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GIS-Based sensitivity analysis in site selection procedures for the disposal of hazardous wastes

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Abstract

Between 1999 and 2002, a multi-scientific working group on behalf of the German Federal Ministry of Environment was under way to determine scientifically founded criteria for a selection and rating procedure for the permanent disposal of radioactive wastes. The Federal Institute for Geosciences and Natural Resources (BGR) accompanied this process by developing a criteria-oriented Geographical Information System (GIS/FIS), titled "Geosciences and disposal of wastes (GEA)". In FIS GEA, 28 crystalline occurrences in Germany were exemplarily chosen for implementing the selected geo-scientific and socio-economic criteria for a future site selection and rating procedure. Currently, 17 crystalline occurrences have been evaluated and analysed. The results of the rating and weighting procedures implemented in a Point-Count-System (PCS) and its sensitivity analysis will be presented. The FIS GEA-application supports national or local authorities in their assessment of criteria-relevant information for a future site selection and rating procedure.

Introduction

In 1998, the German government decided to phase-out the commercial use of nuclear power. This political intention and comprehensive negotiations with important German energy providers led to a consensus, which was signed on June 14, 2000. Since February 1999, the German Federal Ministry of Environment was under way to determine scientifically founded permanent repository criteria for a selection and rating procedure to specify one or more suitable area(s) for the permanent disposal of radioactive wastes. Its AkEnd-working group (Arbeitskreis Auswahlverfahren Endlagerstandorte) had the primary task to develop a transparent site selection procedure by accessing and evaluating geo-scientific and socio-economic criteria. These exclusive and suitable criteria should be used in the future site selection procedure to define an area of crystalline rock, salt or clay for the disposal of hazardous wastes in Germany. In order to ensure the transparency of this site selection procedure and thereby increase the acceptance within the population in Germany, the AkEnd-working group welcomed the participation of the population in every step of its predefinition of the criteria and selection procedure. Its work was completed at the end of 2002 (AkEnd 2002).

The Federal Institute for Geosciences and Natural Resources (BGR) accompanied this process by developing a criteria-oriented multi-layer Geographical Information Sys-

tem (GIS/FIS), titled "Geosciences and disposal of wastes (GEA)". In FIS GEA, 28 crystalline occurrences in Germany (Bräuer et al. 1994) were exemplarily chosen to apply specific geo-scientific and socio-economic criteria to a future small-scale site selection and rating procedure by using GIS. Currently, 17 crystalline occurrences (= investigation areas), all located in the Federal state of Saxony, have been evaluated and analysed. The results of the GIS-based selection procedure of these investigated areas, complemented by a sensitivity analysis, will be presented in this article.

GIS-Methodology

The Geographical Information System FIS GEA comprises two key elements, the ESRI ArcGIS 8.2 environment, which has been used for all geo-processes and visualisation, and an ACCESS 2000 application for all the descriptive data or meta data and especially for the sensitivity analysis of each crystalline occurrence.

The advantages of a GIS-based data management for a future site selection and rating procedure, e.g. double-precision of all map layers or the transparent reproduction of all geo-processes for further verification, have been used to store and to geo-process geo-scientific and socio-economic criteria (see Table 1). The spatial information of the GIS-coverages are linked by a common item (IDENT) with the descriptive information stored in an ACCESS 2000 database. All spatial data are part of a topological model, consisting of geo-referenced coverages in the Gauss-Krüger coordinate system (Germany, zone 4), either digitised from published analogous sources (e.g. maps) or implemented from external spatial data provided by the authorities of the Federal Republic of Germany and of the Federal states, e.g. ATKIS – DLM25, DLM1000, DGM25 and raster data.

The object–oriented ACCESS 2000 application guarantees the integrity and security of both data input and data editing in a multi-user environment. The ACCESS 2000 application is composed of a descriptive data processing tool and a Point-Count-System (PCS), with an integrated sensitivity analysis. The PCS-tool, the linkage between the GIS (spatial information) and ACCESS 2000 database (descriptive information), enables the data representation and the weighting of the defined suitable criteria applied to each crystalline occurrence.

Point-Count-System (PCS) and sensitivity analysis

The public acceptance for regions, areas or sites for the disposal of hazardous wastes is increasing with the transparency of a selection and rating procedure (Risolutti et al. 1999, AkEnd 2002). Therefore, a transparent rating/weighting methodology is an essential part of the FIS GEA-application, which is realised in the PCS-tool and its sensitivity analysis. Due to methodological reasons, FIS GEA applies not only AkEnd defined exclusive and suitable criteria, but various geo- and socio-economic criteria in order to provide incentives for further evaluations of GIS-based information in the case of small scale selection (less than scale 1:100 000) of suitable area(s) (see Table 1).

Based on the criteria-relevant geo-scientific and socio-economic information stored as geo-referenced map-layers (coverages) in GIS, the rating/weighting procedure includes two steps.

Table 1. Criteria-relevant subjects implemented in FIS GEA

exclusive criteria	*suitable criteria*
distance to frontier of FRG	geology
seismicity	tectonics
future potential volcanic activity	hydrogeology
recent vertical crustal movements	seismic epicentres
water reservoir	population density
protected areas including national park, biosphere reservation	protected areas without national park, biosphere reservation
	mining areas

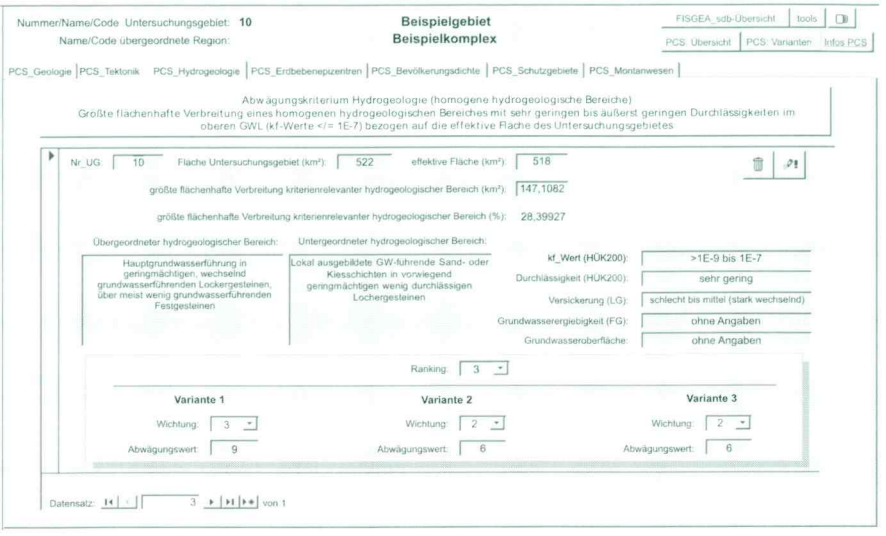

Figure 1. FIS GEA PCS-tool for the suitable criterion "hydrogeology"

The first step of the rating procedure is characterised by geo-processing of the six exclusive criteria in GIS, which leads to one or more positively remaining suitable area(s) within each investigation area. In the second step, these positively remaining suitable area(s) have to be geo-processed first according to seven suitable criteria and second, the spatial information of these GIS coverages have to be integrated into the PCS-application and complemented by descriptive data. The information of both sources provides the ranking and weighting data for each suitable area(s) in the PCS-tool and its sensitivity analysis (Maurer & Balzer 2002). The PCS-tool, the linkage between the GIS (spatial information) and ACCESS 2000 database (descriptive information), enables to specify the specific criteria-related queries and also a sensitive weighting of the applied suitable criteria to each crystalline occurrence in a user interface environment (see Fig. 1 for an example on the suitable criterion "hydrogeology", German version).

The calculation in the PCS-tool is exclusively based on the evaluation of the remaining one or more positive suitable area(s) within each investigation area, which will be weighted by using seven suitable criteria (j = 1-7). These seven suitable criteria finally generate a suitability value (P_j). The suitability value ($P_j = R_j \times W_j$) for each suitable criterion is calculated from a specific parameter ranking value (R_j = 1-10) and a specific parameter weighting value (W_j = 1, 2 or 3). The ranking value (R_j) is associated with the maximum and minimum results of each specific criterion query defined in the PCS. The sum of all suitability values for each suitable criterion can be expressed as a suitability index I, see formula.

$$I = \sum_{j=1}^{7} R_j \times W_j$$

According to the number of suitable criteria and the minimum and maximum ranking and weighting values, the suitability index for each crystalline occurrence can range between 7 and 210 points. The calculated suitability indices allow the comparison of all investigated areas considering the suitability of a region, area or site for the disposal of hazardous wastes (see Table 2). Based on the suitability index ranges (I = 7-210), three suitability classes have been defined to distinguish all investigated areas into site(s) of low, middle or high suitability for a disposal of hazardous wastes.

In order to assess the sensitivity of the rating system, three different weighting procedures have been implemented: the first

emphasises the geo-scientific criteria, the second the socio-economic criteria and, finally, all criteria have been weighted neutrally (see Table 3). The sensitivity analysis has been performed in order to assess the influence of weighting of single or various geo-scientific or socio-economic criteria concerning the final suitability of the areas.

Table 2: Suitability index and suitability classes

suitability index (I)	*suitability classes*
7–74	high (suitable)
75–142	middle (suitable)
143–210	low (non-suitable)

Case Study

The suitability index of all 17 considered crystalline occurrences of Saxony has been analysed and calculated for all three weighting procedures (see Fig. 2). The results show that the weighting procedure with a focus on socio-economic criteria (b) is producing the highest suitability indices. The same weighting procedures with an emphasis on geo-scientifically (a) or neutrally (c) weighted criteria show a heterogeneous distribution and almost no difference between the investigated areas. Five crystalline occurrences have been completely excluded by geo-processing of the exclusive criteria. The three different weighting procedures show,

Table 3.Weighting parameters of the PCS-tool

suitable criteria	*geo-scientific-emphasised weight (a)*	*socio-scientific-emphasised weight (b)*	*neutral weight (c)*
geology	3	2	2
tectonics	3	2	2
hydrogeology	3	2	2
seismic epicentres	3	2	2
population density	1	3	2
protected areas without national park, biosphere reservation	1	3	2
mining areas	1	3	2

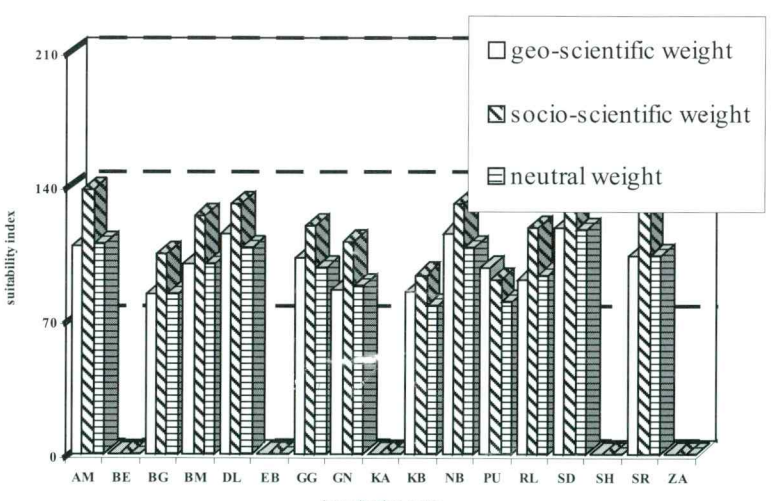

Figure 2. The suitability index of the crystalline occurences in Saxony

that the majority of the crystalline occurrences are characterised by a suitability class of middle degree. Only one investigation area with an emphasis on socio-economic criteria shows a high suitability index in the weighting procedure. The results of the sensitivity analysis can be presented in different digital suitability maps for the chosen crystalline occurrences.

Conclusions

A GIS-based sensitivity analysis was established in order to test influences of the different weighting of geo-scientific and socio-economic criteria with respect to the suitability of different crystalline occurrences in a site selection and rating procedure. The sensitivity analysis is exclusively based on geo-processed spatial data and their complemented descriptive data of the FIS GEA-application, allowing to define suitable criteria and their implementation in a Point-Count-System. The analysis has shown that the majority of the crystalline occurrences are characterised by a suitability class of middle degree, independent from the chosen weight.

Therefore, the FIS GEA-application provides an intelligent system to support national or local authorities in their analysis and assessment of criteria-relevant information for a future site selection and rating procedure, irrespective of the host rock.

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