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Decision Analysis of Slope Ecological Restoration Based on AHP
(Analisis Keputusan Pemulihan Ekologi Cerun Berdasarkan AHP)

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ABSTRACT

The serious deterioration of the ecological environment comes from a large number of geological disasters. These disasters were caused by a number of engineering activities. Ecological restoration is an important measure to reduce geological disasters and protect the ecological environment. On the basis of the introduction of cast-in-situ grids technology, external-soil spray seeding technology and vegetation bag technology, according to the ecological restoration experiment of the road slope attach to the Three Gorges Pumped-Storage Power Station in Hohhot, decision analysis of slope ecological restoration is done with AHP*. It is shown that in arid and semi-arid area, selection of slope ecological restoration scheme mainly needs considering the ecological effect and stability. The major factor of ecological effects is survival rate of vegetation. The major factor of stability is the stability in a whole. Cast-in-situ grids technology will be the first choice for ecological restoration of road slope in arid and semi-arid area. This study provides reference for decision of the slope ecological restoration in arid and semi-arid region.*

Keywords: AHP*; decision analysis; ecological restoration; slope*

ABSTRAK

*Kemerosotan serius berkaitan persekitaran ekologi berlaku disebabkan banyak bencana geologi. Bencana ini telah disebabkan oleh beberapa aktiviti kejuruteraan. Pemulihan ekologi merupakan langkah penting untuk mengurangkan bencana geologi dan melindungi persekitaran ekologi. Berdasarkan pengenalan teknologi grid tuangan-*in-situ*, teknologi penyemburan pembenihan tanah luar dan teknologi tumbuhan beg, menurut pengalaman pemulihan ekologi cerun jalan bersambung dengan Stesen Simpanan Pam Three Gorges di Hohhot, keputusan analisis pemulihan ekologi cerun dilakukan dengan* AHP*. Keputusan menunjukkan bahawa di kawasan gersang dan separa gersang, pemilihan skim pemulihan ekologi cerun perlu mempertimbangkan kesan ekologi dan kestabilan. Faktor utama kesan ekologi ialah kadar kemandirian tumbuh-tumbuhan. Faktor utama kestabilan ialah kestabilan secara menyeluruh. Teknologi grid tuangan-*in-situ *akan menjadi pilihan pertama untuk pemulihan ekologi cerun jalan di kawasan gersang dan separa gersang. Kajian ini memberi rujukan untuk membuat keputusan tentang pemulihan ekologi cerun di kawasan gersang dan separa-gersang.*

Kata kunci: AHP*; Analisis keputusan; cerun; pemulihan ekologi*

Introduction

In recent years, the economic development is extraordinarily fast in China. At the same time, landslide, debris flow, collapse, land subsidence and ground crack (Hu et al. 2014), soil and water loss (Chen et al. 2013; Mei et al. 2015) and other geological disasters have appeared frequently, because of construction of road and railway mining. It can cause environmental pollution (Wang et al. 2007), vegetation destruction and ecological degradation. Besides, project operation and human survival environment are threatened seriously. If these geological disasters cannot be prevented and controlled effectively, they will leave hidden dangers in the locality. Not only it brings the recent economic loss and potential hazards to geological stability, but also the environmental problems due to these geological disasters and landscape variation will affect descendants. Ecological restoration is the important measures for prevention of geological disasters and the protection of ecological environment (Kil 2016; Kil et al. 2016). The main form of it was planting vegetation simply and now it develops into the combination of planting measures and engineering measures (Wang et al. 2015). Different ecological restoration techniques vary widely in cost and ecological effect. How to select suitable ecological restoration technology according to the factors such as climate, geology and topography is a problem to be solved. Decision analysis of slope ecological restoration (Li et al. 2012) is done based on AHP (Choi 2011; Yi & Wang 2013) in arid and semi-arid region (Madsen et al. 2016). In this paper, we use the road slope attach to the Three Gorges Pumped-Storage Power Station in Hohhot as an example.

Materials and Methods

Three experiment areas are built on the slope attach to the Three Gorges Pumped-Storage Power Station. Every test area is 300 m^2. It uses cast-*in-situ* grids technology, external-soil spray seeding technology and vegetation bag technology (Guo et al. 2009), respectively, in the test areas.

MATERIALS

Every technology uses different structure and material.

CAST-*IN-SITU* GRIDS TECHNOLOGY

Cast-*in-situ* grids is a new type of slope ecological restoration technology. It pours scale-like grids by a special mould on the surface of the slope. Steel bar is set in the scale-like grids, as shown in Figure 1. Anchors are built inside the slope, which is combined with scale-like grids firmly so as to form a three-dimensional structure shown in Figure 2. Planting vegetation within the scale-like grid and laying substrates are effective measures to improve the stability (Li & Guan 2013; Wang & Bai 2012) and promote vegetation restoration (Bai et al. 2014).

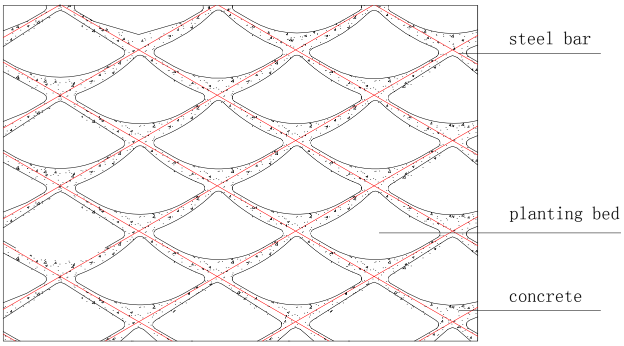

FIGURE 1. Scale-like grids

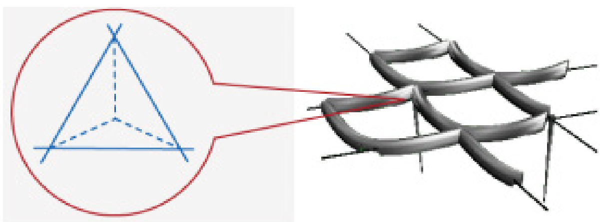

FIGURE 2. Three-dimensional structure

EXTERNAL-SOIL SPRAY SEEDING TECHNOLOGY

External-soil spray seeding technology comes from Japan. It was introduced in China in the 1990s (Gu et al. 2015; Huang 2015). The basic method is to spray the base material mixture of certain proportion on the surface of the slope covered by net through special spray seeding mechanic so as to form external-soil, then vegetation seed is sprayed on the base material. It builds anchors with different length inside the slope and steel meshes or geonets can be hung on it. Anchors and steel meshes or geonets form load-carrying frames. The base material of this technology mainly contains peat soil or humus made up with organic material, fertilizer, wood fiber, crumb agent, PH ease agent, adhesive and water retention agent. Thus, it can form an environment in which plants will grow well.

VEGETATION BAG TECHNOLOGY

Vegetation bag technology comes from foreign countries. Recently, it has been applied and expanded in highway slope ecological restoration in our country (Lu & Feng 2013). The technology is to pile vegetation bags which are full of planting base material and plant seeds in good order along the slope. The bags can be fixed effectively by anchors and steel mesh. The seeds in vegetation bags can root and sprout by absorbing nutrition of the base material. The vegetation bag is landscape greening special bags including plant seeds and planting base material. The bag is divided into five levels. The inside and the outermost layers are nylon fiber nets. The second inside layers are thick non-woven fabrics. The middle layers are planting base material and seeds. Planting base material is mainly composed of planting soil, organic matters, river sand, fertilizer, water retention agent, acidity regulator and disinfectant. Steel fabric is laid on the outer surface of vegetative bag through anchor fixed on the slope.

METHODS

In the experiment, four types of parameters are tested, which include cost saving, ecological effect, stability and advantages of technology. Direct cost saving and environment cost saving are calculated after planting, and maintenance cost saving is calculated two years later. It should survey the plant survival rate and coverage monthly after planting. Strength of anchor is tested with the anchor drawing instrument so as to calculate the coefficient of the slope stability and the quantity of soil erosion is measured because of raining. The number of patent about the three technologies is surveyed so that advantages of technology can be obtained.

RESULTS

According to the experiment, parameters value for the three technologies can be obtained. Contrast to the cast-*in-situ* grids technology, value increased about external-soil spray seeding technology and vegetation bag technology are listed in Table 1.

Discussion

THE ANALYSIS MODEL BASED ON AHP

Considering the cast-*in-situ* grids technology, external-soil spray seeding technology and vegetation bag technology, the best ecological restoration scheme to pumped-storage power station in Hohhot can be decided according to cost saving, ecological effect, stability, advances of technology and other factors. According to Table 1 and the goal of ecological restoration, the analysis model based on AHP is built, as shown in Figure 3.

PARAMETER CALCULATION

By means of mutual comparison of all factors, 9 scale methods (Ahmad et al. 2017; Azratul et al. 2017; Deng et al. 2012; Rahman et al. 2017) is used to build the judgment matrix. Then the relative importance coefficient of various layer (W_i), the maximum characteristic value of judgment matrix (λ_{max}) and consistency ratio ($C.R.$) are listed in the Tables 2-4.

TABLE 1. Value increased contrast with cast-*in-situ* grids technology

Parameters	External-soil spray seeding technology (%)	Vegetation bag technology (%)
Direct cost saving	33	9
Environment cost saving	24	23
Maintenance cost saving	-68	-41
Survival rate of plant	-39	-18
Coverage	-21	3
The number of species increased	-41	-37
Coefficient of Stability	-56	-35
the quantity of soil erosion	-36	-21
Patent	-79	-58

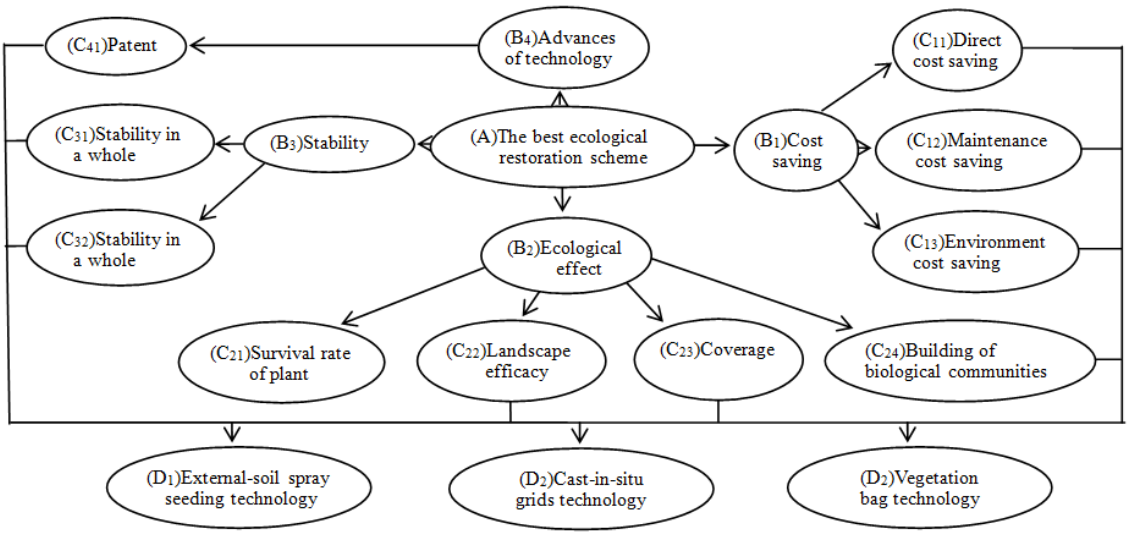

FIGURE 3. Decision analysis model of ecological restoration based on AHP

TABLE 2. Parameter calculation based on AHP for A ~ B

	A	B_1	B_2	B_3	B_4	W_A	
A～B	B_1	1	1/3	1/3	2	0.14	λmax=4.0200
	B_2	3	1	1	5	0.39	
	B_3	3	1	1	5	0.39	$C.R._A$=0.0075
	B_4	1/2	1/5	1/5	1	0.08	

TABLE 3. Parameter calculation based on AHP for B ~ C level

B_1~C	B_1	C_{11}	C_{12}	C_{13}		W_{B1}	λmax=3.0323
	C_{11}	1	4	7		0.71	
	C_{12}	1/4	1	3		0.21	C.R.$_{B1}$=0.0315
	C_{13}	1/7	1/3	1		0.08	
B_2~C	B_2	C_{21}	C_{22}	C_{23}	C_{24}	W_{B2}	λmax=4.1066
	C_{21}	1	2	3	5	0.47	
	C_{22}	1/2	1	3	4	0.31	C.R.$_{B2}$=0.0397
	C_{23}	1/3	1/3	1	3	0.15	
	C_{24}	1/5	1/4	1/3	1	0.07	
B_3~C	B_3	C_{31}	C_{32}			W_{B3}	λmax=2
	C_{31}	1	5			0.83	
	C_{32}	1/5	1			0.17	C.R.B_3=0

TABLE 4. Parameter calculation based on AHP for C~D level

C_{11}~D	C_{11}	D_1	D_2	D_3	W_{C11}	λmax=3.0354
	D_1	1	4	3	0.62	
	D_2	1/4	1	1/2	0.14	C.R.$_{C11}$=0.0344
	D_3	1/3	2	1	0.24	
C_{12}~D	C_{12}	D_1	D_2	D_3	W_{C12}	λmax=3.0820
	D_1	1	1/7	1/3	0.08	
	D_2	7	1	5	0.73	C.R.$_{C12}$=0.0796
	D_3	3	1/5	1	0.19	
C_{13}~D	C_{13}	D_1	D_2	D_3	W_{C13}	λmax=3.0667
	D_1	1	3	2	0.53	
	D_2	1/3	1	1/3	0.14	C.R.$_{C13}$=0.0649
	D_3	1/2	3	1	0.33	
C_{21}~D	C_{21}	D_1	D_2	D_3	W_{C21}	λmax=3.0205
	D_1	1	1/5	1/3	0.10	
	D_2	5	1	3	0.64	C.R.$_{C21}$=0.0200
	D_3	3	1/3	1	0.26	
C_{22}~D	C_{22}	D_1	D_2	D_3	W_{C22}	λmax=3.0205
	D_1	1	1/5	1/3	0.10	
	D_2	5	1	3	0.64	C.R.$_{C21}$=0.0200
	D_3	3	1/3	1	0.26	
C_{23}~D	C_{23}	D_1	D_2	D_3	W_{C23}	λmax=3.0083
	D_1	1	1/3	1/3	0.14	
	D_2	3	1	1	0.43	C.R.$_{C23}$=0.0082
	D_3	3	1	1	0.43	
C_{24}~D	C_{24}	D_1	D_2	D_3	W_{C24}	λmax=3.0444
	D_1	1	1/5	2	0.18	
	D_2	5	1	5	0.71	C.R.$_{C24}$=0.0431
	D_3	1/2	1/5	1	0.11	
C_{31}~D	C_{31}	D_1	D_2	D_3	W_{C31}	λmax=3.082
	D_1	1	1/7	1/3	0.08	
	D_2	7	1	5	0.73	C.R.$_{C31}$=0.0796
	D_3	3	1/5	1	0.19	
C_{32}~D	C_{32}	D_1	D_2	D_3	W_{C32}	λmax=3.0226
	D_1	1	1/5	1/2	0.12	
	D_2	5	1	3	0.65	C.R.$_{C32}$=0.0219
	D_3	2	1/3	1	0.23	
C_{41}~D	C_{41}	D_1	D_2	D_3	W_{C41}	λmax=3.0931
	D_1	1	1/9	1/3	0.06	
	D_2	9	1	7	0.79	C.R.$_{C41}$=0.0905
	D_3	3	1/7	1	0.15	

THE TOTAL SEQUENCING OF EACH LEVEL

$$W^{(3)} = P^{3}W^{(2)} . \quad (1)$$

$$P^{(3)} = \begin{bmatrix} 0.71 & 0 & 0 & 0 \\ 0.21 & 0 & 0 & 0 \\ 0.08 & 0 & 0 & 0 \\ 0 & 0.47 & 0 & 0 \\ 0 & 0.31 & 0 & 0 \\ 0 & 0.15 & 0 & 0 \\ 0 & 0.07 & 0 & 0 \\ 0 & 0 & 0.83 & 0 \\ 0 & 0 & 0.17 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} . \quad (2)$$

$$W^{(2)} = \begin{bmatrix}0.14 & 0.39 & 0.39 & 0.08\end{bmatrix}^{\mathrm{T}} . \quad (3)$$

$$W^{(3)} = \begin{bmatrix}0.10 & 0.03 & 0.01 & 0.18 & 0.12 & 0.06 & 0.03 & 0.32 & 0.07 & 0.08\end{bmatrix}^{\mathrm{T}} . \quad (4)$$

$$P^{(4)} = \begin{bmatrix} 0.62 & 0.08 & 0.53 & 0.10 & 0.10 & 0.14 & 0.18 & 0.08 & 0.12 & 0.06 \\ 0.14 & 0.73 & 0.14 & 0.64 & 0.64 & 0.43 & 0.71 & 0.73 & 0.65 & 0.79 \\ 0.24 & 0.19 & 0.33 & 0.26 & 0.26 & 0.43 & 0.11 & 0.19 & 0.23 & 0.15 \end{bmatrix} . \quad (5)$$

$$W^{(4)} = P^{(4)}W^{(3)} = \begin{bmatrix}0.15 & 0.62 & 0.23\end{bmatrix}^{\mathrm{T}} . \quad (6)$$

THE CONSISTENCY CHECK OF TOTAL SEQUENCING OF EACH LEVEL

The consistency ratio of total sequencing of the k level can be calculated in (7).

$$C.R.^{(k)} = \frac{C.I.^{(k)}}{R.I.^{(k)}} . \quad (7)$$

$$C.I.^{(k)} = (C.I._{1}^{(k)}, \cdots, C.I._{n_{k-1}}^{(k)})W^{(k-1)} . \quad (8)$$

$$R.I.^{(k)} = (R.I._{1}^{(k)}, \cdots, R.I._{n_{k-1}}^{(k)})W^{(k-1)} . \quad (9)$$

The consistency of total sequencing for A~ B level

The consistency ratio of total sequencing for A~B level and A~C level is $C.R.^{(B)} = 0.0075 < 0.1$ and $C.R.^{(C)} = 0.0383 < 0.1$, respectively, according to (7), therefore, they meets requirements.

The consistency of total sequencing for A~ D level

The consistency ratio of total sequencing for A~ D level is $C.R.^{(D)} = 0.0566 < 0.1$ according to Equation (7), so it meets requirements.

THE WEIGHT ANALYSIS

The weight order of B level is $W_{B2} = W_{B3} > W_{B1} > W_{B4}$, as shown in Figure 4. The ecological effect and stability are the most important factors to the selection of slope ecological restoration schemes, and their weights add up to 78%. The second factor is cost saving and the last one is the advances of technology which weight is just 8%. These indicate that ecological effect and stability are the most important factors to measure the ecological restoration schemes.

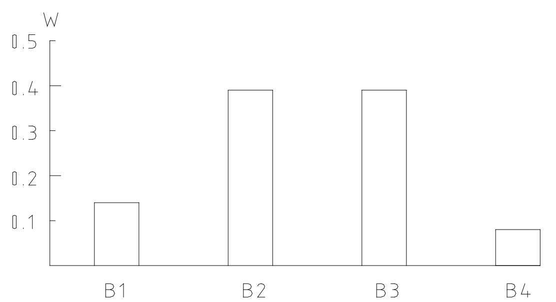

FIGURE 4. The weight distribution map of factors for B level

The weight order of C level is $W_{C31} > W_{C21} > W_{C22} > W_{C11} = W_{C13} > W_{C41} > W_{C32} > W_{C23} > W_{C12} > W_{C24}$, as shown in Figure 5. The stability in a whole and survival rate of vegetation are the most important factors to the selection of slope ecological restoration schemes. Their weights add up to 50%, followed by landscape efficacy, direct cost saving, patent, the capability of conserving soil and water as well as coverage. The last ones are cost saving maintenance, building of biological communities and environmental cost saving, which their weight add up to just 7%. These indicate that it should pay attention to stability in a whole of slope and vegetation survival rate in measuring the slope ecological restoration schemes. On the contrary, cost saving maintenance, building of biological communities and environmental costs should be considered less.

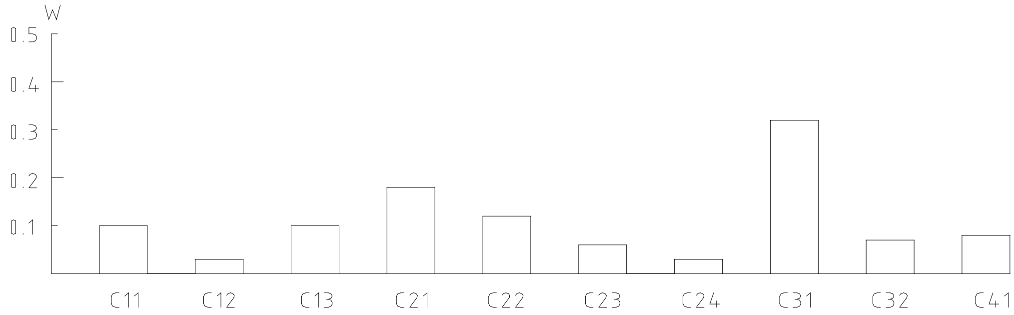

FIGURE 5. The weight distribution map of factors for C level

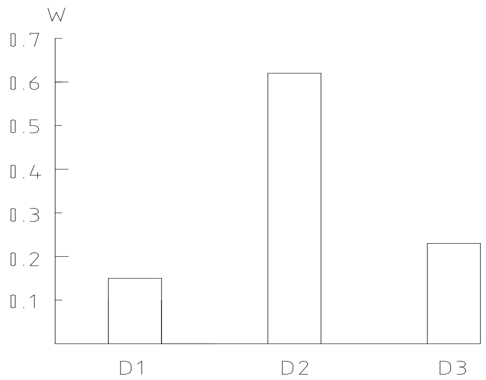

FIGURE 6. The weight distribution map of factors for D level

The weight order of D level is $W_{D2} > W_{D3} > W_{D1}$ as shown in Figure 6. It indicates that the order of three slope ecological restoration technology used in road slope in arid and semi-arid area is cast-in-situ grids, vegetation bag technology, external-soil spray seeding technology.

Conclusion

Cast-*in-situ* grids technology, external-soil spray seeding technology and vegetation bag technology have different characteristics in the respects of cost, ecological effect, slope stability and advances of technology. In arid and semi-arid area, selection of slope ecological restoration scheme mainly needs considering the ecological effects and stability. The major factor of ecological effects is survival rate of vegetation, and the major factor of stability is the stability in a whole. Cast-in-situ grids technology should be the first choice for ecological restoration in arid and semi-arid area.

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References

Ahmad, N., Hussain, T., Awan, A.N., Sattar, A., Arslan, C., Tusief, M.Q. & Mariam, Z. 2017. Efficient and eco-friendly management of biodegradable Municipal Solid Waste (MSW) using naturally aerated windrow composting technique in District Lahore, Pakistan. *Earth Science Pakistan* 1(1): 01-04.

Azratul, A.N.M.D., John, A., Kamaruzzaman, B., Hassan Sheikh, B.Y., Jalal, K.C.A. & Noor Faizul, H.N. 2017. Biomonitoring selected heavy metal concentration in *Nerita* Sp. collected from tanjung lumpur mangrove forest. *Environment Ecosystem Science* 1(1): 04-07.

Bai, J.G., Wang, J.J., Wen, N., Zhang, L.F. & Kang, X.C. 2014. Study on cast-*in-situ* grid ecological restoration technology of mine slope. *Journal of Inner Mongolia Agricultural University* 35: 99-102.

Chen, Q., Gao, J.R. & Wang, Y. 2013. Ecological slope protection by cast-*in-situ* grid: A case study of Yanqing Test Area. *Journal of Yangtze River Scientific Research Institute* 30: 17-20.

Choi, J. 2011. Development of evaluation indicators for riparian restoration with biodiversity consideration. *Journal of Agricultural Science* 38: 18-25.

Deng, X., Li, J.M., Zeng, H.J., Chen, J.Y. & Zhao, J.F. 2012. Research on computation methods of AHP weight vector and its applications. *Mathematics in Practice and Theory* 42: 93-100.

Guo, Y.L., Wang, Q. & Yan, W.P. 2009. Assessment of habitat suitability in the upper reaches of the Min River in China. *Journal of Mountain Science* 104: 23-41.

Gu, W., Jing, Y., Yu, H.L., Yan, X.L. & Shen, Y. 2015. Application status and problems of soil spraying and sowing technology in Northern China. *Road Traffic Technology (Application Technology).* pp. 36-39.

Huang, Y. 2015. Application of suspended net soil spray-sowing technology in the rocky side slope. *Forest Engineering* 28: 62-64.

Hu, Z.Q., Long, J.H. & Wang, X.J. 2014. Self-healing, natural restoration and artificial restoration of ecological environment for coal mining. *Journal of China Coal Society* 39: 1751-1757.

Kil, S.H. 2016. Evaluating erosion risk of revegetated cutslope with seed spraying. *Journal of the Korea Society of Environmental Restoration Technology* 19(6): 63-76.

Kil, S.H., Lee, D.K., Kim, J.H., Li, M.H. & Newman, G. 2016. Utilizing the analytic hierarchy process to establish weighted values for evaluating the stability of slope revegetation based on hydroseeding applications in South Korea. *Sustainability* 8: 31-48.

Li, Y. & Guan, C.S. 2013. Innovation on commercial concrete floor slab construction technology (paper presented at *3rd International Conference on Civil Engineering, Architecture and Building Materials*, Jinan, Peoples R. China. May 24-26).

Li, M.Y., Liu, G. & Xu, W.N. 2012. Analysis of soil fertility in the preliminary stage of ecological slope protection in Guandi Hydropower Station (paper presented at *Global Conference on Civil, Structural and Environmental Engineering / 3rd International Symp on Multi-field Coupling Theory of Rock and Soil Media and its Applications*, China Three Gorges Univ., Yichang. Oct 20-21).

Lu, M.X. & Feng, J. 2013. Design and effect analysis of slope reclamation by vegetation bag technique. *Yangtze River* 44: 94-96.

Madsen, M.D., Davies, K.W. & Boyd, C.S. 2016. Emerging seed enhancement technologies for overcoming barriers to restoration. *Restoration Ecology* 24: 77-84.

Mei, X.M., Gao, J.R., Ma, L., Wang, J.J., Wang, B., Guo, K.L., Zhang, D. & Chen, Q. 2015. Ecological adaptability of plants in beginning period of slope protection by cast-*in-situ* grids. *Science of Soil and Water Conservation* 13: 79-84.

Rahman, M.M., Rahman, M.R., Niimi, M., Khadijah, W.E.W., Akashi, R. & Abdullah, R. 2017. Effects of different levels of oxalic acid administration on feed intake and nutrient digestibility in goats. *Sains Malaysiana* 46(4): 515-519.

Wang, L.Y., Zhang, X.S., Gao, X.B. & Zhai, F.S. 2015. The application progress of spraying foreign soils technique for engineering of ecological protection. *Shanxi Science and Technology* 41: 191-192.

Wang, J.J. & Bai, J.G. 2012. Study on stability of ecology slope protection with cast-in-place grid. *Journal of Inner Mongolia Agricultural University* 33: 113-115.

Wang, L.L., Hu, Z.Q., Zhao, Y.L., Zhang, H.Y. & Li, X.J. 2007. Planning methods of ecological restoration for coal mining area in China and its case study. *Metalmine* 371: 17-20.

Yi, X.B. & Wang, L. 2013. Land suitability assessment on a watershed of loess plateau using the analytic hierarchy process. *Plos One* 8: 39-58.

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