INTRINSIC VULNERABILITY OF COTEȚUL DOBREŞTILOR KARST AQUIFER (BIHOR MOUNTAIN, ROMANIA)

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Abstract: The evaluation of the vulnerability of the karst aquifer and of the source in the Coteţul Dobreştilor system was performed on base of geological, hydro-geological and pedological data. There were used the methods proposed in the Final Report of COST Action 620, the available field data resulting in the assessment if the parameters P, I and in characterizing the saturated aquifer karstic network parameter (K). The soil cover over the carbonate deposits is generally shallow and easily by-passes by the superficial flow, the protection of the karstic aquifer and the source being thus minimal.

Keywords: hydrogeology, karst system, vulnerability, Bihor Mountains, Romania

INTRODUCTION

The development of agro-tourism in the area Gheţar-Ocoale of the Bihor Mountains, encouraged by the of the surrounding karstic landscape and by the presence of the largest ice cave of Romania – the Scărişoara Glacier, will give rise to the development of a network of roads and guest-houses and to the building of a central water supply network of the villages at the watershead Gârda Seacă-Ordâncuşa. This area overlaps roughly the karst system drained by the source of Coteţul Dobreştilor, and the lack of adequate protection measures for the aquifer, associated with the development of the agro-tourism will result in a severe pollution of this important water resource.

In the scope of the Apuseni Project, that was deployed in the watershead Gârda Seacă-Ordâncuşa during the interval 2001-2003 multi-disciplinary research was performed in order to propose a sustainable development of the settlements from Ţara Moţilor, research that was financed by the German Ministry for science and education under no. 0339720/5. The detailed hydro-geological and paleontologic data obtained by the project are used in this paper for assessing the vulnerability of the groundwaters to the impact of the future agro-touristic development of the area.

MORPHOLOGICAL SETTING OF THE AREA

The considered area lays at the Eastern limit of the karst area of Bihor Mountains, in the drainage area of the Arieş river. It includes the Southern part of the Gârda Seacă-

Ordâncuşa water shead, developed between the villages Ocoalele and Mununa, area that is known under the name of Gheţar Plateau.

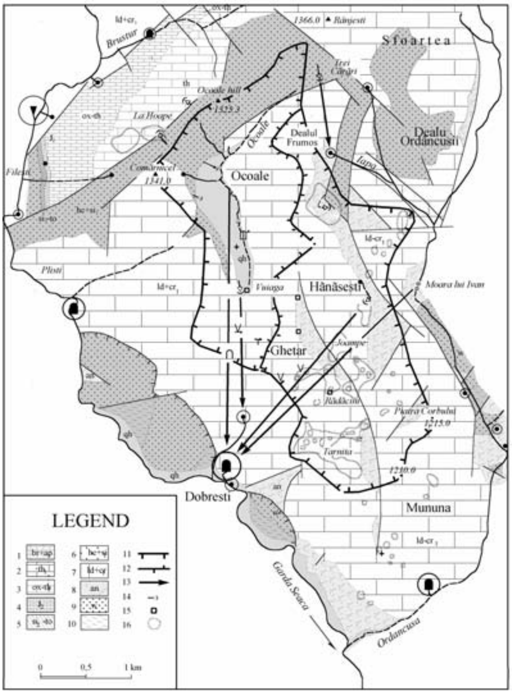

Fig. 1 Hydrogeological map of the Gârda Seacă - Ordâncuşa water divide territory. Legend: .Bihor Autochthon: 1-undivided Urgonian limestones,(br+ap$_1$); 2–black bedded oolithic limestones, (th); 3-reef limestones (ox-th$_1$); 4-red oolithic limestones, yellowish spoted limestones, redish and grey encrinitic limestones, (J $_2$); 5-redish and grey encrinitic limestones, marls, (si$_2$-to); 6-quartzitic sandstones and conglomerates, argillaceous shales, black limstones, (he+si$_1$); 7- white reef limestones - Wetterstein limestone, (ld+cr$_1$); 8-grey dolomites, (an). Bihor Autochthon and Gârda Nappe: 9-quartzitic sandstones and conglomerates, red argillaceous shales, (w); 10-Crystalline schists; 11-Limit of endoreic (inland) areas; 12-Limit between endoreic areas: 13-Proved groundwater flow direction; 14-Temporary shallow hole; 15- Dug well; 16-Karstic depression.

Plateau is elevated by 300-600m above the streambeds of the adjoining streams, and it consists of isolated ridges separated by saddles and chaotically disposed karst depressions, without displaying a single dominating feature. Immediately northward from the junction of Gârda Seacă and Ordâncuşa streams (730 m altitude), the absolute elevations rapidly increase up to Mununa (1100m), then they climb slowly up to Ocoale (1325,3m) and Rânjeşti (1366,0m) summits. The topography assuming the appearance of a karst plateau strewn with the entire range of both above ground and below ground karst land-forms that are characteristic to these areas.

Ocoale stream is the only stream appearing on the carbonate surface of the Plateau (Fig. 1). It has its headwater on the Early Jurassic terrains in the north-western part of the Ocoale-Gheţar depression. The original course, tributary to Gârda Seacă stream, has been concerned in time by a multitude of karst piracy events, marked by the caves network that includes Groapa cu Apă a lui Miron ponor (Fig. 1, no. 1), the pothole in Şesuri (Fig. 1, no. 2), Gheţarul de la Scărişoara (Fig. 1, no. 3) and by the succession of fossil swallet holes which extends northward up to the present day permanent sinking point, situated at the contact of the limestone with the Early Jurassic sandstone and shales. On the plateau are also met several springs that have generally an impermanent character and small flow rates. Their presence is connected with the discharge of the aquifer accumulation from the eojurassik and from aluvial-deluvial (Vuiaga) despoits or with the existence of epi-karst aquifers: Bărâcia (Fig. 1, no. 4), Apa din Cale (Fig. 1, no. 5), Troaca (Fig. 1, no. 6), Rădăcini (Fig. 1, no. 7).

The multi-annual average rainfall recorded at Gheţar is 1315 mm/year and the multi-annual average air temperature is 5.2 ^{O}C (Oraseanu, Varga, 2003, 2004).

GEOLOGICAL AND STRUCTURAL SETTING OF THE AREA

The Gârda-Ocoale area almost entirely consists of sedimentary deposits ascribed to the Bihor Unit. Only in the lower reaches of Gârda Seacă stream, in the south-western part of the area, there are outcrops of Werfenian and Permian sandstone and conglomerate deposits which in structural terms are ascribed to Gârda Nappe of the Codru Nappes System.

The Bihor Unit formations in the considered area include at their bottom Werfenian detritic deposits, that consist of conglomerates and quartzite sandstones and red shales, which are overlain by a thick series of carbonate deposits with gray Anisian dolomites at their bottom, followed by white Ladinian-Early Carnian reef limestone (the Wetterstein limestone). The carbonate deposits are transgressively overlain by the prevalently detritic Early Jurassic deposits, which consist of quartzite sandstone and conglomerates, shales and black limestones, of 200-300 m overall series thickness (Hettangian - Early Sinemurian), reddish and gray encrinitic limestone, marls and marly limestone (Late Sinemurian - Toarcian, 6-80m thick). The series ends with reef limestone (Oxfordian - Early Tithonic) and black oncholithic Tithonic limestone (Dumitrescu R. et al., 1977, Bleahu M. et al., 1980).

The entire sedimentary series of the Bihor Unit forms a homoclinal structure, which generally strikes NE–SE. The ensemble dips from NE to SW in the northern half of the structure and from E to W in the southern one. In general, neither a recurrence of the succession due to strike-slip faulting on reverse faults, nor any folding can be identified. The structural continuity of the Triassic deposits along the NW-SE direction is broken by agraben with Jurassic deposits in their axis, structure that deeply penetrate toward north-east into the homoclinal structure of the Triassic deposits, Brustur brook up to Ocoale area. In the southern part of the concerned area, the sequence of carbonate deposits is longitudinally dissected by the Hănăşeşti-Mununa fault system, with its western compartments uplifted. In this compartment, along the fault, Anisian dolomites outcrops are frequent.

For the hydrogeological map we completed, the geological background is provided by the sheets Poiana Horia and Avram Iancu of the Geological Map of Romania, scale 1:50.000, devised by Bleahu et al. (1980) and Dumitrescu et al. (1977).

HYDROGEOLOGICAL ISSUES

The investigation of the groundwater circulation in the Gârda Seacă-Ordâncuşa watershed was initiated by the fluorescein tracer test performed in the underground stream course of the pothole in Şesuri, in the year 1957, by Serban, Coman and Viehman, Rusu, Racovita and Coman (1970) mention the tracer test performed by Rusu and Racoviță in the month of April 1964 by means of 1,5 kg of fluorescein in the Ocoale sinking stream.

Table 1. Result of tracer labeling performed in Gârda Seacă-Ordâncuşa watershed

No.	Insurgence	H(m)	Resurgence	H (m)	L (m)	ΔH (m)	T (ore)	V (m/h)	Data
1	Undrground course of Şesuri pothole	1134	Poliței spring	920	880	214			1957
2	Losses of Ocoale stream	1160	Cotetul Dobreştilor sources	770	2800	390	38	73.7	1964
3	Troaca Hănăşeşti	1110	Cotetul Dobreştilor sources	770	2430	340	42	57,9	2002
4	Losses of Ordâncuşa stream at Moara lui Ivan	960	Cotetul Dobreştilor sources	770	2900	190	90	32,2	2003
5	Trei Cărări (Aprozar) swallow hole	1300	Iapa spring	1230	840	70	10,5	80	2002

H-elevation, in meters a.s.l., L-horizontal distance between losses and springs, ΔH-vertical drop; T-time of first arrivel of tracer; V-apparent velocity.

The karst system Coteţul Dobreştilor includes the mountainside catchment of the Gârda Seacă stream Eastward of the sources of Coteţul Dobreştilor (0,9 km^2), most of the internal drainage area of the Gheţar Plateau (8.2 km^2) and the diffluence surface Ordâncuşa-Coteţul Dobreştilor (10,3 km^2), area that is overlapping the upper catching area of the Ordâncuşa stream, developed upstream the streame losses from Moara lui Ivan. The underground flow rate transiting from the diffluence surface to the resurgent sources is determined by the methods of hydrogeological balance (Oraseanu, Jurkiewicz, 1982, Oraseanu, 1985).

The karst system discharges through the sources from Coteţul Dobreştilor, located at the contact between the limestone and quartzite sandstones of the Gârda Nappe, sources that are hydrologically interconnected, having a cumulated flow rate of about 350 l/s and an average temperature of 7,6^{O}C. Such sources are: the Coteţul Dobreştilor spring, an temporary source having a multi-annual average flow rate of ca. 270 l/s, the Morii spring and the submerse sources from the valley floor of the Gârda Seacă stream.

Coteţul Dobreştilor karst system displays large values of the discharge time series variation coefficient, Cv, that indicate a well developed underground flow organization, quite probably along large cavities. Cv, the discharge time series variation coefficient, is the ratio between the average deviation of an hydrologic annual series of mean daily discharges values (octomber-september) and the annual average of this series. It ranges between 0 and 1, the large values indicating outlets with large variations of their flow rate, associated to karst systems subject to a strong karst development, with a well organized underground flow (Oraseanu, 2005).

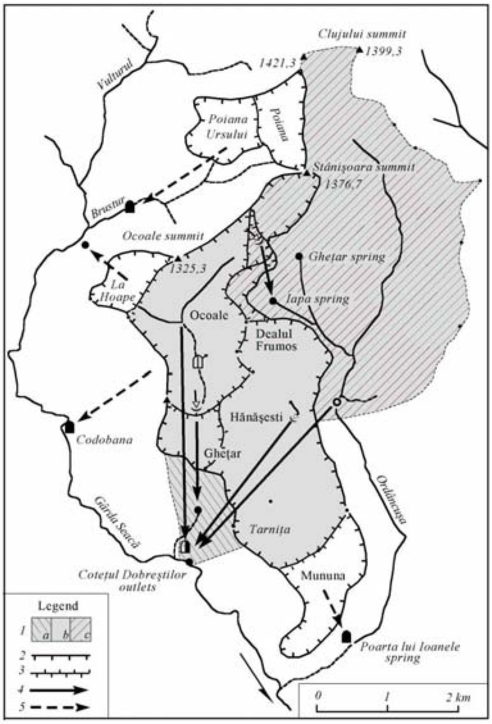

Fig. 2 The Coteţul Dobreştilor karst system. Legend: 1-Extension of the karst system: a-Karstic slope basin; b-Internal drainage area; c- Diffluence surface; 2-Boundary of internal drainage area; 3-Boundary inside intenal drainage areas; 4-Proven groundwater flow connexion; 5-Inferred groundwater flow connexion.

In order to obtain additional information concerning the degree of structuring of the main karst systems, the electric conductivity of the water of the spring Coteţul Dobreştilor was measured every two days in May 2001- July 2003. The water is derived from at least two distinct populations, each one having its own geochemical evolution and own hydrogeological history (Fig. 3).

The aquifer discharging through the outlets at Coteţul Dobreştilor is well structured and organized, with a functional main flow axis that facilitates to the water sunk in Ocoale area a fast arrival to the spring, without significantly mixing with water stored in the annex systems of the karst aquifer

INTRINSIC VULNERABILITY OF AQUIFER AND SOURCE

In our exercise to assessing the intrinsic vulnerability of the aquifer from Coteţul Dobreştilor we considered the internal drainage area and the mountainside karstic catchment (Fig. 2). The impact produced by waters seeping through the Ordâncuşa-Coteţul Dobreştilor diffluence area, that is also part of the karst system, has not been assessed by lack of pedological and hydrological data referring to the quantity with which they contribute to the supply of the system.

The detailed pedologic studies performed in the boundaries of the Gârda Seacă-Ordâncuşa watershead (Parichi et al., 2003, Stanila et al., 2003) resulted in drawing up the pedologic study and of the specific pedologic maps, out of which we chose for our research the soil thickness map, the vegetation map, the field capacity map, the map describing hydraulic conductivity of the soil and the slope map.

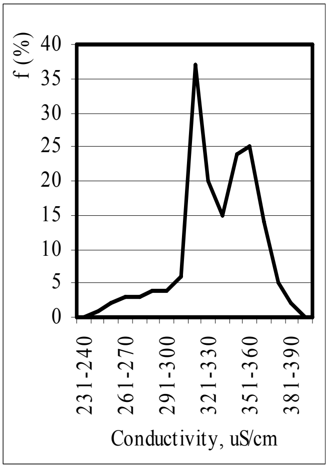

Fig. 3 The distribution diagrams of frequency values of the water conductivity of Cotețul Dobreştilor karst spring

PROTECTIVE COVER

The soil developed in the studied area has a thin thickness, beneath a meter. For assessing the protective capacity of the soil cover we considered the field capacity of the soil, multiplied with its thickness. The field capacity of the soil cover ranks in la 4 classes: very low (under 10 %), medium (21-25 %), medium-high (21-30 %) and high (26-30 %), while its thickness (Fig. 5), has been ranked in 5 classes (0-10, 11-20, 21-50, 51-75, 76-100 cm)

The product obtained by integrating the two maps (n=4x5=20 values) has been distributed in 4 vulnerability classes: P=1, very low protection degree, for n= 1-5; P=2, low protection degree, for n= 6-10; P=3, moderate protection degree, for n= 11-15 and P=4, for n= 16-20, medium protection degree.

There are not non-karst rock between soil and unsaturated karst rock. The development of the crack systems is assumed to be evenly high over the entire considered area. The eojurassic deposits (sandstones, shales) from the North of the considered area occur in sunken tectonic blocks separated from the carbonate deposits by vertical faults. Their lithological structure displays a high protection degree. We allotted the areas covered by eojurassic deposits a medium-high protection degree, P=5. The P map is shown in Fig. 4.

DETERMINATION OF THE I PARAMETER

The I parameter shows the degree to which the protective cover is being bypassed by the water and has two components:

-The I’ parameter estimates the occurring seepage, being controlled by the permeability of the soil, the land slope and the vegetation. The integration of these factors is shown in table 2. Permeability of the soil has been estimated on the basis of saturated hydraulic conductivity.

Table 2. Determination of the I' factor

	Satured hydraulic conductivity K (mm/h)	Forest			Meadow / pature		
		Slope (%)					
		0-5	5-25	› 25	0-5	5-25	› 25
1	0.3-0.5	1.0	1.0	1.0	1.0	1.0	0.8
2	0.6-2.0	0.8	0.8	0.6	0.8	0.8	0.6
3	2.1-10.0	0.8	0.6	0.4	0.6	0.4	0.2
4	10.1-35	0.6	0.4	0.2	0.4	0.2	0.0

-The Surface catchment map. The protective cover are bypassed as a result of lateral surface and subsurface flow in the catchment of shallow holes and sinking streams. Surface catchment map show components which bypass the protective cover. The later has been drown-up on base of the hydro-geological mappings that indicated the presence of the swallowholes and the sinking streams. The 10 m and 100 m „buffer zones" around these features are introduced (table 3).

The I map (Fig. 5) is obtaining by intersecting the I' map and surface catching map according to the scheme presented in table 3. A value I=1,0 indicating that the protective cover is not bypassed. On the other hand, the protective cover is completely bypassed by shallow hole through which surface water directly enters the karst aquifer, the I factor is 0,0.

Table 3. Determination ot the I factor

Surface Catchment Map		I' factor					
		0.0	0.2	0.4	0.6	0.8	1.0
a	Swallow hole, sinking stream and 10 m buffer	0.0	0.0	0.0	0.0	0.0	0.0
b	100 m buffer on both sides of the shallow holes and sinking stream	0.0	0.0	0.2	0.4	0.6	1.8
c	The rest of the catchment area of the sinking stream	0.0	0.2	0.4	0.6	0.8	1.0
d	The rest of the area discharging into the karst	0.2	0.4	0.6	0.8	1.0	1.0

The PI vulnerability map, (Fig. 6), is obtained by intersecting the P map with the I map. Legend of the P-map, I-map and vulnerability map.

Table 4. Legend of the P map, I map and vulnerability map

Color symbol on the maps	P map		I map		Vulnerability map	
	Protective function of soil		Degree of bypassing		Vulnerability of groundwater	
	description	P-factor	description	I-factor	description	Π-factor
1	very low	1	very high	0.0-0.2	extreme	0-1
2	low	2	high	0.4	high	1-2
3			moderate	0.6	moderat	2-3
4			low	0.8	low	3-4
5	very high	5	Very low	1.0		

Fig. 4 P map

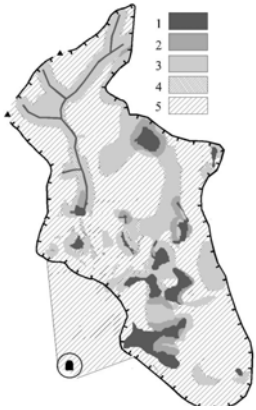

Fig. 5 I map

The hydrogeological data presented in the first part of the paper indicate that in the saturated area of Coteţul Dobreştilor karst aquifer, the karst networks is well developed (K factor in the EPIK method and The European Aproach method), fact sustained also by the large number of caves and potholes and by their significant lengths (Pothole of Şesuri – 3840 m length and 220 m denivelation, Coteţul Dobreştilor cave – 294 m , Pojarul Poliţei cave – 400 m, Scărişoara ice cave – 700 m, etc.). The karst network of the aquifer facilitates a fast transit of the water reaching the aquifer surface, towards the sources from Coteţul Dobreştilor, and thus of the polluting substances, failing to develop physical or chemical processes that might facilitate the degradation of such substances.

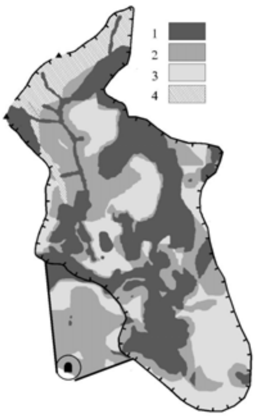

Fig. 6 Vulnerability map of the Gheţar plateau area. The legend of the symbols in table 4.

The protective capacity of the overlying soil is low and very low because of its reduced thickness. The area with very high protective function of soil reflects the distribution of Jurassic rock outcrops (P=5). According to the I map, the degree of runoff bypassing the protective cover is low to very low for most of the area. This is because the Ocoale sinking stream and shallow holes make up only a portion of the area. The PI map shows many areas of extreme and high groundwater vulnerability.

CONCLUSIONS

On base of the available geological, hydro-geological and hydrological data (tracer tests, spring hydrograph, water electro-conductivity time series), pedological data (thickness, field capacity and saturated hydraulic conductivity soil maps), vegetation and slope maps there were drown up the effectiveness of protective cover map (P map) and bypassing of protective cover map (I map) and finally the intrinsic vulnerability of the Coteţul Dobreştilor karst aquifer map.

The soil provides a weak protection to the karst aquifer, being easily and frequently by-passed by the permanent or impermanent superficial flows, while the karstic network is very well developed. Over most of the considered area, the vulnerability of the karst aquifer is extremely high. The source discharging the karst aquifer is also very vulnerable.

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