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GIS-based analysis of rock salt deposits' suitability for underground hydrogen storage

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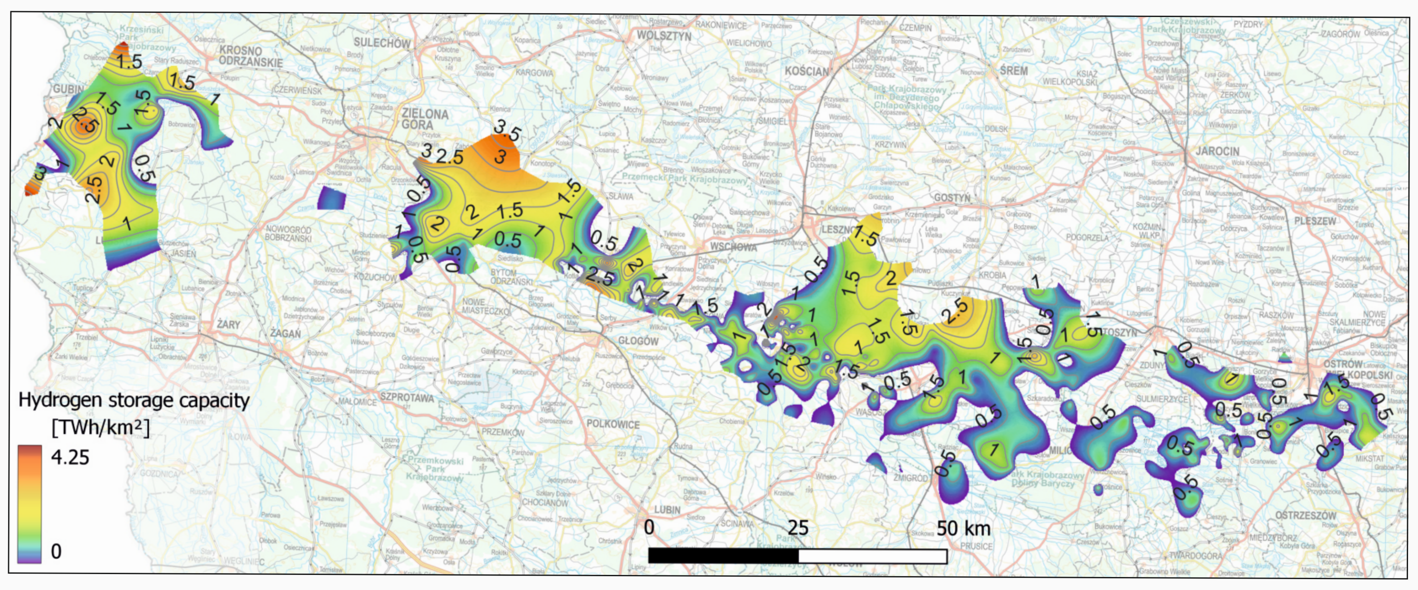
The research is an example of multi-criteria decision analysis (MCDA) coupled with spatial data analysis using GIS (Geographic Information System). The aim of this study was to develop a methodology for selecting the best locations for hydrogen storage in salt caverns. The area of interest was the Permian rock salt deposit in the Fore-Sudetic Monocline in southwest Poland. The methodology allowed the development of rock salt suitability maps for optimal locations for underground hydrogen storage (UHS) in the area of interest.

Methods

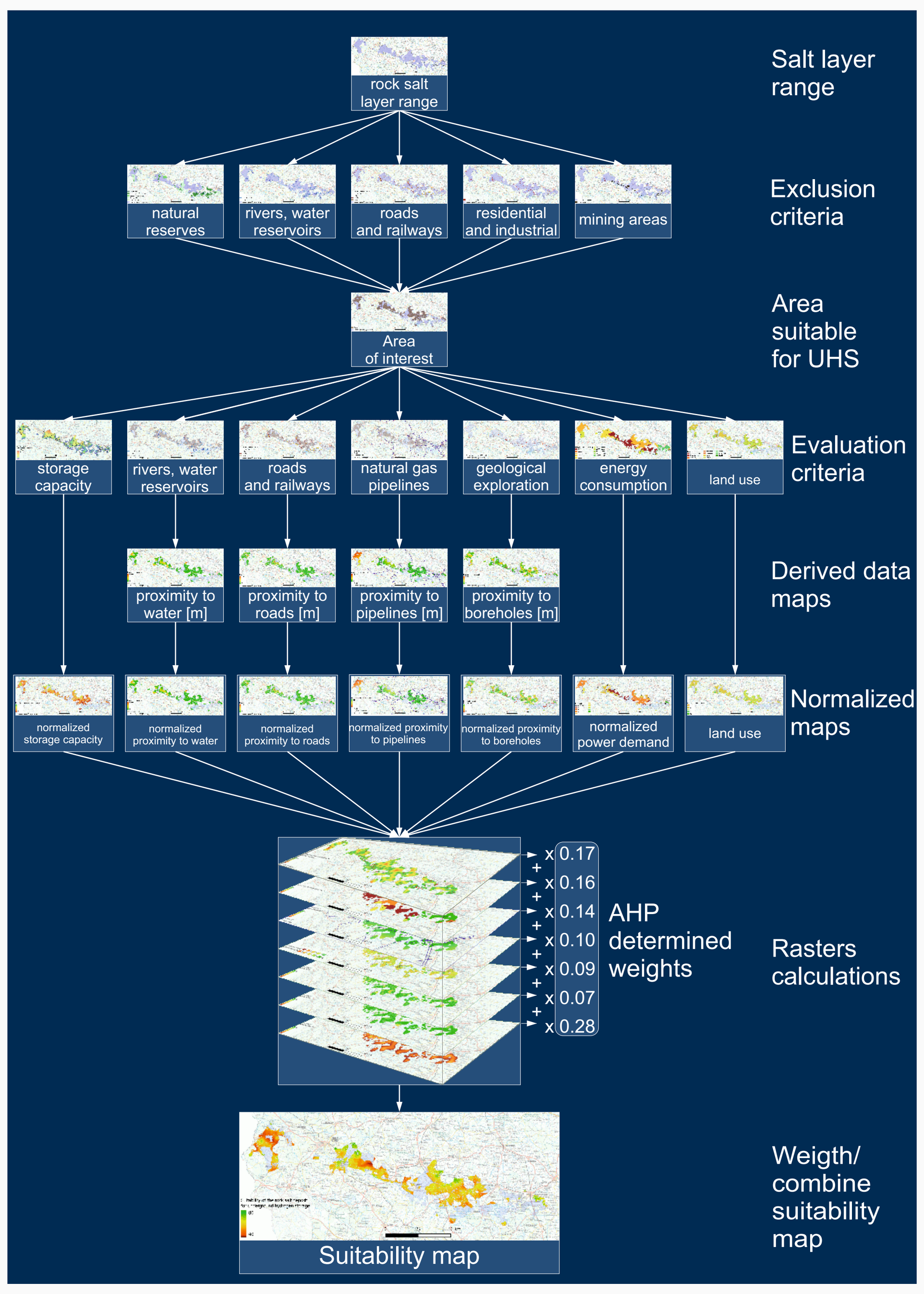
The first and primary criterion determining an area's suitability for analysis was the occurrence of the bedded rock salt deposit with a determined storage capacity. Storage capacity was determined as a result of research conducted by the authors in 2020. The analysis was based on an assumed minimum rock salt layer thickness of 150 m and a maximum depth of 1800 m below ground level. The methodology also considered storage pressure, temperature gradient, convergence, and the shape and layout of salt caverns.



Hydrogen storage capacity in the rock salt layer in the Fore-Sudetic Monocline

The methods used in this study included the following phases:

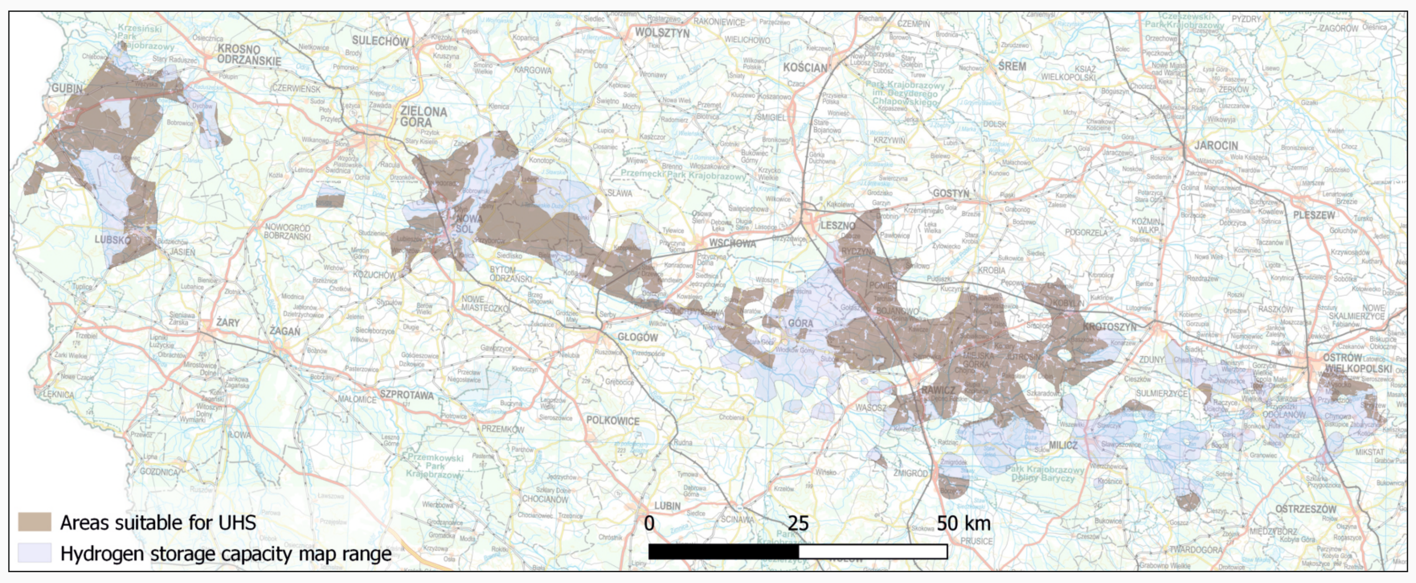
1. Definition of exclusion and evaluation criteria;
2. Development of basic raster maps showing the adopted criteria;
3. Transformation of basic raster maps into proximity maps;
4. Normalization of transformed rasters to a homogeneous scale;
5. Determination of the weights of individual criteria using the AHP method;
6. Development of the final UHS suitability map based on normalized maps and determined weights of individual criteria;
7. Analysis of optimal locations for UHS.



Workflow of the applied method

1. Definition of criteria. The analysis considered two main groups of criteria: those excluding selected areas of the analyzed rock salt deposit from further analysis and evaluation criteria for the classification of its remaining area.
Exclusion criteria: protected areas, residential and industrial areas, communication routes and ports, water reservoirs, and mining areas.
Evaluation criteria determining an area's suitability for analysis: storage capacity of the rock salt layer, land development, access to significant water resources, road infrastructure, proximity to existing gas pipelines, energy demand within the salt bed area, and geological structure exploration.

2. Development of basic raster maps showing evaluation criteria. Seven raster maps have been developed for each evaluation criterion. Maps were developed based on the publicly available geological metadata from the Central Geological Database of the Polish Geological Institute (https://geologia.pgi.gov.pl), Geoportal spatial data services (https://www.geoportal.gov.pl/uslugi), and the results of the authors' previous studies.



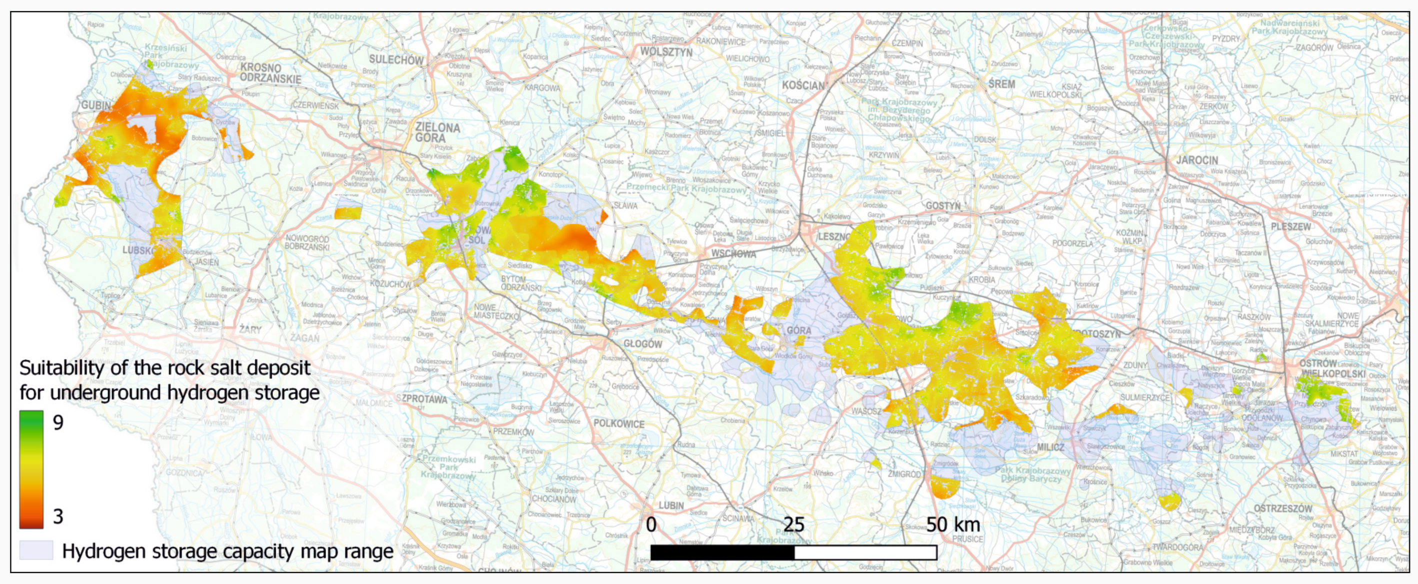
Areas suitable for underground hydrogen storage

3. Transformation of evaluation criteria maps into proximity maps. Some of the evaluation criteria raster maps were then transformed into raster proximity maps. Maps showing roads, gas pipelines, water, and borehole locations required transformation to quantify individual criteria. As a result of the transformation map of proximity to rivers, and water reservoirs, map of proximity to roads and railroads, map of proximity to gas pipelines, and map of proximity to boreholes were developed.

4. Normalization of transformed rasters to a homogeneous scale. Suitability analysis requires maps of individual criteria on the same scale of values. For this purpose, all seven maps of individual criteria were normalized using a scale ranging from 1 to 10. The lowest values indicate the least valuable areas and the highest represent areas most suitable for UHS facilities.

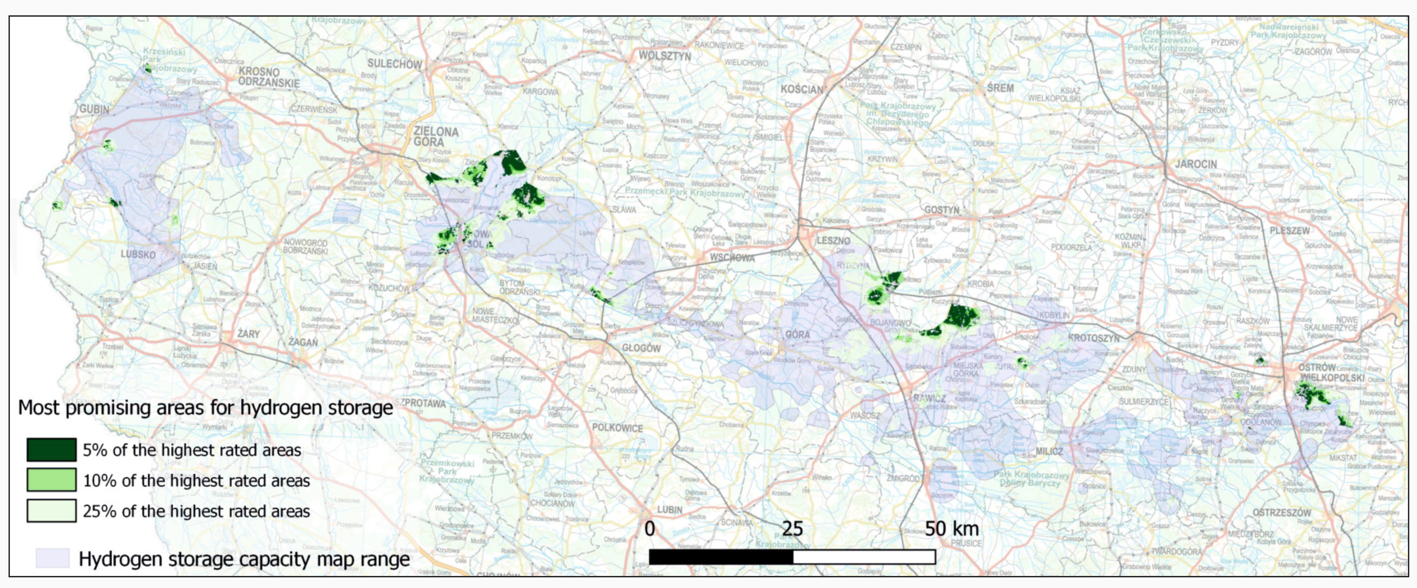
5. Determination of the weights of individual criteria. To obtain reliable weight values for individual criteria, questionnaires with matrices of criteria pairs were prepared for comparison by ten geology, drilling, energy, and economics experts. The comparison matrix included seven criteria for assessing a site's suitability for UHS in salt caverns. A numerical Saaty's scale was adapted to assess the relationship between the analyzed (pairwise criteria comparison).

6. Final UHS suitability map. The final suitability map for UHS facilities was developed using QGIS spatial data analysis software. The values for each pixel of all normalized raster maps were multiplied by the appropriate weight values and then added together using the QGIS built-in raster analysis functions. As a result, the final map of the rock salt deposit suitability for UHS was obtained.



Final map of the rock salt deposit suitability for underground hydrogen storage

7. Analysis of optimal locations for UHS. Based on a statistical analysis of pixels' values of the final suitability map for UHS, a new map of areas with the highest suitability for hydrogen storage (95, 90, and 75th percentile of analyzed areas) was developed. The analysis of raster values showed that over 50% of the analyzed rock salt deposit is suitable for UHS. Considering the adopted criteria relating to the distance between caverns, locating over 2500 caverns within just 1% of the analyzed rock salt deposit is possible. That confirms the vast potential for UHS in the area of interest, together with favorable geological conditions.



The most suitable areas for underground hydrogen storage, selected based on a statistical analysis of final raster values

Conclusions

The presented method is the first example of GIS-based MCDA for selecting optimal UHS sites in bedded rock salts. The suitability map for hydrogen storage in the rock salt layer facilitates the identification of promising areas for UHS. The results show that the applied method significantly influences the resulting map image, helping to identify optimal locations for hydrogen storage facilities. The proposed methods can be used in other countries to select underground energy storage sites.

References: Lankof, L., Tarkowski, R., 2020 – Assessment of the potential for underground hydrogen storage in bedded salt formation. International Journal of Hydrogen Energy 45.
Lankof, L., Tarkowski, R., 2023 – GIS-based analysis of rock salt deposits' suitability for underground hydrogen storage. International Journal of Hydrogen Energy (In Press).