USING THE GIS TECHNOLOGIES AND FUZZY LOGIC METHODS TO SUPPORT DECISION-MAKING ON PLACING LANDFILLS FOR SOLID WASTE

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Introduction. The task of supporting spatial solutions that arises in a wide variety of applied areas, such as territorial management, natural resource management, environmental protection, urban and regional planning, often fails to be successfully resolved without using the geographic information systems (GIS). It is the GIS that are able to integrate various geographic information, to store and analyze spatial data, and may provide spatially distributed systems of decision-making support.

Today, landfills of solid waste represent a significant environmental problem. 160 thousand hectares of land are occupied with garbage landfills and they store about 35 billion tons of waste, and each year about 12 thousand illegal landfills put themselves on the map of Ukraine.

Therefore, the actual task of resolving the problem of waste and garbage dumps in Ukraine includes separation itself, and processing of waste, but there's a need of stocktaking of existing solid waste landfills (SWL) in order to differentiate them according to their ecological condition, as well as to identify dangerous sites for their placement. That is to say that the aim is to zone territories according to their suitability degree for the SWLs placement. Solution of this problem requires an integrated use and processing of different spatial information, therefore, when organizing the informational support of decision-making on waste placement, the GIS using appears the most promising.

When solving this problem, particular attention should be paid to the incoming information, which often consists of a large number of heterogeneous factors that are not object of formalized description. This results in intractability of credible conclusions formulation.

Thereby, the application of methods of the fuzzy set theory is attractive, as it allows obtaining adequate modeling results regarding the possible placement of solid waste landfills but taking into account the uncertainty of the incoming information.

Many authors researched application of geographic information systems to support decision-making in managing processes that affect the state of the environment, rational use of natural resources and territories. Among them should be mentioned [1-5], which are directly devoted to the problem of waste control.

Despite the fact that many Ukrainian and foreign scientists deal with researching the fuzzy sets and their application to the multiple-criteria decision-making under uncertainty, the problem of developing information support on the basis of geo-information technologies and methods of fuzzy logic remains very relevant.

Mathematical foundations of the theory of fuzzy sets. The use of strict rules for territories classification regarding their suitability for placement of landfill sites reduces flexibility and has a limitive effect on the process of making managerial decisions, therefore classification based on the theory of fuzzy sets is more expedient.

Let’s introduce the definition of the fuzzy set according to L. Zadeh [6].

Let U be a universal set, u be an element of U. A fuzzy set $\tilde{A}$ of a universal set **U** is defined as the set of ordered pairs

$$\tilde{A} = \{\langle \mu_A(u) | u \rangle\},$$

where $\mu_A(u)$ is a membership function that takes values in some completely ordered set $M = [0; 1]$.

The membership function indicates the degree of membership of the element u to the fuzzy subset $\tilde{A}$. The larger is the $\mu_A(u)$, the greater is correspondence of the universal set element to properties of the fuzzy subset. The set M is called a membership set. If $M = \{0; 1\}$, then the fuzzy subset can be regarded as a crisp set.

To describe objects in uncertainty, the concept of fuzzy variable is used, which is given by the ternary

$$\langle \alpha, U, \tilde{A} \rangle,$$

where α is name of the fuzzy variable, U={u} is domain of definition of the variable α, $\tilde{A} = \{\langle \mu_A(u) | u \rangle\}$ is a fuzzy set describing limits of possibly value of the variable α.

Fuzzy variable is the same fuzzy number, but with the addition of a name, which formalizes the concept described by this number.

The linguistic variable is a set of fuzzy variables. It is used to give a verbal description of some fuzzy number obtained as a result of some operations and is given by the tuple

$$\langle \beta, U, T, M, G \rangle$$

where β is name of the linguistic variable, U is a universal set, T is set of values of the linguistic variable, each of them is a fuzzy variable to U, M is a syntactic procedure that allows to obtain (to formulate) new values of the linguistic variable, G is semantic rule that allows interpretation of newly retrieved values of a linguistic variable.

The term set is a set of all possible values of a linguistic variable.

A term is any element of the term set. In the fuzzy sets theory, the term is formalized by a fuzzy set using membership functions.

In the fuzzy sets theory, the membership function has a significant role, since this is the main characteristic of a fuzzy object, and all operations with fuzzy objects are performed as operations with their adequate membership functions. As a rule, any membership function is constructed with the participation of an expert (experts’ group), so that the degree of membership is approximately equal to intensity of some property manifestation.

The following types of membership functions are used in practical operations: triangular and trapezoidal sinus (piecewise linear); non-linear (Gauss function, sigmoid function, spline); membership functions of L-R type.

The multiple-criteria model of decision making. The technique of choosing places to place landfills may be described with two successive stages. The first stage is choosing some potentially suitable places, and is aimed at excluding that part of a territory where placing objects is unacceptable due their danger for the environment and human health.

Selection of suitable places is carried out by spatial analysis using GIS and taking into consideration criteria of nature protection (conservation) requirements, specific features of terrain, landscape morphology, socio-economic factors, etc.

The second stage is ranking of selected places according to priority. The procedure is realized as multi-factor analysis of decision-making. The Analytic Hierarchy Process (AHP) or Analytic Network Process (ANP) methods are often used with this purpose. The resulting choice is the most suitable location for construction of a landfill site. In this thesis, the first stage is considered in detail, namely the processing of spatial information based on the fuzzy logic methods.

Let's formulate the task (problem). Let be a set of criteria that determine the optimal area for placing landfills. Each criterion is described by the linguistic variable

$$A = \{A_i\}, i = \overline{1, n}.$$

Each linguistic variable is defined by the set of terms $A_i = \{a_{ij}\}, j = \overline{1, q}$.

It is necessary to determine the influence of each linguistic variables on choosing a part of territory, and to make it a base of rules for fuzzy conclusion should be established to determine the exact value of the output variable B, i.e. suitability level of the point of the site to place the solid waste, which is given with values of the terms $B = \{B_q\}$, $q = \overline{1, m}$, to wit: unsuitable, too little suitable, suitable, completely suitable.

To establish the dependence between the input data and the output variable B, it is necessary to formulate the logical rules, and an expert is to do this. Such rules are established by means of dependencies representing the logical operands IF A, THEN B.

Thus, the rules of the fuzzy output may be formulated as follows: IF $u_1 = A_1 \text{ I } u_2 = A_2 \text{ I} \ldots \text{I } u_n = A_n$ THEN $y = B_{q,}\ q = \overline{1, m}$.

Input data. To formulate the evaluation criteria, the existing regulatory, technical, and environmental requirements should be taken into account. Should be considered, too, geomorphological, hydrological and environmental criteria, which depend on the particular area under study. Requirements in the table 1 are the minimally necessary ones, and in prospect the long-term exploitation of the landfill may be paid respect to (storage of waste, the landfill area increase, etc.).

The requirements for the landfill placing are expressed through appropriate linguistic variables. Below is a fragment of the model that corresponds to the linguistic variable "Distance to the cities' boundaries".

The criterion "Distance to the cities' boundaries" has three linguistic terms: "Near", "Not far" and "Far", which are formalized by formulas (1), (2) and are shown in Fig.1

Table 1. Selection criteria for potentially suitable sites for placement of the

solid waste landfill

	Criteria	Meaning
1	Slope (skew)	no more than 10^0
2	Distance to settlements	not less than 1000 m
3	Distance to open reservoirs and rivers	not less than 1000 m
4	Distance to protected zones	not less than 1000 m
5	Distance to industrial zones	not less than 500 m
6	Distance to agricultural lands	not less than 1000 m
7	Distance to highways	not less than 100 m
8	Depth of groundwater table	not less than 2 m

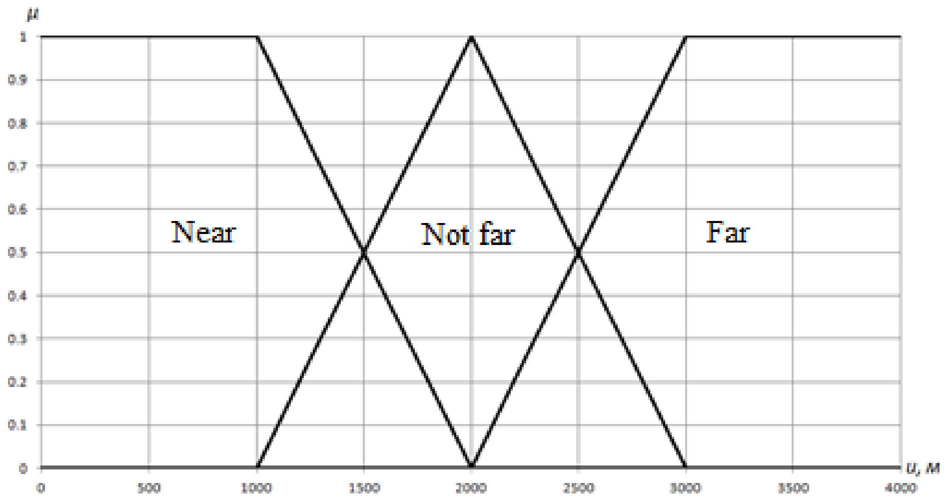

Figure 1. The membership function for terms of the linguistic variable "Distance to the cities' boundaries"

The linguistic variable "Distance to the cities' boundaries":

$$A_2 = \left\{ \begin{matrix} a_{2,1} - \text{Near} \\ a_{2,2} - \text{Not far} \\ a_{2,3} - \text{Far} \end{matrix} \right\}, \qquad (1)$$

$$\mu_{2,1} = \begin{cases} 1, & u_2 \le 1000 \\ \dfrac{2000 - u_2}{1000}, & 1000 < u_2 \le 2000 \\ 0, & u_2 > 2000 \end{cases}$$

$$\mu_{2,2} = \begin{cases} 0, & u_2 \le 1000 \\ \frac{u_2 - 1000}{1000}, & 1000 < u_2 \le 2000 \\ \frac{3000 - u_2}{1000}, & 2000 < u_2 \le 3000 \\ 0, & u_2 > 3000 \end{cases} \qquad (2)$$

$$\mu_{2,3} = \begin{cases} 0, & u_2 < 2000 \\ \dfrac{u_2 - 2000}{1000}, & 2000 \le u_2 \le 3000, \\ 1, & u_2 > 3000 \end{cases}$$

The next step is formulating the base of rules according the expert's knowledge. Using fuzzy sets, the search for a suitable territory may be formulated as follows: IF (moderate slope) and (Distance to settlements 'far') AND (Distance to open reservoirs and rivers 'far') AND (Distance to protected zones 'far') AND (Distance to industrial zones 'far') AND (Distance to agricultural lands 'far') AND (Distance to highways 'not far') AND (Depth of the groundwater table 'low') THEN the territory is suitable for the solid waste landfill placement.

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