Environmental Engineering and Management Journal March 2017, Vol.16, No. 3, 643-651
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

GROUNDWATER RESPONSE TO CHANGES IN PRECIPITATIONS IN NORTH-EASTERN ROMANIA

Ionuț Minea[1*], Adina-Eliza Croitoru[2]

[1]*Faculty of Geography and Geology, Department of Geography, Alexandru Ioan Cuza University, 20 A, Carol I Bd., 700505 Iasi, Romania*
[2]*Faculty of Geography, Department of Physical and Technical Geography, Babeş-Bolyai University, 5-7, Clinicilor Street, 400006 Cluj-Napoca, Romania*

Abstract

Changes in the climatic and hydrological variables in North-Eastern Romania indicate that the region has mostly a common evolution in terms of precipitation and hydrostatic level of groundwater. This can influence human communities in the region, given that sources of public water supply are predominantly from underground. In the analysed region with more than 8.000 sqm, 50% of the population lives in the rural area, where the main water supply source is provided by the underground water, mainly from individual wells with depths between 1 and 10 meters (only 10% from the rural population is connected to a centralized water supply system). That means the underground water resources are subject to overexploitation, especially given the prevailing economic activities associated with agriculture and construction involving high water consumption, predominantly from underground. Seasonal and annual data series of precipitation and hydrostatic level over a period of 31 years (1983-2014) and collected in 36 hydrogeological stations (73 wells) and three weather stations have been used. The trends were detected by employing Mann-Kendall test and Sen's slope, and the correlation between the two variables was performed based on Bravais-Pearson correlation. The main results of the paper are: increasing trends are dominant both for annual and seasonal data sets of precipitation, but the great majority of the slopes detected are not statistically significant. In winter, precipitations have a decreasing trend and the slopes are statistically significant. In terms of hydrostatic level, most of the trends detected for near-surface wells are decreasing, while in depth, increasing trends are dominant; the most important change was seen in the deep gap between 200 and 300 cm; correlation between precipitation and hydrostatic level is stronger and more frequent for summer (more than 86% of pairs were found statistically significant) and autumn (more than 80%), and is fable and less frequent for spring and winter due to trans-seasonal distribution of precipitation.

Key words: climate changes, groundwater level, precipitation

Received: February, 2016; Revised final: February, 2017; Accepted: February, 2017

1. Introduction

The strategic importance and the level of socio-economical security require special attention on the management of underground water resources, especially since they are the main reservoir of fresh water at regional scale. The ration between atmospheric precipitation and hydrostatic level represents the most important change that may challenge a very used resource (Taylor et al., 2013). This topic is emphasized by the IPCC report (Bates et al., 2008; Hiscock et al., 2011; Parry et al., 2007). Moreover, the increasing fequency of severe droughts episodes in Eastern Romania in the last two decades (Stângă, 2012) led to mitigation and adaptation measures that had a little effect required additional water for the population, when extreme drought conditions occurred. The Moldavian Plain located in Northeastern part of the country was one of the most affected regions in Romania. Changes in land use over the last two centuries and especially over the last few decades significantly modified the

* Author to whom all correspondence should be addressed: e-mail: ionutminea1979@yahoo.com; Phone: +40 741 331556

landscapes in Moldavian Plain from mostly forested areas into intensively used agricultural ones (Niacșu, 2012). Consequently, new modifications in underground water management regulations have been issued (Jora and Romanescu, 2011; Minea et al., 2012; Panaitescu, 2009).

Under these circumstances, the need for re-assessment of underground water resources became an urgent requirement, especially because 60% of the population lives in rural areas, where the main source of water supply is groundwater, exploited mainly through individual wells. In the area under study only 10% of the rural population is connected to an integrated water supply system. The matrix of quality and quantity risk assessment of each underground water body showed that all three bodies of underground water, identified in Moldavian Plain under Water Framework Directive (WFD, 2000) are considered to belong to high or medium risk class (Minea and Crăciun, 2012). With this socio-economical background, the impact of climate changes, especially in terms of pecipitation and evapotranspiration, should be assess as it is expected to generate real problems in the area considered (Croitoru et al., 2014). Thus, in the cold season, the most important transfer between the surface water and the groundwater occurs and is controlled mainly by precipitation amount. In summertime the evapotranspiration generated by high temperatures become the factor that influences the relation precipitations-surface water-groundwater (Chen et al., 2008, Minea, 2012).

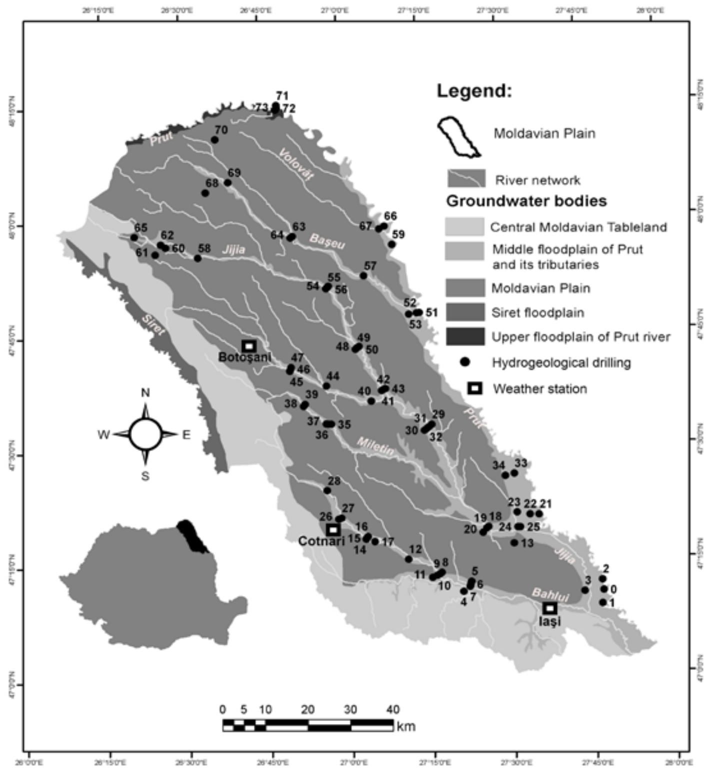
The main objectives of this papers is to identify if the underground water resources is influenced by changes in precipitations in one of the poorest regions of Romania which is dominant rural and where the great majority of population directly depends on groundwaters in terms of water supply.

2. Data base and methodology

2.1. Data base

In this paper, in order to identify changes and connections between precipitation and groundwater level, we used data measured in 36 hydrogeological stations (73 wells) and provided by the Prut-Bîrlad Basins Branch of Romanian Waters Administration. The hydrogeological data were correlated with precipitation from three weather stations of the National Meteorological Network: Iasi, Botosani and Cotnari. The geographical position and location of the both hydro-geological and weather stations are presented in Fig. 1.

The analysis was performed based on four seasonal and one annual data set both for precipitation and the groundwater level. All the hydrogeological data sets were derived from monthly values. Precipitation data for Iasi and Botosani weather stations were derived from daily precipitation provided by ECA&D project (KleinTank et al., 2002) and data for Cotnari weather station were derived from daily modeled data from ROCADA database (Bîrsan and Dumitrescu, 2014). For this paper we have chosen only those locations with no lacks in the data sets over a period of 31 years: 1983-2014.



Nr. Crt.	No.	Hydrogeological stations	Well
0	1	Iași	F8
1			F9
2	2	Cristești	F1
3			F5
4	3	Dumești	F1
5	4	Banu	F1
6			F2
7			F3
8	5	Podu Iloaiei	F2
9			F3
10			F4
11			F5
12	6	Spinoasa	F1
13	7	Moimești	F1
14	8	Belcești	F1
15			F2
16			F4
17			F6
18	9	Țigănași	F1
19			F2
20			F3
21	10	Cimiceni	F1
22			F2
23			F3
24			F5
25			F6
26	11	Cotnari	F1
27			F2
28	12	Hârlău	F1
29	13	Glăvănești	F1
30			F2
31			F3
32			F4
33	14	Lunca Prutului	F3
34			F4
35	15	Prisăcani	F1
36			F2
37			F3
38	16	Cotu Rușii	F1
39			F2
40	17	Cernești	F1
41	18	Todireni	F1
42			F2
43			F3
44	19	Dracșani	F1
45	20	Balușeni	F1
46			F2
47			F3
48	21	Mășcăţeni	F2
49			F3
50			F4
51	22	Ștefănești	F1
52			F2
53			F3
54	23	Dîngeni	F1
55			F2
56			F3
57	24	Mihălășeni	F1
58	25	Corlăţeni	F1
59	26	Dorohoi Sud	F1
60	27	Ripiceni	F2
61	28	Broscăuți	F1
62	29	Dorohoi	F1
63	30	Săveni	F1
64			F2
65	31	Ezer	F1
66	32	Sadoveni	F1
67			F3
68	33	Stînca	F1
69	34	Havarna	F1
70	35	Darabani	F1
71	36	Rădăuți Prut	F1
72			F2
73			F3

Fig. 1. The underground water bodies, weather stations and hydro-geological wells in Moldavian Plain

The geographical map of the region was obtained by use of TNTMips 6.9 software while ArcGIS and Corel Draw X3 were employed to represent the trends and the correlation between precipitation and groundwater level.

The region we focused on in this paper covers the north-eastern part of Romania with altitudes raging between 30 and 250 m. The region is one of the driest and poorest regions in the country where average annual temperatures vary from 8.5 to 9.5^{0}C and rainfall totals is between 450 and 650 mm/yr (Sandu et al., 2008). Largely exposed to continental dry air masses, severe drought events are quite frequent in the area. Sometimes, reverse trajectories of Mediterranean Cyclones can determine the high-floods. Geologically the Quaternary deposits with a thickness of 12-25 m (Vasiliniuc et al., 2013) overlap the dominant clay, marl, and sand deposits (dated in Sarmatian).

2.2. Trend analysis

The nonparametric Mann-Kendall test (Kendall, 1975; Mann, 1945) for the trend and Sen's method for the magnitude of the slope were employed. Sen's method uses a linear model to estimate the slope of the trend (Sen, 1968).

The methods have two important advantages: first, the data sets that do not fit into a basic initial distribution (Moberg et al., 2006); second, the method is based on eliminating outliers that can bring some deviation in statistical analysis (Salmi et al., 2002). Consequently, the methods were largely previously used previously to detect trends in climatic and hydrological data series, such as temperature, precipitation, snow cover, fog, rivers discharge etc. (El Kenawy et al., 2011; Choi et al., 2009; Croitoru and Toma, 2011 Croitoru and Minea, 2015; Croitoru et al., 2012, 2014; Tabari et al., 2011; Tabari and Hosseinzadeh Talaee, 2011; Zhang et al., 2005). For using Mann-Kendall is supposed that x_i of a time series can be assumed with (Eq. 1) (Salmi et al., 2002):

$$x_i = f(t_i) + \varepsilon_i \qquad (1)$$

where: *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean.

The variance of *S* is analyzed using equation (2), which considers that ties may be present (Eq. 2):

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n-5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \qquad (2)$$

where: *n* is the number of values in the group, *q* is the number of tied groups; t_p is the number of data values in the p^{th} group.

Because the number of values in the data sets is greater than 10, the values of *S* and *VAR(S)* are used to compute the test statistic *Z* as it follows (Eq. 3):

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, ifS > 0 \\ 0, ifS = 0 \\ \frac{S+1}{\sqrt{VAR(S)}}, ifS < 0 \end{cases} \qquad (3)$$

Furthermore, to estimate the slope of detected trends, the Sen's nonparametric method is used (Salmi et al., 2002; Sen, 1968) (Eq. 4).

$$f(t) = Qt + B \qquad (4)$$

where: *Q* is the slope; *B* is a constant.

To get the slope estimate *Q* in equation (4), the individual slopes of all consecutive data value pairs as in (Eq. 5):

$$Q_i = \frac{x_i - x_k}{j-k} \qquad (5)$$

where: *i* =1,...,*N;* x_j and x_k are data values at times *j* and *k* (*j* > *k*), respectively.

If there are *n* values x_j in the time series, we get as many as *N* = *n(n-1)/2* slope estimates *Qi*. The Sen's estimator of slope is the median of these N values of *Qi*. The *N* values of *Qi* are ranked from the lowest to the highest and the Sen's estimator (*Q*) is differently calculated if *N* is odd or even (Eq. 6 and Eq.7) (Salmi et al., 2002). Thus,

$$Q = Q_{[(N+1)/2]}, \text{ if } N \text{ is odd} \qquad (6)$$

and

$$Q = \frac{1}{2}\left\{Q_{(N/2)} + Q_{[(N+2)/2]}\right\}, \text{ if } N \text{ is even} \qquad (7)$$

Technically, to detect and estimate trends we employed an Excel template - MAKESENS - developed, based on the two methods in Finnish Meteorological Institute (Salmi et al., 2002). The software performs two types of statistical analyses: first, the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test, and then, the slope of a linear trend estimated with Sen's nonparametric method is computed. Both methods are used here in their basic forms (Salmi et al., 2002). Although the significance levels (α) in MAKESENS detects four level of statistically significance (0.001, 0.01, 0.05, and 0.1) for this paper we retained only the level of α = 0.05.

2.3. Bravais-Pearson correlation

Considering that data sets on precipitation and hydrostatic level follow a bivariate normal distribution to determine a correlation of these two parameters was used the Bravais-Pearson correlation coefficient (ρBP) (Artusi et al., 2002). Because precipitation data and groundwater level were not collected in the same points, the associations were performed between the datasets of each hydrogeological station and the nearest weather stations with available data. This method was successfully used for determining correlation among different natural environemntal (climate, hydrology or geomorphology) data sets (Crétat et al., 2012; Ogouwale et al., 2010). By using it, detection of the presence of a linear correlation between precipitation and groundwater level was possible (Eq. 8).

$$r(P,Q) = \frac{\frac{1}{N}\sum_{i=1}^{n}(P_i - \overline{P})(HL_i - \overline{HL})}{\sigma(P)\cdot\sigma(HL)} \tag{8}$$

where: r - Bravais-Pearson linear correlation coefficient;
N – total number of observations;
P_i, - values of precipitation series;
HL_i – values of the hydrostatic level series;
$\overline{P}$ and $\overline{HL}$ - average values of precipitation and hydrostatic level series;
$\sigma(P)$, $\sigma(HL)$ - standard deviation of precipitation (P) and of hydrostatic level (HL), where (Eq. 9 and Eq. 10):

$$\sigma(P) = \sqrt{\frac{\sum_{i=1}^{n}(P_i - \overline{P})^2}{N-1}} \tag{9}$$

$$\sigma(Q) = \sqrt{\frac{\sum_{i=1}^{n}(HL_i - \overline{HL})^2}{N-1}} \tag{10}$$

H_0 is tested by resorting to a t-test with *n-2* degrees of freedom (Artusi et al., 2002), where *n* is the number of pairs. Further on, based on degrees of freedom calculated (29) and a statistical significance of α = 0.05, we considered as significant correlation between precipitation amounts and hydrostatic levels when *r* value was higher than 0.38.

3. Results and discussion

3.1. Climate and hydrogeological changes

3.1.1. Changes in precipitation

Assessment of climate changes for this area indicates upward trends in both the atmospheric precipitation and air temperature values (Croitoru and Minea, 2015). These increases are reflected in the increase amount of water drained through the river system (Dumitrescu et al., 2014) and the contribution to the groundwater. The annual precipitation amount increase is higher in Botosani and Iasi, where the series slopes exceed 13 and respectively 14 mm/decade and about 30 % lower at Cotnari (more than 9 mm/decade) (Table 1). Although one can notice that increasing precipitation is specific in the area, none of the series is statistically significant.

The analysis based on seasonal series revealed, as a general result, that the trends detected are mostly increasing all over the region, except the winter when precipitation amounts decrease. Moreover, all the slopes detected for winter are statistically significant negative slopes, within the range of 3 - 4 mm/decade.

For the other seasons, all the data sets have upward trends, but only for the extreme North of the country (Botosani) the summer data set was found statistically significant, with a similar rate as the annual series, while for the other weather stations the rates are less than half.

The total negative trends frequency is much lower, but it seems to be generalized at the region scale. The increase of precipitation involves increasing the underground water intake, directly and through the river system (Bîrsan et al., 2014), which consequently reveal upward trends for the most seasonal and annual series. In general, the rate of increase of precipitations is higher than model predictions for 2020 for this region (Parry et al., 2007).

3.1.2. Changes in groundwater level

Regarding changes in the groundwater it was observed a trend of delay of the influence of climatic conditions on hydrostatic level changes depending on the depth of the water is in underground. This is much more visible in wells whose hydrostatic level is higher (even those with artesian character) until a depth of 5-6 m (Minea and Croitoru, 2015).

The hydrogeological regime of the Moldavian Plain marks the maximum values of hydrostatic level (HL) in October-November to a minimum in March-April, being strictly connected to the variations of rainfall and water intake from the river system. The annual trend of HL analyzed for all 73 wells increased with an average of 0.7 cm/decade (Table 2).

Table 1. Slopes of precipitation trends in Moldavian Plain (mm/decade)

Series	***Botosani***	***Cotnari***	***Iasi***
Annual (mm/decade)	13.49	9.25	14.65
Winter (mm/decade)	**-3.80**	**-3.45**	**-3.95**
Spring (mm/decade)	2.40	2.70	3.43
Summer (mm/decade)	**13.51**	5.12	6.31
Autumn (mm/decade)	3.89	4.01	4.28

**Values in bold are statistically significant (α = 0.05).*

This trend is generated by the increase of precipitation and river flows (Bîrsan et al., 2014), leading to increase the surface water intake to the underground. The highest increase is specific to 200-300 cm deep interval. The annual datasets indicate an increase in HL of about 27 cm/decade, while in the summer and autumn the values are even higher (up to 31 cm/decade) (Fig. 2). For wells near to topographic surface mainly negative slope are specific to drilling captured less than 100 cm, and upward and downward trends were found for the depth of 100-300 cm.

Usually, the slopes are low (Table 2, Fig. 3A). For depth greater than 300 cm increasing trends of the hydrostatic level were detected, with moderate slope of 7-11 cm/decade for annual series, and of 9-14 cm/decade, for summer data series.

In general, the frequency of HL positive slopes for all considered datasets is above 80% for the spread located at 300-400 cm depth (Fig. 3A) while for spread located at 100 cm or higher, the frequency of negative slopes in the HL exceeds 70% for annual and seasonal series except autumn (Fig. 3B).

Table 2. Slope of groundwater level in Moldavian Plain (cm/decade)

No.	*Hydro geological stations*	*Well*	*Anual*		*Spring*		*Summer*		*Autumn*		*Winter*	
			HL av.	Slope	HL av.	Slope	HL av.	Slope	HL av.	Slope	HL	Slope
1	Iasi	F8	467.8	1.34	459.6	0.75	435.8	2.83	482.9	2.18	492.8	**0.73**
		F9	383.9	1.69	388.9	2.15	372.0	2.49	380.7	2.29	394.1	1.22
2	Cristesti	F1	487.7	**1.56**	482.1	**0.22**	452.6	2.27	500.0	**2.46**	516.1	1.49
		F5	865.7	6.72	862.2	6.49	862.5	6.54	870.6	6.40	867.4	6.72
3	Dumesti	F1	1367.5	3.65	1341.8	3.44	1345.4	2.77	1347.9	2.23	1435.0	4.43
4	Banu	F1	300.3	1.10	287.6	0.59	289.0	1.56	308.3	1.42	316.3	1.12
		F2	380.8	**-0.14**	373.1	-0.69	372.4	-0.48	384.4	0.21	393.1	**-0.05**
		F3	535.1	-1.12	525.6	-0.91	526.8	-0.70	540.9	-1.23	546.9	-1.39
5	Podu Iloaiei	F2	175.2	1.28	163.1	**0.84**	167.9	0.41	188.5	1.10	181.1	2.72
		F3	126.8	-0.19	115.8	-0.78	114.9	-0.57	136.5	-0.17	139.8	0.31
		F4	102.3	-0.49	88.9	**-1.50**	92.5	-0.82	111.3	**0.12**	116.7	-0.07
		F5	564.3	14.19	563.8	14.16	560.3	14.51	567.6	14.23	565.5	13.89
6	Spinoasa	F1	460.9	-1.59	447.9	-1.53	462.3	-1.88	468.8	**-1.71**	464.8	-1.25
7	Moimesti	F1	999.6	1.48	1047.8	1.67	1051.0	1.20	950.5	1.52	949.1	1.89
8	Belcesti	F1	101.7	-1.35	95.3	-1.92	89.1	-1.03	110.3	-0.82	112.2	-1.34
		F2	61.3	-2.10	55.2	-1.91	46.8	-2.00	68.6	-2.28	74.6	-2.42
		F4	1189.7	-0.82	1186.3	-0.76	1191.2	-0.65	1193.8	-0.54	1187.6	**-0.70**
		F6	121.1	1.63	115.7	**1.43**	106.7	**2.27**	127.9	1.82	134.2	**1.46**
8	Tiganasi	F1	136.3	0.24	113.7	0.15	135.7	0.11	156.5	**0.99**	139.4	-0.60
		F2	128.4	-1.43	107.3	-1.13	133.7	-2.18	143.7	-1.92	128.9	-1.72
		F3	211.5	**0.67**	193.1	**0.37**	201.8	0.39	228.0	1.63	223.1	0.62
10	Carniceni	F1	472.5	1.33	477.9	**0.87**	451.3	1.95	471.3	2.33	489.4	**0.85**
		F2	408.4	3.29	404.0	3.44	400.1	3.33	412.0	3.31	417.6	3.20
		F3	216.3	2.19	207.2	2.38	212.8	2.31	222.9	2.33	222.4	1.67
		F5	172.6	0.90	172.5	**-0.27**	165.2	**0.88**	170.1	2.11	182.8	1.16
		F6	199.6	0.91	198.8	0.26	193.2	1.09	197.2	1.41	209.2	0.74
11	Cotnari	F1	292.8	7.87	275.6	7.77	283.2	8.17	304.0	7.39	308.3	7.23
		F2	851.4	-0.99	849.0	-1.74	846.8	-1.59	854.1	**-0.59**	855.7	-1.05
12	Harlau	F1	233.7	5.23	229.9	5.60	220.2	5.58	239.8	4.33	244.7	4.50
13	Glavanesti	F1	252.4	**4.87**	235.8	3.79	237.1	4.88	267.8	5.18	269.0	4.45
		F2	442.6	2.16	425.9	**1.36**	442.6	2.46	457.4	2.91	444.4	**1.12**
		F3	402.7	-0.30	394.1	-0.73	392.1	-0.43	408.6	-0.09	416.1	**-0.38**
		F4	136.2	2.61	112.4	2.72	122.9	2.81	158.7	2.74	150.7	2.51
14	Lunca Prutului	F3	284.7	5.92	278.6	5.20	274.0	7.08	292.7	6.47	293.6	5.23
		F4	75.9	1.43	67.6	**0.95**	70.3	1.67	86.0	2.44	79.8	1.60
15	Prisacani	F1	133.6	-0.78	118.1	-2.13	107.6	-0.26	153.1	**0.05**	155.7	-0.91
		F2	212.4	-1.05	194.3	**-1.98**	194.4	-0.14	233.2	**-0.41**	227.8	-1.10
		F3	90.2	0.00	69.7	**-0.52**	87.0	0.91	110.5	**0.21**	93.5	-1.42
16	Cotu Rusi	F1	244.5	0.90	215.8	-0.99	225.5	**0.48**	271.4	2.33	265.4	1.59
		F2	148.9	-1.99	126.4	-3.22	135.4	-1.22	171.3	-1.50	162.4	-2.46
17	Cernesti	F1	328.9	2.09	325.8	1.59	320.3	2.56	330.4	2.43	339.0	1.74
18	Todireni	F1	358.7	**0.75**	346.8	**0.59**	353.2	0.84	368.7	0.70	366.2	0.74
		F2	330.9	0.90	319.3	0.47	330.0	1.40	342.4	1.13	332.0	**0.33**
		F3	227.2	-0.10	218.7	-0.91	213.3	-0.02	234.3	0.56	242.7	0.16
19	Dracsani	F1	154.7	**0.21**	165.1	-0.13	149.6	0.48	148.6	0.78	155.4	0.00
20	Baluseni	F1	52.7	**-0.93**	38.3	-1.20	49.2	-0.33	66.6	-0.65	56.5	-1.24

		F2	37.2	*-0.81*	23.8	*-1.27*	33.1	*-0.54*	50.3	*-0.7*	41.6	*-1.33*
		F3	30.8	*-0.38*	12.7	*-0.64*	33.5	***0.31***	46.4	***-0.16***	30.8	*-1.14*
21	Mascateni	F2	350.5	*2.26*	335.5	*2.64*	343.6	*2.47*	364.3	*2.10*	358.7	*2.10*
		F3	459.2	*3.13*	452.2	*2.35*	439.7	*3.70*	468.9	*3.459*	476.1	*3.02*
		F4	666.2	***1.75***	641.1	*0.65*	635.0	*1.15*	692.2	*1.79*	696.5	*1.10*
22	Stefanesti	F1	571.5	*-1.17*	584.1	*-1.51*	543.4	***-1.24***	566.9	*-0.38*	591.5	*-0.94*
		F2	527.2	*0.17*	533.2	***0.08***	515.9	*0.14*	523.5	*0.09*	536.1	***0.47***
		F3	257.9	*-2.78*	250.0	*-3.18*	247.2	*-2.50*	265.9	*-2.37*	268.6	***-2.76***
23	Dingeni	F1	233.9	*-0.64*	219.4	*-1.51*	221.7	*-0.41*	249.8	*-0.57*	244.7	*-0.85*
		F2	190.4	*-1.13*	175.0	*-1.21*	186.3	*-0.93*	206.3	*-1.02*	194.2	*-0.95*
		F3	70.4	*0.07*	65.4	*-0.13*	71.7	*0.00*	75.4	***-0.29***	69.3	*-0.14*
24	Mihalaseni	F1	283.3	*4.37*	272.7	*4.27*	269.0	*4.97*	293.2	*4.46*	298.3	*4.51*
25	Corlateni	F1	113.0	*-0.40*	101.5	***-0.71***	108.5	*-0.23*	123.9	*-0.45*	118.1	*-0.78*
26	Dorohoi Sud	F1	361.7	*1.27*	348.5	*0.80*	348.8	***2.31***	373.9	*1.41*	375.7	*0.53*
27	Ripiceni	F2	652.3	*0.15*	654.0	*0.08*	646.9	*-0.40*	650.2	*-0.06*	658.1	*0.89*
28	Broscauti	F1	759.9	*-10.48*	775.8	*-9.38*	748.0	*-10.65*	745.6	*-10.45*	770.3	*-9.21*
29	Dorohoi	F1	182.6	*-1.08*	176.7	*-0.97*	175.3	*-0.94*	189.0	*-0.91*	189.5	***-0.91***
30	Saveni	F1	255.9	***-0.18***	249.8	*-0.12*	250.9	*0.12*	260.2	*-0.37*	262.8	***0.09***
		F2	124.5	***0.03***	109.1	*-0.52*	121.2	*0.72*	138.2	*0.44*	129.6	***-0.31***
31	Ezer	F1	602.2	*-1.16*	598.2	*-2.21*	569.0	*-0.41*	606.1	*-0.34*	635.6	*-1.76*
32	Sadoveni	F1	681.2	*0.81*	681.9	*0.69*	677.0	*0.76*	681.8	*0.73*	683.9	*0.79*
		F3	780.4	*1.62*	776.9	*1.53*	778.3	*1.43*	783.1	*1.74*	783.4	*1.66*
33	Stinca	F1	542.7	*-2.40*	548.7	*-2.37*	520.9	***-2.35***	540.6	*-1.21*	560.5	*-1.75*
34	Havarna	F1	160.9	***-0.17***	151.5	*-0.58*	162.1	***0.10***	170.1	*-0.01*	159.8	*-0.48*
35	Darabani	F1	320.8	*-3.16*	313.3	*-5.29*	277.5	*-1.66*	328.5	*-2.52*	363.8	*-4.40*
36	Radauti Prut	F1	345.0	*0.59*	334.2	***0.24***	317.0	*0.73*	362.2	***0.67***	368.3	*0.56*
		F2	274.6	*-0.19*	261.8	*-0.54*	253.2	*0.26*	289.1	***0.84***	294.4	*-0.15*
		F3	1145.5	*-1.40*	1143.5	*-1.51*	1132.9	*-1.34*	1153.1	*-1.50*	1152.6	***-1.56***

**Values in bold are statistically significant.*

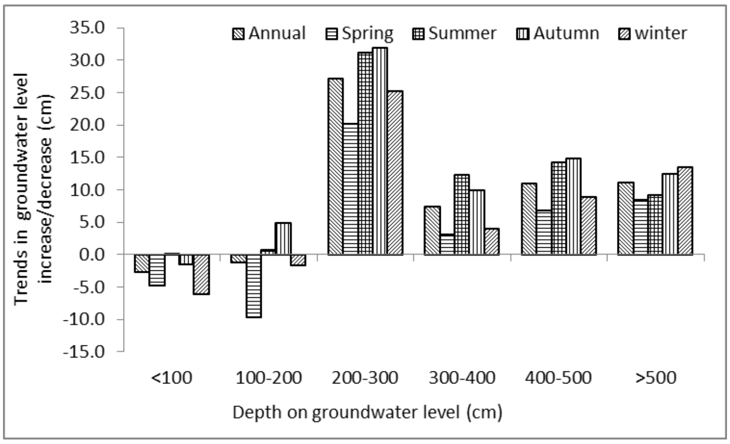


Fig. 2. Trends of groundwater level by depth of wells, in Moldavian Plain

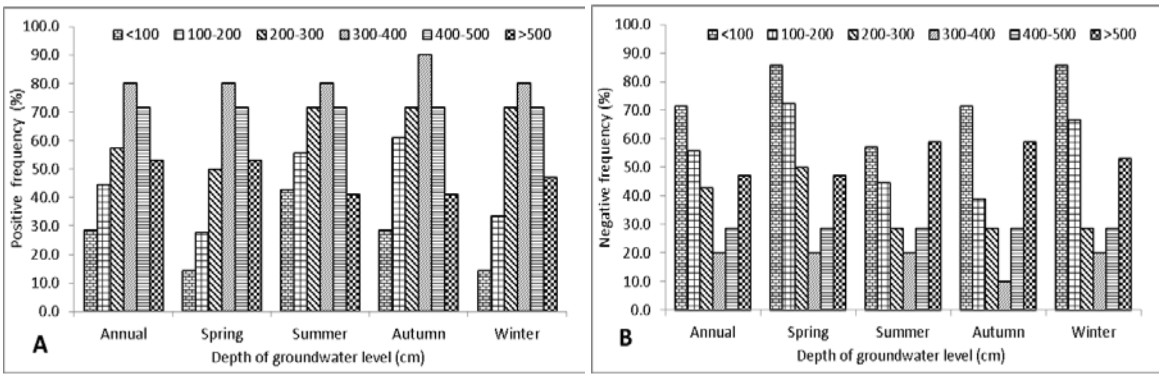


Fig. 3. Frequency of positive (A) and negative (B) slopes of the HL in Moldavian Plain

3.2. Correlations between precipitation and groundwater level

Considering that the variations of HL are controlled by the intake of precipitation water from surface and geological characteristics of the sedimentary deposits, the results related to the correlation between rainfall and underground water level can vary greatly within the same regions. On the basis of Bravais-Pearson linear correlation the annual values show a good statistically significant correlation with *r* values in the range of 0.4 - 0.6. The frequency of accepted correlation covers 69,4% of all annual data series considered.

Analysis performed based on seasonal data sets revealed that the best correlations were identified for summer and for autumn, when precipitation is exclusively liquid and trans-seasonal precipitation are not present (Fig. 4). At the same time, the strongest correlation is specific to summer (up to 0.7), when convective heavy rains generate a rapid infiltration of water in underground with a quick response in HL (Fig. 4).

At regional scale, the best spatial coverage of accepted correlation was found for summer and autumn, with more than 80 % of the data pairs considered in each case (86.2 % for summer data series, and 80.6 %, for autumn). This situation may be explained by the unfrozen soil, as well as diminished or partially lacks of vegetation, which also favour the rapid infiltration of water in to the soil.

The fable correlation detected for winter and spring (generally under 0.3) is a direct consequence of the reduction, in recent decades, of the precipitation amounts recorded in these seasons and retention of water from precipitation as a snow and ice layer. This allows a trans-seasonal distribution of atmospheric volume input into underground over the seasons and thus precipitation fallen in wintertime will melt during next spring. However, winter recorded a low number of data pairs with statistically significant correlation, while for spring a double number of pairs passed the test of statistical correlation.

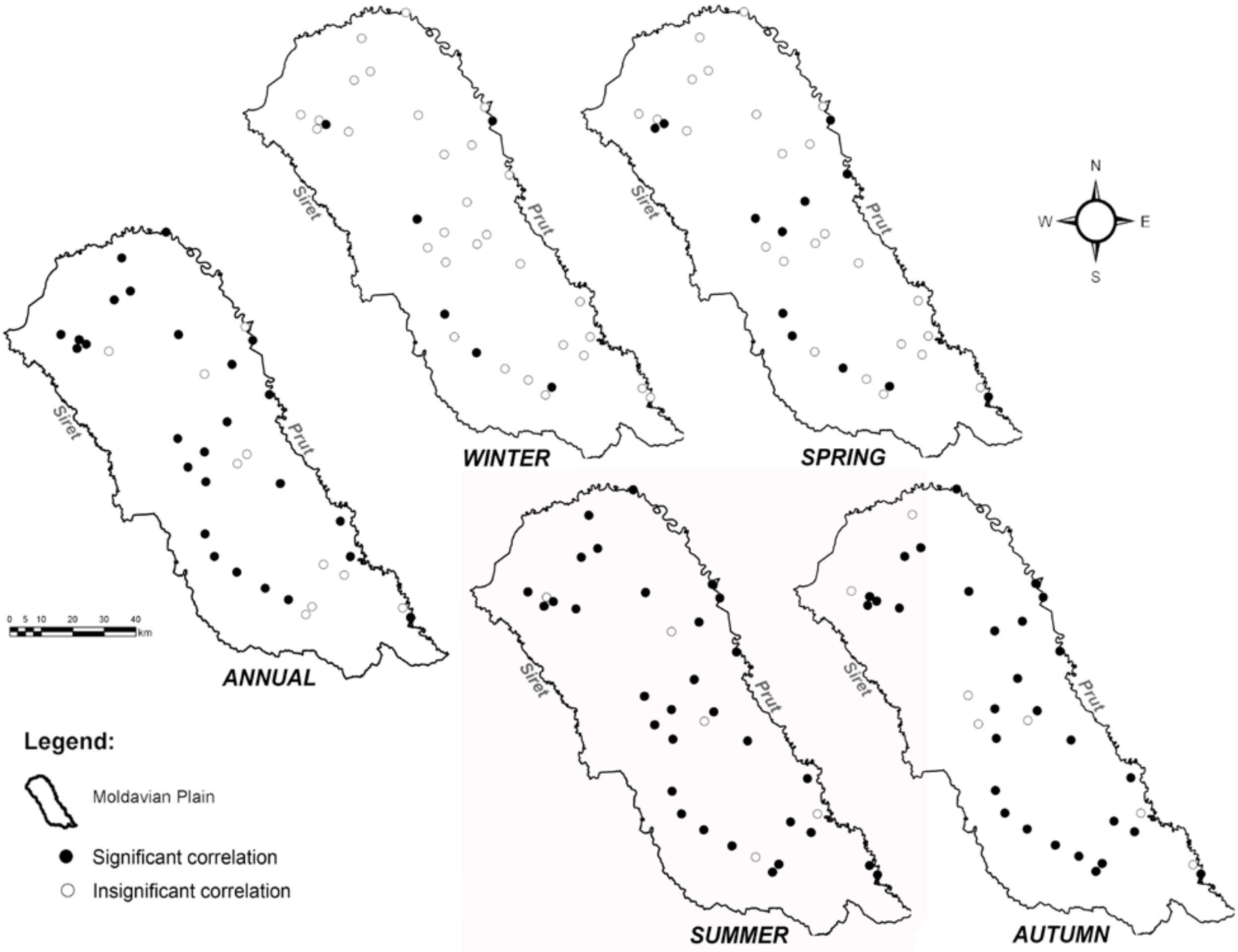


Fig. 4. Correlation between precipitation and hydrostatic level in Moldavian Plain

4. Conclusions

Changes in the climatic and hydrological variables in North-Eastern Romania indicate that the region has mostly a common evolution in terms of precipitation and HL of ground water.

Increasing trends are dominant both for annual and seasonal data sets of precipitation and HL, except winter for precipitation, when all the weather stations considered recorded downward significant trends. The highest increase of precipitation is specific to summer, with slope similar to those found for annual series. However, the great majority of the positive slopes detected are not statistically significant. In terms of HL, most of the trends detected for near-surface drillings are decreasing, while in depth, increasing trends are dominant. The most important change was seen in the deep gap between 200 and 300 cm. This situation implies multiple effects on how managing this resource in terms of human impact in this predominantly rural region where the prevailing economic activities are associated with local agriculture and construction with high demand of water consumption, predominantly from underground.

Correlation between precipitation and HL is stronger and more frequent for summer (more than 86% of the pairs considered were found statistically significant) and autumn (more than 80%), while the correlation is fable and less frequent for spring and winter when trans-seasonal distribution of precipitation is specific: in winter, precipitation is mainly solid and is retained as snow or ice layer until spring when the HL varies not only because of the rainfall recorded during that season, but also because of snow or ice melt.

The socio-economical background in this rural region asociated with climate changes is more and more visible and they can cause a number of real problems that require a thorough analysis of their effects on underground water resources.

Acknowledgements

This research was developed under the framework of the research project "Extreme weather events related to air temperature and precipitation in Romania" project code PN-II-RU-TE-2014-4-0736, funded by the Executive Unit for Financing Higher Education, Research, Development and Innovation (UEFISCDI) in Romania.

The authors acknowledge the daily precipitation data freely provided by the European Climate Assessment & Dataset project initiated by the European Climate Support Network and supported by the Network of European Meteorological Services (Klein Tank et al., 2002) and by National Meteorological Administration (Bîrsan and Dumitrescu, 2014). Also kind acknowledgements are for Prut-Bîrlad Basins Branch of Romanian Waters Administration for hydrogeological data provided.

References

Artusi R., Verderio P., Marubini E., (2002), Bravais-Pearson and Spearman correlation coefficients: meaning, test of hypothesis and confidence interval, *The International Journal of Biological Markers*, **17**, 148-151.

Bates B.C., Kundzewicz Z.W., Palutikof J.P. (Eds.), (2008), Climate Change and Water, *IPCC Technical Paper VI*, IPCC Secretariat, Geneva.

Bîrsan M.V., Zaharia L., Chendes V., Branescu E., (2014), Seasonal trends in Romanian streamflow, *Hydrological Processes*, **28**, 4496-4505.

Bîrsan M.V., Dumitrescu A., (2014), ROCADA: Romanian daily gridded climatic dataset (1961-2013) V1.0. The National Meteorological Administration, Bucharest, Romania, doi:10.1594/PANGAEA.833627.

Chen X., Zhang Z., Zhang X., Chen Y., Qian M., Peng S., (2008), Estimation of groundwater recharge from precipitation and loss for evapotranspiration by lysimeter measurement and soil moisture model, *Journal of Hydrological Engineering*, **13**, 333-340.

Choi G., Collins D., Ren G., Trewin B., Baldi M., Fukuda Y., Afzaal M., Pianmana T., Gomboluudev P., Huong P.T.T., Lias N., Kwon W.T., Boo K.O., Cha Y.M., Zhou Y., (2009), Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955–2007, *International Journal of Climatology*, **29**, 1906-1925.

Crétat J., Richard Y., Pohl B., Rouault M., Reason C., Fauchereau N., (2012), Recurrent daily rainfall patterns over South Africa and associated dynamics during the core of the austral summer, *International Journal of Climatology*, **32**, 261-273.

Croitoru A.E., Toma F.M., (2011), *Climatic Changes and Their Influence on Stream flow in Central Romanian Plain*, 5th Atmospheric Science Symposium, 27-29 April 2011, Istanbul-Turkey, 183-194.

Croitoru A.E., Minea I., (2015), The impact of climate changes on rivers discharge in Eastern Romania, *Theoretical and Applied Climatology*, **20**, 563-573.

Croitoru A.E., Holobaca I.H., Lazar C., Moldovan F., Imbroane A., (2012), Air temperature trend and the impact on winter wheat phenology in Romania, *Climatic Change*, **111**, 393-410.

Croitoru A.E., Drignei D., Dragotă C.S., Imecs Z., Burada D.C., (2014), Sharper detection of winter temperature changes in the Romanian higher-elevations, *Global and Planetary Change*, **122**, 122-129.

Dumitrescu A., Bojariu R., Bîrsan M.V., Marin L., Manea A., (2014), Recent climatic changes in Romania from observational data (1961–2013), *Theoretical and Applied Climatology*, **19**, 111-119.

El Kenawy A., Lopez-Moreno J.I., Vicente-Serrano S.M., (2011), Recent trends in daily temperature extremes over northeastern Spain, *Natural Hazards and Earth System Science*, **11**, 2583-2603.

Hiscock K., Sparkes R., Hodgson A., (2011), *Evaluation of Future Climate Changes Impacts on European Groundwater Resources*, In: *Climate Change Effects of Groundwater Resources: A Global Synthesis of Findings and Recommendations*, Treidel H., Martin-Bordes J.S., Gurdak J.J. (Eds.), CRC Press, UNESCO, International Hydrological Programme, Paris, France, 351-366.

Jora I., Romanescu G., (2011), Groundwater in the hydrographical basin of the Vaslui River, *Lucrările Seminarului Geografic Dimitrie Cantemir*, Al.I.Cuza Iași University Press, **32**, 21-28.

Kendall M.G., (1975), *Rank Correlation Methods*, 4th ed., Charles Griffin, London.

Klein Tank A.M.G.,Wijngaard J.B., Konnen G.P. Böhm R., Demaree G., Gocheva A., Mileta M., Paschiardis S., Hejkrlik L., Kern-Hansen C., Heino R., Bessemoulin P., Müller-Westermeier G., Tzanakou M., Szalai S., Palsdottir T., Fitzgerald D., Rubin S., Capaldo M., Maugeri M., Leitass A., Bukantis A., Aberfeld R., van Engelen A.F.V., Førland E., Mietus M., Coelho F., Mares C., Razuvaev V., Nieplova E., Cegnar T., Lopez A.J., Dahlström B., Moberg A., Kirchhofer W., Ceylan A., Pachaliuk O., Alexander L.V., Petrovic P., (2002), Daily dataset of 20th century surface air temperature and precipitation series for the European climate assessment, *International Journal of Climatology*, **22**, 1441-1453.

Mann H.B., (1945), Non-parametric tests against trend, *Econometrica* **13**, 245-259.

Minea I., (2012), *Bahlui Drainage Basin - Hydrological Study* (in Romanian), „Al.I.Cuza" University Press, Iaşi, Romania.

Minea I., Butelcă D., Niacşu L., (2012), Models variation of the groundwater in drought conditions. Case study upper Barlad drainage basin, *Geographia Napocensis*, **IV**, 1, 75-82.

Minea I., Crăciun I., (2012), Simulation models to evaluate the groundwater resources in Bahlui River basin, Romania, *Journal of Enviromental Protection and Ecology*, **13**, 1600-1607.

Minea I., Croitoru A.E., (2015), *Climate Changes and Their Impact on the Variation of Groundwater Level in the Moldavian Plateau (Eastern Romania)*, Proc. of International Multidisciplinary Scientific Geoconferences, SGEM 2015, Vol. I, Hydrology and Water Resources, 137-145.

Moberg A., Jones P.D., Lister D., et al., (2006), Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000, *Journal of Geophysical Research*, **111**, D22106.

Niacșu L., (2012), *Pereschiv Cathcment (Tutova Hills). Geomorphological and Pedological Study in Correlation with Land Use* (in Romanian), „Al.I.Cuza" University Press, Iaşi, Romania.

Ogouwale R., Donou B., Houssou C., Boko M., (2010), Vulnerabilité des établissements humains aux événements pluviométriques extrèmes dans le bassin de l'Oueme à Bonou (Benin), *Geographia Technica*, **1**, 47-58.

Panaitescu E.V., (2009), *The Groundwater from Barlad Drainage Basin* (in Romanian), Demiurg Press, Iași, Romania.

Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J., Hanson C.E., (2007), *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Cambridge University Press, Cambridge, UK.

Salmi T., Määttä A., Anttila P., Ruoho-Airola T., Amnell T., (2002), Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates - the Excel template application MAKESENS, Publications on Air Quality, No. 31, Finnish Meteorological Institute, Helsinki, Finland.

Sandu I., Pescaru V.I., Poiana I., Geicu A., Cândea I., Ţâştea D., (2008), *Clime of Romania* (in Romanian), Romanian Academy Press, Bucharest.

Sen P.K., (1968), Estimates of the regression coefficient based on Kendall's tau, *Journal of the American Statistical Association*, **63**, 1379-1389.

Stângă I.C., (2012), *Tutova Drainage Basin. Natural Risks and Territorial Vulnerability* (in Romanian) „Al.I.Cuza" University Press, Iaşi, Romania.

Tabari H, Hosseinzadeh Talaee P., (2011), Analysis of trends in temperature data in arid and semi-arid regions of Iran, *Glob Planet Change*, **79**, 1-10.

Tabari H., Hosseinzadeh Talaee P., Ezani A., Shifteh Some'e B., (2011), Shift changes and monotonic trends in autocorrelated temperature series over Iran, *Theoretical and Applied Climatology*, DOI:10.1007/s00704-011-0568-8.

Taylor G.R., Scanlob B., Döll P., Rodell M., van Beek R., Wada Y., Longuevergne L., Lebalnc M., Famiglietti J.S., Edmunds M., Konikow L., Green T.R., Chen J., Taniguchi M., Bierkens M.F.P., MacDonald A., Fan Y., Maxwell M.R., Yechieli Y., Gurdak J.J., Allen M.D.,Shamsudduha M, Hiscock K., Yeh P.J.F., Holman I., Treidel H., (2013), Ground water and climate change, *Nature Climate Change*, **3**, 322-329.

Vasiliniuc I., Patriche C.V., Pîrnău R., Roșca B., (2013), Statistical spatial models of soil parameters. an approach using different methods at different scales, *Environmental Engineering and Management Journal*, **12**, 457-464.

WFD, (2000), Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, Official Journal of the European Communities, **L327**, 1-72.

Zhang X., Aguilar E., Sensoy S., Melkonyan H., Tagiyeva U., Ahmed N., Kutaladze N., Rahimzadeh F., Taghipour A., Hantosh T.H., Albert P., Semawi M., Karam A.M., Al-Shabibi H.S. M., Al-Oulan Z., Zatari T., Al Dean Khelet I., Hammoud S., Demircan M., Eken M., Adiguzel M., Alexander L., Peterson T., Wallis T., (2005), Trends in middle east climate extremes indices during 1930–2003, *Journal of Geophysical Research*, **110,** (D22104),1-12.