"EUROPEAN APPROACH" IN ASSESSING GROUNDWATER VULNERABILITY OF THE MURÁNSKA PLANINA PLATEAU, SLOVAKIA

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Abstract: Muránska Planina Plateau is a Middle Triassic karst structure in Central Slovakia. An attempt to implement "European approached", as defined by COST Action 620, was made to produce a groundwater vulnerability map in the scale of 1 : 50 000. Combined "core factors" O (for Overlying layers) and C (for Concentration of flow) were assessed to achieve for the relative protection factors of groundwater from contamination while taking into account any bypass of the overlying layers, typical for karstic rock environment. Evaluation of the results showed unequal uncertainty connected to different data sources. In the case of Muránska Planina Plateau the main part in the final vulnerability factor is played by the vadose zone thickness, but only very limited data on the groundwater table levels are usually available in mountainous karst. Several other remarks on the method use and its limitations are discussed within the paper.

Introduction

Vulnerability maps have become more and more an essential part of groundwater protection schemes and a valuable tool in environmental management. However applying different existing vulnerability methods in any one study–site, usually gives quite different results (Daly et al. 2001). European COST Action 620 which began in 1997 as a scientific programme sponsored by the European Commission, proposes an objective methodology for – 'intrinsic' and 'specific' vulnerability assessment and mapping in karstic environments, taking into account potential risks. Another important goal of this Action is to achieve some European level of consistency in the establishment of vulnerability and risk mapping, taking into account specific regional environmental variations as well as the different stages of economic development and scientific investigation of karst. Even if the method is karst–centred, it ought to have the potential to consider all aquifer types in a unified methodology.

Methodology, proposed by COST Action 620 is designed to be clearly more physically based than the existing vulnerability mapping techniques. It takes the specificity of the karstic environments into account without necessarily excluding the applicability to other geological conditions. Combined "core factors" O (for Overlying layers) and C (for Concentration of flow) account for the relative protection of groundwater from contamination while taking into account any bypass of the overlying layers. A precipitation factor P is distinguished for describing characteristics of the input of water to the system. Differentiation is made between groundwater resource intrinsic vulnerability mapping and source intrinsic vulnerability mapping. For the latter, a K factor describing the karst network development is relevant (Daly et al. 2001). An attempt to implement such an approach in practice, as a part of European COST Action 620 scientific project, was made to produce groundwater vulnerability map of the Muránska Planina Plateau, following proposed "EU approach".

General site characteristics

Muránska Planina Plateau is a karst structure in Central Slovakia with 126 km^2 of aerial extent (Fig. 1), built mainly by Middle Triassic limestones and marginally by Middle Triassic dolomites. It is a morphologically shifted carbonate plate with edge slopes elevated 300 to 500 m above the neighbouring areas. No deeper boreholes exist within the region; only several drillings were made in the vicinity of springs to make their captions more effective. Water from majority of the exploited springs is directly taken into pipeline. Numerous sinkholes, dry valleys and also several semipoljes cover relatively flat top surface of the Muránska Planina Plateau, present are also several swallow holes. Some parts of the karst conduit network were identified either by tracing experiments or by means of spring's discharge curve analyses. Explored caves are only 10 – 100 m long, surface karst features prevail. The Slovak Hydrometeorological Institute realized extensive gauging of precipitation, surface stream discharge and spring discharge in the past. All water inputs and outputs were monitored by very complex network of 28 spring gaugings, 34 surface stream gaugings and 5 rain gauging stations, during the complete hydrological decade of 1971–1980 (Kullman 1990). Major part of this monitoring network is still in function. Main springs are discharging on the Plateau edges, on the contact with granites, formed by an important fault. There are approximately 16 springs with mean discharge > 10 l/s. The major spring outlet "Pod hradom" reaches 6 130 l/s during snow melt period, but falls down to 4 l/s in summer periods. The mean discharge is 245 l/s. Major springs with mean discharge over 100 l/s are also "Tisovec–dolny" (101 l/s), "Muran – v obci" (116 l/s) and "Pastevnik" (193 l/s). Considering the discharge curves, karstification process is unequally spread through the structure. Major springs are exploited as drinking water sources for the whole region beneath. Reliable data on water consumption is available for 3 year's period. Water quality monitoring was concentrated on several important springs with very high frequency of observations to reveal water–mixing relations. Series of basic qualitative data are available from all exploited springs. Aerial stereophotographs in 1:25 000 scale were used for geomorphologic analyses. Several qualitatively interpreted tracing experiments were carried out by local speleological groups on limited number of swallow holes located on the Plateau top. In the framework of the EU PHARE project EC/90/WAT/11b, co–ordinated by the Slovak Ministry of Environment in the period of 1995–1997, a regional groundwater flow model was set and calibrated for the whole karstic structure (Fendek in Witkowski et al. 1997).

Groundwater vulnerability map using OC method was based on the evaluation of karstification from field investigation and using speleological and remote sensed data. Soil thickness and soil properties were obtained from 255 hand–dug holes (2 holes per 1 km^2). Mean estimated soil thickness was 40,0 cm, with standard deviation of 21,2 cm. GIS and digital terrain model were used to re–classify soil properties to cover the area. For unsaturated zone thickness determination, groundwater levels from the regional groundwater flow model were used. Land–use data were derived from digital topography maps in 1:50 000 scale, slope characteristics from a precise (10 m resolution) digital elevation model.

Overlying Layers

Following the "OC" method concept (Daly, Drew, Goldscheider, Hötzl 2000), based on the PI method principles (Goldsheider et al. 2000), four layers were taken into consideration during the construction of the "Overlaying Layers" – O map: **topsoil**, **subsoil**, **non–karstic bedrock** and **unsaturated karstic bedrock**. Protective functions of the topsoil and subsoil were calculated using data obtained from field soil sampling (Fig. 2). As a base for protective function evaluation for the latter two layers the simplified geological map was used (Fig. 3.). Thus every lithological type of rock has been assigned corresponding permeability and porosity values, as seen in Tab. 1.

Rock Type	**Permeability** [points/m]	**Porosity** [modifier]
Limestones, karstified	5	0.5
Limestones, not karstified	30	0.5
Dolomites	60	1.0
Granites, Jurassic limestones	30	0.2
Lower Triassic shales	60	0.1

Table 1 Key parameter and modifier values for bedrock

By subtracting of modeled altitudes of groundwater table (Fendek in Witkowski et al. 1997) from surface elevations (Fig. 4.), the thickness of the unsaturated zone was obtained. Protective function values of the bedrock were summed with those of topsoil and subsoil and resulting values were interpolated over the whole pilot area, resulting in the "O" – factor map (Fig. 5.). Flow chart of creating the "O" – factor map is depicted on Fig. 15.

Flow Concentration

First step in preparing the "Flow Concentration" – "**C"** map was to determine the dominant flow process dependent on soil properties. To achieve this, two partial maps were prepared, depicting soil and bedrock permeability. For soil permeability, already calculated (O – map) protective function values of topsoil and subsoil were used. Depending on planar curvature and slope of the land surface, the whole area was divided into 9 geomorphological categories, and every such category was assigned by mean value of the soil protective function of all sampling points in the subarea (Fig. 6). Those 9 categories were then reduced into two classes: low and high permeable soils (Fig. 7). For bedrock permeability map less complicated approach was used. Carbonate rocks were assumed to be high permeable and the rest low permeable (Fig. 8).

Combining those two maps three types of flow were identified:

- high permeable soil, no low permeable layers.................................... Type A
- high permeable soil on low permeable layer .... Type B
- low permeable soil or shallow soil on low permeable layer............... Type C

Using this data, plus land cover (Fig. 9) and slope (Fig. 10) maps the **C' – factor** values were calculated. Later, the C' – factor map was combined with the map of swallow–holes and sinking streams buffers (Fig. 11) and "**C" – factor** map was generated in this way (Fig. 12). Flow chart of creating the "O" – factor map is depicted on Fig. 16.

Final groundwater vulnerability map

The final vulnerability map was created by overlaying the O map with the C map and multiplying the values (Fig. 17). The resulting values ranging from 0 to 850 were divided into 5 classes of vulnerability (Figs. 13 and 14).

Discussion

Processing of the groundwater vulnerability map of the Muránska Planina Plateau in the scale of 1 : 50 000, following the European COST Action 620 recommendations (Daly et al. 2001) brought into light several problems. So called "OC" vulnerability map – as each type of environmental map – should be addressed to a certain map scale. It is not possible to apply the same approach to all types of maps (state, regional, local). Buffer extension (10 or 100 m) is connected to certain map scale as well. In the case of active swallow holes, there should be buffer only in the part of the watershed, not in the area around. Uncertainty connected to different data sources is unequal – e.g. in the case of Muránska Planina Plateau the main role is played by the vadose zone thickness – and no borehole date were available at the moment. Groundwater table level was produced by mathematical modelling process – but – does groundwater table exist in all karst environment? And at last, but not least: using the "OC" approach, one parameter (soil & rock permeability) is taken into account twice, in both O and C factors, but in opposite way – and giving contradictory results. Hydraulic function of epikarst zone is not considered too specifically as well – its function in C factor is not well recognized and thus defined, contradictory to the today's knowledge of its meaning. On the other hand, using the more standardized tool, hydrogeologists can find more effective way of communication towards the public relations. The development of the "EU" or "OC" approach is not closed at the moment and the authors hope to bring some helpful information to its "purification process".

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Fig. 1. Overview of the Muranska Planina Plateau pilot area location within the territory of Slovak Republic.

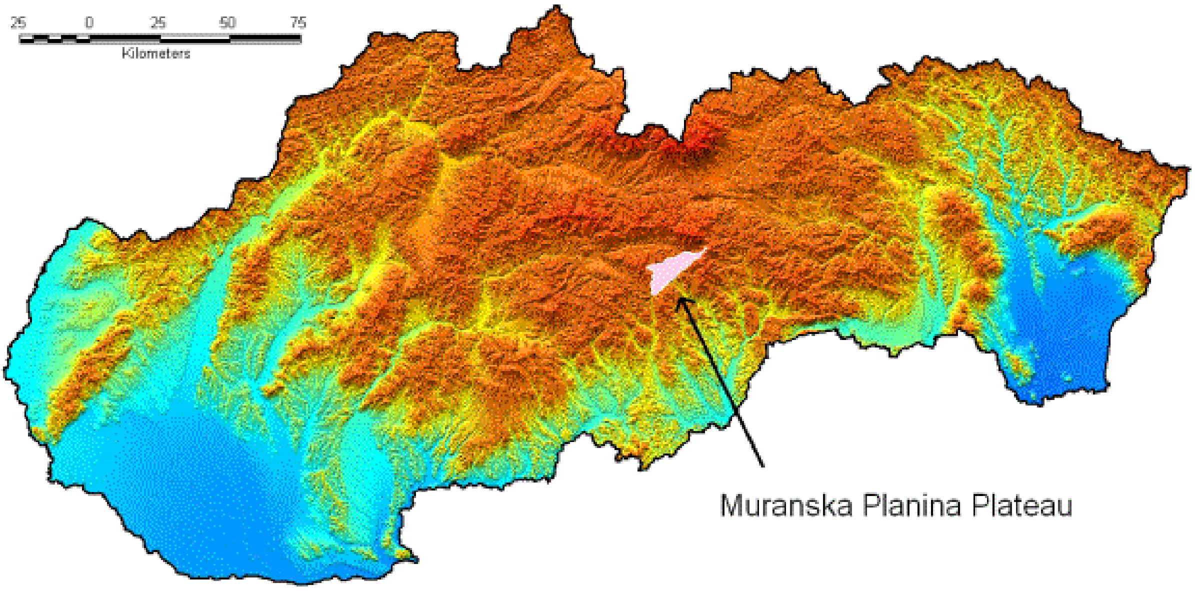


Fig. 2. Soil sampling locations (detail).

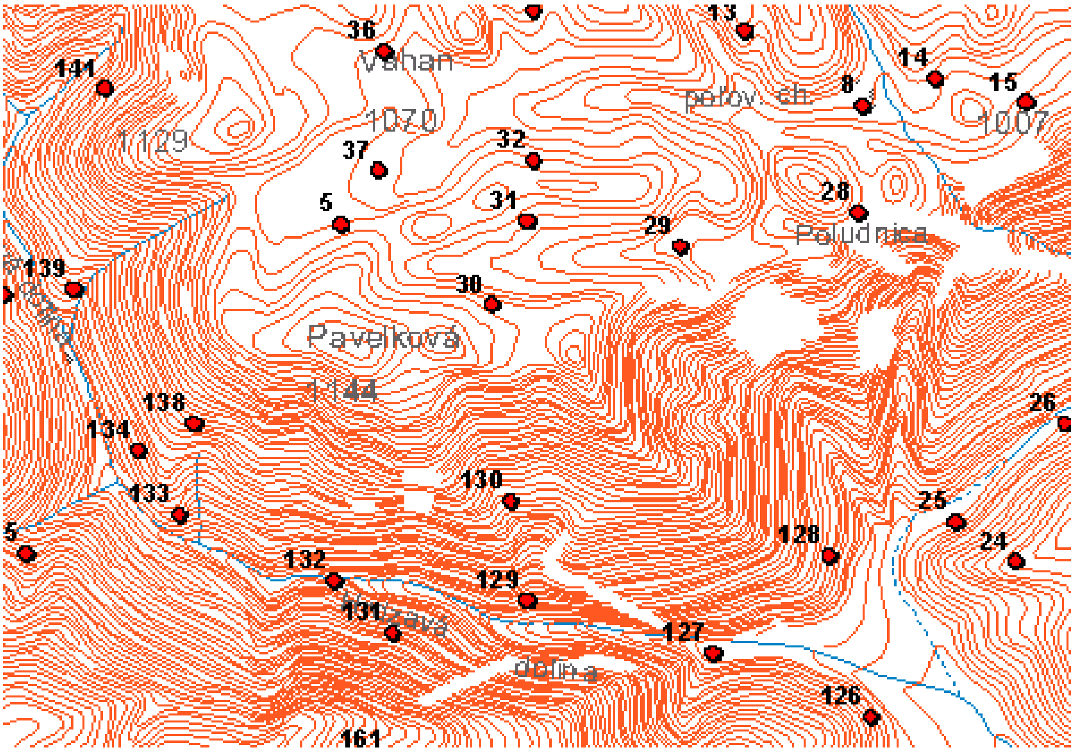
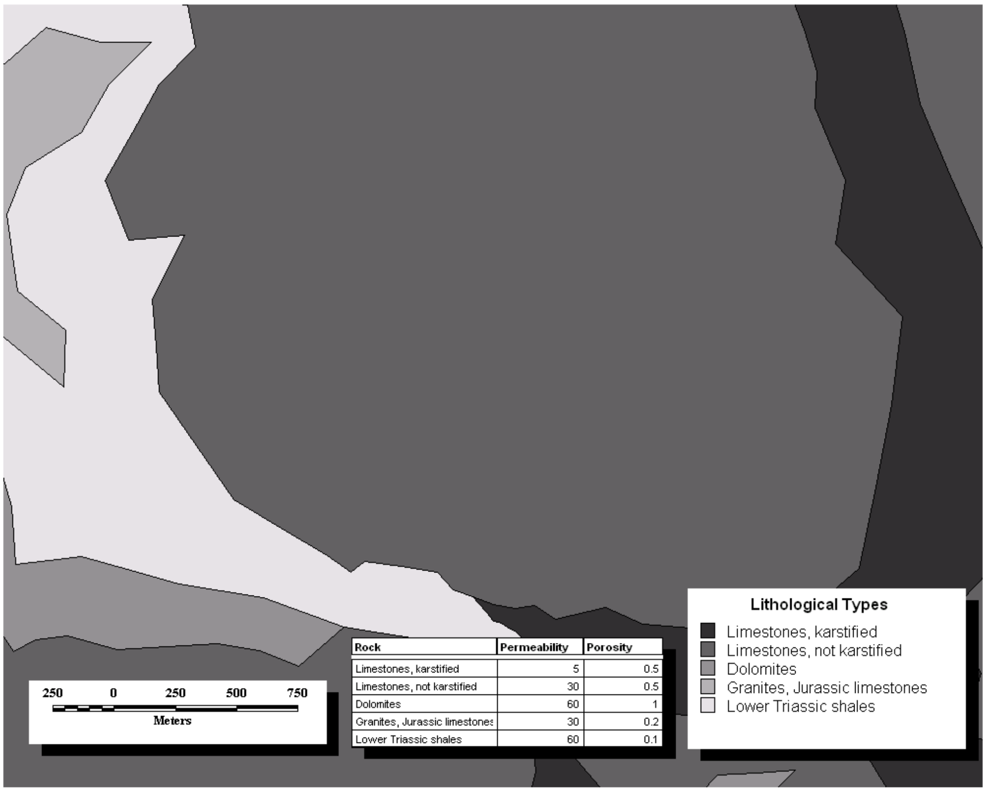


Fig. 3. Geological map (detail).



Rock	Permeability	Porosity
Limestones, karstified	5	0.5
Limestones, not karstified	30	0.5
Dolomites	60	1
Granites, Jurassic limestones	30	0.2
Lower Triassic shales	60	0.1

Fig. 4. Surface elevation and groundwater heads (detail).

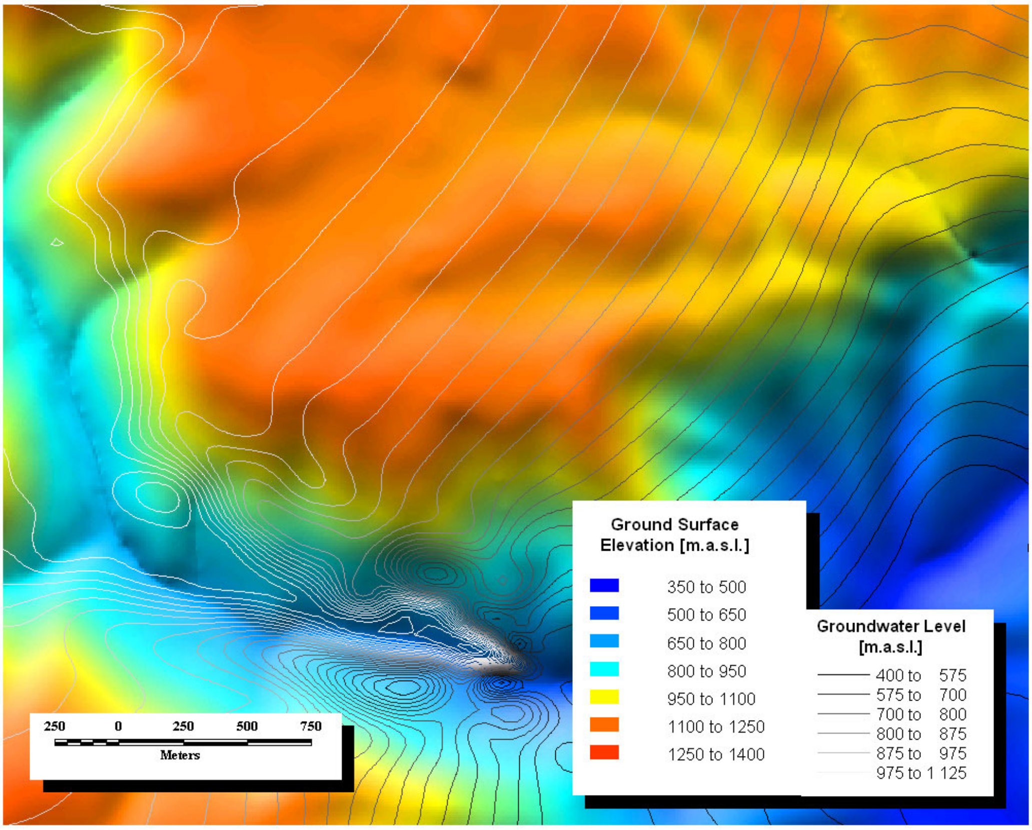


Fig. 5. "O" – factor map (detail).

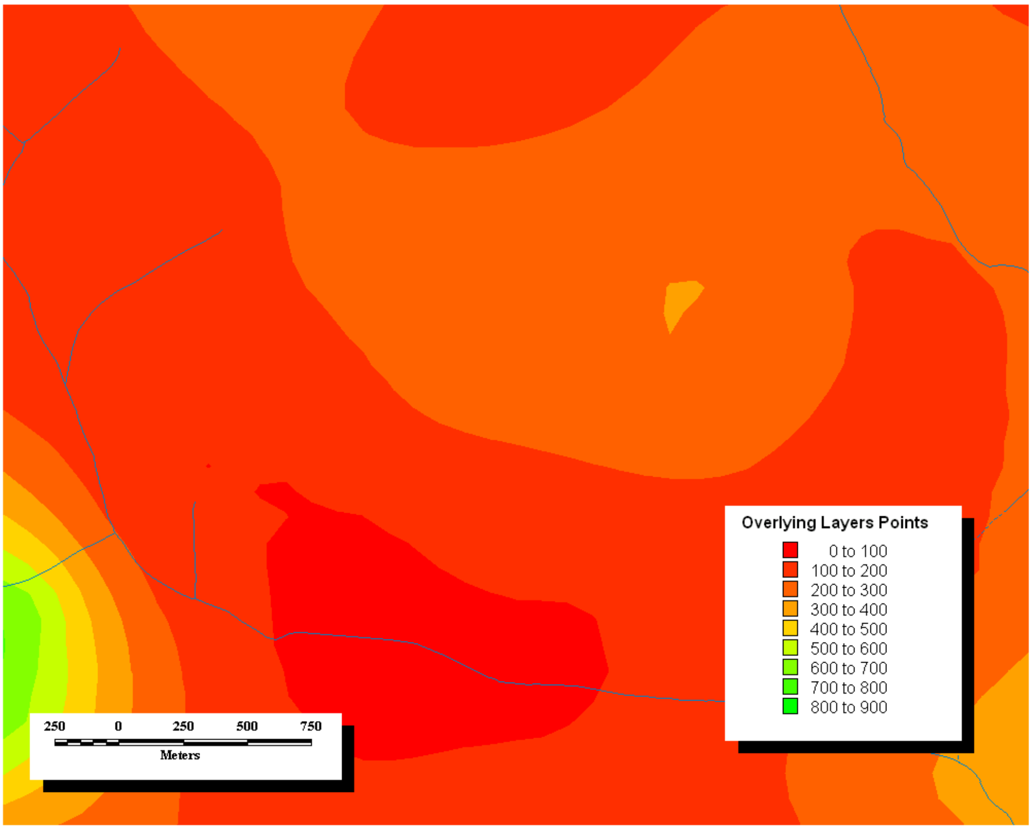


Fig. 6. Geomorphological subareas (detail).

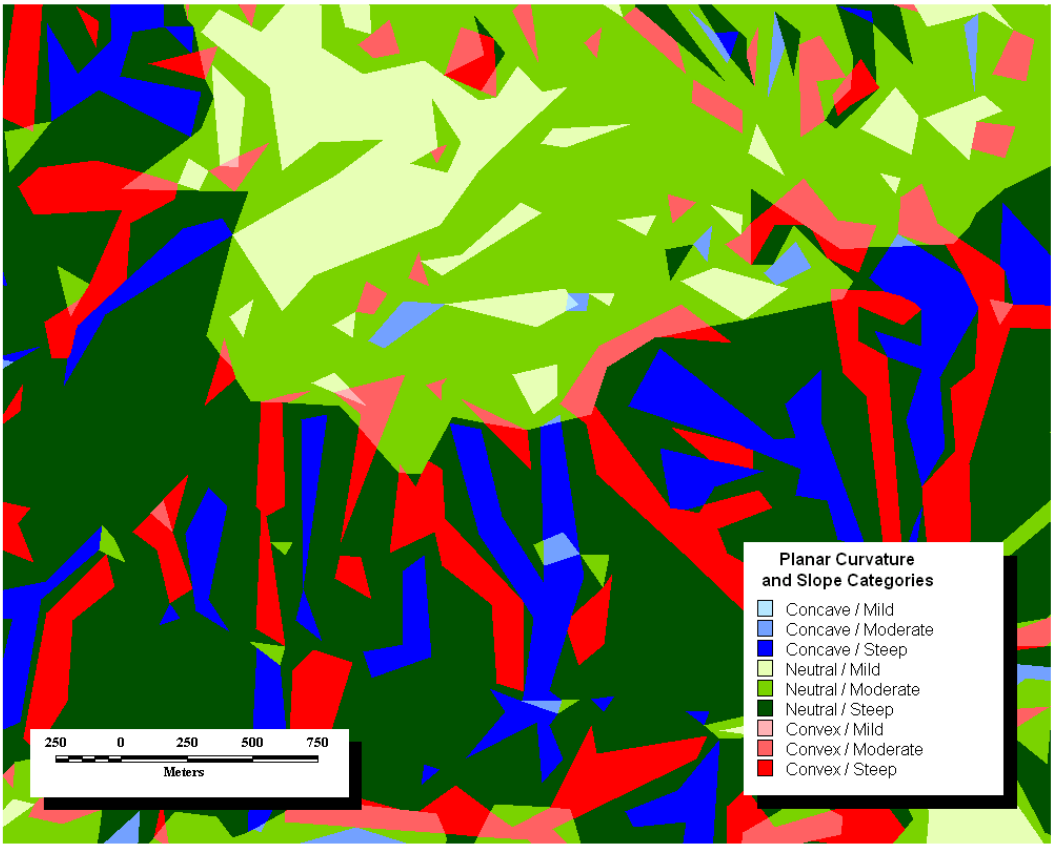


Fig. 7. Soils permeability map (detail).

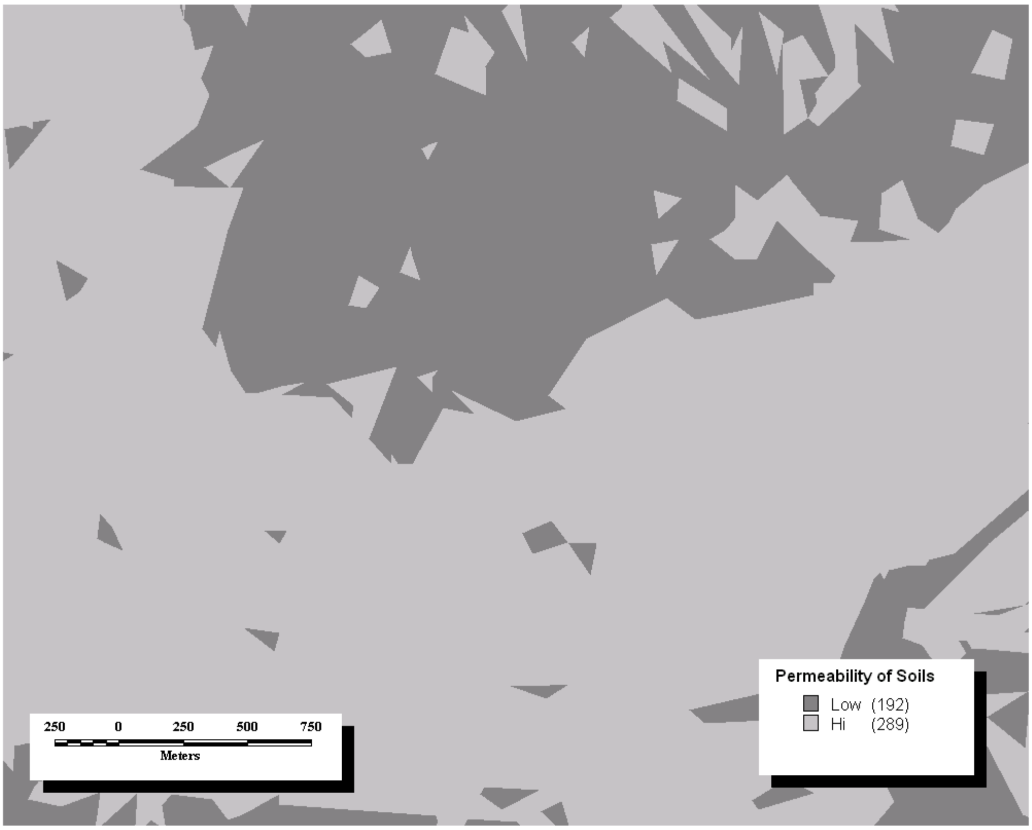


Fig. 8. Bedrock permeability map (detail).

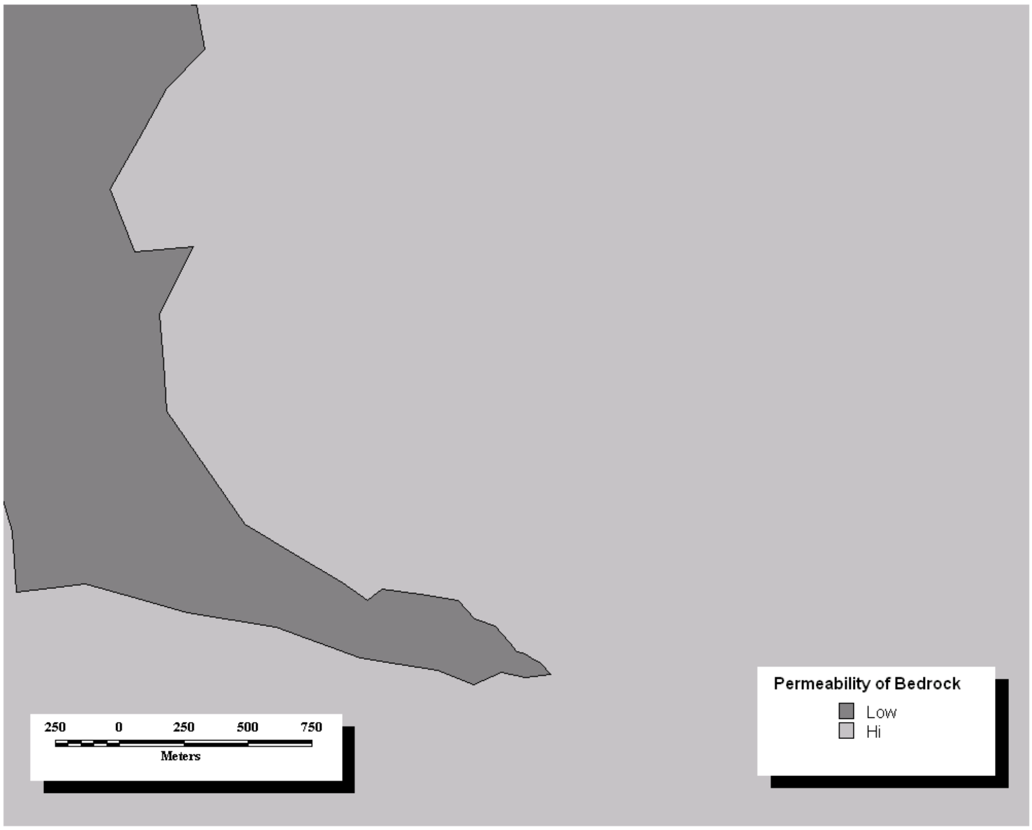


Fig. 9. Land cover map (detail).

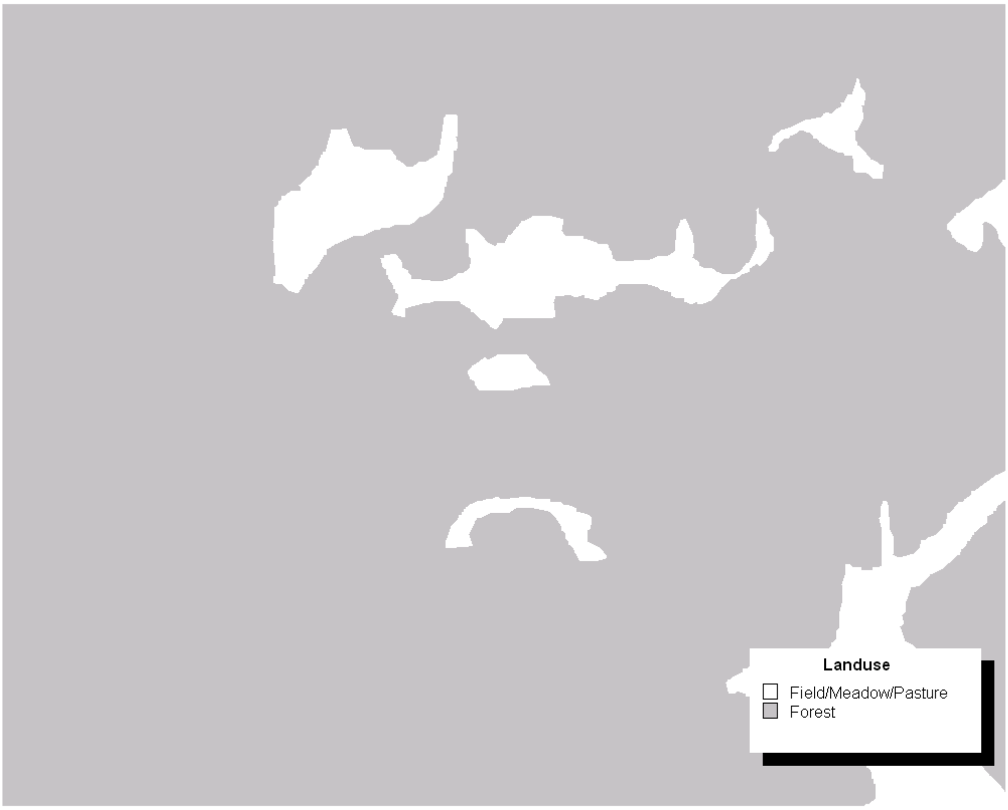


Fig. 10. Slope map (detail).

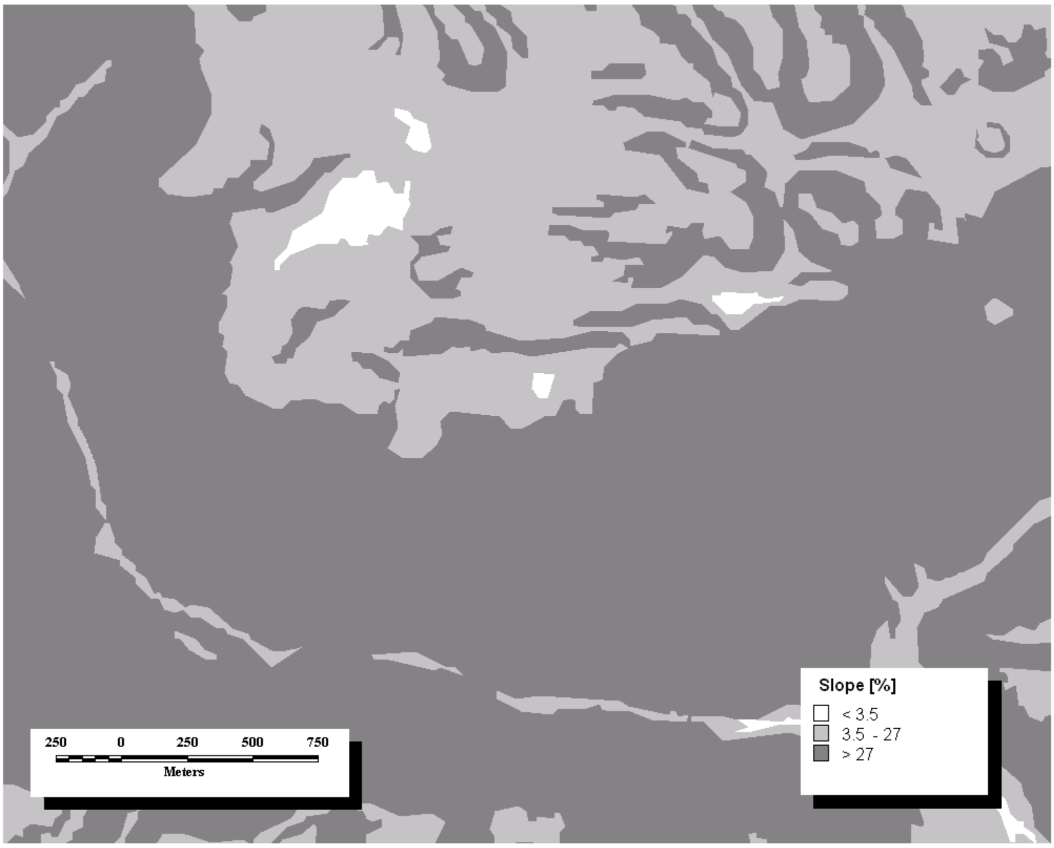


Fig. 11. Swallow holes and sinking streams buffers map (detail).

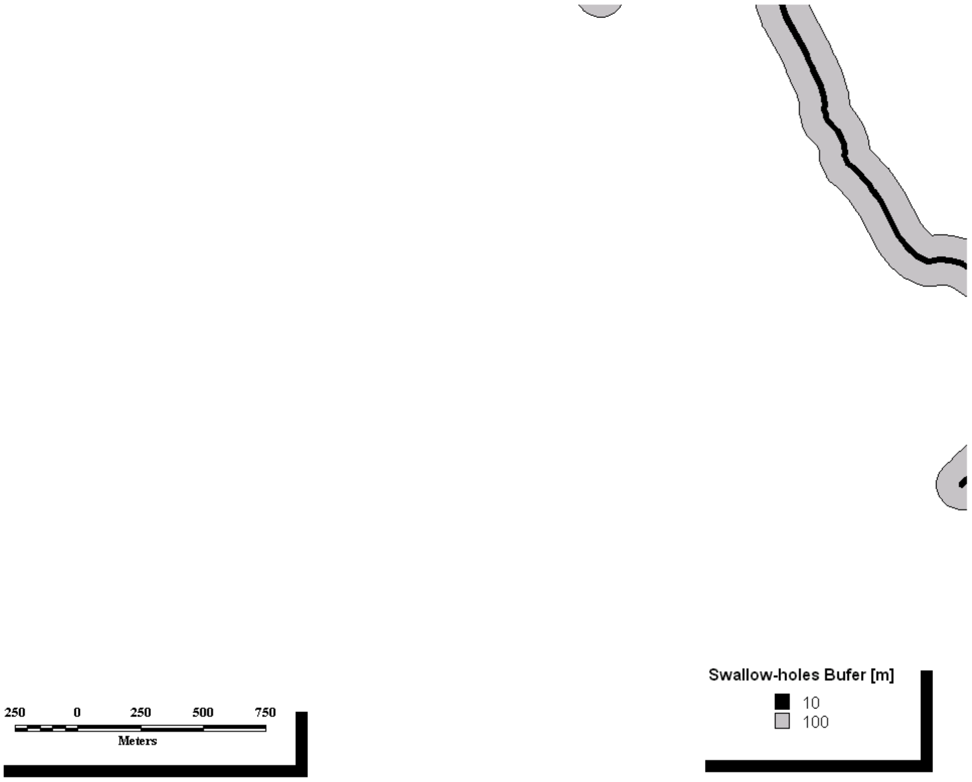


Fig. 12. “C” – factor map (detail).

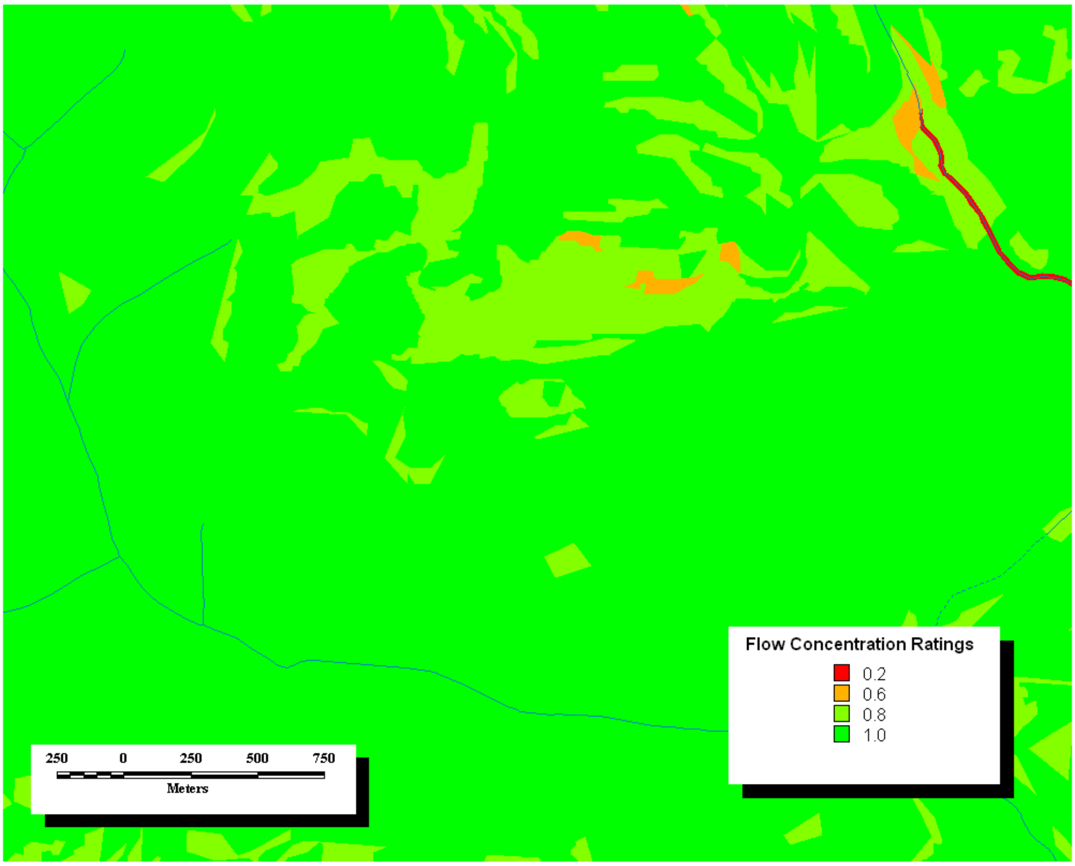


Fig. 13. "OC" – EU method groundwater vulnerability map (detail).

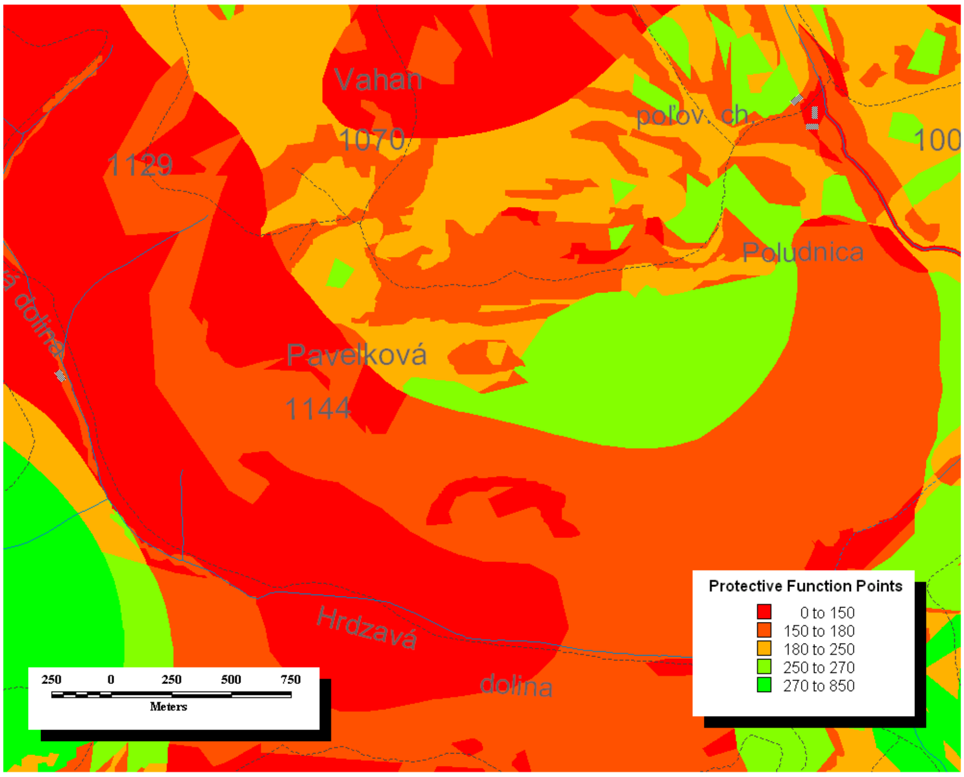


Fig. 14. "OC" – EU method groundwater vulnerability map of the Muranska Planina Plateau pilot area.

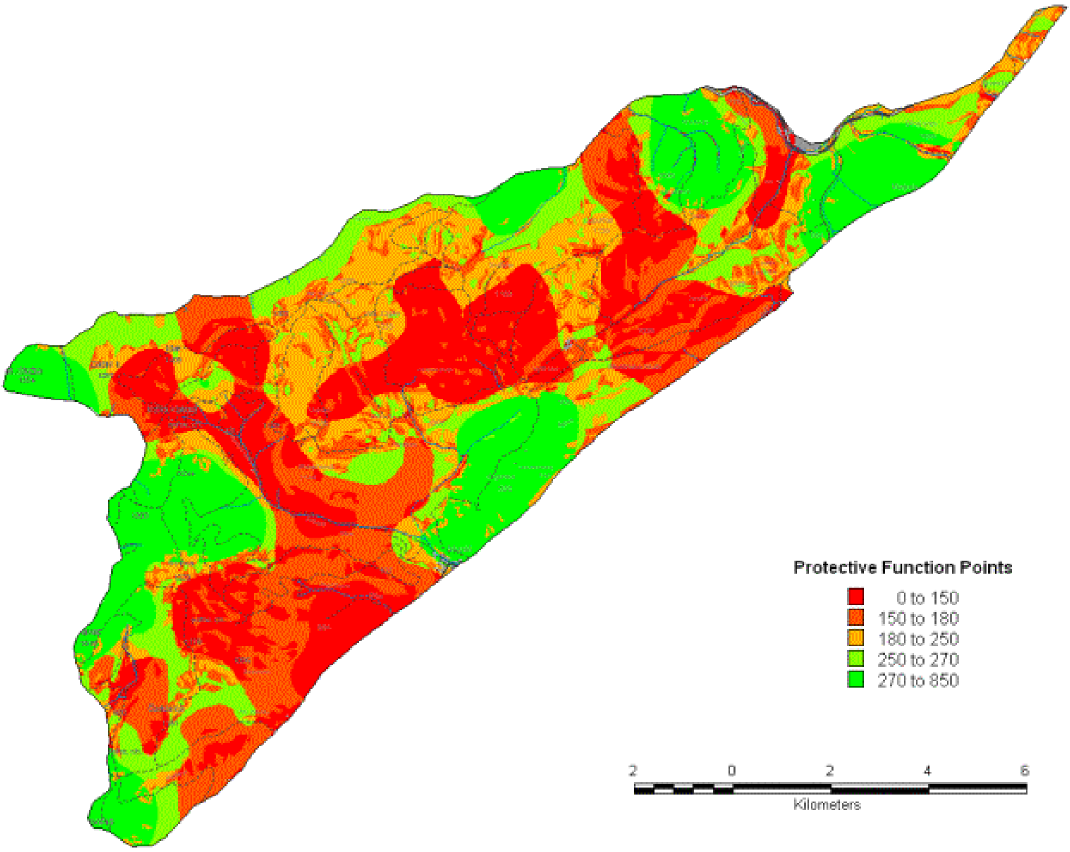


Fig. 15. Flow chart of creating "C" – factor (overlaying layers) map for the Muranska Planina Plateau pilot area.

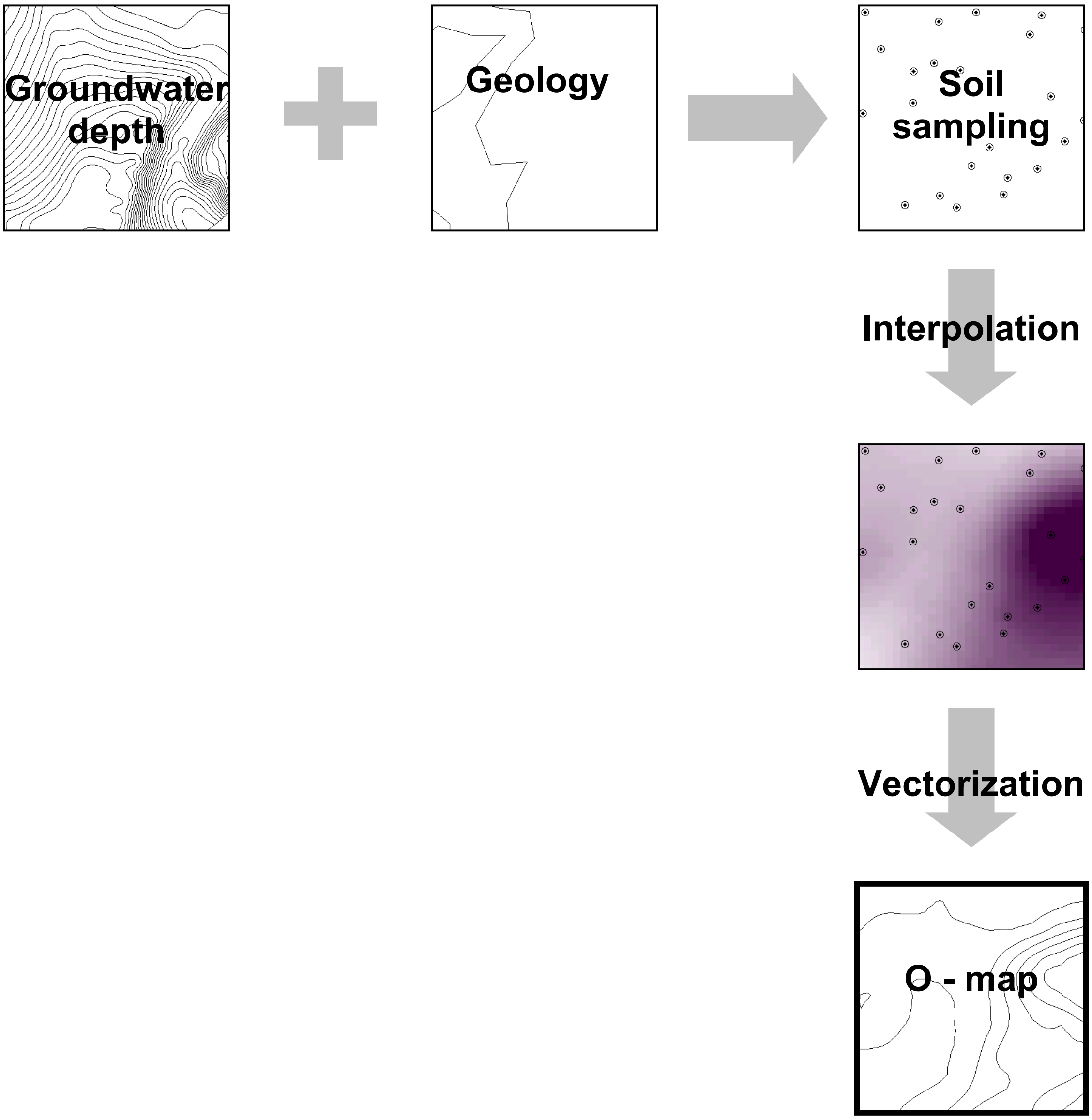


Fig. 16. Flow chart of creating “C” – factor (flow concentration) map for the Muranska Planina Plateau pilot area

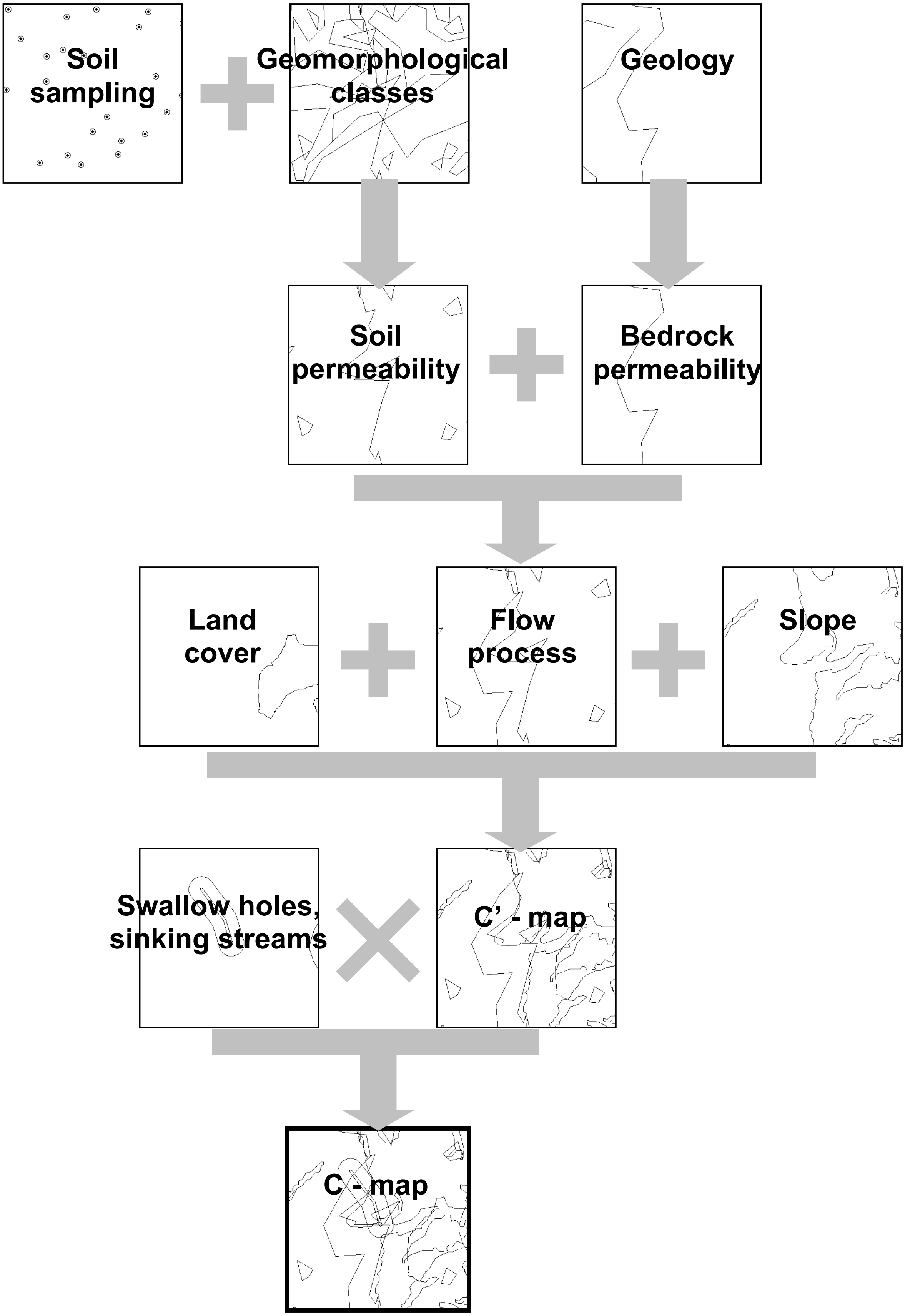


Fig. 17. Flow chart of creating ““OC” – EU method groundwater vulnerability map for the Muranska Planina Plateau pilot area