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Assessment of the Drought Risk in Constanta County, Romania

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Abstract: Drought poses a significant risk in many parts of the world, especially in regions reliant on agriculture. Evaluating this risk is an essential step in preventing and reducing its impact. In this context, we assess the drought intensity at six sites in Constanța County (Romania) using the de Martonne aridity index. The risk of aridity and vulnerability to drought were evaluated by the Drought Hazard Index (*DHI*) and Drought Risk Index (*DRI*), computed based on the Standardized Precipitation Index (*SPI*). The de Martonne index indicates a variation between the slightly arid and semi-arid climates for Adamclisi station, with periodic changes from semi-arid to arid. At Cernavodă station, we notice a passage from an arid period towards a moderately humid one (in 2005), followed by a movement in the opposite direction to the limit of the arid zone (in 2011), and a return inside the "limits" of the semi-arid to moderately arid climate. A similar variation for 2000–2018 is noticed at Medgidia, Hârșova, and Mangalia. *DRI* classifies two stations in the low risk to drought category and one in the moderate risk to drought class. The other two locations experience a high or very high risk of drought. The drought intensities varied in the intervals 0.503–1.109 at Constanța, 0.473–1.363 at Mangalia, 0.511–1.493 at Adamclisi, 0.438–1.602 at Hârșova, 0.307–1.687 at Medgidia, and 0.463–1.307 at Cernavodă, and the prolonged drought periods were over 99 months at all stations.

Keywords: hazard; vulnerability; *SPI*; *DVI*; *DHI*; *DRI*

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1. Introduction

The growing occurrence of extreme events, such as drought, has become a major global concern. Drought, a complex hydro-meteorological phenomenon characterized by prolonged and abnormal moisture deficiency, significantly impacts various sectors, including agriculture, water resources, and ecosystems. The substantial challenges it poses to economies, human welfare, and the environment are evident in diverse geographical locations. Scientists have classified it into hydrological, meteorological, agricultural, and socio-economic drought, further emphasizing its global reach [1–7]. The accumulated water deficit and drought demand immediate attention from governments due to their significant impact on food security and population welfare. The European Commission (EC) and other organizations have taken action by preparing assessments of water losses. These documents underscore the importance of comprehensive management plans for each member of the European Union (EU) in order to conserve water resources. The Water Frame Directive (WFD) is the EU's primary regulation in this regard [8]. In 2007, the EC proposed the "Blueprint to Safeguard Europe's Water Resources" [9], which includes the analysis of the main challenges related to climate change and water scarcity and outlines actions to prevent and mitigate these phenomena's effects. In response to the EU members' need for significant progress in these areas, the EC proposed including the drought risk management plans in the River Basin Management Plans (RBMP) designed by each country [10].

Drought assessment can be conducted using suitable indices based on hydro-meteorological series and their analysis [11]. The Handbook of Drought Indicators and Indices [12], issued by the World Meteorological Organization (WMO) and the Global Water Partnership (GWP), is a comprehensive resource that provides the instruments for the assessment of drought severity. Other sources are also of interest. For example, 74 indices are reviewed in [3] out of 150 known [13].

The SPI is among the most used indices to assess drought, indicating the total rainfall departure from the mean for different periods and study sites based on a comparison with the historical long-term precipitation [14–18]. Given its advantages, which will be emphasized in the next sections, the SPI can be used to develop hazard risk indicators.

Hazard involves climate anomalies impacting drought, including temperature variability, rainfall, and evaporation [19]. Vulnerability represents the extent to which a system can be affected following the impact of a hazard. It includes all the physical, social, economic, and environmental conditions that increase the susceptibility of the respective system. Like hazard, vulnerability is an indicator of the future state of a system, defining the degree of ability or inability of the system to cope with the expected stress [20]. Risk is defined as the probability of the appearance of harmful outcomes arising from natural or anthropic-induced hazards interacting with vulnerable populations [21]. Given that the ultimate consequences of the drought are socio-economic [22,23], its monitoring is essential.

According to [24], about 30% of Romania experiences desertification and is characterized by a humid/dry to arid climate. Using the Expert Team on Climate Change Detection and Indices (ETCCDI), Birsan et al. [25] found that the number of summer days and tropical nights increased. The same behavior was noticed for warm spells, while in the frost season, it decreased. A decrease in agricultural production was noticed in 2010–2019 compared to the average values from the previous decade due to drought episodes. Dobrogea, the region investigated in this study, was the most affected by the temperature increase, shortage of precipitation, and lack of water in the soil [26]. Other studies [27–29] indicate that the temperature increased by 1.7 °C during 1965–2021 in Dobrogea, which has faced severe drought over the last 20 years. The evaluation of the trend of the series span from 1961 to 2018 recorded at Constanța meteorological station (situated in Constanța County, Dobrogea) indicates that the annual, quarterly, monthly, and seasonal minima and maxima data, except for those recorded in autumn, exhibit an increasing trend [29]. While the yearly maxima increased by about 1.3 °C, the augmentation is higher in spring (1.4 °C–1.6 °C) and summer (1.8 °C–1.9 °C) [29]. At the same time, the number of heavy precipitation events decreased, increasing the number of isolated days with moderate and heavy precipitation [30–32].

Located in the southeastern part of Romania, in the Dobrogea region, Constanța County is a significant contributor to the country's economy, particularly in agriculture and the tourism industry, due to its unique geographical position between the Danube and the Black Sea. The literature focuses on the analysis and forecast of the hydro-meteorological variables; no article has yet investigated the population exposure to the drought effect in the county. Exposure involves socio-economic, demographic, and agricultural dynamics [33], and is reflected in the population's well-being.

Therefore, the main objectives of this article are to analyze the aridity level at different locations in Constanța County and assess the risk of drought. The first goal is achieved by computing the de Martonne index, analyzing its trend, and the drought duration and intensity. The second goal is realized by computing the Drought Risk Index (*DRI*) built considering the climate and the socio-economic aspects. Despite the various studies performed for Romania, such an analysis has not been performed until now. It will shed light on the lesser-known aspects of the impact of drought in the region and could significantly aid authorities in making informed decisions to mitigate the effects of drought.

2. Materials and Methods

2.1. Study Area

Constanța County (Figure 1) is one of the most urbanized counties in Romania. Located in the country's southeastern part, it shares its northern border with Tulcea County. Their conventional border crosses the Casimcea Plateau and the Razim, Zmeica, and Sinoe Lakes complex. To the east is the Black Sea. On the western side, Constanța County is flanked by the counties of Călărași, Ialomița, Brăila, and the Danube River. The southern neighbor is Bulgaria.

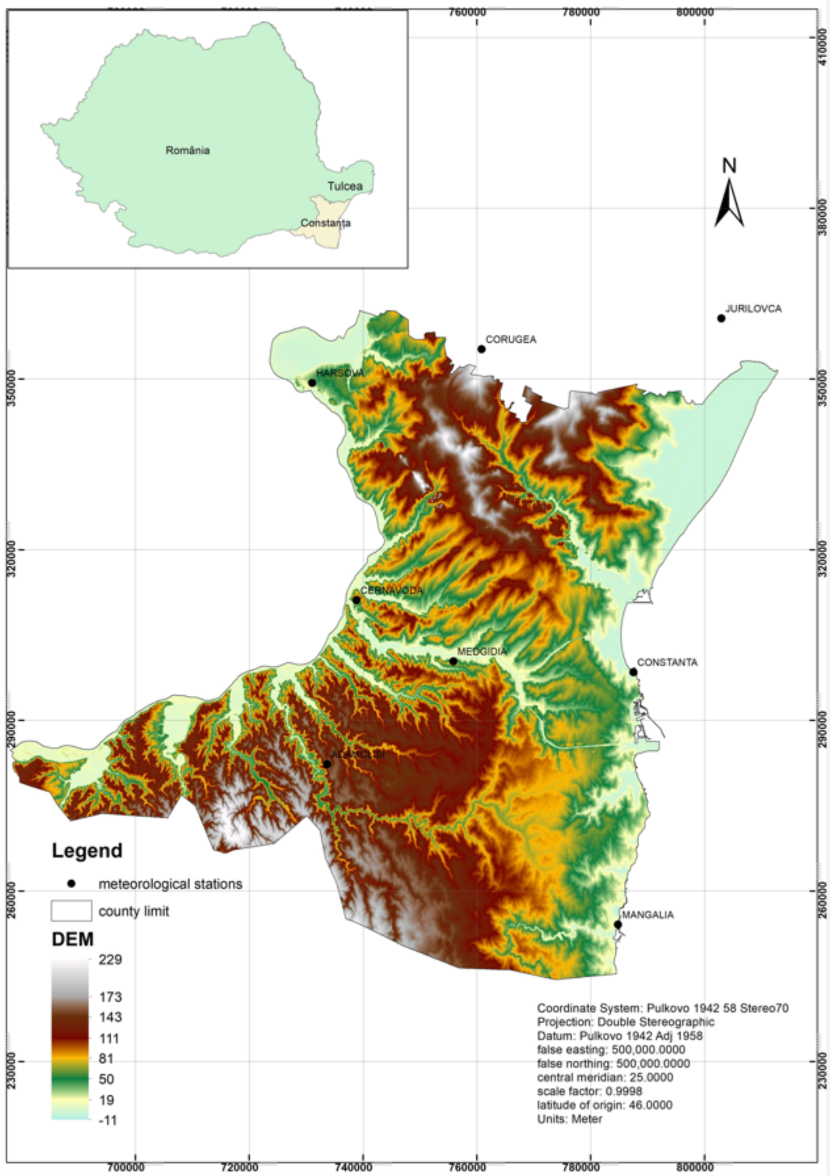


Figure 1. Map of Romania, with Constanța County and the meteorological stations.

Constanța County has predominantly low altitudes (about 200 m). The Măcinului Group, from the northern Massif of Dobrogea, represents the highest form of relief, reaching 467 m at the Pricopan peak. The Casimcea Plateau, with the highest hill of 300–350 m, is the orographic node from which the waters flow to the southwest, south, and southeast.

The Romanian climate is continental temperate, but the Danube Delta, the hydrographical basin Dobrogea (to which Constanța belongs), and the coastal waters give it some specific characteristics. The large water basins, the Black Sea, and the Danube River influence the quantity of precipitation in the area. During the study period, the average multi-year temperature was 11 °C. The precipitation amount is among the lowest in the country. However, over time, the Black Sea has produced exceptional cyclones in Constanța County, which has determined national records of precipitation that still stand today. The Black Sea has substantially impacted the climate, characterized by mild winters. Moderate precipitation and temperature were recorded in autumn and summer.

The Danube River, particularly in the Chiciu–Isaccea sector, the Danube Delta, and the Dobrogea Hydrographic Basin, is a significant water source. The total surface water resources represent approximately 404,136.4 million m^3/year, with the Danube contributing about 12.71% of the total resources. Four important reservoirs, with a volume of about 24.45 million m^3, are found in the Dobrogea Hydrographic Area. The water resources stored in the Dobrogea area are reduced and unevenly distributed in time and space, posing a potential challenge for effective water resource management [34,35]. There are also a few lakes, with salinity ranging from 0.45 g/L at Siutghiol to 75–95 g/L at Techirgiol [36].

2.2. Data Series

The data series used in this study are the monthly precipitation and temperature series recorded during 1965–2018. The National Administration of Meteorology, the Constanța branch, provided the data series recorded at six meteorological stations (Figure 1): Adamclisi, Cernavodă, Constanța, Hârșova, Mangalia, and Medgidia. Unfortunately, the data for the period 2018–2023 are not accessible to the general public.

The average multiannual temperature and precipitation for the investigated period are presented in Table 1. The temperature is higher on the coast (Constanța and Mangalia) than in the rest of the territory, and the precipitation varies between 435 and 500 mm [28,30].

Table 1. Temperature and precipitation- multiannual average during 1965–2018.

Station	Altitude (m)	Temperature (°C)	Precipitation (mm)
Adamclisi	159	11.1	501
Cernavodă	87	11.4	487
Medgidia	72	11.2	456
Hârșova	38	11.2	435
Constanța	14	12.1	453
Mangalia	9	11.7	446

2.3. Methodology

The first research stage was the computation of the annual de Martonne aridity index, I_{DM} [mm/°C], to assess the aridity level at the studied places. The formula used for this aim is [37]

$$I_{DM} = P/(T + 10), \quad (1)$$

where P [mm] is the annual precipitation and T [°C] is the average annual temperature in the region obtained at the previous stage.

The drought intensity is evaluated using the de Martonne index as follows: Hyper-arid if $I_{DM} \in [0, 5)$, Arid (A) if $I_{DM} \in [5, 15)$, Semi-arid (SEA) when $I_{DM} \in [15, 24)$, Moderately arid (MA) for $I_{DM} \in [24, 30)$, Slightly arid (SLA) when $I_{DM} \in [30, 35)$, and Moderately humid for $I_{DM} \in [35, 40)$ [38,39].

Furthermore, we tested the existence of a monotonic trend of IDM against randomness using the Mann–Kendall test [40]. When the randomness hypothesis was rejected, we determined the slope of the linear trend using Sen's slope method [41].

According to the Sendai definition [42], risk includes hazard and vulnerability. Based on this, the methodology proposed aims to estimate the Drought Risk Index (*DRI*) by evaluating the Drought Hazard Index (*DHI*) and Drought Vulnerability Index (*DVI*), in the following stages (Figure 2).

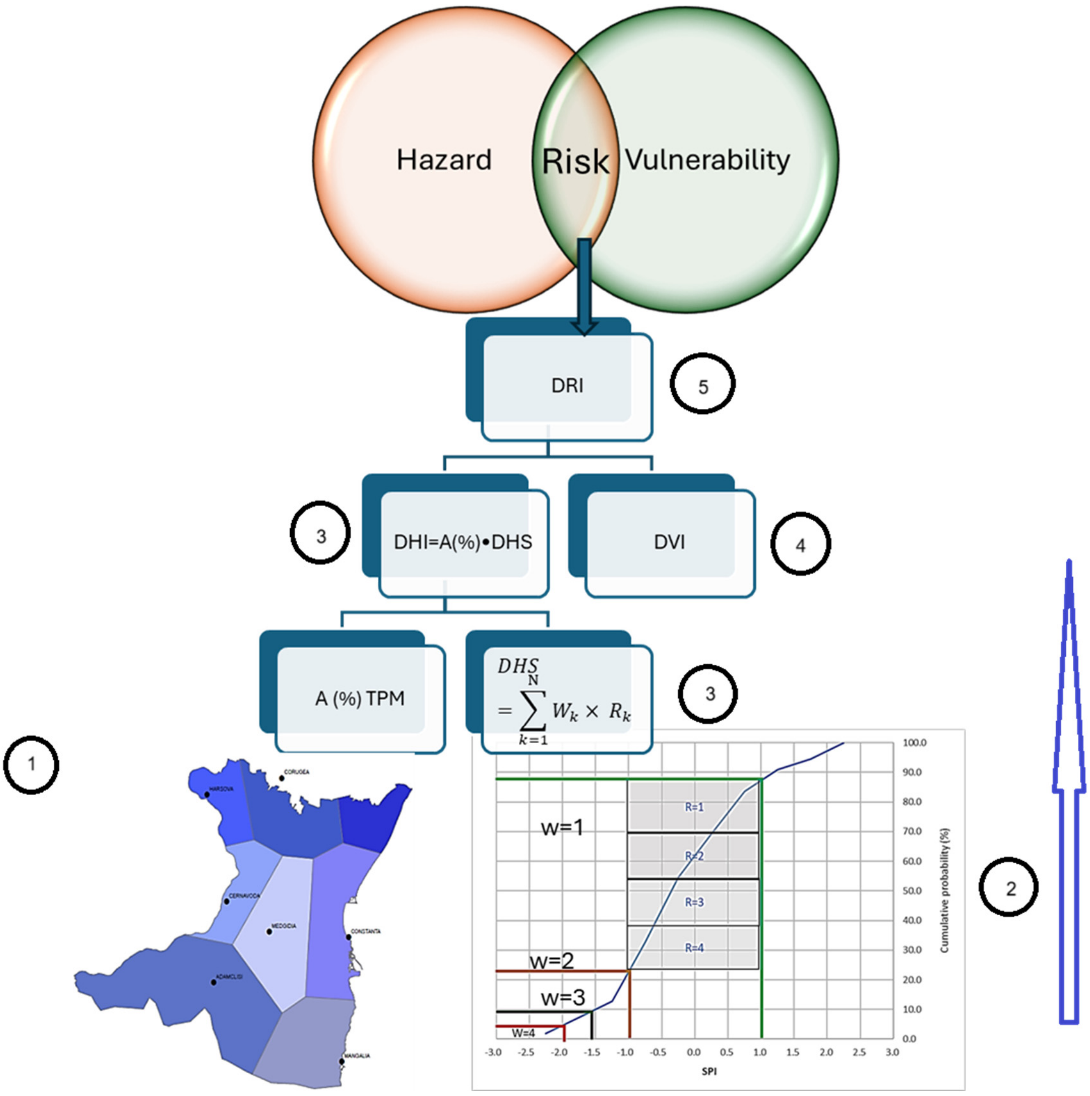


Figure 2. *DRI* index computation—from bottom to top. *A* (%) is the area assigned by the Thiessen Polygon Method. *DHS* is the Drought Hazard Score. *DVI* is the Drought Vulnerability Index.

1. Apply the Thiessen Polygon Method (TPM) to determine the area associated with each station and compute the regional temperature and precipitation.

To this aim, each station is connected by the closest neighbor by lines whose perpendicular bisectors are drawn. The result is a set of polygons, each containing a station. The weight assigned to a station is equal to the ratio between the area of the designated zone and the region's whole area [43,44]. The study area's average temperature (precipitation) is a weighted average of the values recorded at the stations.

2. Compute the *SPI* [45] for a certain period using the precipitation series as input.

First, we fit a gamma distribution to the precipitation series. Then, we determine the cumulative distribution. Then, the cumulative probability, $G(x)$, is determined. Then, the adjustment for the probability of the accumulation zero precipitation is performed by the formula proposed by Edwards and McKee [46], so the cumulative probability will be

$$H(x) = q + (1 - q)G(x), \quad (2)$$

where q is the probability of having null values in the series.

Finally, H is transformed into a standard Gaussian distribution, providing the *SPI* values. According to them, the type of climate can be assessed as follows: Extremely wet for $SPI > 2$, Very wet when $SPI \in [1.5, 2)$, Moderately wet for $SPI \in [1, 1.5)$, Normal drought (ND) for $SPI \in [-1, 1)$, Moderate drought (MD) for $SPI \in [-1.5, -1)$, Severe drought (SD) when $SPI \in [-2, -1.5)$, and Extreme drought (ED) when $SPI < -2$.

Guttman [47] suggested using at least 20 years of monthly records, but the best results are obtained with a series of 50–60 years [48]. Other authors [49,50] appreciate that *SPI* proved its effectiveness in studying long drought or high humidity periods.

The advantages of using this index consist of the following [49]:

- Flexibility: It can be calculated for various time intervals.
- Early warning: The index availability for shorter periods (e.g., one to three months) can help detect drought early and evaluate its severity.
- Cross-location comparison: It allows comparing different locations with varying climates.
- Probabilistic analysis: The index's probabilistic nature enables the analysis of past events, making it suitable for decision-making.

However, there are some drawbacks to using this index:

- Reliance on rainfall records: The index is solely based on rainfall data.
- Lack of soil water ratio component: It does not account for evapotranspiration/potential evapotranspiration (ET/PET) ratios [51].

Since the computation is not easy, different programs were developed, such as the *SPI* [52] and DrinC software [53,54]. We used the last one for this study.

3. Compute the Drought Hazard Index (*DHI*) in the following steps [55]:

- Determine the Drought Hazard Score (*DHS*) for each station, *i*, with the formula

$$DHS = \sum_{k=1}^{N} W_k \times R_k \tag{3}$$

where *N* is the number of *SPI* values for each time interval, *W* is the weight, and *R* is the rating score. The weights are given in correlation to SPI values: $W = 0$ when $SPI > 1$; $W = 1$ for ND, $W = 2$ for MD, $W = 3$ for SD, and $W = 4$ for ED. The ratings (R) are assigned based on the cumulative distribution function (CDF) (Figure 2). Their values are from 1 to 4 in ascending order, based on the quartiles of CDF within each drought category.

- Compute the Drought Hazard Index (*DHI*) by

$$(DHI)_i = A(\%)_i \times (DHS)_i \tag{4}$$

where *A* (%) is the area assigned by the TPM to each station.

- Normalize the *DHI* using Formula (5), presented below in a general context.

The hazard intensity is evaluated as follows: Reduced when $DHI \in [0, 0.25)$, Moderate for $DHI \in [0.25, 0.50)$, High if $DHI \in [0.50, 0.75)$, and Very high when $DHI \in [0.50, 0.75)$.

4. Compute the Drought Vulnerability Index (*DVI*).

Vulnerability is closely related to a region's socio-economic conditions and is a potential indicator of maximum loss or harm during an event. Given the impact on the population, accurate vulnerability assessments to reflect drought scenarios at the local level are urgently needed in the context of climate change. Therefore, selecting the vulnerability indicators must be relevant to the studied hazard and the regional context [56,57].

In this study, the following socio-economic indicators were utilized to determine *DVI*: the Total Agricultural Land (TAL), the Population Density (PD), the Water Consumption (m^3) per Inhabitant (WA) in each city, and the Built Environment (TC). Each indicator was normalized (in its range), then the average was calculated to obtain the *DVI* value.

The vulnerability intensities and the vulnerability classes are the same as for *DHI*.

In all cases when normalizing was necessary, it was performed using the following formula [58]:

$$X_i = \frac{x_{max} - x_i}{x_{max} - x_{min}}, \quad (5)$$

where x_i is the actual value, X_i is the normalized value of x_i, and $x_{min}(x_{max})$ is the minimum (maximum) values in the set subject to the normalizing procedure.

5. Compute the Drought Risk Index (*DRI*).

DRI is defined as the product between *DHI* and *DVI*. If *DHI* = 0 or *DVI* = 0, there is no risk. The degree of risk is evaluated using the same classes as for *DHI*.

3. Results

The annual de Martonne aridity index computed for the study period for the six stations is presented in Figure 3.

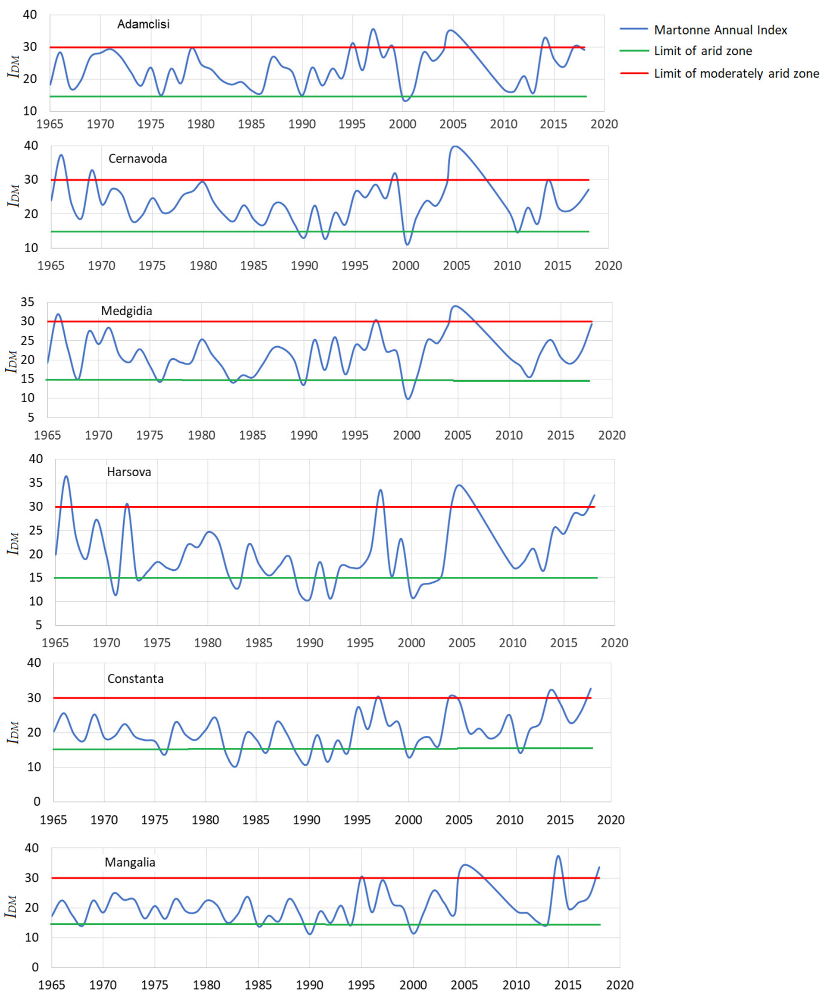


Figure 3. The de Martonne annual aridity index. The red line is the upper limit of the moderately arid zone, the green one is the upper limit of the arid zone, and the blue curve represents the values of the de Martonne annual index.

For Adamclisi, the index values are included (with one exception) in the interval 15–35, indicating a variation between the Slightly arid and Semi-arid climate, with periodic changes from Semi-arid to Arid periods, followed by the reverse behavior. Cernavodă (situated near the Black Sea—Danube Canal) experienced higher variations in the climate, especially after 2000. We notice a passage from an arid period towards a moderately humid one (in 2005), followed by a movement in the opposite direction to the limit of the arid zone (in 2011), and a return inside the "limits" of the semi-arid to moderately arid climate. A similar variation for 2000–2018 is noticed at Medgidia, Hârșova, and Mangalia. The variation of the index, e.g., of the drought episodes, is the lowest at the Black Sea Littoral sites in the Arid–Semi-arid boundaries, at least for the first 35 years covered by this study.

The results of the Mann–Kendall test rejected the hypothesis that there is a monotonic trend for all but the Constanța series, for which an increasing trend with the Sen's slope of 0.09048 was determined (emphasizing increasing aridity at this location).

Figure 4 presents the Thiessen polygons for the precipitation series. The average regional precipitation and temperature computed by TPM are 430.66 mm and 11.3 °C, respectively.

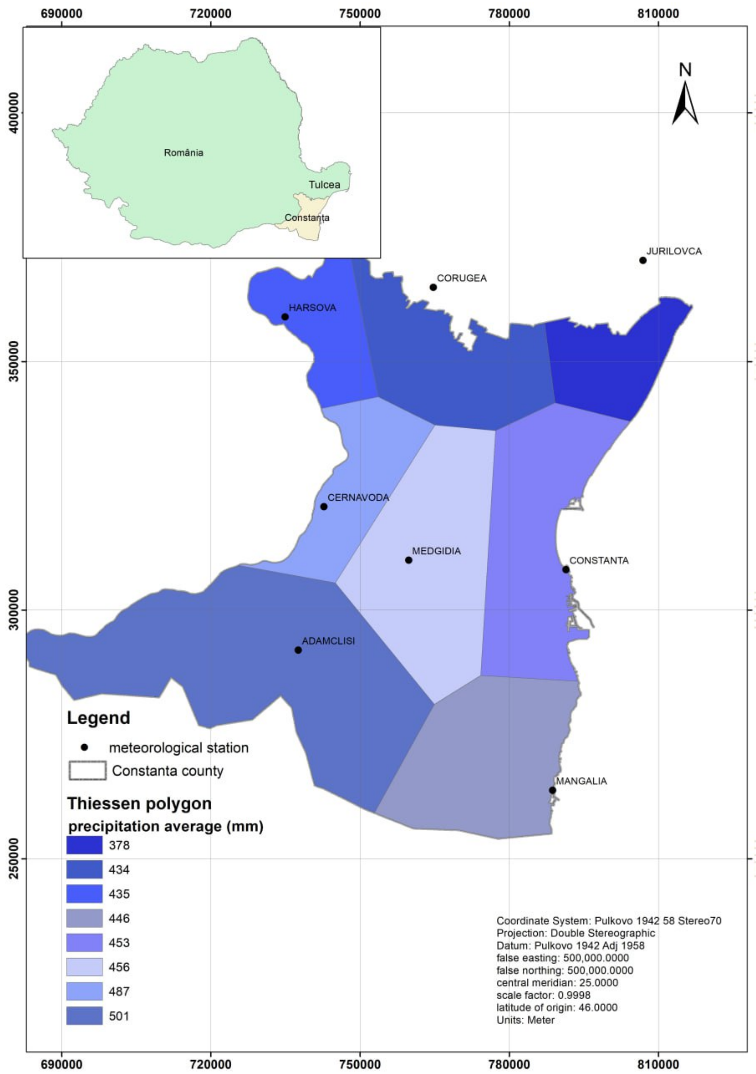


Figure 4. The results of TPM for the precipitation series.

The monthly precipitation series was the input data series for calculating the SPI. DrinC software allows the computation of *SPI* for various intervals (3, 6, 9, 12, 24, or 48 months). Nonetheless, this article focuses on the *DRI* obtained using the *SPI* computed at three months (December, March, June, and September) and 12 months because it is more relevant for monitoring irrigation systems.

The MegaStat Addin in Excel was employed to determine the frequency distribution and cumulative frequencies of the *SPI* values. Figure 5 shows a histogram built using the series Adamclisi for December, and Tables 2 and 3 present the absolute and cumulative frequencies (computed at three months), respectively, together with the classification corresponding to each interval and its weight.

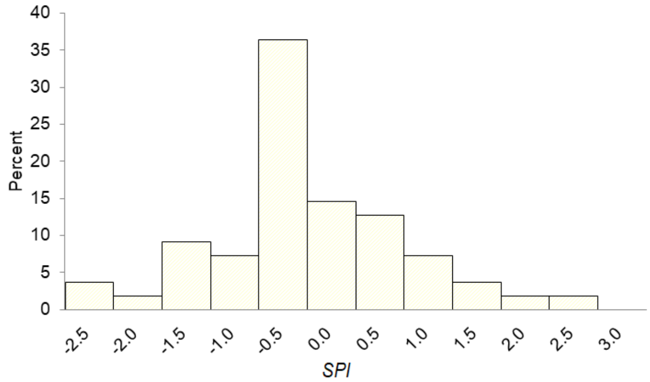


Figure 5. Histogram of SPI for December, at Adamclisi.

Table 2. Absolute frequencies (at 12 months) at five stations.

Interval	Cernavodă	Medgidia	Hârșova	Constanța	Mangalia	Class	W
<−2	2	3	1	1	2	Extreme	4
[−2.0, −1.5)	1	2	4	2	1	Severe	3
[−1.5, −1.0)	6	4	3	7	5	Medium	2
[−1.0, 1.0)	39	40	38	35	41	Normal	1
[1.0, 1.5)	4	3	3	5	2		
[1.5, 2.0)	1	1	5	3	1		
>2	2	2	1	2	3		

Table 3. Cumulative frequencies (%) computed at 12 months at five stations.

Interval	Cernavodă	Medgidia	Hârșova	Constanța	Mangalia	Class	W
<−2	3.64	5.45	1.82	1.82	3.64	Extreme	4
[−2.0, −1.5)	5.45	9.09	9.09	5.45	5.45	Severe	3
[−1.5, −1.0)	16.36	16.36	14.55	18.18	14.55	Medium	2
[−1.0, 1.0)	87.27	89.09	83.64	81.82	89.09	Normal	1
[1.0, 1.5)	94.55	94.55	89.09	90.91	92.73		
[1.5, 2.0)	96.36	96.36	98.18	96.36	94.55		
>2	3.64	5.45	1.82	1.82	3.64		

DHS was computed using Formula (3), and *DHI* was determined at three months using Equation (4). The surface (A) calculated by TPM and percentage surface A(%) were used to obtain *DHI* from *DHS*. The values listed in Table 4 were obtained for December. The columns of Table 4 contain, from left to right, the location (column 1), the rating for Normal, Medium, Severe, and Extreme drought (columns 2–5), *DHS* (column 6), the surface and percentage surface (columns 7 and 8), *DHI* computed by (4) (column 9), and *DHI* Normalized computed by (5) (column 10).

Considering the classification presented in the Materials and Methods section, we found that the drought hazard is very high at Cernavodă, Hârșova, and Mangalia. It is reduced at Adamclisi, moderate at Constanța, and high at Medgidia. The results are in concordance with those of the de Martonne aridity index, which indicates the highest extremes (over 35) at Cernavodă, Hârșova, and Mangalia and abrupt variations in time.

Table 4. Computation of *DHS* and *DHI* for December.

Location	Normal	Medium	Severe	Extreme	*DHS*	A	A (%)	*DHI*	*DHI* Normalized	Class
Medgidia	78.20	3.60	3.60	3.60	110.60	1200.00	0.17	18.69	0.51	High
Adamclisi	70.90	7.30	0.00	5.40	107.10	1900.00	0.27	28.66	0.00	Reduced
Cernavodă	70.90	9.10	1.80	3.60	108.90	590.40	0.08	9.05	1.00	Very high
Hârșova	67.30	7.30	5.50	1.80	105.60	871.92	0.12	12.97	0.80	Very high
Constanța	65.50	7.30	3.60	1.80	98.10	1600.00	0.23	22.10	0.33	Moderate
Mangalia	69.10	3.60	5.50	1.80	100.00	938.51	0.13	13.22	0.79	Very high

According to the DVI values are presented in Table 5, column 2, all stations but Constanța are highly or very highly vulnerable to drought. In turn, *DRI* classifies the Adamclisi and Constanța as having a low risk of drought and Medgidia as having a moderate risk of drought. Hârșova and Mangalia experience a high risk of drought, whereas Cernavodă experiences a very high risk (Table 5, last column).

Table 5. *DVI* and *DRI* for December.

Location	*DVI*	*DVI—Class*	*DRI*	*DRI—Class*
Medgidia	0.71	High	0.36	Moderate
Adamclisi	0.50	High	0.00	Low
Cernavodă	0.94	Very high	0.94	Very high
Hârșova	0.74	High	0.59	High
Constanța	0.40	Moderate	0.13	Low
Mangalia	0.86	Very high	0.68	High

The computation performed using *SIP* at three months (March, June, and September) provided almost similar results. Based on them, the drought vulnerability maps and hazard maps were built. Figure 6 displays the *DHI* and *DVI* maps drawn using the *SPI* indices computed at 3 months.

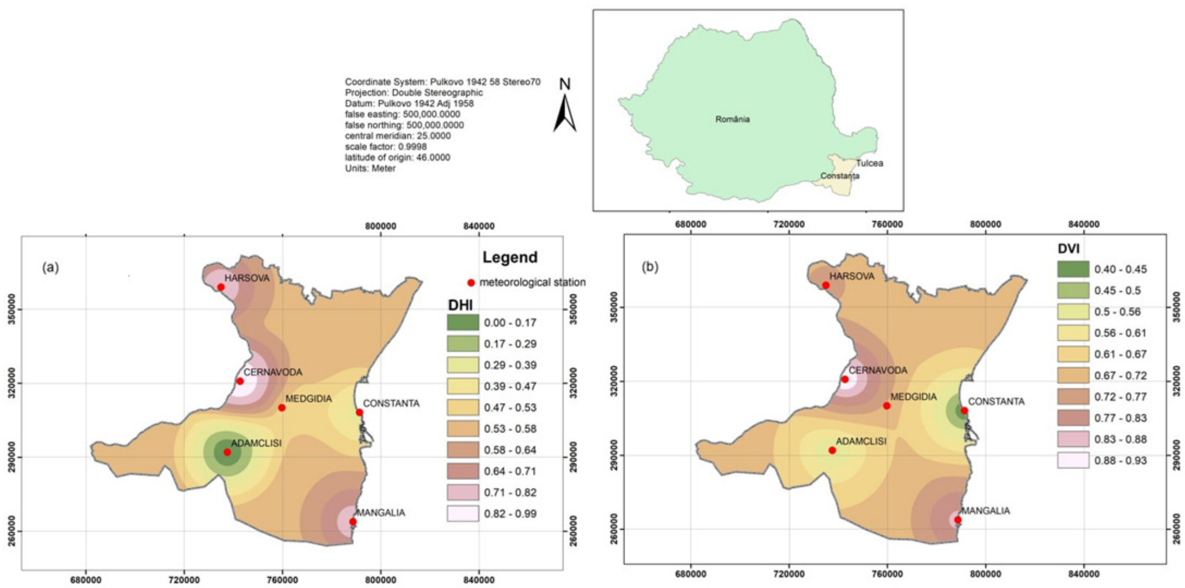


Figure 6. The maps of (**a**) DHI and (**b**) DVI built using the SPI index computed at 3-months.

We notice the uneven distribution of the drought hazard intensity, with the highest intensity appearing in the northwestern and southeastern parts of the region. A similar conclusion is drawn regarding vulnerability to drought.

Figure 7 (left) shows the DRI map built using the SPI computed at 3-months. It indicates the highest risk to drought at Cernavodă and the lowest at Constanța and Adamclisi. The DRI varied between 0.25 and 0.5, which means a medium risk in the rest of the territory. The results are concordant with the actual situation, given the water resources (surface and groundwater) from which both cities benefit.

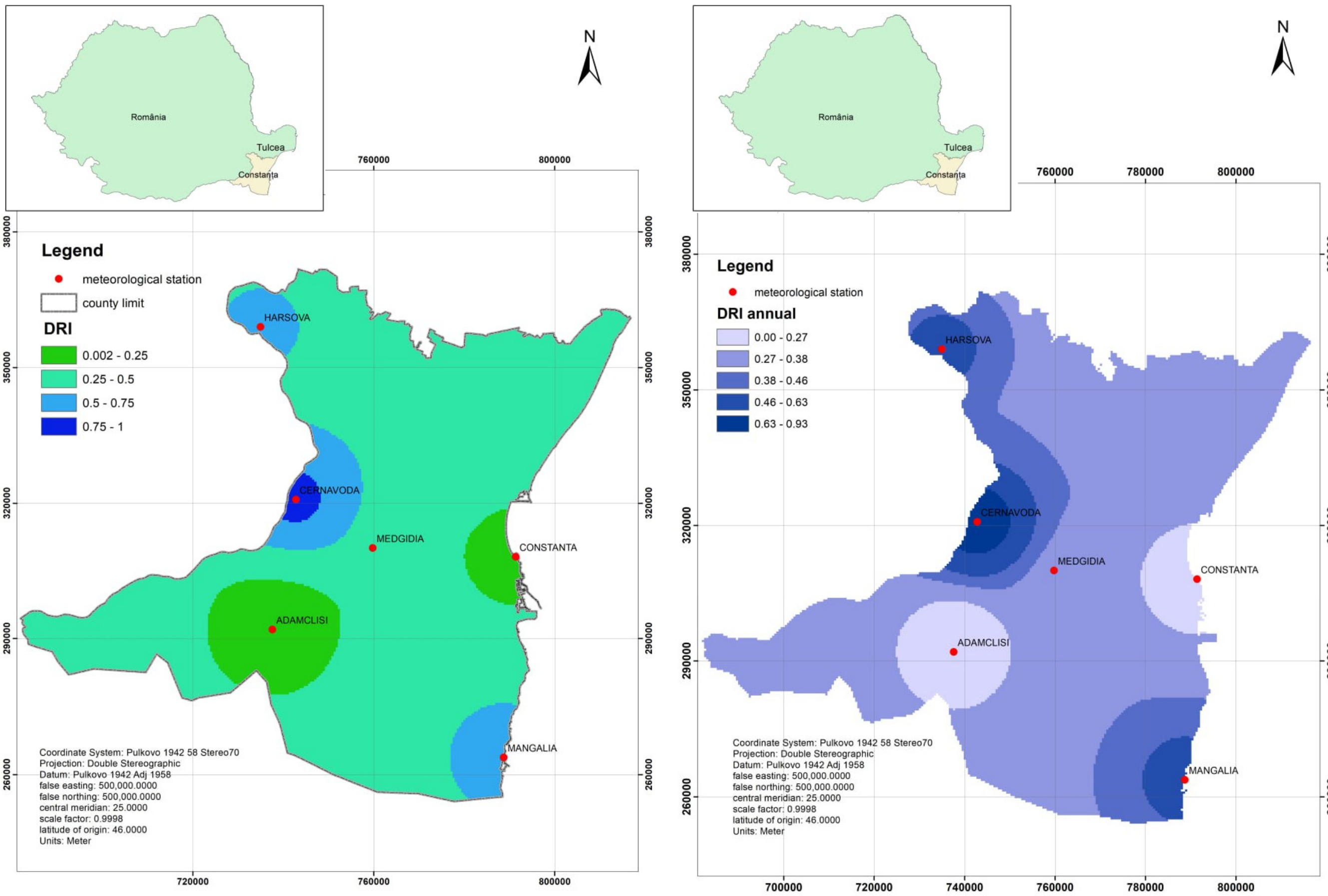


Figure 7. *DRI* map built using the SPI index computed at (**left**) 3-month and (**right**) 12-month.

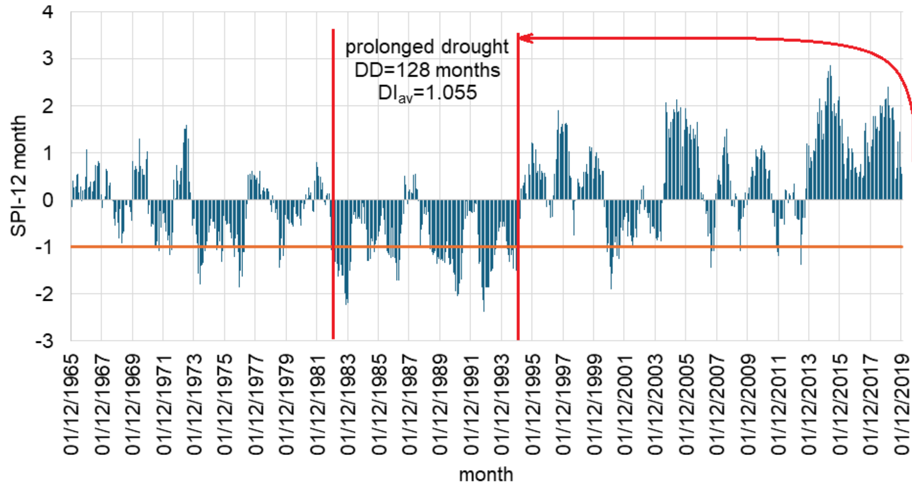
Applying the same method to compute the SPI for 12-month, we obtained the DRI map presented in Figure 7 (right). A slight attenuation in the maximum DRI values is noticed due to incorporating the seasonal effects (high rainfall, snowmelt) that balance the impact of the water deficit in some measure.

4. Discussion

The SPI computation allows one to determine the duration (DD), severity (DS), and intensity (DI) of drought. DD represents the number of months between the drought's start and its end. DS is the sum of the absolute values of the SPI during the period of drought. DI is obtained by dividing DS by DD [59].

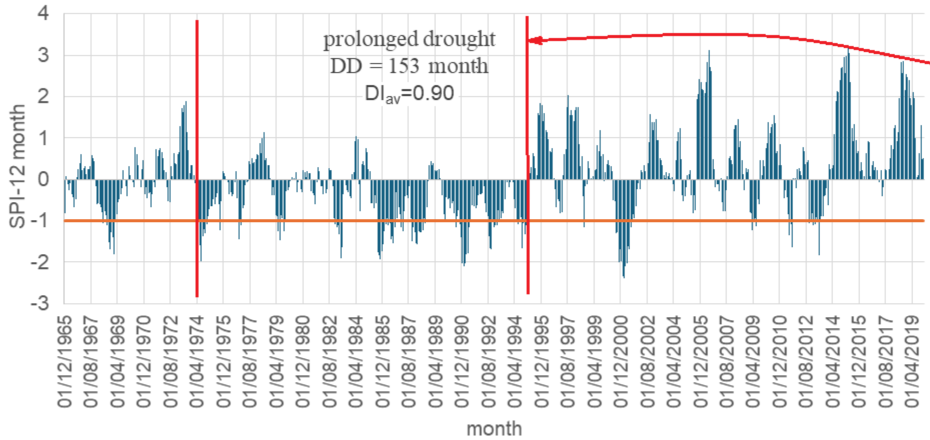
Prolonged drought can be assessed using DD. It is defined as a period where a pattern of precipitation deficiencies persists for more than six months.

The SPI 12-month is presented on the left-hand side of Figures 8 and 9 for Constanța and Mangalia. The right-hand side of the same figures and Table 6 show the values of DD, DS, and DI at all the studied stations. To compute DD, DS, and DI, we used only the drought events for which the SPI values are less than -1.



start_date	end_date	DD	DS	DI
1/8/1971	/1/81972	12	8.12	0.677
1/3/1974	1/6/1977	39	35.94	0.922
1/6/1979	1/3/1981	21	11.44	0.545
1/11/1982	1/8/1987	57	57.26	1.005
1/4/1989	1/3/1995	71	78.76	1.109
1/10/2000	1/1/2003	27	22.14	0.820
1/7/2007	1/11/2007	4	4.2	1.050
1/6/2009	1/10/2009	4	2.01	0.503
1/11/2011	1/5/2012	6	4.05	0.675
	max	71	78.76	1.109
	min	4	2.01	0.503

Figure 8. SPI-12 month DD, DS, and DI for Constanța. The yellow-highlighted region contains the periods that belong to the prolonged drought periods. Considering only the period included in the red rectangle, DD = 128 months, and the average drought intensity DI_{av} = 1.055.



start_date	end_date	*DD*	*DS*	*DI*
1/5/1968	1/8/1969	15	14.95	1.00
1/4/1974	1/11/1975	19	17.84	0.94
1/11/1976	1/7/1977	8	5.15	0.64
1/5/1979	1/3/1980	10	7.64	0.76
1/12/1982	1/1/1984	13	10.27	0.79
1/8/1985	1/11/1988	39	42.92	1.10
1/11/1989	1/3/1995	64	54.64	0.85
1/8/1998	1/11/1998	3	1.42	0.47
1/8/2000	1/3/2002	19	25.58	1.35
1/3/2009	1/9/2009	6	5.41	0.90
1/7/2011	1/10/2011	3	4.09	1.36
10/1/2012	1/1/2014	15	13.2	0.88
	max	64	54.64	1.36
	min	3	1.42	0.47

Figure 9. SPI-12 month, DD, DS, and DI for Mangalia. The yellow-highlighted region contains the periods that are included in the prolonged drought periods.

The number of drought events (NDE) was between 9 at Constanța and Cernavodă and 12 at Mangalia and Medgidia. The drought duration was between 3 months (at Mangalia and Cernavodă) and 71 months (at Constanța). The highest drought severity was 78.76 at Constanța, 65.61 at Medgidia, 54.64 at Mangalia, 50.94 at Adamclisi, 41.25 at Cernavodă, and 37.83 at Hârșova. The drought intensities varied in the intervals 0.503–1.109 at Constanța, 0.473–1.363 at Mangalia, 0.511–1.493 at Adamclisi, 0.438–1.602 at Hârșova, 0.307–1.687 at Medgidia, and 0.463–1.307 at Cernavodă.

The sums of highlighted DD values in the rectangles in Figures 8 and 9 give the prolonged drought duration at Constanța (128 months) and Mangalia (153 months). The corresponding average drought intensities are 1.055 and 0.905. Considering for Constanța the period 1 March 1974 to 1 March 1995, the number of months of prolonged drought will be 188, and the average drought intensity DI_{av} = 0.976.

Table 6 shows, highlighted in yellow, the intervals belonging to prolonged drought periods. Summing up the highlighted values in column 3, for each station, we obtain 106 at Adamclisi, 99 at Hârșova, 109 at Cernavodă, and 27 months at Medgidia. The average drought intensities for these prolonged drought periods were, respectively, 0.902, 1.059, 1.052, and 0.997. Thus, the highest average drought intensity for the prolonged drought periods was recorded at Constanța from 1 November 1982 to 1 March 1995.

Table 6. DD, DS, and DI for (**a**) Adamclisi, (**b**) Hârșova, (**c**) Cernavodă, and (**d**) Medgidia. The yellow-highlighted zones contain the periods included in the prolonged drought periods.

(a)	Start_Date	End_Date	*DD*	*DS*	*DI*
	1 December 1965	1 September 1966	9	4.60	0.511
	1 December 1967	1 May 1969	17	13.04	0.767
	1 March 1974	1 June 1975	15	20.32	1.355
	1 June 1976	1 September 1977	15	20.16	1.344
	1 May 1982	1 March 1984	22	15.81	0.719
	1 August 1984	1 September 1987	37	50.94	1.377
	1 May 1989	1 August 1989	3	1.66	0.553
	1 November 1990	1 March 1992	16	11.56	0.723
	1 October 1992	1 February 1995	28	15.68	0.560
	1 October 2000	1 September 2002	23	34.35	1.493
	1 July 2011	1 June 2014	35	32.30	0.923
		max	37	50.94	1.493
		min	3	1.66	0.511

(b)	Start_Date	End_Date	*DD*	*DS*	*DI*
	1 August 1971	1 September 1972	13	20.83	1.602
	1 November 1973	1 November 1975	24	21.91	0.913
	1 June 1976	1 May 1977	11	6.56	0.596
	1 July 1983	1 April 1984	9	9.61	1.068
	1 June 1986	1 March 1988	21	17.56	0.836
	1 June 1989	1 July 1991	25	37.83	1.513
	1 May 1992	1 March 1995	34	33.92	0.998
	1 July 1995	1 May 1996	10	5.97	0.597
	1 October 2000	1 May 2004	43	47.91	1.114
	1 April 2007	1 August 2007	4	3.78	0.945
	1 March 2009	1 July 2009	4	1.75	0.438
		max	43	47.91	1.602
		min	4	1.75	0.438

(c)	Start_Date	End_Date	*DD*	*DS*	*DI*
	1 January 1969	1 April 1969	3	1.39	0.463
	10 January 1973	1 July 1975	21	21.54	1.026
	3 January 1985	1 March 1988	36	36.91	1.025
	5 January 1989	1 March 1992	34	36.52	1.074
	6 January 1992	1 September 1995	39	41.25	1.058
	9 January 2000	1 August 2002	23	30.06	1.307
	10 January 2006	1 March 2009	29	25.05	0.864
	7 January 2011	1 May 2012	10	10.43	1.043
	5 January 2013	1 August 2014	15	12.99	0.866
		max	39	41.25	1.493
		min	3	1.39	0.511

(d)	Start_Date	End_Date	*DD*	*DS*	*DI*
	1 September 1968	1 July 1969	10	10.27	1.027
	1 March 1974	1 October 1974	7	9.03	1.290
	1 September 1975	1 June 1978	33	25.46	0.772
	1 June 1979	1 July 1980	13	9.03	0.695
	1 May 1982	1 June 1987	61	65.51	1.074
	1 July 1990	1 August 1991	13	17.53	1.348
	1 January 1994	1 October 1995	11	7.55	0.686
	1 August 2000	1 August 2002	24	40.48	1.687
	1 April 2007	1 September 2007	5	5.52	1.104
	1 January 2009	1 September 2009	8	9.03	1.129
	1 July 2012	1 August 2013	13	13.26	1.020
	1 June 2017	1 December 2017	6	1.84	0.307
		max	61	65.51	1.698
		min	5	1.84	0.307

The existence of drought in Dobrogea was less investigated. There are only a few historical references to such periods. Hepites [60] drew up a map of the precipitation regime based on the values recorded between 1884 and 1898, published in the Annales of the Meteorological Institute of Romania in 1900. The precipitation values for the period investigated by Hepites are 406 mm in Mangalia and 412 mm in Constanța. The southern zone recorded annual precipitations between 400 and 500 mm, while it varied between 500 and 600 mm in the inner territory. Hepites indicated that in 1986, an average of 279 mm of precipitation was recorded in Dobrogea. In Mangalia, there was 164 mm, in Hârșova 189 mm, and 261 mm in Constanța.

Otetelișanu and Elefteriu [61] drew a map of the rainfall distribution for 1891–1915. We note that the isohyet of 400 mm passed in the coastal area, the rest of the territory being located between the isohyets of 400 and 500 mm. In the document presented in the Bulletin of the Romanian Royal Society of Geography, pages 209–222, the two researchers noted the low rainfall on the Black Sea coast, considering that there were severe drought periods.

During the period investigated in this study, we determined periods of prolonged drought, but also shorter periods (2007, 2011–2013). They correspond to those determined by other authors [28,62,63]. Importantly, our results are concordant with those of Dobrica [28], who investigated hydrological drought based on the data series covering 1965–2005 (in the Nuntasi Lake basin, in Constanța County), using the Standardized Streamflow Index (SSFI). He found that after 1999, the SSFI had only negative values, indicating hydrological drought.

Different researchers indicated an increase in drought events in Europe. For example, Poljanšek [64] reported the augmentation of the meteorological drought frequency in southern and central Europe since 1950. Stahl et al. [65] and Gudmundsson et al. [66] found hydrological drought during 1950–2015 in the same European zones. In Belarus, drought events became more frequent after 1950 [67]. In a study covering the last 120 years, Ionita and Nagavciuc [68] pointed out after analyzing the SPEI12 index that most Central European and Mediterranean countries experience a significant drying trend. The results are similar to those of Vicente-Serrano et al. [69] based on the SPI12.

The study of Tsakiris and Vangelis [70] identified pan-European drought events in 1950–1952, 1953–1954, 1972–1974, and 2003, confirming some of our findings. The augmentation of average temperatures after the 1990s also increased the severity of drought events in southern Europe, especially in summer [71,72].

5. Conclusions

The present article investigated the intensity of drought and assessed the vulnerability to drought and the drought risk in Constanța County. It analyzed long-term data series collected at six meteorological stations within the county.

The de Martonne index values varied between slightly arid and arid zones at all stations. The results indicated a high and very high vulnerability to drought in most locations and a very high and high drought risk in half of them.

The number of drought events varied between 9 and 12, with durations from 3 to 71 months, and drought severities between 37.83 and 78.76. The prolonged drought duration above 99 months indicates the necessity to better investigate the extent of the drought for taking action to mitigate its effects.

To fully understand the drought's impact, one should compare the SPI for different periods and other drought indicators that emphasize the actual effects on plants and different parts of the economy. The SPI only measures water supply and does not consider evapotranspiration. Therefore, it cannot fully capture how higher temperatures affect moisture availability and demand. Additionally, it does not consider the precipitation intensity and its influence on streamflow, runoff, and water availability. Therefore, the research will be extended using other indices that incorporate evapotranspiration and take into account soil moisture, which is critical in evaluating agricultural drought and water stress. Since we currently do not have access to such data, we shall also use satellite data.

The present study used data from only six meteorological stations. The number of stations will be increased to extend the spatial resolution of the drought assessment and better capture the diverse geographical features of Constanța County. Moreover, more factors (such as agricultural resilience and yield losses, crop-specific vulnerabilities, and infrastructure) should be considered for building the DRI to reflect the drought risk better.

Both natural and human-made factors contribute to the triggering of risks, amplifying dryness and drought in various ways. Understanding the meteorological factors that lead to drought, like atmospheric circulation, is also essential. Therefore, these factors should be considered and analyzed to determine their impact on drought intensity. Based on these findings, forecast models should also be built.

Considering the study's results, we conclude that addressing the complex climatic risks in Dobrogea, such as dryness and drought, urgently requires a collaborative and interdisciplinary approach.

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