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Front cover photography: The central part of the Durmitor mountains in Montenegro with the highest peak, Bobotov Kuk (2523 m), and distinctive high-mountain karst shaped by glacial processes (photograph: Jure Tičar).
Fotografija na naslovnici: Osrednji del gorovja Durmitor v Črni gori z najvišjim vrhom Bobotov kuk (2523 m) ter značilnim visokogorskim krasom, ki so ga preoblikovali ledeniški procesi (fotografija: Jure Tičar).

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PRECIPITATION VARIATION AND WATER BALANCE EVALUATION USING DIFFERENT INDICES

Lidia Maria Apopei, Dumitru Mihăilă, Liliana Gina Lazurca, Petruț Ionel Bistricean,
Emilian Viorel Mihăilă, Vasillică Dănuț Horodnic, Maria Elena Emandi

LIDIA MARIA APOPEI

The Cotnari Cellar and vineyard. Cătălina Hill (east view).

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Lidia Maria Apopei[1], Dumitru Mihăilă[1], Liliana Gina Lazurca[1], Petruț Ionel Bistricean[1], Emilian Viorel Mihăilă[2], Vasillică Dănuț Horodnic[1], Maria Elena Emandi[1]

Precipitation variation and water balance evaluation using different indices

ABSTRACT: The study evaluates the variability of water balance using different indices for the period 1961–2018 in Cotnari and surroundings, in the middle part of the Moldavian Plateau (MP), Romania. With the aid of statistical analysis and remote sensing, we discovered that the Cotnari's SPEI (Standardized Precipitation and Evapotranspiration Index) variability is characterized by severe values that alternate between significant excess and significant deficits. According to SPEI, between 57.2 and 61.4% of the months were near normal in terms of water balance. There were between 19.3 and 25.1% months with water excess and between 17.1 and 20.8% with water deficit. The links between NDVI and SPEI become stronger as SPEI reaches extreme values (above 1.5 units or below −1.5 units). The water balance indicates a decrease in available water resources.

KEYWORDS: SPEI, water balance, NDVI, trend analysis, Romania

Preučevanje sprememb v količini padavin in vodni bilanci z uporabo različnih indeksov

POVZETEK: Avtorji v članku z različnimi indeksi preučujejo spremenljivost vodne bilance v romunski vasi Cotnari in njeni okolici na osrednji Moldavski planoti med letoma 1961 in 2018. Statistična analiza in daljinsko zaznavanje sta pokazala, da je za standardizirani padavinsko-evaporacijski indeks (SPEI) preučevanega območja značilna velika spremenljivost, pri kateri vrednosti nihajo med izrazitimi presežki in primanjkljaji. Na podlagi vrednosti indeksa SPEI je bila vodna bilanca v 57,2 do 61,4 % mesecev blizu normale, v 19,3 do 25,1 % mesecev je bila pozitivna (s presežki), v 17,1 do 20,8 % mesecev pa negativna (s primanjkljaji). Korelacija med indeksoma NDVI in SPEI se okrepi, ko SPEI doseže ekstremne vrednosti (nad 1,5 enote ali pod −1,5 enote). Vodna bilanca v preučevanem obdobju kaže upadanje razpoložljivih vodnih virov.

KLJUČNE BESEDE: SPEI, vodna bilanca, NDVI, analiza trendov, Romunija

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1 Introduction

In the last 60 years, the frequency of extremes and rainfall imbalances has increased in the middle part of the temperate climate zone (Mihăilă et al. 2017). The Cotnari territory and its surroundings are in this climatic type and are frequently subject to these extremes. The Carpathian region itself, located only 50 km to the west, is higher and more exposed to oceanic influences. Its vulnerability to climate changes was revealed by various indices: Standardized Precipitation and Evapotranspiration Index (SPEI), Standardized Precipitation Index (SPI), Drought Recognition Index (RDI) and Palfai Aridity/Drought Index (PADI) (Spinoni et al. 2013). The alternation of excess and deficit rainfall in relation to different components of the geographical landscape requires an adaptation of risk management induced by these rainfall extremes (Mihăilă and Tanasă 2013; Morar et al. 2021). SPEI as a multiscale index of water balance analysis has not raised research constraints in any climate zone regardless of the spatial or temporal extent of the analysis. The World Meteorological Organization (2012) recommends SPEI for scientific research purposes. SPEI gives significant results regardless of the size of the area surveyed if its calculation algorithm is applied correctly (Cheval 2015; Stagge et al. 2015). SPEI can be used from global scale (Begueria et al. 2013) to regional and local scale (Hakam et al. 2022). SPEI was proposed by Vicente-Serrano et al. (2010; 2012) and was mainly used to analyse the drought phenomenon at different time scales.

In Romania and the Republic of Moldova relevant water balance (WB) studies have been carried out based on SPEI and other indices (Mihăilă et al. 2017). Pascoa et al. (2020) analysed the relationship between drought and vegetation stress between April and October, since 1998 until 2014. Dragotă et al. (2012) and Roşca (2020) studied, using SPEI, Normalized Difference Vegetation Index (NDVI) and other indices, the effects of rainfall excess or deficit on land use for the Carpathians and the Curved Subcarpathians, respectively the Romanian Plain. The results of the cited studies practically justify the approval of SPEI as a regional indicator in the water excess/water deficit assessment for the EU Member States according to Global Water Partnership. Water deficit in the soils of the eastern and southern Carpathians is stronger than in the interior of the intracarpathian area, negatively affecting all environmental components (Onțel et al. 2021). The water balance dynamics in the eastern and southern Carpathian Mountains show that, in equivalent periods to those in our study, there has been recorded an increase in climatic water scarcity, which is of concern to both researchers and local communities (Bandoc and Prăvălie 2015). Potop (2003; 2011) and Neadealcov et al. (2015) have studied droughts in the Republic of Moldova based on SPEI (and SPI). The current and prospective climatic context indicates through the Palmer Drought Severity Index (PDSI) for the area under investigation a trend towards drought (Dascălu et al. 2016). NDVI was used in the present study to validate SPEI values and especially its extremes. This index is normally used for the analysis of vegetation dynamics (Milanović et al. 2019), but also for the identification of major land cover categories such as water bodies, barren soil, grasslands, moderate vegetation and dense vegetation (tropical forest). NDVI has been used early in such climate-related studies (Rouse et al. 1973; 1974) and is the most widely used index in remote sensing analyses of vegetation cover (Tucker 1979). In Romania, a close analysis using NDVI was performed by Angearu et al. (2020) for the Oltenia Plain, the Baragan Plain and the Banat Plain. However, the NDVI index along with other spectral indices, such as Normalized Difference Water Index (NDWI), Temperature Condition Index (TCI) has been quite rarely used in Romania (Prăvălie Sîrodoev and Peptenatu 2014; Bordun, Nertan and Cimpeanu 2018).

The lack of water balance studies focusing on the Cotnari wine region, and its surroundings was reason enough for this analysis. The Cotnari territory and its surroundings are intensively used in agriculture (viticulture in Cotnari, viticulture and cereal-cultivation in Iasi, cereal and technical crop cultivation in Roman), and the deterioration of the water balance in recent years requires in-depth studies to support efficient agricultural management. For agronomists, this study can provide a basis for the analysis of crop varieties, sowing periods, phytosanitary treatments, etc.

The objectives of our study are the following: i) to outline the SPEI parameters (minimum, average, maximum) by month and season (cold: October–March; warm: April–September) in Cotnari to evaluate the variability of water excess/deficit in the analysed area; ii) to validate the consequences of SPEI extremes on the vegetation by analysing several relevant satellite scenes and NDVI; iii) to identify trend evolution of SPEI for the period 1961–2018, its magnitude and degree of confidence in order to predict the future value trajectory of these indices.

2 Study area

The territory around Cotnari weather station is part of the geographical landscape of forest and steppe, heavily modified by human interventions. The water balance in the investigated area has tended to lean toward a water deficit in recent years (Piticar 2013; Piticar et al. 2016; Mihăilă et al. 2017). This study also complements and updates the water balance research for Cotnari as base station and two other supporting meteorological stations (Iasi and Roman).

Cotnari station is in the southeastern extremity of the Suceava Plateau at the contact with the Moldavian Plain. The Iasi station is in the southern end of the Moldavian Plain and Roman station is in the north of the Siret Corridor. The data representativeness from Cotnari and Iasi weather stations extends within a radius of up to 70 km around the station in the Moldavian Plain and is reduced to 30–35 km towards the Suceava Plateau and Central Moldavian Plateau. The representativeness area of Roman station is

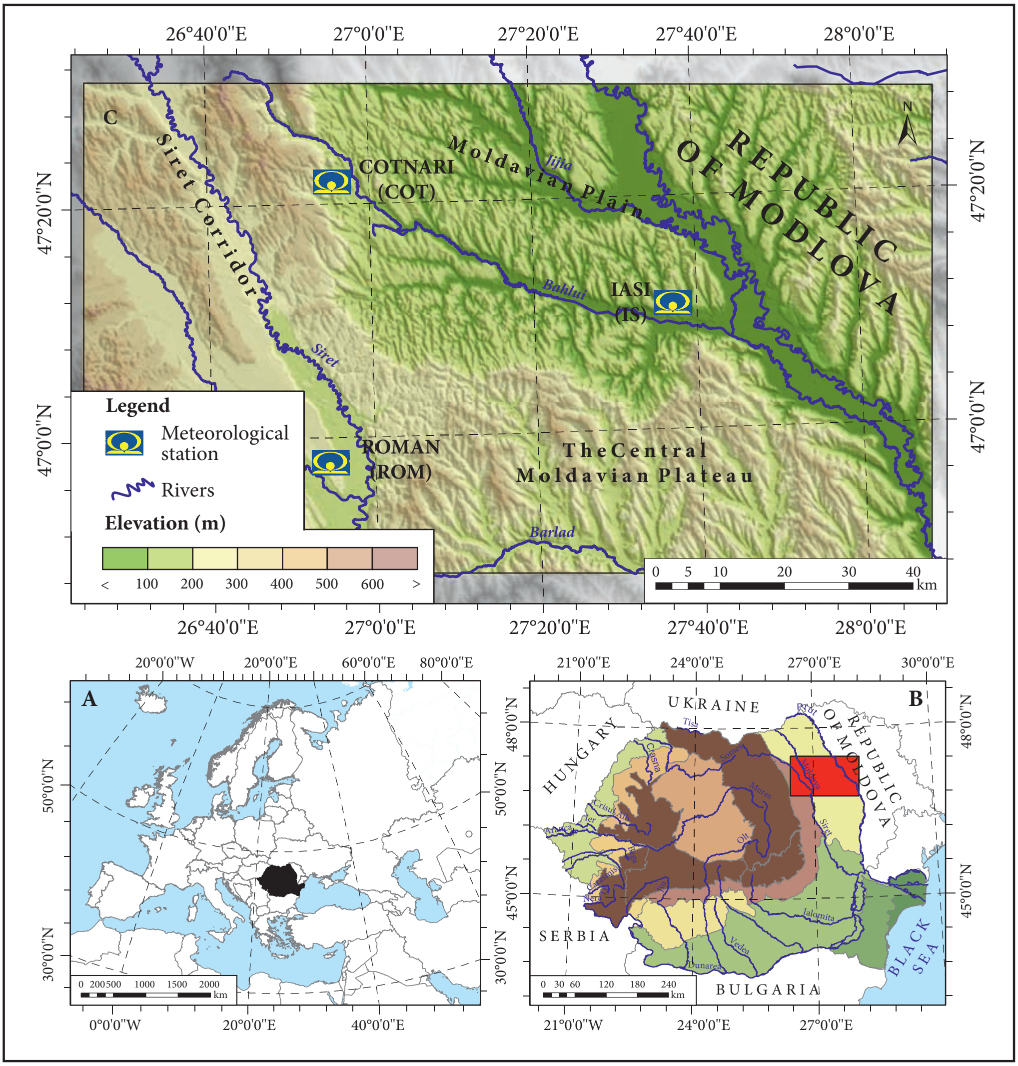


Figure 1: The Cotnari, Iași and Roman weather stations in Moldavian Plateau territory and its location within NE Romania.

limited to a circle with a radius of 30–35 km having the station in question in the center (World Meteorological Organization 2018).

At the mesoclimatic level, the three stations are found in the continental climate with warm summers (Dfb), according to the Köppen-Geiger classification (KG) (Sandu 2008). The geographical weather station position, the atmospheric circulation and the variety of the relief, determine, however, a great spatio-temporal variation of the climatic elements and phenomena. The Moldavian Plateau has a temperate climate with continental influences from the east and oceanic influences from the west (Mihăilă 2006; Tănasă 2011).

At Cotnari, the local hilly topography favours the formation of foehn circulation when the westerly winds descend, firstly over the eastern flank of the Eastern Carpathians and afterwards over the eastern slopes of the Moldavian Coast. The foehn effect, the moderate slopes, the favorable exposure to the east-southeast and the carbonaceous chernozems soils favored the cultivation of the vine on large areas (1750 ha) (Cotea et. al. 2006).

For this study we choose to focus on SPEI analysis around the Cotnari viticultural area (influenced by dynamic foehn processes; Apopei, Mihăilă and Bistricean 2020) comparing the results with those from Roman and Iași, because Roman station is a landmark for the Siret River valley topoclimate (Sfîcă 2015), and Iași station is a typical lowland station, where the influences of the continental climate and of the city are more obvious (Sfîcă et al. 2018).

3 Data and methodology

We took three steps in order to assess the water balance variation in the study area. In the first phase, we extracted, processed, and examined the SPEI value variability. In the second phase, we collected and processed satellite images, extracted NDVI values, and analysed their spatial and statistical distribution in comparison to SPEI values. In the third phase, we tested the SPEI values with Mann-Kendal trend tests.

3.1 Extraction and processing of SPEI data

The total amount of precipitations, air temperatures, latitude, and potential evapotranspiration are used to calculate SPEI (Vicente-Serrano, Beguería and López-Moreno 2010). The normalized monthly difference between precipitation and potential evapotranspiration is represented by relative values of the water balance. The three weather stations' SPEI data series are uninterrupted and homogeneous since 1961 until 2018. SPEI values have been retrieved out of the University of East Anglia's Climatic Research Unit's database. Table 1 lists the SPEI value thresholds and ratings.

The processing of SPEI data was performed by statistical methods in the Microsoft Excel program. Monthly SPEI values represent the actual SPEI values for the month in question. For monthly values denoted by SPEI 3, 6, 9 and 12 the calculation was made based on the SPEI simple moving averages, this procedure involved dragging these averages into units of 3, 6, 9, 12 months including the month actually referred to. Following a similar algorithm, we calculated SPEI by quarters (winter, spring, summer, autumn), seasons (warm, cold) and years. Through boxplot charts we analysed the annual regime of the SPEI index. Boxplot charts were made in the Python programming language (in the Pycharm program), using different libraries containing data types that help to process .csv files and functions for building boxplots both for retrieving data from the Excel document and for creating the charts.

Table 1: Framing according to the SPEI values of the analysed time units (according to Jianqing et al. 2016).

Categories	SPEI
Extremely wet	≥ 2
Severely wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Near normal	−0.99 to 0.99
Moderately dry	−1.49 to −1.0
Severely dry	−1.99 to −1.5
Extremely dry	≤−2.0

3.2 Extraction and processing of NDVI data

NDVI is calculated as the ratio of the difference to the sum of the reflectance in the infrared and red spectral regions of electromagnetic radiation.

The NDVI calculation formula is:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{1}$$

where NIR is the reflectance measured in the near infrared wave bands and RED is the reflectance corresponding to the red wave bands (Rouse et al. 1974). Note that these are average values and that it varies spatially and temporally. Based on spectral signature variation, NDVI differencing method helps to delineate land cover variation, and more specifically to assess the change in vegetation cover (Table 2).

3.2.1 Acquisition and processing of NDVI data for temporal analysis

In this step we have made a quantitative analysis based on mean values of NDVI for the last 36 years (16th April, 1984 – 29th December, 2020). The statistic values were obtained by the help of Climate Engine platform (https://app.climateengine.com/climateengine), which allowed us to extract the available mean values of NDVI for the pixels related to our study area, generated from corrected surface reflectance Landsat 5, 7 and 8 images (Figure 5a). In this step of the methodology, the extracted data are related to the entire study area and are used to present the general dynamic of NDVI index. After this the data was organized and the daily, monthly, seasonal, and yearly time profiles were generated using Microsoft Excel software and these are presented in the section 4.2.1.

3.2.2 Acquisition and processing of NDVI data for spatial analysis

In this stage we have conducted a spatial analysis based on Landsat satellite images that cover the study area and from which the NDVI values were obtained by extracting the pixel values representing the three weather stations reported in this analysis.

The Landsat 5 TM and 8 OLI&TIRS satellite images corresponding to Path 182 and Row 27 from Collection 2 – Level 2 related to the period 16th April, 1984 – 29 December, 2020 were downloaded from the USGS Earth Explorer portal, because they are already corrected at the level of surface reflectance. More specifically, the bands 3 and 4 were downloaded from 29 Landsat 5 TM satellite images corresponding to the periods with a rainfall surplus, while for the rainfall deficit intervals bands 3 and 4 were downloaded from other 21 Landsat 5 TM satellite images. We have identified only two Landsat 8 satellite images from the years 2015 and 2018 because they are the only years corresponding to the rainfall deficit time step according to SPEI values. We have also noted that Landsat 5 TM satellite data were only available until June 2013, so we had to rely on Landsat 8 OLI&TIRS satellite images, available since February 2014.

The relevant yearly SPEI values for the two rainfall contexts were the criteria for choosing the representative years for which to calculate and extract the specific NDVI values. The starting point were the SPEI values: greater than 1.5 for the rainfall surplus periods and –1.5 for rainfall deficit periods.

The spatial resolution of the satellite images used in the analysis was 30 m, and the degree of cloudiness of the downloaded satellite scene bands was less than 10%, and strictly for the study area the level of cloudiness was less than 5%, a requirement met according to the results of Chavez (1996).

Table 2: Land cover categories related to NDVI values (according to Bannari et al. 1995; Weier and Herring 2000).

Categories	NDVI
Water, snow, clouds	–1.0 to 0.0
Barren land, built up, rocks	0.0 to 0.2
Grassland and shrubland vegetation	0.2 to 0.3
Coniferous forests	0.3 to 0.4
Deciduous forests	0.6 to 0.8
Very dense and healthy vegetation	≥ 0.8

At this stage the monthly SPEI values were analysed in relation to NDVI. The spatial analysis was broken down into two approaches: 1) spatial-statistical quantification of the yearly average for representative years in terms of the variation of SPEI and 2) illustration of two case studies reflecting the extremes of the two types of SPEI values (above 1.5 units, below –1.5 units corresponding to wet and dry weather conditions).

Firstly, we have made two synthetic maps with associated histograms which emphasize the spatial and statistical distribution of NDVI values by the mediation of 29 satellite images for wet weather conditions and 23 satellite images for dry weather conditions, respectively. The entire procedure was made by applying the raster calculator and cell statistics functions from ArcGIS 10.4.

Secondly, the case studies of the extremes of the two types of weather were based on the processing of two representative images: one from 17th August, 1991 for rainy weather and one from 28th July, 2007 for dry weather. In this case, we have generated two different NDVI maps at 30 m spatial resolution and their associated histograms using ArcGIS 10.4.

The results of this part of the study are presented in the chapter 4.2.2.

3.3 Trend analysis (Mann-Kendall test)

To analyse the trend with SPEI values we used the Mann-Kendall statistical test. The Mann-Kendall statistical test is widely used because it does not require a normal distribution of data and is straightforward to calculate. The Mann-Kendall test is applicable if the Xi data values of a time series are subordinate to the model: $Xi = f(ti) + \varepsilon i$ where: $f(ti)$ is a monotonous continuous function and εi is residue (Patriche 2009). The non-parametric Mann-Kendall test is widely used to analyse climatic trends (Mann 1945; Sen 1968; Kendall 1975).

4 Results and discussion

4.1 SPEI analysis

4.1.1 Multiannual statistical framework of SPEI variability in Cotnari and the surrounding areas

Regional warming is a proven reality for NE Romania and for the stations related to our study (Mihăilă and Briciu 2012; Piticar 2013) as in all regions of Europe, where increases in average and extreme temperatures are reported (Pörtner et al. 2022).

Analysing the statistics of the monthly values of SPEI 1 to SPEI 12 for the entire period 1961–2018 (Figure 2), we can firstly notice that the number of months considered near normal for all SPEI calculation intervals is between 57.2% for SPEI 1 in Iași and 61.4% for SPEI 6 in Roman. The months in which the values of SPEI 1–12 indicated surplus (varying between 19.1% SPEI 3 in Roman and 25.1% SPEI 12 in Iași) or pluvio-hydric deficit (varying between 17.1% for SPEI 6 in Iași and 20.8% for SPEI 3 in Roman) were numerous. For all three considered stations, significant percentages can be distinguished that must be taken into account (between 0.4% SPEI 12 Iași and 2.4% SPEI 3 Cotnari) during severely dry months when the SPEI values 1–12 were below –1.99. Additionally, the percentages of months with very high humidity held between 0.6% and 3% in Iași for SPEI 9 and SPEI 3, respectively.

SPEI renders the reality of the water balance in the MP very accurately. The results provided are in agreement with those obtained by calculating other climatic indices (potential evapotranspiration, water balance) for geographic territories neighbouring or including the analysed stations (Mihăilă et al. 2017; Piticar et al. 2016).

4.1.2 Annual and multiannual variability of SPEI

The seasonal SPEI values at Cotnari (Figure 3) reveal a series of temporal differences in precipitation and water balance in the MP. First, we note that the variability of SPEI is higher in the warm season than in the cold season in all cases. The water balance for the investigated territory was at the limit of a dysfunctional dynamic equilibrium, with evolution towards water deficit and increasing vulnerability in relation to SPEI extremes. The seasonal extremes of SPEI varied in the value range between –2.4 and +2.7 (Figure 3), indicating a contrasting and pluvio-hydric continentalism. We notice a slight preponderance of months with SPEI 3 mean values above the 0 threshold. Most months have average SPEI values between –1 and +1. In the case of SPEI 3, the minimum values are below –2 in most months and the maximum values are above the 2 threshold.

The extreme SPEI values (–2.4 and 2.7) and those defining the ends of the Q1-Q3 interquartile range (–1.6 and 1.7) increase from SPEI 1 to SPEI 12 (Figure 3).

The variation spaces of the extremes and of the Q1–Q3 interquartile range preserve their graphical and statistical pattern in the aggregation ranges of SPEI 3–6, where both deficit and excess water are most pronounced. SPEI shows extremely dry/wet ranges in both seasons across all averaging intervals (SPEI 1–12). This is a signal that the investigated territory has a water balance that can be significantly unbalanced, regardless of the season, and above the 6-month cumulation threshold. Both the deficit and the extreme surplus are more pronounced in the warm season of the year, indicating a higher risk for drought or excess water from precipitation.

The graphic arrangement of the monthly values of SPEI 1–12 shows us the whole picture of the value variations of these indices, for the period between 1961 and 2018 at Cotnari (Figure 4).

As a standardized index SPEI does not have a uniform multi-year regime. The pattern of the index becomes more regular as we move from one-month analysis to longer time frames (3–12 months). The high variability of this index is induced by the variability of atmospheric dynamics (Boroneant et al. 2011).

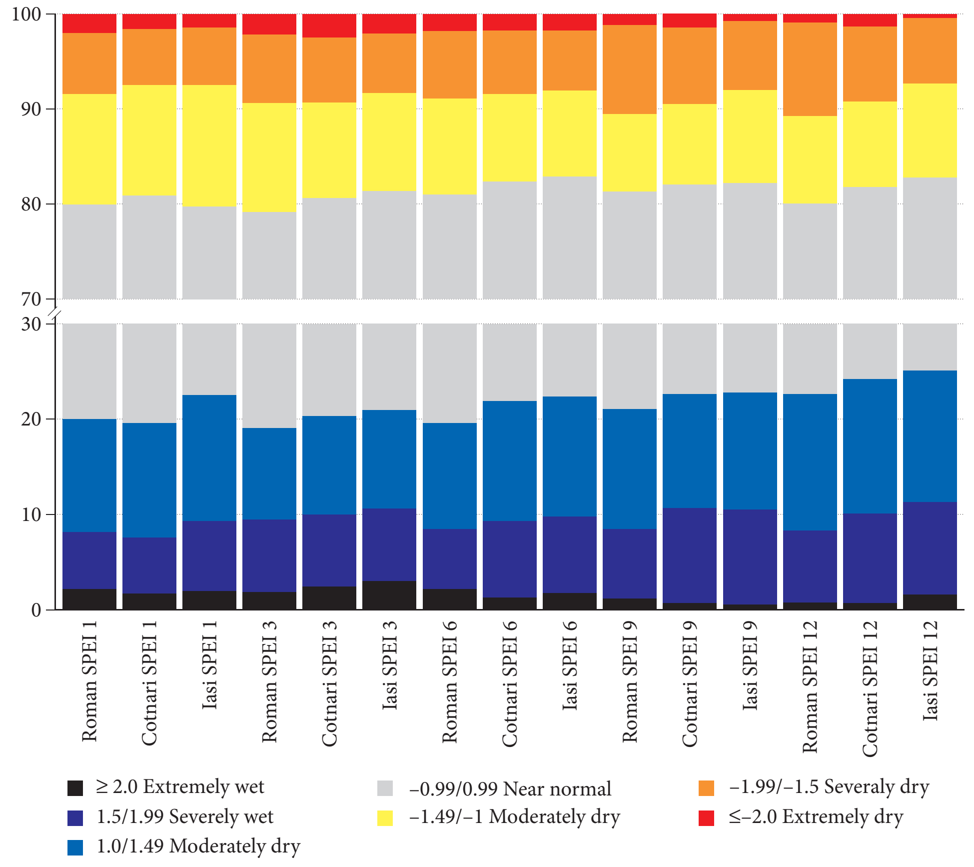


Figure 2: Percentage distribution (0–100%) of monthly SPEI values (from 1 to 12) by classes (from extremely wet months to extremely dry months) for the Roman, Cotnari and Iaşi weather stations for the period 1961–2018.

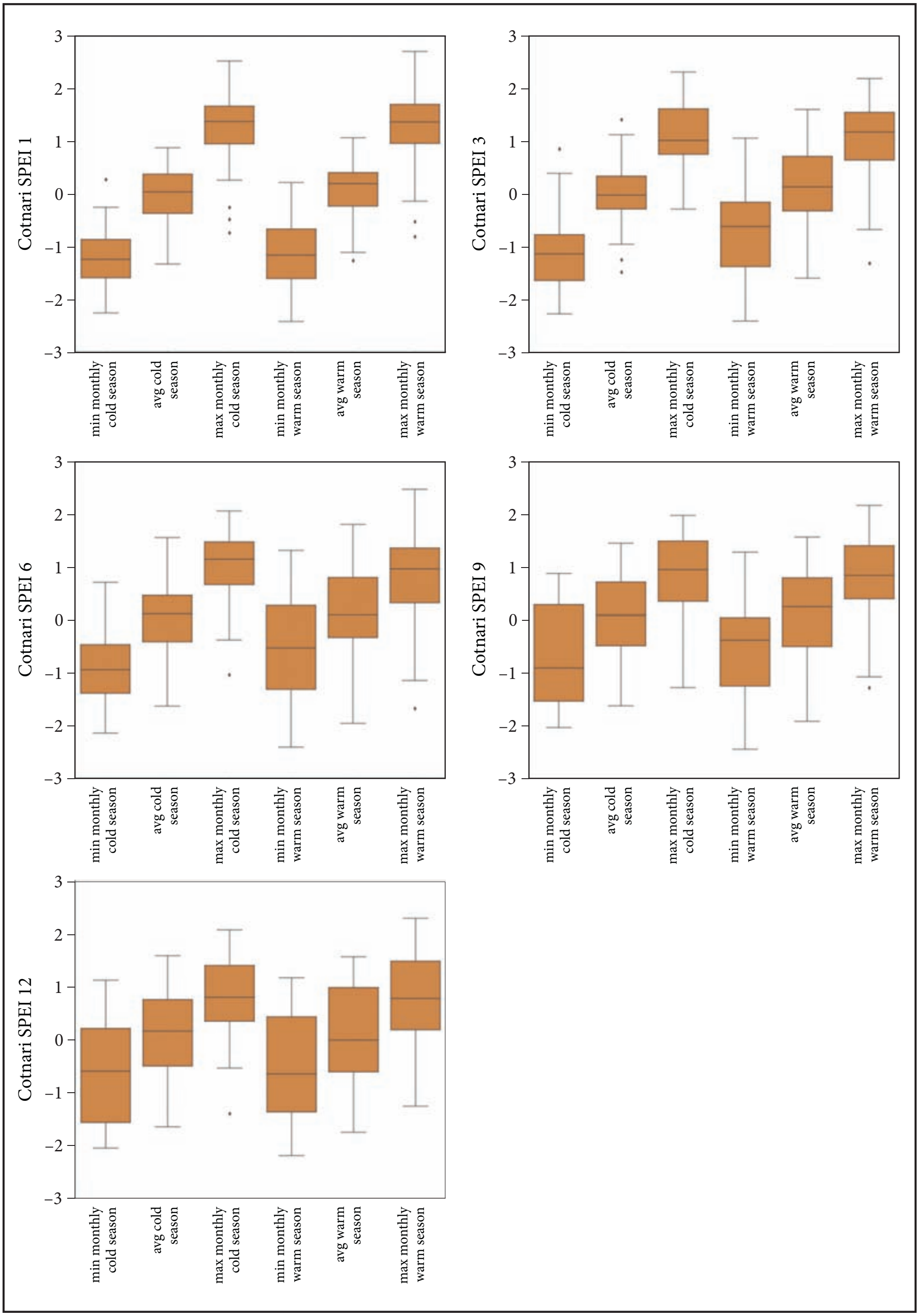


Figure 3: SPEI 1–12 parameter values (monthly minimum, mean, and maximum) by season (cold, warm) at the Cotnari weather station (1961–2018).

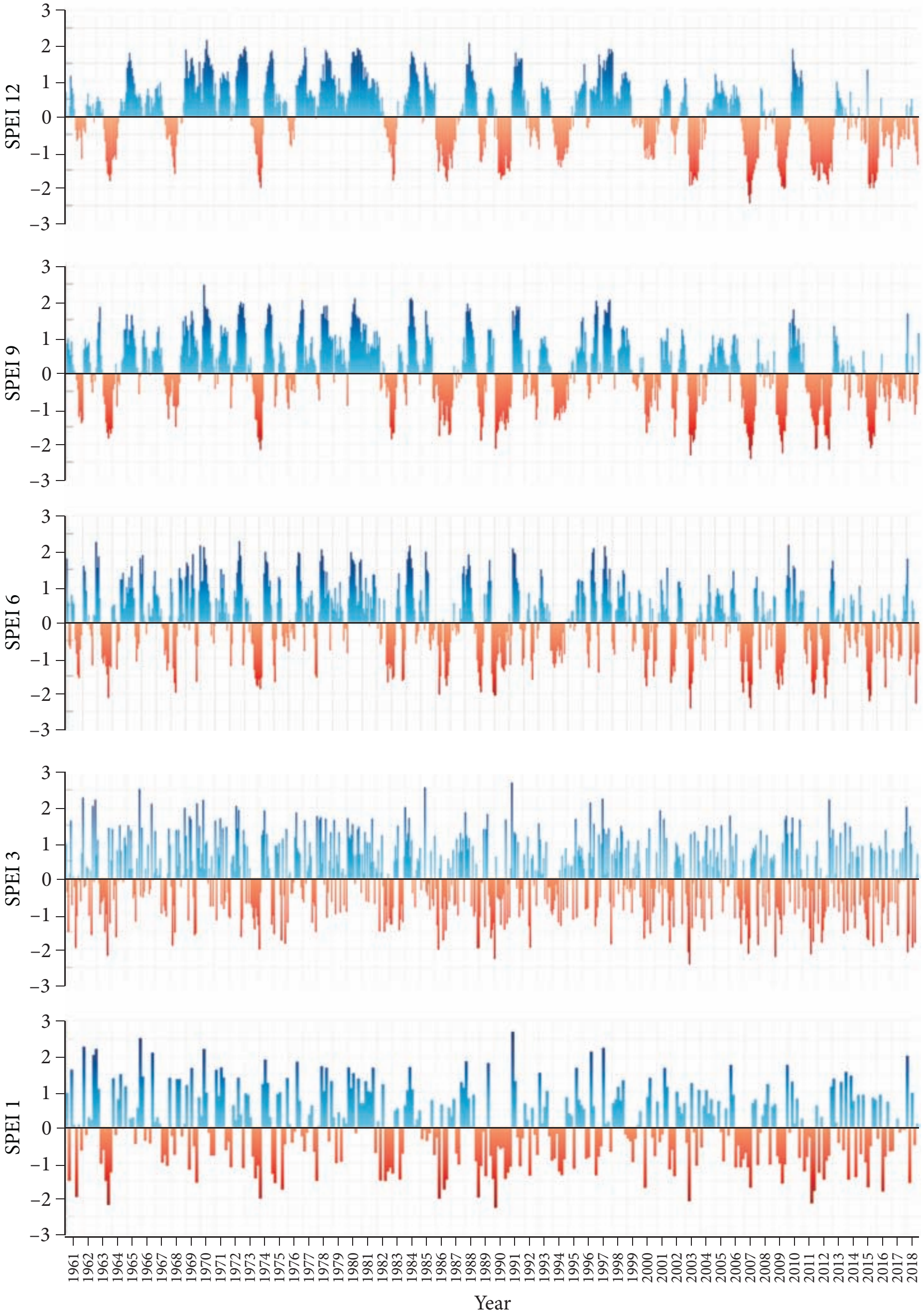


Figure 4: Multi-annual variation of monthly SPEI 1–12 values at the Cotnari weather station (1961–2018); blue – excess, red – deficit.

The variability of SPEI lacks a specific pattern for SPEI 1–3. Repetitive increases and decreases in SPEI become more obvious and orderly as we move from SPEI 1 to SPEI 12 in modelling and analysis. For shorter time frames (1–3 months), SPEI deviations from threshold 0 may indicate more frequent excessive humidity or, less frequently, severe drought. For longer intervals of averaging the monthly values of SPEI (9–12 months), the cumulative intervals with rainfall and water balance either strongly in excess or strongly deficient become more obvious (Figure 4).

It is obvious that periods of excess or rainfall deficit can turn into periods with water excess or water deficit. The 2007 warm season, which was deficient in precipitation, had a similar reflection in SPEI values. If we analyse separately only the SPEI 1–12 data of the last two decades, we observe an amplification of the water balance deficit parameters for all three stations. Torrential rains of a frontal nature of the warm seasons 2006, 2008, 2010, 2014, 2019 generated large accumulations of precipitation. These precipitations were not assimilated by the environmental components due to its torrential character. Therefore, the SPEI values, which take into account evapotranspiration, clearly indicate a deficit water balance for the last two decades (Figure 4).

Piticar et al. (2016) highlighted the sudden increase in the evapotranspiration reference value for the period 1981–2012 for weather stations in the Republic of Moldova, a territory in the immediate vicinity of the studied area and where climate, rainfall and water balance have many similarities. It is certain that the increase in evapotranspiration reference values after 1981 has left a very strong imprint on the investigated SPEI for Cotnari and surroundings.

The representation in figure 4 can be very useful for agronomists and viticulturists, to assess the amplitude and duration of the risk intervals and to predict or anticipate the size of the water surplus or deficit that various agricultural and viticultural crops may experience in the surveyed area (Potop 2011; Nedealcov et al. 2015; Apopei, Mihăilă and Bistricean 2020).

4.2. Validation of SPEI by NDVI

4.2.1 Temporal validation

NDVI values reflect the regime of climatic elements in the analysed interval: high values are specific to those days in the warm season with normal or surplus rainfall, and low values to those days in the cold season with rainfall deficit (Figure 4 and 5a).

The method of choosing satellite images for the months April–September was similar to that applied by Mihai et al. (2016), Angearu et al. (2020) or Dobri et al. (2021). The inter-seasonal dynamics for the analysed interval show a gait dependent on the meteorological particularities of each season and calendar year (Figure 5b). In the case of the analysis of the inter-annual course of the NDVI average values, we identified a minimum in 1987 (0.33) and a maximum in 2013 (0.53) – Figure 5b.

The value for the cold season in 1985 was calculated by averaging the monthly values for the months: (October 1984 + November 1984 + December 1984 + January 1985 + February 1985 + March 1985) / 6. Following this model, all NDVI values for the cold seasons from 1986 to 2020 were calculated, since cold seasons include months from two consecutive years.

4.2.2 Spatial validation

The cartographic products compare the two different meteorological moments: rainy and dry, both from the perspective of approaching the multi-annual mean variation (Figure 6), as well as from the perspective of the case study approach (Figure 7).

The spatial distribution of the NDVI index variation highlights the rainy and dry intervals, especially when we consider the values of the NDVI classes for the two analysed situations (Figure 6 and 7). For the two case studies, NDVI values ranged from 0.00 to 0.95. Values close to 0 showed exposed soils and those over 0.35 (up to 0.95) were specific to areas with forest vegetation or crops that benefited from an optimal rainfall amounts during the phenological development period.

In the case of multi-annual average variation, NDVI recorded values ranged from –0.85 to 0.89 (values below 0 have been excluded from the calculation). For generating the annual average there were years for which we had six satellite images available (1986) and years for which we had only two satellite images available (1985). The years considered according to time availability and correlation with the rainy time SPEI values were: 1984, 1985, 1988, 1991, 1997, 2005, 2006 and 2010. On the other hand, the years analysed

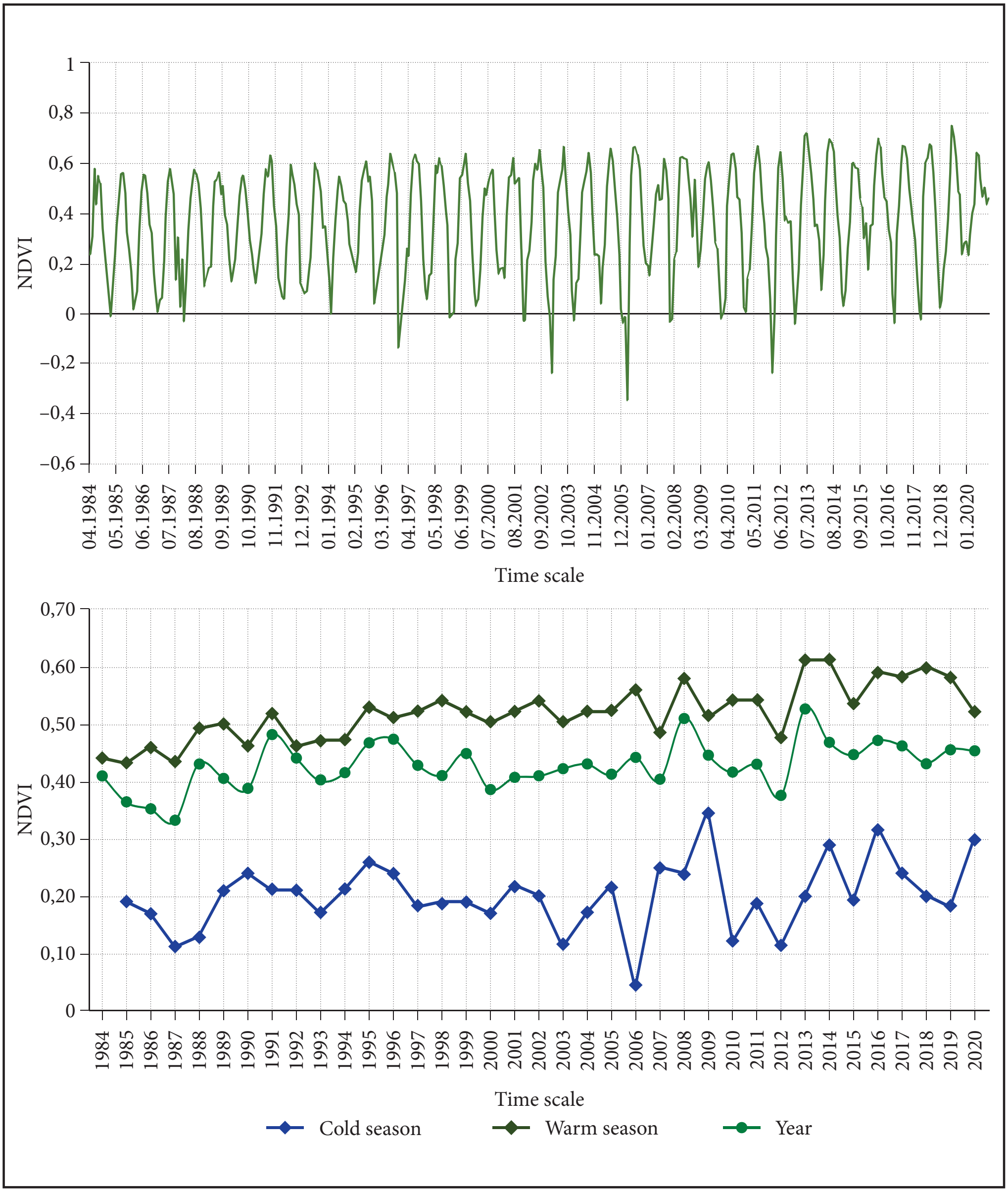
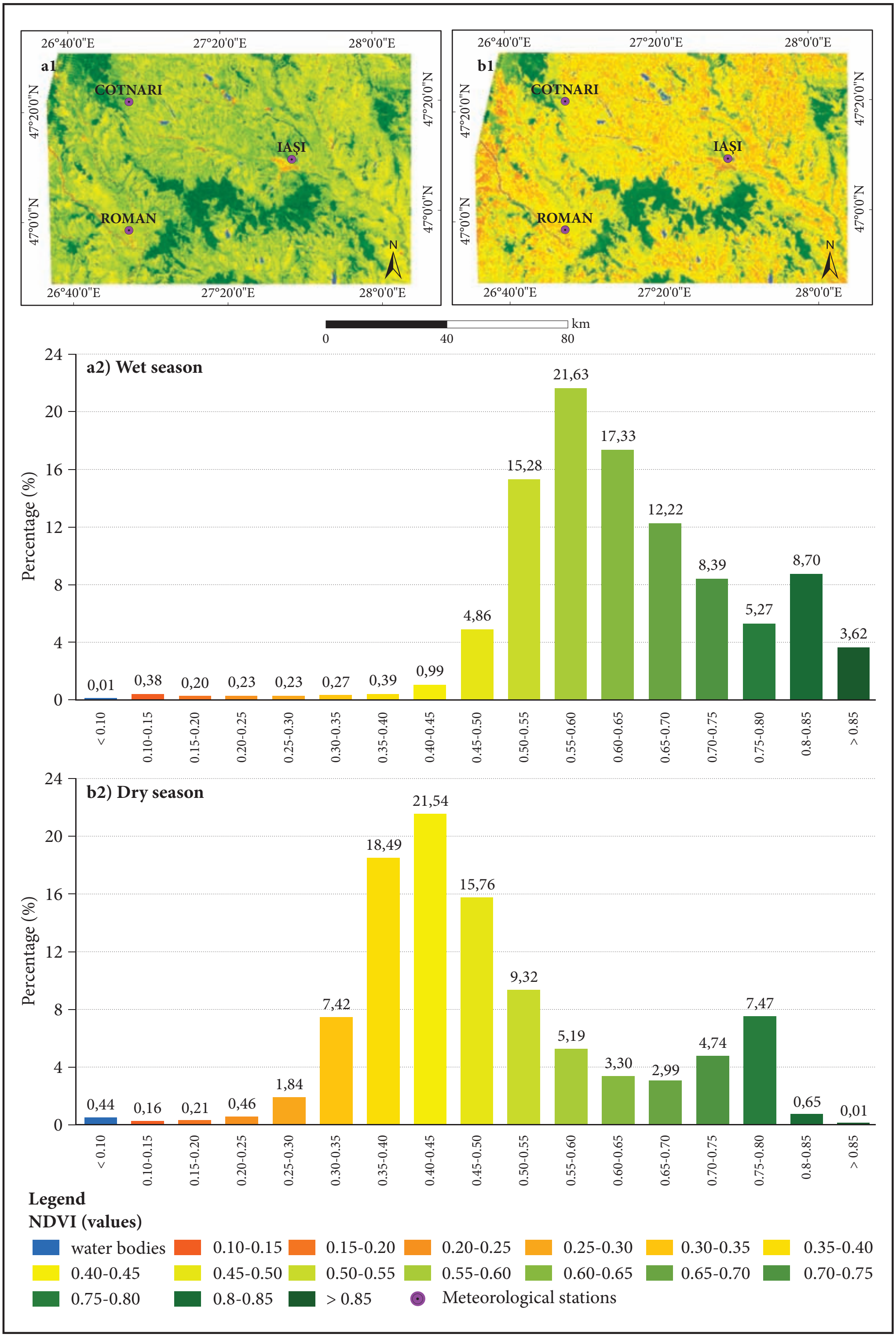
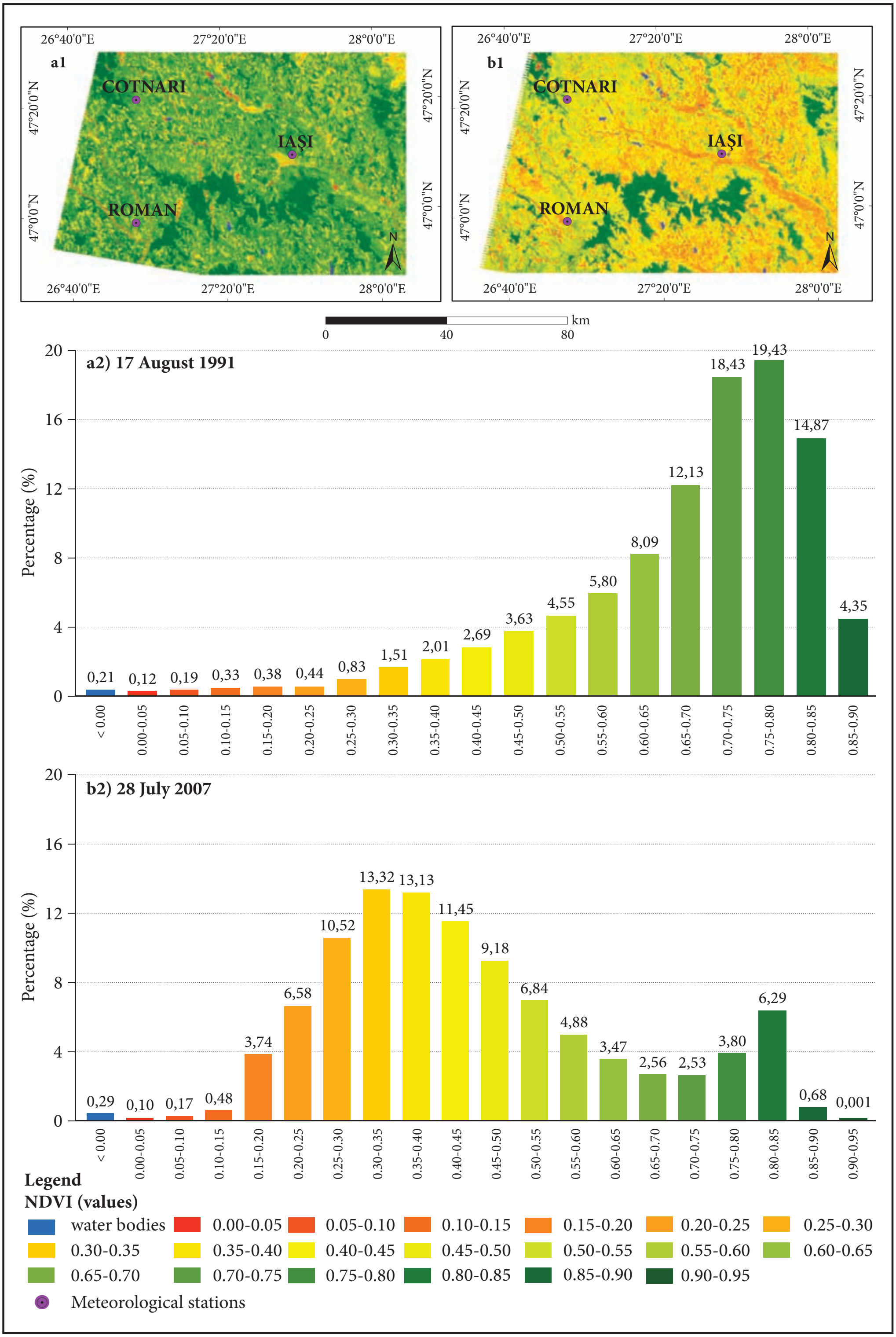


Figure 5: a) Changes in mean daily NDVI values from 1984 to 2020, b) Inter-annual trend of seasonal and annual NDVI values over the period 1984–2020.

Figure 6: Territorial distribution of NDVI in MP region: a1) wet season, b1) dry season. Histograms of NDVI values related to the surface of the surveyed area and to the two specific situations analysed: a2) wet season, b2) dry season. ➤ p. 53

Figure 7: Territorial distribution of NDVI in MP region: a1) 17 August 1991 – rainy weather and b1) 28 July 2007 – dry weather). Histograms of the NDVI value weights related to the surface of the surveyed area and to the two specific situations analysed a2) 17 August 1991, b2) 28 July 2007. ➤ p. 54


a1
b1
26°40'0"E
27°20'0"E
28°0'0"E
47°20'0"N
47°0'0"N
COTNARI
IAȘI
ROMAN
N
0
40
80
km
a2) Wet season
Percentage (%)
0
4
8
12
16
20
24
0,01
0,38
0,20
0,23
0,23
0,27
0,39
0,99
4,86
15,28
21,63
17,33
12,22
8,39
5,27
8,70
3,62
< 0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.8-0.85
> 0.85
b2) Dry season
Percentage (%)
0,44
0,16
0,21
0,46
1,84
7,42
18,49
21,54
15,76
9,32
5,19
3,30
2,99
4,74
7,47
0,65
0,01
Legend
NDVI (values)
water bodies
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.8-0.85
> 0.85
Meteorological stations


a1
26°40'0"E
27°20'0"E
28°0'0"E
47°20'0"N
47°0'0"N
COTNARI
IAŞI
ROMAN
N
b1
26°40'0"E
27°20'0"E
28°0'0"E
47°20'0"N
47°0'0"N
COTNARI
IAŞI
ROMAN
N
0
40
80
km
a2) 17 August 1991
Percentage (%)
0
4
8
12
16
20
0,21
0,12
0,19
0,33
0,38
0,44
0,83
1,51
2,01
2,69
3,63
4,55
5,80
8,09
12,13
18,43
19,43
14,87
4,35
< 0.00
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
b2) 28 July 2007
Percentage (%)
0
4
8
12
16
20
0,29
0,10
0,17
0,48
3,74
6,58
10,52
13,32
13,13
11,45
9,18
6,84
4,88
3,47
2,56
2,53
3,80
6,29
0,68
0,001
< 0.00
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
0.90-0.95
Legend
NDVI (values)
water bodies
0.00-0.05
0.05-0.10
0.10-0.15
0.15-0.20
0.20-0.25
0.25-0.30
0.30-0.35
0.35-0.40
0.40-0.45
0.45-0.50
0.50-0.55
0.55-0.60
0.60-0.65
0.65-0.70
0.70-0.75
0.75-0.80
0.80-0.85
0.85-0.90
0.90-0.95
Meteorological stations

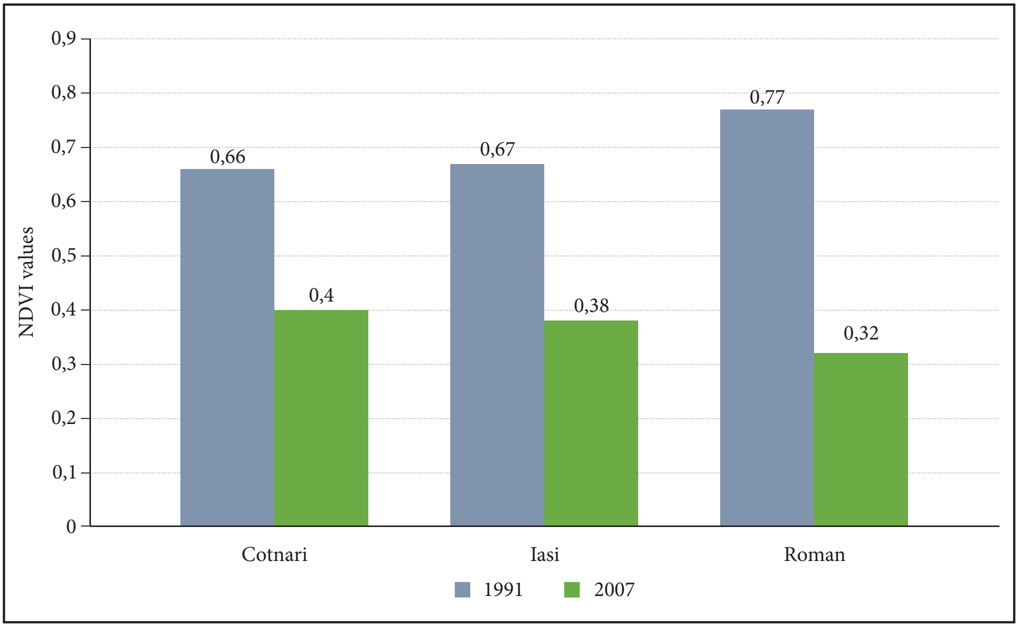


Figure 8: NDVI values for satellite scenes 1991 and 2007

for the dry time were also eight: 1986, 1990, 2000, 2007, 2009, 2011, 2015 and 2018. It turned out that the biggest differences in the value of NDVI were in Cotnari: 0.37 for dry time and 0.57 for rainy time. At the other two stations, the variations were smaller but still visible: 0.59 for rainy time and 0.44 for dry time in Iași, respectively 0.60 for rainy time and 0.48 for dry time in the case of Roman.

The obtained values complete, at least for the case of Roman, the meteorological and phenological picture specific to a site located in the meadow of a river where the rainfall contribution from the soil moisture reserve at the level of the terrace steps is felt. A similar situation was identified by Mihai et al. (2016). Moreover, the histogram analysis of the NDVI rainy-time map highlights the higher share of classes 0.50–0.55 (15.28%), 0.55–0.60 (21.63%) and 0.60–0.65 (17.33%). On the other hand, in the case of water scarcity, the NDVI histogram of the dry time map shows the higher share of classes 0.35–0.40 (18.49%), 0.40–0.45 (21.54%) and 0.45–0.50 (15.76%).

Next, we extracted the NDVI values of the three weather stations included in our study area, in order to observe if there are visible differences from a quantitative point of view. We found that the highest values of NDVI were recorded in 1991 at all 3 weather stations: 0.66 at Cotnari, 0.67 at Iași and 0.77 at Roman. In opposition, NDVI values from 2007 (0.40 at Cotnari, 0.38 at Iași and 0.32 at Roman) confirm the dry weather specific to this year (Figure 8).

4.3 SPEI trends after 1961

The variability and repeatability of the SPEI oscillations as shown in Figure 4 hide the negative trends of the SPEI. They are highlighted by applying the Mann-Kendall statistical test. In a region with a temperate climate, characterized by meteorological excesses, the knowledge of the climatic parameters trend and amplitude was of capital theoretical and practical importance (Mihăilă 2006; Tanasă 2011; Sfîcă 2015).

At SPEI 1, water balance trends indicate a downward evolution. The most pronounced decreases are specific to July and especially August, a month in which both the magnitude of the decrease and its statistical confidence becomes larger and stronger. Summers and springs became the time frame for the manifestation of SPEI depreciation, this decrease being imprinted on longer time intervals such as the warm seasons (April–September) and even on an average annual level (Table 3). October maintains the growth trends of SPEI, with relevant statistical significance.

Table 3: The 10-year trends of the evolution of SPEI 12 (1961–2018) highlighted by the Mann-Kendal in Roman, Cotnari and Iaşi (blue – positive trend, red – negative trend). Non-significant trends are not presented.

Period	Roman SPEI 1 MKt S/ Ss	Cotnari SPEI 1 MKt S/ Ss	Iasi SPEI 1 MKt S/ Ss	Roman SPEI 3 MKt S/ Ss	Cotnari SPEI 3 MKt S/ Ss	Iasi SPEI 3 MKt S/ Ss	Roman SPEI 6 MKt S/ Ss	Cotnari SPEI 6 MKt S/ Ss	Iasi SPEI 6 MKt S/ Ss	Roman SPEI 9 MKt S/ Ss	Cotnari SPEI 9 MKt S/ Ss	Iasi SPEI 9 MKt S/ Ss	Roman SPEI 12 MKt S/ Ss	Cotnari SPEI 12 MKt S/ Ss	Iasi SPEI 12 MKt S/ Ss
January										–0.15+	–0.21*	–0.18*	–0.15+	–0.21*	–0.21**
February											–0.25**	–0.19*	–0.12+	–0.20**	–0.19**
March					–0.15+						–0.22*	–0.17+	–0.12+	–0.18*	–0.17*
April				–0.12+	–0.17*	–0.14+		–0.15*	–0.15*		–0.19*	–0.16+	–0.17*	–0.23**	–0.21*
May					–0.15*	–0.17*		–0.18**	–0.17*		–0.15+		–0.19*	–0.28**	–0.24**
June					–0.16+			–0.18*	–0.16+			–0.13+	–0.17*	–0.23**	–0.22*
July		–0.19*	–0.16+		–0.18*	–0.15+	–0.17+	–0.22*	–0.18*	–0.16*	–0.16*	–0.18*	–0.14+	–0.21*	–0.20*
August	–0.18*	–0.20*	–0.18*	–0.18*	–0.24**	–0.21*	–0.22*	–0.25**	–0.24**	–0.22*	–0.28**	–0.24**	–0.18*	–0.24**	–0.22**
September				–0.21*	–0.25**	–0.22*	–0.22*	–0.22**	–0.21**	–0.20*	–0.26**	–0.22**	–0.15+	–0.20*	–0.18*
October	0.20*	0.17*	0.16*				–0.15+	–0.19*	–0.18*	–0.17*	–0.25**	–0.20*	–0.18+	–0.23*	–0.19*
November								–0.20*	–0.19+	–0.15+	–0.22*	–0.19*	–0.16+	–0.21*	–0.19*
December				0.16+					–0.17+	–0.17+	–0.22*	–0.20*	–0.17+	–0.24**	–0.22**
Annual		–0.07*	–0.07*		–0.11*	–0.10*	–0.10*	–0.15*	–0.15**	–0.14*	–0.21**	–0.19**	–0.17*	–0.22**	–0.22**
Winter									–0.10+	–0.16*	–0.24***	–0.20***	–0.17**	–0.22***	–0.21***
Spring		–0.09*	–0.09*		–0.15*	–0.13+		–0.14+	–0.13+		–0.20*	–0.16*	–0.17*	–0.24**	–0.22**
Summer	–0.12*	–0.16**	–0.14**	–0.15*		–0.18*	–0.16*	–0.21**	–0.18*	–0.15*	–0.18*	–0.18*	–0.17+	–0.23**	–0.21**
Autumn							–0.17*	–0.21*	–0.18*	–0.18*	–0.23**	–0.20**	–0.17+	–0.22*	–0.18*
Oct – Mar					0.08**			–0.10*	–0.11*	–0.16**	–0.24***	–0.20***	–0.17**	–0.22***	–0.20***
Apr – Sep	–0.10*	–0.12**	–0.11*	–0.15*		–0.16**	–0.016*	–0.19**	–0.18**	–0.14*	–0.21**	–0.17*	–0.17*	–0.23**	–0.22**

[Ss = Statistical significance; MKt = Mann-Kendall test; S = Slope; + = $p < 0.1$, the statistical link is significant (Ss, 85% confidence), * = $p < 0.05$, the statistical link is significant (Ss, 95% confidence), ** = $p < 0.01$, the statistical link is significant (Ss, 99% confidence); *** = $p < 0.001$, the statistical link is highly significant (Ss, 99.9% confidence)]

For SPEI 3, in Cotnari, the water balance worsens in 7 months of the year, from April to September, the decrease of SPEI value was accentuated and statistically significant. In Roman, and especially in Iași, the situation is similar. The springs, summers and years as a whole have declining SPEI values. Only at Cotnari, throughout the period October–March 1961–2018, the values of SPEI 3 increased slightly, imprinting a trend of improving the water balance in the cold season.

From the mediation level SPEI 6 to that of SPEI 12, the trends of precipitation quantities and water balance from 1961–2018 acquire a similar arealographic contour for the 3 stations (Table 3).

Considering only SPEI 6–12, the water balance indicates an intensity (with increasing statistical representativeness) of the water deficit (Table 3). Water shortages for environmental components increased over the analysed period and will most likely increase in the future.

According to our results, SPEI values in the vegetation season in Cotnari indicate the accentuation of the water deficit in the period 1961–2018, when the SPEI values that showed statistical significance ranged between –0.12 ($p < 0.01$) for SPEI 1 and –0.23 ($p < 0.01$) for SPEI 12. Also, the annual values of SPEI in Cotnari decreased during the analysed period from –0.07 ($p < 0.05$) for SPEI 1 to –0.22 ($p < 0.01$) for SPEI 12.

In 2011, Potop highlighted for a territory located east of our study area (for the Republic of Moldova and for the period 1955–2009) through SPI and SPEI the tendency of increased intensity of droughts during the summer months. The same author noted the high rate of increase in the evapotranspiration reference value for the summer season.

The fact that the decreasing trends of SPEI 12 are statistically significant for all the analysed time units, it is a warning sign, which should warn those responsible for the management of water resources in the considered area, so that in the future, water shortages in the Cotnari area and NE Romania can be controlled.

The results obtained by us are in agreement with those obtained on a larger scale (the territory between the Carpathians and the Dniester) for the period 1961–2012 by Mihăilă and Tanasă (2013), Mihăilă et al. (2017) and for Europe by Kingston et al. (2015) and Dukat et al. (2022).

Through SPEI, we have presented the depreciation of the involutive climatic context of the water balance for Cotnari and its surroundings in a complex and comprehensive manner, and the results obtained are consistent with those in the cited studies. Cumulative and amplified SPEI deficit for the 58 years analysed could be able to introduce many changes in the geographical landscape of the region (Mihăilă et al. 2017).

5 Conclusion

This study assesses the variability of the water balance in Cotnari and surroundings using SPEI (and NDVI) for the period 1961–2018.

The variability of the SPEI in the Cotnari area is characterized by extremes, oscillating between large surpluses and significant deficits. According to SPEI, between 57.2 and 61.4% of the months were normal in terms of water balance. Between 19.3 and 25.1% were water surplus months (extremely wet months were between 0.6 and 3% of cases) and between 17.1 and 20.8% were water deficit months (extremely dry months were between 0.4 and 2.43% of cases). SPEI showed extremely dry or wet intervals in both seasons across all averaging intervals (SPEI 1–12). Both extreme deficit and extreme surplus are more pronounced in the warm season of the year. SPEI ranged from –2.4 units to +2.7 units.

The links between NDVI and SPEI become stronger as SPEI reaches extreme values (above 1.5 units or below –1.5 units). The claim that vegetation always responded to water surplus, or deficit episodes as indicated by SPEI through NDVI values is supported by satellite images averaged for water surplus (29 scenes) and water deficit (23 scenes), as well as satellite scenes from August 1991 and July 2007 (selected for SPEI extremes).

SPEI trends become clearer, more pronounced and with increasing statistical confidence for the entire investigated area as the reference interval increases from SPEI 1 to SPEI 12. The water balance indicates a decrease in available water resources during the analysed interval (1961–2018).

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