HYDRODYNAMIC BEHAVIOUR ASSESSMENT OF THE MOTRU SEC – BAIA DE ARAMA KARST SYSTEM

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***Abstract*:** The Motru Sec-Baia de Arama karst system is a complex system with a recharge both diffuse by precipitations and organized from Motru Sec river swallet. The outlet is a line of sources in the Baia de Arama zone. Labeling have proved both the Danubian Autochtone carbonate deposits and karst system continuity under the Getique Nappe.

The analysis performed for the registered hydrographs of tree most important sources have provided the system complexity. The hydrodynamic behaviour is characterized by existence of two components of discharge. The first one is the fast component which gives to the system vulnerability to pollution. The second is the slowly component which gives to the system good storage capacity.
***Keywords*:** karst, system analysis, Mehedinti Mountains, Romania

HYDRODYNAMISCHE VERHALTEN-EINSCHÄTZUNG DES MOTRU SEC - BAIA DE ARAMA KARST SYSTEM

Zusammenfassung: Der Motru Sec-Baia de Arama karst System ist ein kompliziertes System mit wieder laden sowohl weitschweifig durch Niederschlag als auch organisiert von Motru Sec Fluß Ponor. Der Auslaß ist eine Linie von Quellen in der Zone von Baia de Arama.

Die Markierungen haben sowohl die Donauautochtone-Karbonat-Ablagerungen als auch karst System-Fortbestand unter dem Getique Deckblatt bewiesen. Die Analyse durchgeführt für die drei eingetragenen hydrographs des meisten wichtigen Quellen hat die System-Kompliziertheit versorgt. Das hydrodynamische Verhalten wird durch Existenz von zwei Bestandteilen der Ablauf charakterisiert. Der erste ist der schnelle Bestandteil, der zur System-Verwundbarkeit zu Verunreinigung gibt und der zweite ist langsam Bestandteil, der zum System gute Lagerungskapazität gibt.
Schlüsselwörter: karst, System-Analyse, Mehedinti Berge, Rumänien

1.Introduction

The analytical approach which is quite general in the hydrodynamic study of the aquifers does not operate in the case of karst aquifers because of karst properties. The karstification induces a discontinuity in the environment by creating structured and hierarchical voids from upstream to downstream, leading to a progressive water drainage to an unique exurgence (Mangin, 1975, 1994). Essentially, karstification leads to an hydraulic conductivity contrast between the different parts of the aquifer.

The analytical study is abandoned for the systemic approach which is based on the inlet-outlet relationship study (Mangin, 1975, 1984). Starting from the karst system entity defined by Mangin as: "The assembly at the level of which the karstic runoff is organized to build an drainage unit" the analysis of inlet and outlet function will determinate the dynamic process and, according to this one, the karst system properties will be identified and characterized.

The aim of this study was to build the better possible outlook of the Motru Sec-Baia de Arama karst system structure and behaviour by using the existing data, data which was gathered for a balance study performed by the National Institute for Meteorology and Hydrology

(Bulgăr, 1986). This image could be an answer to the questions regarding the use of the system outlets for water supply.

2. Methodology

The system analysis, which was used as working methodology for our study, was developed by Mangin (1975) for cumulated percents of the discharge analysis and also for the recession curves analysis respectively by Mangin (1984) for the correlation and spectral analysis.

2.1. Cumulated percents of the discharge analysis

To obtain the discharge cumulated percents curve a certain number of discharge classes are defined and their frequency is counted. It results the classified discharges histogram. To facilitate a model adjustment it is necessary to work with cumulated percents. A function was experimentally adjusted to the histograms (Mangin, 1975):

$$F(x) = \Pr ob(X < x) = \frac{2}{\sqrt{2\pi}} \int_0^x e^{-u^2/2} du \qquad (1)$$

When the discharge time series are homogenous, only one function can express the entire classified discharge curve, transformed in a line by anamorphosis. If there is some heterogeneity, two or tree functions will be needed. The heterogeneity could be the effect of existence of overflow witch starts to work from certain discharge values.

2.2. Recession curves analysis

Through this method, starting from physical models, a characterization of the manner in which the flood propagate and also of the depletion, is made by some numerical parameters. The model decomposes the system in two sub systems corresponding to the saturated zone, respectively to the infiltration. Those subsystems are described by the first and the second terms of the equation proposed by Mangin (1975):

$$Q_{(t)} = Q_{R0} e^{-\alpha t} + q_0 \frac{1-\eta t}{1+\varepsilon t} \qquad (2)$$

where Q_{R0} is the base flow at the moment when the recession starts (t=0) ; q_0- the flow corresponding to the vadose zone; α-depletion coefficient; η-coefficient of infiltration velocity; ε-coefficient of heterogeneity.

Moreover, through this method a distinction between different configuration types of karst systems can be made. Classification (table 1) is made according to the values of two parameters, k and i:

- k – is the report between maximal stored dynamic volume V_{dyn} calculated for a cycle and the total transit volume for the same cycle V_t ;
- i – is the value of the curve $y = \frac{1-\eta t}{1+\varepsilon t}$ for t=2 days.

Table. 1. Classification of the karst aquifers from the result of the recession curves analysis

k<0,1 i<0,25	Upstream very karstified systems Very developed speleological networks domain
0,1<k<0,5 i<0,25	Upstream well developed karst systems having downstream an important saturated karst

k<0,5 0,25<i<0,5	Systems that are more karstified upstream than downstream with delay in recharge (binary karst systems)
k<0,5 i<0,5	Complex systems domain
k>0.5	Non karstic systems

2.3. Correlation and spectral analysis

Here the karst system is assimilated to a filter which modifies, more ore less, the information contained in the inlet signal. The inlet and outlet records structures are analysed separately (simple analysis) or one against the other (cross analysis). The correlation analysis is made in the temporal domain and the spectral analysis in the frequencies domain

Simple correlation illustrates the manner in which the events are related one to each other for different time intervals. The diagram can be obtained from the expression (Iurkiewicz & Mangin, 1994):

$$r_k = \frac{C_k}{C_0} \quad (4) \qquad \text{where}: C_k = n^{-1}\sum_{1}^{n-k}(x_i - \bar{x})(x_{i+k} - \bar{x}) \quad (3)$$

The record is defined by its values x, with the mean $\bar{x}$; r is the correlation lapse of time k, k ranging from 0 to m, which is a parameter called truncation. From correlation a parameter called “memory effect” can be deduced, and it is the time in which the correlation reach the value of 0.2. The parameter characterizes the decreasing velocity of the correlation and a big memory effect proves the inertial character of the system which often is connected to the reserves magnitude.

Variance density spectrum corresponds, by Fourier transforming, to the passage from the temporal domain to the frequency domain. Because the frequency is the reverse of the period, the spectrum structure reveals

- long term trends (low frequencies);
- short term component (high frequencies);
- periodicities superior to the observation window (big spectrum values in axis origin);

Cross correlation can be obtained similar to the simple one. It expresses the inlet-outlet relationship. If inlet function can be considered as a randomly one, (rainfall case) the cross correlation shapes unitary hydro gram of the system. However, when the inlet function cannot be considered as a randomly one, the cross correlation reveals some informations on the inlet-outlet relationship: causative relation or not; the importance of the relation, etc.

The correlation and spectral analysis results were compared with the results of the same analysis applied to some well-known karst (Iurkiewicz and Mangin, 1994). The reference scale (table 4) has four parameters as classification elements:

- -memory effect directly connected to the reserves magnitude;
- -spectral width, which reveals the filter effect of the system and accordingly, the drainage organization inside the system;
- regulation time which corresponds to the duration of the unitary hydrogram;
- - the unitary hydrogram shape.

3. Geological and hidrogeological setting

The karst system Motru Sec-Baia de Arama lies in the northwest side of Mehedinți Mountains. The main river of the hydrographic network is Motru River (fig. 1). On the right bank his tributaries are Motru Sec, Motruşor and Brebina. Important for our study is Motru Sec with a hydrographic basin surface over 40 km^2, which is, sometimes totally, sinking in calcareous area.

Also, Brebina with his right bank tributary Bulba, on which downstream areas the system sources are located.

From geological point of view the area is situated in the southern part of Danubian Autochtone which displays metamorphic rocks covered by Mesozoic and Neozoic sedimentary deposits (fig. 1).

The Mesozoic formations belongs to the Jurassic and to the Cretaceous. The Jurassic starts with formation in Gresten facieses. A carbonate series of Middle Jurassic-Lower Cretaceous age follows, which thickness exceeds 500 m. The limestone lies in northern part of the area, in the Motru-Motru Sec interfluves and also in the southern part of the area in the Baia de Aramă town proximity where the system springs are located

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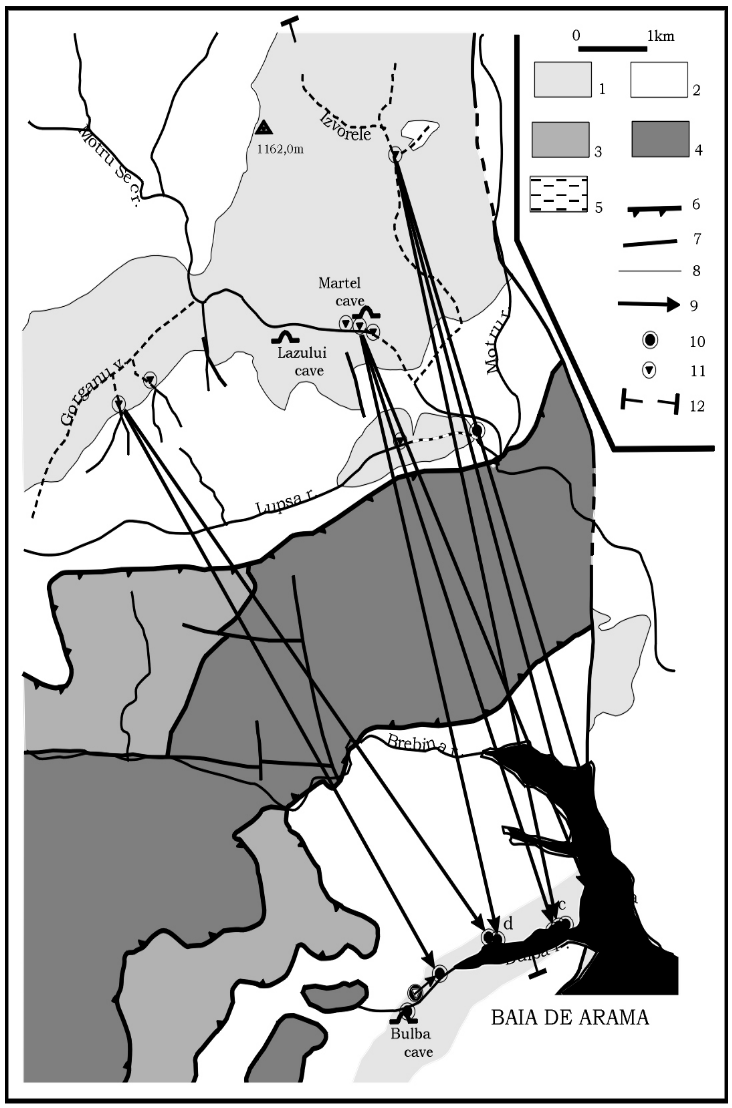
Fig.1: Hydrogeological sketch of the Motru Sec-Baia de Aramă zone 1. karst formations of the Danubian Autochtone; 2. non karst formations of the Danubian Autochtone; 3.Severin Nappe; 4. Getique Nappe; 5. Cuaternary deposits; 6. overthrust boundary; 7. fault; 8 . geological boundary; 9.tracings; 10 springs: a)Ovid ; b)Muncelu ; c)Abator ; d)Bolboros ; E)La Icoană F)Bulba Amonte ; 11. swallets; 12. Geological cross-sections (after Iurkiewicz et al., 1991 modified)



The Upper Cretaceous as well as the Neozoic formations are entirely impervious (shales, schistose clays or marls). Those deposits are covered by formations which belongs to the Getique and Severin Nappes which are generally impervious. The karst morphology displays the entire range of surface and underground features. The „E. A. Martel” and Lazului caves are to be mentioned here because in rainy periods they are acting like overflow springs for the system. (Decou et al. 1967)

The tracing experiments have proved the hydrogeologic connections between the Motru Sec and his tributary Gorganul and the Baia de Aramă springs (Slăvoacă et al.,1970), as well as the connection between the Isvorele stream (left tributary of Motru Sec) and the same sources (Diaconu 1989). These experiments are also important because they have proved the limestone continuity under the Getique and Severin Nappes (see tab.2).

One special mention we have to make for the experiment performed by Povară in 1992 (verbal information). He has labeled the Bulba Amonte estavella while it was functioning as a swallet. The tracer appeared in “La Icoană” spring after 52 hours (see fig 1.).

Table 2. Features of the labelings of the Motru Sec-Baia de Aramă karst system

Swallet	Gorganul July 1970			Motru Sec October 4, 1983			Isvorele October 2,1989		
Source	H(m)	L(km)	t(d)	H(m)	L(km)	t(d)	H(m)	L(km)	t(d)
Ovid	-	-	-	-	-	-	407	9.8	15
Muncel	175	9.2	3	75	8.1	5	405	9.7	15
Abator	-	-	-	-	-		390	10	15
Bolboros	150	8.4	3	50	7.9	5	380	10	15
La Icoană	159	8.6	3	-	-		-	-	-

4. Data acquisition

For our study we have used the time series for tree sources situated near of Baia de Aramă village as follows:(fig. 1):

1. Ovid Spring with discharge serial ranging from 20.08.1977 to 31.12.1987
2. Muncel Spring with discharge serial ranging from 20.08.1977 to 31.12.1987
3. Abator Spring with discharge serial ranging from 01.01.1977-30.06.1986

Discharge values were computed from two daily records on limnimetric lines. As input signal we used, in a first approach, the daily records of the rainfall at Cloşani station in the upstream area of the Motru river basin. In the second approach according to the importance of Motru Sec water loses in the karst area (difference value between upstream and downstream measured yields ranges from 0,166 to 2,450 m^3/s) we considered as input signal the Motru Sec yields recorded at hydrometric station Valea Pietrei which is located upstream of the karstic area.

5. Results and discussion

5.1. Discharge cumulated percents analysis

Ovid and Muncel springs have similar behaviour (fig. 2). The small water regime ranges up to 210 l/s for Ovid and 250 l/s for Muncel spring. The percentage of small discharges is around 50 %. For discharges over 410 l/s for Ovid spring and 430 l/s for Muncel spring it seems that an overflow spring starts to flow.

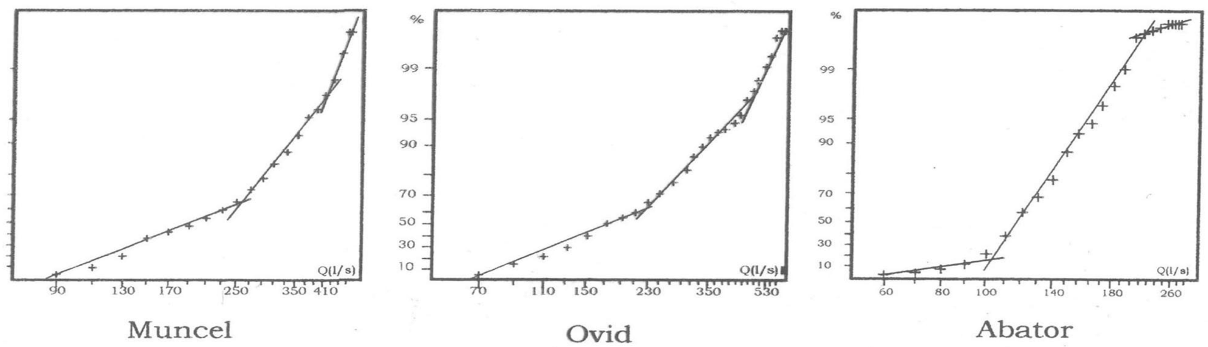


Fig.2 : Cumulated percents of the discharges

Abator spring have a peculiar behaviour. The small water regime was installed for flow rates bellow 110 l/s which represents under 30%. This behaviour is probably the effect of Bulba Amont estavella functioning as swallet in dry seasons Over 210 l/s flow rates the source seems to feel some contributions from other areas of the system. We have to remark that the Abator spring is situated between Ovid and Muncel sources on the one hand and the Bulba Amont estavella on the other hand. This leads us to suppose that the Abator spring is an intermediary overflow spring.

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5.2. Recession curves analysis

There are two reasons that make us to regard cautiously the results of this analysis:

- the method considers as an initial hypothesis that the hydrograph results from an unit rainfall (Dirac type signal), but the floods preceding the recessions are the snow melting result which is, more or less, a slow phenomena
- the Motru Sec River loses are very strong (more than 0.166 m^3s). This phenomena leads to an overestimation of the parameters regarding the saturated zone (depletion coefficient –α and dynamic stored water volume – Dyn vol).

The parameters that result from the recession curves analysis are shown in table 3. We have delimited two recessions for Ovid spring and three for Muncel spring. We also studied two recession curves for the Motru Sec River (cycles with the biggest and the smallest mean flow rate) for a better understanding of its influence on the regulation capacity of the system.

For the Motru Sec River the parameters (small depletion coefficients and big dynamic stored water volumes) shows a big regulation capacity. This fact is reflected in the values of calculated parameters for the system recession curves. So, the depletion coefficients are very small (0,0004-0,0022 for Muncel spring and 0.0004-0,001 for Ovid spring) the dynamic volumes are very big as well as the k parameters (1,5-6,5). Those parameters, according to the Mangin's classification excludes the system from those with karstic behaviour

Table 3. Recession curves parameters

Para-meter	Ovid		Muncel			Motru Sec	
	1983	1987	1982	1983	1986	1983	1986
α	0,0004	0,0010	0,0022	0.0019	0.0004	0.0008	0.0020
$Q_{R0}(m^3/s)$	0.136	0.067	0.293	0.142	0.138	0.340	0.334
t_i(days)	16	31	15	11	104	37	171
V_{dyn}	$29.4*10^6$	$5.6*10^6$	$11.1*10^6$	$6.7*10^6$	$28.5*10^6$	$35.6*10^6$	$10.3*10^6$
i	0.77	0.81	0.67	0.76	0.89	-	-
k	6.05	2.30	1.50	1.45	4.16	-	-

For the Abator source we could not delineate a recession period. The lack of such a period must be related to the Bulba Amont estavella which in recession periods behave as a sinkhole.

5.3. Correlation and spectral analysis results

Input signals analysis

First of all we have to notice that the correlation short term analysis (observation window with truncation m=125 days and step k=1 day) performed on the rainfall shows that this signal is randomly (fig. 3). We have also performed a spectral analysis on the filtered record of the rainfall (mobile equiponderate mean with 80 days amplitude and observation window with m=750 days and k=6 days). This analysis displays 6 months respectively 12 months periodicities (fig.4).

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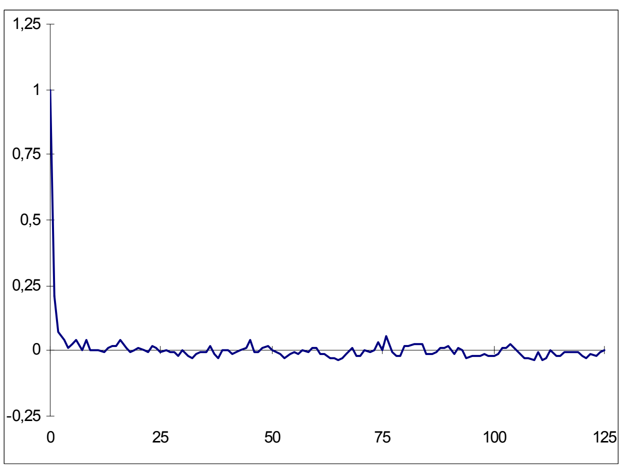


Fig. 3. Simple correlation of the rainfall

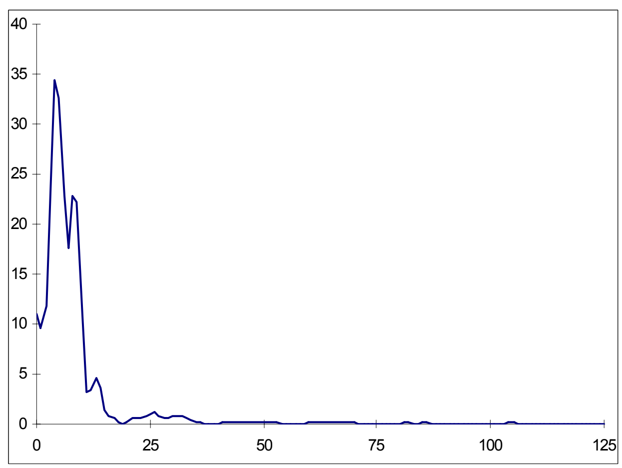
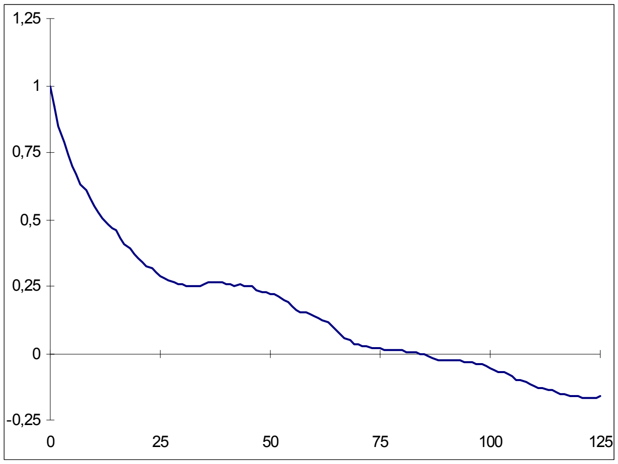


Fig 4. The rainfall variance density spectrum



The second input signal is a structured one (fig. 5). The correlation coefficient reaches the 0.2 value after 54 days, which means a „54 days memory effect”. In the same time the diagram reveals two components of the runoff. The first one is a rapid one, expressed by the strong decreasing in the origin vicinity (nugget effect). The second component of the runoff is a slow one and is revealed by the diagram slope recovery starting after approximately after 30 days. This component is generated, probably, by superficial aquifers in the basin.

Fig. 5. Simple correlation of the Motru Sec

<u>Output signal analysis. Simple correlation</u>

The correlation shape (m=125 days, k=1 days) for all three studied springs shows an extremely slow decreasing of the correlation coefficient, behaviour that expresses a trend which hide the small periodicities and makes any interpretation of the diagram unsatisfactory (fig. 6). To eliminate the trend effect we have analyzed the residual time series that results by filtering the records with a equiponderate mobile mean that have a 365 days amplitude (fig 7).

The Ovid and Muncel simple correlation have similar behaviour. The correlation coefficient r_k=0.2 value is reached after 61 respectively 60 days that proves the big system inertia (important „memory effect”). It can be also observed a weak „nugget effect” characteristic of a rapid component of the runoff.

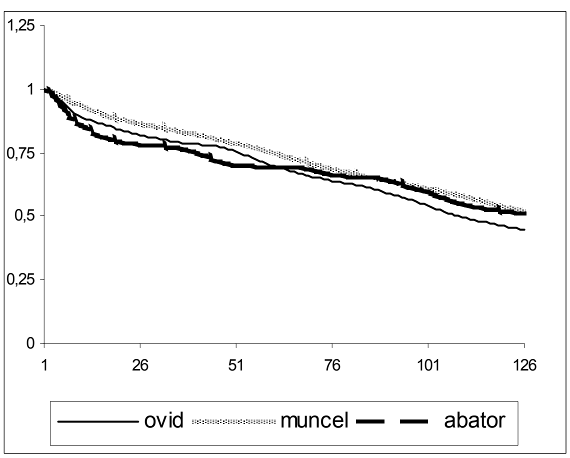


Fig. 6. Simple correlation of the flow rates

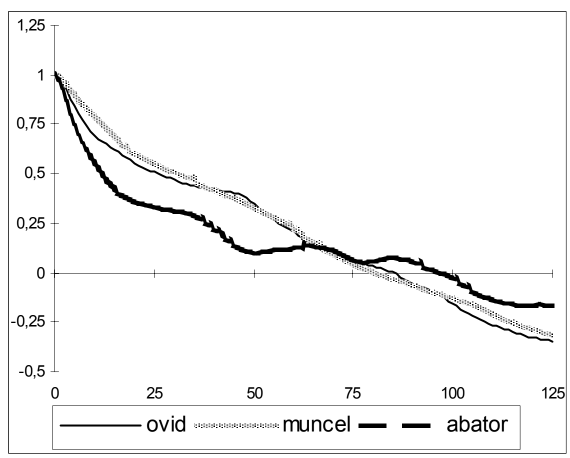


Fig. 7. Simple correlation on the filtered record

The Abator spring reveals, as in the case of cumulated percents, a peculiarly behaviour. So, the 0.2 value of the correlation coefficient is reached after 41 days which means a smaller inertia. In the same time, in the origin vicinity it can be seen a strong decreasing up to 15 days of the diagram (nugget effect) which means that the rapid component of the runoff is more important for this source. The strong decreasing is followed by an oscillatory decreasing that seems to confirm the complex behaviour supposed for the Abator spring.

<u>The cross analysis</u>

The cross analysis of the sources flow rates against the rainfall displays a weak correlation between the two signals. However, the unit response is quite clear shaped for each of the three charts. The shape suggests the importance of the slow component of the runoff. In the case of the Abator spring, the bigger value of the peak near the origin seems to confirm that for this source, the rapid component of the runoff is more important.

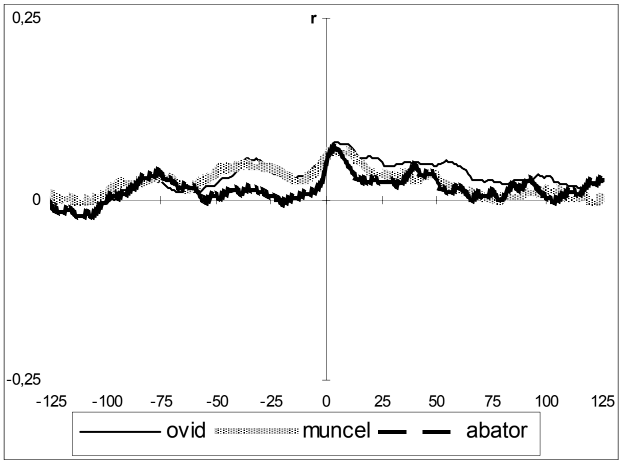


Fig. 8. Cross correlation: rainfall against springs flow rates

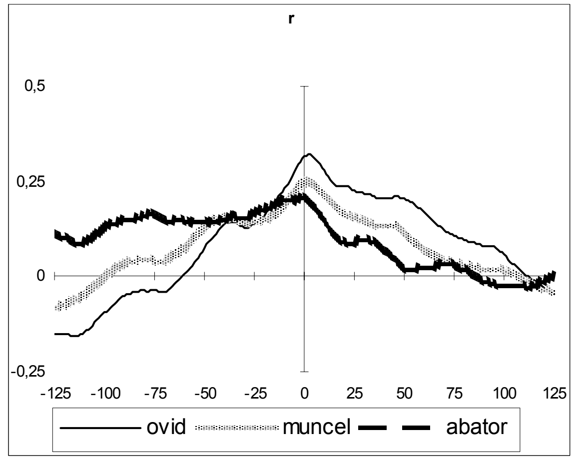


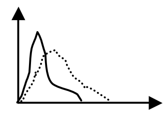
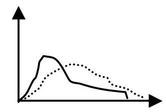
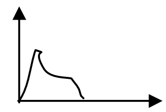
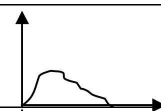
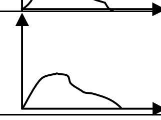
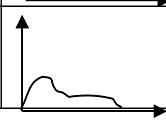
Fig. 9. Cross correlation; Motru Sec against springs flow rates

As we already mentioned, the importance of the Motru Sec loses in the karst area has lead us to study the relationship between the river flow rates and system outlets (fig 9). Unlike the correlation with rainfall, the spring discharges correlate much well with the Motru Sec flow rates. The cross correlograms of Muncel and Ovid springs shows again similar behaviour. As we already mentioned, the importance of the Motru Sec loses in the karst area has lead us to study the relationship between the river flow rates and system outlets (fig 9). Unlike the correlation with rainfall, the spring discharges correlate much well with the Motru Sec flow rates. The cross correlograms of Muncel and Ovid springs shows again similar behaviour. The maximal values of the correlations are r_k=0.282 for Muncel source and respectively r_k=0.320 for Ovid spring. Unfortunately, because of the fact that the input signal is not a randomly one, the correlation shape do not displays the unitary hydrogram of the system. The cross correlation shows positive values in the negative part of the abscissa which, in fact, represents the correlation with the input signal memory.

The cross correlation of the Abator spring displays, one more time, a different shape, the decreasing of the diagram being stronger and oscillatory which indicate the importance of the fast component in his recharge. The maximal value of correlation coefficient is r_k=0.205 and it is touched right in the origin In the same time it can be remarked the slow decreasing of the diagram on the negative side of the axis. Those facts suggests a good connection between Motru Sec loses and the slow component of the runoff at the sources

In the second part of the table 4 we have the values of the obtained parameters in the frame of correlation and spectral analysis. The parameters show identical behaviour for the Muncel and Ovid springs. These parameters values indicate for the Motru Sec-Baia de Arama karst system a Fontestorbes type behaviour. The parameters for the Abator source show again peculiar behaviour. The parameters values situates this spring behaviour between Fontestorbes and Baget types. Just the unitary hydrogram follow the general behaviour of the system.

Table 4. Classification of karstic aquifers according to the results of correlation and spectral analysis and the results of this analysis for the karst system Motru Sec-Baia de Aramă.

Types	«Memory effect»		Spectral width	Regulation time		Unitary hydrogram
	raw	filtered		raw	filtered	
Aliou	Poor 5 days		Very wide (0,30)	10-15 days		
Baget	Small 10-15 days		wide (0,20)	20-30 days		
Fontestorbes	Large 50-60 days		Tight (0,10)	50 days		
Torcal	Extensive 70 days		Very wide (0,05)	70 days		
Motru Sec la Valea Pietrei	54 days		0,15	50 days		
Muncel	>125 days	61	0,10	103 days	58 days	
Ovid	>125 days	60	0,10	98	55 days	
Abator	>125 days	41	0,13	96 days	40 days	

The strength of the connection between the flow rates of the Motru Sec river and system outlets was confirmed by the cross analysis. Cross correlation coefficients are big by comparing them with those of the correlation with rainfall but according to the fact that the input signal is a structured one, the cross correlation does not shape the unitary hydrograph of the system. The peculiar behaviour of the Abator source situated between Fontestorbes and Baget types as well as the peculiar shape of the cross correlation leads to the same hypothesis that this spring is strong influenced by a fast component of the runoff.

6. Conclusions

The Motru Sec-Baia de Aramă karst system is a complex system which did not allowed us an analytical approach. However, the system analysis reveals some informations regarding the hydrodynamic behaviour and the internal structure synthesized in fig.10. The chart displays a system defined by the subsystems interactions network and by the input-output relationship of each subsystem. The conclusions that spotlights this diagram are:

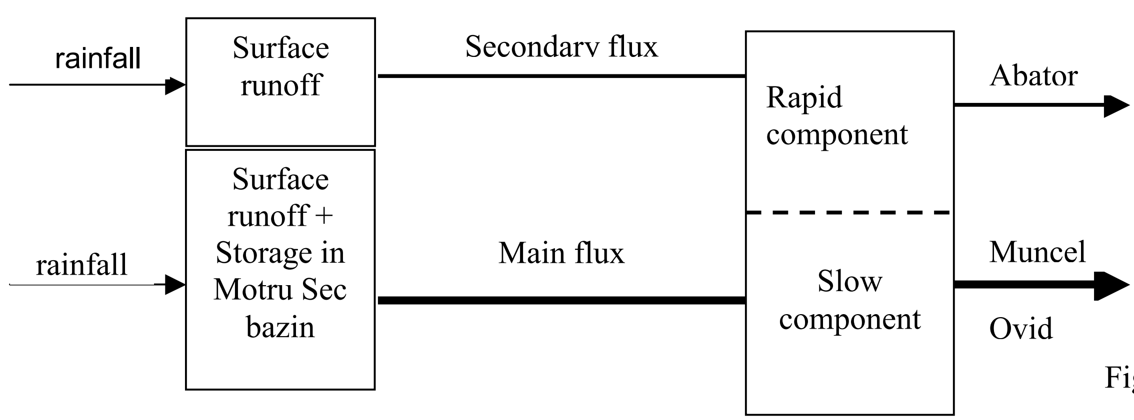
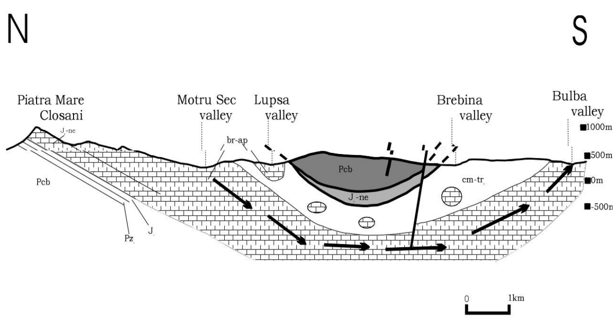
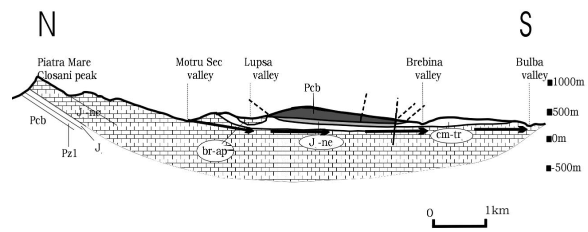


Fig.10

a) From geological point of view the tecto-structural image general accepted today for the Motru Sec-Baia de Aramă area is that of a syncline with carbonate deposits on flanks and impervious formations of Getique and Severin Nappes in the axis (Pop et al. 1975). The depth of the carbonate formation top is supposed to be at 1000 m in the axis (fig. 11). More recently, Diaconu(1989) elaborated a new hypothesis. In his point of view the thickness of the impervious formations in the axis is much smaller (fig. 12).





Geological cross section in Motru Sec - Baia de Arama area (after Diaconu 1989, modified)

Geological cross section in Motru Sec - Baia de Arama area (after Pop et al., 1975)

The existence of a rapid component of the runoff as well as the short time of mass transfer between inlets and outlets are strong arguments for the second hypothesis.

b) From hydrodynamic point of view. The Ovid and Muncel springs are the main outlets of a slow component of the runoff. The connection of this component with Motru Sec River loses makes this component as vulnerable as the fast one to chemical or physical pollution. One of the fast components of the runoff outlets is Abator spring.

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