GROUNDWATER VULNERABILITY ASSESSMENT IN THE MOTRU SEC KARST AREA, THE MEHEDINȚI MOUNTAINS

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Abstract. Karst aquifers represent an important source of drinking water supply, therefore their vulnerability analysis in regions affected by human interventions is needed. Vulnerability assessment mapping, establishes an adequate framework on the karst aquifers catchment areas extension. The present study emphasizes the significant role of lithology, structure and epikarst, on the one hand, infiltration conditions, soil and quaternary deposits (karst protective cover), on the other hand, in groundwater vulnerability assessment of a typical karst area, located in the Mehedinți Mountains. The EPIK method is a conceptual model of karst systems vulnerability assessment, based on four attributes: epikarst (***E***), protective cover (***P***), infiltration conditions (***I***), and karst network development (***K***). Each of these attributes is divided into classes, each class having a value according to its relative importance. Weighting coefficients, specific to every attribute, are applied and after their adding results the vulnerability assessment map. The map creates an adequate framework regarding the karst aquifers catchment areas extension.

Key words: karst management, karst vulnerability, EPIK, GIS, Motru Sec.

1. INTRODUCTION

Karst aquifers are considered to be highly vulnerable to pollution as a result of their particular structure, hence it appears that the supply is made by a dispersed *input* and the discharge – by a concentrated *output.* Due to this fact, contaminant elements attenuation doesn't take place effectively, as in porous aquifers (DOERFLIGER *et al.*, 1999).

The vulnerability of a given system depends on the degree of the effects exerted by the exposure to a certain type of hazard (CORELL *et al.*, 2001, cited by GRECU, 2006). Karst aquifer vulnerability represents a function of soil and overlying formations natural properties or of the aquifers unsaturated zone (FOSTER & HIRATA, 1988, ADAMS & FOSTER, 1992, ROBINS *et al.*, 1994, cited by DOERFLIGER *et al.*, 1999), which can facilitate groundwater contamination with pollutants, at a given moment.

The *intrinsic karst vulnerability* describes geological, hydrogeological and morphological main characteristics which determine groundwaters permissivity to pollution, closely linked with human activities.

EPIK is the first method which suggests the karst systems vulnerability assessment at *input*-scale and allows the groundwater protective areas identification.

The method is based on the hydrogeological conceptual model and takes into account the most significant parameters considered for it.

2. STUDY AREA

The EPIK method was implemented on an area of 29 km^2, in the Motrului Sec Basin (Mehedinți Mountains – Fig. 1), located in the central part of the Gorganu-Piatra Cloşanilor karst microunity (TÖRÖK-OANCE, 2005). It is defined by intense karst processes and a large diversity of endo- and exo-karst forms; generally, the caves from the Motru Sec Basin[1] are featured by a large development and an interesting morphohydrography (Lazului Cave, Martel Cave, Cioaca cu Brebenei Cave, Cave-Pothole No. 2 from Sohodoalele Mici and Cave from Poiana Lazului).

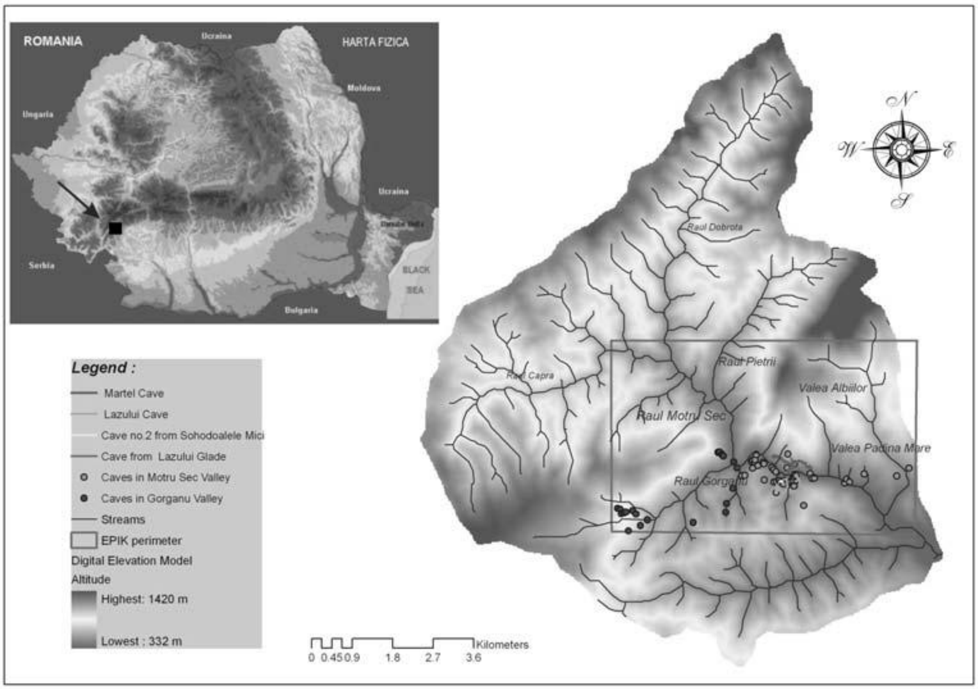

Fig. 1. – Study area.

Almost 60% (17.3 km²) of the analyzed area is occupied by carbonate rocks as part of the Danubian Autochthonous. These include Middle Jurassic-Neocomian limestones (Piatra Cloşanilor-Gorganu Crest) and Barremian-Aptian limestones, in

[1] 113 caves are well-known in the Motru Sec Basin (source: Romanian Karst Inventory).

Urgonian facies, forming extended karst plateaus, developed in the Piatra Cloşanilor and Sohodoalele Mici area (Fig. 2). The limestones transgressively and unconformably overlie the basement which consists of quartzites, feldspar quartzites, paragneisses, micaschists and skarnes (outcropping in the northwestern part of the area) and the Lower Jurassic black schists, from the Piatra Cloşanilor-Gorganu scarp base, which outcrop only in the northwestern part of the Gorganu Crest. Another category of non-karst rocks is represented by the marly-clayey schists (wildflish tu-sn), from the south-west, which cover carbonate formations.

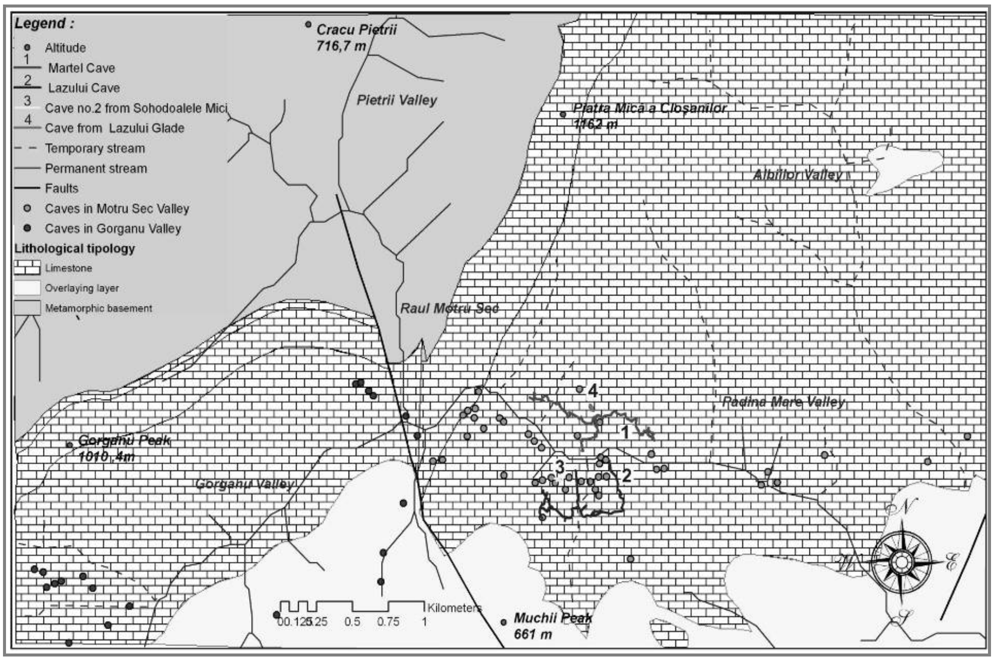

Fig. 2. – Lithological map (source: geological maps 1:50000, Tismana – POP *et al.*, 1975 and Obârşia-Cloşani – ILIAŞ *et al.*, 1977).

The limestone crest of Piatra Cloşanilor marks the general morphology of the region; it is continued in the south-west by the Gorganu Hill, in the south – by a large monocline karst plateau, and in the north-west by the Piatra Cloşanilor scarp, which highlights the transition from the sedimentary to the Danubian crystalline. The Motru Sec River crosses, from the west to the east, the carbonate formations, through a gorges sector, between the Gorganului Valley and the Motru Sec village.

The narrowing sector of the river overlaps a low compartment, generated by a sub-vertical fault. Dipping direction of the layers is between 40°, in the Middle Jurassic-Neocomian base limestones, and close to 30°, in the Barremian-Aptian limestones. In this sector, the valley slopes are steep and forested, while the river loses most of its debit underground. Near the Martel Cave entrance, during summer, the water is totally catched in the valley thalweg swallow holes and re-emerges on a spring line in the Brebina Valley, situated 12 km southward, near Baia de Aramă. The groundwater drainage from the Motru Sec area has been shown by the fluorescein dye-tracing tests performed by I.M.H in 1973. Other elements to complete the area morphology are small suspended valleys in the gorges slopes (Padina Mare Valley, Sohodoalele Mici and Seacă Valley), karren fields, swallow holes and sinkholes, on plateaus surface (Gorganului Hill, Sohodoalele Plateau and Piatra Cloşanilor).

The caves formed on the river slopes were created by Motru Sec or by lateral infiltrations, on three levels: 460–475 m, 395–420 m and 365–375 m (BLEAHU *et al.*, 1976).

Piatra Mică a Cloşanilor (1213 m) reaches the maximum altitude of the studied perimeter, while the minimum altitude was recorded in the Motru Sec Valley (ca. 330 m). Related to these, the karst plateaus on the left and the right side of the Motru Sec River, are developed at an average altitude of 700–800 m. Relief fragmentation ranges between a maximum of 2,8 km/km², at the limestones-wildflish boundary (near the Sohodoalele Mici Plateau area) and 0,1 km/km² on the uniform peak of Piatra Cloşanilor.

The average annual air temperature of 9–10°C and the rainfall (900–1000 mm/year), represent favourable conditions for the karst development (DECU *et. al.*, 1967).

3. THE EPIK METHOD

The EPIK method evaluates the karst groundwater vulnerability bringing forward complexity classes and weighting coefficients for the appraised attributes. These weighting coefficients reflect the attributes relative importance for the karst aquifers protection.

For each analyzed class of attributes, the assessment is made by the class value, multiplied with a weighting coefficient ($\alpha, \beta, \gamma, \delta$), specific to the protective function of every attribute. After adding all data, the final result provides the protection factor (F), showing therewith the groundwater vulnerability degree. The bigger the sum, the smaller vulnerability value of the referred area is.

The vulnerability assessment can be achieved by following the next formula, a simplified hydrogeological model:

- $F = (\alpha \times E) + (\beta \times P) + (\gamma \times I) + (\delta \times K)$, wherefore:

Table 1

The relative values of the weighting coefficients (α, β, γ, δ)

Epikarst (E)	**Protective cover (P)**	**Infiltration conditions (I)**	**Karst network (K)**
α	β	γ	δ
3	1	3	2

Table 2

The EPIK attributes

Epikarst			**Protective cover**				**Infiltration conditions**				**Karst network development**		
E_1	E_2	E_3	P_1	P_2	P_3	P_4	I_1	I_2	I_3	I_4	K_1	K_2	K_3
1	3	4	1	2	3	4	1	2	3	4	1	2	3

3.1. THE EPIK ATTRIBUTES ASSESSMENT

Epikarst ***(E)*** "is the subsurface rock layer, affected by karst processes, on 1–2 m to 10–20 m thickness, which represents a contact domain between exokarst and endokarst (epikarst interface), morphologically difficult to delineate, but important due to its role and hydrogeological function. The epikarst is featured by karst voids, carved in the shallow rock layer, and other interconnected rock discontinuities (open fissures, karren, sinkholes etc.), with a distinct hydrogeological function" (GORAN, 2000).

The three epikarst classes (E_1, E_2, E_3) mapping (Fig. 3) was made on the basis of both the geomorphological studies results and the airborne orthoimagery. Topographic maps (1:25000) were used to identify and to mark the exokarst structures which correspond to the above mentioned epikarst categories. As for all attributes, their maps were obtained in GIS, wherein the classes are evaluated according to Table 2.

For the EPIK method, the epikarst is indirectly described, taking into account the surface geomorphological forms (DOERFLIGER, 1999), by three specific classes:

- E_1 – *well-developed* epikarst, marked by swallow holes, sinkholes, karren fields and deeply fractured openings (caused by anthropogenic digging or by the use of explosives).
- E_2 – *moderately developed* epikarst, present in the intermediate zones of sinkholes alignment, dry valleys or medium fissured outcrops.
- E_3 – *undeveloped or absent* epikarst, defined by the lack or the slow activity of the karst processes, in areas with slightly fissured rocks.

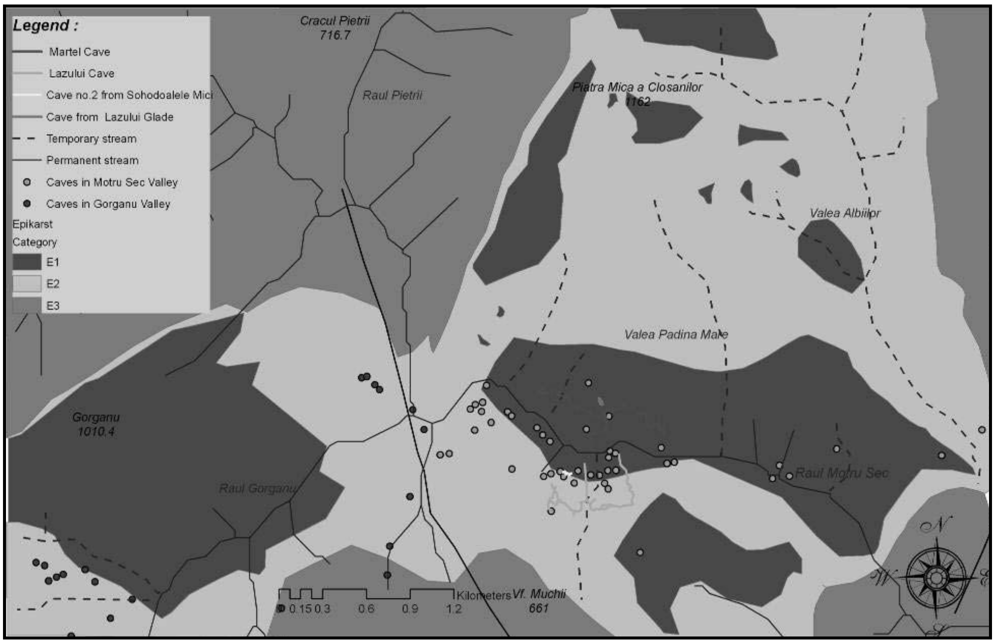

Fig. 3. – Epikarst map.

*Protective cover (**P**)*. The overlaying deposits represent the upper, unconsolidated zone, which protects the aquifer, being considered one of the most important attributes in groundwater vulnerability assessment. Soil, as well as other shallow formations, has an important mitigation capacity, reducing the contaminant substances impact over aquifers (ZAPROZEC, 1985, cited by DOERFLIGER *et al.*, 1999), due to their specific parameters (physical, chemical and biological properties), such as texture, structure, organic matter content, water saturation degree and hydraulic conductivity.

For the ***P*** attribute assessment, soil, overlaying deposits (quaternary – coluvial or proluvial deposits and clays) are being analyzed, and as a common feature, the deposit thickness is also considered.

The protective cover classes were outlined accordingly to an existing methodology (DOERFLIGER *et al.*, 1999, IURKIEWICZ *et al.*, 2005, VLAICU *et al.*, 2007), by field observations (using the morphological equivalence principle – meaning that lowlands, sinkholes, concave slopes have major soil thickness, while crests, steep slopes, have either a thin soil or no soil at all). The mapping of the four types of protective cover (Fig. 4) was based on field observations, as well as on the study of maps: geological (1:50000 – Tismana, 1975 and Obârşia-Cloşani, 1977; DIACONU, 1983), pedological (1:1000000, R.S.R Atlas, 1976) and topographic, along with airborne orthoimagery.

The resulting classes are:

- P_1 – soil or overlaying deposits less than 20 cm thick.
- P_2 – soil or overlaying deposits 20–100 cm thick.
- P_3 – soil or overlaying deposits 100–200 cm thick.
- P_4 – soil or overlaying deposits thicker than 200 cm.

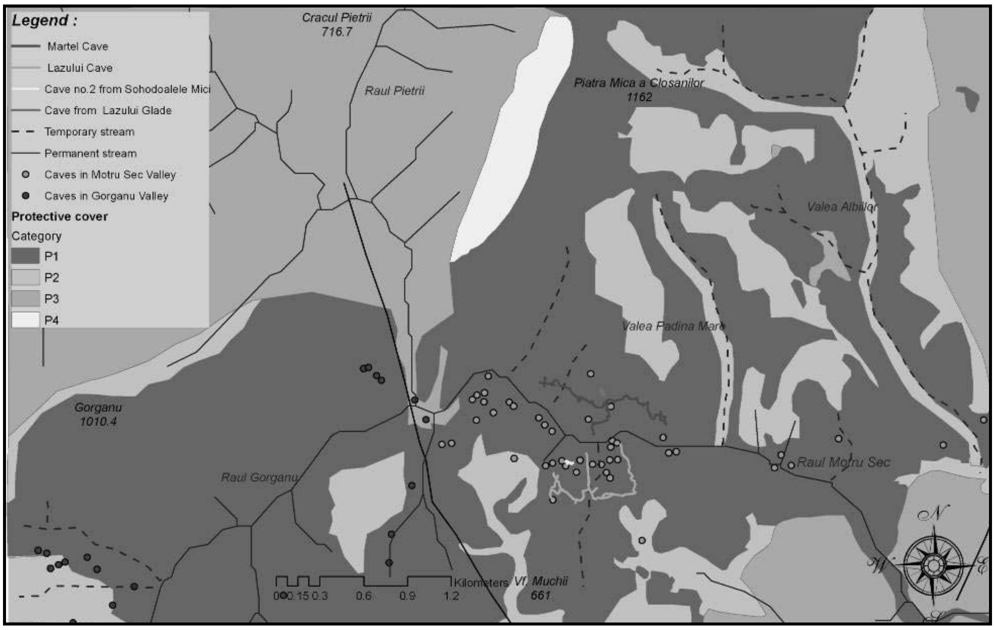

Fig. 4. – Protective cover map.

*Infiltration conditions (**I**)*. Their assessment was accomplished appealing to criteria slightly different than those used by DOERFLIGER *et al.* (1999). Infiltration conditions mapping (Fig. 5) was worked out by juxtaposing the land use map over the declivity map and airborne orthoimages. The delineation of this attribute first class is especially based on field observations and previous investigations (BLEAHU *et al.*, 1976). The study area is relatively well-forested and the EPIK method does not quantify the infiltration conditions for this kind of terrains.

Therefore, the second and the third class were assessed by following the criteria set up by MUSY (2005):

- I_1 – perennial or temporary swallow holes, temporary or permanent sinking streams, runoff infiltration.
- I_2 – areas with slopes less than 10° for arable lands, 25° for meadows and pastures and 35° for forests.

- I_3 – areas with slopes steeper than 10° for arable lands, 25° for meadows and pastures, and 35° for forests.
- I_4 – non-karst terrains.

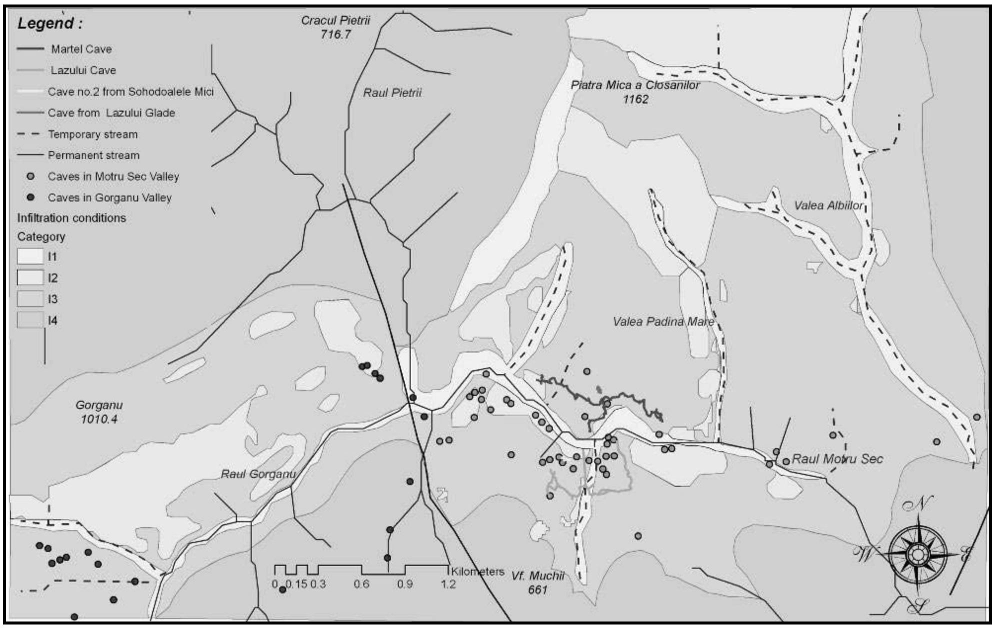

Fig. 5. – Infiltration conditions map.

Karst network development (***K***) is defined by the underground system, comprising openings more than 10 mm diameter wide, the minimum value for the turbulent flow to be recorded (BÖGLI, 1980, cited by DOERFLIGER *et al.*, 1999). The K attribute assessment was made by considering speleological archived data, related to the caves, potholes and swallow holes localization and dimensions. The caves with a special morphohydrography (Martel Cave, Lazului Cave, Cave-Pothole No. 2 from Sohodoalele Mici and Cave from Poiana Lazului) were represented in plan by the means of topography (direct aiming traversing, raying) and by GIS methods.

We mention that the karst aquifers vulnerability is influenced by the water flow velocity through aquifers and by the karst system organizational degree. On the basis of the karst network development, the following three classes were established (Fig. 6):

- K_1 – developed karst network, with large conduits from decimeters to meters;
- K_2 – less-developed karst network;
- K_3 – mixed and fissured aquifers.

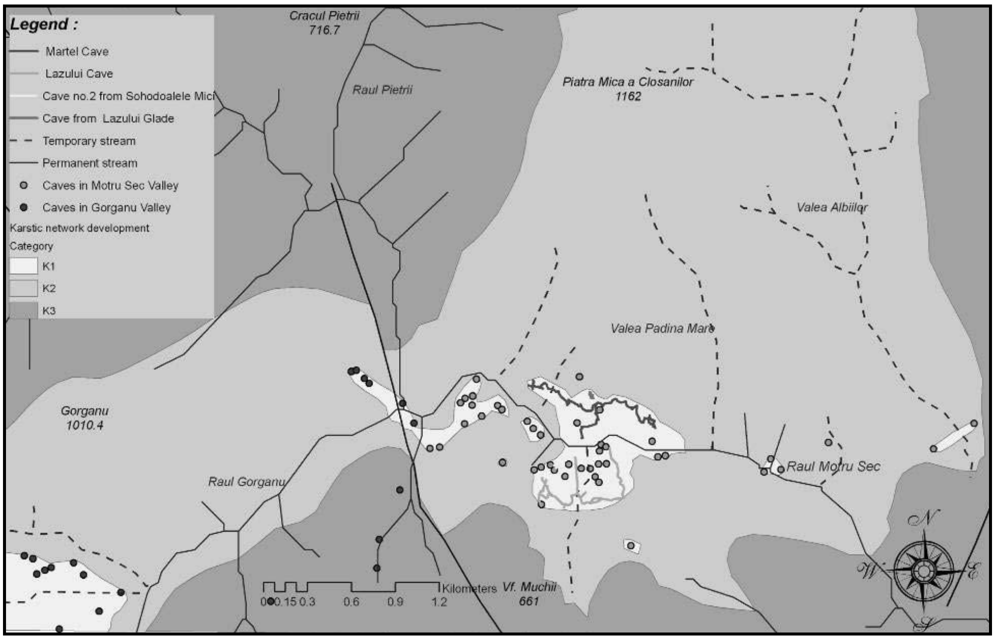

Fig. 6. – Karst network development map.

4. RESULTS AND DISCUSSIONS

Vulnerability assessment. The EPIK method was applied in the Motru Sec Basin, the central part of the Piatra Mare-Gorganu karst microunity, the rest of the basin being developed mostly on non-carbonate rocks.

The vulnerability map is the result of the EPIK method parameters assessment, according to a simplified hydrogeological model (DOERFLIGER *et al.,* 1999). The ***F*** factor values may be divided into four classes of vulnerability: *very high* (9–20), *high* (20–25), *moderate* (25–30) and *low* (30–34). The highest vulnerability category characterizes areas with swallow holes or many concentrated infiltration points, with well-developed epikarst, marked by the lack of protective cover or by the presence of a very thin layer of it. Low vulnerability perimeters are, in most of the cases, steeped surfaces or terrains without karst features.

Groundwater vulnerability study indicates the presence of numerous very highly vulnerable perimeters, located on both sides of the Motru Sec (between the Gorganu Valley and the Motru Sec locality), on the left slope of the Gorganu Valley, on the Piatra Cloşanilor crest and also on the Albiilor Valley. Their common feature is the relatively large density of karst forms. Moderate and low vulnerability areas are either lacked of major karst forms or constituted of non-karst rocks: the Motru Sec upper catchment, the Pietrele Valley, the Gorganu Valley right slope, the Morii Valley.

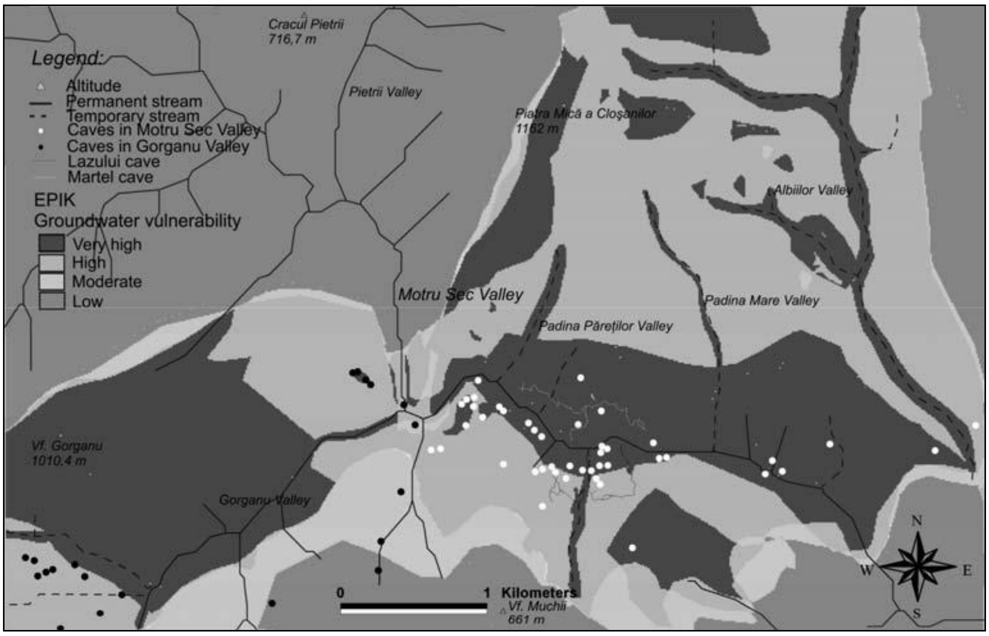

Fig. 7. – Karst vulnerability map.

In the Motru Sec locality area, the very high vulnerability degree is imposed by the large number of swallow holes, located in the thalweg, which drive underground the most of the stream debit. Residual water discharge, manure and waste dumping on the Motru Sec river banks are causing a very severe contamination of surface water and groundwater. Due to the existence of certain drainage systems between the infiltration points from the Motru Sec karst area and the Brebina Valley springs, partially catched for the Baia de Aramă city water supply, we consider necessary an appropriate karst management in the Motru Sec area, particularly focused on the karst water protection.

As a result of the assessment by the EPIK method, it has been shown that, methodologically, protective cover attribute is underestimated comparing to its relevance, regarding karst groundwater vulnerability. The analyses have driven to the conclusion that, in the Motru Sec Basin, areas with very thick (over 200 cm) protective cover have very high vulnerability, such as the lower scarp of Piatra Mică a Cloşanilor, morphologically constituted of an extended colluvial glacis, formed as a consequence of the frost cracking processes from the limestone slope upper part. The very high vulnerability degree is justified by the deposits high permeability. For an accurate assessment of the protective cover we propose that the classes assignation should take into account, beside the deposits thickness, their permeability, which depends on the textural-stratigraphic features (grain size, matrix nature, compressibility degree etc.). Therefore, we state that the conjugated analysis of the main permeability classes – soil, as well as quaternary deposits (Table 3) – along with the thickness classes may represent a more adequate approach.

The vulnerability classes, dependent on the permeability, have been delineated on the basis of BEAR (1972) and the FAO calculated values. *Low, moderate* and *high* vulnerability classes were quantified according to the pre-existent methodology (the lower is the parameter value, the higher is its vulnerability). The final assessment of the ***P*** attribute can be performed by arithmetically averaging the two parameters values.

Table 3

Protective cover permeability classes

Permeability classes	**Permeability (cm/s)**		**Vulnerability**	**Value**
	Minimum	**Maximum**		
Permeable (*gravels and sands, silts, soil*)	10^{-6}	10^{2}	High	1
Moderately permeable (*marly deposits*)	10^{-11}	10^{-7}	Moderate	2
Impermeable (*compact clays*)	10^{-13}	10^{-12}	Low	3

Aiming to improve the EPIK method precision, another series of analyses, regarding the *epikarst* role quantification by indirect methods like infiltration tests, dye-tracing tests, geophysical methods or microtectonic measurements (in order to relieve the drainage plan at epikarst level) should be applied. Moreover, for the *protective cover*, methods focused on the cation exchange capacity (CEC) and the anion exchange capacity (AEC) may be applied (DOERFLIGER *et al.*, 1999).

5. CONCLUSIONS

Intrinsic karst vulnerability assessment in the central area of the Piatra Mare-Gorganu microunity, revealed the presence of some extended, very high, vulnerability areas, on both sides of the Motru Sec River – between the Gorganu Valley and the village entrance, most of the Gorganu Valley left slope, the Piatra Cloşanilor scarp and the Albiilor Valley. Regarding the regional management, the human settlements development and the resource exploitation, a special interest must be paid to very high and high vulnerability areas with karst systems (active caves, swallow holes, karst intermittent springs). Due to their flow capacity, amplified by underground cavities, the karst groundwater may be rapidly contaminated.

Protective cover permeability and thickness appraisal may represent a more accurate karst vulnerability assessment method. It can drive to three vulnerability categories, according to the three major permeability classes: *permeable* (highly vulnerable), *moderately permeable* (moderately vulnerable) and *impermeable* (lowly vulnerable).

For the improvement of the karst aquifers vulnerability assessment, the quality of the epikarst and protective cover attributes analysis may be raised by appealing to microtectonic studies, infiltration tests, dye-tracing tests, geophysical methods, CEC, AEC. Other parameters should be also quantified, such as structural (faults, bedding planes) or stratigraphic features (deposits compressibility degree), due to their great importance for the karst vulnerability assessment.

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