Carpathian Journal of Earth and Environmental Sciences, July 2017, Vol. 12, No. 2, p. 513 - 524

STABLE ISOTOPE HYDROLOGY OF PRECIPITATION AND GROUNDWATER OF A REGION WITH HIGH CONTINENTALITY, SOUTH CARPATHIANS, ROMANIA

Ana-Voica BOJAR[1,2], Stanisław HALAS[3], Hans-Peter BOJAR[2] & Stanisław CHMIEL[4]

[1]*Department of Geography and Geology, Salzburg University, Hellbrunnerstraße 34, A-5020 Salzburg and Department of Mineralogy, ana-voica.bojar@sbg.ac.at*
[2]*Studienzentrum Naturkunde, Universalmuseum Joanneum, Weinzöttlstraße 16, A-8045 Graz, Austria.*
[3]*Mass Spectrometry Laboratory, Institute of Physics, UMCS, 20-031 Lublin, Poland.*
[4]*Faculty of Earth Sciences and Spatial Management, Maria Curie-Skłodowska University, ul. Kraśnicka 2cd, 20-718 Lublin, Poland*

Abstract; Stable isotopic composition of hydrogen and oxygen of precipitation and groundwater along with climatic information from a region situated in the external part of the South Carpathians were collected every month from 2012 to 2015. Climate monitoring indicates that the region is characterised by a high continentality index, and seasonal distribution of precipitation amount. The $\delta^{18}O$ and δD values in precipitation varied from -4.0‰ to -15.9‰ and -22.8‰ to -118.8‰, respectively The LMWL for the monthly based data is $\delta D = 7.40*\delta^{18}O + 4.4$ showing the effect of secondary evaporation of falling raindrops with lower intercept and slope. The significant relationship between $\delta^{18}O$ and δD values and average air temperature is $\delta^{18}O = 0.36T - 13.36$ ($r^2 = 0.69$, n = 40) and $\delta D = 2.57T – 92.80$ ($r^2 = 0.58$, n = 40), respectively. The distribution of deuterium excess over the year indicates seasonal variation for the origin of moisture, with high values during wintertime. We interpret this as the result of the input of seasonal related Mediterranean moisture during the late autumn and winter. 3-D modelling of spring distribution shows the presence of mainly two aquifer levels, slightly deepening toward south and southeast. The isotopic distribution of groundwaters reflects weighted mean of the $\delta^{18}O$ and δD of precipitation, -9.8 and -67.8 respectively, demonstrating locally derived groundwaters.

Key words: stable isotopes; continentality, precipitation; moisture sources, groundwater; South Carpathians

1. INTRODUCTION

The Mehedinți country is situated in the extra-Carpathian area, between the South Carpathians to the north and Danube to the south. During the last decade, extreme events as temperature maxima (Tomozeiu et al., 2002; Rimbu et al., 2014) and droughts (Stefan et al., 2004; Cheval et al., 2014) have been documented for the region. Busuioc et al., (2014) compiled for the period 1961-2010 increasing temperatures and concluded that in wintertime the increasing trend is higher over the extra-Carpathian regions and in summertime over the entire country. Increasing mean annual temperatures in Romania and neighbourhood countries have been also documented by Efthymiadis et al., (2011), Bârsan et al., (2014), Cheval et al., (2014) and Bajat et al., (2015).

The Dumbrava area investigated in this study, part of the Mehedinți district, is represented by a plateau situated between 200 and 350m elevation crossed from north-west to south-east by dry valleys, which cut Pleistocene clastic deposits (Fig. 1 a). Through these valleys water is flowing only temporarily after strong storms or during rainy periods. For the period 1961-2010, Vladut & Ontel, (2014), compiled a general trend of decreasing precipitation amount. The primary source of drinking and irrigation is related to natural springs or more recently to wells. During summer and early autumn, population and crops suffer of water shortage and heat.

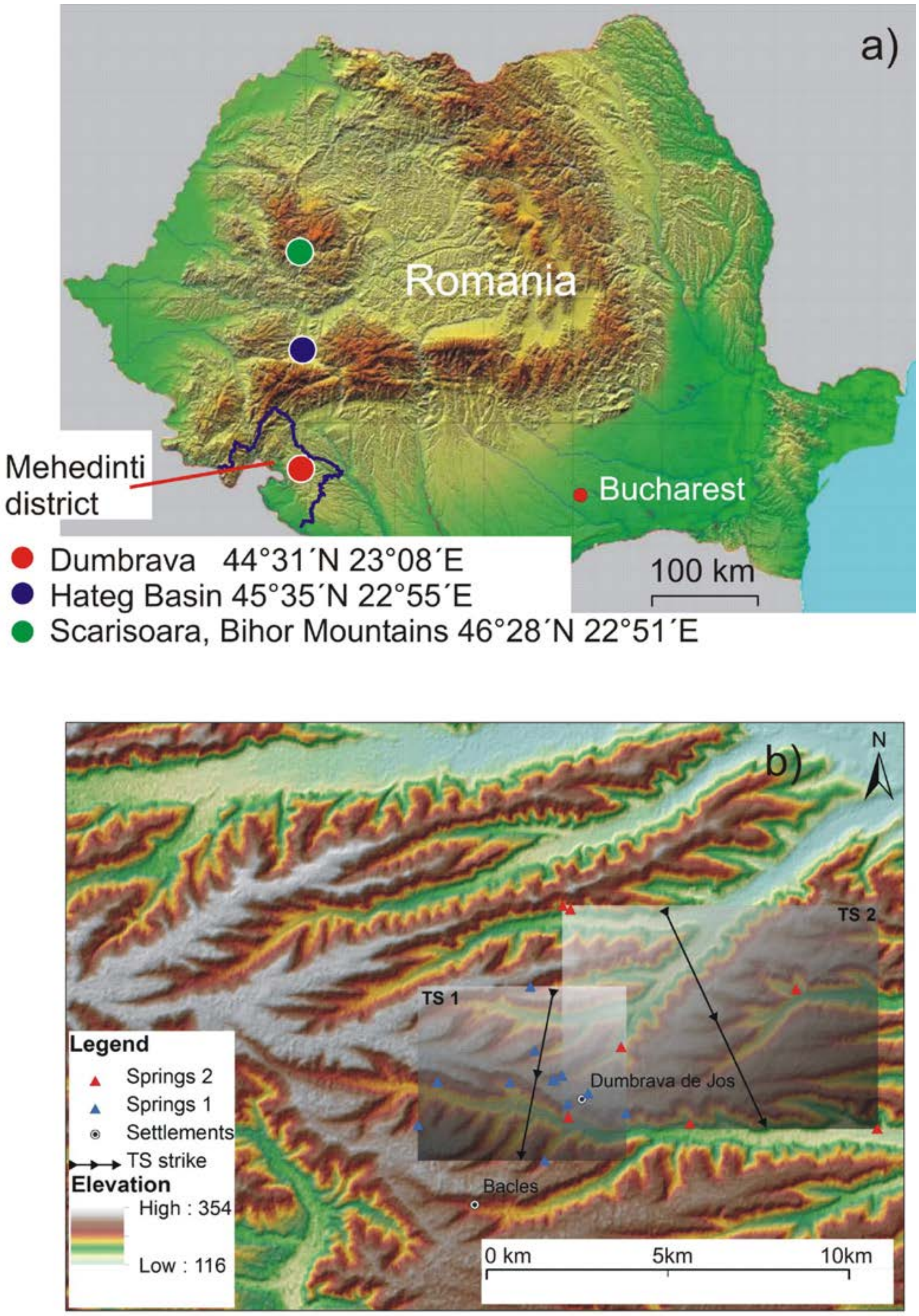

Figure 1. Location of the investigated regions with position of: a) precipitation sampling sites; b) groundwater sampling sites in the Dumbrava region, Mehedinți district and the position of the aquifer planes TS1 and TS2. The mapped areal encompass c. 100 km^2.

Since the hydrology of Dumbrava area with medium to low quantity of precipitation and strong seasonality is sensitive to changes in climatic conditions, the present study considers aspects of climate and water supply during April 2012 to July 2015. This study aims are to (i) bring a complete data set concerning daily and seasonal temperature and humidity variations; (ii) determine the Local Meteoric Water Line (LMWL) and sources of moisture for the region; (iii) investigate seasonal variation for the source of moisture and local effects during precipitations; (iv) determine the spatial position of aquifers and their isotopic signatures.

2. MATERIAL AND METHODS

The data set consists of monthly monitoring of precipitation isotopic composition and amount, regional distribution of springs and their isotopic composition and variations of air temperature and humidity monitored each half an hour. The data were collected over three years. The results are given in Tables 1 and 2. We present below the collecting and measurement methodology.

2.1 Precipitation samples

40 precipitation samples were collected from April 2012 to July 2015 using a collector with paraffin oil added to prevent evaporation (De Groot, 2009). The location has been collected monthly representing integrated precipitation samples and has been monitored for amount and stable isotope composition (Table 1). For precipitation, plastic barrels were used, through a plastic funnel attached to the mouth of a barrel and every month an aliquot was sampled and stored for analyses. The surface of water in the barrel was coated with liquid paraffin. Before resuming collection, the barrel was emptied, cleaned and dried. Dust was settled on the bottom of the water and the decanted water was taken for analysis.

Table 1. Isotopic composition of precipitation, air temperature, humidity and amount of rainfall for the Dumbrava region.

Month	$\delta^{18}O$ (‰)	δD (‰)	d-excess (‰)	Rainfall (cm)	Air temp. (°C)	Humidity
April 2012	-7.5	-50.5	9.9	1.9	8.0	88.7
May	-7.3	-45.4	12.7	7.3	13.5	77.8
June	-5.3	-37.3	4.7	2.5	21.0	70.4
July	-4.0	-22.8	9.0	8.6	25.1	67.5
August	-5.9	-46.5	0.7	0.3	24.5	48.1
September	-7.2	-51.5	6.1	1.1	20.4	52.7
October	-7.9	-50.5	12.6	53	13.8	70.3
November	-7.9	-51.0	12.5	1.6	7.4	86.2
December	-14.1	-96.5	16.3	6.1	-0.8	85.8
January 2013	-15.9	-118.8	6.6	7.3	0.2	89.5
February	-12.5	-88.2	11.5	11.0	2.0	77.5
March	-9.6	-69.2	7.6	7.3	5.2	81.6
April	-7.4	-48.8	10.1	8.2	8.0	77.8
May	-6.9	-46.3	9.2	5.7	13.5	70.4
June	-8.6	-63.1	5.7	4.1	21.0	53.9
July	-5.6	-38.0	6.5	10.6	25.0	53.9
August	-3.6	-32.9	-3.8	3.3	23.6	62.2
September	-9.6	-67.0	9.9	6.1	16.4	66.8
October	-10.2	-73.5	8.6	26.9	12.0	80.9
November	-14.7	-103.9	14.0	14.9	7.9	86.5
December to February	-15.2	-113.0	8.6	12.2	1.1	87.4
March	-14.6	-108.0	8.9	4.1	9.0	73.6
April 2014	-8.4	-58.5	9.0	10.6	10.7	72.5
May	-10.6	-77.4	7.4	11.7	15.4	79.7
June	-6.7	-42.7	10.8	12.6	19.1	76.6
July	-4.9	-30.5	8.8	9.0	21.3	74.3
August	-4.90	-27.46	11.75	9.0	21.3	74.3
September	-6.82	-41.54	13.03	6.0	21.8	-
October	-8.55	-49.60	18.78	9.1	16.9	-
November	-8.55	-49.74	18.63	5.6	11.3	-
December	-13.90	-98.04	13.18	7.4	5.1	-
January	-14.03	-99.11	13.15	7.1	1.8	-
Feburary	-12.17	-82.92	14.44	5.1	1.2	-
March	-10.02	-65.03	15.16	7.3	1.0	-
April	-6.03	-41.33	6.89	2.8	5.5	-
May	no rain	no rain	-	no rain	11.4	-
June	-4.53	-33.52	2.69	9.5	17.8	-
July	-2.84	-19.77	2.93	0.5	20.5	-
Mean	**-8.8**	**-60.5**	**9.6**		**12.7**	**75**
Amount-weighted mean	**-9.8**	**-67.8**	**9.3**			

Table 2. Description of spring locations investigated in this study and their isotopic composition.

Sample	Month	Long	Lat	Elev. (m)	$\delta^{18}O$ (‰)	δD (‰)	pH
VM2_2012	May, 2012	23°09'17"	44°30'33"	229	-10.26	-71.21	6.9
VM3_2012	June	23°09'17"	44°30'33"	229	-10.34	-71.91	6.9
VM3bis_2012	July	23°09'17"	44°30'33"	229	-10.33	-71.98	
VM4_2012	July	23°09'17"	44°30'33"	229	-10.38	-72.08	
VM5_2012	August	23°09'17"	44°30'33"	229	-10.46	-72.24	
VM6_2012	September	23°09'17"	44°30'33"	229	-10.41	-72.19	
VM7_2012	October	23°09'17"	44°30'33"	229	-10.37	-72.09	
VM8_2012	November	23°09'17"	44°30'33"	229	-10.44	-72.36	
VM9_2012	December	23°09'17"	44°30'33"	229	-10.42	-72.28	
VM10_2013	January	23°09'17"	44°30'33"	229	-10.4	-72.32	
VM11_2013	Feburary	23°09'17"	44°30'33"	229	-10.47	-72.53	
VM12_2013	March	23°09'17"	44°30'33"	229	-10.78	-71.01	
I1_2013	July	23°08'26"	44°32'29"	281	-9.88	-70.46	7
I3_2013	July	23°06'33"	44°31'02"	265	-10.19	-72.02	7
I4_2013	July	23°06'10"	44°30'23"	277	-10.53	-73.71	6.3
I5_2013	July	23°06'26"	44°30'48"	255	-4.7	-40.91	7
I6_2013	July	23°08'49"	44°29'54"	260	-10.41	-72.43	6.6
I8_2013	July	23°09'08"	44°31'10"	277	-9.48	-70.23	6.3
I9_2013	July	23°08'33"	44°31'32"	274	-9.61	-68.86	6.6
I10_2013	July	23°08'03"	44°31'03"	261	-9.94	-70.44	6.3
I11_2013	July	23°10'29"	44°30'38"	270	-10.64	-75.37	6.6
I12_2013	July	23°09'16"	44°30'45"	277	-10.28	-73.51	6.9
I14_2013	August	23°15'43"	44°30'29"	194	-9.96	-72.15	6.6
I15_2013	August	23°13'58"	44°32'32"	230	-10.38	-73.81	6.6
I16_2013	August	23°10'21"	44°31'37"	210	-10.12	-70.99	6.6
I17_2013	August	23°09'04"	44°33'42"	234	-10.1	-72.31	7
I18_2013	August	23°09'14"	44°33'39"	223	-10.21	-72.46	7
I19_2013	August	23°11'49"	44°30'30"	214	-10.3	-73.09	6.6
I20_2013	August	23°11'18"	44°30'15"	230	-10.33	-73.5	6.3
I21-2014	May	23°08´41´´	44°30´55´´	277	-10.07	-70.88	
I22-2014	May	23°08´57´´	44°31´7´´	277	-10.31	-71.86	
I23-2014 (same location as I3)	May	23°06´33´´	44°31´02´´	265	-10.06	-70.38	
I24-2014 (same location as I5)	May	23°06'26"	44°30'48"	255	-8.26	-61.55	

The water samples were stored in bottles with a small neck. The bottles were filled completely and closed tightly preventing evaporation. On the surface of water a thin film of paraffin was added and the bottle were stored in a cool and dark place.

2.2 Air temperature and humidity

Air temperature and humidity were measured every 30 minutes using a data logger. The monthly average for both air temperature and humidity are given in Table 1.

2.3 Ground and surface water sample*s*

A total number of 35 samples from springs, water well and lake water were collected (Table 2). Unfiltered water samples were collected in plastic bottles as described above. One spring (23°09'17" and 44°30'33", Valea Mare) was sampled monthly, from May 2012 to March 2013. The other springs, the drill well and surface water from a temporary lake were collected in July 2012 and May 2014 (Table 2).

2.4 Stable isotopic analyses

Water samples were analysed for δD and $\delta^{18}O$ at the Maria Curie-Skłodowska University, Lublin, Poland. Analyses were done using a Picarro water analyser. Laboratory standards, previously calibrated to the VSMOW-VSLAP scale were OH-13 (δD = -2.84‰, $\delta^{18}O$ = -0.96‰) and OH-16 (δD =

-114.68‰, $\delta^{18}O$ = -15.43‰). These standards were used to normalize the results to the VSMOW-VSLAP scale. The laboratory precision was ±1.0‰ for δD and ±0.2‰ for $\delta^{18}O$ values.

2.5. 3-D modelling of spring locations

The position of springs was mapped in the field by means of a GPS-apparatus. In order to visualize the spatial context of spring positions, we employed a Digital Elevation Model (DEM) of 30 meters spatial resolution, derived from SPOT (Satellite Probatoire d'Observation de la Terre) imagery. The spring GPS position and altitude were imported in ArcGIS® (ESRI, 2011) as a shapefile, based on the geographic coordinates. The shape file, as well as the DEM were projected into Romanian system (Stereo 70). According to observations obtained from a N-S axiometric projection, the samples were split into two sets and trend surfaces (TS) were calculated from each set. For each TS, the first order polynomial regression was performed on the recorded altitude values to fit a least-squares plane to the set of points. Azimuth and slope gradient were then calculated for each TS. The modelling is illustrated in Fig. 1b.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of meteorological data

The meteorological data set of Dumitrescu & Bârsan, (2015) shows that, over the year, the Mehedinți district is characterised by highly variable climatic conditions with large differences within regions. For the present study, we collected data between 2012 and 2015. The integration of these data over this period indicates mean temperatures of 12.7°C, and mean precipitation of 817 mm, in Table 1 also monthly values are given. Barry and Chorley, (2009) proposed a quantitative formula in order to estimate continentality index at a given site: $K = 1.7*\Delta T/\sin(\phi)-24.4$, where ΔT is the annual temperature range (°C) and ϕ is the latitude. Accordingly, we calculate the continentality index for the investigated site as well as for other three neighbouring stations (Table 3). The data demonstrate that, among the others sites, the present station is characterized by an index of 40, and the largest difference between mean temperature for summer (July) and winter (January) of 25°C. Continentality index map over Europe (Barry & Chorley, 2009) indicates only one region for central Europe with an index over 40, the Dumbrava site investigated in this study being located in the northern part of this area.

Regarding daily variations, maximal summer temperatures may increase up to 37°C during the day, with late spring and summer day to night temperature variations reaching up to 18°C. Also for summer, day-night humidity variations are up to 35% with a minimum humidity recorded daily of 20%. Winter temperatures may reach -15°C during the night, temperature variation day-night are of a few degrees, day-night humidity variations of up to 10%. The dominant rainy seasons are winter and spring, while the driest months are May to September with periods characterised by drought.

Table 3. Characteristic parameters for individual stations

Station	Slope (‰ $C^{-}1$)	Intercept (‰)	Mean T (°C)	Altitude (m)	Mean $\delta^{18}O$ (‰)	Lat.	T_{Max}-T_{Min}	Continentality (Barry & Chorley, 2009)
Dumbrava, Romania (this study)	0.36	-13.36	12.7	335	-8.8	44°30'33"	25	41
Lubljana, Slovenia (Vreca et al., 2006, 2008)	0.29	-11.86	10.6	299	-8.6	46° 3'25.01	21	31
Zagreb – Gric, Croatia (Barešić et al., 2006; Vreca et al., 2006)	0.33	-12.6	12.9	157	-8	45°48'54.03	20.9	27
Debrecen, Hungary (Vodila et al., 2011)	0.32	-11.33	9.9	110		47°31'53.78	22.8	35

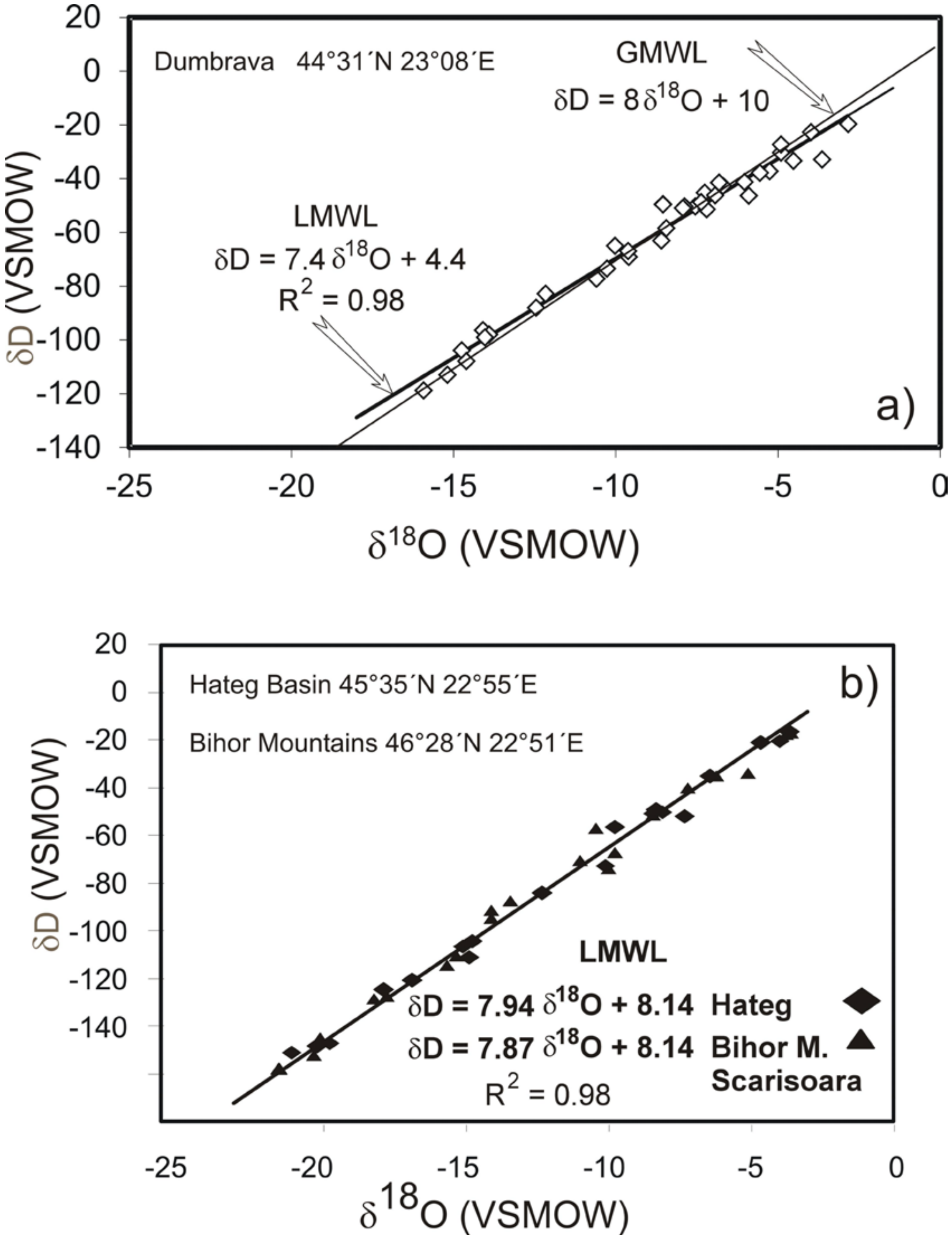

Figure 2. The LMWL compared with the GMWL for: a) Dumbrava, b) Hațeg basin and Scărișoara area, Bihor Mountains (Bojar et al., 2009)

The intensive agricultural and farm activities are subject to considerable drought stress because of: 1) increase in number and length of periods without rain; 2) water shortage related to inefficient use of the local resources.

3.2 Stable isotope distribution in precipitation

Isotopic compositions of 40 precipitation samples collected between April 2012 and July 2015 are presented in Fig. 2a. Data concerning precipitations as well as monthly average temperature and humidity are given in Table 1. The δD and δ^{18}O values range from -119‰ to -23‰ and -16‰ to -3‰, respectively. Amount-weighted mean for δD and δ^{18}O values are -67.8‰ and -9.8‰ respectively. Regression of the data results in a highly significant local meteoric water line (LMWL): $\delta D = 7.40*\delta^{18}O + 4.4$ ($r^2 = 0.98$) with a lower slope than the global meteoric water line

(GMWL) (Craig, 1961). The LMWL has a slight lower slope than for the intramontane Haţeg basin (South Carpathian Mountains) and Scărişoara area (Bihor Mountains) with $\delta D = 7.9*\delta^{18}O+8.14$ ($r^2 = 0.98$), as shown in Fig. 2b (Bojar et al., 2009).

The higher mean for the δD and $\delta^{18}O$ values for the present extra-Carpathian site (mean δD of -60.5 and $\delta^{18}O$ of -8.8) in comparison to Haţeg (mean δD of -76.04 and $\delta^{18}O$ of -10.6) and Scărişoara sites (mean δD of -88.60 and $\delta^{18}O$ of -12.2), reflects that temperature effect overwhelms the rainout process. In this case, the rainout process is related to the fact that vapour masses from Atlantic preferentially lose deuterium and ^{18}O as they move over the Carpathian Mountains toward the areas situated southward, including the present investigated site which has an extra-Carpathic position.

The $\delta^{18}O$ and δD values of the monthly integrated precipitation and the air temperature (T°C) for the monitored interval were plotted on a $\delta^{18}O$ and δD versus temperature diagrams (Fig. 3, 4). The significant relationships between $\delta^{18}O$ and δD values and average air temperature are $\delta^{18}O = 0.36T - 13.36$ ($r^2 = 0.69$, n = 40) and $\delta D = 2.57T – 92.80$ ($r^2 = 0.58$, n = 40) demonstrating temperature-dependent seasonality. Monthly distribution of isotopic values and rainfall amount shows that lower δD and $\delta^{18}O$ values occur in winter to early spring interval (November–April), higher values occur in the late spring to fall interval (May–October) (Fig. 5, 6). Low $\delta^{18}O$ and δD values correlate with higher precipitation amount and low air temperature, high $\delta^{18}O$ and δD values with both low precipitation and high air temperature. The determined slope for $\delta^{18}O$/T of 0.36 is higher than for other intracontinental stations (Table 3).

The deuterium excess (d-excess), defined as $d = \delta D - 8\delta^{18}O$ (Dansgaard, 1964), provides information concerning evaporation of water for the oceanic or continental moisture source region (Rozanski et al., 1993; Araguas-Araguas et al., 2000; Pfahl & Sodemann, 2014). High d-excess values are associated with low atmospheric humidity (Merlivat & Jouzel, 1979). For Europe, values of d-excess around 10‰ indicate moistures of Atlantic origin, whilst values higher than 14‰ indicate moistures from the Mediterranean realm (Gat & Carmi, 1970; Celle-Jeanton et al., 2001).

Secondary evaporative effects at the site of precipitation after condensation, as evaporation of falling rain drops in warm and dry atmosphere, will lower d-excess values (Gat and Carmi, 1970; Stewart, 1975; Froechlich et al., 2008; Managave et al., 2015). In this study, d-excess values range between 18.8 ‰ and -3.9‰, with an amount weighted mean of 9.3 ‰ and a mean of 9.6 ‰ (Table 1, Fig. 7 a, c), low values occurring during summer and high values during winter months. We interpret late autumn and winter d-excess with values up to 18.8‰ as indicative for moisture transport from the Mediterranean Sea. Also, at the present investigated site, evaporative processes occur during summer months, which are characterized by high temperatures and large day-night humidity and temperature oscillations. For example, in July 2013 registered day-night temperature variations spanned from 37°C to 19°C and relative humidity from 20% to 62%.

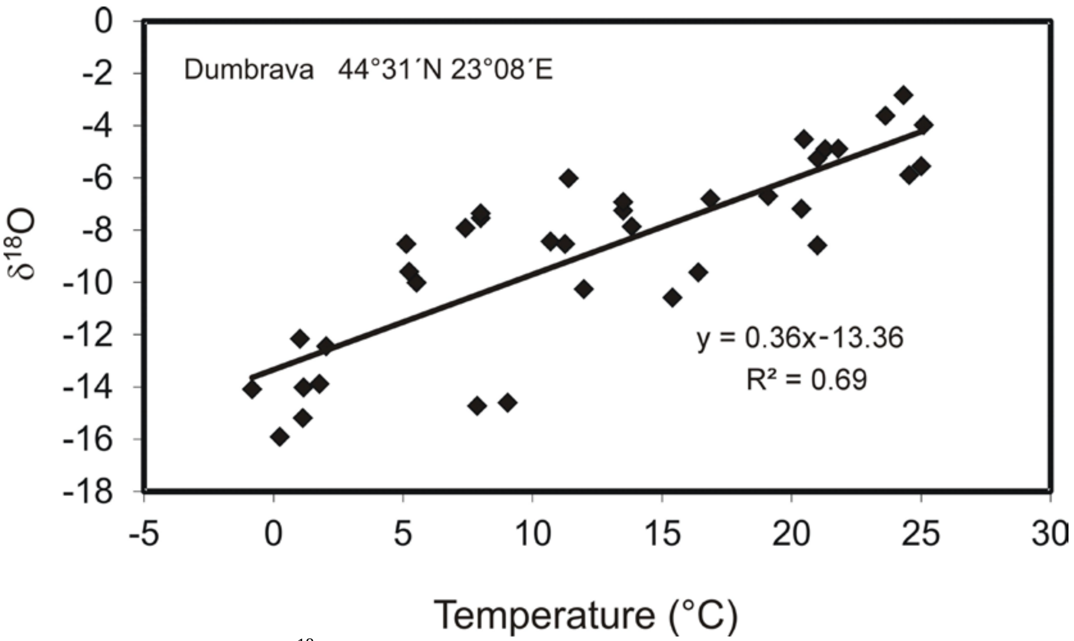

Figure 3. Monthly mean $\delta^{18}O$ in precipitation and air temperature, April 2012 through July 2015.

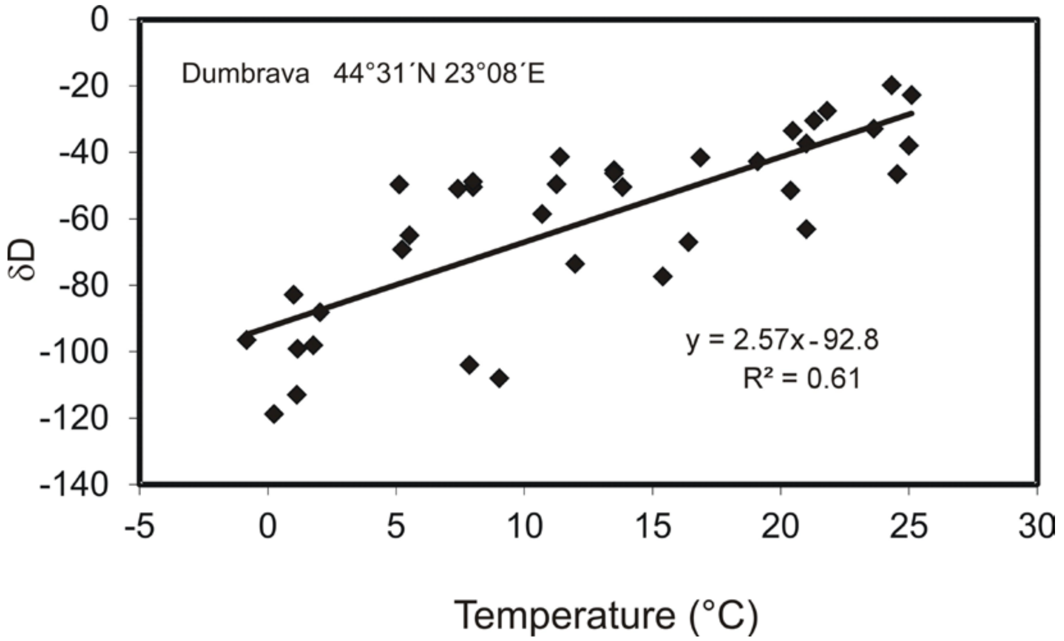

Figure 4. Monthly mean δD in precipitation and air temperature, April 2012 through July 2015.

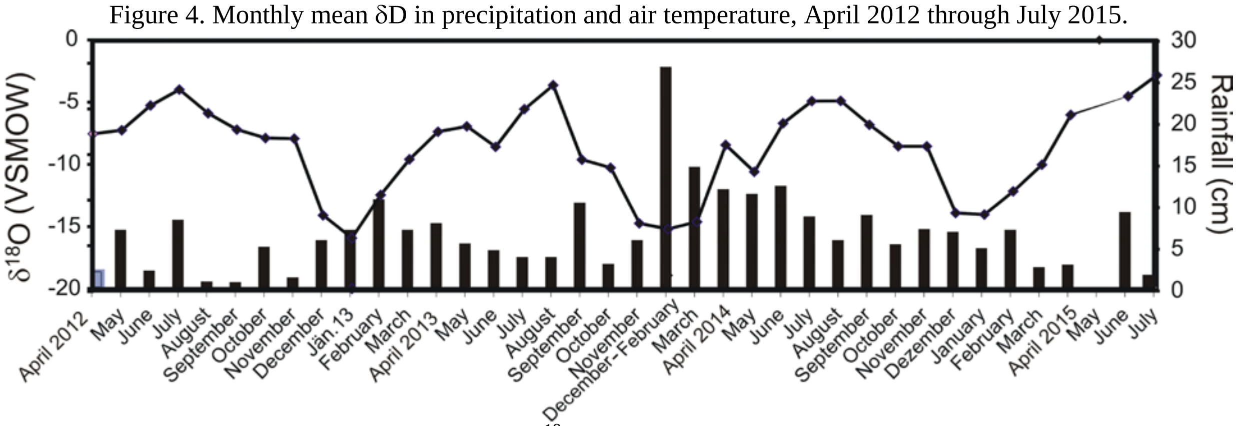

Figure 5. Temporal variation of the monthly mean $\delta^{18}O$ values vs. rainfall amount, April 2012 through July 2015. The red horizontal line represents the amount-weighted mean.

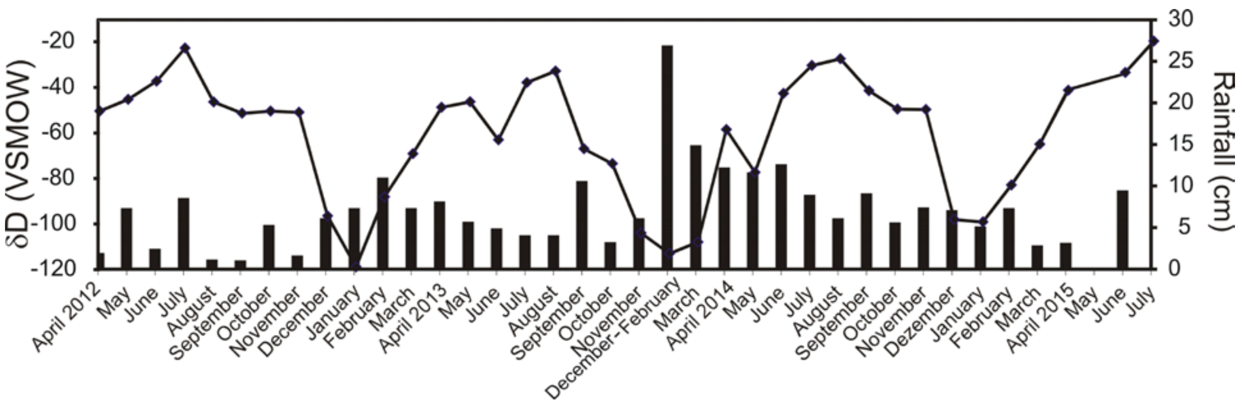

Figure 6. Temporal variation of monthly mean δD vs. rainfall amount, April 2012 through July 2015. The red horizontal line represents the amount-weighted mean.

Such conditions drive partial evaporation of falling rain drops, thus summer low d-excess values related to sub-cloud evaporation processes. For the intramontaneous Hațeg the mean d-excess value of 8.8‰ (Fig. 7 b) is lower than for Dumbrava, accordingly we suggest that Mediteranean moisture input is less significant at this site.

Seasonal variation of d-excess, with high values over late autumn and winter were put in evidence for the continental Lubljana station (Vreca et al. 2006, 2008) for Zagreb (Barešić et al., 2006; Vreca et al., 2006) and for Debrecen (Vodila et al., 2011). Hunjaka et al., (2013) came to a similar result for the investigated stations from Croatia, namely that deuterium excess values are higher during the winter time. For littoral stations like Portoroz (Vreca et al., 2005, 2006), seasonal d-excess variation is even more pronounced, with maxima during winter. Using distributions of humidity fronts, Sodemann & Zubler, (2010) investigated the sources of moisture for Alpine precipitations. The authors show that the Alps, especially the Southern Alps, receive a large fraction of precipitation from the Mediterranean Sea. Moreover the amount of moisture from the Mediterranean Sea shows strong seasonality, with maxima during autumn and winter months. The conclusion of Sodemann and Zubler, (2010) study agrees with the present investigation, supporting that at regional scale, high deuterium-excess values are characteristic for late autumn and winter and are related to increasing moisture input from the Mediteraneean Sea.

3.3 Stable isotope distribution in groundwater

Groundwater was collected from natural springs and wells from an area covering c. 100 km^2 (Fig. 1 b). According to the geological map sheet Craiova (1968), springs are situated into Lower Pleistocene clastic deposits. Two aquifer horizons were put in evidence by mapping the springs and 3-D modelling of the data. These aquifers show an altitude between 190 m to 230 m (TS 2) and 250 m to 290 m (TS 1) (Fig. 1 b and Fig. 8). Inclinations of ~0.25° of the TS planes toward south south-east were derived from the 3D modelling of mapped spring positions.

Isotopic compositions of groundwater samples are given in Table 2 and plotted in Fig. 8 and Fig. 9. The pH values vary from 6.3 to 7, i.e. spring waters being slightly acid to neutral. Some of the springs from the higher elevation aquifer, TS1 are drying during the summer months.

The mean δD and $\delta^{18}O$ values of all spring waters are -70.7‰ and -10.0‰, respectively. These values are similar with the amount-weighted mean of -67.8‰ and -9.8‰, determined for precipitation. One spring from the group situated at lower altitude TS2, namely the VM spring (elevation 229 m) was sampled every month, between May 2012 to March 2013. If we consider the variation of VM spring over the year, than mean δD and $\delta^{18}O$ values are -72‰ and -10.4‰ thus with -4.2‰ and -0.6‰ respectively lower than the amount-weighted mean of precipitation.

Integrating worldwide available isotopic compositions of precipitation and groundwater, Jasechko et al., 2014 conclude that: isotopic composition of groundwater close matches amount-weighted mean for precipitation and in seasonal climate regions lower isotopic values of groundwater express higher winter recharge ratio. In the present study, our data support as well that lighter isotopic composition of groundwater in respect to the isotopic composition of precipitation are related to recharge of aquifer during the cold season.

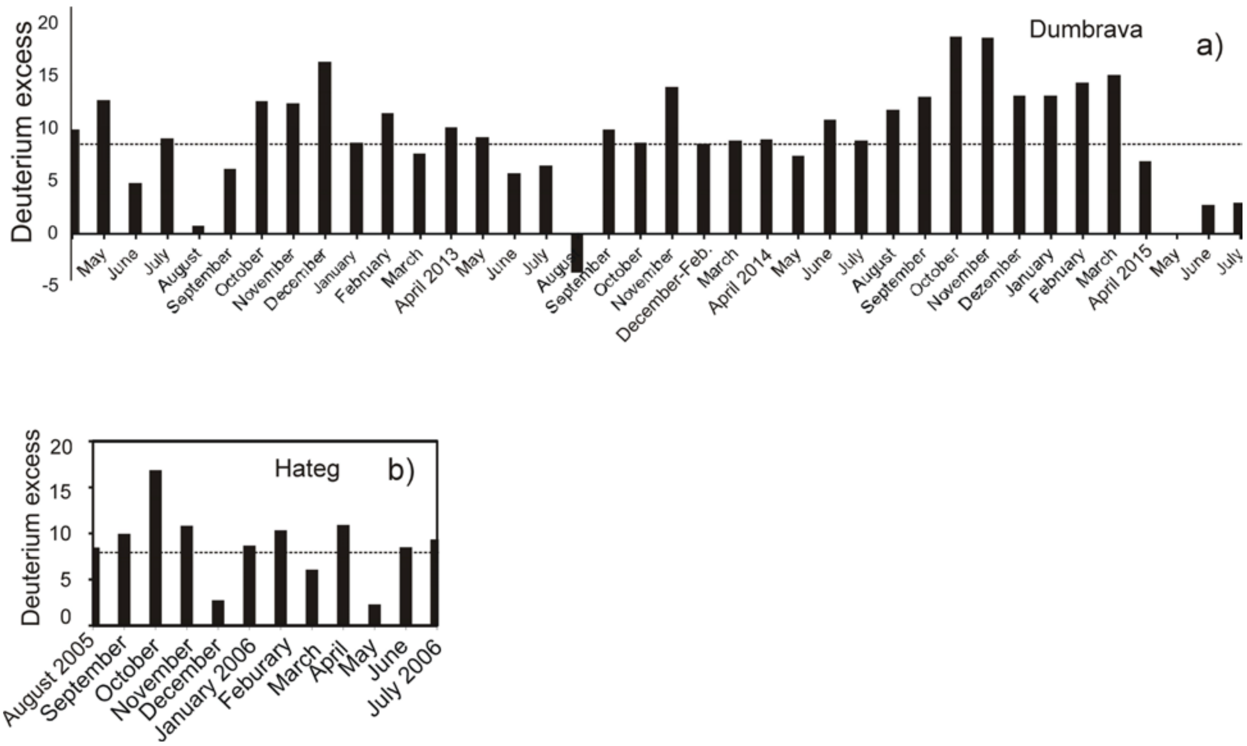

Figure 7. Deuterium-excess distribution in precipitation, April 2012 through July 2015. a) Dumbrava; b) Hațeg.

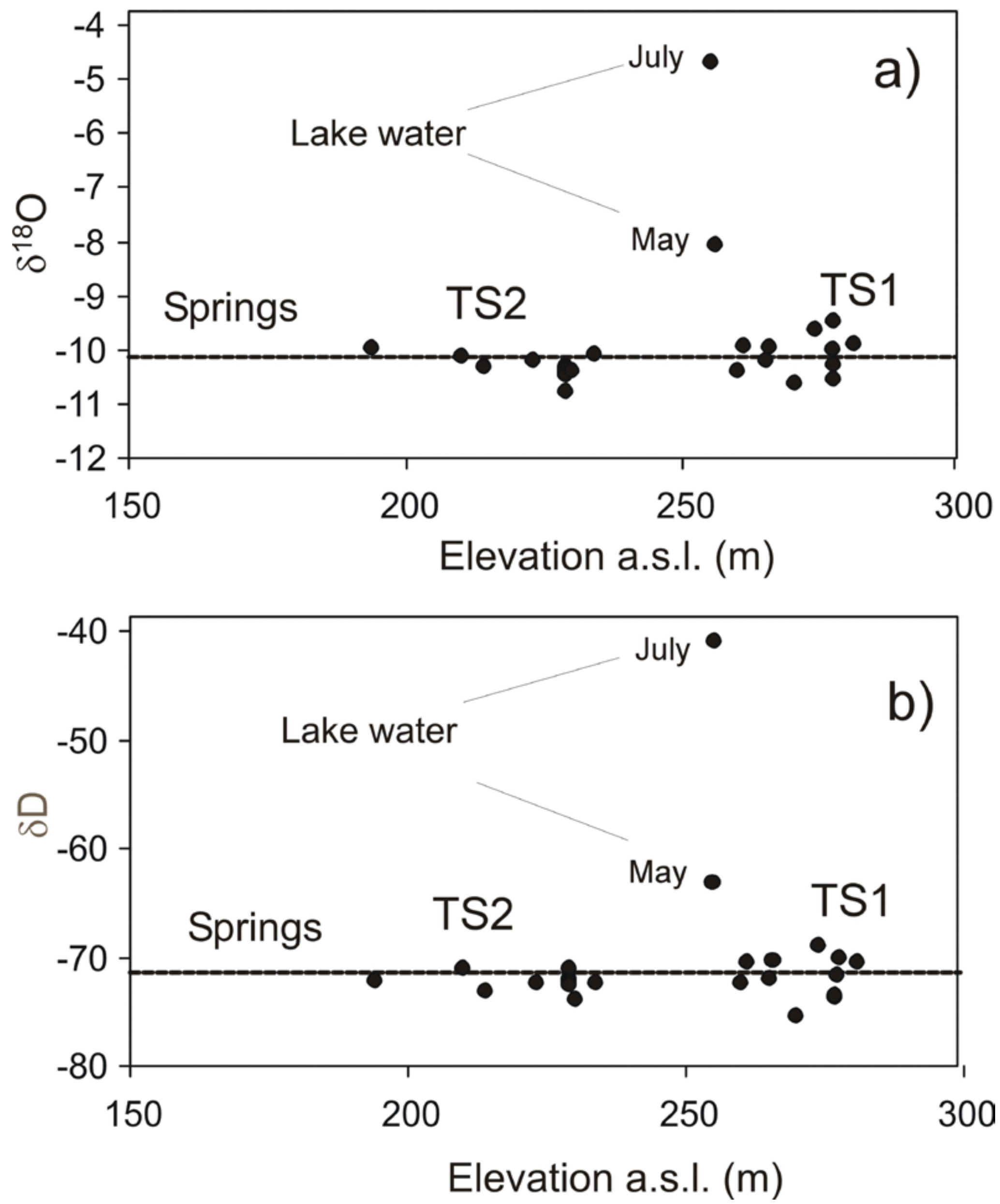

Figure 8. a) $\delta^{18}O$ and b) δD of spring waters versus elevation.

Moreover, our calculated $\delta^{18}O_{groundwater}$-$\delta^{18}O_{precipitation}$ and $\delta D_{groundwater}$-$\delta D_{precipitation}$ values are characteristic for temperate grasslands and forests (Jaseckho et al., 2014).

Progressive isotopic enrichment of evaporating surface waters is dependent on relative humidity of air, temperature and salinity (Gonfiantini, 1986; Gibson et al., 2016). The isotopic composition of surface waters subjected to evaporation evolves along a line with a lower slope than that of the local meteoric water line.

This line, described as the local evaporation line (LEL), originates at the initial isotopic composition of the water prior to evaporation and exhibits increasing D and ^{18}O contents along with degree of evaporation. Evaporating water bodies are therefore characterized by a displacement of the isotopic composition in a δD–$\delta^{18}O$ diagram along the LEL. The isotopic composition of springs and lake (two data point for samples collected in May and July) determine the Local Evaporation Line (LEL) represented by the equation $\delta D = 5.41*\delta^{18}O - 16.5$ ($r^2 = 0.96$, n = 35) with slope of 5.4 characteristic for surface waters situated in temperate regions (Gibson et al., 2016).

4. CONCLUSIONS

The collection of precipitation for Dumbrava region, Mehedinți district, resulted in a local meteoric water line of $\delta D = 7.40*\delta^{18}O + 4.4$ with amount-weighted mean δD and $\delta^{18}O$ of -67.8‰ and -9.8‰, respectively.

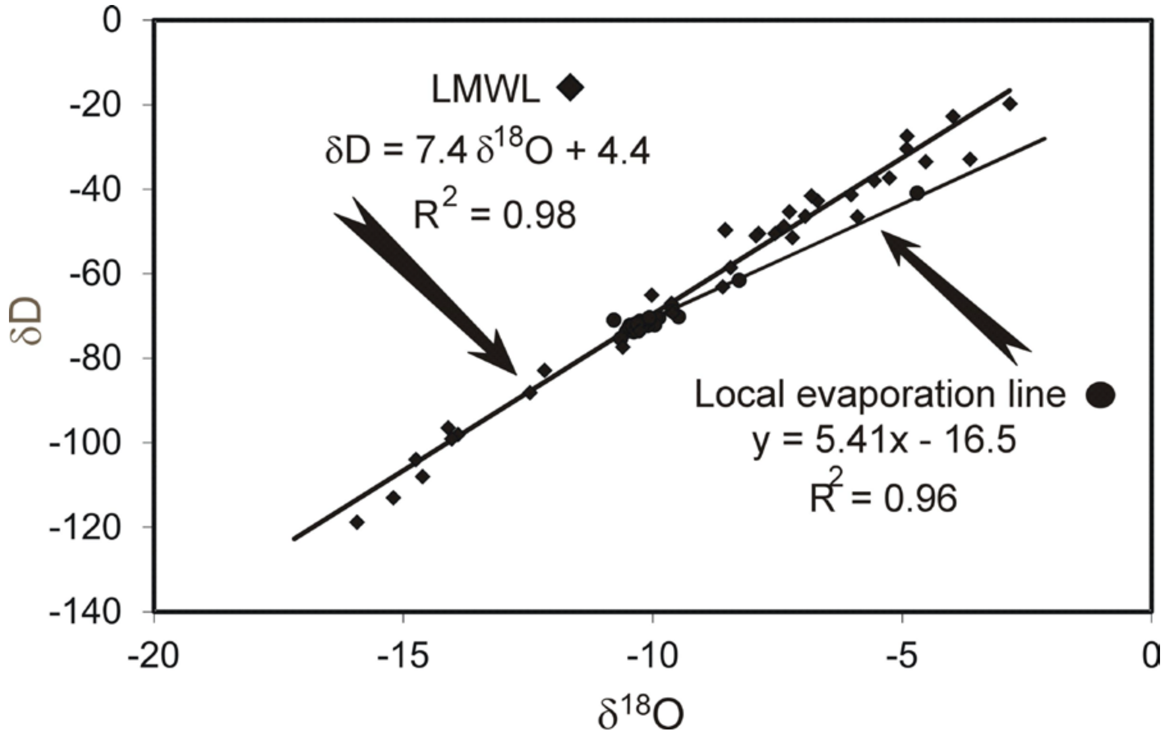

Figure 9. Isotopic composition of springs and lake plotted with the LMWL. The isotopic composition of spring water and lake determine the Local Evaporation Line (LEL) displayed with orange colour.

Collection of meteorological data indicates a high continentally index with a value of over 40. Seasonality of the isotopic composition of precipitation is evident, we propose that summer precipitation is affected by processes such sub-cloud evaporation of rain. D-excess seasonal distribution supports moisture input from the Mediterranean realm during the late autumn and winter months.

Mean δD and $\delta^{18}O$ values indicate that precipitation is source for water for both aquifers TS1 and TS2. Spring variations for the TS 1 group are dominantly influenced by climate, including amounts of precipitation gain and summer evaporation loss. Moreover, basin scale evaporation during summer is also indicated by the δD and $\delta^{18}O$ values of lake water, which are higher and offset from the weighted mean of annual precipitation and springs, indicating basin scale evaporation. Qualitatively, aquifer recharge ratio is higher for to the cold season.

The demonstrated interconnectivity between precipitation and aquifers should be seriously considered when deciding areas for waste disposal. This issue is not related only to the investigated site but for all the areas with multiple aquifer levels situated in Miocene and Quaternary clastic rocks of the intra- and extra-Carpathian regions.

Acknowledgements

The authors thank to Lucian Draguț for 3-D modelling of spring locations, to Vistiana Pauleț for carefully sampling and storying water samples and to CEEPUS for the mobility grant to Ana-Voica Bojar that facilitated the collaboration with Mass Spectrometry Laboratory, MCS University. We appreciate constructive comments on the early version of the manuscript by Christophe Lecuyer. Marian Lupulescu is thanked for careful reading of the manuscript and valuable suggestions.

REFERENCES

Araguas-Araguas, L., Froehlich, K. & Rozanski, K., 2000. *Deuterium and oxygen-18 isotope composition of precipitation and atmospheric moisture*. Hydrologycal Processes 14,8, 1341–1355.

Bajat, B.., Blagojević, D., Kilibarda, M., Luković, J. & Tošić, I., 2015. *Spatial analysis of the temperature trends in Serbia during the period 1961–2010*. Theoretical and Applied Climatology, 121, 289–301.

Bârsan, M.-V, Dumitrescu, A., Micu, D.M. & Cheval, S., 2014. *Changes in annual temperature extremes in the Carpathians since AD 1961*. Natural Hazards, 74, 1899–1910.

Barešić, J., Horvatinčić, N., Krajcar Bronić, I., Obelić, B. & Vreča, P., 2006. *Stable isotope composition of daily and monthly precipitation in Zagreb*. Isotopes in Environmental and Health Studies, 42, 3, 239-249.

Barry, R.G. & Chorley, R.J., 2009. *Atmosphere, Weather and Climate*. Published by Routledge, ISBN 978-0-415-46570-0, 506 pp.

Bojar, A.-V., Ottner, F., Bojar, H.-P., Grigorescu, D. & Persoiu, A., 2009. *Stable isotope and mineralogical investigations on clays from the Late Cretaceous sequences, Haţeg Basin, Romania*. Applied Clay Sciences 45, 155–163.

Busuioc, A., Dobrinescu, A., Birsan, M.V., Dumitrescu, A. &

Orzan, A., 2014. *Spatial and temporal variability of climate extremes in Romania and associated large-scale mechanisms.* International Journal of Climatology, 1278-1300.

Celle-Jeanton, H., Travi, Y. & Blavoux, B., 2001. *Isotopic typology of the precipitation in the Western Mediterranean region at three different time scales*. Geophysical Research Letters, 28,7, 1215-1218.

Cheval, S., Busuioc, A., Dumitrescu, A. & Birsan, M.V., 2014. *Spatiotemporal variability of the meteorological drought in Romania using the Standardized Precipitation Index (SPI).* Climate Research, 60, 235–348.

Craig, H., 1961. *Isotopic variations in meteoric waters*. Science, 133, 1702–1703.

Craiova geological map 1:200.000, Sheet 41, Geological Institute of Romania, 1968.

Dansgaard, W., 1964. *Stable isotopes in precipitation*. Tellus, 16, 436–468.

De Groot, P., 2009. *Handbook of Stable Isotope Analytical Techniques*, Volume 2, Elsevier, 1372 pp.

Dumitrescu, A. & Bârsan, M.-V. 2015. *ROCADA: a gridded daily climatic dataset over Romania (1961–2013) for nine meteorological variables.* Nat Hazards, doi:10.1007/s11069-015-1757-z.

Efthymiadis, D., Goodess, C.M. & Jones, P.D., 2011. *Trends in Mediterranean gridded temperature extremes and large-scale circulation influences*. Nat. Hazards Earth Syst. Sci., 11, 2199–2214.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Froehlich, K., Kralik, M., Papesch, W., Rank, D., Scheifinger, H. & Stichler, W., 2008. *Deuterium excess in precipitation of Alpine regions – moisture recycling*. Isotopes in Environmental and Health Studies, 44, 1, 1–10

Gat, J.R. & Carmi, I., 1970. *Evolution of the isotopic composition of atmospheric waters in the Mediterranean Sea area.* Journal of Geophysical Research, 75, doi:10.1029/JC075i015p03039.

Gibson, J.J., Birks, S.J. & Yi, Y., 2016 *Stable isotope mass balance of lakes: a contemporary perspective*. Quaternary Science Review, 131, 316-328.

Gonfiantini R., 1986. *Environmental isotopes in lake studies.* In: Handbook of Environmental Isotope Geochemistry (eds Fritz, P. and Fontes, J. – Ch.), B. Elsevier, Amsterdam, vol. 2, The Terrestrial Environment, 113-168.

Hunjak, T., Lutz, H.O. & Roller-Lutz, Z., 2013. *Stable isotope composition of the meteoric precipitation in Croatia*. Isotopes in Environmental and Health Studies, 49, 3, 336–345.

Jasechko, S., Jean Birks, S., Gleeson, T., Wada, Y., Fawcett, P. J., Sharp, Z.D., McDonnell, J. J. & Welker, J.M., 2014. *The pronounced seasonality of global groundwater recharge*. Water Resour. Res., 50, 8845–8867, doi:10.1002/2014WR015809.

Managave, S.R., Jani, R.A., Narayana Rao, T., Sunilkumar, K., Satheeshkumar, S. & Ramesh, R., 2015. *Intra‐event isotope and raindrop size data of tropical rain reveal effects concealed by event averaged data.* Climate dynamics, doi:10.1007/s00382-015-2884-7.

Merlivat, L. & Jouzel, J., 1979. *Global climatic interpretation of the deuterium-oxygen 18 relationship for precipitation*. Journal of Geophysical Research, 84, 5029–5033.

Pfahl, S. & Sodemann, H., 2016. *What controls deuterium excess in global precipitations?* Clim. Past, 10, 771–781.

Rimbu, N., Stefan, S. & Necula, C., 2014. *The variability of winter high temperature extremes in Romania and its relationship with large-scale atmospheric circulation.* Theoretical and Applied Climatology, doi:10.1007/s00704-014-1219-7.

Rozanski, K., Araguas-Araguas, L. & Gonfiantini, R., 1993. *Isotopic patterns in modern global precipitation*. In: Swart, P.K., et al (eds.), Climate Change in Continental Isotopic Records. Geophysical Monography Series, 78, 1–36.

Sodemann, H. & Zubler, E., 2010. *Seasonal and inter-annual variability of the moisture sources for Alpine precipitation during 1995–2002.* International Journal of Climatology, 30, 947–961.

Stefan, S., Ghioca, M., Rimbu, N. & Boroneant, C., 2004. *Study of meteorological and hydrological drought in southern Romania from observational data.* International Journal of Climatology, 24, 871–881.

Stewart, M.K., 1975. *Stable isotope fractionation due to evaporation and isotopic exchange of falling water drops: applications to atmospheric processes and evaporation of lakes.* Journal of Geophysical Research, 80, 9, 1133–1146.

Tomozeiu, R., Busuioc, A. & Stefan, S., 2002. *Changes in seasonal mean of maximum air temperature in Romania and their connection with large-scale circulation.* International Journal of Climatology, 22, 1181–1196.

Vladut, A. & Ontel, I., 2014. *Analysis of precipitation characteristics and trends for for the Getic Piedmont and Subcarpathians, Oltenia region, Romania.* Forum geografic. Studii și cercetări de geografie și protecția mediului 13(2):147-152.

Vodila, G., Palcsu, L., Futó, I. & Szántó, Sz., 2011. *A 9-year record of stable isotope ratios of precipitation in Eastern Hungary: Implications on isotope hydrology and regional palaeoclimatology.* Journal of Hydrology 400:144–153.

Vreca, P., Kanduc, T., Žigon, S. & Trkov, Z., 2005. *Isotopic composition of precipitation in Slovenia*. In Isotopic Composition of Precipitation in the Mediterranean Basin in Relation to Air Circulation Patterns and Climate. IAEA-TECDOC-1453. IAEA, Vienna, 157–172.

Vreca, P., Krajcar-Bronic, I., Horvatincic, N. & Barešic, J., 2006. *Isotopic characteristics of precipitation in Slovenia and Croatia: comparison of continental and maritime stations.* Journal of Hydrology, 330, 457–469.

Vreca, P., Krajcar-Bronic, I., Leis, A. & Brencic, M., 2008. *Isotopic composition of precipitation in Ljubljana (Slovenia).* Geologijy, 51, 2, 169-180.

Received at: 14. 10. 2016
Revised at: 25. 02. 2017
Accepted for publication at: 09. 03. 2017
Published online at: 15. 03. 2017