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ENVIRONMENTAL PROTECTION SYSTEM OF MINING AND ENERGY COMPLEXES BASED ON THE USE OF THE AHP METHOD FOR THE RANKING OF INDICATORS AND WATER POLLUTION EFFECTS

Abstract: *Use of the Analytic Hierarchy Process (AHP) methodology for the assessment of mining and energy complex impact on water quality involves the ranking of key environmental aspects and the prioritization of environmental protection measures. This paper reduces the choice of indicators to four dominant effects of operational activities, which to the largest extent disturb the quality of basic environmental elements. The criteria were developed with the aim to facilitate the comparison of results from multiple mining and energy complexes, improve safety system modelling, and facilitate the assessment of the effects of critical operational activities on water quality.*

Key words: environmental, energy complex, indicators, safety engineering, water

INTRODUCTION

We performed a pairwise comparison of the assessments of the impact of coal mining on water quality in order to establish the first and second rank of the impact of the effects of key operational activities.

This paper considers the impact of the mining and energy complex in Kostolac, which incorporates three surface mines (Ćirikovac, Klenovik, and Drmno) and two thermal power stations (TE "Kostolac A" (100MW) and TE „Kostolac B" (2x348.5 MW)) [1].

Based on the Reports on Emission Values [2] it can be concluded that the smoke channels of thermal stations TE "Kostolac A", Block 1, Boiler 1; TE "Kostolac A", Block 1, Boiler 2; TE "Kostolac A", Block 2; TE "Kostolac B", Block 1; and TE "Kostolac B".

Management of environmental systems based on the Analytic Hierarchy Process (AHP) increases the level of objectivity and reduced personal views to a minimum. The concept of this model was developed by Thomas Saaty in 1978 [3,4].

The assessment of the impact of mining and energy complexes on water quality was performed based on the effects, ranked as follows: untreated pit water runoff into the surrounding soil (E1), runoff of overflowing and drainage water from tailings ponds and ash-holes into groundwater courses (E2), release of process water used for boiler rinsing and slag slaking and cooling into the recipient (E3), and runoff of atmospheric precipitation contaminated with coal dust (E4).

ENVIRONMENTAL ASPECTS OF THE MINING AND ENERGY COMPLEX

The importance of the selected environmental aspects that typically disturb water quality, shown in Table 1, enables the application of the decision-support program that pertains to the definition of aspect importance. The ranking of aspects and the definition of importance (I) are based on the value of the product of impact level (IL) and the likelihood of occurrence (L) [5].

The first phase of AHP use involves the assessment of importance of selected criteria for the choice of key operational activities. Comparison of importance assessments of selected criteria in terms of defining priority environmental protection measures is based on a matrix comparison of assessment pairs of criteria C1, C2, and C3. Assessment of importance (I), weight coefficients (W), and ranks (R) of comparison of the impact of defined criteria in relation to key environmental aspects [5,6].

This matrix (A1) presents the assessments of the criteria. Aspect importance assessments, results of pairwise comparison of selected criteria, and weight coefficients are given in table 2 and 3.

The second phase of AHP use is based on the importance assessment for the effects of operational activities, which degrade environmental quality.

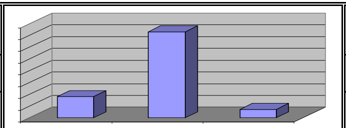
Table 1. *List of water quality disturbance aspects dueto activities of "Kostolac" mining and energy complex*

Environmental aspects of the mining and energy complex	
1	Unfavourable location of the mine in relation to the catchment area
2	Irregular treatment of pit water
3	Increased area of covered humus layer
4	Tailings pond drainage
5	Irregular treatment of tailings pond leachate
6	Atmospheric precipitation runoff from roads into groundwater courses
7	Oil runoff by atmospheric precipitation from roads and loading/unloading sites
8	Road sprinkling and polluted water runoff into groundwater courses
9	Atmospheric precipitation runoff from roads into surrounding soil
10	Release of untreated process wastewater
11	Release of process water used for slag slaking and cooling
12	Improper sludge disposal
13	Ash-hole rinsing by atmospheric precipitation
14	Increased concentration of heavy metals in leachate, overflowing, and drainage water
15	Dam failure and flowing of water and ash into the recipient

Table 2. *Aspect importance assessments, results of pairwise comparison of selected criteria*

Criteria	Assessments			Matrix				Results of pairwise comparison		
C	W	R	I	A	C 1	C 2	C 3	C 1	C 2	C 3
C 1	2	1	2	$A_1 = \begin{bmatrix} 1 & 1/5 & 3 \\ 5 & 1 & 8 \\ 1/3 & 1/8 & 1 \end{bmatrix}$				1. 0000	0.2000	3. 0000
C 2	2	3	6					5. 0000	1. 0000	8. 0000
C 3	1	1	1					0.3333	0.1250	1. 0000

Table 3. *Results of pairwise comparison of selected criteria - weight coefficients C*

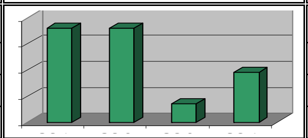
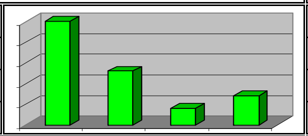
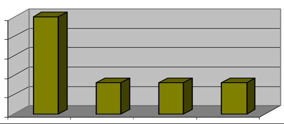
Criteria	Weight coefficients		Rang
C 1	0.18		II
C 2	0.73		I
C 3	0.07		III

The assessment was performed in relation to oversights in the organization of the management system (C1), lack of finances for safety measure implementation (C2), and the response of environmental organizations and the public (C3). Matrix pairwise comparison of importance assessments of operational activities E1, E2, E3, and E4 in relation to criteria C1, C2, C3, and C4 is shown in matrices A1, A2, and A3. The results of pairwise comparison of assessments of the effects of operational activities E1, E2, E3, and E4 were determined in relation to the selected criteria C1, C2, C3, and C4. The results of the second phase of AHP use are given in table 4 and 5.

Table 4. *The results of pairwise comparison of assessments of the effects of operational activities*

C	SC	Assessments			Matrix	Results of pairwise comparison			
		W	R	I	A SC 1 SC 2 SC 3 SC 4	E 1	E 2	E 3	E 4
I	SC 1	3	2	6	$A_1 = \begin{bmatrix} 1 & 1 & 5 & 2 \\ 1 & 1 & 5 & 2 \\ 1/5 & 1/5 & 1 & 1/3 \\ 1/2 & 1/2 & 3 & 1 \end{bmatrix}$	1. 0000	1. 0000	5. 0000	2. 0000
	SC 2	3	2	6		1. 0000	1. 0000	5. 0000	2. 0000
	SC 3	2	1	2		0.2000	0.2000	1. 0000	0.3333
	SC 4	2	2	4		0.5000	0.5000	3. 0000	1. 0000
II	SC 1	3	3	9	$A_2 = \begin{bmatrix} 1 & 2 & 5 & 4 \\ 1/2 & 1 & 3 & 2 \\ 1/5 & 1/3 & 1 & 1/2 \\ 1/4 & 1/2 & 2 & 1 \end{bmatrix}$	1. 0000	2. 0000	5. 0000	4. 0000
	SC 2	3	2	6		0.5000	1. 0000	3. 0000	2. 0000
	SC 3	3	1	3		0.2000	0.3333	1. 0000	0.5000
	SC 4	2	2	4		0.2500	0.5000	2. 0000	1. 0000
III	SC 1	2	1	2	$A_3 = \begin{bmatrix} 1 & 3 & 3 & 3 \\ 1/3 & 1 & 1 & 1 \\ 1/3 & 1 & 1 & 1 \\ 1/3 & 1 & 1 & 1 \end{bmatrix}$	1. 0000	3. 0000	3. 0000	3. 0000
	SC 2	1	1	1		0.3333	1. 0000	1. 0000	1. 0000
	SC 3	1	1	1		0.3333	1. 0000	1. 0000	1. 0000
	SC 4	1	1	1		0.3333	1. 0000	1. 0000	1. 0000

Table 5. *Results of pairwise comparison of selected criteria - weight coefficients SC*

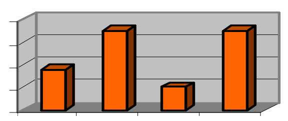
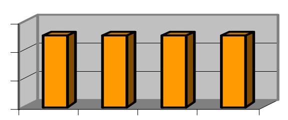
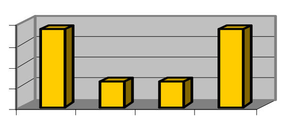
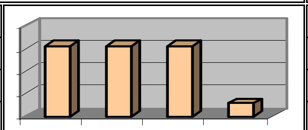
C	SC	Weight coefficients		Rang
I	SC 1	0.36		I
	SC 2	0.36		I
	SC 3	0.07		IV
	SC 4	0.19		III
II	SC 1	0.50		I
	SC 2	0.26		II
	SC 3	0.08		IV
	SC 4	0.14		III
III	SC 1	0.50		I
	SC 2	0.16		II
	SC 3	0.16		II
	SC 4	0.16		II

The third phase of AHP use involves the assessment of importance of the effects of key operational activities for environmental quality degradation. The assessment was performed in relation to environmental effects of operational activities. Pairwise comparison of assessments of operational activity effects in relation to the sub-criteria SC1, SC2, SC3, and SC4 is shown in matrices A1, A2, A3, and A4. Effect assessments and (SC1), employees (SC2), stakeholders (SC3), and the financial status of the mining and energy complex in the event of accidents (SC4). We assessed the degree of impact and the probability of occurrence of the effects the results of pairwise comparison of matrix-presented assessments of operational activities E1, E2, E3, and E4 in relation to the selected criteria SC1, SC2, SC3, and SC4 are given in table 6 and 7.

Table 6. *Effect assessments and the results of pairwise comparison of matrix-presented assessments of operational activities*

SC	E	Assessments			Matrices	Results of pairwise comparison			
		W	R	I	A E1 E2 E3 E4	E 1	E 2	E 3	E 4
I	E 1	2	2	4	$A_1 = \begin{bmatrix} 1 & 1/2 & 2 & 1/2 \\ 2 & 1 & 3 & 1 \\ 1/2 & 1/3 & 1 & 1/3 \\ 2 & 1 & 3 & 1 \end{bmatrix}$	1. 0000	0.5000	2. 0000	0.5000
	E 2	3	2	6		2. 0000	1. 0000	3. 0000	1. 0000
	E 3	1	3	3		0.5000	0.3333	1. 0000	0.3333
	E 4	3	2	6		2. 0000	1. 0000	3. 0000	1. 0000
II	E 1	1	1	1	$A_2 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$	1. 0000	1. 0000	1. 0000	1. 0000
	E 2	1	1	1		1. 0000	1. 0000	1. 0000	1. 0000
	E 3	1	1	1		1. 0000	1. 0000	1. 0000	1. 0000
	E 4	1	1	1		1. 0000	1. 0000	1. 0000	1. 0000
III	E 1	2	2	4	$A_3 = \begin{bmatrix} 1 & 3 & 3 & 1 \\ 1/3 & 1 & 1 & 1/3 \\ 1/3 & 1 & 1 & 1/3 \\ 1 & 3 & 3 & 1 \end{bmatrix}$	1. 0000	3. 0000	3. 0000	1. 0000
	E 2	2	1	2		0.3333	1. 0000	1. 0000	0.3333
	E 3	2	1	2		0.3333	1. 0000	1. 0000	0.3333
	E 4	2	2	4		1. 0000	3. 0000	3. 0000	1. 0000
IV	E 1	3	2	6	$A_4 = \begin{bmatrix} 1 & 1 & 1 & 5 \\ 1 & 1 & 1 & 5 \\ 1 & 1 & 1 & 5 \\ 1/5 & 1/5 & 1/5 & 1 \end{bmatrix}$	1. 0000	1. 0000	1. 0000	5. 0000
	E 2	3	2	6		1. 0000	1. 0000	1. 0000	5. 0000
	E 3	2	3	6		1. 0000	1. 0000	1. 0000	5. 0000
	E 4	1	2	2		0.2000	0.2000	0.2000	1. 0000

Table 7. *Results of pairwise comparison of selected criteria - weight coefficients E*

SC	E	Weight coefficients		Rang
I	E 1	0.18		III
	E 2	0.35		I
	E 3	0.10		III
	E 4	0.35		I
II	E 1	0.25		I
	E 2	0.25		I
	E 3	0.25		I
	E 4	0.25		I
III	E 1	0.37		I
	E 2	0.12		III
	E 3	0.12		III
	E 4	0.37		I
IV	E 1	0.31		I
	E 2	0.31		I
	E 3	0.31		I
	E 4	0.06		IV

Aspect importance indicates that activities 1, 10, 2, 13, 14, and 15 have priority in the resolution of water pollution issues. Figure F.3q shows the results of calculated impact of untreated pit water runoff (1), runoff of overflowing and drainage water from tailings ponds and ash-holes (2), release of process water used for boiler rinsing (3), and runoff of atmospheric precipitation contaminated with coal dust (4). The presented results, obtained by the use of the theory of probability and the AHP (F.3q), suggest a necessity for a priority-based problem solving, such as: release of untreated pit and process water, disposal of ash pulp with high water content, and unfavourable location of the mine in relation to the catchment area.

Based on the presented results of priority ranking in the elimination of the effects, we observed a negative impact of operational activities of the mining and energy complex on air, water, and soil quality, exemplified by runoff of untreated pit water into the surrounding soil (E1), with importance rank one according to all the defined criteria (C1, C2, C3, and C4), runoff of atmospheric precipitation contaminated with coal dust (E4), ranked first according to the assessment of the impact on the environment (SC1), employees (SC2), and stakeholders (SC3), and runoff of overflowing and drainage water (E2), ranked first according to the environmental impact assessment (SC1).

CONCLUSION

The results of a multiple-criteria decision analysis provide the groundwork for the improvement of the environmental protection system and for prioritizing environmental protection measures, but also reveal the serious nature of the issues with the operation of the environmental protection system in mining and energy complexes.

BIOGRAPHY

Jelena Malenović Nikolić was born in Knjaževac, Serbia, in 1974.

She received the diploma in environmental protection engineering and the Magister of technical sciences degree in same field from the University of Nis, Faculty of Occupational Safety in Niš.Doctoral dissertation: Environmental management system modelling in mining and energy complexes, University of Belgrade, Faculty of Mining and Geology in Belgrade, Scientific field: Mining Engineering, Special Scientific field: Occupational Safety and Environmental Protection.

Her main areas of research include environmental protection, environmental management, air quality, environmental security, etc.

Shi is currently working as an assistant professor at the Faculty of Occupational Safety in Nis, University of Niš.

SISTEM ZAŠTITE ŽIVOTNE SREDINE RUDARSKO-ENERGETSKOG KOMPLEKSA BAZIRAN NA PRIMENI AHP METODE U RANGIRANJU INDIKATORA I POSLEDICA ZAGAĐIVANJA VODA

Jelena Malenović Nikolić

Rezime: *Primena metodologije Analitičko hijerarhijskog procesa (AHP) za ocenu uticaja rudarsko-energetskog kompleksa na kvalitet voda podrazumeva rangiranje ključnih aspekata životne sredine i definisanje prioritetnih mera zaštite životne sredine. U radu je izbor indikatora sveden na četiri dominantne posledice radnih aktivnosti, koje u najvećoj meri narušavaju kvalitet osnovnih elemenata životne sredine. Kriterijumi su formirani s ciljem da se olakša upoređenje rezultata više rudarsko-energetskih kompleksa, unapredi modeliranje sistema zaštite i olakša ocenjivanje posledica kritičnih radnih aktivnosti na kvalitet voda.*

Ključne reči: životna sredina, energetski kompleks, bezbednost, voda