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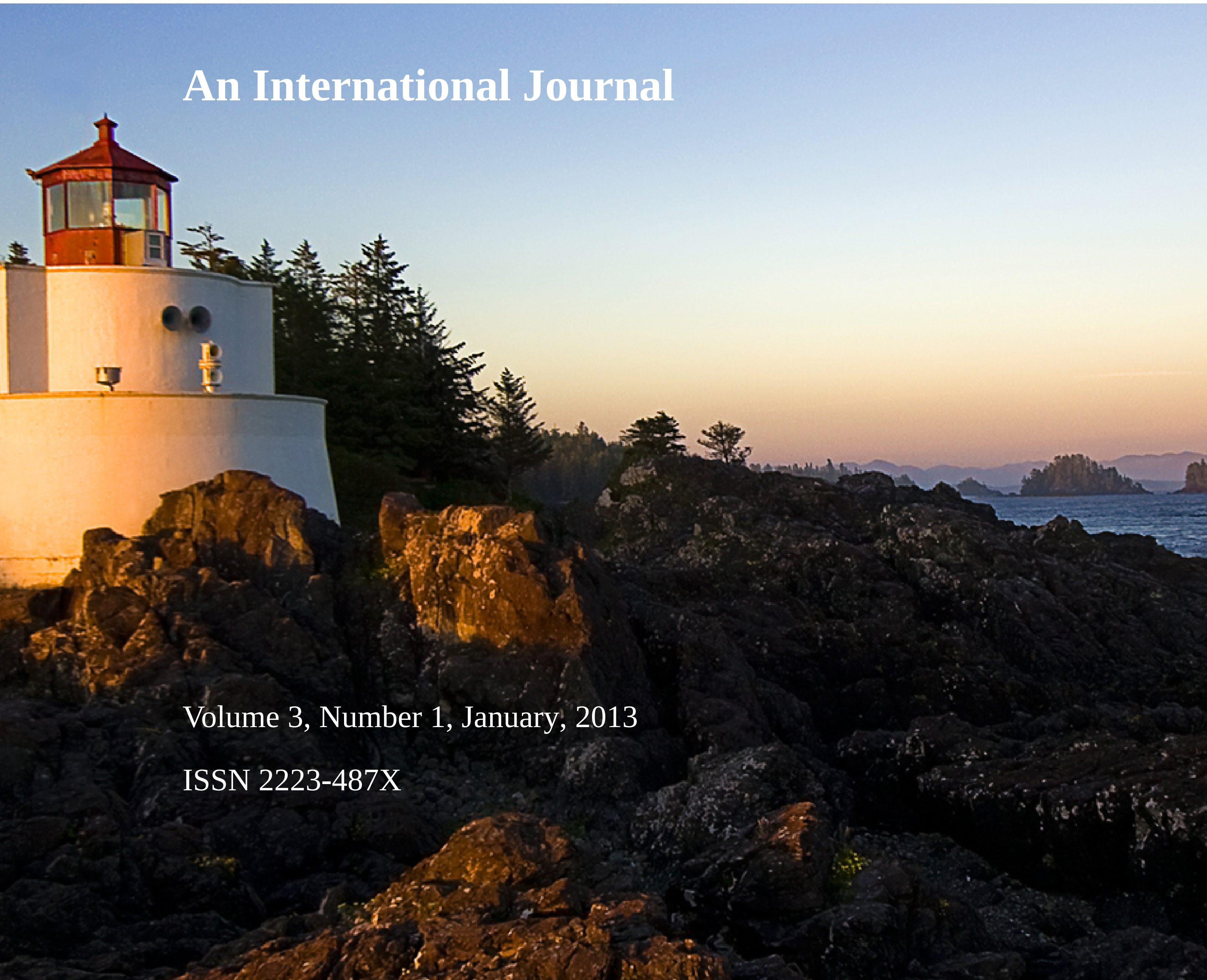

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Selection of an Optimal Landfill Location Using the Multi-Criteria Decision Analysis Methods

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Abstract. This paper identifies the components necessary to develop a decision analysis framework on issues concerning the selection of a landfill location, to facilitate the selection of a multi-criteria decision analysis process, and thereafter to provide guidance on the implementation of the selected multi-criteria decision analysis method within the larger context of the people, processes, and tools used in decision making. The main subject of research of this paper is the applicability of multi-criteria decision analysis methods for selection of an optimal landfill location considering the complexity of the problem influenced by numerous and sometimes even contradictory aspects.

Introduction

This paper elaborates on the specific chapters of waste management focusing on the landfills as complex objects for permanent disposal of solid communal waste and the waste which cannot be used in any way. Special attention have been paid to the selection of the landfill location as a basic and essential step in the successful realization of all future activities related to the construction, operation and closure/rehabilitation.

Bearing in mind that the optimal location selection depends on a series of complex contradictory factors (environmental, technological, economic, sociological, etc.), the problems related to the integration and processing of the large amount of information and subjectivity of each decision maker, clearly imposes the inevitable need to use some of the multi-criteria decision making methods. These methods could help in the development of an analysis and decision making framework which would facilitate the understanding of all processes and influential factors related to decision making, including the risks, criteria and confronting interests which are specific to the available alternatives for problem solution.

The data from the research carried out in order to select the optimal location, and the characteristics of the possible locations of the prospective regional landfill site in the central-eastern part of the Republic of Macedonia are presented. The most feasible alternative solutions have been analyzed in details using the multi-criteria decision making methods, whereupon the Analytic Hierarchy Processes (AHP) method has been used as the most suitable method. The last part of the paper presents the research conclusions which make a solid basis for a final selection of the regional landfill site location in Central-Eastern Macedonia.

Identification of factors influencing the problem definition and resolution

Waste creation and its landfilling causes a number of negative effects on the environment, particularly in terms of terrain degradation and environmental pollution with various harmful substances. These consequences could be of a larger scale if the waste masses are larger. Landfills could be found in any environment, hence the impact on the environment is different.

Mass waste creation as a consequence of the enhanced development further endangers the environment. Landfill construction, waste transportation to the landfill sites and its depositing present the most complicated phases in terms of environmental protection, considering also the economic and financial indicators. Landfill locations and transportation routes to the landfill sites pass through various environments; hence it is necessary to appropriately evaluate the impact of these factors in order to make a decision on the selection of the optimal landfill location.

A landfill could be located significantly away from the waste sources. The selection of the most optimal landfill location is carried out on the basis of a number of parameter groups and all of them have different impact on the decision making process. It is necessary therefore that this impact is quantified in order to compare it to the other parameters.

The selection of a landfill location, concerning the environmental protection, economic, and financial indicators must meet the following criteria:

- Terrain degradation as a consequence of landfill and transportation routes construction should be reduced to a minimum evaluated by the environmental criteria;
- The influence on the geological, hydro-geological, and hydrological parameters which are specific to the surrounding area of the landfill should be reduced to a minimum;
- The strategic planning for the area should be observed to a maximum;
- The cost-effectiveness should be maximized, i.e. the expenses for the landfill construction and waste transportation from the collection points to the landfill site should be minimized. This should be followed by a maximum protection of the environment.

The decision on the landfill location selection could be made after a detailed analysis of all these factors. The proper definition of each of the aforementioned factors and the selection of the appropriate landfill location provide for a minimum pollution of the environment, minimum disturbance of the geological, hydrogeological, and hydrological characteristics specific to the area, minimal area destruction, and minimal expenses. This procedure involves finding a solution that maximizes the environmental protection during landfill construction, i.e. the environmental degradation and pollution is reduced to a minimum, and the expenses for the landfill construction, waste transportation and depositing are also reduced to a minimum. The problem solution, i.e. the selection of the most convenient landfill location, concerning the environmental protection, economic, and financial indicators could be reached using the multi-criteria decision analysis.

The application of multi-criteria optimization is carried out if several variations od landfill locations are available. In addition, the multi-criteria optimization produces a ranking of variations ranked in accordance with the criteria upon which the optimization has been done.

Problem analysis and establishing the variations

The general problem case can be defined in the following way: An optimal location for a landfill site needs to be established. A suitable landfill location should be established on the basis of the previously determined criteria upon which the evaluation of impact is carried out so that the landfill location impact on the environment and expenses are reduced to a minimum.

In this specific example, and in accordance with the contemporary experience in solid waste management industry and landfilling, four alternative solutions for landfill location have been established (Table 1):

Table 1 – Alternative solutions for the landfill location

	Alternative	Mark
1	Stip municipal landfill	A_1
2	Karbinci natural terrain	A_2
3	Probishtip – Sudik natural terrain	A_3
4	Bogoslovec natural terrain	A_4

Criteria selection and identification

After the problem identification and analysis have been done, the criteria with the highest impact on the model solution are selected and identified. For easier model organization, the criteria have been divided into four characteristic groups:

1. Environmental parameters;
2. Geological, hydro-geological, and hydrological parameters;
3. Planning parameters;
4. Economic and financial parameters.

A detailed list of each criteria group is presented in Tables 2.1, 2.2, 2.3, and 2.4.

Table 2.1 – Environmental criteria

	Criterion	Mark
1	Environmental value of the flora	K_1
2	Environmental value of the fauna	K_2
3	Negative impact on the ecosystems	K_3
4	Cultural-historic value of the area	K_4
5	Possibilities for visual incorporation into the area	K_5
6	Geomorphological and archaelogical value of the area	K_6

Table 2.2 – Geological, hydro-geological, and hydrological criteria

	Criterion	Mark
1	Permeability of the lower soil layer	K_1
2	Presence of impermeable layers in the lower soil layer	K_2
3	Soil subjection to solidification	K_3
4	Position of vulnerable objects related to the underground water flow direction	K_4
5	Levels of underground waters and river waters	K_5
6	Odour and unpleasantness for the surrounding area	K_6
7	Disturbance by the traffic	K_7
8	Risks to the surrounding area	K_8
9	Other unpleasantness to the surrounding area	K_9

Table 2.3 – Planning criteria

	Criterion	Mark
1	Gross-net surface ratio	K_1
2	Interference to infrastructure use	K_2
3	Distance to the dwelling areas	K_3
4	Distance to industrial, tourist/recreation areas	K_4
5	Distance to natural protected areas	K_5

6	Distance to the main road	K_6
7	Distance between the landfill location and the waste creation concentration	K_7
8	Consequences to the agricultural planning	K_8
9	Possibilities for final use	K_9

Table 2.4 – Financial and economic criteria

	Criterion	Mark
1	Land acqusition expenses	K_1
2	Access to the landfill expenses	K_2
3	Transportation expenses	K_3
4	Personnel and maintenance expenses	K_4
5	Additional expenses for environment protection	K_5
6	After use rehabilitation expenses	K_6

Each of these criteria has its own impact (weight) on the alternative solutions. For this specific model, an analysis of the negative effects that the construction of each location causes to the environment (environmental criteria) has been carried out; also, an analysis has been carried out on the geological, hydro-geological, hydrological, planning, and financial and economic paramters. An evaluation of the impact of each location has been carried out based on the contemporary experience for the given model.

The model computation has been done using the multi-criteria decision making analysis method Analytical Hierarchy Processess. The computation has been done for each criteria group separately. The variation ranked the highest of all variations in two or more criteria groups would be selected as the most acceptable variation for the landfill location.

Each of the criteria within the specific criteria groups has its own nature, i.e. goal. An example has been given for the environmental criteria group in Table 3. The same principle applies to the rest of the criteria groups which has not been presented in this paper due to the space limitations.

Environmental criteria

Table 3– Evaluation factors and criteria goals

Mark	First level criteria	Evaluation factor	min/max
K_1	Environmental value of the flora	Qualitative evaluation	min
K_2	Environmental value of the fauna	Qualitative evaluation	min
K_3	Negative impact on the ecosystems	Qualitative evaluation	min
K_4	Cultural-historic value of the area	Qualitative evaluation	min
K_5	Possibilities for visual incorporation into the area	Qualitative evaluation	max
K_6	Geomorphological and archaelogical value of the area	Qualitative evaluation	min

Decision matrix

After the quantification calculations have been made, the decision matrix gets the following values (Table 4):

Table 4 – Decision matrix

	K_1	K_2	K_3	K_4	K_5	K_6
	min	min	min	min	min	min
A_1	Extremely high	High	High	Extremely high	High	Extremely high
A_2	Average	Low	Average	Extremely high	Average	Extremely high
A_3	High	Low	High	Extremely high	Extremely high	Extremely high
A_4	Extremely high	High	High	Extremely high	Extremely high	Extremely high

Table 5 presents the model of transformation of qualitative into quantitative values.

Table 5 – Decision matrix model of transformation of qualitative into quantitative values

Qualitative evaluation	**Extremely low**	**Low**	**Mean (average)**	**High**	**Extremely high**	**Type of criterion**
Quantitative evaluation	1	3	5	7	9	max
	9	7	5	3	1	min

After the transformation of qualitative into quantitative values has been done, the decision matrix gets the following values (Table 6):

Table 6 – Transformed decision matrix

	K_1	K_2	K_3	K_4	K_5	K_6
	min	**min**	**min**	**min**	**min**	**min**
A_1	1	3	3	1	7	1
A_2	5	7	5	1	5	1
A_3	3	3	3	1	9	1
A_4	1	3	3	1	9	1

Phases of AHP

Phase 1: Problem structuring (Fig. 1)

1. Environmental criteria

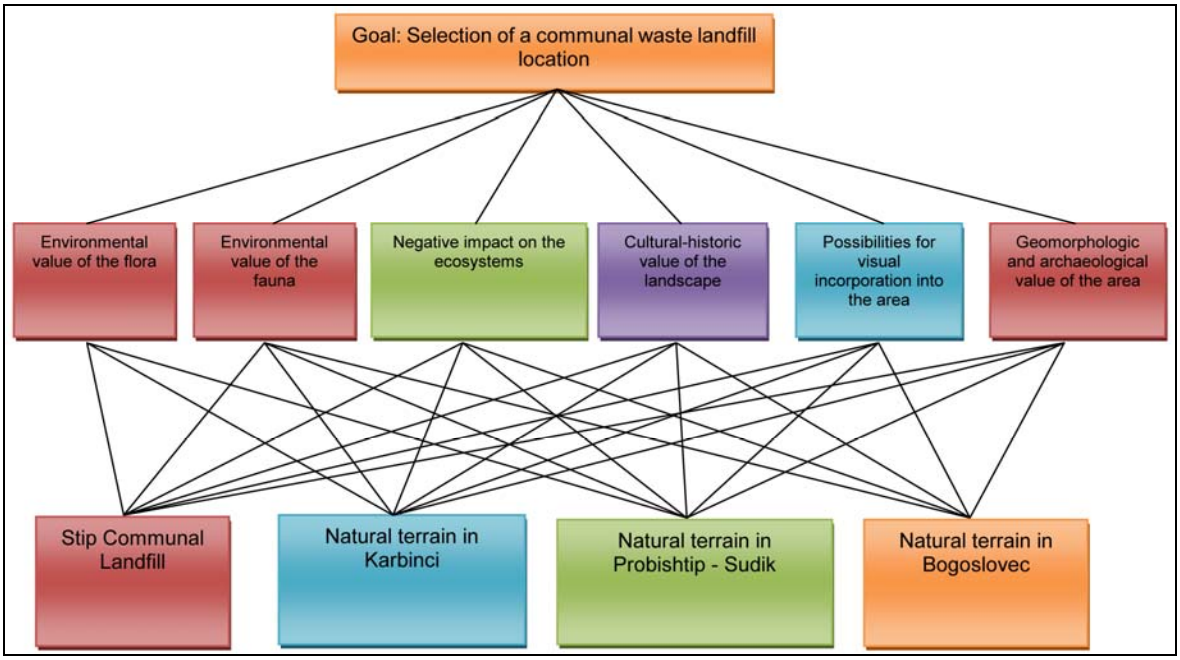

Fig. 1 – Hierarchical problem structuring for the municipal waste landfill location selection

The same principle of problem structuring is applied to the rest of the groups of criteria. *Phase 2: Data collection.* First, a comparison of the significance of the individual attributes (criteria) should be carried out in accordance with the scale defined in Table 7 (Saaty 9-point scale).

Table 7 – Saaty 9-point scale

Scale	**Ranking**	**Explanation**
1	Equally important	Both criteria or alternatives contribute to the objective equally

3	Moderately important	Based on experience and estimation, moderate preference is given to one criteria or alternative over the other
5	Strictly more important	Based on experience and estimation, strict preference is given to one criteria or alternative over the other
7	Very strict, proven importance	One criteria or alternative is strictly preferred over the other; its dominance has been proven in practice
9	Extreme importance	The evidence based on which one criteria or alternative is preferred over the other has been confirmed to the highest confidence
2, 4, 6, 8	Mid-values	

Phase 3: Relative weight evaluation. In order to solve the given model, an approximate procedure for obtaining the eigenvector is used. This procedure involves the following steps:
Step 1: Pairwise comparison in the matrix and summarizing the elements in each column (Tables 8 and 9);

Table 8 – Pairwise comparison matrix of criteria

	K_1	**K_2**	**K_3**	**K_4**	**K_5**	**K_6**
K_1	1.00	1.00	1.00	1.00	1.00	1.00
K_2	1.00	1.00	1.00	1.00	1.00	1.00
K_3	1.00	1.00	1.00	1.00	1.00	1.00
K_4	1.00	1.00	1.00	1.00	2.00	2.00
K_5	1.00	1.00	1.00	0.50	1.00	2.00
K_6	1.00	1.00	1.00	0.50	0.50	1.00

Table 9 – Normalized relative weight of each of the elements

	K_1	**K_2**	**K_3**	**K_4**	**K_5**	**K_6**
K_1	1.00	1.00	1.00	1.00	1.00	1.00
K_2	1.00	1.00	1.00	1.00	1.00	1.00
K_3	1.00	1.00	1.00	1.00	1.00	1.00
K_4	1.00	1.00	1.00	1.00	2.00	2.00
K_5	1.00	1.00	1.00	0.50	1.00	2.00
K_6	1.00	1.00	1.00	0.50	0.50	1.00
Sum	6.00	6.00	6.00	5.00	6.50	8.00

Step 2: Dividing the elements of each column by the sum of values of that column obtained in the previous step. In that way, the normalized relative weight of each of the elements is obtained (Table 10).
Step 3: Summarizing the elements in each row and determining the average of each row. The column containing these averages is actually the normalized eigenvector, also called the priority vector (Table 10). Given that the vector is normalized, the sum of all elements in the priority vector equals to 1. The priority vector represents the relative weights of the elements compared.

Table 10 – Normalized Eigen vector (priority vector)

	B_1	**B_2**	**B_3**	**B_4**	**B_5**	**B_6**	**B_7**	**B_8**
	K_1	**K_2**	**K_3**	**K_4**	**K_5**	**K_6**	**Total**	**Middle value**
K_1	0.1667	0.1667	0.1667	0.2000	0.1538	0.1250	0.9788	0.1631
K_2	0.1667	0.1667	0.1667	0.2000	0.1538	0.1250	0.9788	0.1631
K_3	0.1667	0.1667	0.1667	0.2000	0.1538	0.1250	0.9788	0.1631

K_4	0.1667	0.1667	0.1667	0.2000	0.3077	0.2500	1.2577	0.2096
K_5	0.1667	0.1667	0.1667	0.1000	0.1538	0.2500	1.0038	0.1673
K_6	0.1667	0.1667	0.1667	0.1000	0.0769	0.1250	0.8019	0.1337

Table 11 – Final level I priority (Environmental criteria)

Final level I priority	
K_4	0,2096
K_5	0,1673
K_1	0,1631
K_2	0,1631
K_3	0,1631
K_6	0,1337

Calculation of the comparison consistency. Considering that the comparison is based on a subjective evaluation, it is necessary to define a consistency measure in order to ensure the accuracy. Saaty introduces this measure through the consistency index (C.I.) (Eq. 1) as a deviation or as a consistency degree. It is calculated as:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

Where:

λ_{max} – matrix Eigen value,
n – Matrix size (number of matrix rows), n = 6.

The matrix Eigen value is calculated by summarizing the products of each element of the normalized Eigen vector and the sum of columns of the reciprocal matrix.

$$\lambda_{\max} = 6{,}3625$$

Hence, the consistency index is as follows:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} = 0{,}0725$$

Saaty proposes the use of this index in a way that it is compared to another corresponding index. The corresponding consistency index is called random consistency index (R.I.). Saaty randomly generated a reciprocal matrix using the scale 1/9, 1/8,...,1,..., 8, 9 and got the random consistency index to check if it around 10% or smaller. The random consistency index values (R.I.) are given in the Saaty table (Table 12):

Table 12 – Saaty random consistency index

n	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

In this case, for n = 6, R.I. = 1,25.

Saaty also proposed the use of the so called consistency ration (Eq. 2) which is a comparison between the consistency index and the random consistency index or:

$$C.R. = \frac{C.I.}{R.I.} \tag{2}$$

If the consistency ratio is smaller or equal to 10%, the consistency is acceptable. If the consistency ratio is above 10%, the subjective evaluation should be revised.

For the environmental group of criteria:

$$C.R. = \frac{C.I.}{R.I.} = 5{,}8\% < 10\%$$

This means that the subjective evaluation of the criteria preference is consistent. The same method of consistency calculation is applied to the rest of the criteria.

In the next phase of calculation, the decision maker evaluates all four landfill locations and the ratio of each single criterion within each group of criteria, i.e. the decision maker calculates the contribution of each alternative separately within the reviewed criterion.

Phase 4: Determining the problem solution. The overall problem synthesis follows at the end of the procedure. The overall problem synthesis is calculated so that each alternative, for example A_1, is multiplied by its own weight within the reviewed criterion. The same procedure is applied to all criteria in a row, and the obtained results are then summarized. This is done for each group of criteria separately and four different rankings are produced.

The results are presented in Tables 13.1, 13.2, 13.3, 13.4.

Table 13.1 – Alternatives ranking by environmental criteria

Alternative	Ranking
A_4	**0,41791**
A_1	0,39899
A_3	0,09497
A_2	0,08813

Table 13.2 – Alternatives ranking by geological, hydro-geological, and hydrological criteria

Alternative	Ranking
A_1	**0,4025**
A_4	0,3242
A_3	0,1436
A_2	0,1298

Table 13.3 – Alternatives ranking by planning criteria

Alternative	Ranking
A_1	**0,4072**
A_4	0,2620
A_3	0,1482
A_2	0,1826

Table 13.3 – Alternatives ranking by financial and economic criteria

Alternative	Ranking
A_1	**0,34806**
A_1	0,24031
A_2	0,22163
A_3	0,19000

Table 14 - Final ranking table by groups of criteria

Criteria group	Alternative	Rank
Environmental criteria	A_4 – Natural terrain Bogoslovec	1
Geological, hydro-geological, and hydrological criteria	A_1 – Stip municipal landfill	1
Planning criteria	A_1 - Stip municipal landfill	1
Financial and economic criteria	A_1 - Stip municipal landfill	1

On the basis of the results given in the previous alternatives ranking table, it is obvious that the A_1 alternative, i.e. *the Stip municipal landfill location is the highest ranked in three groups of criteria which is an evident indicator for selection of this alternative as the most optimal landfill location.*

Conclusion

The negative impact of landfill construction requires that everyone involved in this field of work fully focuses on this problem. In order to achieve that, it is necessary to know all the possible consequences caused by the landfill operation in the environment.

The assessment of possible damages to the land, water, and air as well as economic and financial analysis should precede each review of the landfill location. The harmful consequences are not the same for each environment, and a classification into separate categories is done accordingly. The environment categorization is done in multiple levels, i.e. further classification is possible within an established category in order to carry out more specific damage quantification.

Multi-criteria decision making methods could be used as the most acceptable methods for selection of the most convenient landfill location regarding the environmental protection and the cost-effectiveness. This creates an opportunity for the environmental protection, in its quantified form, to be considered as one of the criteria for the selection of an optimal landfill location along with the rest of the important criteria, such as the geology, hydrogeology, hydrology, area planning, capital investment, required workforce, energy supply, waste transportation costs, etc.

Each landfill location has its own specific characteristics requiring special analysis. Decision makers have to thoroughly know the possible consequences emerging from the selection of any landfill location before making or applying any decision. In order to achieve that, it is necessary to possess all the information on the environment, on the cost-effectiveness, and on the rest of the influencing parameters.

Efficient decision making about environmental issues requires clear coordination structure on the mutual understanding of the environment, ecology, technology, economics, and social policy relevant to the evaluation and selection of management alternatives. Each of the factors involves multiple sub-criteria which inseparably make the process to be directed to multiple goals. The integration of this heterogeneous information in relation to the human ambition and technical application requires systematic and meaningful framework of organization of people, processes, and tools in making a structured and sustainable decision.

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