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# SITE SELECTION CRITERIA FOR TIPPING OF SPECIAL WASTES

It was conventional to select landfill sites by taking into account only descriptive parameters and neglecting the measurements. In the total rank of a landfill site presented in this paper the site and soil parameters are expressed in form of empirical formulae. These formulae permit a suitable site selection consisting in a minimization of the total rate, leading to minimization of undesired effect of hazardous wastes on the environment.

## 1. INTRODUCTION

Hazardous wastes, or special wastes, are defined as those industrial waste materials which impose considerable environmental impact on the ecosystem. They are usually classified according to their properties as: radioactive, toxic chemical, biological, and miscellaneous (flammables, explosives, irritants, etc.).

In the basic method of disposal so far employed, hazardous wastes usually after physical and/or chemical pretreatment have been placed in a specific landfill. Nowadays preference is given to the storage and management of hazardous wastes in systems of regional disposal sites. The regional systems will permit the design and planning of disposal facilities with improved technological parameters [2].

Any design of a future landfill site must be made with a full recognition of the characteristics of the wastes, air, water, and land. The criteria of a suitable landfill site selection are either of an economical or non-economical character. The non-economical criteria gain special consideration, as they contribute to the minimization of a deleterious effect on the total ecosystem.

## 2. GENERAL

A potential site is characterized by a certain system of parameters, such as geological and hydrological conditions of the bottom soil, meteorological conditions, distance from the urbanized area (zone of sanitary protection), and the like. The sum of these parameters is an indication as to the suitability of the area selected for the location of a landfill site for

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such wastes. The set of qualitative site-parameters may be ranked quantitatively in form of a vector

$$[C_i] = [C_1, C_2, \ldots, C_n], \tag{1}$$

including $n$ qualitative parameters ($C_n$). The total site rank $F$ is a function of variable qualitative parameters

$$F = f(C_i) = f(C_1, C_2, \ldots, C_n). \tag{2}$$

Some of these parameters, e.g., the filtering capacity of the soil or the groundwater table, are measurable in a physical sense and may be expressed in natural units. Other parameters, such as the aesthetic factor cannot be measured and are, therefore, incomparable. That is why a scale of qualitative criteria should be established. The measurement results, expressed in physical units, should be transformed and presented on a special scale. This scale is graduated by using empirical formulae, whose numerical values are included in the given range of variability. It is a method of a quality assessment [3].

Considering that the individual parameters are more or less affecting the total site rank, it is also necessary to develop a punctal scale of importance for selecting the site parameters.

The total importance rank may be defined by the following vector:

$$a_i = a_1, a_2, \ldots, a_n \tag{3}$$

where $a$ — importance of the $i$-th parameter.

Thus, the total site rank will be expressed either as an additive function

$$F = a_1 C_1 + a_2 C_2 + \ldots + a_n C_n = \sum_{i=1}^{n} a_i C_i \tag{4}$$

or as a product function

$$F = a_1 C_1 \times a_2 C_2 \times \ldots \times a_n C_n = \prod_{i=1}^{n} a_i C_i. \tag{5}$$

Formula (4) is usually employed when the particular site characteristics are not interrelated; in other cases it is advisable to use formula (5). In order to minimize the rate of subjectivity in establishing the punctual assessment of the conditions given by the formulae and rank coefficients, it is advisable to use the expert's opinion to estimate the same quality. The resultant site rank assessment should be used in further works on the total site ranking.

## 3. DETAILED FORMULAE OF THE RANKING SYSTEM

In the present paper, the selection of potential landfill sites for the storage, handling and disposal of hazardous wastes has partially been based on the Landfill Site Ranking System developed by J. Hagerty, et al. [1]. Ten parameters which are believed to have a significat bearing upon the site rank have been selected and characterized. To each of these parameters a scale of priority ranking units from 0 to 10 has been assigned. Then, considering the importance of parameter, the site parameters have been classified into four categories, with the importance factors: 1.5; 0.8, and 0.5, respectively.

The additive function of the total site rank, expressed by the equation

$$F = \sum_{i=1}^{10} a_i C_i \tag{6}$$

takes the values from the interval [0, 100]. The values of the individual site parameters and of their importance factors are listed in table 1. The criteria according to which the site parameters are to be estimated will be discussed in the subsequent sections.

Table 1

Ranking parameters and factors of importance for potential landfill sites

| Parameter | Rank $C_i$ | Factor of importance $a_i$ | Product $a_i \times C_i$ |
|---|---|---|---|
| Infiltration potential of landfilled wastes | 0–10 | 1.5 | 0–15 |
| Bottom permeability | 0–10 | 1.5 | 0–15 |
| Groundwater flow rate | 0–10 | 1.5 | 0–15 |
| Filtering capacity of soil | 0–10 | 1.2 | 0–12 |
| Adsorptive capacity of soil | 0–10 | 1.2 | 0–12 |
| Organic content in groundwater | 0–10 | 0.8 | 0–8 |
| Buffering capacity of groundwater | 0–10 | 0.8 | 0–8 |
| Distribution of pollution in the atmosphere | 0–10 | 0.5 | 0–5 |
| Distribution of population | 0–10 | 0.5 | 0–5 |
| Distance from reservation areas and state-roads | 0–10 | 0.5 | 0–5 |
| | 0–100 | 10 | 0–100 |

### 3.1. INFILTRATION POTENTIAL

The infiltration potential of the waste deposit $C_1$ is expressed quantitatively by the formula

$$C_1 = \frac{Q_d}{2V} \tag{7}$$

where

$Q_d$ — volume of water which may enter the landfill, $m^3/a$,

$V$ — porosity of the deposited waste material and the cover soil, $m^3$.

The value of $Q_d$ is calculated from the formula:

$$Q_d = HA\delta Q_0, \quad m^3/a, m^3 \tag{8}$$

where

$H$ — average yearly precipitation, m,

$A$ — landfill site area, $m^2$,

$Q$ — amount of gravitational water contained in the slurry wastes disposed,

$\delta$ — percolating factor of the cover soil layer.

The percolating factor is evaluated as follows:

$$\delta = 1-\psi-\gamma \tag{9}$$

where

$\psi$ — superficial run-off coefficient,

$\gamma$ — evaporation factor.

To determine the value of $V$ the following formula was used:

$$V = V_m p_m + V_0 p_0, \quad m^3/a, m^3 \tag{10}$$

where

$V_m$ — volume of the cover soil, $m^3/a$, $m^3$,

$p_m$ — porosity of the cover material, %,

$V_0$ — volume of the landfilled wastes, $m^3/a$, $m^3$,

$p_0$ — porosity of the landfilled wastes, %.

### 3.2. BOTTOM LEAKAGE POTENTIAL AND GROUNDWATER VELOCITY

The permeability of the bottom soil layer is a significant factor determining the potential hazard of the leachate to enter the groundwater flow system. Since any soil has a strictly determined permeability it is unreasonable to believe that an impermeable bottom can ever exist in a sanitary landfill. Even though an artificial lining material is applied, it may occur that the linear cracks and the hazardous substances enter the groundwater system. However, the migration time for a hazardous substance may be sufficiently long to diminish its toxic nature. Hence the bottom leakage potential is expressed by the formula

$$C_2 = \frac{150\sqrt[3]{k_f}}{h} \tag{11}$$

where

$k_f$ — bottom soil permeability, cm/s,

$h$ — bottom soil thickness, m.

It is to be noted that in practice $k_f$ ranges between $10^{-10}$ cm/s, whereas $h$ varies from 1.5 to 15 m.

At the same time, the groundwater velocity is a measure which determines how fast a hazardous material may be spread over the environment. Groundwater velocities are estimated according to the following formula:

$$C_3 = \frac{2.5 \times s}{\log \frac{1}{k_f}} \qquad (12)$$

where

$s$ — gradient, m/km, which ranges approximately between 0 and 4 m/km.

### 3.3. FILTERING CAPACITY AND ADSORPTIVE CAPACITY

Filtering capacity is the ability of the bottom soil to remove solid particles which travel through the bottom soil layer in a fluid suspension. The filtering capacity can be expressed in the following form

$$C_4 = -2.5 \log \frac{6 \times 10^{-4}}{d_{10}} \qquad (13)$$

where

$d_{10}$ — effective size of the soil particles. The average effective size is $6 \times 10^{-4}$–3 mm.

The adsorptive capacity is a factor determining the decrease of a potential groundwater pollution since organic and inorganic materials contained in the migrating lechate are adsorbed on colloidal-size particles of the soil. The adsorptive capacity $C_5$ is measured generally by the cation exchange capacity (CEC) of the minerals included in the soil according to the formula

$$C_5 = \frac{6.25 \times S}{(\log P) + 1} \qquad (14)$$

where

$S$ — organic content of the soil expressed in per cent (in practice it varies approximately from 0 to 1%),

$P$ — CEC of minerals contained in the soil, mval/100 g (ranging within 0.4–150 mval//100 g).

### 3.4. ORGANIC CONTENT OF GROUNDWATER

The organic content of the groundwater can be expressed in terms of BOD. The higher the BOD value in the groundwater, the higher is the potential of reproducibility of pathogenic microorganisms. To evaluate the organic content, the following formula is used:

$$C_6 = 0.8 \times S_{BOD} \qquad (15)$$

where $S_{BOD}$ — biochemical oxygen demand of groundwater, mg $O_2/dm^3$ maximum value is 12.50 mg $O_2/dm^3$,

### 3.5 BUFFERING CAPACITY OF GROUNDWATER

The buffering capacity of the groundwater is an important parameter which influences considerably the transmission of pollutants into groundwater system. If its buffering capacity is high, the acidity or alkalinity of the waste substances flowing in would be neutralized within a wide range of pH.

The buffering capacity $C_7$ can be ranked as follows:

$$C_7 = 10 - N \tag{16}$$

where

$N$ — the smallest number of milliequivalents (ranging from 0 to 10 mval) of an acid or base required either to decrease (down to 4.5) or to increase (above 8.5) the pH of groundwater from the natural level.

### 3.6. PREVAILING WIND DIRECTION AND POPULATION FACTORS

Air is another important site characteristic to be considered. There potential hazard exists that the population situated in the surrounding of the landfill site, dwellings distributed along the prevailing wind direction in particular, will be adversely affected by toxins, pathogens or odours escaping from the site to the atmosphere. Therefore to evaluate quantitatively the prevailing wind direction factor, the following procedure was employed.

A circle described by the 20-kilometer radius, its centre being landfill site, was divided into four quandrants by means of N-S and E-W lines. In each quadrant both the number of inhabitants and site population density were determined. There upon the population densities of each quadrant were connected (by a radius) with the site. The established prevailing wind direction was represented by another radius drawn from the centre of the circle. The angles formed by the two radii were determined and used in calculation of the prevailing wind potential

$$C_8 = \sum_{i=1}^{4} \frac{\left(5 - \frac{A_i}{36}\right) \log L_i}{7.5} \tag{17}$$

where

$A_i$ — the angle between the prevailing wind direction and population density radius in each quadrant, deg,

$L_i$ — the population in each quadrant.

The population in the surrounding of the landfill site within a 20-kilometer radius, particularly the inhabitants of the immediate vicinity, are exposed to health hazards. The population factor $C_9$ is evaluated from the formula

$$C_9 = 1.5 \log P \tag{18}$$

where $P$ — population within a 20-kilometer radius of the landfill site.

Table 2

Ranking parameters for potential landfill sites

| Physical and/or chemical parameter | Unit | Site 1 | Site 2 |
|---|---|---|---|
| Annual precipitation | m | 1.0 | 1.0 |
| Soil type | | fine sand | clay |
| Percolating factor, $\delta$ | | 0.75 | 0.10 |
| Filtrability capacity factor $k_f$ | cm/s | $10^{-3}$ | $10^{-8}$ |
| Soil cover thickness | cm | 150 | 60 |
| Bottom thickness, $h$ | m | 6.0 | 4.5 |
| Effective size $d_{10}$ | mm | 0.25 | 0.002 |
| Organic content in soil, $S$ | % | 0.5 | 0 |
| Groundwater BOD, $S_{\mathrm{BOD}}$ | $mgO_2/dm^3$ | 2.5 | 2.5 |
| Cation exchange capacity, CEC | mval/ 100 g | 10 | 80 |
| Buffering capacity of groundwater, $N$ | mval | 7 | 4 |
| Gradient, $s$ | m/km | 1 | 1 |
| Population within a 20-kilometer radius, $P$ | | $10^5$ | $10^5$ |
| Distance from the state-road, $D_j$ | m | $10^2$ | $10^{5.2}$ |
| Class of the state-road, $k$ | | 3 | 4 |
| Prevailing wind direction | | W | W |

### 3.7. AESTHETIC AND ECOLOGICAL FACTORS

In landfill site selection aestetic and ecological factors are also worth considering, of which the most important is the distance to protected reservation and recreation areas within the radius of 0.10–20 kilometers, or to state roads and highways within the radius of 100–1000 meter. These factors can be evaluated by means of the following equation

$$C_{10} = \frac{\sum_{j=1}^{m} \frac{1}{\log D_j}}{m} + \frac{\sum_{j=1}^{n} \frac{3}{\log D_j}}{n} + \frac{\sum_{j=1}^{p} \frac{5}{\log D_j}}{p} + \frac{\sum_{j=1}^{r} \frac{7}{\log D_j}}{r} + \frac{\sum_{j=1}^{t} \frac{4-\log D_j}{k}}{t} \tag{19}$$

where

$D_j$ — distance from landfill site to reservation area or to state road, m,

$m$ — number of protected plant aggregations,

$n$ — number of monuments of nature,

$p$ — number of reservation areas,
$r$ — number of areas under special protection,
$t$ — number of state roads or highways,
$k$ — class of the road ($k = 1, 2, \ldots, 6$; $k = 1$ represents the type of highway roads, and $k = 6$ denotes the 5th-class state-roads).

The total landfill site ranking procedure as well as the rating of the individual factors require a detailed analysis of the local conditions in the immediate vicinity of the potential specific landfill site.

The total ranks for two planned landfill sites (characterized by the parameters listed in table 2) are shown in table 3. As it follows from the data presented in both the tables, the rating of landfill 2 being much lower than that of landfill 1 is, therefore, more desirable for land disposal of hazardous wastes.

Table 3

Ranking comparison of two potential landfill sites

| Parameter | Symbol $C_i$ | Factor of importance $a_i$ | Rank | | | |
|---|---|---|---|---|---|---|
| | | | Site 1 | | Site 2 | |
| | | | $C_i$ | $a_i \times C_i$ | $C_i$ | $a_i \times C_i$ |
| Infiltration potential of landfilled wastes | $C_1$ | 1.5 | 5 | 7.5 | 0.5 | 0.75 |
| Bottom permeability | $C_2$ | 1.5 | 2.5 | 3.75 | 0.33 | 0.10 |
| Groundwater flow rate | $C_3$ | 1.5 | 0.83 | 1.25 | 0.31 | 0.47 |
| Filtering capacity of soil | $C_4$ | 1.2 | 3.0 | 3.6 | 3.70 | 4.44 |
| Adsorptive capacity of soil | $C_5$ | 1.2 | 3.12 | 3.74 | 0 | 0 |
| Organic content in groundwater | $C_6$ | 0.8 | 2 | 1.60 | 2 | 1.60 |
| Buffering capacity of groundwater | $C_7$ | 0.8 | 3 | 2.4 | 6 | 4.8 |
| Distribution of pollution in the atmosphere | $C_8$ | 0.5 | 4.0 | 2.0 | 3.0 | 1.50 |
| Distribution of population | $C_9$ | 0.5 | 7.5 | 3.75 | 7.5 | 3.75 |
| Distance from reservation areas and state-roads | $C_{10}$ | 0.5 | 0.66 | 0.33 | 0.37 | 0.18 |
| Total rank | $\sum_{i=1}^{10} a_i C_i$ | | | 29.92 | | 17.59 |

## 4. SUMMARIZING REMARKS

Until recently, the selection of a specific landfill site has been based on some a priori assumed descriptive criteria not defined mathematically. The ranking method presented here encompasses both the total landfill site rank and the total soil system rank to which appropriate values and weighting factors have been assigned. The lower the rank the better the landfill for special waste disposal.

The formula for total landfill site ranking has been obtained by combining various soil, water, and air parameters. The resultant value indicates whether, or not, the selected area is suitable for land disposal of hazardous wastes. If necessary the list of site parameters is supplemented with the required factors defined by the adequate empirical formulae.

## REFERENCES

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[3] Wołowski W. J., *Programowanie nowej techniki*, PWN, Warszawa 1975.

## KRYTERIA WYBORU TERENÓW NA WYSYPISKA ODPADÓW SPECJALNYCH

Na lokalizację wysypisk wybierano zwykle tereny według pewnych założonych kryteriów opisowych, z pominięciem pomiarów. Przedstawiona w artykule metoda oceny jakości kompleksowej ujmuje cechy terenu i gruntu w wartości liczbowe, obliczone wzorami empirycznymi. Zastosowanie tego prostego aparatu matematycznego umożliwia wybór optymalnego terenu przez minimalizację wartości sumarycznej. Minimalizujemy zatem wpływ odpadów na środowisko, co jest szczególnie ważne w przypadku składowania odpadów specjalnych.

## BEURTEILUNGSKRITERIEN ZUR AUSWAHL WON DEPONIEN FÜR GEFÄHRLICHE ABFALLSTOFFE

Bisher war es üblich, dass ein Gelände für die Ablagerung von Müll und Abfall nur gewissen Merkmalen beschrieben wurde. Man bediente sich selten messbarer Grössen. Die im Beitrag beschriebene Methode der Borechnung eines komplexen Qualitäts-Wertes, basiert auf mehreren empirischen Formeln. Die Anwendung der mathematischen Summen-Rechnung ermöglicht die Auswahl eines optimalen Geländes anhand der Minimierung der Summe. Man minimalisiert dadurch den Einfluss der Abfallstoffe auf die Umwelt, was bei Ablagerung von toxischen und speziellen Abfallstoffen von besonderer Bedeutung ist.

## КРИТЕРИЙ ВЫБОРА ДЛЯ СВАЛКИ СПЕЦИАЛЬНЫХ ОТХОДОВ

Для свалки отходов и мусора отводилось обычно место, соотвествующее предположенным описательным критериям, причем не производились никакие измерения. В изложенном методе оценки комплексного качества свойства местности и грунтов приобретают определенные численные занечения, полученные в результате использования эмпирических формул. Применение несложного математического инструмента позволяет произвести выбор оптимального места путем минимизации суммарного значения. Таким образом, снижается влияние отходов на окружающую среду, что особенно важно для определения места свалки специальных отходов.