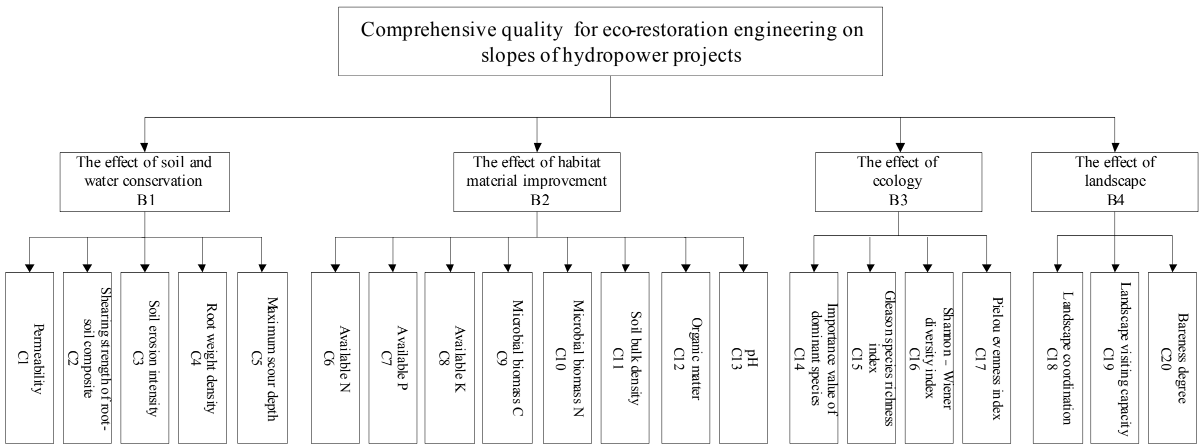

Fig. 2: The evaluation index system for eco-restoration engineering on slopes of hydropower projects.

(a) Before eco-regulation (b) Eco-regulation process (c) After eco-regulation

Fig. 3: Eco-regulation effect for Case IV

ral Science Foundation of the People's Republic of China (Program SN: 51708333, 51678348), Open Research Program of Key Laboratory of Disaster Prevention and Mitigation, Hubei Province (Program SN: 2016KJZ13), Natural Science Foundation of Hubei Province(Program SN: 2016CFA085), Open Research Program of the Engineering Research Center of Eco-environment in the Three Gorges Reservoir Region of the Ministry of Education (Program SN: KF2016-05).

REFERENCES

Ardente, F., Beccali, M. and Cellura, M. 2004. FALCADE: a fuzzy software for the energy and environmental balances of products. Ecological Modelling, 176(3): 359-379.

Calabrese, A., Costa, R. and Menichini, T. 2013. Using fuzzy AHP to manage intellectual capital assets: An application to the ICT service industry. Expert Systems with Applications, 40(9): 3747-3755.

Hou, Y.M., Xu, W.N. and Xia, Z.Y. et al. 2012. Research on evaluation index system of ecological slope protection effect for hydropower project. Yangtze River, 43(3): 62-64.

Hsu, W.K.K., Huang, S.H.S. and Tseng, W.J. 2016. Evaluating the risk of operational safety for dangerous goods in airfreights-a revised risk matrix based on fuzzy AHP. Transportation Research Part D: Transport and Environment, 48: 235-247.

Kahraman, C., Kaya, Ý. and Cebi, S. 2009. A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. Energy, 34(10): 1603-1616.

Karahalios, H., Yang, Z.L. and Williams V. et al. 2011. A proposed system of hierarchical scorecards to assess the implementation of maritime regulations. Safety Science, 49(3): 450-462.

Macharis, C., Springael, J. and De Brucker, K. et al. 2004. PROMETHEE and AHP: The design of operational synergies in multicriteria analysis: Strengthening PROMETHEE with ideas of AHP. European Journal of Operational Research, 153(2): 307-317.

Men, B.H., Long, R.S. and Zhao, Y.W. et al. 2015. Correlation analysis and forecasting changes in Yongding River water quality based on information entropy and gray system theory. Nature Environment and Pollution Technology, 14(3): 655.

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3): 234-281.

Tan, Z., Zhong, W. and Qi, K. et al. 2013. Selection and optimization for mining structural parameters of shallow hole chamber and pillar succedent filling method. Electronic Journal of Geotechnical Engineering, 18(Q): 3573-3580.

Taylan, O., Bafail, A.O. and Abdulaal, R.M. 2014. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. Applied Soft Computing, 17: 105-116.

Wang, T., Wu, H. and Li, Y. et al. 2013. Stability analysis of the slope around flood discharge tunnel under inner water exosmosis at Yangqu hydropower station. Computers and Geotechnics, 51: 1-11.

Weck, M., Klocke, F. and Schell, H. et al. 1997. Evaluating alternative production cycles using the extended fuzzy AHP method. European Journal of Operational Research, 100(2): 351-366.

Xie, S.W., Wang, T.Y. and Lü, Y.L. 2012. AHP-based assessment on POPs pollution control technologies. Chinese Journal of Environmental Engineering, 6(2): 692-698.

Zeng, X., Chen, F.Q. and Xu, W.N. et al. 2009. Vegetation restoration in disturbance area of large hydropower project-a case study of Xiangjiaba hydropower project. Resources and Environment in the Yangtze Basin, 18(11): 1074-1079.

Zhang, J., Hu, X. and Li, Q. et al. 2015. Evaluation and comparison of the resource and environmental carrying capacity of the 10 main urban agglomerations in China. Nature Environment and Pollution Technology, 14(3): 573.