ORIGINAL PAPER

Aridity conditions within the region of Oltenia (Romania) from 1961 to 2015

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Abstract

Aridity and drought assessment at a global level or within particular regions has lately gained an importance on the background of global warming, variability of rainfall amounts and, of course, their impact on social welfare. Aiming at understanding this impact, there were analysed spatial distribution (based on the data from 15 meteorological stations, generally covering the period 1961–2015) and temporal variability of three aridity indices. Thus, there were calculated De Martonne aridity index (I_{DM}) at annual, seasonal and monthly level, Pinna combinative index (I_p) and Selyaninov's hydrothermal coefficient (HTC). I_p indicates humid conditions all over the analysed area, with slight differences within the extra-Carpathian region, confirming thus that it does not give relevant results for the temperate region. I_{aDM} illustrates a greater territorial differentiation, namely semi-humid conditions in the plain area and in the eastern part of the entire region, humid and very humid conditions in the Subcarpathians and the mountains. At monthly level, there are up to 5 months (in the plain area) with semiarid conditions, generally covering the summer period, as well as September and October. The same monthly pattern is highlighted by HTC, especially in the summer months, which are moderately or slightly arid, mainly in the plain area. However, if analysing the long-term trends (for I_{aDM}), it results that there is not a statistically significant tendency of aridization in the analysed region.

1 Introduction

There is no doubt that, presently, climate conditions undergo a more or less obvious change, depending on the region, which triggers a direct or indirect impact on societal welfare, as food and water resources highly depend on climate. According to IPCC (2018), global mean surface temperature for the decade 2006–2015 was 0.87 °C higher than the average of the period 1850–1900, while precipitation amounts registered non-uniform changes. Consequently, there have been developed different simple or composite indices to render these relations and there have been published numerous studies about drought and dryness, aridity or desertification at global, national or regional scale. Focusing on Europe's situation, there emerged different situations in terms of aridity, but most of the studies indicate an increase in aridity, particularly in the

southern Mediterranean region. Aridity, defined as a permanent feature of the climate, emerges on the background of the correlation between large-scale and persistent circulation patterns and topography of a particular region (Maliva and Missimer 2012).

In Europe, most studies indicate an increase in aridity, particularly in the southern Mediterranean region.

For northern Greece, for example, Baltas (2007) emphasized different degrees of aridity based on the De Martonne aridity index, while Nastos et al. (2013) focused on the present shift from humid to semi-humid and semiarid climates in certain parts of Greece, indicating a projected increase in aridity over large parts of the country based on the Thornthwaite aridity index in the next 40 years. Based on the same indices (De Martonne and Thornthwaite aridity index), Coscarelli et al. (2004) and Colantoni et al. (2015) analysed the aridity increase in Italy, while Deniz et al. (2011) highlighted increasing aridity in Turkey based on the De Martonne aridity index and the Johansson continentality index. For the Iberian Peninsula, Andrade and Corte-Real (2016) emphasized drier conditions in the south, central and the Pyrenees regions, while Moral et al. (2017) reached the same conclusion for the southwestern Spain based on the De Martonne aridity index and the Pinna combinative index. For the Balkan Peninsula, both Hrnjak et al. (2014) and Bačević et al.

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(2017) found no significant changes in aridity in different parts of Serbia based on the Pinna combinative index and on the De Martonne aridity index, while Moteva et al. (2010) and Kazadjiev et al. (2012) indicated an increase in aridity for Bulgaria.

In Romania, drought and aridity have represented one of the main research topics for numerous climate experts in the last two decades, on the background of temperature increase and higher variability of rainfall amounts. Aridity is more intense in the extra-Carpathian regions of Romania corresponding mainly to the plain and plateau areas of the country, where polar and tropical continental air masses predominate compared with oceanic air masses. Most of the studies indicate an increase in aridity in these regions triggered by ever-increasing temperature and potential evapotranspiration rather than by the reduction of the rainfall amounts. Aridity was highlighted and analysed by Croitoru et al. (2013) for the extra-Carpathian regions, by Păltineanu et al. (2007), Vlăduț et al. (2017a) for southeastern and southern regions of Romania, by Dragotă et al. (2011), Peptenatu et al. (2013), Prăvălie (2013), Vlăduț (2010) for the region of Oltenia, by Lungu et al. (2011), Prăvălie and Bandoc (2015), Tiscovschi et al. (2013) for Dobroudja, by Pelin (2016) for Moldova, and by Lungu et al. (2012) for the Danube Delta.

In this paper, we assessed aridity based on three indices—De Martonne aridity index, Pinna combinative index and Selyaninov's hydrothermal coefficient. The statistical significance of the identified trends in the case of the annual values of the De Martonne aridity index was tested using the Mann-Kendall test. The Pearson correlation coefficient was used to establish the correlation between the three indices.

2 Study area, data and methods

2.1 Study area

The region of Oltenia is located in the southwestern part of Romania, with the following geographical coordinates: 43°40′ N lat. in the south, 45°35′ N lat. in the north, 22° E long. in the west, and 24°53′ E long. in the east. It covers all types of landforms in Romania: plain, Oltenia Plain (the western part of the Romanian Plain) and the Danube Alluvial Plain in the south; plateau, Getic Piedmont; hills, Getic Subcarpathians; and mountains, Parâng and Retezat-Godeanu Mountains (part of the Southern Carpathians) and Banat Mountains (part of the Western Carpathians) (Fig. 1). Consequently, there is registered a great altitudinal range, as the region has only 3 m within the Danube Alluvial Plain (at the confluence between the Olt and the Danube rivers) and 2519 m in the mountain area (Parângul Mare Peak). The altitude in this region ranges from 3 m within the Danube Alluvial Plain (at the confluence

between the Olt and the Danube rivers) and 2519 m in the mountain area (Parângul Mare Peak). Its largely moderate continental climate is influenced by the increased penetration of Mediterranean air masses (Badea et al. 1983). This means greater rainfall amounts from November to December, higher maximum temperatures in summer and frequency of warm spells in winter compared with the other parts of southern Romania. In this context, Oltenia is one of the regions most prone to aridity in Romania.

2.2 Data

We used mean monthly temperature and precipitation data from 15 meteorological stations located in Oltenia (Fig. 1, Table 1). The data cover a mean period of 55 years (1961–2015), except for certain stations, such as Vânju Mare (1961–2002), as the meteorological station stopped its activity, and Parâng (1961–2007, as the data were not available to the authors). At four of the stations—Drobeta Turnu Severin, Craiova, Târgu Jiu, Râmnicu Vâlcea—the data come from Klein Tank et al. (2002) (data and metadata available on line at http://www.ecad.eu). For the other stations, the data were provided by the National Meteorological Administration – Oltenia Regional Meteorological Centre for the period 1961–2010 (provided under the framework of the strategic grant POSDRU/89/1.5/S/61968, Project ID61968 (2009), *University Partnership in Research—A step forward towards a postdoctoral school of the future*, co-financed by the European Social Fund within the Sectorial Operational Program Human Resources Development 2007–2013), while for the period 2011–2015, meteorological data were taken from the annual reports elaborated by the Environmental Protection Agency or Inspectorates for Emergency Situations (for each county in the region).

2.3 Methods

2.3.1 De Martonne aridity index

The De Martonne aridity index (I_{DM}), introduced by de Martonne (1926), is one of the oldest and widely used indices in the assessment of aridity. It was applied in numerous studies, on small or large areas, such as Coscarelli et al. (2004) for southern Italy, Baltas (2007) for northern Greece, Vlăduț (2010) for the western part of the Romanian Plain, Croitoru et al. (2013) for extra-Carpathian Romanian regions, Hrnjak et al. (2014) for Vojvodina, Murărescu et al. (2014) for the central and eastern parts of the Romanian Plain, Haider and Adnan (2014) for Pakistan, Bačević et al. (2017) for Kosovo and Metohija, Vlăduț et al. (2017a) for southern Romania and northern Bulgaria, Radaković et al. (2018) for Central Serbia, etc.
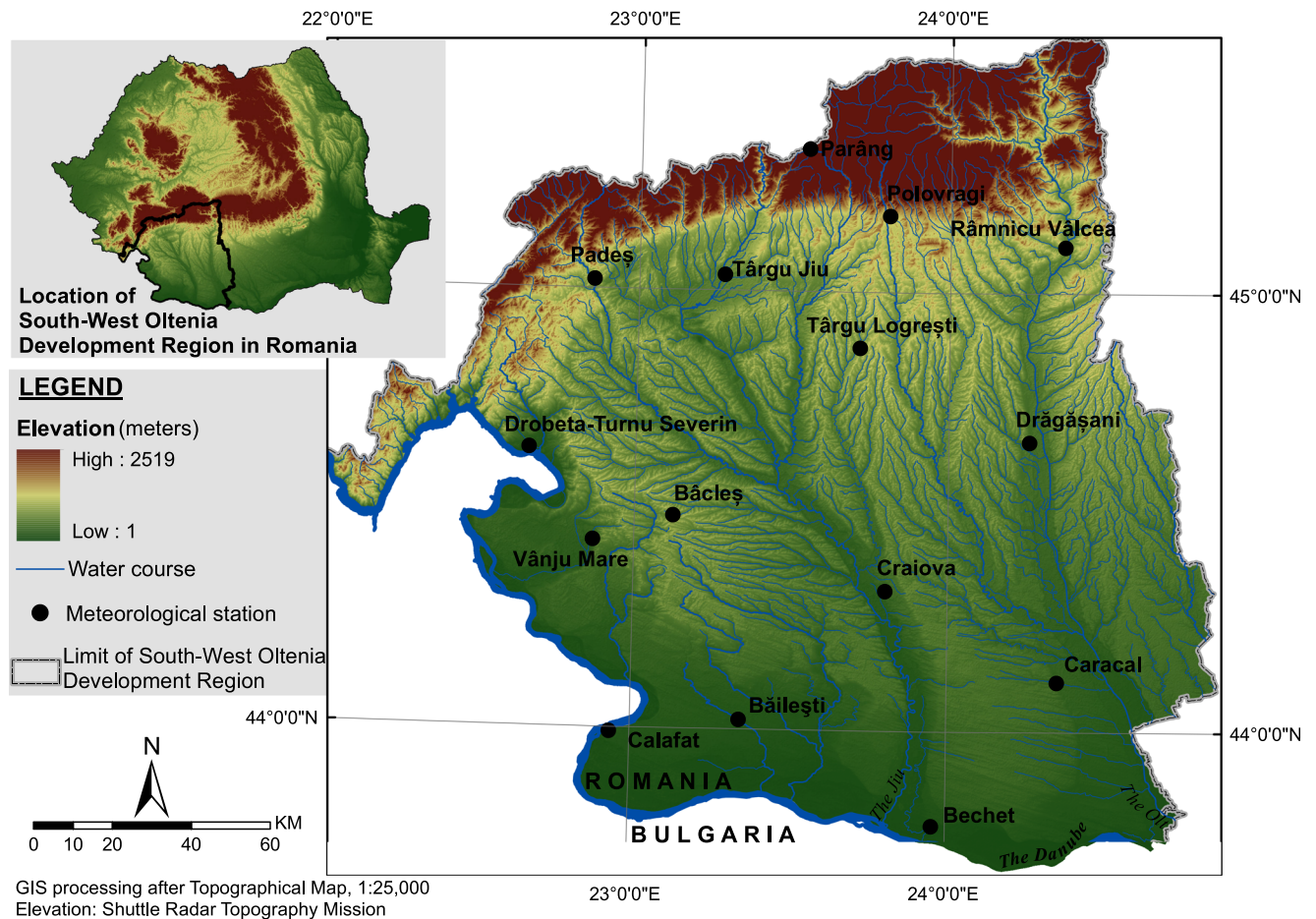
Fig. 1 Location of the Region of Oltenia in Romania, main landforms, and the meteorological stations we considered. Source: Vlăduț et al. 2017b

Table 1 Geographical coordinates of the meteorological stations we considered

No.	Meteorological station	Altitude (m)	Latitude	Longitude
1	Calafat	61	43°59′	22°57′
2	Bechet	36	43°47′	23°57′
3	Băileşti	57	44°01′	23°20′
4	Caracal	106	44°06′	24°22′
5	Craiova	192	44°19′	23°52′
6	Vânju Mare	86	44°26′	22°51′
7	Dr. Turnu-Severin	77	44°38′	22°38′
8	Bâcleş	313	44°29′	23°07′
9	Drăgăşani	280	44°40′	24°17′
10	Târgu Logreşti	265	44°53′	23°42′
11	Apa Neagră (Padeş)	258	45°00′	22°52′
12	Târgu Jiu	203	45°02′	23°16′
13	Polovragi	531	45°11′	23°49′
14	Râmnicu Vâlcea	237	45°06′	24°22′
15	Parâng	1548	45°23′	23°28′

At the annual level, the index is calculated according to the following formula:

$$I_{aDM} = \frac{P}{T + 10} \tag{1}$$

where P is the annual amount of precipitation, T is the mean annual temperature, and 10 represents a coefficient that is added in order to obtain positive values. The climate classification according to the values of I_{aDM} is included in Table 2.

At the seasonal level (I_{sDM}), the following formula was applied:

$$I_{sDM} = \frac{4P_s}{T_s + 10} \tag{2}$$

where P_s represents the seasonal amount of precipitation and T_s is the mean seasonal temperature (see type of climate in Table 2).

At the monthly level, the de Martonne aridity index (I_{mDM}) was calculated based on the following equation:

Table 2 Climate type according to the de Martonne aridity index

Climate classification	Values of I_{aDM}/I_{sDM}	Climate classification	Values of I_{mDM}
Dry	$I_{aDM} < 10$	Dry or arid	$I_{mDM} < 10$
Semi-dry	$10 \leq I_{aDM} < 20$	Semiarid	$10 \leq I_{mDM} \leq 24$
Mediterranean	$20 \leq I_{aDM} < 24$	Moderately arid	$24 < I_{mDM} \leq 30$
Semi-humid	$24 \leq I_{aDM} < 28$	Slightly humid	$30 < I_{mDM} \leq 35$
Humid	$28 \leq I_{aDM} < 35$	Moderately humid	$35 < I_{mDM} \leq 40$
Very humid	$35 \leq I_{aDM} < 55$	Humid	$40 < I_{mDM} \leq 50$
Extremely humid	$I_{aDM} > 55$	Very Humid	$50 < I_{mDM} \leq 60$
		Extremely humid	$I_{mDM} > 60$

Source: I_{aDM}/I_{sDM}, Andrade and Corte-Real (2016); I_{mDM}, Hydrological Observatory of Athens http://hoa.ntua.gr/contours/monthlyidm. (Hydrological Observatory of Athens, 2018, P. Mean, 2018)

$$I_{mDM} = \frac{12P_m}{T_m + 10} \qquad (3)$$

where P_m is the amount of precipitation and T_m is air temperature for the month in question. The classification of I_{mDM} values is shown in Table 2.

2.3.2 Pinna combinative index

The Pinna combinative index (I_p) was developed by Pinna (Zambakas 1992, quoted by Baltas 2007):

$$I_p = \frac{1}{2}\left(\frac{P}{T+10} + \frac{12P'_d}{T'_d+10} \right) \text{ (Baltas 2007)}$$ where P and T rep-

resent the annual mean values of precipitation and air temperature and P'_d and T'_d are the mean values of precipitation and air temperature of the driest month, if applied on mean values. If I_p is less than 10, the climate is considered to be dry, between 10 and 20 as semi-dry, and above 20 as humid (Andrade and Corte-Real 2016). Most of the studies refer to the Mediterranean region, northern Greece (Baltas 2007), Turkey (Deniz et al. 2011); Portugal (Andrade and Corte-Real 2016); Italy, Emilia-Romagna region (Nistor 2016); or nearby areas, the extra-Carpathian region of Romania (Croitoru et al. 2013), Kosovo and Metohija (Bačević et al. 2017), Central Serbia (Radaković et al. 2018). Cheval et al. (2017) calculated I_p at the continental scale.

2.3.3 Selyaninov's hydrothermal coefficient

The Selyaninov's hydrothermal coefficient (HTC), developed by Selyaninov (1958), was calculated based on the following formula:

$$HTC = \frac{P}{\sum_{T>10} \frac{T}{10}} \qquad (5)$$

where P is the sum of precipitation amounts (mm) and T is the sum of temperatures (°C) for the months when mean temperatures exceed 10 °C, which mostly correspond to the period of April–October. The index can be also calculated at monthly level. HTC was applied in different studies related to the determination of moist and dry periods (Riazanova et al. 2016; Vlăduţ et al. 2017a), or to the favourability of climate for the development of different plants, both cultivated and natural (Kwiatkowski 2015; Evarte-Bundere and Evarts-Bunders 2012; Leblois and Quirion 2013). HTC is mainly used in Bosnia and Herzegovina, Bulgaria, Kazakhstan, Lithuania and Ukraine, but it can be successfully applied to the conditions in Romania, too. The significance of the HTC values is shown in Table 3.

2.3.4 Temporal evolution of the aridity indices

In order to identify long-term changes, we computed the linear trend of the I_{aDM} for each station. We used the Mann-Kendall test to test the statistical significance of the annual and seasonal values of De Martonne aridity index, and processed the data in the MAKESENS Excel template, developed by the researchers of the Finnish Meteorological Institute (Salmi et al. 2002). Based on this test, one can statistically assess if there is a monotonic upward or downward trend (a positive value of test Z for time series indicate an increasing/upward

Table 3 Climate classification according to the HTC

HTC	Climate classification
0.3	Very dry or arid
0.31–0.60	Dry
0.61–0.80	Moderately dry
0.81–1.00	Slightly dry
1.01–1.20	Slightly humid
1.21–1.40	Moderately humid
1.41–1.60	Humid
>1.61	Very humid

Source: Vlăduţ et al. 2017a (adapted from Selyaninov 1930)

trend, while a negative value of test Z marks a decreasing/downward trend). We also calculated the correlation coefficient for mean annual values, based on the Pearson correlation coefficient, between I_{aDM} and I_p, I_{aDM} and HTC, HTC and I_p, as well as between I_{mDM} and HTC for the common months. When the values of the coefficient are between + 0.70 and + 1.0, it is considered to have a strong positive association, between + 0.30 and + 0.70 a week positive association, and between − 0.30 and + 0.30 little or no association (P.Mean http://www.pmean.com/definitions/correlation.htm).

2.3.5 Interpolation

The processing and spatial representation of the analysed indices was realized in GIS environment. We conducted a comparison of the performance of several spatial interpolation methods available (IDW, Kriging, Natural Neighbor, Spline) for the spatial projection of mean air temperature and precipitation values, as well as for those of the derived indices.

Abundant data lead to similar results with most interpolation techniques, whereas in case of sparse information, the assumptions made about the underlying variation that has been sampled, as well as the choice of method and its parameters, can be critical (Tveito et al. 2006).

Accordingly, for the interpolation of the De Martonne and Selyaninov indices computed for the 15 meteorological stations in our respective area and for the support stations, the spline tension method, readily integrated in the ArcGIS spatial analyst tools, proved to be the most appropriate. It takes into account the climatic dependence on topography and the accuracy of the yielded results was satisfactory.

3 Results and discussion

3.1 Spatial and temporal distribution of the De Martonne aridity index

Aridity conditions can be assessed by applying different simple or composite climatic indices. Depending on the location and climatic features of a particular region, certain indices are more adequate than other indices. For temperate regions, viable results were obtained based on the De Martonne aridity index. We applied the index for the region of Oltenia at annual, seasonal and monthly level.

I_{aDM} values highlight different types of climatic conditions mainly induced by the altitudinal range within the region and exposure to different air masses, which generally triggers higher rainfall amounts as altitudes increase. Thus, in the southern part, which corresponds to the plain area, the characteristic climatic conditions are semi-humid, except for the higher areas (i.e. in the north, where the City of Craiova is located) and for the western extremity (i.e. at the contact with

Mehedinţi Plateau and Banat Mountains), where climate displays humid characteristics. At the stations located within the Danube Alluvial Plain, the values of I_{aDM} are very close to the upper limit of the Mediterranean climate, as temperatures are among the highest in the region and rainfall amounts the lowest. The humid climate is also characteristic to the Getic Piedmont and to the eastern extremity of the Getic Subcarpathians, while within the rest of the Subcarpathians, the climate is very humid. In the mountains, at lower altitudes, the climate is also very humid, while at altitudes above 1500 m, it becomes extremely humid (Fig. 2).

I_{sDM} illustrates distinct climate conditions for each season. In winter, for example (Fig. 3a), the climate conditions of the entire region are very humid in the plain and the piedmont areas and extremely humid in the Subcarpathians and in the mountains. In spite of the fact that there are similar climate conditions, a territorial distribution pattern emerges, which is different compared with the one captured by the annual values. That is, the lowest values appear in the eastern part of the region, east of the Jiu River more precisely, from the plain up to the mountains, as there is a greater predominance of dry continental air masses. Moreover, the extremely humid conditions appear as two nuclei located in the north and northwest of the region, not only in the mountains but also in the hilly area (Apa Neagră – Padeş).

Starting with spring, the heterogeneity of climate condition increases, but the conditions are quite similar to those characteristic for annual values (Fig. 3b). More precisely, in the plain area, the values of the index indicate a semi-humid climate, with the same two parts (northern and western) displaying a humid climate. The lowest values are also characteristic to the southeastern part of the plain, starting from Caracal to the Danube River, but the area displaying such conditions is a little more extended compared with the one registered at annual level. The piedmont area also presents humid conditions, as well as the eastern part of the Subcarpathians. Very humid conditions are characteristic to the rest of the Subcarpathian area and extremely humid conditions to the higher altitudes in the mountains. The similarity between annual and spring values was also mentioned by Croitoru et al. (2013) for the extra-Carpathian regions.

Summer is the most heterogeneous season in terms of I_{sDM}. It is also the driest season in the region of Oltenia, as temperature values increase a lot within the entire extra-Carpathian area, without obvious differences imposed by altitudinal range, while rainfall amounts generally decrease, especially in August. However, summer is still the rainiest season in the region, which means the low values of I_{sDM} are mainly induced by high temperatures. Thus, in the southern half of the plain, semi-dry conditions set in, the values of the index being below 20 °C/mm, while in the northern half, as well as in the western part of the Getic Piedmont, Mediterranean conditions prevail (Fig. 3c). Consequently, the two classes (semi-dry and
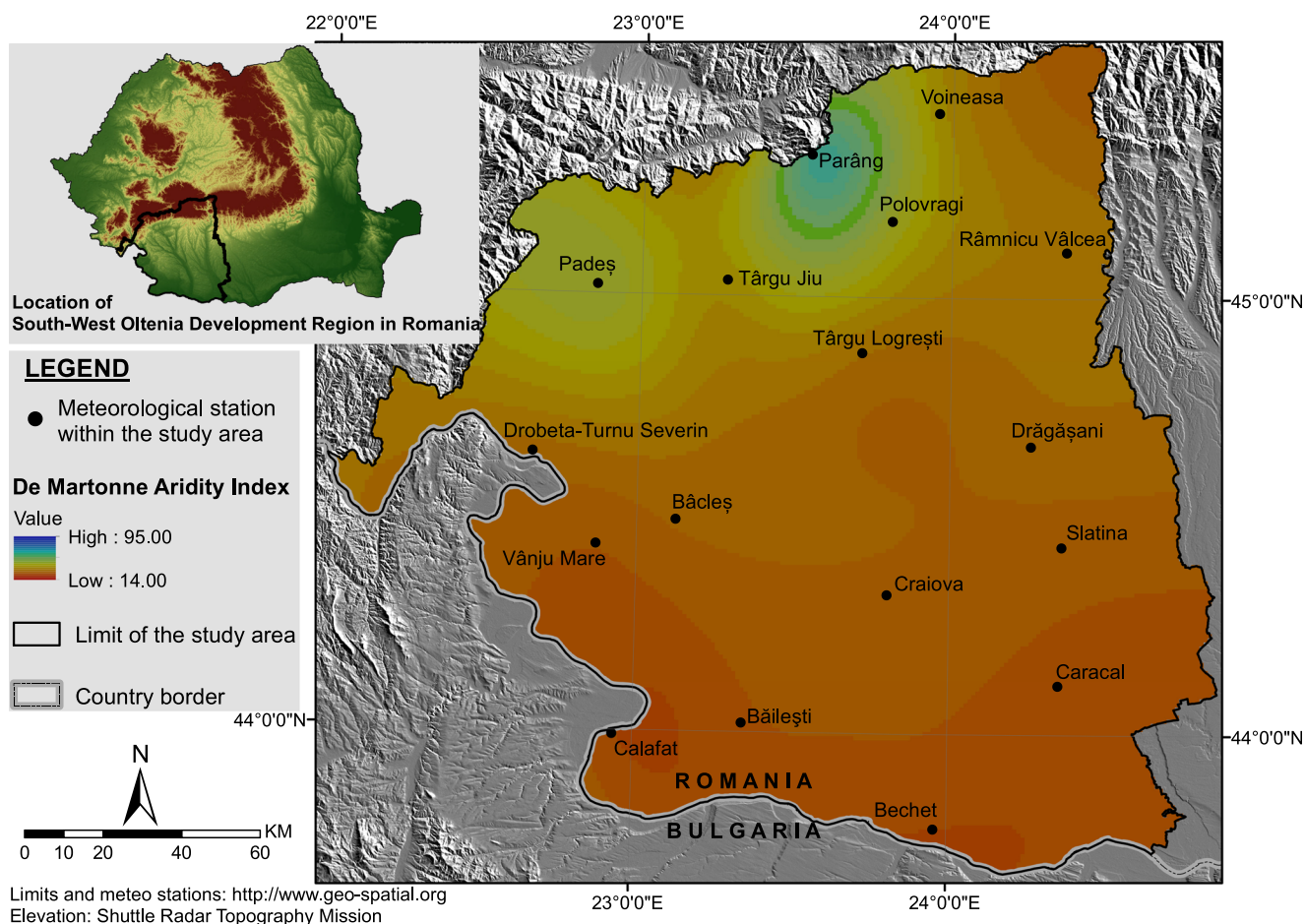
Fig. 2 Annual De Martonne aridity index (I_{aDM}) within the Region of Oltenia based on mean temperature and rainfall values

Mediterranean) cover almost half of the region under study. In the hilly area, both piedmont and Subcarpathians, there are humid conditions, except for Polovragi, which is located at a higher altitude and presents very humid conditions. Extremely humid conditions are registered in the mountains, at higher altitudes, just as was the case in the other two previously analysed seasons.

In autumn, the area characterized by semi-dry conditions no longer appears, but Mediterranean conditions set in instead. In the rest of the plain, as well as in the piedmont area, semi-humid conditions emerge. Humid conditions appear in the eastern part of the Subcarpathians, while very humid conditions set in within the rest of the hilly area and in the mountains (Fig. 3d). This means that autumn is the driest season at higher altitudes.

At the monthly level (I_{mDM}), we mainly focussed on the warm half of the year, as most plants, both cultivated and natural species, have greater water requirements during this part of the year. Based on the multiannual mean temperature and rainfall values, there are no dry or arid months in the region of Oltenia. However, in the south of the region, there are up to 8 months characterized as semiarid or moderately

arid. It is mainly in the eastern part of Oltenia Plain, between the Olt and the Jiu Rivers, where the interval from July to October is semiarid and the interval from March to June is moderately arid. In fact, within the entire plain area and even the western part of the piedmont, the interval July–September is semiarid. In the Subcarpathians, the number of months characterized by moderately arid conditions increases from West (1 month, June, at Apa Neagră) to East (2 months, August and September, at Târgu Jiu; 3 months, August, September and October, at Râmnicu Vâlcea). The only station without aridity conditions is Polovragi, where September is the only month with slightly humid conditions. In the mountains, all the months are humid to extremely humid, with the lowest values of I_{mDM} corresponding to the interval from August to September. Consequently, August is the driest month in the Region of Oltenia, except for its eastern extremity, where the lowest values are registered in September.

During the winter-half, the values of the I_{mDM} indicate conditions from moderately to extremely humid, which is favourable to winter crops. Consequently, wheat can be cultivated in good conditions within most of the region, as it can fully mature before aridity conditions emerge. As for maize,
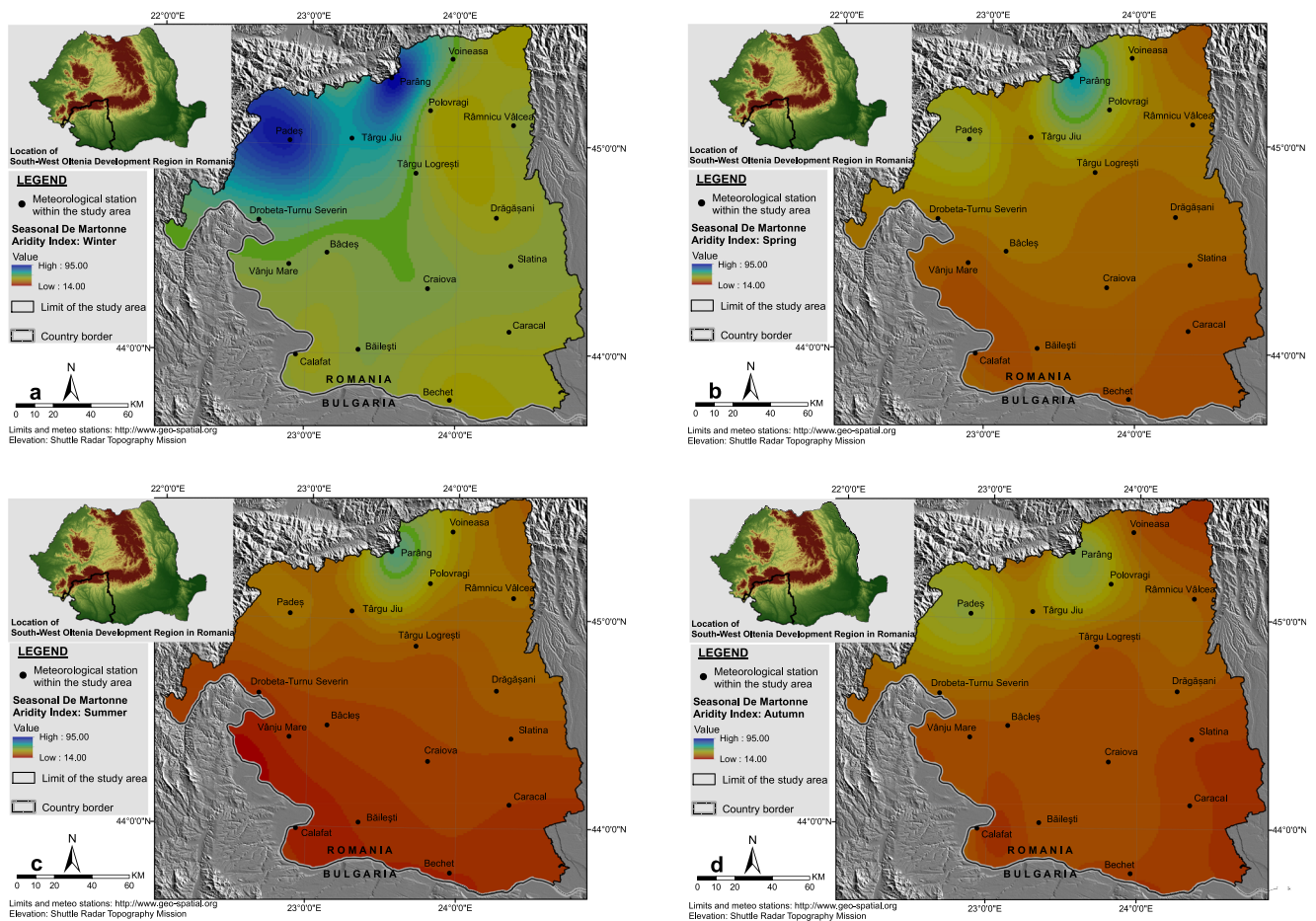
Fig. 3 Seasonal De Martonne aridity index (I_{sDM}) within the Region of Oltenia based on mean temperature and rainfall values

certain varieties, in particular the ones that mature in 3 months, can be also cultivated in good conditions, but for higher productions, irrigations are necessary, mainly in the plain area.

In terms of temporal distribution, we analysed the annual values from 1961 to 2015, with a more detailed presentation of the plain area. This is because the plain area faces the most severe problems in regard to aridity in the Region of Oltenia, even though this is also where most agricultural activities take place. Linear trends, calculated for all the stations for annual values, are both positive and negative, but they are statistically insignificant. Positive values indicate a decrease in aridity, while negative values indicate an increase in aridity. Notably, the linear trend for the plain area indicates an increase in the aridity conditions at Caracal (Fig. 4a) and Drobeta Turnu Severin (Fig. 4b), in the east and west of the region, while the northern part (i.e. Craiova) displays a decrease in aridity (Fig. 4c). The central part of the plain does not undergo any changes in terms of aridity (Fig. 4d–f). In the hilly area, at most stations, the trends are slightly negative, except for Apa Neagră, where the trend is slightly positive, but totally insignificant from a statistical viewpoint.

The statistical significance was also tested with the non-parametric Mann-Kendall test (Salmi et al. 2002), which revealed the same situation—increase or decrease trends, but, in most of the cases, with no statistical significance. However, most of the values for the annual De Martonne aridity index time series displayed a decreasing trend (Z negative values), denoting intensifying arid conditions, especially within the low eastern part of the region—plain and south of the piedmont (Table 4). Caracal is the only station where the decreasing annual trend has a 0.1 level of significance. Similar results were obtained for other European regions as well (Hrnjak et al. 2014; Moral et al. 2017).

At seasonal level, there is a greater heterogeneity. Winter values of I_{sDM} display negative trends within the plain, piedmont and eastern part of the Subcarpathians, with no statistical significance. In spring, I_{sDM} has slightly positive trends in the plain area, except for the eastern and western extremities (Caracal and D. T. Severin) where the trend is negative and the level of significance is 0.05. This means that aridity increases only in the western and eastern parts of the plain. The trend is also negative in the piedmont and the Subcarpathian regions (except Târgu Logreşti and Târgu Jiu), with no
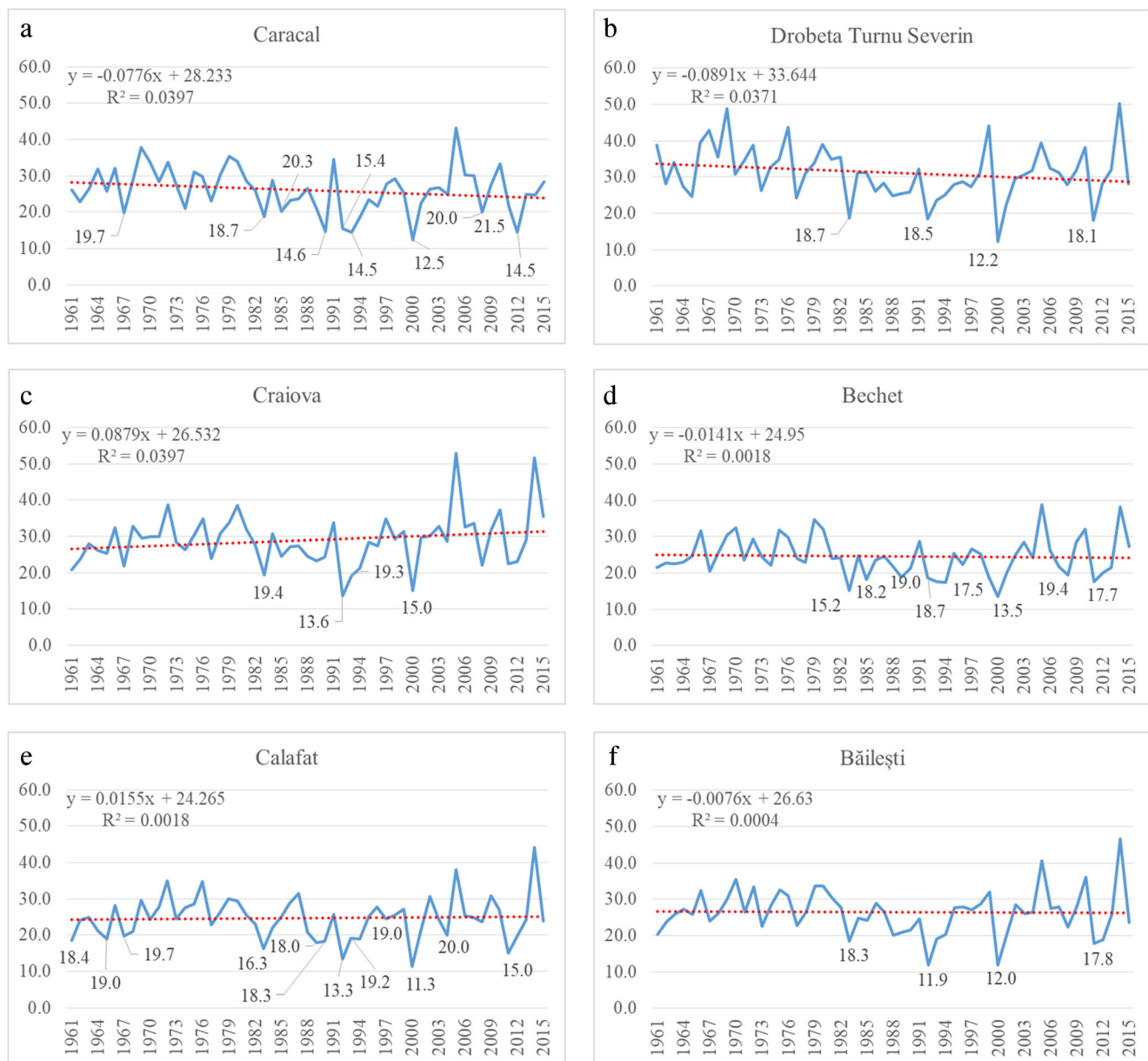
Fig. 4 Annual values of the De Martonne aridity index (I_{aDM}) within the Region of Oltenia

statistical significance. Summer I_{sDM} values present an upward trend in the north part of the plain (Craiova), eastern part of the piedmont (Drăgăşani and Târgu Logreşti) and western half of the Subcarpathians (Apa Neagră and Târgu Jiu), which means aridity decreases. The only values with statistical significance (0.1) are registered at Caracal (negative Z—decreasing trend and increasing aridity) and Drăgăşani (positive Z —increasing trend). In autumn, all I_{sDM} trends are positive, only three stations (Craiova, Drăgăşani and Târgu Jiu) displaying a 0.1 level of significance. Based on these results, aridity increases only in the eastern part of Oltenia Plain (around Caracal), where the trends for year, winter, spring, and summer values of the de Martonne Aridity Index were

negative, in three cases these being also statistically significant.

The analysis of the annual values emphasized that there were no dry years ($I_{aDM} < 10$ °C/mm), but quite a significant share of semi-dry years (I_{aDM} between 10 °C/mm and 20 °C/mm). The greatest number of years characterized by aridity is registered within the Danube Alluvial Plain. At Calafat, almost 22% (12 cases) of the years under analysis qualify as semi-dry and 16.4% (8 cases) at Bechet. The same situation is registered at Caracal, in the east of the plain. At Băileşti, there were 5 years with semi-dry conditions, while at the other two stations, 4 such cases were registered. If we add the years with Mediterranean conditions, the percentage of

Table 4 Test Z, statistical significances (SS) and Sen's slope estimate (Q) for I_{aDM} and I_{sDM} (1961–2015)

Station/period	Calafat			Bechet			Băilești			Caracal		
	Z	SS	Q	Z	SS	Q	Z	SS	Q	Z	SS	Q
Year	−0.49		−0.025	−0.49		−0.025	−0.35		−0.016	−1.70	+	−0.103
Winter	−1.18		−0.209	−1.18		−0.209	−0.51		−0.089	−1.39		−0.242
Spring	0.26		0.025	0.26		0.025	0.07		0.008	−2.13	*	−0.169
Summer	−0.30		−0.020	−0.30		−0.020	−0.17		−0.007	−1.67	+	−0.131
Autumn	0.74		0.077	0.74		0.077	0.87		0.113	1.25		0.140
Station/period	Craiova			Dr. T. Severin			Drăgășani			Târgu Logrești		
	Z	SS	Q	Z	SS	Q	Z	SS	Q	Z	SS	Q
Year	1.23		0.069	−1.39		−0.095	0.92		0.105	0.97		0.129
Winter	−0.28		−0.056	−0.51		−0.125	−0.34		−0.058	−0.11		−0.066
Spring	0.06		0.015	−2.06	*	−0.221	−0.22		−0.037	0.23		0.058
Summer	0.81		0.072	−0.93		−0.065	1.69	+	0.227	0.94		0.179
Autumn	1.99	*	0.252	0.44		0.055	2.11	*	0.343	1.05		0.300
Station/period	Apa Neagră			Târgu Jiu			Polovragi			Râmnicu Vâlcea		
	Z	SS	Q	Z	SS	Q	Z	SS	Q	Z	SS	Q
Year	0.17		0.020	−0.42		−0.026	0.26		0.021	−0.29		−0.025
Winter	0.67		0.220	0.44		0.126	−0.30		−0.086	−0.06		−0.006
Spring	−0.19		−0.030	0.36		0.045	−0.83		−0.110	−1.15		−0.109
Summer	0.48		0.060	0.84		0.082	−0.23		−0.041	−0.22		−0.029
Autumn	0.93		0.221	2.25	*	0.271	1.12		0.154	1.10		0.131

***, if trend at $\alpha = 0.001$ level of significance; **, if trend at $\alpha = 0.01$ level of significance; *, if trend at $\alpha = 0.05$ level of significance; +, if trend at $\alpha = 0.1$ level of significance

the years that can be characterized as affected by different degrees of aridity increases a lot. For example, at Bechet, the share of these years is 49.1%, at Calafat 40%, and at Caracal 38.2%.

Dry conditions generally occur in the same years all over the plain region, but there are situations when drought intensifies because of local factors. In the analysed time series, semi-dry conditions set in all over the plain in 3 years—1983, 1992 and 2000 (the year with the lowest I_{aDM}). 1993 was also semi-dry, except the western extremity. Equally was the case of 2011 and 2012, except the western and northern parts of the plain, respectively. On the contrary, 1961 and 1965 were semi-dry only at Calafat, and 1999 only at Bechet, indicating the importance of local factors when it comes to drought.

3.2 Spatial distribution of the Pinna combinative index

The spatial distribution of the Pinna combinative index (Ip) indicates that the entire region under study displays humid conditions, as there are no established threshold values for other categories at values higher than 20 of this index. Croitoru et al. (2013) established the same territorial pattern for the extra-Carpathian regions (even if the period is shorter, 1961–2007). However, if applying the threshold proposed by

Cheval et al. (2017), who differentiate three categories for values above 20 (20.1–30, moderately dry; 30.1–40, moderately wet; > 40, wet), a different territorial pattern gets shaped. There are moderately dry conditions along the Danube River, moderately wet conditions within the plain, piedmont and most of the Subcarpathians, while wet conditions are typical in the western extremity of the Subcarpathians and in their higher parts, as well as in the mountain area. In this case, there is a higher similarity with the I_{aDM} calculated for the same period and with the results highlighted by Cheval et al. (2017) for the 1961–1990 period. According to the same authors, the moderately dry conditions are projected to extend over the 2021–2050 period, inclusively in the region under study.

3.3 Spatial distribution of the Selyaninov's hydrothermal coefficient

The spatial distribution of the Selyaninov's hydrothermal coefficient (HTC) generally displays the same pattern as the I_{aDM}. The climate is slightly dry in the plain area, with the lowest values within the Danube Alluvial Plain (Calafat, HTC: 0.85 and Bechet, HTC: 0.89) and slightly humid at higher altitudes (i.e. in the proximity of Craiova, in the north) or near the contact with the mountains (i.e. Drobeta Turnu Severin, in the west). In the piedmont area, the climate is also
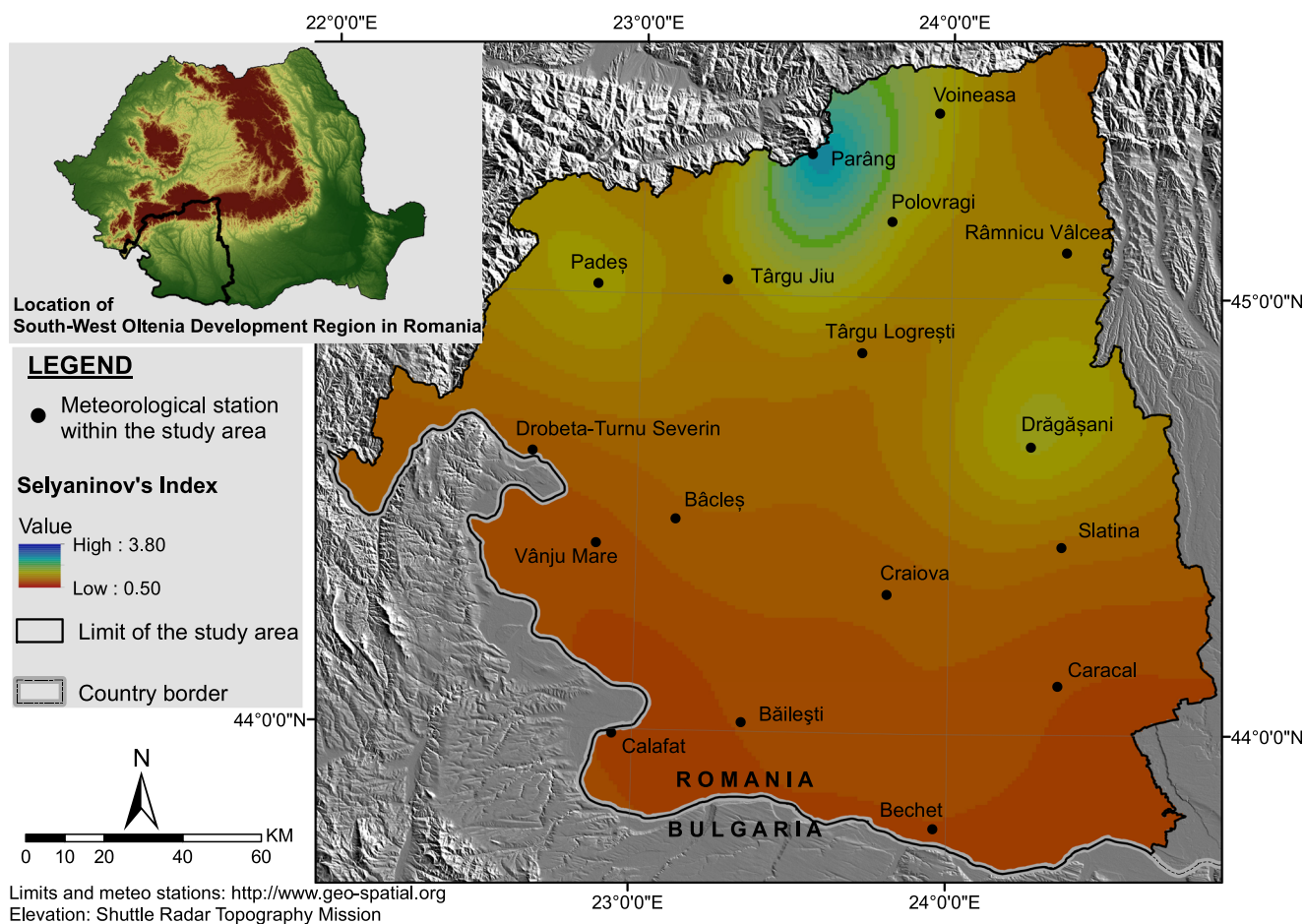
Fig. 5 The annual Selyaninov's hydrothermal coefficient (HTC) within the Region of Oltenia based on mean temperature and rainfall values

slightly humid in the west and moderately humid in the east, as well as in the eastern sector of the Subcarpathians (Fig. 5). Humid conditions are registered in the central and western sectors of the Subcarpathians, while very humid conditions are characteristic in the higher parts of the hilly area and in Parâng Mountains (HTC: 2.83).

As the HTC can be calculated at monthly level only for those months with mean temperatures > 10 °C, the interval taken into consideration decreases from south (i.e. 7 months, April–October) to the north (i.e. 3 months, June–August). Generally, the spring months, as well as October, are characterized by different degrees of humidity, from slightly humid to very humid, all over the Region of Oltenia, including the extreme south plain area. The most problematic interval in terms of aridity is from June to September and the most problematic area is, as expected, the plain area. In fact, only the Subcarpathian and the mountain areas do not have any type of dry months, based on mean temperature and rainfall values.

Dry conditions start to set in in June in the southernmost part of the plain, in spite of the fact that this is the month with the highest rainfall amounts within most of the rest of the analysed territory. At the same time, temperature values increase by about 4 °C compared to May, while rainfall amounts are almost similar, which explains why May is a humid month (from slightly humid to very humid) and June is a slightly dry month (Fig. 6a). However, in the Subcarpathians and in the mountains, where temperatures are below the 20 °C threshold, the HTC indicates humid and very humid conditions.

In July, aridity intensifies in the south, where moderately dry conditions occur, and extends northwards, within the entire plain area and the western part of the Getic Piedmont, where HTC indicates slightly dry conditions. Even in the Subcarpathians, the climate becomes moderately humid (Fig. 6b).

The driest month is August, which is classified as dry at the stations located along the Danube River, the lowest value corresponding to Calafat (HTC: 0.53) (Fig. 6c). Moderately dry conditions are observed in August within the plain area and the western part of the piedmont, while in the eastern part of the piedmont, there are slightly dry conditions. In the Subcarpathians and the lower mountain area, as rainfall amounts decrease compared to June and July, the climate conditions become slightly humid, while very humid conditions are typical only at high altitudes (above 1500 m). Starting with
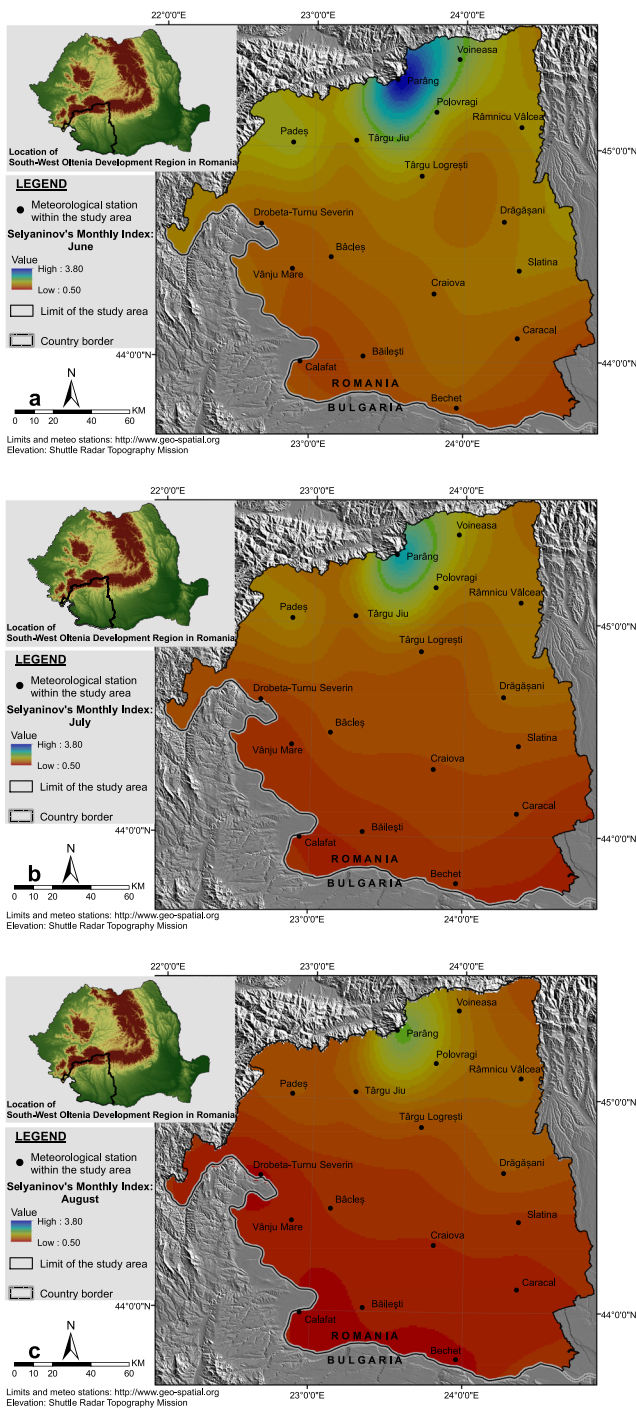
Fig. 6 The Selyaninov's hydrothermal coefficient (HTC) within the Region of Oltenia based on mean temperature and rainfall values for the summer months

September, aridity loses intensity, and only the plain area is still affected by moderately or slightly dry conditions.

3.4 Correlation of the analysed indices

The relation between the analysed aridity indices was studied based on the Pearson correlation coefficient calculated in Microsoft excel. We calculated a strong positive correlation between all the analysed indices—values above + 0.70 of the Pearson correlation coefficient. However, it is only values above 0.95 ($\alpha = 0.05$) that we considered highly statistically significant, as they are closer to 1, namely to a perfect positive correlation. Based on this criterion, it resulted that the best correlation was between the HTC and I_{aDM} (0.976) (Fig. 7a), followed by the I_{aDM} and the I_p (0.91) (Fig. 7b), which certifies the similar spatial distribution of the analysed indices (Table 5). Baltas (2007) obtained a close value for the correlation between the I_{aDM} and the I_p for northern Greece (0.88). In Romania, Croitoru et al. (2013) established a correlation coefficient of 0.7 between the I_{aDM} and the I_p, but for a shorter time range and for a wider region. The weakest correlation is between the HTC and the I_p (0.88) (Fig. 7c). We also calculated the correlation coefficient between the I_{mDM} and the monthly HTC values, for all the common months. In this case, it resulted a strong positive correlation for the interval from June to August (0.995). If excluding Parâng station, for which the HTC can be calculated only for the summer months, the correlation coefficient is also above 0.994 in April, May and September. In fact, May displays the highest correlation value, 0.999, which can be considered a perfect correlation.

4 Conclusions

We explored the aridity issues within the Region of Oltenia based on three distinct indices: the De Martonne aridity index (I_{DM}) at annual, seasonal and monthly levels; the Pinna combinative index (I_p) only at the annual level, as it cannot be calculated for shorter time intervals; and the Selyaninov's hydrothermal coefficient (HTC), both for the entire interval with mean monthly temperatures > 10 °C and for each individual month included in this interval. Aridity in Oltenia, particularly in the southern part of the region, is extremely important if we associate temperature increase, rainfall variability and the presence of large surfaces covered by sands or sandy soils.

Based on annual values, the applied indices indicate that the area most sensitive to aridity is the southern part of the plain, including the Danube Alluvial Plain. Even if aridity is less severe northwards, the entire plain area and important parts of the plateau area are also prone to semi-aridity risk, in case temperature continues to increase (i. e. it influences the evapotranspiration, and of course, aridity). This is valid in all climate evolution scenarios, even presuming that no significant change in the precipitation regime and amounts will occur. For this particular region, temperature increase (2021–2050) is estimated to about 1 °C more than the present mean annual temperature (Cheval et al. 2017), which may greatly influence aridity intensity. As the distance to the mountains reduces, aridity is no longer a problem, the area displaying
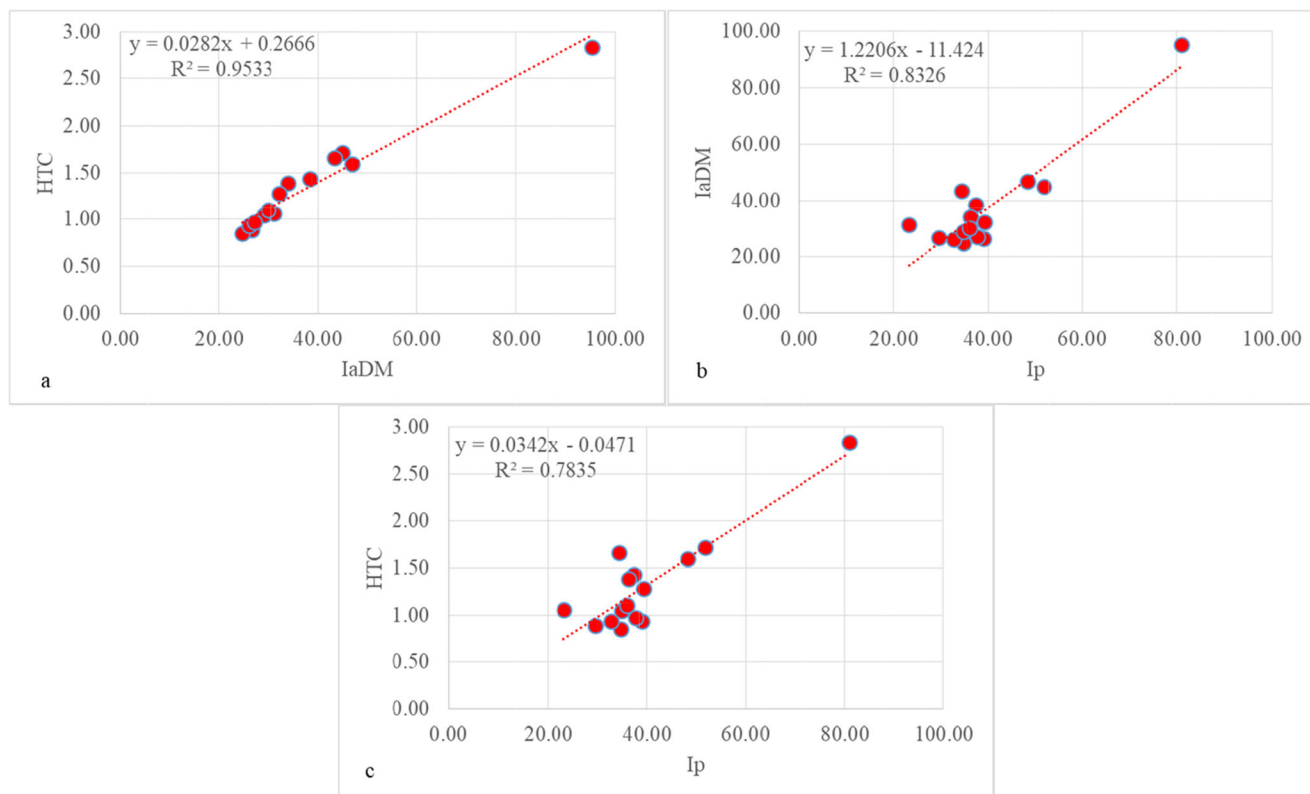
Fig. 7 Statistical analysis between the analysed aridity indices

humid or very humid conditions according to all applied indices.

We applied the De Martonne aridity index for seasonal values, too. As expected, summer and autumn are the most sensitive seasons. In summer, for example, almost half of the territory of Oltenia displays semi-dry or Mediterranean conditions, which highlights water deficit over large surfaces. In autumn, the southern part of the plain area is still affected by a certain degree of aridity, as there are Mediterranean conditions. Thus, except for the mountain area and the eastern extremity of the entire region, where autumn is the driest season, for the rest of the territory, summer is the most prone to aridity season. At the monthly level, it resulted the same territorial pattern in terms of sensitivity to aridity as in case of annual and seasonal values, both for the I_{mDM} and the HTC. August is the driest month at all the stations included in the present

study, followed by July and September. In fact, according to the I_{mDM}, all the values for the plain and the piedmont areas are below 20 °C/mm in August, as well as for the south and east of the plain area in July and September, which means irrigations are greatly required (Zambakas 1992), mainly for maize crops.

In spite of the fact that the Pearson correlation coefficient showed a strong positive correlation both for annual and monthly values, based on the obtained values, it can be assumed that the best indices to be used at the annual level in the analysed region are the I_{DM} and the HTC. At the monthly level, they have a similar number of climate classes (Croitoru et al. 2013) and display an almost perfect positive correlation, indicating a very precise type of climate for each part of the analysed region.

Table 5 Pearson correlation coefficient for annual values of the three analysed indexes and monthly values of I_{aDM} and HTC

Level	Annual values				Monthly values (IaDM and HTC)				
	IaDM/ HTC	Ip/ IaDM	Ip/ HTC	April	May	June	July	Aug	Sep
Pearson correlation	0.976	0.912	0.885	0.994	0.999	0.995	0.995	0.994	0.998
Stations included	All	All	All	Except Parâng	Except Parâng	All	All	All	Except Parâng

One of the aims of the present study was to emphasize the evolution trend of aridity. Linear trends, calculated for annual values (I_{aDM} and I_p), displayed both positive and negative values, which stands for a decrease and an increase in the aridity conditions, respectively. In most cases, the obtained values are negative, which means an increase in the aridity intensity. Positive values were obtained for the I_{aDM} at Craiova, Calafat, and Apa Neagră and for the I_p also at Râmnicu Vâlcea. The statistical significance of the I_{aDM} was also tested based on Mann-Kendall test, but it resulted that the positive or negative trends are not statistically significant, as it was also emphasized by Croitoru et al. (2013) for the extra-Carpathians regions of Romania, Hrnjak et al. (2014) for Vojvodina, Bačević et al. (2017) for Kosovo and Metohija, and Andrade and Corte-Real (2016) for most of the Iberian Peninsula. Consequently, for the moment, it is difficult to estimate if aridity will increase in intensity or extend territorially in the near future, as it totally depends on the relations between temperature, rainfall amounts and their distribution throughout the year, as well as on evapotranspiration.

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