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NORTHEAST ROMANIA WATER RESOURCES MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE ISSUE - IAŞI COUNTY CASE STUDY

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ABSTRACT

After 1980, drought became a cyclic phenomenon that has spread over subtropics and mid-latitudes ecosystems and society. Agriculture and domestic or industrial water supply are the fields that received the most severe damage. Climate change in terms of water supply was expressed through UNESCO 1979 *Aridity Index*, which identified critical areas and periods affected by drought in north-eastern Romania. The most vulnerable areas, where the annual rainfall amount is usually less than 500 mm/year, are the most prone to severe droughts. However, as a result of the extension of built surfaces, the urban areas of the region are very affected by drought. For agricultural management, as well as for general water supply, the aridity in north-eastern Romania needs to be investigated at seasonal and monthly scales, using also other indices. Northeastern Romania is a region rich in surface water resources: the annual discharge volumes of Prut River and its tributaries reached 1.917 billion m^3 in the year 2017. In the, the demand for industrial water supply has diminished, while the big demands came from fish farms. Two billion m^3 from Prut River in its main tributary, Jijia were transferred, for water supply of the Ciobarciu wetland in 2017.

Keywords: drought, trend, water supply, mitigation.

INTRODUCTION

After 1980, drought became a cyclic phenomenon, which has spread over subtropics and mid-latitudes ecosystems and society. The authorities, the scientific community, and the press concentrated their attention on global climate change, because adaptation to dryness or aridity and mitigation represent an evolution part of economy key sectors. Agriculture and water supply are the fields that received a multitude of damages. The humidity is a limiting factor with consequences on plant growth and distribution, when it is associated with a high temperature (Zheng, 2000).

In Romania, changes in precipitation and temperature were identified using annual and seasonal samples over the entire country (Busuioc et al., 2010; Croitoru et al., 2012). Changes in the surface runoff have been studied for narrow regions, but they did not emphasize the trends or correlation between rainfall and streamflow (Salit et al., 2013; Bîrsan et al., 2012).

Croitoru and Minea (2015) showed that in Eastern Romania all three variables describe an increase, thus statistically significant slopes resulted from annual and spring series of air temperature. It was also mentioned that precipitation increase entail upward trends of annual and seasonal discharge values.

Drought research has relied so far on quantitative appraisals using aridity indices obtained from the values of several climatic elements: rainfall only (standardized precipitation index), temperature and rainfall (de Martonne aridity index, Pinna combinative index).

Widely used were indices reckoned with precipitation - only (SPI - McKee et al., 1993, 1995), but the majority of scientists elect to recognize drought or aridity using parameters obtained from the reference evapotranspiration

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as it was done when UNESCO 1979 *aridity index* was chosen for this study.

Agricultural crops and gathering are responsive to extreme climatic events, especially to those which imply temperature and precipitation variations. The study assigns changes through an index that combines two climatic variables, as this type of research was poorly approached in Romania.

The temporal evolution of reference evapotranspiration is a topical research direction of other studies (Păltineanu et al., 2012; Croitoru et al., 2013b), in addition, this paper contains an estimate of real water resources in 2017, to answer if the solutions promoted by the authorities for small communities water supply in Iaşi County have been efficient or if they have encountered difficulties as they did in the dry year 2012.

MATERIAL AND METHODS

To estimate the trends of climatic variables, the modified Mann-Kendall test was used. The operation is based on the non-parametric Mann-Kendall test for trends (Mann, 1945) and on the statistic distribution test for non-linear trends and turning points. The null hypothesis says that the values are independent and arbitrarily ordered. The existence of positive autocorrelation increases the probability of detecting trends when actually none exists. To refrain from autocorrelation the modified Mann-Kendall test was used, thus the results should not be influenced. The slopes of the trends detected were calculated based on Sen's slope method.

Four annual data samples and a seasonal one was considered for Iaşi, Bârnova, Cotnari, Darabani, Botoşani, Stânca-Ştefăneşti meteorological stations. The null hypothesis was tested at a 95% confidence level ($\alpha = 0.05$) for average temperature (annual and vegetation period values), precipitation, potential evapotranspiration, UNESCO 1979 *aridity index* data series respectively. Addinsoft's XLSTAT software was used to perform the modified Mann-Kendall test.

These two methods offer the following advantages: missing values can be accepted and the sample does not describe a specific distribution: single data errors or outliers do not significantly influence Sen's method (Croitoru et al., 2011a, 2012).

Climatic and hydrological studies which include the soil balance of water or agricultural crops humidity requirements frequently are based on potential evapotranspiration (ET_0), they bring information about the nature of the landscape and the type/class of soil.

Penman-Monteith method, used as an alternative to other empirical practices to obtain ET_0, offers precise and similar results to the direct determinations in lysimeters, as it considers all the variables that affect potential evapotranspiration (Monteith, 1965).

For the six data recording sections (Darabani, Botoşani, Stânca-Ştefăneşti, Cotnari, Iaşi, and Bârnova) they were not made measurements for the required sample in the mathematical determination of ET_0. A significant correlation between the average temperature and the values of potential evapotranspiration acquired through the standard method was applied as the determination coefficient (R^2) is very high within the first equation:

$$ET_0 - PM = 0.0048*T_a^2+0.0678*T_a+0.4888$$
$$(R^2 = 0.93^{***})$$
(Păltineanu et al., 2007) (1)

in which:

ET_0 - PM - potential evapotranspiration;
T_a - average temperature.

UNESCO 1979 *aridity index* $I_{R/ET0}$ is obtained from the annual or monthly report of rainfall and ET_0 - PM, even if potential evapotranspiration was reckoned with the aid of the correlation. In Romania the values of $I_{R/ET0}$ lower than 0.03 and those in 0.03-0.20 class do not exist, therefore the desert and arid climate will not be discussed. The areas characterized by values belonging to semi-arid class are: the eastern region of Danube Delta, the Black Sea coast, Dobrogea and north-east of Bărăgan. A thin strip of the Danube meadow and the south-eastern part of Moldavian Plateau are enclosed by the 0.65 isoline (Păltineanu et al., 2007).

Hydrological balance indicates water circulation in the catchment area or quantitative report between the possibilities of water supply and consumption there of (Degre et al., 2013; Giurmă et al., 2009). For hydrological balance determination in the Prut River basin was used the equation (2) proposed by Lvovici (quoted by Minea, 2012):

$$X_0=Y_0+Z_0=S_0+U_0+Z_0 \quad (2)$$

where:

X_0 - total annual average rainfall;
Y_0 - global average discharge;
Z_0 - evapotranspiration;
U_0 - groundwater discharge;
S_0 - surface discharge.

The total amount of soil water is the sum between the amount of water which through infiltration contributes to groundwater discharge (U_0) and the one which is consumed by evapotranspiration (Z_0) (Edwards and McKee, 1997).

Runoff coefficient is a transfer function applied to the inputs of the hydrological system and provides the size of output (Giurmă et al., 2009).

Annual average coefficient η_0 of total discharge (on the surface and on the groundwater) is:

$$\eta_0 = \frac{hQ}{hP} \quad (3)$$

RESULTS AND DISCUSSION

Air temperature trends of seasonal and annual series show general heating, all annual series as well as those obtained for growing season highlight increasing trends, which are statistically significant at the 6 meteorological stations: Darabani, Botoşani, Stânca-Ştefăneşti, Cotnari, Iaşi and Bârnova. In case of precipitation, as shown in previous studies, we did not find any coherent trend and Z values were statistically not significant (ns – notation given in Table 1). Potential evapotranspiration increases with 1.37-1.45 mm/decade in Iaşi County and with 1.38-1.42 mm/decade in Botoşani considering annual series. Significant changes of its own are located near Stânca-Costeşti reservoir, consequence of evaporation with high values, but also in urban areas (Table 1).

To express climate changes in terms of water supply were used the aridity or humidity indices (Kafle and Bruins, 2009). By means of UNESCO 1979 *aridity index, were distinguished* vulnerable areas and periods affected by drought were distinguished in north-eastern Romania. Monthly values were obtained and we took into consideration that each meteorological station has a fair spatial overlay that's why may appear local fluctuation of the indices in the studied area.

Previous studies that followed the spatial distribution of UNESCO 1979 aridity index underlined annual values between 0.6 and 0.8, which place north-east Romania in the second place in terms of aridness intensity even if they appertain to the wet class (Corduneanu et al., 2019).

Monthly values were considered for this analysis and in May a negative trend was highlighted in the entire area. The test values approaching the value - 1.5 are not statistically significant, but 28 and 39% of the processed indices belong to the arid and semi-arid climate class.

In October the air masses circulation of Atlantic origin is diminished, when the role of convective processes is extremely small, UNESCO 1979 *aridity index* describes an upward trend, statistically assured ($Z > 1.5$), with the exception of Bârnova meteorological station ($Z = 1.48$) (Figure 1). Half of the Sen's slopes describe increases of 0.006 mm/mm/decade of UNESCO 1979 *aridity index* (Bârnova, Darabani, and Botoşani meteorological station), while in the other half its values grow with 0.008 mm/mm/decade (Cotnari, Iaşi County) (Figures 2, 3).

Table 1. Mann-Kendall test values and their statistical significance

Variable	Mann-Kendall test value / statistical significance					
	Bârnova	Cotnari	Iaşi	Botoşani	Darabani	Stânca-Ştefăneşti
T_a (°C) / annual value	3.69	3.61	3.44	3.54	3.64	3.41
	***	***	***	***	***	***
T_a (°C) / vegetation period value	3.27	3.67	3.73	3.72	3.67	3.61
	**	***	***	***	***	***
P (mm)	- 0.14	0.85	-0.67	0.67	0.85	0.33
	ns	ns	ns	ns	ns	ns
ET_0 (mm)	4.13	3.75	3.95	3.99	3.98	3.89
	***	***	***	***	***	***

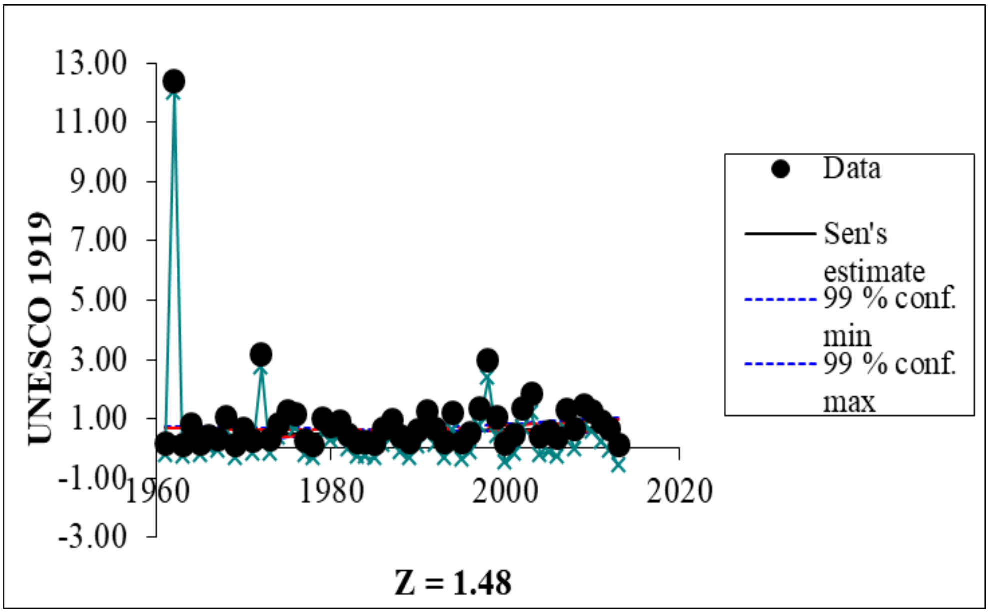

Figure 1. Mann-Kendall test value and Sen's slope for October at Bârnova meteorological station

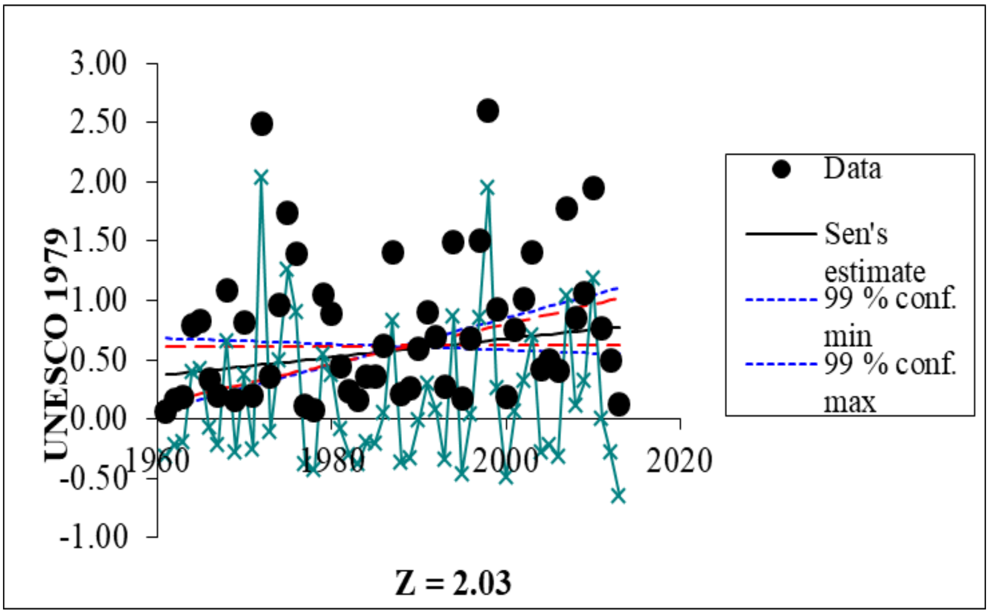

Figure 2. Mann-Kendall test value and Sen's slope for October at Cotnari meteorological station

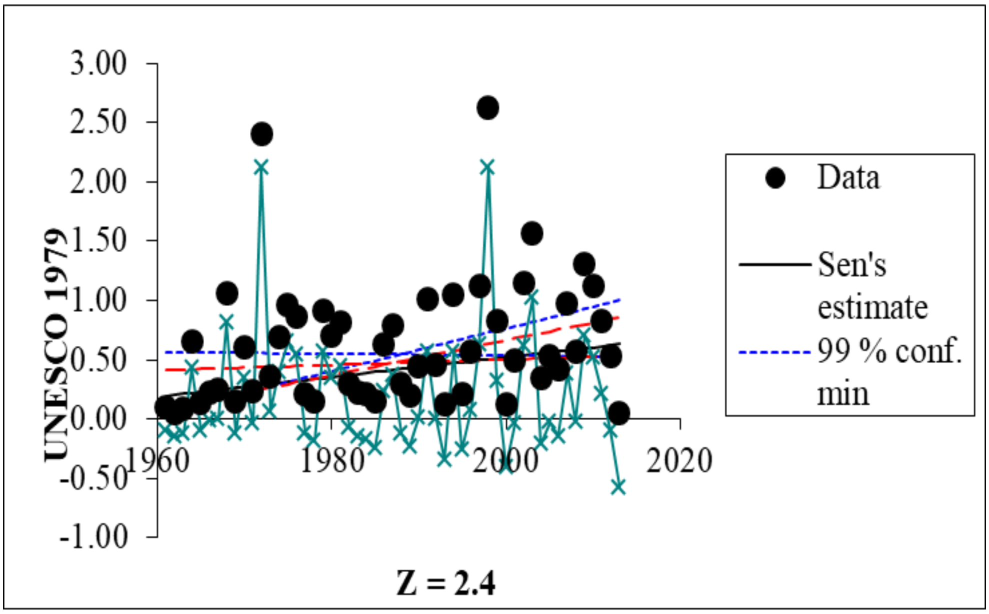

Figure 3. Mann-Kendall test value and Sen's slope for October at Iaşi meteorological station

In July, the areas affected by drought in the south of Botoşani County cover a larger surface towards the Prut valley, where 35% of the analyzed values show traces of the arid and semi-arid climate. In the southern half of Iaşi County, their weight reaches 50%, which is why the negative trend of UNESCO *aridity index* cannot be neglected, even if it is not statistically significant.

Croitoru and Minea (2015) pointed out that in the case of annual, summer and autumn rivers discharge series, at a regional scale, positive slopes prevail; at more than 80% of the station located in eastern Romania. Although the increase of discharge is dominant in winter and spring, too, the frequency of decreasing trends is higher compared to the other seasons.

Despite the outstanding changes in climatic conditions, the statistically significant tendency in annual runoff is difficult to reveal (McCabe and Wolock, 1997).

For north-eastern Romania, as in other studies worldwide, where statistically significant changes were found in climatic parameters, statistically insignificant ones were detected in the case of discharge flows. Lettenmaier et al. (1994) showed that the trends in temperature and precipitation do not predetermine the distribution of significant trends in rivers discharge, the hydrologic effects of climate changes will not generate a constant percentage conversion across the same region, fluctuation of the considered factor will not remain at the current level (McCabe and Wolock, 1997).

For this reason, we wanted to estimate the water availability in the year 2017, a normal year from a rainfall point of view, and for certain sections, we followed its distribution to the economic agents or population with the purpose of seeing if the requests are honored by the authorities.

From Stânca-Costeşti reservoir was evacuated in the year 2017 a flow of 4.46 l/s/km^2, the specific average flow climbed to 2.84 l/s/km^2 in the closing section of the studied area, a value corresponding to a reception area of 21300 km^2. The annual drained water layer (h_0) records values between 89.79 mm in the lower area of the basin (Prisăcani) and 140.96 mm in the middle one (Stânca-Aval).

The volume (W) discharged by the hydrographic network in 2017 reached 1.917 billion m^3. Contribution of the major tributaries to achieve this amount of water varies according to the drained surface and the relief unit in which they have developed their hydrographic basin. The River Jijia from Andrieşeni to Chipereşti transports between 1.42 and 1.52 l/s/km^2, with its tributaries, has a contribution of 198 billion m^3 (10.34 % from the annual volume transported by the Prut River, corresponding to the Prisăcani hydrometric station). Downstream of Vlădeni hydrometric station, it receives 8.676 billion m^3 water from the River Miletin (Table 2).

In Prut River basin, the elements of hydrological balance describe a uniform territorial variation: at the wellhead (on the territory of Ukraine) there is a vertical distribution, the most significant value of the average discharge is about 900 mm at an altitude of 1200 m, where rainfall increases up to 1300 mm (Vartolomei, 2012).

Table 2. Elements of hydrological balance at the main hydrometric station in Prut River basin in 2017

Hydrometric station	q (l/s/km^2)	Y (mm)	Z (mm)	S (mm)	U (mm)	X (mm)	W (m^3)	η_0	H (m)
Prut - Stânca-Aval	4.46	140.96	420.43	98.67	42.29	561.4	1694744640	0.25	480
Prut - Ungheni	3.53	111.53	352.06	78.07	33.45	463.6	1745962984	0.24	361
Prut - Prisăcani	2.84	89.79	336.30	62.85	26.93	426.1	1917036455	0.21	374
Başeu - Ştefăneşti	0.90	28.66	532.73	20.06	8.60	561.4	26148096	0.05	168
Jijia - Todireni	0.71	22.56	483.23	15.79	6.76	505.8	24145056	0.04	186
Sitna - Todireni	1.59	50.36	455.43	35.25	15.10	505.8	47361571.2	0.09	167
Jijia - Andrieşeni	1.03	32.81	329.08	22.97	9.84	361.9	71635752.4	0.09	176
Jijia - Vlădeni	1.16	36.76	347.33	25.73	11.02	384.1	83627994.5	0.095	160
Miletin - Hălceni-Aval	1.01	31.98	265.61	22.39	9.59	297.6	21347715	0.107	166
Jijia - Victoria	1.03	32.61	463.08	22.82	9.78	495.7	116487745.1	0.065	159
Jijia - Chipereşti	1.11	35.32	438.97	24.73	10.59	474.3	198274755.6	0.074	155
Bahlui - Parcovaci	2.59	81.86	425.03	57.30	24.56	506.9	8287980.3	0.161	323
Bahlui - Hârlău	2.96	93.52	319.47	65.46	28.05	413	12856151	0.226	317
Bahlui - Belceşti	1.03	32.66	400.13	22.86	9.79	432.8	11278075.7	0.075	254
Bahlui - Podul Iloaiei	1.13	35.69	478	24.98	10.70	513.7	21050243.9	0.069	202
Bahlueţ	1.54	48.69	465	34.08	14.60	513.7	25531559	0.094	159
Bahlui - Iaşi	1.25	39.70	540.49	27.79	11.91	580.2	68341817.1	0.068	150
Bahlui - Holboca	1.51	47.78	532.41	33.44	14.33	580.2	92104682.7	0.082	155
Nicolina -Iaşi	1.37	43.41	536.78	30.39	13.02	580.2	7540052.6	0.074	139
Ciric - Iaşi	2.38	75.39	504.80	52.77	22.61	580.2	4089254.4	0.129	122
Voineşti - Cucuteni	1.23	39.08	379.71	27.36	11.72	418.8	5100039.9	0.093	199
Locii - Ciurbeşti	1.66	52.46	527.53	36.72	15.74	580	4233772.8	0.090	139

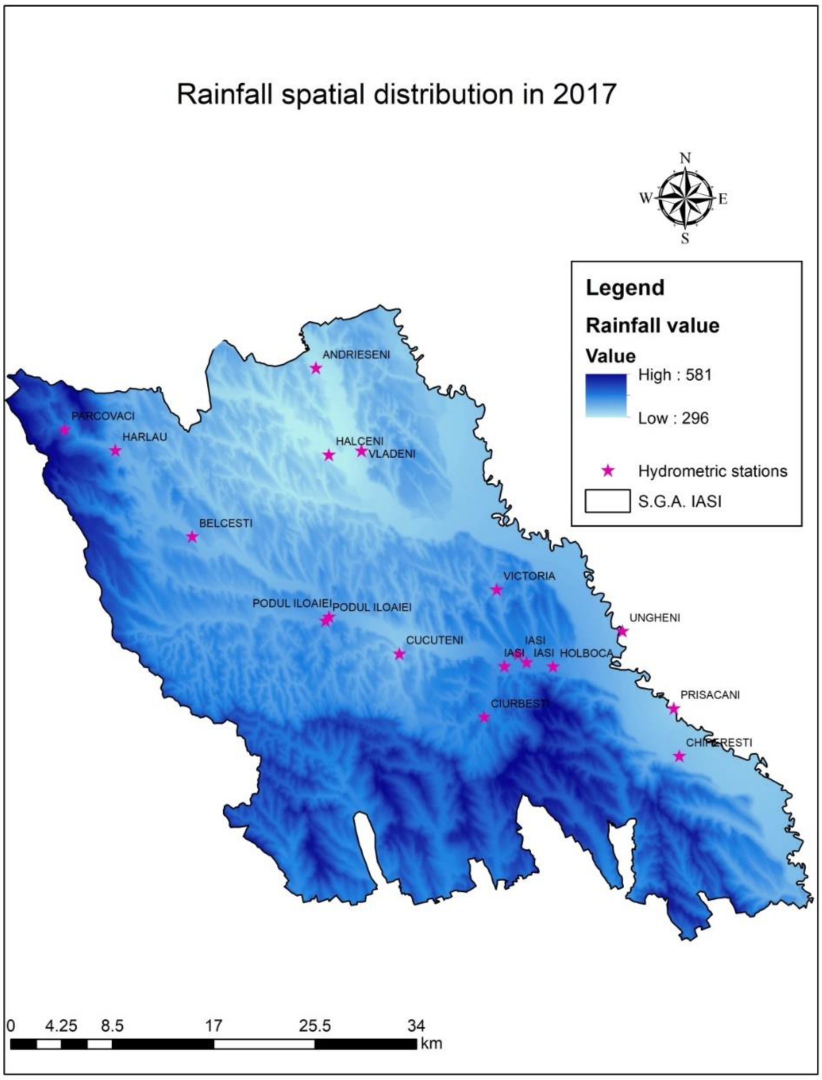

Figure 4. Rainfall distribution on Iasi County territory in the year 2017

Rainfall (X) is the most important element of the equation, which also represents the unit of comparison for the sum of the other components of the balance. 22 rainfall stations located in the Prut river basin were analyzed and the values oscillated between 297.6 al Hălceni-Aval hydrometric station and 580.2 at Iaşi hydrometric station.

Rainfall amount decreases from the north-west, and south towards the central-east area as a consequence of the remissive altitude in this direction but also due to the removal from the high area that limits Moldavian Plain which is forested. This allows the air masses continentalization, so the humidity decreases moving away from the saturation point. The amount of water from precipitation that fell on Iaşi County territory in the year 2017 varied between 296 and 581 mm (Figure 4).

Global average runoff (Y) gradually decreases in the case of the Prut River from hydrometric stations at higher altitudes, to sections located at lower ones where the supply surfaces grow considerably (140 mm at Stânca-Aval, 111 mm at Ungheni and 89.7 mm at Prisăcani hydrometric station) (Figure 5).

In the Jijia basin, the global average discharge is inversely proportional to the altitude: 22.5 mm at Todireni hydrometric station, while in Iaşi county lies between 36.7 mm at Vlădeni and 35.3 mm at Chipereşti, respectively (Table 2).

Towards the middle course, the hydro-technical works which increased the transport capacity of the riverbed (discharge sills, gabions) generate that higher value (Figure 6). Its main tributary, Bahlui River, records between 93.6 mm at Hârlău hydrometric station and 47.7 at Holboca.

The average surface runoff (S) varies in the same direction as the global average discharge in the Prut River basin, inversely proportional to the altitude, only in the case of the Jijia River in the lower course area at an altitude of 155 m, the groundwater is closer to the topographic surface and the underground supply is 10.59 mm (Chipereşti hydrometric station).

The average surface runoff (S) varies in the same direction as the global average discharge in the Prut River basin, inversely proportional to the altitude, only in the case of the Jijia River in the lower course area at an altitude of 155 m, the groundwater is closer to the topographic surface and the underground supply is 10.59 mm (Chipereşti hydrometric station).

Evapotranspiration (Z), the third major component of the hydrological balance equation, has values between 420 and 336 along Prut River's meadow. On the territory of Iaşi county, Dealul Mare - Hârlău area, they are approaching 400 mm, while on the lower course of Bahlui River rise above 530 mm (Iaşi, Holboca).

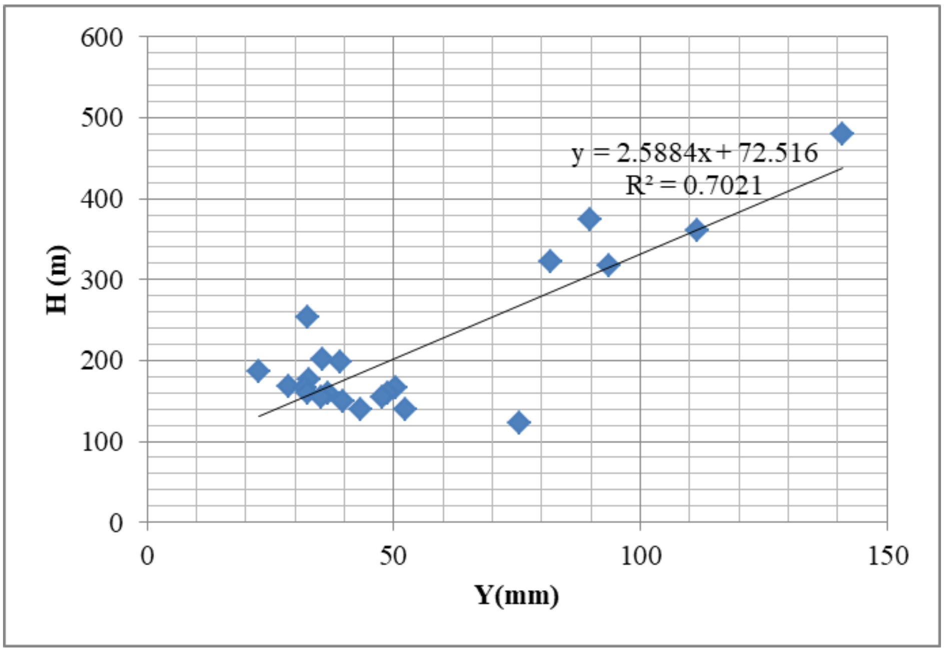

Figure 5. Correlation between global average runoff and altitude of hydrometric stations

In the River Jijia's meadow, where the average altitude is 152 m, evapotranspiration has higher values in the south-east and varies between 438 and 463 mm (Table 2).

In Moldavian Plain, a unit that comprises 80% of the analyzed area, the elements of hydrological balance change according to the rainfall amount while in the high hills from west and south (Hârlău, Iaşi) these components also vary according to the average altitude of the river basins.

Runoff coefficient records higher values in the Prut River meadow (0.21-0.25), but on the tributaries have low values compared to the national average, oscillating between 0.04 at Todireni hydrometric station in Jijia River basin (or 0.05 at Ştefăneşti along Başeu River) and 0.22 at Hârlău hydrometric station in Bahlui upper course.

Hălceni reservoir has a volume of 11.249 billion m^3, at the normal level of retention (54.5 meters above Sea Level), and the one corresponding to the minimum level of exploitation measures 2.117 billion m^3 (at the 51.5 maSL). The uses contracted in the year 2017 were the following: water supply for the population - 0.2555 billion m^3/year, for the industry - 0.0945 billion m^3/year, for fish farming - 9,841 million m^3/year. In the year 2012, the water supply of the population meant only 0.100 million m^3/year, while the local industry received 0.040 billion m^3/year. The volume of water allocated to the population and to the industry was 60% lower than in the year 2017, but in the year 2012 the fish farms in the region received 11.960 billion m^3/year.

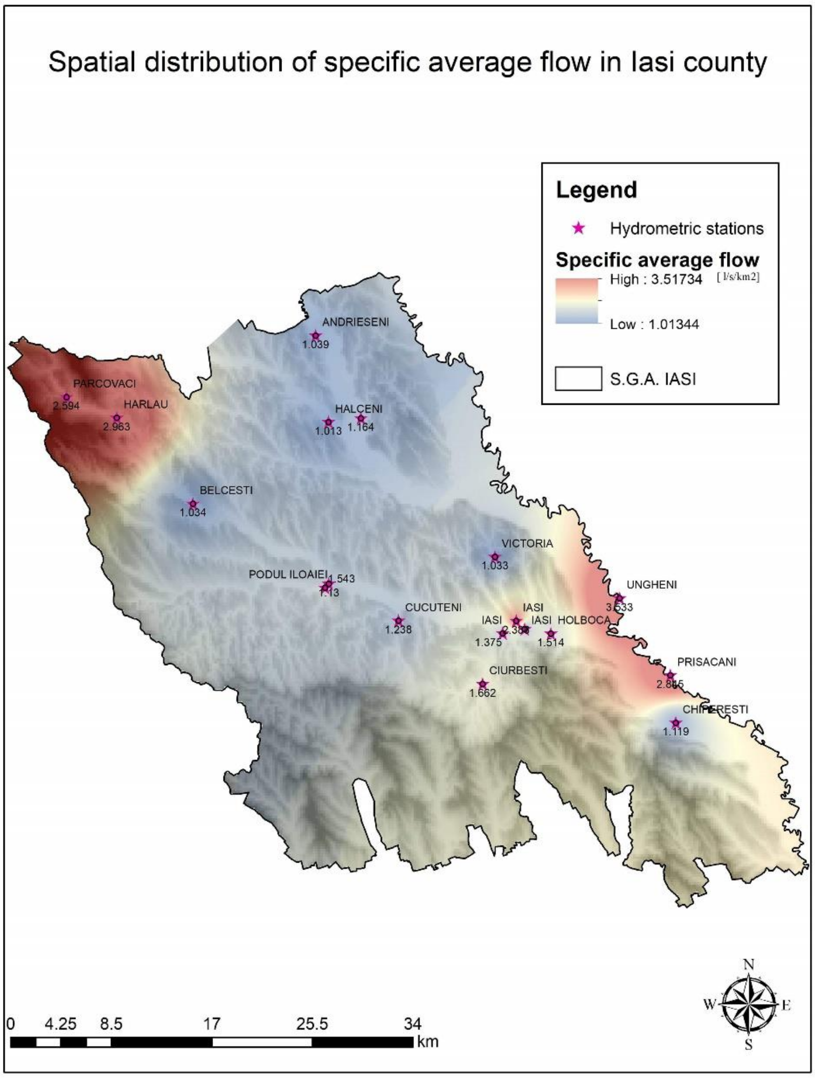

Figure 6. Spatial distribution of specific average flow in 2017 - Iaşi County

On the lower course of Jijia River, the Ciobarciu wetland with a total area of about 250 ha proposed an example of efficient management of water resources. Four polders are located in the former floodplain of Prut and Jijia River, and two small brooks enter in the first polder also, Comarna and Covasna. This one was constructed to store the water at peak discharges, to prevent floods on limitrophe agricultural land while the fourth polder allows discharge regularization in the old riverbed.

Restoration of the water flow in the Old Jijia is necessary for Ciobarciu wetland because the discharge of the two streams is insufficient and unreliable in the rainfall deficient periods. Through the Chipereşti hydrotechnical node, in the year 2017, this sector was supplied with 18 billion m^3 from May to the end of the year. At Victoria hydrometric station the transfer of water from the River Prut appears as a novelty element, in June, when the old riverbed received also 2 billion m^3.

CONCLUSIONS

In north-eastern Romania, temperature, potential evapotranspiration, and UNESCO 1979 *aridity index* reveal, based on annual values, that urban and river meadows are prone to semi-aridity risk. Although droughts may occur at any period of the year, the incidence of droughts is more severe in spring and summer. Obtaining UNESCO *aridity index* for shorter timescales, it showed that the entire region is exposed to dry conditions, especially in May and July. As presented, the trends are negative for the two months, they are not statistically significant, but the weather stations serve large areas and we consider that drought has a more pronounced impact at a local level.

In the most vulnerable areas, the annual rainfall amount is usually less than 500 mm/year, they are the most severe prone to droughts. However, as a result of the extension of built surfaces, urban areas of the region are very affected by drought, even if the precipitation exceeds this threshold. For agricultural management, as well as for general water supply, the aridity in north-eastern Romania needs to be investigated at seasonal and monthly scales, using also other indices.

Risk assessment implies the existence of methodologies which can be applied in the fields where drought can bring imbalances and notable material losses: agriculture, water supply, and environment. Each sector must be properly quantified as drought associated risk in clear terms. It appears that there is the necessity to use appropriate methods for each sector of activity exposed to the risk associated with drought, in order to get real estimates.

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