

Rainfall surplus and/or deficit in the territory between the Carpathians and the Dniester River, based on De Martonne's aridity index (1961-2022)

Andrei Mihalache^{1,3} *  Dumitru Mihăilă^{1,2,3}  Petruț-Ionel Bistricean^{2,3} 
Anatolie Puțuntică^{3,4}  Elena Medei (Pop)¹ 

¹ Doctoral School of Applied Sciences and Engineering, "Ștefan cel Mare" University of Suceava, Romania

² Department of Geography, "Ștefan cel Mare" University of Suceava, Romania

³ Center for Applied Geography Research (GeA-USV), Suceava, Romania

⁴ Ion Creangă State Pedagogical University, Chișinău, Republic of Moldova

*Correspondence: mihalacheandrei57@gmail.com

Keywords: De Martonne aridity index; rainfall deficit; rainfall surplus; climate risks

Abstract: The study aims to identify areas with varying degrees of rainfall deficit and/or surplus in the space between the Carpathian Mountains and the Dniester River. The assessment of the water surplus or deficit of the studied territory was carried out by applying the De Martonne aridity index (DMai) for the period 1961-2022 at annual, seasonal, and monthly levels for a number of 29 meteorological stations. Following the assessments, we observed that the wettest areas in the study area are located in the mountain and sub-mountain zones. The areas identified as having the highest rainfall deficit are located in the south and southeast of the study area. In addition to the specific elements of the DMai regime and distribution, we also analyzed its trend at 27 stations for the same interval using Mann Kendall trend tests. For October, the highest decadal increase in the index was calculated at the Comrat station in the Republic of Moldova (+0.272**), and at the Briceni station in January-February, the strongest decadal decrease in the index was calculated (-0.905*).

1. Introduction

The deficit or surplus of water resources is a topical issue that is being intensively analyzed on a global scale. Climate variability includes numerous specific risks (Bogdan, 1978, 1999, 2004) that can disrupt regional natural or anthropogenic systems (Grecu, 2009). Climate risk analysis involves identifying, parameterizing, and managing these risks through prevention and control plans. Depending on the geographical characteristics of an area, various risks may arise within it, including periods of drought (Potopová, 2019) or periods when precipitation becomes excessive (Apăvăloae, 1997; Buruiană, 2015). This article aims to analyze the territory between the Carpathian Mountains and the Dniester River in terms of rainfall over a long period of time (1961-2022), using DMai (De Martonne, 1920). The De Martonne aridity index has been used in numerous studies on large areas such as the Iberian Peninsula (Andrade et al., 2021), Central Europe (Charalampopoulos et al., 2023a) and Southeast Europe (Charalampopoulos et al., 2023b), with different long-term trend scenarios being developed. At the same time, this index has also been used for numerous other studies

for regions in different countries: northern Greece (Baltas, 2007), the Thriasio Plain in Greece (Mavrakakis and Papavasileiou, 2013), the lowlands of Bulgaria (Koleva and Alexandrov, 2008), northwestern Spain (Fernández et al., 2009), Hungary (Blanka et al., 2013; Kis et al., 2023), Italy in the Emilia Romagna region (Nistor, 2016a), Calabria (Pellicone et al., 2019), Serbia (Radaković et al., 2018; Dimkić et al., 2022), northern Germany (Emadodin et al., 2021), etc. In Romania, studies have been conducted applying DMai to different areas, especially those where the main economic activity is agriculture. These studies covered larger or smaller areas, such as those east of the Carpathians (Croitoru et al., 2013), the Transylvanian Plain (Rastilantie et al., 2014), localities in the Apuseni Mountains (Nistor et al., 2016b), and Bucharest (Ardelean, 2017). Many studies based on this index have been carried out for the Oltenia region, which is frequently affected by periods of rainfall deficit (Prăvălie, 2013; Ontel and Vlăduț, 2015; Vlăduț and Licurici, 2018; Mărăcineanu et al., 2021). For the territory between the Carpathian Mountains and the Dniester River, in relation to the topic studied, the water balance elements at the land surface level were analyzed by Mihăilă et al. (2017) and Jibu and Mihăilă (2021). *The main objective* of the study is to identify, analyze, evaluate the variability, and observe the trends of temporal entities with water surplus or deficit in the territory between the Carpathians and the Dniester using DMai. *The objectives of the study* are: i) to identify territories with water deficits/surpluses in the geographical area between the Carpathians and the Dniester River through annual, seasonal, and monthly value analysis of the selected index; ii) to explain the causal relationship (in spatial and temporal context) of meteorological and climatic reality, as reflected in the values of this index; and iii) to identify trends in rainfall surplus and/or deficit in the study area by applying the Mann Kendall trend test.

2. Materials and Methods

2.1. Study area

Located in southeastern Europe (Figure 1), the study area is a complex geographical space. Encompassing the Carpathian Mountains and the Dniester River, it has characteristics that influence the thermo-pluviometric complex, which differs significantly between the western mountainous/submontane areas and the central and eastern hill and plain areas.

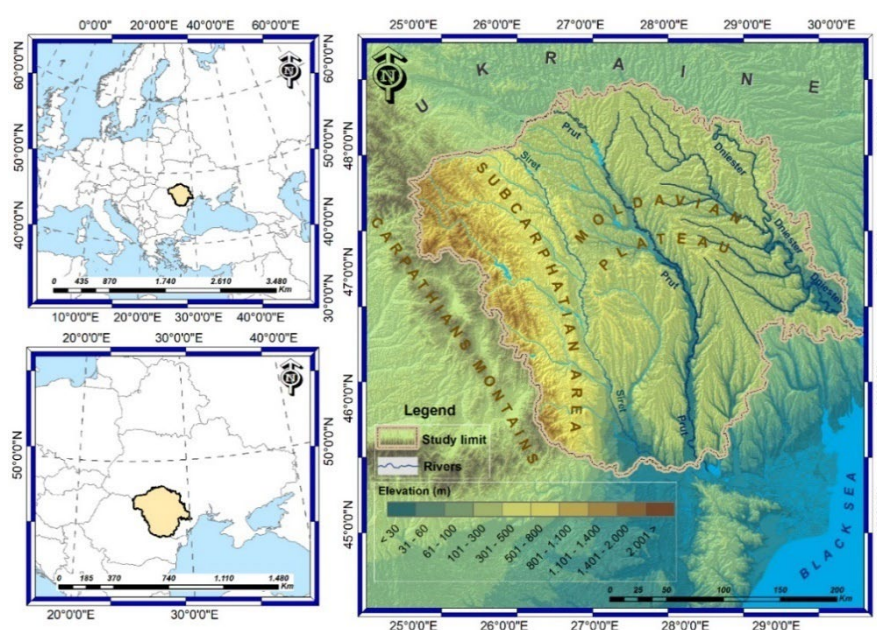


Figure 1. Study area.

The relief is arranged in steps from west to east, with altitudes decreasing from over 2100 meters in the west to less than 30 meters on the Dniester terraces (in the east). The orographic barrier formed by the Carpathian arc is an impediment to the penetration of air masses (oceanic from the west or continental from the east), so that the rainfall regime is strongly affected by the presence and features of the Carpathian mountain range in the west of the studied region. Altitude has the greatest influence on the climate, imposing its stratification and rainfall and water processes. The climate is temperate transitional with continental influences, more clearly expressed towards the eastern end. In addition to the Dniester, two other important hydrographic arteries cross the analyzed territory, namely the Siret and the Prut. Forest vegetation dominates in the western part of the region and on the hilly cuestas of the central plateaus. The geographical features of the territory directly influence the frequency, length, and intensity of periods of water surplus or deficit.

2.2. Methods

The DMai analysis used air temperature values and precipitation amounts recorded at 29 weather stations distributed throughout the study area. The large number of stations for which this index was applied gives us a detailed picture of the distribution of the index values in the analyzed territory. To carry out the study, existing studies in the literature were analyzed and documented, to identify aspects of the approaches to rainfall deficit and/or surplus for different areas using this index. The statistical-mathematical method was used to process an extensive meteorological database that included time series of temperature and precipitation from 1961 to 2022. The next step was to integrate the values obtained by the cartographic method into classes that give the resulting climate types (Table 1). Formulas [1], [2], and [3] used in calculating DMai values were taken from the studies by Baltas, 2007, and Piticar, 2013. The following formula was used to calculate the annual DMai values:

$$P/Ta+10, [1]$$

where: P – represents the annual amount of precipitation; Ta - average annual temperature.

The following formula was used to calculate the seasonal DMai values:

$$4Ps/Tas+10, [2]$$

where: Ps – represents the seasonal amount of precipitation; Tas – seasonal average temperature.

The following formula was used to calculate the monthly values of DMai:

$$PI*12/TI+10, [3]$$

where: PI – monthly precipitation; TI – monthly average air temperature.

Table 1. Classification of DMai values (Baltas, 2007 cited by Piticar, 2013).

Type of climate	De Martonne index value
Arid	< 10
Semi-arid	10.1 - 20
Mediterranean	20.1 - 24
Humid	24.1 - 28
Wet	28.1 - 35
Very wet	35.1 - 55
Extremely humid	> 55

The statistical data comes from the National Meteorological Administration network for the meteorological stations analyzed for the territory of Romania, and from the meteorological stations in the Republic of Moldova from the State Hydrometeorological

Service. To complete the database, data from the website <http://meteomanz.com/> was used to a lesser extent. The maps were created using ArcGIS 10.8. The difference method (IDW plus linear regression) was used for interpolation. To identify DMai trends, its values (except for the Ceahlău and Iezer stations) were tested using the Mann Kendall test (Kendall, 1975), a method also used in other studies on various meteorological (Gocic and Trajkovic, 2013) and climatic (Agbo, 2022) parameters, as well as in drought analysis (Szinell et al., 1998; Ozocak et al., 2024), or the thermo-pluviometric complex (Mondal et al., 2012; Supervisor, 2012; Zhang et al., 2016).

Table 2. Weather stations between the Carpathians and the Dniester*.

Number	Weather station	Latitude	Longitude	Altitude
1	Briceni	48° 21' 7.661" N	27° 6' 7.407" E	258
2	Camenca	48° 2' 59.528" N	28° 41' 10.930" E	154
3	Radauti	47° 50' 16.222" N	25° 53' 25.562" E	389
4	Balti	47° 46' 28.637" N	27° 57' 2.298" E	103
5	Ribnita	47° 46' 20.743" N	29° 0' 58.255" E	97
6	Botosani	47° 44' 8.274" N	26° 38' 43.907" E	161
7	Suceava	47° 37' 58.368" N	26° 14' 25.924" E	350
8	Iezer	47° 36' 9.514" N	24° 39' 4.775" E	1785
9	Falesti	47° 35' 0.261" N	27° 42' 17.220" E	160
10	Bravicea	47° 22' 19.951" N	28° 26' 17.930" E	81
11	Cornesti	47° 22' 1.867" N	27° 59' 38.294" E	234
12	Cotnari	47° 21' 29.882" N	26° 55' 32.206" E	289
13	Poiana Stampei	47° 19' 28.730" N	25° 8' 3.977" E	923
14	Dubasari	47° 16' 50.046" N	29° 7' 44.853" E	41
15	Iasi	47° 10' 15.416" N	27° 37' 41.819" E	102
16	Baltata	47° 3' 19.436" N	29° 2' 10.069" E	79
17	Ceahlau Toaca	46° 58' 38.978" N	25° 56' 59.718" E	1897
18	Chisinau	46° 58' 18.208" N	28° 50' 53.858" E	17
19	Roman	46° 58' 8.707" N	26° 54' 42.515" E	216
20	Tiraspol	46° 51' 56.324" N	29° 35' 3.008" E	38
21	Vaslui	46° 38' 45.966" N	27° 42' 51.898" E	116
22	Bacau	46° 31' 54.803" N	26° 54' 44.984" E	184
23	Leova	46° 29' 18.345" N	28° 17' 0.165" E	158
24	Comrat	46° 18' 10.273" N	28° 37' 46.101" E	136
25	Targu Ocna	46° 16' 21.702" N	26° 38' 27.673" E	242
26	Barlad	46° 13' 58.931" N	27° 38' 39.909" E	172
27	Cahul	45° 53' 57.242" N	28° 12' 48.373" E	113
28	Focsani	45° 41' 15.047" N	27° 11' 59.134" E	57
29	Galati	45° 28' 22.469" N	28° 1' 56.159" E	69

*Weather stations were ordered from north to south by latitude

Altitude is an essential factor in the climatic stratification of the study area (Bâzac, 1983; Apostol, 2000, 2004; Tănasă, 2017). The weather stations whose data we used are presented in Table 2 and Figure 2. The stations located at the highest altitude are Ceahlău Toaca (1897 m), Iezer (1785 m), and Poiana Stampei (923 m). At lower

altitudes are: the Balta weather station – 79 m, Galați – 69 m, Focșani – 57 m, Dubăsari – 41 m, and the Tiraspol weather station – 38 m.

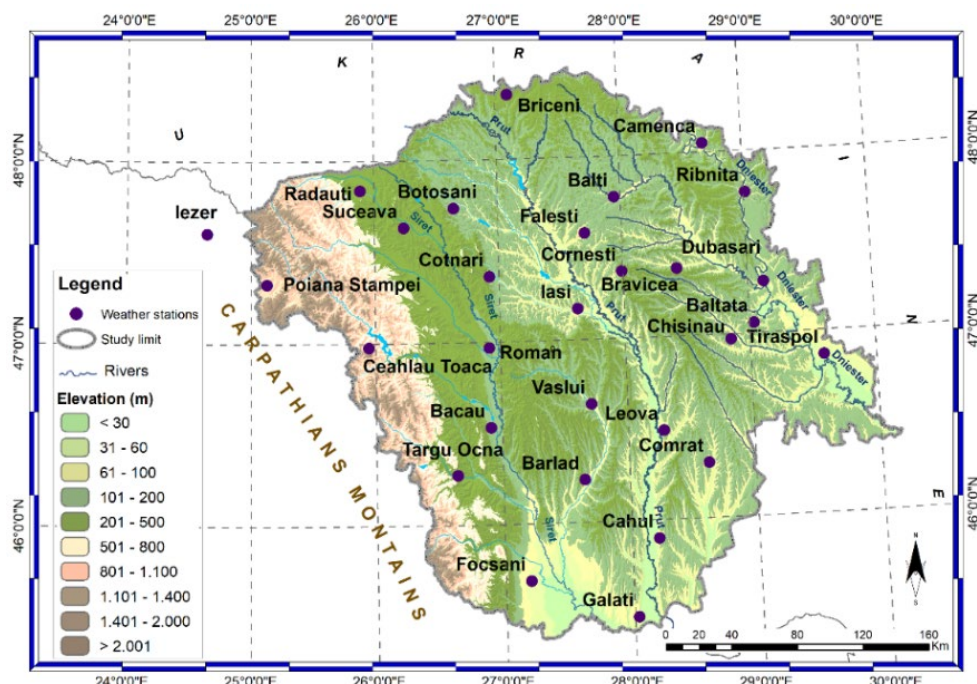


Figure 2. Weather stations for which de Martonne index values were calculated.

The high density of the 29 weather stations included in the analysis (Figure 2) was an advantage in presenting the thermo-pluviometric characteristics of the studied area in detail.

3. Results and Discussion

3.1. Average annual values of the de Martonne aridity index. Their trends

On an annual basis, for the period analyzed, in the study area, based on Dmai values,

Table 3. Average annual values of DMai (1961–2022).

Weather stations	Annual	Weather stations	Annual
Rădăuți	35.7	Briceni	33.5
Botoșani	29	Camenca	28.3
Suceava	33	Balți	25.9
Iezer	109.4	Fălești	28.6
Cotnari	27.5	Cornești	32.7
Poiana Stampei	46.2	Rîbnița	27.1
Iași	28.4	Dubăsari	26.7
Roman	27.4	Bravicea	29.9
Ceahlau	64.0	Balța	26
Vaslui	27	Chișinău	27.4
Bacău	29.7	Tiraspol	24.8
Targu Ocna	32.5	Leova	26.7
Bărlad	25.2	Comrat	25.3
Focșani	26.1	Cahul	26.2
Galați	23.3		

very wet and extremely wet areas are identified for the mountainous area (Iezer – 109.4, Ceahlău – 64.0, Poiana Stampei – 46.2). In the hill and plain zones, the DMai values indicate a wet type in the north and a semi-wet type in the south and southeast. Piticar reached similar results in his 2013 study. The lowest DMai values fall within those corresponding to the Mediterranean type. These are identified in the extreme south of the study area. The arrangement of the DMai value classes analyzed in steps from W-NW to E-SE (Figure 3) is mainly caused by the penetration of air masses with predominantly western and Scandinavian-Baltic influences. In addition to atmospheric dynamics, another equally important factor is the relief. The differences in altitude of the studied territory have a direct influence on the two meteorological components that make up DMai. Both temperature and precipitation are strongly correlated with altitude. According to the calculations (Table 3), the lowest annual values of the index were recorded in the S-SE part of the region: Galați (23.3), Tiraspol (24.8), Bârlad (25.2), Comrat (25.3), Bălți (25.9).

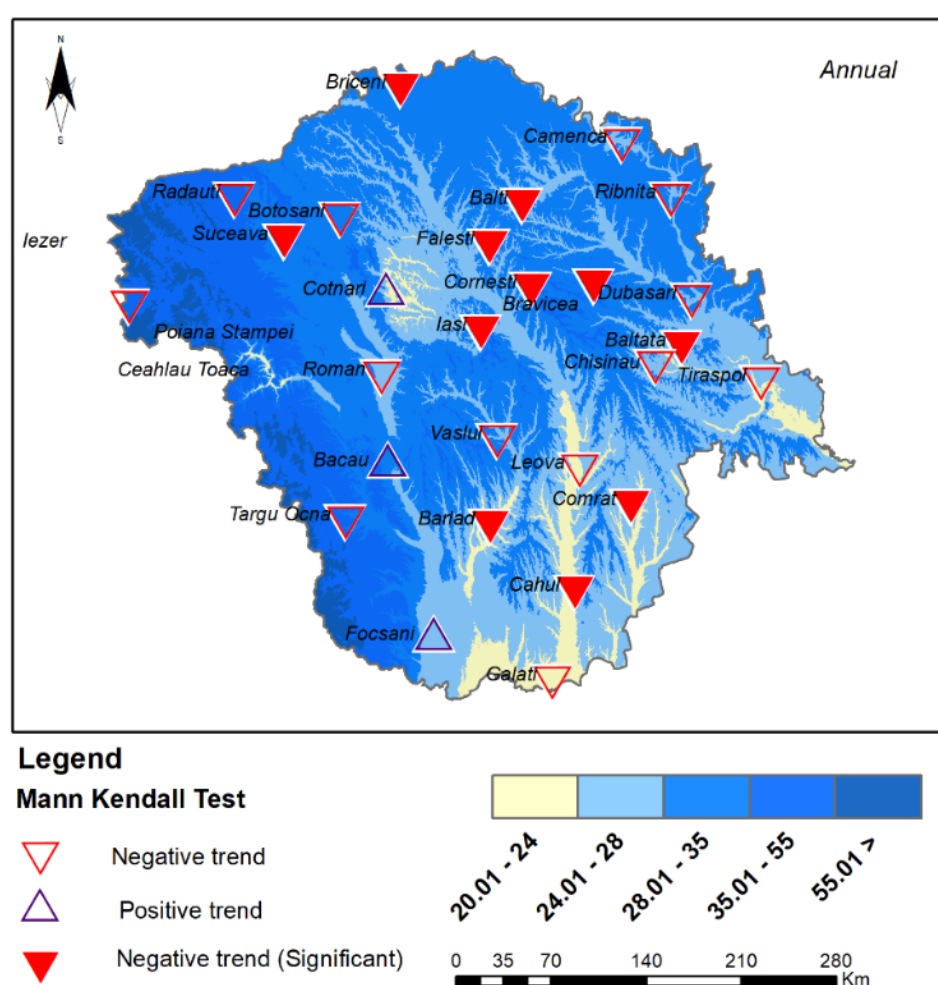


Figure 3. Territorial distribution of annual DMai values (1961-2022).

By following the percentage share of DMai across different value ranges and climate classes for stations west of the Prut River, we observe two key aspects. According to station data and calculations, the DMai climate type classifies the territory as predominantly humid (Rădăuți 32.3%; Botoșani 37.1%, Iași 35.5%, Vaslui 41.9%, Bacău 43.5%, Târgu Ocna 43.5%), an aspect that can be observed in Figure 4. The exception is the mountainous area, with the highest percentages of extremely humid climate (Iezer 98.4%, Ceahlău 82.3% and, to a lesser extent, Poiana Stampei 16.1%).

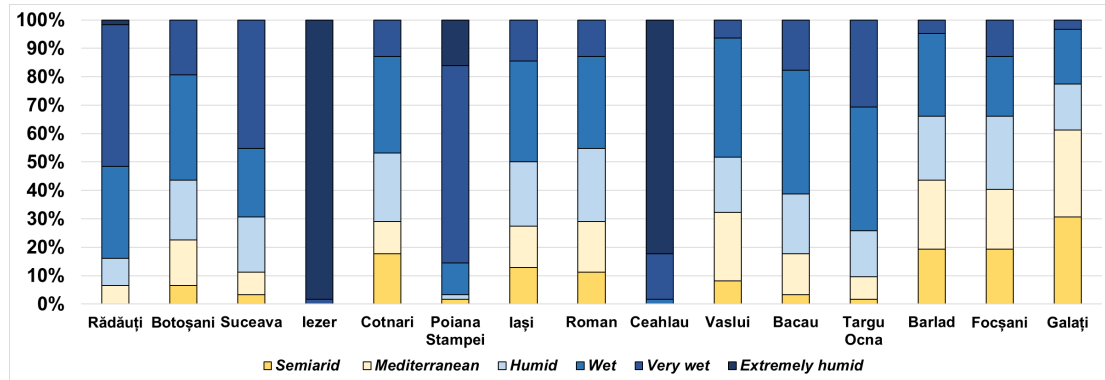


Figure 4. Percentage share of annual DMai values west of the Prut River (1961-2022).

East of the Prut River (Figure 5), the humid type remains dominant (Bălța 35.5%, Briceni 37.1%, Chișinău 40.3%, Camenca 40.3%, Rîbnița 43.5%). However, throughout the studied territory in the south (in Galați) and southeast (in Tiraspol), the Mediterranean and semi-arid types have percentage values over 50%.

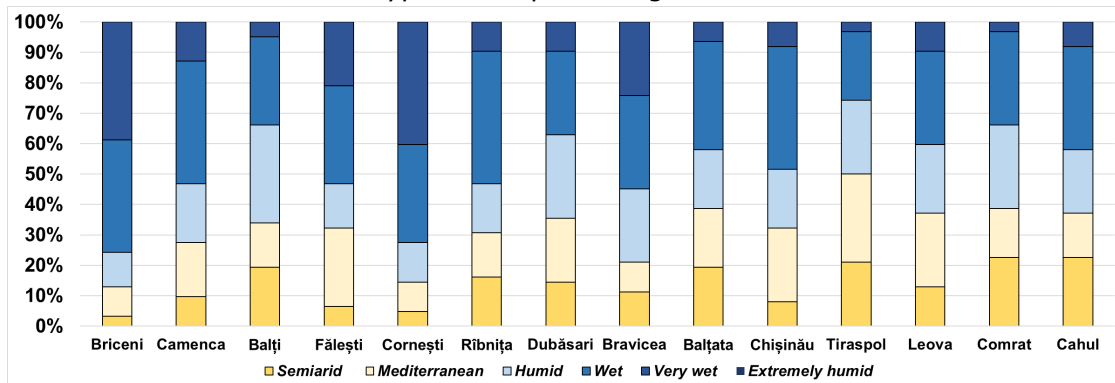


Figure 5. Percentage share of annual DMai values east of the Prut River (1961-2022).

Table 4. Decadal trends in DMai* at stations between the Carpathians and the Dniester (1961-2022)

Time series	Bacău	Bălăd	Botoșani	Cotnari	Iași	Rădăuți	Roman	Suceava	Tg. Ocna	Vaslui	Galați	Focșani	P. Stampei
J	-0.07	-0.24	-0.14	-0.03	-0.05	-0.02	-0.15	-0.22	-0.31	-0.03	0.12	0.14	0.16
F	-0.3*	-0.36*	-0.09	-0.17	-0.48*	-0.30	-0.13	-0.24	-0.3*	-0.3+	-0.26	-0.05	0.08
M	0.01	-0.02	-0.12	-0.02	-0.20	-0.13	-0.05	-0.19	-0.13	0.03	-0.03	0.08	-0.16
A	0.01	-0.02	-0.09	-0.06	-0.11	-0.16	-0.01	-0.18	-0.04	-0.04	-0.02	0.04	-0.07
M	-0.05	-0.11	-0.03	-0.02	-0.04	-0.10	-0.02	-0.18	-0.04	0.02	-0.11	-0.08	0.08
J	0.23+	-0.09	-0.10	0.21	-0.17	0.00	0.08	-0.03	-0.07	-0.11	-0.04	0.10	-0.03
J	-0.03	-0.3**	-0.16	-0.16	-0.25*	-0.22	-0.07	-0.23	-0.20	-0.2*	0.00	-0.11	-0.3*
A	-0.13	-0.05	-0.16+	-0.09	-0.05	-0.05	-0.08	-0.10	-0.07	-0.02	-0.1*	-0.06	-0.10
S	-0.02	-0.03	0.08	0.11	-0.04	0.10	0.09	0.02	0.04	-0.06	-0.02	0.02	0.16
O	0.26*	0.18*	0.20+	0.22*	0.21*	0.13	0.22*	0.13	0.21+	0.19*	0.16+	0.27*	0.05
N	-0.01	-0.06	-0.09	0.02	-0.11	-0.09	0.02	-0.14	-0.16	-0.03	0.02	0.00	-0.22
D	0.16	-0.06	-0.09	0.10	-0.11	-0.04	0.07	-0.14	0.06	-0.07	0.15	0.20	-0.64+
Annual	0.01	-0.09*	-0.04	0.01	-0.2**	-0.09	-0.01	-0.11+	-0.07	-0.03	-0.03	0.02	-0.09
W	-0.06	-0.21	-0.23+	-0.10	-0.4**	-0.13	-0.17	-0.39**	-0.19	-0.17	-0.08	0.10	-0.22
S	-0.02	-0.05	-0.10	-0.05	-0.10	-0.15	-0.05	-0.18+	-0.09	0.01	-0.06	-0.01	0.00
S	0.04	-0.14*	-0.06	-0.03	-0.19*	-0.10	-0.01	-0.10	-0.06	-0.07	-0.08	-0.04	-0.15
A	0.06	-0.01	0.05	0.13	0.03	0.08	0.09	0.00	0.02	0.02	0.06	0.08	0.01
Jan-Feb	-0.19	-0.30+	-0.17	-0.22	-0.47*	-0.31	-0.21	-0.26	-0.3+	-0.18	0.00	0.14	-0.27
Jun-Jul	0.13	-0.2**	-0.09	0.04	-0.2**	-0.10	0.05	-0.12	-0.07	-0.12	-0.03	-0.01	-0.18

Time series	Briceni	Bălțata	Bălți	Bravicea	Camenca	Rîbnița	Fălești	Dubăsari	Chișinău	Tiraspol	Leova	Comrat	Cahul	Cornești
J	-0.05	-0.16	-0.01	-0.22	0.04	-0.09	-0.01	0.08	-0.07	0.24	0.05	0.07	0.02	-0.11
F	-0.48*	-0.25	-0.46*	-0.48*	-0.30	-0.38	-0.31	-0.61*	-0.44+	-0.45+	-0.46*	-0.49*	-0.58**	-0.56*
M	-0.32+	-0.16	-0.16	-0.19	-0.04	-0.18	-0.12	-0.18	-0.14	-0.08	-0.02	-0.04	-0.11	-0.20
A	-0.19+	-0.09	-0.08	-0.10	0.01	-0.08	-0.04	0.00	-0.04	-0.03	-0.04	-0.04	-0.05	-0.18
M	-0.19	-0.09	0.00	0.01	-0.04	-0.01	-0.01	0.05	0.01	-0.06	0.02	-0.10	-0.11	-0.06
J	0.00	-0.16	-0.06	-0.12	-0.03	-0.10	-0.13	-0.20+	-0.09	-0.11	-0.02	0.01	-0.09	-0.24
J	-0.27+	-0.26*	-0.19	-0.14	-0.35**	-0.14	-0.22*	-0.17	-0.01	-0.08	-0.06	-0.16	-0.21*	-0.24
A	-0.13	-0.05	-0.06	-0.08	-0.19*	-0.14+	-0.03	-0.01	-0.04	-0.10	-0.07	-0.07	-0.16+	-0.10
S	0.05	0.00	0.01	-0.05	0.13	0.07	-0.01	0.06	-0.04	0.05	-0.02	-0.06	-0.06	-0.07
O	0.12	0.14	0.21*	0.18+	0.14	0.15	0.16+	0.17+	0.25*	0.20*	0.18+	0.27**	0.20*	0.22*
N	-0.07	-0.09	-0.06	-0.06	-0.07	0.03	-0.08	0.03	-0.06	-0.01	-0.11	-0.09	-0.08	-0.05
D	-0.36	-0.13	-0.21	-0.16	-0.05	-0.18	-0.04	-0.16	-0.11	-0.22	0.05	-0.19	-0.20	-0.06
Annual	-0.13*	-0.12**	-0.07+	-0.14*	-0.05	-0.07	-0.09*	-0.06	-0.05	-0.06	-0.05	-0.08+	-0.14**	-0.16**
W	-0.77**	-0.38*	-0.51*	-0.54**	-0.25	-0.37+	-0.43*	-0.48*	-0.46*	-0.37*	-0.23	-0.37+	-0.47**	-0.54**
S	-0.18*	-0.10	-0.02	-0.06	-0.01	-0.08	-0.07	0.01	-0.04	-0.04	-0.01	-0.07	-0.10	-0.11
S	-0.06	-0.17*	-0.08	-0.12+	-0.15*	-0.10	-0.10*	-0.12+	-0.03	-0.10	-0.06	-0.09	-0.14*	-0.19*
A	0.07	0.04	0.04	0.01	0.03	0.10	0.04	0.07	0.03	0.08	0.02	0.04	0.01	0.02
Jan-Feb	-0.90*	-0.39+	-0.28	-0.44+	0.03	-0.10	-0.32	-0.25	-0.23	-0.09	0.00	-0.14	-0.39+	-0.42
Jun-Jul	-0.09	-0.17*	-0.10	-0.13	-0.16+	-0.09	-0.14+	-0.15+	-0.05	-0.07	-0.06	-0.11	-0.13	-0.21*

*The numbers represent the Sen slope (blue indicates an increase, red indicates a decrease in DMai, bold numbers indicate a statistically significant value), and the symbols represent the alpha significance level of the Sen slope (+ = statistical certainty is 90%; * - assurance is 99%; ** - assurance is 99.5%; *** - assurance is 99.9%); at the Ceahlău and Iezer stations, the Mann-Kendal tests were not applied

The trends in the annual DMai values resulted from the application of the Mann Kendall test (Table 4). Of the total number of stations analyzed, 41% (11 stations) showed a negative trend with strong statistical assurance. A total of 13 stations recorded a negative DMai trend, but without relevant statistical significance, and 3 stations recorded a positive trend, without conclusive statistical assurance (Figure 3, Table 4). Thus, statistical tests show that years with rainfall deficits and droughts are becoming increasingly frequent throughout the region, reinforcing the fact that water deficits are increasing over time, as noted by other climatologists in previous studies (Erhan, 1983; Apostol, 2020; Mihăilă et al., 2017).

3.2. Seasonal average values of the de Martonne aridity index. Their trends

Seasonal analysis shows that periods of rainfall deficit or surplus alternate over an average year for a period of 61 years. The climate of the study area is changing at rates that vary according to regional and local geographical specificities (Busuioc et al., 2010; Dumitrescu et al., 2014), as can be seen from the seasonal analysis of DMai.

During *winter*, the index values are highest at all stations analyzed, falling into the extremely wet, very wet, and wet categories. West of the Prut River (except for the mountainous area, where the DMai averages range from 78.3 in Poiana Stampei to 146.3 in Ceahlău-Toaca), the index ranges from 33.6 in Roman to 45.9 in Iași. East of the Prut River valley, the average winter values of the index ranged between 46.3 in Bălțata and 70.7 in Briceni.

In *autumn*, the index analysed has the lowest values. The stations where the index values are specific to the Mediterranean and semi-arid types dominate. There is no clear, unequivocal territorial differentiation of the values of this index. At stations in the Siret basin or corridor, the index has average values in autumn ranging from 22.2 in Roman to 26.3 in Rădăuți. At stations in the Prut river basin, the index has average values in autumn ranging from 19.9 in Galați to 27.5 in Cornești. In the eastern part of the study area, on the Dniester River valley, the average DMai values ranged between 15.7 in Camenca and 23.8 in Rîbnița (Table 5). In autumn, the weather pattern determined by DMai indicates a moderate to severe rainfall deficit.

Table 5. Average seasonal values of DMai (1961–2022).

Stations	Winter	Spring	Summer	Autumn	Stations	Winter	Spring	Summer	Autumn
Rădăuți	45.1	35.5	41	26.3	Briceni	70.7	31.9	32.8	26.9
Botoșani	39.6	29.8	31.4	22.3	Camenca	56.6	25.9	27.3	15.7
Suceava	43.1	33.9	37.6	24.3	Bălți	48.4	23.7	24.5	22.8
Iezer	146.0	123.8	88.1	93.8	Fălești	51.2	26.5	28.0	24.5
Cotnari	36.7	28.6	29.2	21.5	Cornești	62.7	31.4	30.6	27.5
P. Stampei	78.3	46.4	46.6	34.7	Rîbnița	54.4	24.4	26.1	23.8
Iași	45.9	28.0	28.5	23.2	Dubăsari	55	25.1	23.6	23.4
Roman	33.6	28.0	29.9	22.2	Bravicea	56.5	28	28.5	25.3
Ceahlău	146.3	72.6	62.9	38.9	Bălțata	46.3	24.2	26.2	21.7
Vaslui	45.6	27.8	26.1	23.3	Chișinău	56.1	25.5	24.3	24.3
Bacău	39.3	31.0	30.5	24.4	Tiraspol	48.9	22	22.8	21.9
Tg. Ocna	39.2	34.6	35.0	25.3	Leova	52.8	25.9	24.0	23.4
Barlad	39.1	25.3	24.4	21.6	Comrat	50.3	23.8	22.8	21.9
Focșani	40.9	27.2	23.9	22.6	Cahul	48	24.9	23.9	23.1
Galați	42.8	22.7	19.9	22.0					

The DMai values for the *spring* season are highly significant. During this period, the main agricultural crops are sown, and they have specific thermal and rainfall requirements in order to enter the vegetation period. In the north (Rădăuți station – 35.5; Suceava station – 33.9; Briceni – 31.9) and in the west of the region (mountain stations Iezer, Ceahlău and Poiana Stampei, stations Tg. Ocna – 34.6; Bacău – 31), very wet, wet and extremely wet weather types dominate at altitudes above 1500 m. In the Covurlui Plain, in the lower sector of the Prut Valley and in the Lower Nistru Plain, the weather is drier, falling within the Mediterranean type (the index value is 22.7 in Galați, 23.8 in Comrat and 22.0 in Tiraspol). In these regions, the spring rainfall deficit is more pronounced.

In *summer*, west of the Prut River, the dominant weather types are very humid and humid in northern Moldova, with aridity index values of 41 in the Rădăuți Depression, 37.6 in the Suceava Plateau, and 31.4 in the Moldavian Plain in Botoșani. In the south of the Moldavian Plateau, the climate is drier with Mediterranean influences (in Bârlad and Focșani, the index values are 24.4 and 23.9, respectively). In the Tecuci Plain and the Covru Plain, the water deficit is highest, with a DMai value of 19.9, falling within the semi-arid climate type, with similar values calculated for stations east of the Prut River valley.

The low values of the index for the southern part of the study region, both in spring and summer, represent a risk factor for the region's agricultural economy.

In the analysis of seasonal trends, a negative trend is observed for *winter* in most of the analyzed area, with strong statistical certainty in the northern, central-eastern, and eastern parts. Only in Focșani the trend is positive, but without statistical significance (Figure 6 and Table 4). At 55.6% of stations, DMai has a negative trend, with relevant statistical assurance. The negative trend continues in *spring* at most stations, but is statistically significant only at the Suceava and Briceni stations (7.4% of stations). The data series from the Poiana Stampei, Vaslui, and Dubăsari stations show a positive trend in DMai, but without statistical significance. In *summer*, the trend test continues to show a water deficit, especially in the center of the Moldavian Plateau (Cornești, Iași, Bravicea, Dubăsari, Bălțata), but also in the south (in Bârlad and Cahul). Only in Bacău is there a slight improvement in the water situation. In summer, 33.3% of DMai stations show statistically significant negative trends. For the *autumn* season, with the exception of Suceava and Bârlad, the DMai trend is positive, without statistical significance, showing a

slight improvement in the rainfall balance. In autumn, no DMai station showed a statistically significant decrease in value.

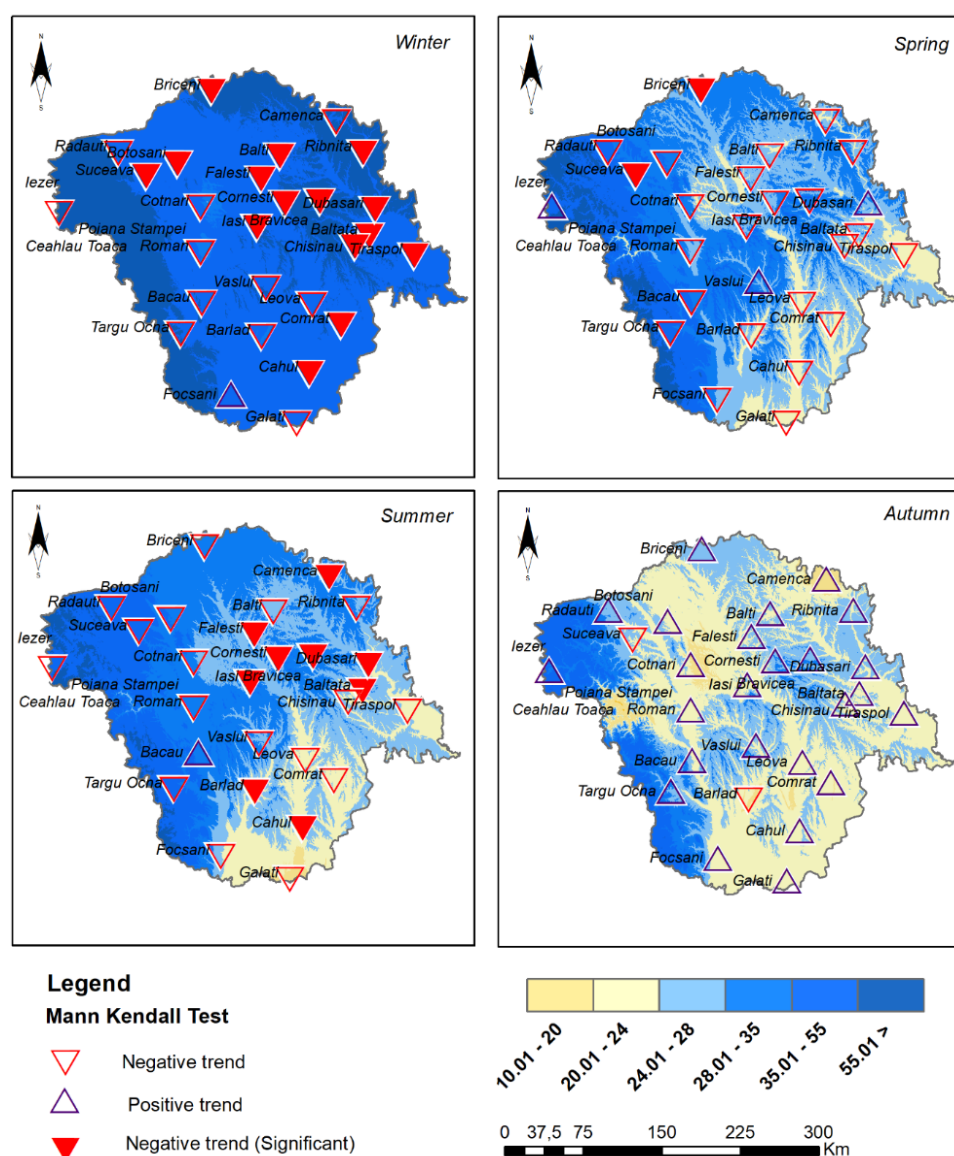


Figure 6. Distribution of seasonal DMai values (1961-2022).

3.3. Monthly average values of the de Martonne aridity index. Their trends

For an easier analysis of the regime/distribution of the monthly average values of DMai, from 1961 to 2022, we used a tabular model resulting from the conditional formatting of DMai (Table 6). This process helps us to more easily observe the spatial differences in DMai and the annual regime of this index in the studied region.

In an average year, DMai has the highest values in December-February. During these months, very wet (35.1-55) and extremely wet (>55) weather types predominate. The extremely wet (>55) type is specific to mountain stations (Iezer, Poiana Stampei, Ceahlău). At stations in the valleys or corridors of rivers that drain the region (Bârlad on the Bârlad Valley and Roman in the Siret Corridor), DMai values fall within the very wet and wet types, respectively. Overall, we can note that weather stations throughout the region, regardless of relief or latitudinal position, have DMai values in the winter months that vary within limits indicating excess humidity, with no deficient classes.

The percentage distribution of DMai classes for the winter months (Figures 7 and 8) shows a predominance of wet weather types across the entire area analyzed, with

regional differences due to altitude, position relative to the Carpathians, and eastern continental influences. In the mountainous area (Ceahlău-Toaca, Iezer, Poiana Stampei) sub-Carpathian and contact areas, extremely wet and very wet weather types have a high weight, with months with such DMai values exceeding 50-60% (even 70% in Ceahlău) of the total number of months analyzed. In the extra-Carpathian regions, at stations in the plateau area, months with DMai values specific to extremely wet and very wet types represent approximately 30-50% (even 60% in Cornești) of the total proportion of the months analyzed, due to low temperatures and moderate precipitation during the cold season (Mihăilă and Tănăsă, 2005; Mihăilă, 2006a). At stations in the hilly plains, extremely wet, very wet, and wet types remain dominant, but with lower percentages.

Table 6. Average monthly values of DMai between the Carpathians and the Dniester 1961-2022.

Weather stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rădăuți	45.1	50.6	32.8	33.3	40.4	47.8	42.5	33.1	26.8	25.9	29.6	46
Botoșani	41.8	39.4	29.4	30.9	30.8	37.3	34.3	23.1	21.1	22.4	26.7	39.5
Suceava	45.5	41.4	30.8	32.3	38.1	44	41.6	27.8	24.2	23.2	29.3	40.3
Iezer	76.9	83.9	125.9	112.5	108	104	92.3	70.8	79.3	85.7	115	127.3
Cotnari	45	38.5	28.3	30.5	29.2	34.9	31.5	21.8	20.6	20.6	27	37.9
Poiana Stampei	74.7	64	49.4	39.9	50.9	53.9	49	37.5	32.4	33.2	44.6	93.7
Iași	46.6	39.9	28.9	28.5	28.1	35.8	29.1	21.1	23	20.8	29.3	43.4
Roman	36.8	27.6	23.5	29.3	30.4	36	31.8	22.5	22.1	21.7	25.4	36
Ceahlau	78	59.8	97	71.3	65.2	73.3	63.3	53.4	34.8	36.9	59.5	94
Vaslui	53.4	38.1	27.7	27.3	29.4	30.6	27.1	20.8	21.6	21.7	30.3	46.7
Bacau	44	38.4	28.2	31.2	33.6	36.4	33.5	21.9	23.6	24	28.5	40.9
Targu Ocna	48.3	37.1	30.7	34.3	38.6	40.4	36.7	28.5	24.6	25.3	28.5	41
Barlad	46.2	33.7	24.2	25.5	26.7	29.4	23.9	20.3	19.5	21	28	40.9
Focșani	46.9	44.7	26.5	26.9	28.8	28.7	24.2	19.4	20	22	29.4	41.4
Galați	47.2	38.3	24.9	22.5	22.5	26.6	18.6	15.1	19	21.8	28.7	45.6
Briceni	64	62.3	36.3	29.4	33.9	37.2	37.1	24.8	25.7	21.8	39.2	63.1
Camenca	52.3	46.2	29.4	25.5	25.6	30.9	30.4	21.1	23.5	19.2	34.3	52.1
Bălți	51.8	44.2	27.9	23.4	22.9	29.1	25.8	19.2	21.2	20.1	30.5	45.9
Fălești	54.6	42.8	31.1	25.7	26.6	33.9	30.1	20.6	24.4	19.8	34.2	48.2
Cornești	72	54.3	38.5	32	29	39.3	32.5	21	27.1	22	38.7	59.3
Rîbnița	50.7	48.6	27.9	24	24	30	27.4	21.2	23.2	18.8	33.5	50.1
Dubăsari	59.6	51.9	30.2	23.3	25.4	27.9	24.9	18.4	21	19.9	34	49.7
Bravicea	63.9	53.8	33.7	28	26.7	35.5	28.5	22	24.9	20.4	34.9	51.2
Spotted	51.6	39.4	27.4	23.9	23.9	31.2	28.3	19.5	21.7	17.3	29.6	42.9
Chisinau	65.6	52.5	32.7	24.4	24.2	28.1	26.4	18.8	21.9	21.2	35.1	52.8
Tiraspol	56.2	44.9	25.9	19.9	22.7	27.3	23	18.7	19.9	18.9	31.2	45.7
Leova	61.4	43.9	29.1	24.7	26.5	27.4	24.2	20.8	21.5	20.7	32.2	52.8
Comrat	60.2	46.1	26.8	22.9	24.1	28	22.1	18.8	19.8	19	31.7	50.2
Cahul	48	47.2	28.4	24.1	24.6	29.5	23.2	19.8	22.3	20.7	29.9	48.4



Both west and east of the Prut River (Figure 8), the months with a typology indicating a water deficit according to DMai values are better represented in percentage terms at stations located at lower altitudes, where the moderating influence of the mountains decreases, but the continental influence from the east increases (Erhan, 1983; Mihăilă, 2002; Puțuntică, Sofroni, 2011; Sfîcă, 2015).

In the spring months, we observe a transition from excess moisture to less humid weather types, with clear differences between the north and south of the region, as well as between the west and east, as latitude and altitude decrease. East of the Prut River, with a decrease in altitude, there is a noticeable decrease in DMai values, which fall within the wet (28.1-35) and semi-wet (24.1-28) categories. These DMai values reflect the fact that in spring, when temperatures are still low, the amount of precipitation is sufficient to maintain a high $P/(T+10)$ ratio (Mihăilă 2002). Towards the south, southeast, and east, as the altitude decreases, the temperature increases and the climate becomes more continental, the DMai values are lower, indicating wet and Mediterranean weather types (Bârlad, Galați, Bălți, Chișinău). The lowest DMai value calculated for this season was 19.9 in Tiraspol in April.

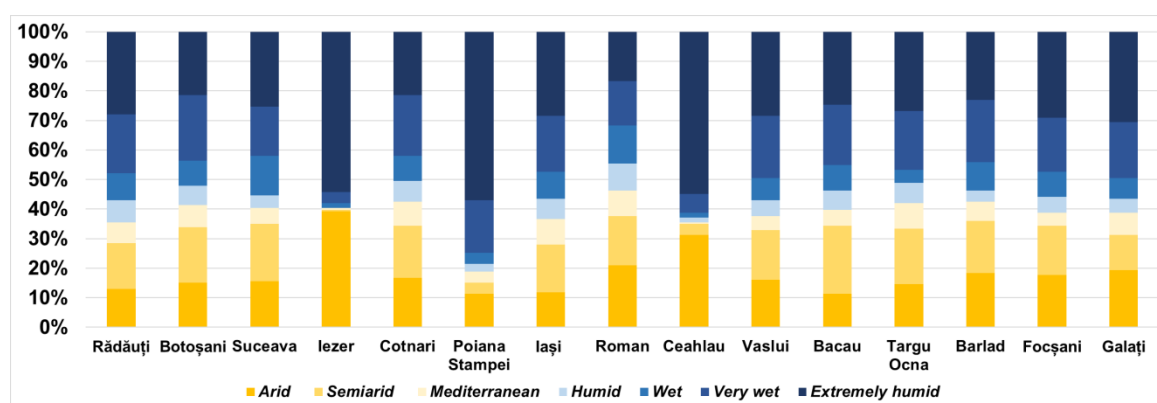


Figure 7. Percentage share of DMai values during the winter months west of the Prut River (1961-2022).

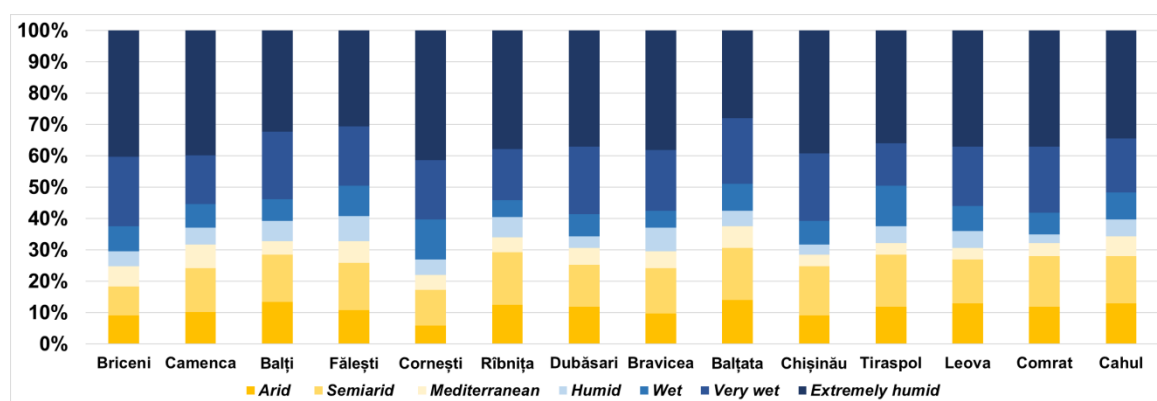


Figure 8. Percentage share of DMai values during the winter months east of the Prut River (1961-2022).

After June (the month with the highest annual rainfall), as the air temperature rises during the summer months, the DMai values gradually decrease, with extremely humid and very humid weather giving way to Mediterranean and semi-arid conditions (15.1 in Galați). The central-southern part of the studied territory, which corresponds to the

plateau and plain areas, is subject to a more pronounced eastern continental influence during the summer months, which is reflected in lower DMai values, corresponding to semi-arid and Mediterranean types (Dubăsari 18.4, Tiraspol 18.7, Chişinău 18.8, Comrat 18.8, the minimum calculated value of DMai east of the Prut valley being 17.3 in Bălţata). The decrease in the index value in August, September, and October is determined both by the decrease in the amount of precipitation and by the intensification of evapotranspiration, closely related to the high temperatures in these months (Mihăilă, 2004; Apopei et al., 2024). As we move eastward from the Carpathian Mountains, which represent an obstacle to Atlantic air masses (Apostol, 2000; Puţuntică and Sofroni, 2011), the decrease in DMai is accentuated by eastern continental influences, from which hot and dry air masses originate. There is a risk of climatic drought (Busuioc et al 2010, Piticar and Ristoiu 2012). The differences in DMai values between mountains and plateaus/plains can be explained by the increase in temperature with decreasing altitude, correlated with the quantitative decrease in precipitation, thus maintaining high DMai values in mountainous areas (Mihăilă and Tănasă, 2005; Nistor, 2014; Sfîcă, 2015; Tănasă, 2017). As we move eastward from the Carpathians, the frequency of Atlantic advections, responsible for heavy precipitation, decreases, and the meteorological and climatic typology changes from one with excess moisture to one with a marked rainfall and water deficit (Croitoru, 2003; Ilie, 2018).

The analysis of the percentage distribution of the DMai classes for the summer months (Figure 9 and Figure 10) highlights the most pronounced spatial differentiation of DMai values throughout the year. This is determined by the marked increase in temperature, as well as the irregular nature of precipitation and the influence of eastern continentalism. In the mountainous and submontane area west of the Prut River (Ceahlău, Iezer, Poiana Stampei), we find a predominance of months with high proportions of wet, very wet, and extremely wet types, as a result of excessive rainfall and moderate temperatures (Apostol, 2000, 2004; Mihăilă and Tănasă, 2005).

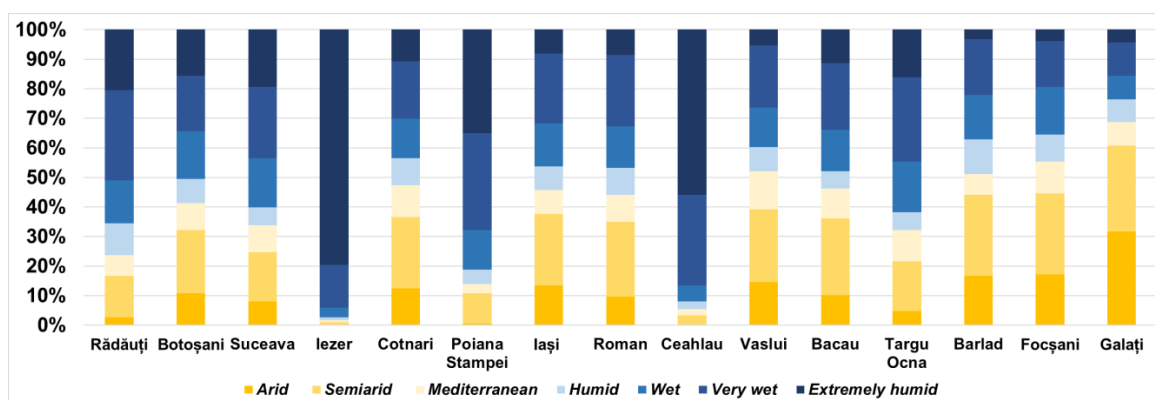


Figure 9. Percentage share of DMai values during the summer months west of the Prut River (1961–2022).

At the plain and plateau stations west of the Prut River, the percentages of Mediterranean and semi-arid classes increase significantly, especially towards the south (Bârlad, Galați), indicating an increase in the process of accentuating moisture deficit (Erhan, 1983; Grecu 2009). East of the Prut River (Figure 10), continental influences are more pronounced. In the north and center (Briceni, Camenca, Bălți, Fălești, Rîbnița), the percentage distribution of weather types in the summer months remains relatively balanced, but the percentages of Mediterranean and semi-arid types are higher than in the west, reflecting not so much higher temperatures, but especially lower precipitation during the summer (Erhan, 1983; Puţuntică and Sofroni, 2011).

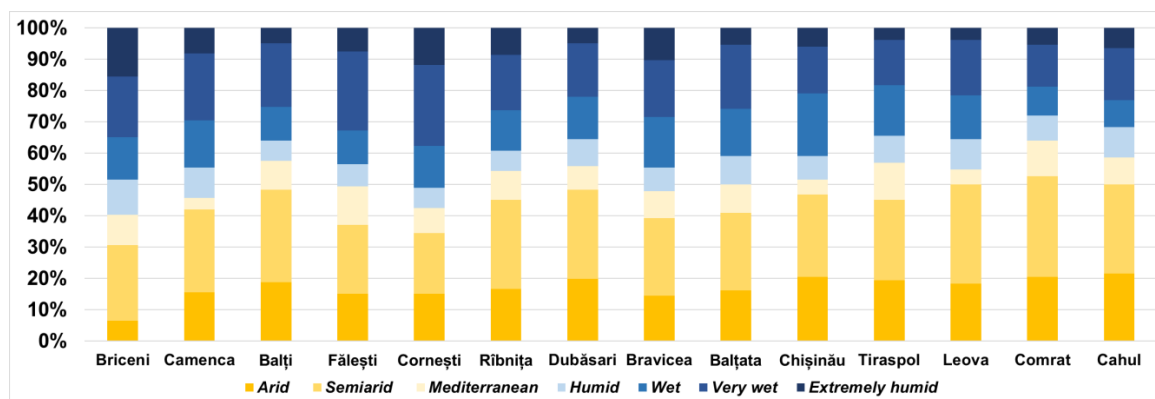


Figure 10. Percentage share of DMai values during the summer months east of the Prut River (1961-2022).

In the south of the region (Tiraspol, Leova, Comrat, Cahul), the proportion of months classified as semi-arid and arid becomes significant, exceeding 40% of the total, which indicates a decrease in humidity and an accentuation of the deficit (Potopová et al., 2019; Apostol, 2020).

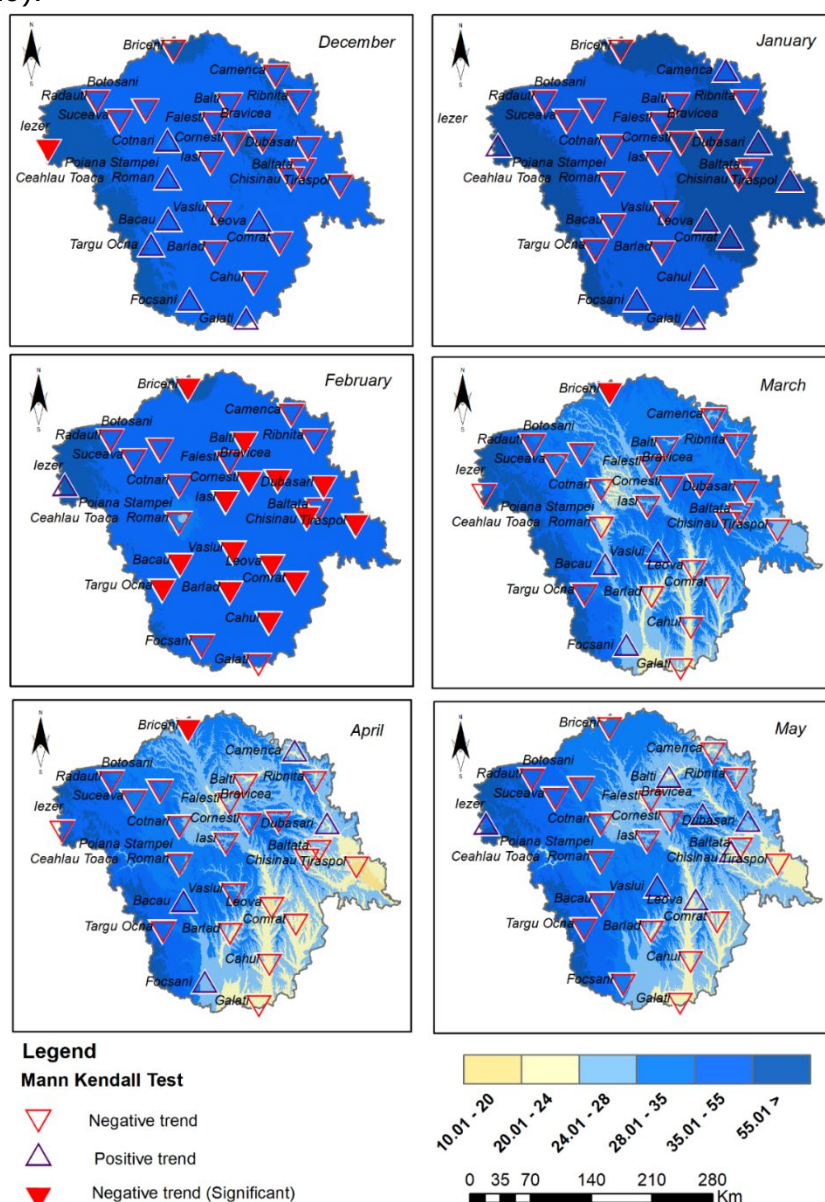


Figure 11. Territorial distribution of DMai values in December-May (1961-2022).

We identified that in the summer months, DMai has a more differentiated territorial distribution in the west of the studied territory, remaining within the limits of predominantly humid types due to the orographic influence, while in the east and southeast, the specific Mediterranean and semi-arid types imposed by the east-continental influence are better represented (Figure 10). In the autumn months, especially at the beginning of this season, we observed a prolongation of the water deficit.

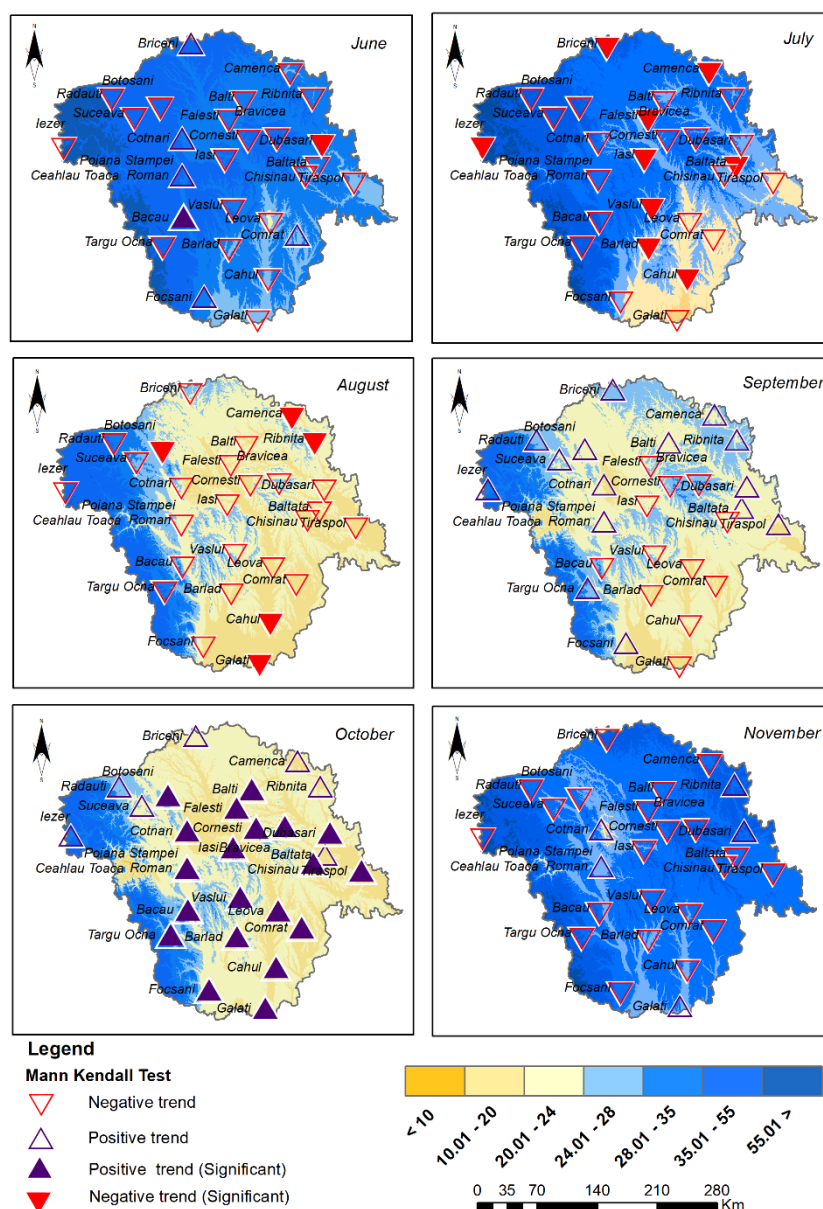


Figure 12. Territorial distribution of DMai values in the months V-VIII (1961-2022).

Analyzing the DMai trends in *December-February*, we observe that stations with decreasing DMai predominate: 79.3% of stations, and of these, at 20% of stations the DMai decrease trend is statistically significant (Figures 11 and 14). All these trends occur due to low temperatures and moderate precipitation specific to the winter period, with the typology of weather conditions explained causally in many studies in the field (Croitoru, 2003; Mihăilă and Tănasă, 2005; Mihăilă, 2006a; Nistor, 2014; Sfîcă, 2015). In February, the downward trend in DMai is most evident, with relevant statistical assurance at 15 (55.6%) of the 27 stations whose time series data were tested using the Mann-Kendall test.

In March-May (Figures 12 and 14), at 77.8% of stations, the decadal trends of DMai were decreasing in value, but only at the Briceni station was the decrease statistically significant. Overall, the DMai trends during spring indicate a slight shift in the rainfall balance towards a deficit.

In June-August, at 74.1% of stations, the DMai trends are negative (Figures 11 and 14), not statistically significant, but indicating that the quantitative parameters of rainfall are decreasing. In July, at 37% of stations, the decrease in DMai is statistically significant, and in August this is true for 18.5% of stations.

Analyzing *September*, we observe a change in the DMai trend in the sense that at 55.5% of stations, the index recorded an increase in the 1961-2022 interval, but the increase was not statistically significant. In *October*, however, we identified a special situation, in that at 74.1% of stations the index showed positive trends with strong statistical assurance (Figures 12 and 14). At the other 25% of stations, the DMai trend was also upward, an increase that lacked statistical reliability but showed an improvement in the quantitative parameters of rainfall throughout the region studied. In *November*, at most stations, the DMai trend returns to a predominantly negative one (81.5% of stations), without relevant statistical certainty (Figure 14).

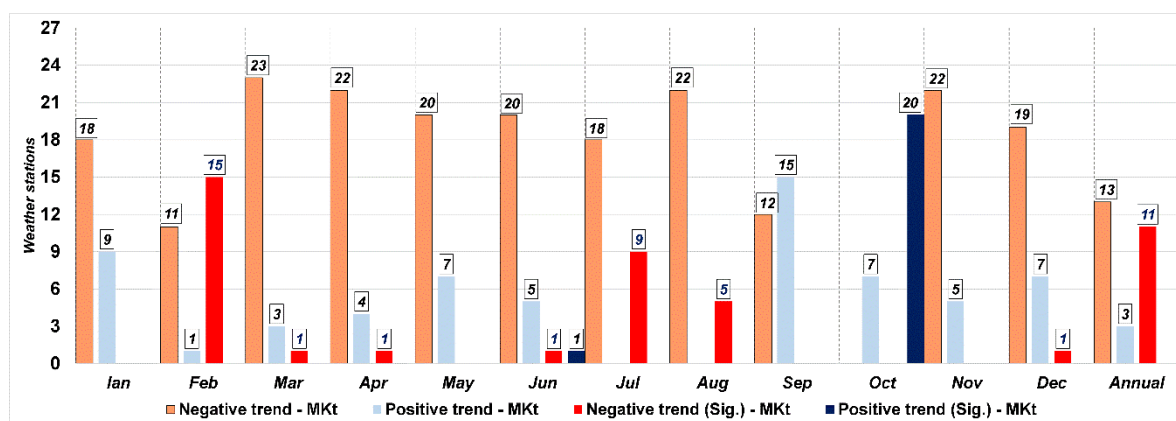


Figure 14. DMai trends for monthly and annual average values of the index (1961-2022)

The DMai trends show that the largest decadal decrease was calculated for the one-year time sample at the Iași station (-0.2^{**}) and for the seasonal time sample, winter, at the Briceni station (-0.77^{**}). For a group of months, DMai decreased by -0.9^{*} for the period January–February at Briceni. At the monthly level, in October at the Focșani station in Romania and Comrat in the Republic of Moldova, the increase was the highest ($+0.272^{*}$), and the strongest ten-year decline in the index was recorded at the Dubăsari station in February (-0.61^{*}).

On a monthly basis, in 64% of cases, the DMai trend was downward, without statistical assurance, and in 10.2% of cases, the decline was supported by statistical assurance on which we can rely. At 19.4% of stations, on a monthly basis, the DMai trends were unsustained by relevant statistical assurance, and only at 6.5% of stations is the DMai increase statistically relevant.

4. Conclusions

The results obtained based on DMai show that, on average over a year, the territories with water surpluses are those in the Carpathian area with extremely wet and very wet areas, while those with deficits overlap with the plains at the eastern and southern ends of the study area. At the monthly level, the territorial distribution of surplus and deficit is clearly dynamic. The spring and summer months, which are of increased importance in the agricultural sector, fall within the semi-humid and humid types in most of the study area, with the exception of the southern and eastern areas, which are Mediterranean and semi-arid according to the DMai classes.

The trends observed for the annual DMai values indicated that at 41% of the stations included in the study, the index values decreased, and the decreases were statistically significant. The most relevant in terms of percentage and statistical certainty are the decreases in DMai values during winter (55.6% of stations), followed by those during summer (33.3% of stations). Analyzed on a monthly basis, DMai trends show unequivocally that in February the decrease in DMai values is most representative in terms of number of stations (26 out of 27) and also in terms of number of stations where the decrease in DMai is statistically representative (15 stations). This is followed by July and August, when the decrease in DMai is general, but the statistical representativeness of the decreases is currently statistically representative for 33.6% and 18.5% of stations, respectively. Climate warming will increase these percentages. In October, DMai increased in value at all stations, and at 74.1% of them, the index showed positive trends with strong statistical certainty. This indicates an improvement in rainfall accumulation for this month and for the autumn season as a whole for the period 1961–2022. The largest decadal decrease in the index was recorded at the Briceni station in January–February (-0.905^*). The trend values, even the highest ones, do not suggest a significant change in the classification of stations into other DMai classes in the next 20–30 years. However, this transition is possible within a 50-year horizon.

References

1. Agbo, P. E., Nkajoe, U., Edet, O. C. (2022). Comparison of Mann–Kendall and Şen’s innovative trend method for climatic parameters over Nigeria’s climatic zones. *Springer Nature Link*, volume 60, p. 3385–3401, <https://doi.org/10.1007/s00382-022-06521-9>.
2. Apăvăloae, M., Pârvulescu, I., Apostol, L. (1997). Characteristics of atmospheric precipitation amounts in 24 hours in the Moldavian Subcarpathians and the Siret Corridor, *Proceedings of the “Dimitrie Cantemir” Geography Seminar*, 13–14, 53–67.
3. Apopei, L.M., Mihăilă, D., Lazurca, L.G., Bistricean, P.-I., Mihăilă, E.V., Horodnic, V.-D., Emandi, M.E. (2024). Precipitation variation and water balance evaluation using different indices. *Acta geographica Slovenica*, 64-1, p. 41–60, <https://doi.org/10.3986/AGS.11416>.
4. Apostol, L. (2000). *Atmospheric precipitation in the Subcarpathians of Moldova*. Suceava University Press. Suceava, p. 236.
5. Apostol, L. (2004). *Climate of the Moldavian Subcarpathians*, Suceava University Press, ISBN. 973-9408-81-8.
6. Apostol, V. (2020). Climate risks in the Prut basin: hail and drought, *Scientific Bulletin of the State University of Moldova*, 3, 93–104.
7. Andrade, C., Contente, J., Santos, J. A. (2021). Climate change projections of aridity conditions in the Iberian Peninsula, water (switzerland), 13(15), <https://doi.org/10.3390/W13152035>.

8. Ardelean, F., Vartires, A. A. (2017). The use of the aridity index in the evaluation of negative effects of climate change. 17th International Multidisciplinary Scientific Geoconference Sgem 2017, Sofia. DOI:10.5593/sgem2017/41.
9. Baltas, E. (2007). Spatial distribution of climatic indices in Northern Greece, *Meteorological Applications*, 14(1), 69–78, <https://doi.org/10.1002/Met.7>.
10. Bâzâc, G. (1983). The influence of relief on the main characteristics of Romania's climate, Editura Academiei București.
11. Bogdan, O., (1978). Winter and summer climatic phenomena. Science for All Publishing House. Bucharest.
12. Bogdan, O., Niculescu, E., (1999). Climate risks in Romania, Romanian Academy, Institute of Geography, Bucharest.
13. Bogdan, O. (2004). Cascading development of climate risks. *Annals of Spiru Haret University, Geography series*, no. 7. Romania of Tomorrow Foundation Publishing House. Bucharest, pp. 13-18.
14. Blanka, V., Meyer, B. C., Mezősi, G., Meyer, B. (2013). Projected changes in the drought hazard in Hungary due to climate change. In *Időjárás Quarterly Journal Of The Hungarian Meteorological Service* (Vol. 117, Issue 2), <https://www.researchgate.net/publication/261870735>.
15. Buruiană, D. (2015). Risks caused by precipitation and flooding in the Moldavian Plain. Doctoral thesis. Iași.
16. Busuioc, A., Caian, M., Cheval, S., Bojariu, R., Boroneanț, C., Baci, M., Dumitrescu, A. (2010). Climate variability and change in Romania. Pro Universitaria, Bucharest.
17. Charalampopoulos, I., Droulia, F., Kokkoris, I. P., Dimopoulos, P. (2023a). Future bioclimatic change of agricultural and natural areas in Central Europe: An Ultra-High Resolution Analysis Of The De Martonne Index. *Water (Switzerland)*, 15(14), <https://doi.org/10.3390/W15142563>.
18. Charalampopoulos, I., Droulia, F., Tsiros, I. X. (2023b). Projecting Bioclimatic Change Over The South-Eastern European Agricultural And Natural Areas Via Ultrahigh-Resolution Analysis Of The De Martonne Index. *Atmosphere*, 14(5), <https://doi.org/10.3390/Atmos14050858>.
19. Croitoru, A-E. (2003). Climate Risk Phenomena, Practical Workbook, Nereamia Napocae Publishing House, Cluj-Napoca.
20. Croitoru, A. E., Piticar, A., Imbroane, A. M., Burada, D. C. (2013). Spatiotemporal Distribution of Aridity Indices Based on Temperature and Precipitation in the Extra-Carpathian Regions of Romania. *Theoretical And Applied Climatology*, 112(3–4), 597–607, <https://doi.org/10.1007/S00704-012-0755-2>.
21. De Martonne, E. (1920). *Physical Geography* (Vol. 3).
22. Dimkić, D., Anđelković, A., Babalj, M. (2022). Droughts in Serbia through the analyses of de Martonne and ped indices. *Environmental Monitoring And Assessment*, 194(4). <https://doi.org/10.1007/S10661-022-09911-Y>.
23. Dumitrescu, A., Bojariu, R., Bîrsan, M.V., Marin, L., Manea, A., (2014). Recent climatic changes in Romania from observational data (1961–2013). *Theor Appl Climatol*, Doi 10.1007/s00704-014-1290-0.
24. Erhan, E., (1983). The phenomenon of drought in the Moldavian Plateau, *Annals of Science, University "Al. I. Cuza", vol. XXIX, s.II b, Geol-Geogr. Iași*.
25. Emadodin, I., Corral, D. E. F., Reinsch, T., Kluß, C., Taube, F. (2021). Climate change effects on temperate grassland and its implication for forage production: A case study from Northern Germany. *Agriculture (Switzerland)*, 11(3), <https://doi.org/10.3390/Agriculture11030232>.
26. Fernández, C., Vega, J. A., Fonturbel, T., Jiménez, E. (2009). Streamflow drought time series forecasting: A case study in a small watershed in North West Spain. *Stochastic Environmental Research And Risk Assessment*, 23(8), 1063–1070, <https://doi.org/10.1007/S00477-008-0277-8>.

27. Gocic, M., Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and Planetary Change*, 100, 172–182, <https://doi.org/10.1016/j.gloplacha.2012.10.014>.
28. Grecu, F. (2009). *Natural Hazards and Risks*, Editura Universitară, Bucharest.
29. Ilie, N., (2018). Climate risks in northern Moldova and generating synoptic conditions. Doctoral thesis, Al. I. Cuza University, Iași.
30. Jibu, M.N., Mihăilă, D., (2021). Climate evolutionary trends resulting from a thermo- pluviometric profile made between the Carpathian peaks and the Dniester Valley, <http://georeview.ro/ojs/index.php/revista/article/view/434>.
31. Kendall, M.G., 1975. Rank correlation methods, 4th ed. Charles Griffin, London.
32. Kis, A., Szabó, P., Pongrácz, R. (2023). Spatial and temporal analysis of drought-related climate indices for Hungary for 1971–2100. *Hungarian Geographical Bulletin*, 72(3), 223–238. <https://doi.org/10.15201/Hungeobull.72.3.2>.
33. Koleva, E., Alexandrov, V. (2008). Drought in the Bulgarian low regions during the 20th century. *Theoretical And Applied Climatology*, 92(1–2), 113–120, <https://doi.org/10.1007/S00704-007-0297-1>.
34. Mărcăneanu, C., Giugea, N., Mărcăneanu, E., Căpruciu, R. (2021). Climate trends in Oltenia. Case study: Craiova-Banu Mărcăne.
35. Mavrakakis, A., & Papavasileiou, H. (2013). Ndzi And E. De Martonne Indices In An Environmentally Stressed Area (Thrasio Plain – Greece). *Procedia Technology*, 8, 477–481, <https://doi.org/10.1016/J.Protcy.2013.11.062>.
36. Mihaila, D., (2002). Some aspects regarding the distribution and regime of atmospheric precipitation in the Moldavian Plain, *Annals of the "Ștefan cel Mare" University of Suceava, Geography Section*, Year XI, 55–65.
37. Mihăilă, D., (2004). Some aspects related to the variability of the evolution over time of climatic elements and phenomena in the Moldavian Plain, *Annals of the University "Ștefan cel Mare", Section G., Vol. XIII.*, pp. 89–98.
38. Mihăilă, D., Tănasă, I. (2005). Trends in air temperature evolution in the Suceava Plateau, *Annals of the University "Ștefan cel Mare" Suceava, Geography Section*, 14, 57–68, <https://georeview.usv.ro/wp-content/uploads/2024/07/Article.6-Vol.14-1.pdf>.
39. Mihăilă, D. (2006a). Air temperature variability in Northern Moldova, *Annals of the University of Suceava, Geography Section*, 15, 123–132.
40. Mihăilă, D. (2006b). *The Moldavian Plain—Climatic Study*, University of Suceava Press, Suceava.
41. Mihăilă, D., Bistricean, P. I., Lazurca, L. G., & Briciu, A. E. (2017). Climatic Water Deficit and Surplus Between the Carpathian Mountains and the Dniester River (1961–2012). *Environmental Monitoring and Assessment*, 189(11), <https://doi.org/10.1007/S10661-017-6253-3>.
42. Mondal, A., Kundu, S., Mukhopadhyay, A. (2012). Case study 70 rainfall trend analysis by mann-kendall test: a case study of north-eastern part of cuttack district, Orissa. In Online) *An Online International Journal Available at* (Vol. 2, Issue 1), <http://www.cibtech.org/jgee.htm>.
43. Nistor, B., (2014), *Suceava Plateau – thermo-pluviometric study*, George Tofan Publishing House, Suceava.
44. Nistor, M. M. (2016a). Spatial Distribution Of Climate Indices In The Emilia-Romagna Region. *Meteorological Applications*, 23(2), 304–313, <https://doi.org/10.1002/Met.1555>.
45. Nistor, M. M., Dezs, Ș., Cheval, S., Baci, M. (2016b). Climate change effects on groundwater resources: a new assessment method through climate indices and effective precipitation in Belș district, western Carpathians. *Meteorological Applications*, 23(3), 554–561, <https://doi.org/10.1002/Met.1578>.

46. Ontel, I., Vlăduț, A. (2015). Impact of drought on the productivity of agricultural crops within the Oltenia Plain, Romania. *Geographica Pannonica*, 19, 9–19.
47. Ozocak, M., Akay, A. O., Esin, A. İ., Yurtseven, H., & Akgul, M. (2024). A new framework to spatial and temporal drought analysis for 1990–2020 period with Mann–Kendall and innovative trend analysis methods in Turkey. *Natural Hazards*, 120(2), 1463–1517, <https://doi.org/10.1007/s11069-023-06258-6>.
48. Pellicone, G., Caloiero, T., Guagliardi, I. (2019). The De Martonne Aridity Index in Calabria (Southern Italy). *Journal Of Maps*, 15(2), 788–796, <https://doi.org/10.1080/17445647.2019.1673840>.
49. Piticar, A. (2013). Studies on recent climate change in northeastern Romania, doctoral thesis. Babeş-Bolyai University, Cluj-Napoca.
50. Piticar, A., Ristoiu, D. (2012). Trends in temperature and precipitation in Moldova, *Risks and Catastrophes*, 11(1), 67–78.
51. Potopová, V., Cazac, V., Boincean, B., Soukup, J., Trnka, M. (2019). Application of hydroclimatic drought indicators in the transboundary basin of the Prut River, *Theoretical and Applied Climatology*, 137(3–4), 3103–3121, <https://doi.org/10.1007/s00704-019-02789-w>.
52. Puțuntică, A., Sofroni, A. (2011). Variations in annual and monthly precipitation amounts in the Republic of Moldova, *Bulletin of the Academy of Sciences of Moldova, Life Sciences*, 3, 55–63.
53. Prăvălie, R. (2013). Climate issues on aridity trends of southern Oltenia in the last five decades.
54. Radaković, M. G., Tošić, I., Bačević, N., Mladjan, D., Gavrilov, M. B., Marković, S. B. (2018). The analysis of aridity in Central Serbia from 1949 to 2015. *Theoretical And Applied Climatology*, 133(3–4), 887–898, <https://doi.org/10.1007/S00704-017-2220-8>.
55. Rastilantie, M.-, Rusu, T., Moraru, P., Coste, C., Cacovean, H., Chetan, F., Chetan, C. (2014). Wfl publisher science and technology impact of climate change on climatic indicators in Transylvanian Plain, Romania. In *Agriculture & Environment* (Vol. 12, Issue 1).
56. Sfîcă, L. (2015). Climate of the Siret Corridor and Neighboring Regions, Edit. Univ. "Al. I. Cuza", Iași.
57. Supervisor, N. K. (2012). Trend detection in annual temperature & precipitation using the Mann Kendall Test—a case study to assess climate change on select states in the northeastern United States.
58. Szinell, C. S., Bussay, A., Szentimrey, T. (1998). Drought tendencies in Hungary. *International Journal of Climatology*, 18(13), 1479–1491, [https://doi.org/10.1002/\(sici\)1097-0088\(19981115\)18:13<1479::aid-joc325>3.0.co;2-p](https://doi.org/10.1002/(sici)1097-0088(19981115)18:13<1479::aid-joc325>3.0.co;2-p).
59. Tănasă, D.I. (2017). The climate of the Suceava Plateau – risk phenomena, implications for sustainable development – doctoral thesis, Suceava, p. 261.
60. Vlăduț, A., Licurici, M. (2018). Influence of climatic conditions on the territorial distribution of the main vegetation zones within Oltenia region, Romania, <https://www.researchgate.net/publication/322266872>.
61. Zhang, Y., Cabilio, P., & Nadeem, K. (2016). Improved seasonal Mann–Kendall tests for trend analysis in water resources time series. In *Fields Institute Communications* (Vol. 78, pp. 215–229). Springer New York LLC, https://doi.org/10.1007/978-1-4939-6568-7_10.
62. ***Meteomanz.com, <http://www.meteomanz.com/index?l=1>.

