XXXVIII IAH Congress

Groundwater Quality Sustainability
Krakow, 12–17 September 2010

Extended Abstracts

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

University of Silesia Press 2010

abstract id: **361**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Groundwater vulnerability maps of large areas — application of DRASTIC method in the National park "Djerdap"**

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keywords: groundwater vulnerability, small scale map, DRASTIC method

Groundwater vulnerability methods became a standard tool for creating a base for sustainable groundwater management. In the past decade a number of new methods were created for more precise determination of groundwater vulnerability. However, a large number of input parameters are needed for more precise evaluation of groundwater protection and vulnerability and as a consequence the whole procedure became very complex. This is especially evident when groundwater vulnerability maps of large areas are created. That is why new methods are difficult to apply when **small scale** groundwater vulnerability maps are made.

This paper describes the creation of groundwater vulnerability map of the **National park Djerdap**. The National park is situated in the southeast of Europe, in the northeast of Serbia, along the border with Romania. The most famous natural phenomenon is the beautiful Djerdap canyon, through which the Danube River flows. The National park covers the area of **650 km²**, and the protection zone of the park covers the area of nearly **940 km²**.

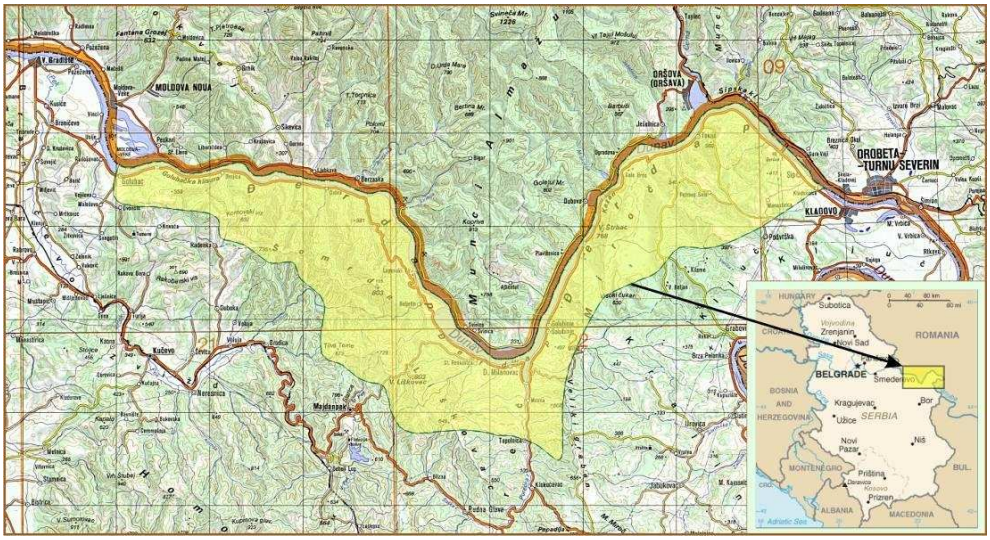

Figure 1. Geographic location of the National Park Djerdap.

This large region is characterized with very complex geological structure. Most extensive are sedimentary rocks, although igneous and metamorphic rocks are easily found. The oldest rocks are of Precambrian age, while the youngest are of Quaternary age. There are more than 80 stratigraphic units found on the territory of the National Park. This resulted in existence of different types of aquifers (Figure 2). Although a large area of the National Park is characterized with insignificant aquifers, there are large areas with karst and fissured aquifers, especially in the eastern part of the Park (Miroc Mountain).

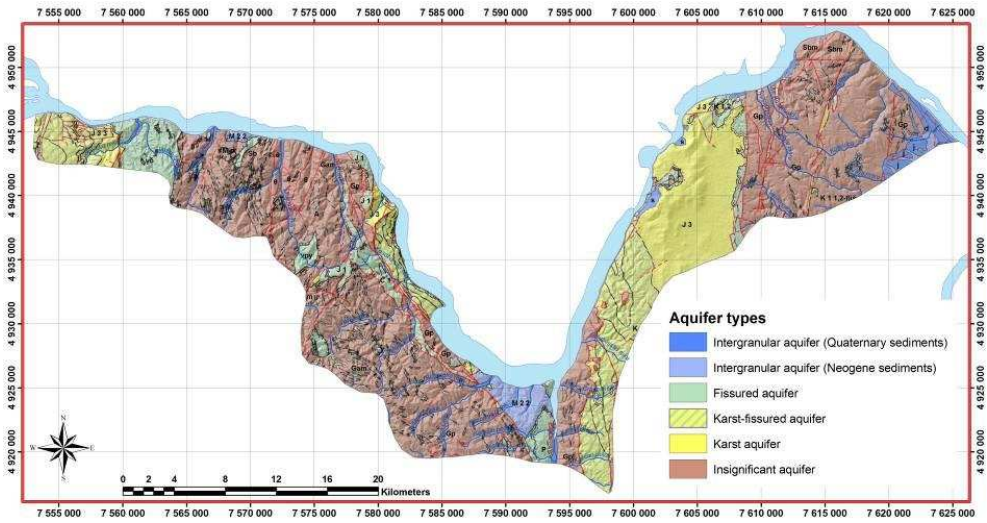

Figure 2. Hydrogeological map of the National Park Djerdap.

DRASTIC method is developed by US EPA and is intended to be a standardized system for evaluating groundwater vulnerability to pollution (Aller, 1985). This method uses seven parameters in order to evaluate the groundwater vulnerability: **D** (Depth to the Water Table), **R** (Net Recharge), A (Aquifer Media), S (Soil Media), T (Topography), I (Impacts of the Vadose Zone) and **C** (Hydraulic Conductivity of the Aquifer).

There are several reasons why DRASTIC method is being chosen:

- Very large area of investigation characterised with different types of aquifers
- Small scale of investigation (1:200 000), which limits the use of some new methods like PI (Goldscheider, 2000), COP (Vias et al., 2006) etc.
- Insufficient geological and hydrogeological data, particularly in the vertical profile.

While using DRASTIC methodology, most difficult was to define the first two parameters, factor D and factor R. Parameters A, I and C were easily defined based on geological and hydrogeological settings in the area. Parameter S was determined using the pedological maps of the National Park, while the map of factor T was easily obtained using the DEM model. In the further text close attention is given to describing how factors D and R are determined.

Factor D. Main parameters which affect the depth of groundwater levels are: hydrogeological characteristic of the terrain on the one hand and distance of the water features on the other. First, the map showing the nearness to the springs, streams and rivers was made (Figure 3).

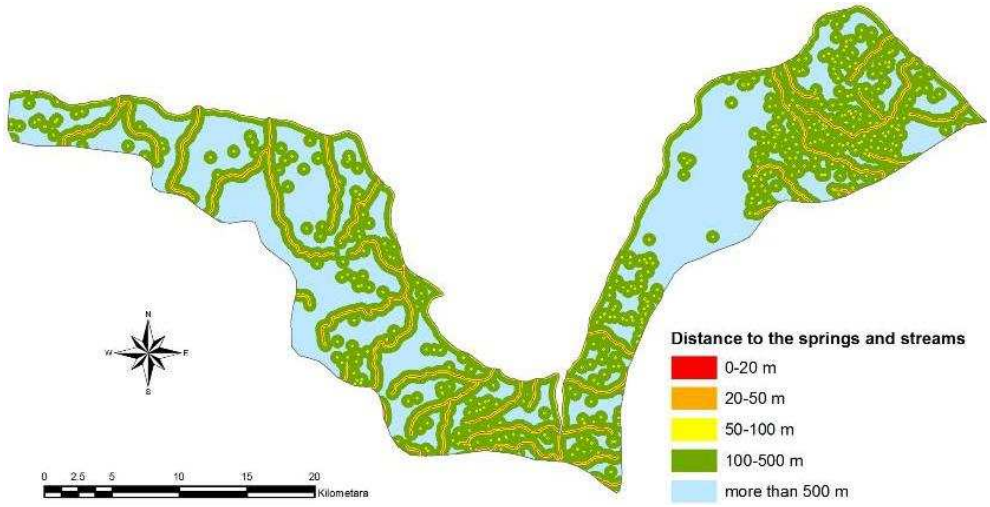

Figure 3. Map showing the nearness to the springs, streams and rivers.

This map is combined with hydrogeologic map of the National Park Djerdap where the depth to the groundwater level is being defined using Table 1.

Table 1. Determination of R factor.

Aquifer type	Distance to the spring or stream (m)	Groundwater depth (m)	R factor
Intergranular aquifer	0–20	0.0–1.5	10
	> 20	1.5–4.5	9
Karst aquifer	0–20	0.0–1.5	10
	20–100	9.0–15.0	5
	100–500	15.0–22.0	3
	> 500	> 30	1
Fissured aquifer and insignificant aquifer	0–20	0.0–1.5	10
	20–50	1.5–4.5	9
	> 50	4.5–9.0	7

Using these values and using the range and rating for factor D according to DRASTIC methodology, map shown in Figure 4 is crated.

Factor R. There are no earlier investigations about infiltration degree at the territory of National park Djerdap. That is why factor R is defined using special methodology where parameters influencing the recharge are being analysed (Piscopo, 2001):

1. Slope analysis and DEM model were used to create the slope map were 4 categories are isolated
2. Precipitation. Data from 21 rainfall stations on the territory of the National park were used Kriging interpolation was used to create the map of spatial distribution of precipitation and classes were isolated based on the degree of the rainfall.
3. Soil permeability map was created using pedological maps of the research area.

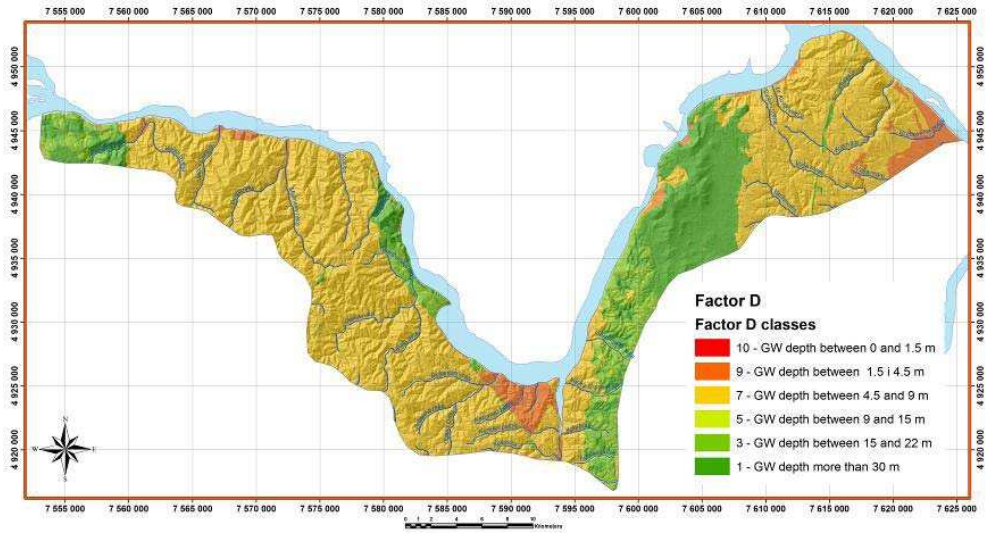

Figure 4. Factor D map.

Scheme presented in figure 5 was used to calculate the R factor and to produce R map shown i figure 6.

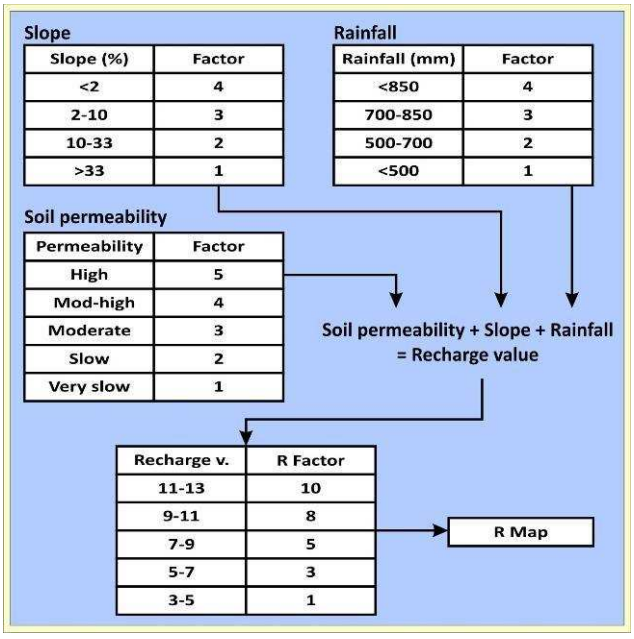

Figure 5. Determination of R factor (Piscopo, G., 2001).

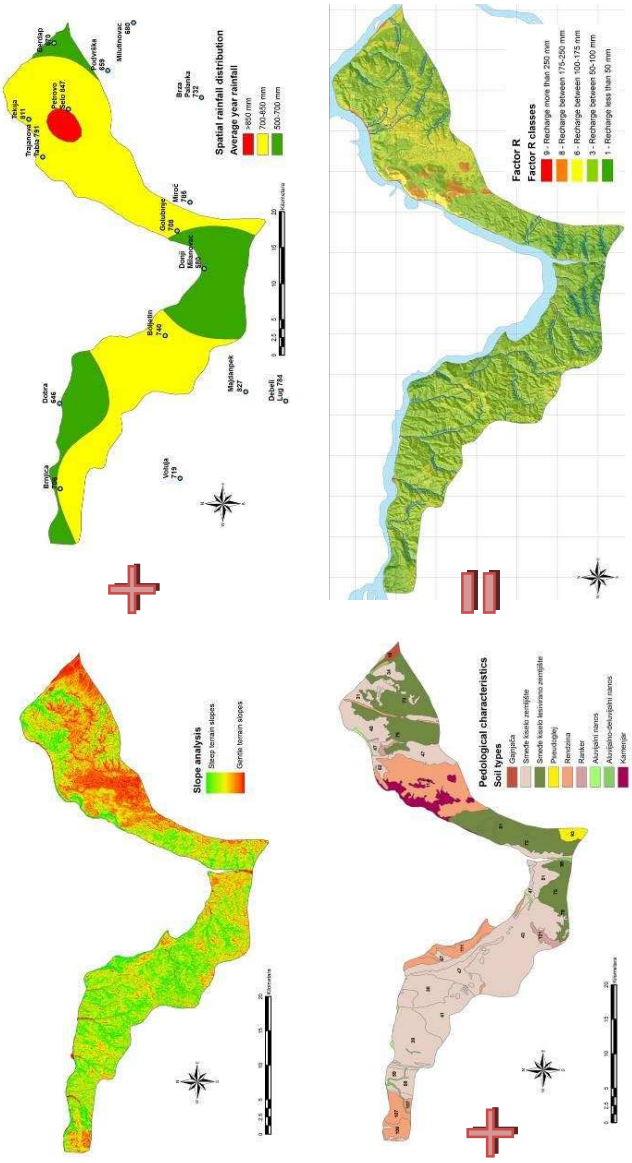

Figure 6. Map of R factor.

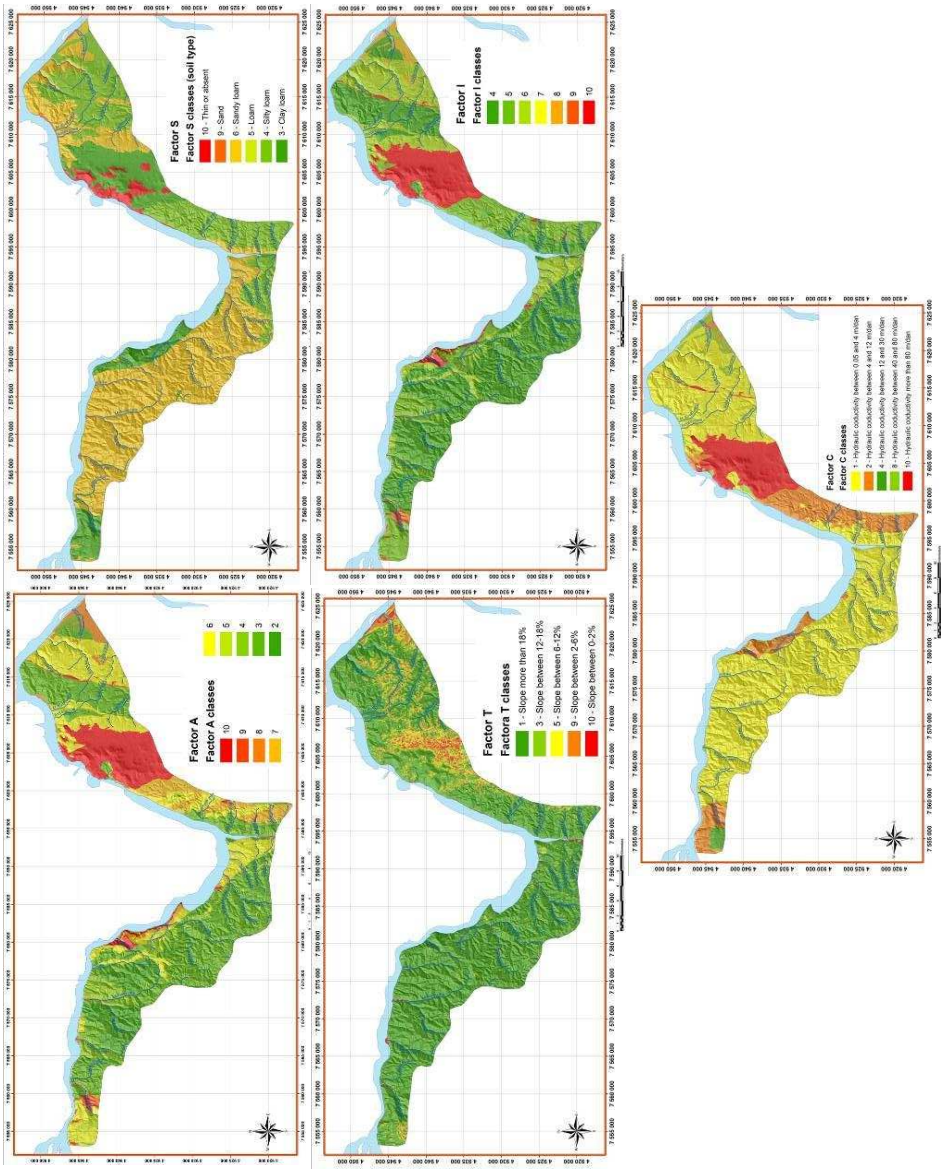

Figure 7. Maps showing spatial distribution of A, S, T, I and C factors.

Determination of the other factors which were necessary to produce the groundwater vulnerability map was much easier. A, I and C factors are determined in descriptive way using the data about geological and hydrogeological settings of research area and rating proposed by the authors of DRASTIC method. Evaluation of pedological properties was done in order to produce the S map, while slope analysis was used to create the T factor map. Final maps of these factors are showed in Figure 7.

Final Groundwater vulnerability map

Aquifer vulnerability or DRASTIC index is calculated by using this formula (Aller, 1985):

$$Drastic\ index = D_r \cdot D_w + R_r \cdot R_w + A_r \cdot A_w + S_r \cdot S_w + T_r \cdot T_w + I_r \cdot T_w + C_r \cdot C_w$$

where: r — ratings, w — weight (D_w=5, R_w=4, A_w=3, S_w=2, T_w=1, I_w=5, C_w=3).

Calculated DRASTIC index was used to classify the territory of the National Park Djerdap into areas with different vulnerability degree. Classes are determined by using table 2.

Table 2. DRASTIC index and vulnerability classes (Aller, L., 1985).

DRASTIC index	Vulnerability degree
Less than 75	Very low
between 75 and 100	Low
between 100 and 125	low-moderate
between 125 and 150	moderate-high
between 150 and 175	High
more than 175	very high

Final groundwater vulnerability map using DRASTIC method is shown in figure 8.

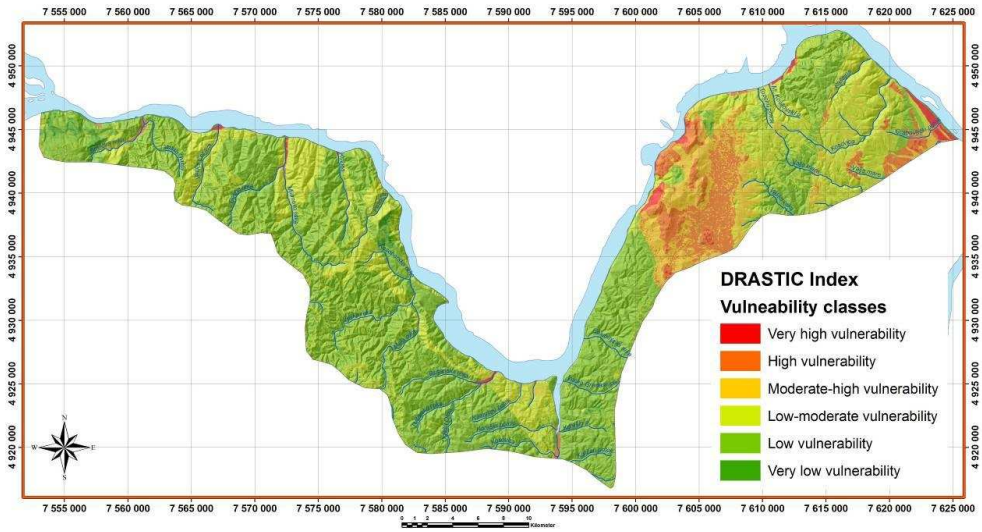

Figure 8. Groundwater vulnerability map of the National Park Djerdap.

Vulnerability map has showed that the biggest part of the National Park area is characterized with low or very low vulnerability. This was expected because the biggest part of the research area is made of rocks where water flows through small fissures and where groundwater level is not near the surface. In these areas soil is well developed as a result of weathering and infiltration is limited due to steep slopes of the terrain. High and very high vulnerability is characteristic for areas in the eastern part of the National Park Djerdap, especially for karst terrains of Miroc Mountain and Quaternary sediments near Kladovo city. These areas are characterized with very good infiltration conditions, high permeability soils, good aquifer conductivity and with very gentle terrain slopes in general.

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International Association of Hydrogeologists

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2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0