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Short Communication

Application of Multi-Criteria Analysis for Selection of a Reclamation Method for a Hazardous Waste Landfill

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Abstract

Our paper presents a detailed comparative analysis and methodology of selection of a reclamation procedure for the Górka hazardous waste landfill in Trzebinia, Poland. The most favorable solution offered by the authors is based on the measurable evaluation criteria and the decision analysis. Evaluation criteria have been selected to meet the assumptions of a sustainable development concept and take into account ecological, economical, and social aspects of the analyzed options. At the same time, the most favorable technical and technological solutions have been proposed. The principal conditions of the properly carried out reclamation include:

- Permanent elimination of harmful environmental effects caused by the solid waste landfill and leachate from the reservoir, mainly through reduced emission of pollutants to ground and surface waters.
- Reclamation of soil within the disused quarry up to the standards required by Polish Law.
- Reclamation and land development according to municipal zoning plan guidelines.

Keywords: industrial solid waste, landfilling, reclamation, multi-criteria analysis

Introduction

During the course of industrial operations of the former cement plant Górka in Trzebinia, the Górka quarry was established, from which marl for cement production was sourced. Both Górka and Miejski (current Balaton lake) quarries (the latter also operated by the former Górka cement plant) were linked up with the underground adit used for material transport. In 1962-84 the existing Górka excavation pit served as a storage place for waste from the production of aluminum hydroxide from bauxite, whereas Balaton, after being filled with water, serves as a recreational lake [1]. The excavation holds about 400,000 tons of waste; the thickness of the waste layer is 16-18 m while its overall area covers approx. 2.8 acres. Also, other waste materials such as fire-clay rubble, slag, ash, etc. have been deposited in the excavation pit. The overall volume of the waste material deposited at this place amounts to 600,000 m^3, or about 1 million tons. Geological structure of the surrounding area is not very promising from the perspective of environmental hazards [1, 2]. Jurassic and trias formations hold underground water reservoirs and the landfill is located right within their recharging zone; the reservoirs are sited i.e. inside excavation pits of the "Trzebionka" zinc and lead mine. Groundwater from these pits is used as a source of drinking water for the Trzebinia community. Uncontrolled intrusion of polluted water to the mine may result in irreparable contamination of groundwater and possible hydraulic contact with the underground reservoir (that serves as the main water supply source for the Chrzanów

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District) cannot be excluded. The actions undertaken by the Trzebinia community focused on reclamation of the area degraded by the already gone neighboring industry.

Literature Review for Decision-Making Process

Systems enhancing the decision-making process are used as the systems that help to select the best possible option. Such an approach considers many different factors, determines measurable evaluation criteria, and then processes numerous information. Both criteria and evaluation factors have to be selected in such a way that the proposed solution is safe for people's health and the environment; on the other hand, it has to be evaluated in a clear, precise, and measurable way [3-7]. Due to a broad spectrum of evaluated investment projects and the variety of their operating conditions, the procedures of environmental effect evaluation still remain vague and the unified standard have not yet been developed. Considering the environmental safety standard, the current law imposes the regulations specified as best available technologies (BAT) or BAT-NEEC [7, 8].

Landfill Reclamation Options

Each of the options discussed below assumes that the existing dam will be demolished and the adit made accessible. This job is considered one of the most important actions protecting the quarry from flooding. Clearing the adit enables discharge of storm water and groundwater from the quarry. Additionally, each option assumes complementary works associated with removal and treatment of the caustic liquid collected at the bottom of the quarry [1, 9, 10].

Option I assumes removal of the entire volume of waste and bottom sediments collected in the quarry and their deposition at the corresponding landfill. Once the waste had been hauled to the landfill the quarry would be cleaned and their slopes protected through slopes and bank formation. Water from the quarry, after passing through a weir and a buffer tank, would be discharged to the surface waters. The last phase of the project includes biological reclamation of the recovered area with plans typical for a local ecosystem.

Option II assumes that the waste will remain in the Górka excavation pit. Only the sediments exposed at the bottom of the pit after its draining will be dewatered *in situ* with a filter press and then hauled to the landfill, outside. A cover-up of waste with an insulating layer seems to be the crucial element, influencing the environment quality in the quarry. Formation of proper slopes and a water-tight surface of a dump will insulate the facility from stormwater impact. However, Option II does not solve the leachate problem. Incoming leachate will be collected and discharged together with rainwater through adit to the treatment plant. The last phase of the project includes biological reclamation of the recovered area with plans typical for a local ecosystem (which is the difference between biological reclamation beetwen options I and II).

Option III assumes that waste from the Górka excavation pit will be displaced to a specially designed and sealed sector. Sediments exposed at the bottom of the pit after draining off the caustic liquid will be dewatered *in situ* with a filter press and then hauled to the landfill, outside. Insulation of all collected wastes from both groundwater and stormwater remains the crucial element of this option. Clean water from the quarry (both stormwater and spring water) will be collected with a drainage system and then pumped to the surface waters. Biological reclamation is as in Option II.

Option IV leaves most of waste within the Górka excavation pit. Bottom sediments, exposed at the bottom of the pit after draining off the caustic liquid, will be dewatered *in situ* with a filter press and then hauled to the landfill, outside. The options include insulation of a site from water incoming from the neighborhood areas. Formation of the waste dump, as to create a gorge in the headwaters zone, remains the crucial element of this option.

During the course of Option IV also some earthworks would be required related to: formation of banks and slopes of the waste dump, relocation and removal of sediments remaining at the bottom of the closed water reservoir, and removal of municipal wastes covering the area planned for reclamation [1, 9, 10].

SWOT analysis for Górka and Balaton [1] shows the strengths, weaknesses, opportunities, and threats of the proposed solutions. SWOT analysis for proposed solutions taking into consideration municipal multi-aspects was made, taking into account:

1. Image of the object on the background of the municipality
2. Spatial structure – functional
3. Quality and condition of the natural environment
4. Legal considerations – economic and marketing.

The analysis showed that the weaknesses of the financial and environmental aspects should not be a barrier for remediation, as it may lead to the marginalization of the whole area. Opportunity for the development of the region is reclamation and investment in such a way as to create a recreational complex.

Selecting the Best Option

The options presented above differ not only from the technological perspective but they also bring on different environmental consequences; they have to be discussed with respect to different administrative/social conditions and an economic potential of the region. The characteristic of the options combines impact of a different number of factors, and their quantity and features vary depending on the particular region, technology used, or economic factors.

General characteristics and then a detailed description of the evaluative elements allows us to set the solid criteria of values that can be used to form a structure for the options evaluation. Evaluation, comparison, and a rank of the proposed technological options is a multi-criteria task. Its complexity comes from both the number of analyzed factors and their variety or intensity of reaction. Moreover, the analyzed factors may be inconsistent. A decision-making

Table 1. Estimated value of a harmful effect of waste on the environment-fixed fees [10].

Ecologic criterion	Option 1	Option 2	Option 3	Option 4
Annual harmful effect	4,302,211,200	4,302,211,200	4,302,211,200	4,302,211,200

Table 2. Results of the economic analysis for the options [10].

Economic criterion	Option I	Option II	Option III	Option IV
Capital costs	140,965,200	18,401,700	30,625,200	21,275,200
Operation costs, no depreciation (during 20 years)	2,720,000	59,580,000	1,870,000	1,870,000

process in this case is a system-oriented task that requires a special tool. It will develop the model that enables the system evaluation.

The proposed methodology breaks down to the following phases:

- Phase 1 – assumption of the preliminary descriptive criteria and possible reclamation options, based on the preliminary and general evaluation criteria, in all aspects.
- Phase 2 – analysis of the accepted options, refining of criteria for which the measurable values will be found, that define the advancement of the assumed tasks.
- Phase 3 – final acceptance of the criteria (group of criteria) and the methods of their determination for a multi-criteria analysis.
- Phase 4 – multi-criteria analysis and selection of the best reclamation option, as a compromise.

Criteria of Evaluation of Different Options

The following principles of sustained development, economic, ecological, and social aspects of each option have to be considered. Hauling the waste away from the quarry or their isolation from the environment reduces their hazardous impact. To valuate ecological benefits of the particular options, a system of fees and fines for environment use may be used as a good measure of impact assessment. The table below presents estimated values of an annual environmental impact of waste for each option.

As shown in Table 1 for all assumed and calculated options, fees for environmental use remain the same, therefore this criterion will not make any difference for option evaluation. However, it has been included into calculations to present the whole analysis and description of the decision task, though its impact on the final result is none.

Determination of indicators of task economic evaluation was possible due to economic analysis of all options. For each option, it was assumed that the period of cost/benefits analysis covers 20 years, beginning from the date when construction work started. Over that time costs of realization of the assumed option was investigated. A 5% discount rate was assumed in the analysis. The table below presents the results of the cost/benefit analysis for all discussed options.

Economic criteria, having been taken into account in the calculations, differentiate the options. The highest capital costs have been associated with Option 1, while operations costs in this case remain acceptable. High investment costs are generated by removal of the entire volume of deposited waste. From the economic perspective, the most favorable option seems to be No. 4, since its small expenditures offer the lowest operational costs. Such an outcome results from the simplest technology applied (reclamation of the degraded land area).

Values of social benefits have been determined analyzing the changes in land appreciation in the vicinity once the proposed option has been implemented. The unquestioned benefit of the project implementation (except Option 3) is higher land value. It should be expected that, once the reclamation takes place, the land value in close proximity to the quarry will increase. According to the local zoning plan, the land area north from the excavation pit has been designated for production/services and production/technical operations, while south of the pit single and multi-family housing projects are planned. The highest growth of a land price is expected for Option 1, when all "red mud" type waste is completely removed from the excavation site. It was assumed that once Option 1 is complete, the land value may go up even by as much as 15%. Implementation of Option 4 may increase the land value approximately by 10%; the lowest increase of a land price is expected for Option 2, which it may range from 1% to 2%. Such a low estimate results from leachate generation and its further treatment. In the case of Option 3 (construction of a formal landfill) a possible scenario may even include a decrease of land value by about 5%. The results of the calculations have been presented in Table 3.

Multi-Criteria Analysis as a Tool for Selection of the Best Option

The above data and analysis have been used as estimation criteria for particular options in the decision analysis. Evaluation, comparison, and selection of the most favorable solution is possible due to a numerical representation of estimating factors. They show the consequences of introduction of optional solutions and serve as a measurement of goal realization [11-13].

Table 3. Calculations of soil reevaluation (social criterion) [10].

Social criterion	Option 1	Option 2	Option 3	Option 4
Benefit/cost due to soil reevaluation [PLN]	8,302,500	1,107,000	-2,767,500	5,535,000

Table 4. Normalized decision matrix for different technological options (authors' own estimation).

Evaluating criterion	Option 1	Option 2	Option 3	Option 4
Annual harmful effect	1	1	1	1
Capital costs	0	1	0.9	0.98
Operation costs, no depreciation	0.98	0	1	1
Benefit/cost due to soil reevaluation	1	0.35	0	0.75

Decision analysis enables a complex and comparative evaluation. It usually starts with a decision matrix that is a formal mathematical interpretation that enables us to use one of many methods of multi-criteria analysis to solve a decision task [11, 12, 14, 15]. The decision matrix that compares the previously discussed technological options is presented in Table 4; as a solving tool a methods of weighted sum was used.

The method of weighted sum is used for solving discrete decision problems. It is one of the methods of decision analysis that utilizes all information on criteria ranking hierarchy and is based on the concept of measuring the distances between evaluation strategies and the pre-set utopia strategy. The method is based on the utility theory and determines each evaluated strategy with regard to all assumed and normalized evaluation criteria. Utility is defined as the distance between the analyzed strategy and a pre-set nadir (the least favorable solution with respect to all criteria). Utility of strategy s_n with respect to all criteria may be expressed as:

$$U(s_n) = \sum_{m=1}^{M} w_m \cdot (r'_{nm} - x^*_m); m = 1,..., M \qquad (1)$$

...where:

$U(s_n)$ –function of utility of strategy sn

n – number of strategies

m – number of criteria

w_m– weight of particular criterion, assumed by the decision maker

r'_{nm} – normalized evaluation criterion

x^*_m – m – coordination of nadir, the least favorable strategy

Searching for the most favorable strategy proceeds according to the principle:

$$s_j \Leftrightarrow U(s_j) = \max U(s_n); n = 1,..., N \qquad (2)$$

...where:

s_j – the most favorable option

Table 5. Results of a multi-criteria analysis organizing the technological options (authors' own concept).

Criterion ranks	Options rank
1:1:1:1	Option 4→ Option 1→ Option 3→ Option 2
2:1:1:1	Option 4→ Option 1→ Option 3→ Option 2
5:1:1:1	Option 4→ Option 1→ Option 3→ Option 2
1:2:1:1	Option 4→ Option 3→ Option 2→ Option 1
1:2:2:1	Option 4→ Option 3→ Option 1→ Option 2
1:5:5:1	Option 4→ Option 3→ Option 1→ Option 2
1:1:1:2	Option 4→ Option 1→ Option 3→ Option 2
1:1:1:5	Option 1→ Option 4→ Option 2→ Option 3
2:1:1:2	Option 4→ Option 1→ Option 3→ Option 2
5:1:1:5	Option 1→ Option 4→ Option 2 → Option 3

The applied method organizes all elements of the area of decision-making. The results and a final arrangement of the options are presented in Table 5, where they have been displayed in order from the most to the least favorable A final arrangement depends also on the assumed weights of the groups of criteria or just the weights of criteria. The weights of criteria proposed by the authors have been presented in Table 5 (first column).

Analyzing the results, one may notice that:

- In most cases Option 4 is selected as the most favorable, regardless of different evaluation criteria and different weights; this option allows most of the waste to stay within the excavation pit. The sediments exposed at the bottom of the pit, after draining, will be dewatered *in situ* with a filter press and then hauled to the landfill, outside.
- Two out of 10 cases prefer option 1 as the most favorable solution. It takes place when weight 5 is assigned to the social criterion, i.e. changes in land values; the value of this criterion is the highest for all analyzed options. Option 1 assumes relocation of all waste and bottom sediment from the quarry to a properly designed landfill, and then clean-up and land reclamation.
- In most cases the least favorable is option 2, though its investment cost remains the lowest; the option assumes that the waste remains in the excavation pit and only the sediments, exposed at the bottom of the pit after its draining, will be dewatered *in situ* with a filter press and then hauled to the landfill; a cover-up of the waste with the isulating layer is an environmentally friendly element of this option.
- Option 4 has been selected for implementation, so the multi-criteria analysis presented in this paper has confirmed the experts' choice.

Conclusions

- Our paper uses multi-criteria analysis to compare different options of reclamation of the disused landfill and a land area after its anthropological degradation. To evaluate different technological options of reclamation the group of evaluation criteria were used: ecological, economical, and social, according to the sustained development concept.
- The proposed methodology delivered a solution in a form of option arrangements, ranked from the most favorable to the least favorable, considering the evaluation criteria and additionally assigned weights. Therefore, the methodology provides a qualitative, multidimensional and objective evaluation of the proposed options.
- Finally, the option for implementation was selected. It assumes that the waste remain in the excavation pit, while the sediments exposed at the bottom of the pit after its draining will be dewatered *in situ* with a filter press and then hauled to the landfill, outside; the analysis confirmed the experts' choice.
- The applied methodology enabled performing a comparative evaluation of different options and select the best one, according to the requirements of environmental management and the principle of sustainable development. The method may serve as a tool of environmental management.

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