Groundwater Quality in Suha Basin (Northern Group of Eastern Carpathians)

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The mountainous climate of Suha drainage basin manifests through important rainfall quantities, which despite their relatively reduced length ensure a rich and constant discharge of rivers. The study of groundwater and their quality has been conducted by analyzing three wells drilled in 1972. Observations thus sum up over 40 years, sufficient time for a correct evaluation of water resources. The three wells are located on Gemenea (F1), Suha (F2) and Negrileasa (F3) rivers. The wells depths are different (F1 - 11 m, F2 – 10.5 m and F3 – 4.25 m) and present a water table depth of 9.5 m at F1, 8.60 m for F2 and 2.87 m in F3 section. Ostra and Stulpicani townships are alimented with groundwater from the aquifer represented by Suha and its tributaries' common floodplain. In order to analyze water quality, samples from Tarnicioara and Stulpicani sections have been used. All chemical parameters (pH, Ca, Mg, Na, K, Fe, Cr, Cu, Zn, Cl etc.) do not present exceeding of the maximum admissible concentration (MAC). The aquifer represented by gravels and sands is rich and contains good quality water. Water resources present in Suha basin can sustain alimentation with drinkable and industrial water in the conditions in which mining activities at Lesu Ursului have stopped.

Keywords: groundwater supply, representative basin, chemistry, water body, pollution

Romanian groundwater began to be monitored after 1970, when the national hydrogeological network established by Siret Water Basin Administration, Bacau was created. Field measurements and laboratory results lead to a synthesis of data regarding groundwater resources and quality in Suha basin. It is the first study of this type in a mountainous area, which approaches groundwater resources in a well-populated basin, based on personal and institutional observations. The careful monitoring of groundwater is necessary because the Lesu Ursului mining exploitation represented an important pollution source. The two tailings ponds have been cleaned.

For the groundwater of Suha basin data have been recorded for over 40 years. These allow for a relatively close estimation of the real resource, especially in the present context of local economic development, based mainly on subsistence agriculture. The most pressing problem in the context of a high population density is represented by drinkable water supply. The problem of groundwater supply is extremely important because the old mining exploitation from Lesu Ursului has led to the pollution of surface waters on almost half the length of the river (the sector between the exploitation and Ostra township) [1-20].

The present study analyses for the first time the quantitative and qualitative characteristics of groundwater in Suha basin (mainly phreatic waters from the water body of the floodplain, downstream Tarnicioara). National and international references are quite many in what regards qualitative aspects of groundwater generally and of those in Eastern Romania in particular, but relatively few for Suha basin [21-40].

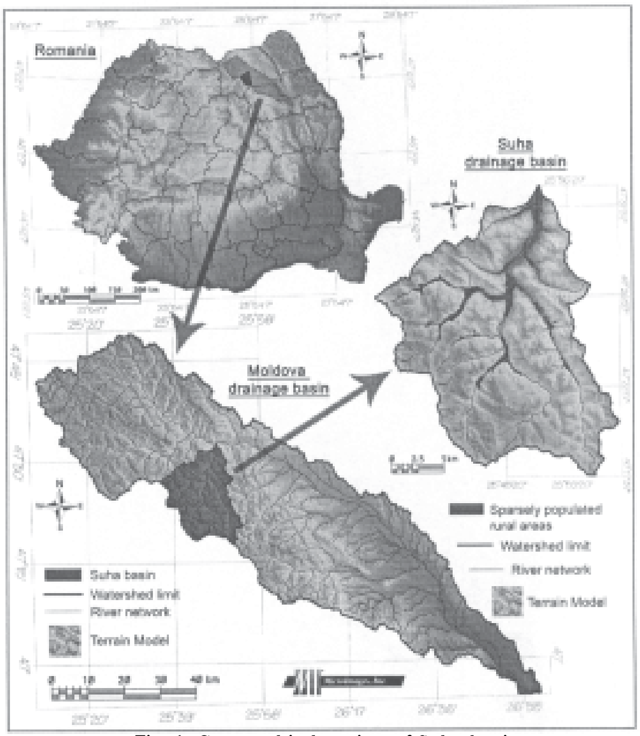

Fig. 1. Geographic location of Suha basin

Geographic location

Suha hydrographic basin is situated in the North Group of the Eastern Carpathians, corresponding to the flysch of Stanisoara Mountains and the crystalline of Rarau Massif. It occupies the southern part of Obcina Feredeului, the SE

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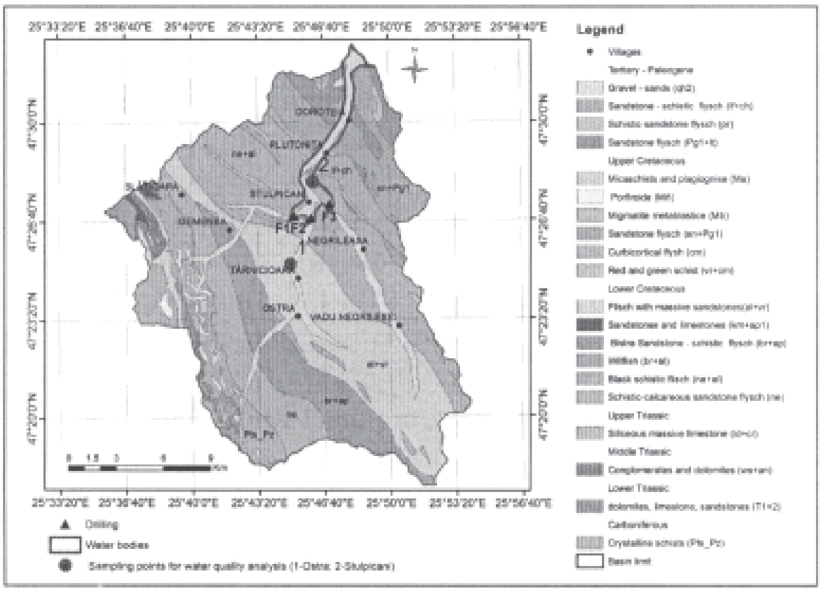

Fig. 2. Map of water bodies, position of the main hydrogeological bores and the main points of quality monitoring in Suha basin

slope of Rarau Massif, the eastern part of Ostra and Suha Mountains and the NW part of Obcina Voronetului [41]. The basin has a surface of 356 km^2, being considered medium sized. Suha springs from under Baisescu peak, from an altitude of 1270 m, and has a length of 33 km. It collects the waters of over 100 tributaries of small dimensions. The mean annual discharge rate in the lower sector is of 0.426 m^3/s for the 1950-1998 period and of 0.507 m^3/s for 1999-2013 [42-44]. It receives as tributaries on the left the brooks of Brateasa, Botosana, Muncelu, Gemenea, Slatioara, Ursoaia Valea Seaca, and on the right side Doroteia, Branistea, Negrileasa (fig. 1).

The watershed of the Suha drainage basin starts at the confluence with Moldova at Frasin, continues to north-west through the peaks of Alunetu (656 m), Ascutita Mare (1014 m), Magura Sarata (1146 m), Magura Batrana (1132 m), Arsita Caprei (1126 m), Culmea Todirescu and Coltii Raraului (1628 m), then turns to SSE following the peaks of Ostra Mts. (Diac -1163 m, Botusan - 1290 m, Batca Nedeii - 1380 m), Suha Mts. (Baisescu - 1340 m, Suha - 1108 m, Strajii - 1018 m, Cladita Mare - 1066 m, Brusturosu - 1089 m) and Obcina Voronetului (Batcuta Brusturosului - 897 m, Bucsoita Hill - 846 m), descending toward Moldova valley at Frasin (Bucsoaia).

Experimental part

Methodology

Groundwater bodies are continuously monitored in order to evaluate long term tendencies in the changes of natural conditions and anthropic activities. The surveillance monitoring of groundwater gives information for their quantitative and qualitative classification. Deep bores in the national hydrogeological network are periodically tested in all aspects. Due to technical difficulties which imply complex equipment and high costs, these bores are pumped only during their initial setup. Monitoring their behavior in time implied only the fluctuations of hydrostatic levels and only rarely water quality control. Random sampling is not relevant because water is taken only from the upper part of the wells, where it stagnates for a long period of time.

Water exploitation from groundwater aquifers may lead to quantitative changes in their natural regime. The tap sizing and the correct calculation of optimum exploitation discharge rates is made only knowing how the water source behaves in time. For this reason relevant authorities have started a program of experimental pumping for these wells. Experimental pumping represents measurements of groundwater discharge rates, followed by water sampling for physical, chemical and bacteriological analyses.

The groundwater in Suha basin is monitored in a classic measurement system – the network of hydrogeological wells. The usual measurements are: determinations of the piezometric level at intervals of 3, 6 and 15 days for phreatic water and quarterly for deep groundwater; periodic flow rate measurements for the experimental pumping; water sampling during the execution of experimental pumping for physical and chemical determinations.

The 60/2000/E.C. Framework Directive stipulates that all water bodies in Suha basin are identified based on geological and hydrodynamic criteria and their qualitative and quantitative status. Starting with 2006, the classic monitoring functions in parallel to the system of the 60/2000/E.C. Framework Directive. In 2005 the basin has been equipped with automatic stations for measuring levels and temperatures in the low depth hydrogeological wells. The waters of three bores (F1, F2, F3) situated in Suha's floodplain, downstream Tarnicioara, have been analyzed. In order to analyze water quality samples have been taken from two sections: Ostra and Stulpicani (fig. 2) and determinations were made in the laboratory of the Siret Water Basin Administration, Bacau.

Results and discussions

Phreatic groundwater is directly influenced by surface waters, mainly in the conditions of a high porosity of geological deposits. The quality of the latter influences phreatic water quality. For this reason the upper sector of Suha, directly influenced by the Leşu Ursului mining exploitation, is characterized by a high degree of surface and aquifer water pollution.

The 60/2000/EC Framework Directive has a defining role in establishing a common environment for the sustainable and integrated management of all groundwater bodies. Groundwater bodies from Suha basin are phreatic, being contained in a Tertiary - Paleogene aquifer consisting mainly of gravels and boulders with small intrusions of sands, sometimes covered by clayey-sandy or sandy-clayey silt deposits [45-53]. The phreatic groundwaters have good quality and are used for population and food industry supply. Level monitoring is conducted in three points in the bores F1 on Gemenea, F2 on and F3 on Negrileasa rivers, all on the territory of Stulpicani township,

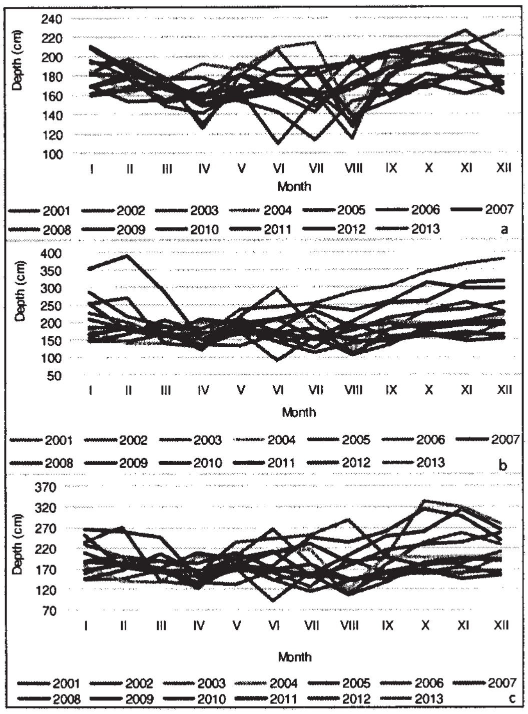

Fig. 3. Phreatic level variations: (a)-section F1, (b)-section F2, (c)-section F3 (without elevation)

in the confluence areas of Gemenea and Negrileasa with Suha (fig. 2).

The groundwater bodies correspond to Tertiary-Paleogene formations represented by gravels, boulders and sands. Waters are also stored on reduced areas in the Upper Cretaceous curbicortical flysch. They occupy a surface of 10.5 km^2 under the shape of a longitudinal strip directed north-south, positioned in the northern part of the Suha basin (downstream sector). The levels of these bores, similar to surface flow, are influenced by rainfall quantities. They have the following mean annual values: in section F1 the phreatic has values that gradually decrease from January to April (from 182 to 156 cm); in May the level increases to 170 cm, decreasing in August from 169 to 160 cm. The level starts to gradually increase up to December (from 160 to 188 cm). The maximum oscillations of the phreatic level in the F1 section were between 110 cm (June 2006) and 226 cm (November 2002) (fig. 3).

The variations of the phreatic level in section F2 (fig. 3) have registered a decrease of mean annual values during January - April, from 212 cm in January up to 160 cm in April. From April to May they increase by 6 cm, then from the 167 level they constantly increase up to 231 cm in December. The minimum annual level was measured in June 2006, when the phreatic had a thickness of 89 cm, while the maximum thickness in the F2 section, of 391 cm, was measured in November 2012.

In the F3 section, phreatic levels register a decrease during January-April from 196 to 160 cm, followed by an increase till 184 cm in May. From here levels start to decrease up to 167 cm in August, then easily increase till December (211 cm) (fig. 3). The annual minimum value was also registered in 2006, in June (92 cm), while the maximum value was measured in November 2013, being of 335 cm. The analysis of the phreatic level variations for the 2001-2013 period show that they are influenced by rainfall quantities. Thus the rainy years will be characterized by a high phreatic level during the summer, when evapotranspiration is higher, but the general tendency is of significant level decrease during summer, especially in August, and by an important increase during February and November.

Drinkable water consume raises the problem of phreatic water quality. The two townships from the basin, Stulpicani and Ostra, are supplied from phreatic groundwater. On the territory of Siret Water Basin Administration have been identified, delineated and described a number of 6 groundwater bodies, all presenting a good quality state. The delimitation of groundwater bodies has only been conducted for the areas where there are aquifers with significant importance for water supply. In the rest of the area, although there are local conditions for water accumulation in the underground, according to the 60/2000 /EC Framework Directive they are not defined as groundwater bodies. The only groundwater body delineated is the one from the lower floodplain sector, which represents an extension of the water body from Moldova river's floodplain (GWSI03).

In order to establish the groundwater bodies at risk in what regards quality have been used the key parameters specified by 60 /2000 /EC Framework Directive existing in the reports of Water Basin Administrations for 2002 and interpreted according to maximum admissible concentrations (MAC) from the 458/2002 Law of Drinkable Water. The specifications of the German Guide in this field, which consider a groundwater body at risk on the overall if at least 30% of its surface is polluted, were also applied. The phreatic aquifer corresponding to Suha basin is made of gravels and boulders and less sands, sometimes covered

Table 1
THE MAIN CHARACTERISTICS OF THE HYDROGEOLOGICAL BORES IN SUHA BASIN

Water body GW	Drilling name	Drilling indicative	Construction year	Depth (m)	Stereo coordinated		Share land drilling (m)	Filters depth (m)		NHs (m)	Water column height (m)	Pumping						River name
					X	Y		Up	Down			Q1 (L/s)	S1 (m)	Q2 (L/s)	S2 (m)	Q3 (L/s)	S3 (m)	
GWSI03	Stulpicani	F1	1972	11.00	557224.2	661521.5	62010	2.08	10.0	1.46	9.54	1.15	0.15	8.00	0.32	10.3	0.45	Gemenea
				11.00	557224.2	661521.5	62010	2.08	10.0	1.46	9.54	1.15	0.15	8.00	0.32	10.3	0.45	
		F2		10.50	557921.3	661639.4	61377	2.50	10.0	1.90	8.60	11.1	0.15	13.25	0.25	-	-	Suha
				10.50	557921.3	661639.4	61377	2.50	10.0	1.90	8.60	11.1	0.15	13.25	0.25	-	-	
		F3		4.25	558908.0	662164.7	61313	1.60	2.8	1.38	2.87	2.28	0.13	2.86	0.24	-	-	Negrileasa
				4.25	558908.0	662164.7	61313	1.60	2.8	1.38	2.87	2.28	0.13	2.86	0.24	-	-	
				4.25	558908.0	662164.7	61313	1.60	2.8	1.38	2.87	2.28	0.13	2.86	0.24	-	-	
				4.25	558908.0	662164.7	61313	1.60	2.8	1.38	2.87	2.28	0.13	2.86	0.24	-	-	

Drilling indicative	Harvesting depth (m)	pH	Fix Residue	Total hardness	O_2	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)
F1	99.9	8.6	213	6.9	-	34.0	4.8	33.0	33.0	0.00
F1	99.9	7.9	211	11.2	-	56.0	14.6	23.0	23.0	0.00
F3	99.9	7.4	378	15.4	-	80.0	18.0	31.0	31.0	0.00
F3	99.9	7.8	323	14.7	-	73.6	19.4	37.5	37.5	0.00
F3	0.0	7.6	313	13.5	8.24	0.0	13.4	14.2	0.0	0.01
F3	0.0	7.7	260	10.3	0.00	0.0	12.5	0.0	0.0	0.02
F2	99.9	7.6	297	9.8	-	68.0	6.0	35.0	35.0	0.00
F2	99.9	7.9	217	9.4	-	44.8	13.6	20.5	20.5	0.00

Table 2
GROUNDWATER QUALITY IN 2013 (further displayed in TABLE 3)

by clayey-sandy or sandy-clayey silt deposits. The mean specific flow rates are higher than 10 L/s/m, and the filtration coefficients vary between 50 – 80 m/day, with different values depending on the grain-size distribution of the deposits.

The terrains in the Suha basin occupied by the Lesu Ursului – UP Tarniţa mining complex has a surface of 71.18 ha, of which din care 24.08 ha are occupied by the proper exploitation with the following components: Lesu Ursului, Isipoaia and Paraul Ursului Put 7 enclosures, dumps, roads, pumping stations etc. 41.70 ha are occupied by Tarnita processing plant which includes: the barite flotation, the non-ferrous metals flotation, the failure pond, pumping stations and Valea Straja tailing pond.

As a result of operating and mineral processing activities resulted: mining waters (63 L/s) in the basin of the pumping station, which were mixed with tailings and hydraulically transported to the tailing pond; waters downstream U.P Tarnita which were evacuated gravitationally into Brateasa brook; water coming from Valea Straja tailing pond which were evacuated into Straja brook downstream the pond with the help reverse probes. The technology used in the processing section included: partial flotation of copper and zinc and total flotation of copper, zinc and lead, and the separation of the Cu+Zn concentrate from pyrite and tailings. The result of this technologic process is a copper concentrate with the following content: 15.49% Cu, 1.56% Pb, 3.53% Zn. To this is added a collective concentrate containing 5.65% Cu, 1.79% Pb, 46.17% Zn and waste which were deposited in the tailings pond.

The analysis of water quality on Brateasa river in Ostra section, conducted by Siret Water Basin Administration, Bacau, points out that it enters the 2nd, 3rd and 4th quality classes. Still, the movement of tailing materials from the pond might generate water pollution on Straja, Brateasa, Suha and Moldova rivers, with a strong economic and social impact. The water samples taken from the surface of the tailing pond have shown the need for reclamation. The analyses have included the water from the entrance into the reverse probe, from the exit from the reverse probe which has the role of taking over water from the pond surface, and from Straja brook (situated upstream the tailings pond).

The monitoring of groundwater quality is made constantly by Siret Water Basin Administration, Bacau through a program well established at national level, in the three bores from Stulpicani, located on Gemenea (F1), Suha (F2) and Negrileasa (F3) rivers. All the bores have been drilled in 1972, with different execution depths (F1 - 11 m, F2 – 10.5 m and F3 – 4.25 m) and water column height (9.5 m at F1, 8.6 m at F2 and 2.87 m at F3). All the three drills are managed in a pumping program established at national level (table 1) [54].

The activities of identifying phreatic groundwater quality take place in all drainage basins at hydrogeological stations which include, in the present case, three observation gauges. Their monitoring program is made through measurements of water level at 3, 6 or 15 days according to its variation, measurements of water temperature at 6 days from pumping, and periodical sampling for the determination of physical and chemical properties etc. At the gauges in Suha basin are conducted determinations for: pH, total dissolved solids, total hardness, oxygen, Ca, Mg, Na, K, Fe, ammonium, Mn, Cr, Cu, Zn, nitrites, nitrates, sulfate, bicarbonate, Cl and phosphate (tables 2 and 3).

From the national syntheses for drainage basins a fist observation drawn is linked to the critical situation of phreatic groundwater quality from some areas, determined by exogenous anthropic impact, even if lately occurred a reduction in the volume of industrial production and implicitly of quantities of polluting substances evacuated into natural receptors. In Suha basin the chemical elements which determine phreatic groundwater quality enter normal limits (without exceeding the MAC), with values of: *p*H 7.4-8.6, Ca 0.0-80.0 mg/L; Mg 4.8-19.4 mg/L, Na 0-37.5 mg/L, K 0-37.5 mg/L, Fe insignificant values; ammonium 0-0.58 mg/L; Mn 0.02 mg/L; chrome, copper and phosphate have been determined very few times, and the recorded

Drilling indicative	NH4 (mg/L)	Mn (mg/L)	Cr (mg/L)	Cu (mg/L)	Zn (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	PO_4 (mg/L)
F1	0.38	0.00	-	-	-	10.00	0.00	69.60	88.40	14.2	-
F1	0.00	0.00	-	-	-	2.60	0.00	0.00	213	17.6	-
F3	0.38	0.00	-	-	-	0.00	0.00	105	245	17.8	-
F3	0.58	0.00	-	-	-	0.00	0.06	73.0	314	28.0	-
F3	0.00	0.02	2.24	30.1	8.34	1.41	0.00	18.96	0.00	14.2	0.00
F3	0.01	0.00	0.00	0.00	0.00	1.06	0.00	16.98	0.00	12.8	0.01
F2	0.38	0.00	-	-	-	10.00	0.00	82.60	. 151	24.8	-
F2	0.00	0.00	-	-	-	4.10	0.09	36.00	170	14.2	-

Table 3
GROUNDWATER QUALITY IN 2013

values are not considered to be representative; nitrite 0-10 mg/L; nitrate 0-0.09 mg/L; sulfate 0-82.6 mg/L; bicarbonate 0-314 mg/L; phosphate 12.8-28.0 mg/L. According to the standard chemical and physic-chemical quality elements, the phreatic waters from Suha basin enter the 1st and 2nd quality classes (good waters). The analyses regard only the lower sector, which is not influenced by the old mining exploitation from Lesu Ursului. For this reason the phreatic is used for the drinkable and food industry supply.

Conclusions

From a hydrologic point of view, Suha basin presents a local importance. Water resources are rich and constant. During the communist period, when mining activities were at their peak, the need for water imposed detailed hydrogeological studies. After mining activities have stopped, a vital importance has been given to the supply with water of localities where human densities were very high. The influence of the old mining exploitation from Leşu Ursului is manifested only in the upper sector. Surface waters also influence phreatic waters. Only the groundwater body from the lower sector of the river (GWSI03) is under monitoring.

The pollution sources represented by mining activities have not stopped to day even after the closure of the complex minerals exploitation. The tailings dumps, tailings ponds and the materials remaining on the exploitation sites represent an important pollution source for surface and underground waters. The two tailings ponds are adequately constructed and pollution is practically lacking. The tailings dump is an important source of pollution only for surface waters, especially in the upstream sector. Dilution contributes to a diminishing in the pollution effects on a few kilometers downstream. The most important pollution source is represented by households, especially by stables and toilets lacking septic tanks, which affect phreatic waters in their vicinity.

The mountainous climate with high rainfall quantities, the relatively friable geological strata which ease water entering the aquifers, and the high forestation degree determine a very good quality of phreatic groundwater. Water reserves are rich especially in the wide floodplain of Suha and on its most important tributaries. An extension of the monitoring process in the upstream, especially in the circumstances in which human pressure is high, is expected.

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