Original Research

A Multi-Criteria Approach to Selecting a Landfill Site with the Aim of Protecting the Environment

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Abstract

This paper presents a new, transformed multi-criteria model for selecting a landfill site. The selection of a landfill site was treated as a problem of meeting several criteria from communal, construction, environmental, economic, and aesthetic aspects, for the reason of finding an optimal solution for a landfill. In that aim, selection of a landfill site by selecting the performances of criteria and alternatives is a very important decision for successful environmental protection. The paper depicts the transformed procedure on the principle of maximal value and selection of a landfill site done by the weighted value on the basis of geometric mean. An illustrated example also is presented.

Keywords: landfill site, multi-criteria analysis, waste, environment

Introduction

The intensive urbanization of settlements followed by raising living standards, industrialization, and general modernization has resulted in an increased production of waste, which is a particular problem in terms of protection and improvement of the environment [1]. The only way to eliminate waste from settlements, for now, is its disposal at prearranged landfills. Waste disposed in landfills continues its process of material degradation, which results in potential harm to the environment. The main source of contamination of the filtrate is the decomposition of food waste and oxidation of the metal, and the complex process of decomposition of organic substances [2]. Decomposition of organic materials can create various microorganisms that can reach the human environment and cause infection in humans, animals, or plants. One of the most significant ways pollution is created at the landfill sites is surface and ground waters flowing from the landfills during heavy rains, or the filtrate that is removed from waste while raising storm water through a layer of debris [3].

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For the protection of groundwater against harmful effects of landfills, it is necessary to perform a partial or complete waterproofing of the deposit of waste. The best thing is to set a landfill in a place where there is an impermeable layer. If you miss it, then you need to inject a curtain of heavy clay more than 0.5 m thick by placing polythene sheets, applied clean or with cement solution with additives, bitumen, etc. [2]. It is possible that the landfill leachate waters have a lot of intestinal pathogens of tuberculosis, tetanus, and gas gangrene.

The amount of landfill leachate water pollution approximates the average microbial contamination of a sewage system, and their quantity-index exceeds them 2-3 times. The composition of inorganic and organic pollution of water passing through the layer of deposited waste depends on their composition, methods of operation, and the nature of the storage process, and decomposition layer, as well as overall climate, intensity of rainfall, temperature, insolation, etc. In the landfill sites where anaerobic decomposition process occurs, the gases contain large quanities of methane, sometimes in dangerous concentrations [2]. Limited spreading of air pollution from landfills requires a proper site selection by analysis of winds, i.e. deployment on the down-wind site of a settlement. Locating landfills in areas with strong winds is not recommended, just as it is not desirable to set a landfill in non-ventilated areas, since the exchange of air at the landfill sites is necessary.

Transportation of waste to large landfills is still probably the most popular method of waste management in the country and in the world [4]. Unfortunately, many of these landfills are not equipped with the appropriate equipment for preventing emissions of harmful substances into the environment, such as the collection of leachate and gases occurring at landfills in large quantities, especially in the early stages of stabilization of waste [5]. In order to preserve the environment, protect human health, and the normalization of the biosphere, all generated waste in the human environment should be eliminated and disposed off in adequate landfills [6]. Dumps should fulfill all the necessary construction, utility, sanitary, aesthetic, and other criteria. For a landfill to meet all these criteria, it is necessary to include more criteria as required in the selection or implement them in existing landfills. In this regard, this paper proposes a new model of multi-criteria selection of the location of landfills.

Literature Review

The problems of landfill site selection and processing of biomass have been dealt with by many researchers. In [7] two models we developed a simulation model and a model of optimization, dealing with obtaining fuel from waste parts of biomass. The simulation model was developed to calculate costs and consumption of energy in biomass processing. The optimization model, based on mixed integral linear programming, is used to optimize the network structure. Fundurulja D. et al. [8] indicates the legal obligations on protection of the environment and human health. Ivšić T. et al. [9] point out the specific importance of sealing layers of landfill contact surfaces. If contact surfaces do not have the appropriate parameters, they should be improved by filling or putting a foil on them. Erdelez A. et al. [10] presents a new integrated approach to optimization of waste collection systems by transport optimization. Optimization of transport, in terms of shortening the distance traveled, better organizational setting, or better capacities utilization, as well as the inclusion of GIS, contributes to better and more efficient waste collection. The estimation of efficiency by using numerical transport modeling was done by [11], while analysis of monitoring the quality of water at the landfills was done in [12]. In [13] the problem of selecting the most appropriate regional landfill site was solved as a problem of multi criteria optimization. Solving of this problem is done by use of geographical information system (GIS). The attention is focused on finding possibilities, advantages, and limitations in using GIS in selecting a micro site for regional landfill waste. In [14] the problem of selecting the most suitable biomass location is set as a linear programming (LP) issue. The main objective of the function is defined as the minimization of the total net consumption for waste disposal. In paper [15], by method of sustainable development, Ribic introduces sanation of hazardous material and social progress, economic growth, and increasing the employment rate planned by the project. Paper [16] points out contamination of groundwater by selection of an improper site, or by sanation of the existing one.

This paper is based on the problem of multi-criteria analysis. Selection of the appropriate landfill site is made on the basis of defined criteria. A professional team of several members suggests possible locations that meet all property, legal, and technical requirements for the future landfill site. Also, these decision-makers define the necessary criteria to be used for the evaluation of landfill site eligibility. Evaluation of the relative importance of the criteria and their weights is done on the basis of the defined scale for criteria assessment. Maximal value as a product of weight of each criterion and value of criteria obtained by measuring or recording in practice is done on the basis of the defined procedure. The obtained values are used as the value for the ranking of landfills.

Mathematical Formulation

The procedure of mathematical formulation of the problem of landfill site selection was presented in the following points

Basic Assumptions

Mathematical formulation of the problem of landfill site selection is based on the following assumptions:

- A set of I possible sites is proposed. The set of possible sites is formally presented by the set of sites indexes i ($i = 1, 2, 3, \dots \dots \dots, I$).
- A professional team of decision makers is formed consisting of: a town planner, geologist, doctor, electrical engineer, technical engineer, and environmentalist.
- The decision makers team defines the number and type of criteria to be used as a basis for evaluation of any possible landfill site.
- The decision makers team defines the set of possible sites on the basis of:
  a) An analysis of historical data based on the experiences of other countries
  b) Using the data found in official bulletins
  c) Professional observation, etc.

  In practice, different approaches are usually combined.
- The value of relative importance of weighted criteria is determined for each defined criterion.
- Relative importance of weighted criteria does not depend on a landfill site, but it is determined on the basis of decision makers experience and knowledge.

Defining Criteria and Determination of Relative Importance of Weighted Criteria

The expert decision-makers team, consisting of six members on the basis of their knowledge, experience, information available, the expertise, skill, etc… proposes

Table 1. Criteria for landfill site selection.

S. n.	Criteria for the selection of landfill sites	Mark
1	Ownership of land	OL
2	Planning and design documentation	PD
3	Distance from residential areas	DR
4	Distance from surface waters	DW
5	Average path taken	AT
6	The average of infrastructure	AI
7	Available space locations	AS
8	Terms of exploitation – overlay material	OM
9	Relief characteristics of the site	RC
10	Distance from agricultural land	DA

10 criteria for assessing the landfill site. Criteria for evaluation of a landfill are presented in Table 1.

The decision makers also define the scale for criteria assessment. The proposed scale of assessment of the criteria for landfill site selection is presented in Table 2.

According to the authors, proper landfill selection requires selection of all the influential criteria and making a detailed description of the criteria for each landfill and evaluates them. The description of the criteria and their evaluation (1-5) is presented in Table 2.

Multi-criteria landfill site selection is done by the analytical hierarchical process (AHP) [17]. The decision-maker compares elements at the certain level of hierarchy to each other, in relation to all (superior) elements at the higher level of hierarchy. In basic hierarchy this means that all the criteria in relation to the objective are first compared in pairs, and then all the alternatives in pairs are compared individually for each criterion. Each comparison is done by giving verbal or numerical grades according to Saaty's fundamental scale. Numerical grades of comparing pairs of elements at the certain level of hierarchy are inserted into the matrix that is reciprocal, i.e. the upper triangle elements are symmetrically reciprocal to the elements from the lower triangle, while the elements on the main diagonal are equal to 1. The local vector of elements weighs at the same level of hierarchy in relation to the superior element from the lower level of hierarchy is calculated from the matrix of comparison. The calculation of the local vectors is carried out by some known method [20]. The proposed analytical hierarchical process is presented in Fig. 1.

The Proposed Algorithm for Selecting the Location of Landfills

We will mark the I set of landfills with i ($i = 1, 2, 3, \ldots \ldots \ldots, I$). Then evaluate these landfills by criterion J ($j = 1, 2, 3, \ldots \ldots \ldots, J$). Evaluation of landfills will be done by converting multiple measures (criteria) of landfills into a single measure S_i. The measures of landfills i under criteria j are denoted as X_{ij} ($i = 1, 2, 3, \ldots \ldots \ldots, I, j = 1, 2, 3, \ldots \ldots \ldots, J$). We convert values X_{ij} into the values Y_{ij} by formula [18]:

$$y_{ij} = \frac{x_{ij}}{\max_{j=1,2,3,\ldots J}\{x_{ij}\}} \tag{1}$$

The scores of selected landfills are expressed as a weighted sum of converted values:

$$S_i = \sum_{j=1}^{J} W_{ij} y_{ij}$$

...where W_{ij} ($i = 1, 2, 3, \ldots \ldots \ldots, J$) is the weight of criterion j from landfill i. The criterions are arranged in the descending order of importance ($W_{i1} \geq W_{i2} \geq W_{i3} \geq \ldots \geq W_{ij}$). The weights must be non-negative values and their sum $\sum_{j=1}^{J} W_{ij} = 1$. All normalization scores S_{ij} ($i = 1, 2, 3, \ldots, I$) are always between 0-1. Multi-criteria model for a landfill site selection has the following form:

$$\max S_i = \sum_{j=1}^{J} y_{ij} W_j \tag{2}$$

$$\text{s.t.} W_{ij} - W_{i(j+1)} \geq 0, \quad j = 1, 2, 3, K\ (J-1)$$

$$\sum_{j=1}^{J} W_{ij} = 1$$

$$W_{ij} \geq 0, \; j = 1, 2, 3, K, J$$

$$y_{ij} = \frac{x_{ij}}{\max_{j=1,2,3,\ldots J}\{x_{ij}\}}$$

$$G = \sqrt[N]{x_1 x_2 x_3 \cdots x_N} \tag{3}$$

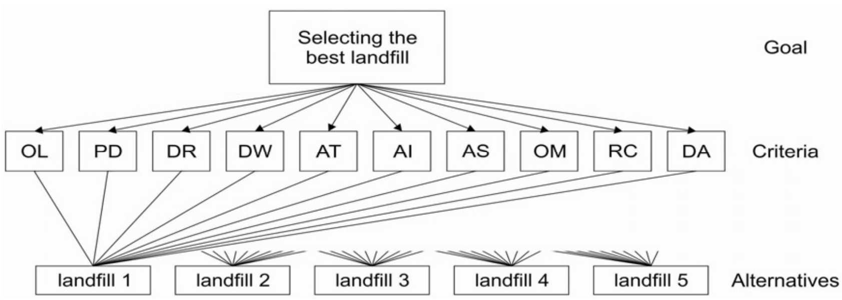

Fig. 1. AHP model for the selection of the location of landfills.

Table 2. Scale for assessment of the criteria for landfill site selection.

No.	Criterion	Criterions description	Evaluation
1	Ownership of land at the landfill site (OL)	- Utility company owned	5
		- State owned	4
		- State owned 50%, utility company owned 50%	3
		- Private ownership 50%, utility company owned 50%	2
		- Private ownership, several parcels of various owners.	1
2	Planning and design documentation of the landfill and documents about environment protection (PD)	- The landfill has a full-investment technical documentation, and use permission	5
		- The landfill has a complete investment technical documentation, but without use permission	4
		- The landfill has major projects for the opening and operation	3
		- The landfill has only planning documents related to site selection	2
		- The landfill has no technical documentation	1
3	Distance from residential areas or individual construction facilities (DR)	- Landfill is sufficiently distant, noise and odors do not reach the residential area	5
		- The noise does not bother, but side winds occasionally bring the scent to a residential zone	4
		- The noise does not bother, but the smell and fumes can be occasionally felt	3
		- Noise and smell from time to time felt	2
		- Noise, odors, and pollutants are always present	1
4	Distance from surface waters (DW)	- There are no surface water courses	4
		- Surface water courses are not in a residential zone or river	3
		- Surface waters are partially going to the settlement or river	2
		- Surface waters go into the town and the river through the settlement	1
5	Average path taken by a vehicle during waste disposal (AT)	- Not longer than 10 km.	3
		- From 10-20 km.	2
		- Longer than 20 km.	1
6	The average of infrastructure at the landfill site (AI)	- Access road, electricity, water, and grounds; no recycling,	4
		- Access road; no electricity or water	3
		- Bad road, nothing more	2
		- No road, electricity, water, or grounds	1
7	The available space locations beginning with the year of analysis and evaluation (AS)	- In the next 70 years	4
		- In the next 50 years	3
		- In the next 30 years	2
		- In the next 20 years	1
8	Terms of exploitation-over lay material (OM)	- Satisfactory	3
		- They could be improved	2
		- Dissatisfactory	1
9	Relief characteristics of the site (RC)	- Slightly sloped between the two hills	3
		- Slightly sloped at the open area	2
		- On flat terrain	1
10	Distance from the location of agricultural land (DA)	- Sufficiently distant – it does not bother	4
		- Sufficiently distant – occasionally bothered by gases	3
		- Insufficiently distant – occasionally bothered by gases and water courses	2
		- The site bothers agricultural land	1

Table 3. Values of criteria for various landfill sites.

Criterion / Landfill	OL	PD	DR	DW	AT	AI	AS	OM	RC	DA
L1	5	3	4	2	1	2	2	2	3	2
L2	4	4	3	4	3	3	2	2	3	4
L3	4	5	5	3	2	3	4	2	3	3
L4	2	2	2	1	2	3	4	1	2	4
L5	4	4	3	3	3	4	2	2	3	4

The procedure of multi-criteria landfill site selection is a simple and fast procedure and is performed in the following steps:

Step 1. Determine the dominant criteria of a landfill site and evaluate its compliance with marks from 1 to 5.

Step 2. Transform the values of the criteria into the values proper for operation by the following formula: $y_{ij} = \frac{x_{ij}}{\max_{j=1,2,3,...J}\{x_{ij}\}}$ where $\min_{i=1,2,3,...j}\{Y_{ij}\}$ and $\max_{i=1,2,3,...j}\{Y_{ij}\}$ minimal and maximal value of the items of a certain factor.

Step 3. Calculate all partial average weights by the formula for geometric mean: $G = \sqrt[N]{x_1 x_2 x_3 \cdots x_N}$

Step 4. Calculate maximal values by formula:

$$\max S_i = \sum_{j=1}^{J} y_{ij} W_j$$

Step 5. Align the landfills on the basis of weight and select the best one/ones.

An Experimental Example

For the purpose of illustration, we are presenting a hypothetical example of a landfill site selection. We are observing a medium sized city, with an average infrastructure and poorly developed industry. The city has 5 sites available that could be legal landfills and several illegal landfills. In order to permanently solve the problem of waste disposal, it is necessary to choose one or two locations where the waste is disposed of in the future. According to the factual state of the city, the authors use 10 most important criteria proposed by the decision makers showed in the Table 1, and the scale for the evaluation of the value of the criteria in the process of the landfill site selection (1-5) presented by the last column in Table 2. The values of the criteria and their grades are given in Table 3.

In order to apply the principle of multi-criteria classification, we first convert the values x_{ij} (i=1,2,3,…, I, j=1,2,3,…, J) into the value y_{ij}, which is proper for further work. The conversion of values is done in the way that each value X_{ij} is divided by the maximal value for the given criterion. The transformation of values is done by Step 2 of the proposed model. The converted values are presented in Table 4.

Equalizing the values of the weighted criteria is done for equalizing the effects of some criteria. Equalizing the values in this paper has been done by geometric mean. The calculation of partial average values of weights has been performed by the formula of geometric mean (Step 3). The calculation of partial average values of the criteria is done by using transformed values from Table 4, and the obtained average values of weights were presented in Table 5.

Table 4. Converted values of the criteria and landfills.

L	OL tra	PD tra	DR tra	DW tra	AT tra	AI tra	AS tra	OM tra	RC tra	DA tra
1	1.00	0.60	0.80	0.50	0.33	0.50	0.50	0.67	1.00	0.50
2	0.80	0.80	0.60	1.00	1.00	0.75	0.50	0.67	1.00	1.00
3	0.80	1.00	1.00	0.75	0.67	0.75	1.00	0.67	1.00	0.75
4	0.40	0.40	0.40	0.25	0.67	0.75	1.00	0.33	0.67	1.00
5	0.80	0.80	0.60	0.75	1.00	1.00	0.50	0.67	1.00	1.00

Table 5. Maximal values of partial weights.

L	OL	PD	DR	DW	AT	AI	AS	OM	RC	DA	Score
1	**1.00**	0.77	0.78	0.70	0.60	0.58	0.57	0.58	0.62	0.61	1.00
2	0.80	0.80	0.73	0.79	**0.83**	0.81	0.76	0.75	0.77	0.79	0.83
3	0.80	0.89	**0.93**	0.88	0.83	0.82	0.84	0.82	0.84	0.83	0.93
4	0.40	0.40	0.40	0.36	0.40	0.45	0.50	0.48	0.49	**0.53**	0.53
5	0.80	0.80	0.73	0.73	0.78	**0.81**	0.76	0.75	0.77	0.79	0.81

Table 6. Values of multi-criteria weights.

Landfill	L1	L3	L2	L5	L4
Ponder	1.00	0.93	0.83	0.81	0.53

Defining the maximal assessment value is done by the formula proposed in Step 4. On the basis of assumptions and limitations of the model in Chapter "*The Proposed Algorithm for Selecting the Location of Landfills,*" we obtain the maximal weight value, calculated as the sum of all the criteria weights using the following formula:

$$MaxScore = W_{i1}+W_{i2}+W_{i3}+W_{i4}+W_{i5}+ W_{i6}+W_{i7}+W_{i8}+W_{i9}+W_{i10}$$

...where W_{i1}, W_{i2}, W_{i3}, W_{i4}, W_{i5}, W_{i6}, W_{i7}, W_{i8}, W_{i9}, $W_{i10} \geq 0$ are the values of weighted coefficients and maximal values of partial weights as presented in Table 5 in bold. The final values of maximal weights were presented in Table 5 in the last column as the value – score.

The last column of Table 5 contains maximal values of partial weights of the observed landfills and is denoted as "score." These values present the value of the weight for a landfill site selection.

The pondered values have been aligned in descending order and presented in Table 6.

The total value of weight coefficients calculated for various landfills are presented in Table 6. From this table we can see that landfill L1 has a maximal value of 1.00. This means that landfill L1 maximally or 100% meets the set criteria for the landfill. The next site is L3, with a weight of 0.93 or 93% compliance of set criteria, and so on. The last position belongs to landfill L4 with weight 0.53, or 53% compliance of set criteria. Selection of landfill sites can now be quickly and easily carried out, based on weight and Table 6. If the town/city has a need for a single site, that is landfill site L1. If there is a need for two sites, they will be sites L1 and L3.

Conclusion

This paper presents a new model of multi-criteria landfill site selection aimed at protecting the environment. The model proposed treats the problem of multi criteria and alternatives of making a single decision on the validity of the problem observed. Unlike previous research where selection or reconstruction of an existing landfill site was done on the basis of one criterion (being treated as the dominant one according to the decision maker), this model allows application of several criteria that are, according to the authors, the most influential. They allow involvement of a decision maker in the process of selection of relative importance of a criterion. The role of a decision maker is not a subjective one, but allows objectivity in decision making.

Five landfill sites, being partially used as illegal landfills and 10 criteria that have to be met by a landfill, are presented in this paper. According to the given model landfills L1, L2, L3, L4, and L5 got the weights 1.00, 0.83, 0.93, 0.53, and 0.81, respectively. Landfill L1 has the value 1.00 or 100%. This landfill meets the set criteria 100% and it has priority in selection. Landfill L2 has the value 0.83 or meets the set criteria 83% and so on. Landfill L4 has the value of 0.53 or meets the criteria 53%, so it is the worst one among the proposed sites and is not recommended to be selected for a landfill site.

According to the obtained results (Table 6), we can conclude that landfill L1 maximally meets the set criteria and it has a priority in the process of legal landfill site selection. If a residential area needs two landfills, another one would be landfill L3. Landfill L4 has the lowest weight and it cannot be selected for a landfill site.

The landfill site selection performed in this way gives a clear picture on landfill sites, their compliances of the set criteria, and chances to be selected as a legal landfill site. By knowing the weight list (Table 6), you can easily make a decision on selection of the best landfill site. By selecting the landfill site on the basis of the proposed model, the decision maker fulfilled all the legal, environmental, communal, construction, aesthetic, economic, and other criteria, so that it can be said he or she made an optimal decision. Regarding the low-weight landfills, the decision maker has an extra alibi for their reconstruction or removal. The landfill site selection procedure is a fast and simple one and it can be applied in any circumstance in any town.

The main contributions of this paper are: landfill site selection has been performed on the basis of 10 criteria, including all the relevant facts necessary for optimal landfill site selection. The selection and assessment of the criteria is done by a professional team so that all the expert ideas from various points of view have been included. At the same time, all the urban, geological, and sanitary criteria belonging to engineering, as well as environmental criteria, have been met. The assessment of the criteria is done by a professional team by the assessment scales, where the relative importance of weighted criteria is defined for every single criterion. The selection is done on the basis of maximal values of the partial values.

Our method contributes to a better understanding of the negative impact of improper waste disposal, which is the consequence of badly selected landfill sites and their irregular maintenance and exploitation. Making a report that can be used as a basis for a very simple and convenient analysis and evaluation of the selected sites and ways of their exploitation, as well as for estimation of possible impacts on the environment and human health. As information to the decision makers in the local communities, to be active participants in faster and better quality solving the problems regarding the management system and waste disposal in the safest ways regarding protection of human health and environment.

The model is simple and its use does not require particular knowledge or experience in the field. It can be applied in any situation of landfill site selection.

In this paper, research is still at an initial stage. Much more research can be carried out on the basis of the results from this paper. Recommendations for further work:

- Similar research can be repeated when the transformation of performance values is carried out by arithmetic mean, square, or cubic means.
- Model of research when fuzzy data are used.

The disadvantage of this method is that two landfills may happen to have the same weight and we cannot precisely say which of the two landfills is better. In such a case, some new criteria should be introduced and the procedure of landfill site selection should be repeated.

References

1. TRIFUNOVIĆ G. Implementation of manicipal waste management system in health centers. Ecologica. 18, (63), **2011**.
2. BIOČANIN R. Ecology and waste management. Strategic Research Center for National Security, Belgrade **2011**.
3. KODA E. Landfill stability under reclamation and pollutant transport using the observational method. SGGW, Warsaw. 275, **2011** [In Polish].
4. STEGMANN R. Concepts of waste landfilling. In: Christensen T.H., Cossu R., Stegmann R., Ed. Proceedings of the 5-th International Landfill Symposium, Sardinia, 95; 2-6. Listopad 1995, Cagliari, italija. **1**. Cagliari: CISA; pp. 2-12, **1995**.
5. AHEL M., TERZIĆ S., TEPIĆ N. Organic contaminants in the Jakusevac lanfill and their impact on groundwater quality. Arh Hig Rada Toksikol. **57**, 307, **2006**.
6. KOMILIS D.P., HAM R.K., STEGMANN R. The effect of municipal solid waste pretreatment on landfill behavior. Waste Manage. Res. **17**, 10, **1999**.
7. De MOL R.M., JOGEMS M.A.H., VAN BEEK P., GIGLER J.K. Simulation and optimization of the logistics of biomass fuel collection. Neth. J. Agr. Sci. **45**, 219, **1997**.
8. FUNDURULJA D., MUŽINIĆ M., PLETIKAPIĆ Z. Minicipal waste disposal sites in the territory of Croatia. Građevinar **52**, (12), 727, **2000**.
9. IVŠIĆ T., PETROVIĆ I., VERIĆ F. Overview of parameters for stability analysis on waste disposal sites. Građevinar **56**, (11), 665, **2006**.
10. ERDELEZ A., MARGETA J., KNEZI S. An integrated approach to minicipal waste collection system management. Građevinar **59**, (6), 505, **2007**.
11. MICHALAK J., NAWALANY M., SADURSKI A. Schematization of hydrogelological conditions due to JCWPd numerical modeling of flow. Methodical assumptions, Nat. Geo. Inst., Warsaw. 176, **2011** [In Polish].
12. KODA E. Local water quality monitoring on surroundings of the sanitary landfill. Ann. of Warsaw Agri. Uni., Land Reclam. **35**, (a), 131, **2004**.
13. JOKSIMOVIĆ B., KRUNIĆ N. Implementation of GIS in selection of locations for regional landfill in the Kolubara region. Spatiumbr. **17**, (18), 72, **2008**.
14. LEDESMA E.P., POGODZINSKI J. M. Determining the Optimal Location for a Municipal Solid Waste facility. Study, Department of Economics San Jose State University, **2008**.
15. RIBIĆ I. Sustainable redevelopment of hazardous waste landfills-the hazardous waste landfill of sovjak (Rijeka, Croatia) as case study. Zagreb, Croatian Natural, **17**, (4), 375, **2008**.
16. BARČIĆ D., IVANČIĆ V. Impact of the Prudinec/Jakusevac landfill on environment pollution. Šumarski list br. **7-8**, CXXXIV, 347, **2010**.
17. SAATY T.L. How to make a decision: the analytical hierarchy process. Eur. J. Oper. Res., **48**, (1), 9, **1990**.
18. HWANG C.L., YOON K. Multiple Attribute Decision Making. Springer-Verlag, Berlin, **1981**.
19. BRONJA H. Multi-criteria approach to ranking suppliers in the supply chains concept. Technical Gazette **18**, (3), 393, **2011**.
20. SRDJEVIC B., JANDRIC Z., POTKONJAK S. Evaluation of alternatives to the use of accumulation by the Analytic Hierarchy Process. Waterpower engineering, **0350-0519**, 32, 183-185, 237-242, **2000**.