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THE IMPACT OF METEOROLOGICAL DROUGHT CASE STUDY - NORTHEASTERN ROMANIA

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Abstract

Prut River basin is located in the south-eastern Europe, in a temperate climate of transition with significant variations of the precipitation regime. This study proposes a spatial and temporal analysis of drought in northeastern Romania, in the area drained by Prut River and its tributaries, between hydrological sections Oroftiana and Gorban, to emphasize its impact on a region where water resources need to be managed efficiently. Excessively dry months, with a frequency over 20% and excessively rainy ones placed between 18.08% and 21.69, lead to the frequent occurrence of drought. According to Topor aridity index a 67.60% frequency was obtained and most of the years have proven to be moderate-dry. Between 1997 and 2013 the multiannual average values and the number of the extreme months have grown. The territorial variation of their weight, proved an increased torrentiality in the region delimited by the Botosani, Stefanesti-Stanca and Cotnari sections. UNESCO aridity index between 0.6 and 0.8 claim that this region is the second in terms of aridness intensity from Romania even if they belong to the wet class. Water has been a major limiting factor in the region as a result of the steadily decreasing amount due to the pollution and its insufficient reserves according to the riparian communities' requirements.

Key words: *correlation, drought, evapotranspiration, indices, shortage.*

INTRODUCTION

Prut River between Oroftiana (the point of entry of the river into the country) and Gorban (south-eastern extremity of Iasi County) has a length of 241 km and drains an area of 8020 km^2, divided as follows: 4469 km^2 in Botosani county and 3551 km^2 in Iasi (Figure 1).

In the analyzed region the main climatic elements are: central and southern of Moldavian Plain is crossed by 9°C isoterm, but values may exceed 9.5°C at altitudes below 120 m.

As the altitude increases, temperature drops below 8°C to over 350 m (7.5 at Harlau).

Moldavian Plain is crossed by 500 mm isohyet in center and east, however in the high hills frame from west and south and in north may approach 560 mm (Oroftiana, Harlau - Figure 2).

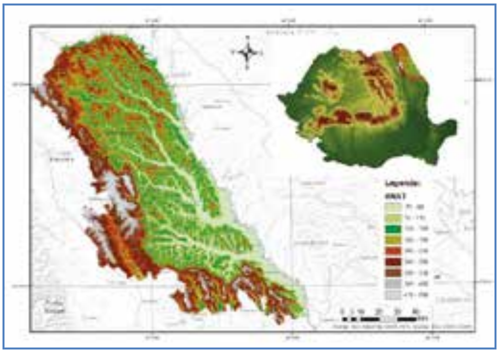

Figure 1. Hypsometric map - Prut River catchment area between Oroftiana and Gorban

Maximum values are recorded in the summer (June and July) and reach a 39-45% frequency, spring follows with 21.5 to 25.6% and in autumn the frequency is between 18.3% and 22%.

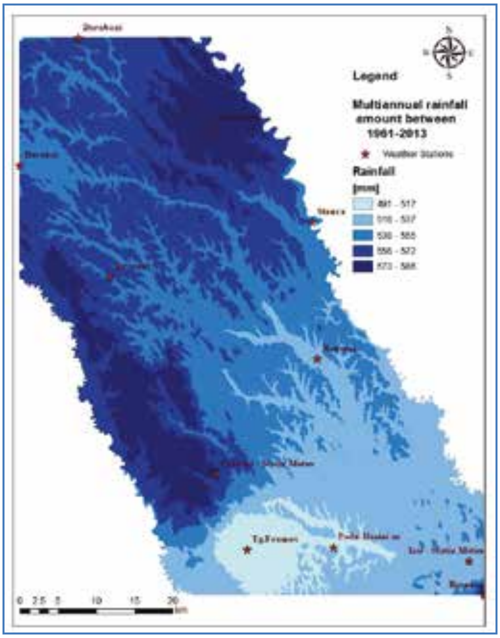

Figure 2. Multiannual rainfall amount between 1961-2013

In the winter values are within the range 12.3% to 15.9%.

Hydro - climatic risks study is based on a set of empirical and statistical analysis of involved variables closely related with the components of natural setting: geology and geomorphology of the region, biological, climatic and pedological conditions, to which was added the increased influence of human activities.

Drought is defined as the period and state of water deficit caused by negative difference between water intakes and outputs from the system, which causes reversible or irreversible imbalances and malfunctions (Stanga I.C., 2009).

Drought and the phenomena generated by it (aridization, desertification) are based, in addition to the natural and anthropogenic causes, which have a negative effect on the water balance, also on changes that arise in the general circulation of the atmosphere inflicted by the manifestation of the greenhouse effect, the irrational land use, deforestation, etc.

MATERIALS AND METHODS

For the study of drought was used a large amount of data recorded by the National Meteorological Administration and Water Basin Administration Prut-Barlad. Discrete continuous variables had been processed and the established range (1961-2013) was considered optimum for the statistical analysis.

The rainfall characterization of a month was based on Hellmann's criterion. The framing is based on the percentage deviations of the monthly precipitation quantities from the multiannual average of the period (Romanescu et al., 2014).

Under this criterion were assessed:

- normal month (NM) – when the rainfall varies between +10% and –10% compared to the multiannual average amount;
- moderately rainy month (MRM) - when varies between +10.1% and +20%;
- rainy month (RM) - when varies between +20.1% and +30%;
- very rainy month (VRM) - when varies between +30.1% and +50%;
- extremely rainy month (ERM) - when varies with more than +50%;
- moderately dry month (MDM) - when varies between 10.1% and –20%;
- dry month (DM) - when varies between –20.1% and –30%;
- very dry month (VDM) - when varies between –30.1% and –50%;
- extremely dry month (EDM) - when varies with more than –50% (Topor, 1964).

Topor aridity index (T_{AI}) was obtained from the equation 1:

$$T_{AI} = \frac{N+2R}{N+2D} \quad (1)$$

where:

- N - number of normal months;
- R - number of rainy months;
- D - number of dry months;

$T_{AI} < 0.33$ - exceptionally dry year;
$0.33 < T_{AI} < 0.41$ - excessively dry year;
$0.41 < T_{AI} < 0.71$ - very dry year;
$0.71 < T_{AI} < 0.85$ - dry year;
$0.85 < T_{AI} < 1.0$ - less dry year;
$1.0 < T_{AI} < 1.18$ - normal year;
$1.18 < T_{AI}$ - rainy year (Apostol L., 2000).

Annual values of De Martonne aridity index were obtained from: $I_{DM-a} = R / (T_a + 10)$, where: R = sum of annual rainfall and T_a =

average annual temperature. The value of 10ºC is added to the denominator to generate positive results. Monthly values were calculated as follows: $I_{DM-monthly\ ai} = r * 12/(t_a + 10)$, where r and t_a define monthly values of rainfall and average temperature.

Potential evapotranspiration (ET_0) is a commonly used variable in climatic and hydrological studies which count in the soil balance of water or the moisture requirements of agricultural crops; brings geographic information about the sort of landscape and the type / class of soil.

Standard method, Penman-Monteith, which has substituted other empirical methods to reckon ET_0, is precise and close to direct determinations, in lysimeters, because it uses most of the factors that influence the potential evapotranspiration (Monteith J.L., 1965). The six meteorological stations to which this study refers, did not record the entire climate data set required in the estimation of ET_0, which is why very significant correlations have been used. They have been set between the average monthly temperature and the potential evapotranspiration obtained through the standard method ($ET_0 - PM$). The value of the determination coefficient (R^2) is very high, according to the equation 2, Paltineanu et al. (2007):

$$ET_0 - PM = 0.0048*Ta^2 + 0.0678*Ta + 0.4888 \quad (R^2 = 0.93***) \quad (2)$$

Compared to I_{DM-ai} this difference between annual precipitation and reference evapotranspiration values ($ET_0 - PM$) is called annual climate (or hydrological) water deficit. It is calculated as a difference between two variables that characterize the essence of the natural landscape presents absolute values (mm), not relative, percentages from ET_0.

UNESCO 1979 aridity index (I_{R/ET_0}) is obtained from the annual or monthly report of rainfall and $ET_0 - PM$, even if potential evapotranspiration was obtained by means of the correlation. The desert climate, characterized by lower values than 0.03 and those in 0.03-0.20 class (arid climate) of I_{R/ET_0} does not exist in Romania. The eastern part of the Danube Delta, the Black Sea coast, Dobrogea and northeastern of Baragan are the areas with the lowest values, but they belong to the semi-arid class. The southeastern part of Moldavian Plateau and a narrow strip of the Danube meadow are framed by the 0.65 mm isoline (Paltineanu et al., 2007).

RESULTS AND DISCUSSIONS

In northeastern Romania predominates excessively dry months (with a frequency over 20%, the maximum value of 24.37% was obtained for Barnova weather station) and excessively rainy ones whose frequency is between 18.08% and 21.69% (Figure 3).

Thus, explains the high frequency of droughts in the analyzed region, where the temperate – continental climate has excessive influences.

Torrentiality increases in the region from north to south, as a consequence of the high frequency of pluviometric extremes. In Iasi county the frequency of extremely dry months is higher than in Botosani, but the significant values calculated for the extremely rainy months belong to the Botosani (19.81%) and Stefanesti (21.69%) meteorological stations, the latter highlights local climate elements as is placed in the proximity of Stanca-Costesti reservoir.

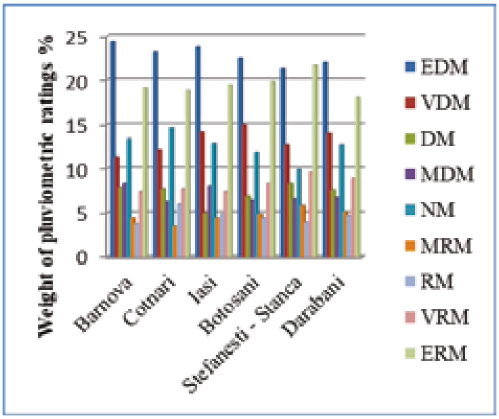

Figure 3. The weight of the pluviometric ratings at the meteorological stations in northeastern Romania, during 1961-2013 (according to Hellmann's criterion) (%)

As in previous research (Corduneanu et al., 2016) where Topor aridity index was used, drought frequency reached 67.60% and most of the years were moderate-dry. Temporal variability, a defining feature of the temperate -

continental climate is supported by the fact that the exceptionally dry years frequency in the entire region was between 3.77 and 9.43%. T_{AT} smallest value of 0.09 was recorded at Cotnari meteorological station in 1967.

A study that highlighted the drought and relied on Topor aridity index (Minea I., Stanga I.C., 2004) shows that the trend of climate aridization spatially varies from the mountain area to the Moldavian Plain, here having pronounced character as a consequence of the continental - eastern influences. In Iasi and Botosani counties, the frequency of the dry years oscillates between 75.47% at the Barnova meteorological station and 62.26% at Stefanesti-Stanca. Statistics of extreme values indicate that 2000 was exceptionally dry throughout the studied region just like 1986, when the intensity of the drought diminished in narrow areas, in Iasi had an excessive character.

Table 1. Multiannual average values of T_{AT} in northeastern Romania

The analysed period	Weather stations					
	Darabani	Botosani	Stefanesti-Stanca	Cotnari	Iasi	Barnova
1961-1978	0.891	0.941	0.858	0.809	0.853	0.822
1979-1996	0.790	0.830	1.016	0.904	0.897	0.757
1997-2013	**1.034**	**0.943**	**1.145**	**1.127**	**0.953**	**1.006**

Between 1961 and 1978 the drought was moderate (Table 1) while in the middle period, the phenomenon has become stronger, T_{AT}<0.84 south of Iasi county (Barnova - T_{AT} = 0.757), as well as in the northern half of the studied region (Botosani - T_{AT} = 0.830, Darabani - T_{AT} = 0.790). In the last interval the mean values of the Topor aridity index and the number of the extreme months, from the pluviometric point of view, are growing (EMD+ERM).

The territorial variation of their weight, which is between 43.13 and 50.49% indicates an increased torrentiality in the region delimited by the Botosani, Stefanesti-Stanca and Cotnari meteorological stations.

In the last years (1997-2013) the mean of the aridity index changes very little from a spatial point of view, it is maintained quite high at Stefanesti-Stanca and Cotnari (Table 2). Fact explained by the pluviometric extremes growth, the highest multiannual average of the Topor aridity index (Cotnari - T_{AT} = 1,127) was obtained from values ranging between 0.2 (extreme drought) and 3.8 (value corresponding to 2010 which was very rainy).

Table 2. Weight of the extreme months from the pluviometric point of view (EDM+ERM) in northeastern Romania (%)

The analyzed period	Weather stations					
	Darabani	Botosani	Stefanesti - Stanca	Cotnari	Iasi	Barnova
1961-1978	39.81	42.59	42.12	41.20	35.18	41.20
1979-1996	40.27	41.20	37.96	42.12	39.35	46.75
1997-2013	41.17	43.13	50.49	43.13	42.64	42.64

The territorial distribution of the De Martonne aridity index I_{DM-ai} shows that northeastern Romania is characterized by values between 20 and 30 mm/ºC (Paltineanu et al., 2007), dry areas with values between 15 and 20 mm/ºC are highlighted in the southeastern extremity (Baragan or the South of the Romanian Plain).

In Iasi county, values of I_{DM-ai} lower than 20 (semiarid climate, after De Martonne 1926) were calculated for 2000 (15.92 mm/ºC – Iasi, 19.27 mm/ºC – Barnova and 19.29 mm/ºC – Cotnari), also for 2011 (Iasi – 17.76 mm/ºC), when this value was exceeded at Cotnari – 20.42 mm/ºC and Barnova – 21.19 mm/ºC.

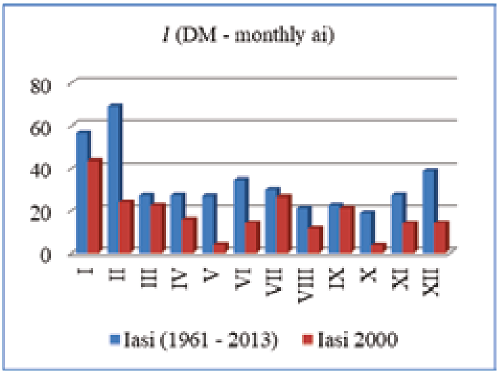

Figure 4. De Martonne monthly aridity index - Iasi meteorological station

At Iasi (Figure 4) monthly multiannual values vary between 18.7 and 34.3 mm/ºC, showing a downward trend since August $I_{DM-monthly\ ai}$= 20.9 mm/ºC (in September - 22.36 mm/ºC, and in October - 18.7 mm/ºC). At the other two meteorological stations, the values are in the range of 20 - 30 mm/ºC (Figures 5 and 6), except the related ones of June (36.6 at Cotnari and 34.9 at Barnova) and July (34.1 and 31.3, respectively). During 2000 year $I_{DM-monthly\ ai}$ is below the multiannual values, with the exception of the one calculated for July at Cotnari (41.02 mm/ºC > 34.1 mm/ºC) and Barnova (34.7 mm/ºC > 31.3 mm/ºC).

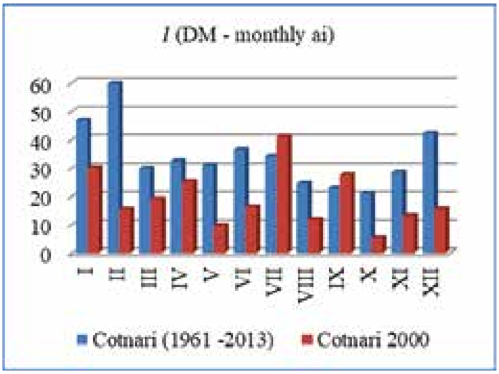

Figure 5. De Martonne monthly aridity index - Cotnari meteorological station

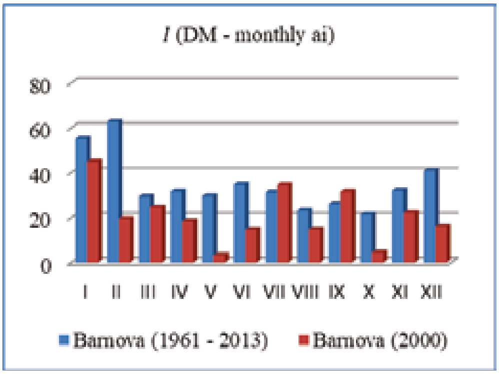

Figure 6. De Martonne monthly aridity index - Barnova meteorological station

In May, Moldavian Plain is crossed by the isoline of de 30 mm/ºC (Paltineanu et al., 2007) but a trend of aridization of the climate has been identified, due to average monthly temperature increase and the decrease of rainfall amount. De Martonne aridity index is in the 0-5 mm/ºC class (very dry and arid climate) at Iasi and Barnova, respectively 5-15 mm/ºC (semiarid) at Cotnari in May 2000. Similar values (between 5.13 and 7.44 mm/ºC), therefore severe climatic conditions, can be observed in Botosani county at the same period (Figures 7, 8 and 9).

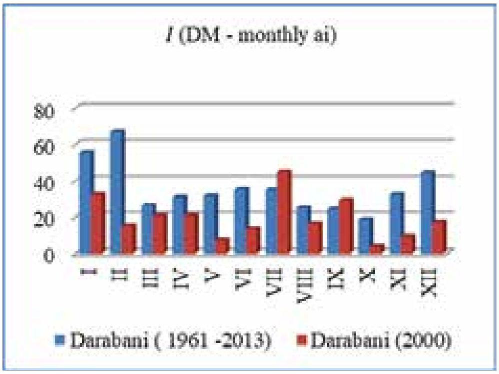

Figure 7. De Martonne monthly aridity index - Darabani meteorological station

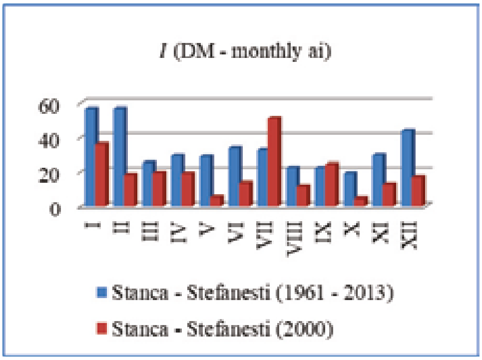

Figure 8. De Martonne monthly aridity index - Stanca-Stefanesti meteorological station

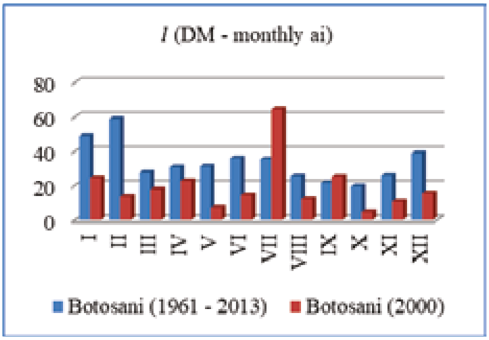

Figure 9. De Martonne monthly aridity index – Botosani meteorological station

Northeast Romania, with values of I_{R/ET_0} between 0.6 and 0.8 is the second in terms of aridness intensity.

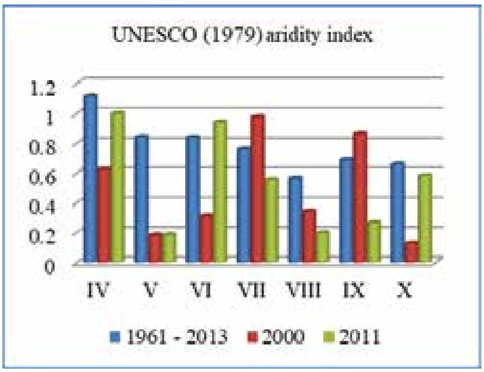

Figure 10. Monthly/multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Darabani meteorological station

After UNESCO classification, these belong to the wet class. In the north part (Figures 10, 11 and 12) the vegetation period of 2011 and 2000 was characterized by monthly values of the UNESCO (1979) aridity index lower than multiannual ones.

In this interval June made an exception I_{R/ET_0} – 0.939 (> 0.838). Both in 2011 and in 2000, the values corresponding to May $I_{R/ET_{0\,2000}}$ – 0.182, $I_{R/ET_{0\,2011}}$ – 0.183, respectively, emphasize severe climatic conditions.

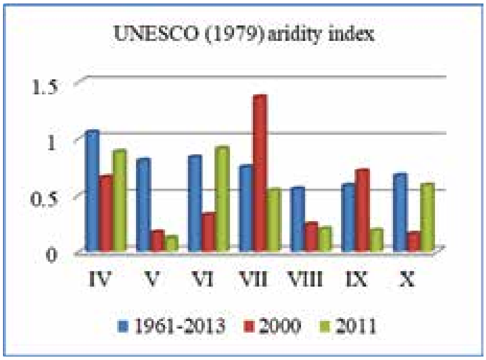

Figure 11. Monthly/multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Botosani meteorological station

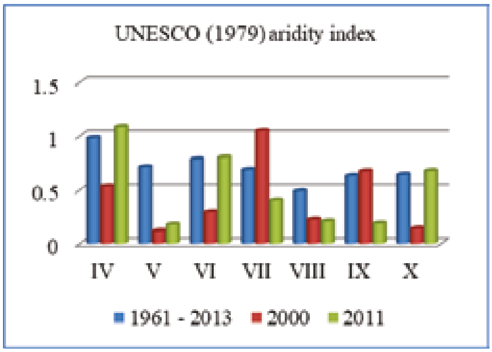

Figure 12. Monthly / multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Stanca-Stefanesti meteorological station

It can be observed that in 2000, May values are descending to the south I_{R/ET_0} < 0.20, ranging from 0.096 to 0.083 at the Iasi and Barnova weather stations. Aridity extends over wide areas in May 2011, the indicators are maintained in the same gap, less in the south of the region: at Iasi I_{R/ET_0} was 0.343, while at higher altitudes, at Barnova, I_{R/ET_0} reached 0.525 (Figures 13, 14 and 15).

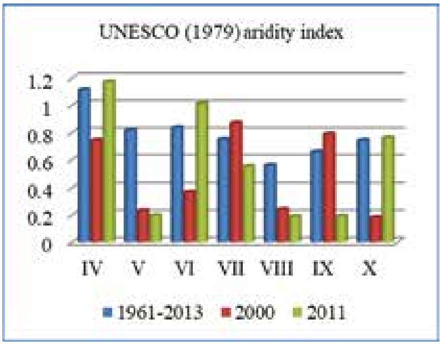

Figure 13. Monthly/multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Cotnari meteorological station

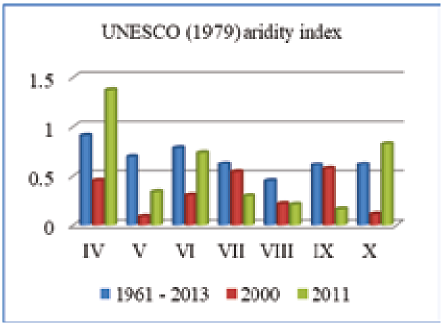

Figure 14. Monthly/multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Iasi meteorological station

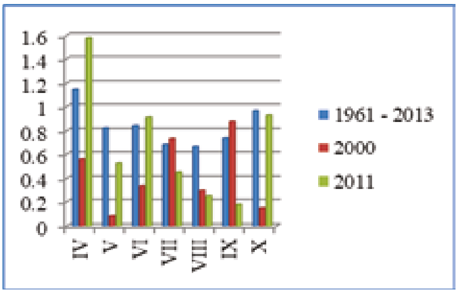

Figure 15. Monthly / multiannual values of I_{R/ET_0} calculated with ET_0–*PM* (mm/mm) at Barnova meteorological station

Table 3. UNESCO (1979) aridity index - annual/multiannual values for northeastern Romania (mm/mm)

The analyzed period	Weather stations					
	Darabani	Botosani	Stefanesti-Stanca	Cotnari	Iasi	Barnova
1961-2013	0.972	0.927	0.892	0.964	0.850	0.967
2000	0.641	0.674	0.598	0.627	0.498	0.628
2011	**0.597**	**0.565**	**0.535**	**0.633**	**0.536**	**0.670**

Moldavian Plain is characterized by multi-annual values ranging from 0.85 and 1 (0.972 at Darabani meteorological station, 0.967 at Barnova) specific to the high hills that shape it in the north and southwest. 2011 was characterized by values ranging from 0.535 to 0.633 dry climate **under** wet conditions where I_{R/ET_0} = 0.670 value influenced extensive areas with forest from the region.

Analyzing the annual water deficit, Paltineanu shows that the annual values between –200 to –300 mm cover the southern and central part of Moldavian Plateau, they descend to the north, ranging from –200 to –100 mm. For Barnova meteorological station, the multiannual value of this indicator is –109.4 mm, years with a deficit greater than –200 mm are: 1986 (–246.13 mm), 2000 (–232.2 mm) and 2011 (–203.2 mm). In the lower area of the county, in Iasi, the annual climate water deficit has a value of –149.55 mm between 1961 and 2013, significant values of –339 mm (2000), –310 mm (2011) and –304 mm (1994), are explained through the influence of the urban landscape on evapotranspiration and through the reduced amounts of rainfall. At Cotnari, multiannual value of this parameter is –110. 45 mm and in the dry years 1986, 2000 and 2011 there were obtained –258.41mm, –236.10 mm, –234.91 mm respectively.

In Botosani County, the annual water deficit increases in the NW-SE direction and is between –114.98 at the Darabani and –127.81 at Botosani meteorological station. In the vicinity of Stanca-Costesti reservoir, the multi-annual average water deficit has the highest value, –155.038, consequence of the increased evapotranspiration values at the level of the cuvette.

CONCLUSIONS

Northeastern Romania, Prut basin delimited by Oroftiana and Gorban, is influenced by a pluviometric regime with large monthly variations, specific to the transitional temperate continental climate. Excessively dry months, with a frequency over 20% and excessively rainy ones whose frequency is between 18.08% and 21.69%., lead to the frequent occurrence of the drought.

From the values of Topor aridity index a 67.60% frequency of droughts was obtained, most of them are moderate-dry years. Between 1997 and 2013 the multiannual average values of Topor aridity index and the number of the extreme months, from the pluviometric point of view, have grown. The territorial variation of their weight, proved an increased torrentiality in the region delimited by the Botosani, Stefanesti-Stanca and Cotnari sections.

The territorial distribution of the De Martonne aridity index stressed that northeastern Romania is characterized by values between 20 and 30 mm/ºC, but in 2000 and 2011 were considerably lower. Values of UNESCO aridity index between 0.6 and 0.8 claim that this region is the second in terms of aridness intensity even if they belong to the wet class.

In the last years water has been a major limiting factor of the environment as a result of the steadily decreasing amount due to the pollution and its insufficient reserves according to the society requirements.

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