J. Geogr. Sci. 2015, 25(11): 1307-1327
DOI: 10.1007/s11442-015-1236-1

Climatic water balance dynamics over the last five decades in Romania's most arid region, Dobrogea

Georgeta BANDOC[1,2], Remus PRĂVĂLIE[1,2]

1. University of Bucharest, Faculty of Geography, Department of Meteorology and Hydrology, 1 Nicolae Bălcescu str., 010041, Bucharest, Romania;
2. Center of Coastal Research and Environmental Protection, University of Bucharest, 1 Nicolae Bălcescu str., 010041, Bucharest, Romania

Abstract: The analysis of a territory's climatic water balance dynamics against the background of climate change is a key component for increasing water resource management efficiency. The present study aims to analyse climatic water balance (CWB) dynamics in Romania's most arid region, Dobrogea, located in the southeast. The study covers the 1961–2009 period, and is based on annual and seasonal CWB values (mm), provided by nine weather stations located throughout the region. The study, based on statistical and GIS techniques, is divided into two main stages, both carried out at annual and seasonal scales – trend analysis using the Mann-Kendall test, the Sen's slope method, and CWB value distribution type analysis. In order to identify the probabilistic types of distributions, four mathematical models were identified–*Pearson*, *Gamma*, *Chi-Squared* and *Wakeby*, statistically verified with the P-P Plot, Q-Q Plot and Probabillity Difference Graph (PDG) curve tests. Thus, in terms of trends, the results showed a deficit increase especially at the northern stations, mainly for annual values (with a peak in the northeast, where CWB rates reached –3.2 mm/yr). While general CWB declines occurred in winter, spring and summer, apparent decrease rates were found in the northern region (highest negative rates–summer, northwest, –1.4 mm/yr). Autumn is an exception, due to overall increase rates which peaked in the southwest (2.3 mm/yr). However, the entire trend analysis indicated a general lack of statistical significance. The distribution type histogram analysis showed that, annually and seasonally, deficit values are generally dominant (more noticeable in the northern region), except for the winter season, mainly characterized by surplus intervals. Thus, the results suggest a climatic water deficit increase over the last five decades especially in northern Dobrogea, which signals the need for a spatial prioritization targeting a more efficient water resource management, necessary first and foremost for increasing regional agricultural system productivity.

Keywords: Dobrogea; climatic water balance; temporal trends; Mann-Kendall; distribution types; water deficit; climatic changes

---

Received: 2013-12-18 **Accepted:** 2015-04-20

Author: Georgeta Bandoc, PhD and Professor, specialized in systemic analysis of the environment, climatology, renewable energy resources, interaction ocean – atmosphere. E-mail: geobandoc@yahoo.com
Remus Prăvălie, PhD Candidate, specialized in environmental and climatology research.
E-mail: pravalie_remus@yahoo.com

1 Introduction

Due to the notable climate changes which occurred over the last century, the main climatic parameters have undergone significant modifications in numerous regions. These parameters are mostly related to temperature and precipitation, but also evapotranspiration, which plays an essential role in the energy and mass cycles of the global atmospheric system (Sellers *et al*., 1997; Thomas, 2000; Fisher *et al*., 2008). Changes in evapotranspiration values, driven mainly by thermal variability, as well as by that of other important factors (solar radiation, wind, water vapor pressure etc.) (Cohen *et al*., 2002), play alongside rainfall dynamics an essential role in a territory's climatic balance variation (and, implicitly, in hydrological variation) (Jhajharia *et al*., 2009; Bandoc and Golumbeanu, 2010; Bandoc, 2012a; Bandoc *et al*., 2013; Xu *et al*., 2013; Prăvălie *et al*., 2014b; Zhao and Zhao, 2014).

Regarding the climatic water balance variation, on a global scale, a water deficit increase can be noticed especially in the regions which are affected by rainfall amount decreases, rising temperatures and, implicitly, increasing evapotranspiration. Regions presenting such apparent changes (mainly related to decreasing rainfall rates, as climate warming is generally confirmed on a global scale), especially in the second half of the 20th century, are Central America (certain areas), southern Europe, western and southern Africa, the Sahel, Middle East, parts of southern and eastern Asia and south-eastern Australia (IPCC, 2007).

Thus, in the context of the two climatic parameters' dynamics, an expansion of global drylands has been noticed over the past six decades (hyper-arid, arid, semiarid, and dry subhumid areas), and it is deemed possible that, by the end of this century, the world's drylands increase by 10% from the 1961–1990 climatological baseline (in terms of the ratio precipitation – potential evapotranspiration) (Feng and Fu, 2013). The issue becomes even more elaborate given that the land degradation process in global drylands is currently accelerating (severely degraded land occupies between 10% and 20% of the total drylands) (Reynolds *et al*., 2007), and it is estimated that they will expand extensively as a result of climate change and population increase-related anthropogenic pressure (Reynolds *et al*., 2007; Feng and Fu, 2013).

Therefore, in addition to the terrestrial ecosystems pressure as a result of water scarcity (Breshears *et al*., 2011; Glazer and Likens, 2012; Mertz *et al*., 2012), anthropogenic systems (especially agricultural ones) are among the most vulnerable components to the climatic water deficit typical for drylands (Dregne, 2002; Le Houérou, 2002; Eitzinger *et al*., 2003; Yang *et al*., 2008; Rockström and Karlberg, 2010; McDonald *et al*., 2011; Liu *et al*., 2013; Jiang *et al*., 2013; Prăvălie *et al*., 2014b). In the European region, but not exclusively, while climate changes (and, indirectly, water balance changes) had a negative impact on agriculture productivity (especially in semi-arid areas), the effects of climate change mostly depended on other variables such as pedological features, land use, but also economic, political and infrastructural conditions (Bouma *et al*., 1998; Olsen and Bindi, 2002; Reidsma *et al*., 2010; Olsen *et al*., 2011).

Romania is one of the states affected by global climate changes (Cuculeanu *et al*., 2002; Busuioc *et al*., 2010; Marin *et al*., 2014), with apparent effects on the humidity balance level (humidity deficit increase in numerous regions of the country), which indirectly affects agricultural productivity, especially in the highly vulnerable southern regions (Cuculeanu *et al*., 1999; Peptenatu *et al*., 2013; Prăvălie *et al*., 2013; Murărescu *et al*., 2014; Prăvălie *et al*., 2014b). It is expected that the potential future annual mean temperature rises, due to global warming, will increasingly influence the evapotranspiration regime (Marica and Busuioc, 2004), with direct consequences on water balance levels, by accelerating the water deficit.

Southern Romania is currently the most strongly affected region by the effects of global warming (aridity and drought), and the Dobrogea region is the most representative example. In terms of humidity balance, the mean multiannual water deficit values (1900–2000 period) generally exceed –300 mm threshold (Păltineanu *et al.*, 2007), but for the heavily drought and aridity-affected years, in the eastern part the annual mean values exceed the critical threshold of –550 mm (Păltineanu *et al.*, 2009; Prăvălie and Bandoc, 2015), thus making Dobrogea the most arid climatic region of the country.

The present study analyzes the climatic water balance temporal dynamics, in seasonal and annual regimes (trends and distribution types), in Romania's most arid region, Dobrogea, using statistical and GIS techniques. The study aims to carry out a complex analysis of this indicator's dynamics, with the ultimate goal of providing climate information which is primarily relevant for ensuring a better water resource management for agricultural systems which, in this semi-arid/dry sub-humid region of the country, largely depend on climatic conditions.

2 Data and methods

2.1 Study area

Dobrogea is situated in south-eastern Romania, with the Danube River bordering its western (up to Romanian Plain) and northern extremities (Ukrainian border), the Black Sea, its eastern limit, and the Bulgarian border delimiting the south side (Figure 1a). It is roughly situated between 43°44′2″–45°26′55″N and 27°16′40″–29°43′17″E. It covers approx. 15,500 km^2 (Prăvălie and Bandoc, 2015) and comprises three main landform units: the Dobrogea plateau (most of the analyzed area), the Razim-Sinoe lagoon complex (northeastern central part) and the Danube Delta (northeast) (Figure 1a).

With regard to climate peculiarities, the 1961–2009 temperature, potential evapotransiration (Thorntwaite method), rainfall and climatic water deficit mean multiannual values show noticeable differences between the nine analyzed stations (Table 1). Mean multiannual temperatures range between 10.1 and 11.8°C, while rainfall and potential evapotranspiration values range from 257.5 to 535 mm, and from 639.2 to 700.9 mm respectively (Table 1). Therefore, the available data for the study period points to a considerable mean multiannual deficit, which varies throughout the study area from –165.9 to –424.2 mm (Table 1).

Thus, in terms of climate, Dobrogea is known to be the most arid region of the country, and numerous specialized studies confirm this particularity (Păltineanu *et al.*, 2000; Păltineanu *et al.*, 2007; Maftei and Bărbulescu, 2008; Păltineanu *et al.*, 2009; Marinică and Văduva, 2010; Lungu *et al.*, 2011; Croitoru *et al.*, 2013; Prăvălie and Bandoc, 2015). The main causes for the high aridity conditions are due to certain specific features such as the high influence of Eurasian anticyclones throughout the year (humidity deficit generators), the Black Sea influence, which plays an important role in the genesis of coastal thermal inversions (precipitation formation inhibitor), and the fact that the analyzed region is located at the extremity of oceanic influences in Romania (Drăghici, 1988; Bogdan, 2005).

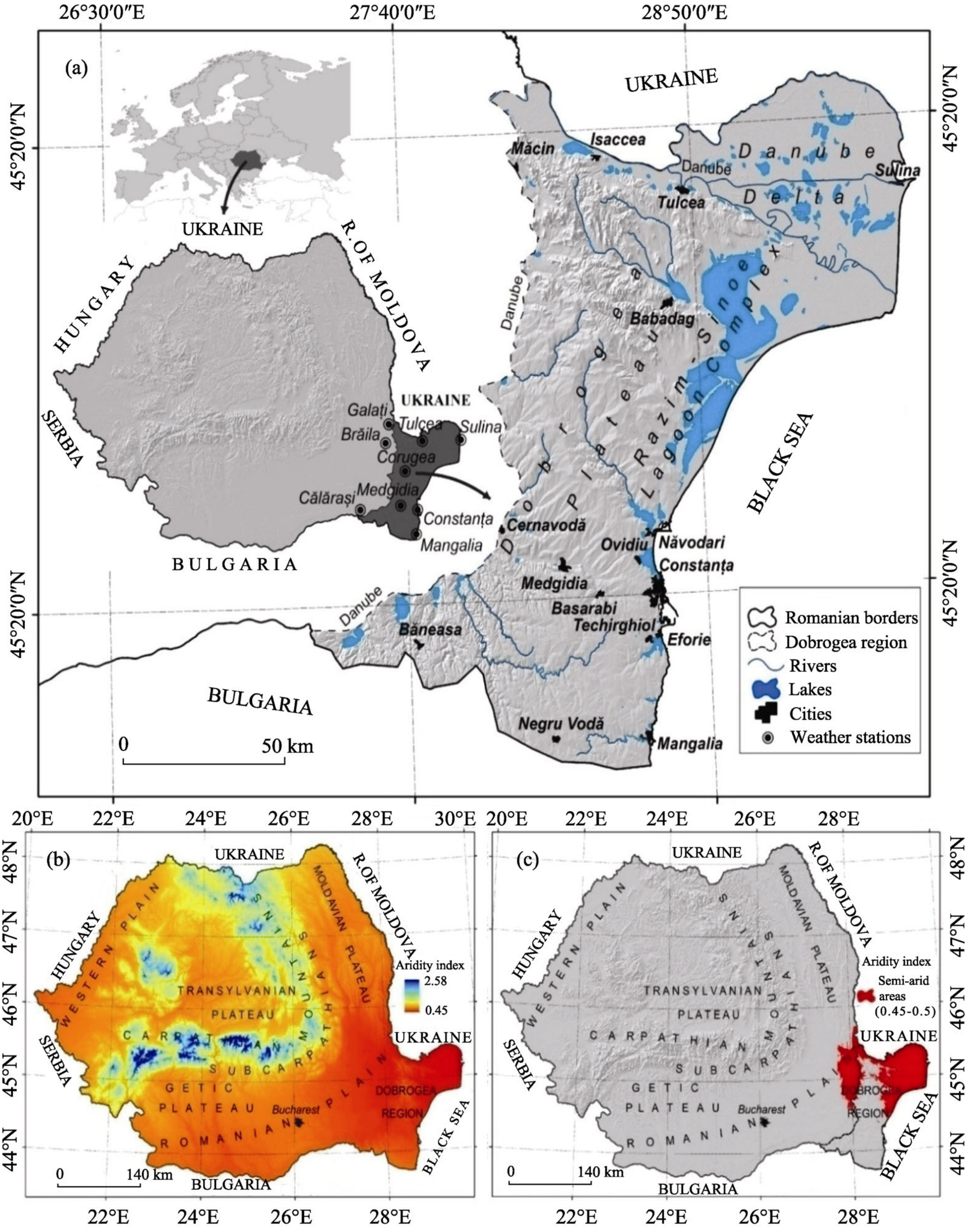


Figure 1 Dobrogea's location in Romania (a); spatial representation of the UNEP Aridity Index (mm/mm) for Romania (b) and semi-arid southeastern areas (c) (data processed after Trabucco and Zomer, 2009)

Spatially, according to the values of the Global Aridity Index, or UNEP Aridity Index (Trabucco and Zomer, 2009), Dobrogea (and adjacent territories from the north-west) is the region with the highest degree of aridity in Romania (considering the relation between precipitation and potential evapotranspiration), corresponding to the 0.2–0.5 (mm/mm) value range of the index, which indicates a semi-arid climate in north (as in Romania the minimum values reach 0.45, semi-arid areas are located between 0.45–0.5 mm/mm) (Figures 1b and 1c); the 0.5–0.65 (mm/mm) value range of the index is also important in terms of climatic restriction, as it indicates a dry sub-humid climate in the central-southern region. This index, developed on a global scale at a high spatial resolution (30 arc seconds or ~1 km at equator), indicates that semi-arid areas in Romania (south-eastern region) total approx. 9000 km^2, which cover about 4% of the country's territory (238,391 km^2). Thus, approx. 70% of semi-arid areas (~6300 km^2) overlap the study region, Dobrogea (Figure 1c).

Table 1 Mean multiannual values (1961–2009) for temperature, rainfall, potential evapotranspiration (PET), and climatic water deficit (CWD) at the nine analyzed weather stations

Weather stations	Latitude	Longitude	Altitude (m)	Temperature (ºC)	Rainfall (mm)	PET (mm)	CWD (mm)
Galați	45°28′23″	28°01′56″	70.4	10.8	487.2	671.7	–184.5
Brăila	45°12'24"	27°55′11″	15	10.8	452.3	671.1	–218.8
Tulcea	45°11′26″	28°49′26″	5	11.2	460.5	676.9	–216.4
Sulina	45°08′54″	29°45′32″	3	11.6	257.5	681.7	–424.2
Corugea	44°44′04″	28°20′31″	220.4	10.1	429.8	639.2	–209.4
Călărași	44°12′52″	27°20′18″	19.9	11.8	535.0	700.9	–165.9
Medgidia	44°14′35″	28°15′05″	70.7	11.2	452.9	671.7	–218.8
Constanța	44°12′49″	28°38′41″	13	11.8	424.0	687.7	–263.7
Mangalia	43°48′58″	28°35′14″	7.2	11.6	425.9	676.4	–250.5

Therefore, given that Dobrogea, especially in the plateau area, is one of the country's important agricultural regions (of the total study area, agricultural land covers nearly 60%) (CLC, 2006), the climatic water balance dynamics analysis in this region is particularly relevant, especially due to the fact that, over the past two decades, agriculture has become largely dependent on climatic conditions, due to the country-wide collapse of irrigation systems after 1990, a year which marked a major political transition (Prăvălie *et al.*, 2014b). The study can also be of ecological use, as it covers the Danube Delta region, the third largest delta in Europe (~3500 km² in the Romanian sector) (Vespremeanu, 2000; Gâştescu and Posea, 2005), and one of the world's most important wetlands in terms of biodiversity.

2.2 Climate data

In order to analyze the climatic water balance temporal dynamics, temperature and precipitation parameters were used from nine regional weather stations – Galati, Brăila, Tulcea, Sulina, Corugea, Călăraşi, Medgidia, Constanța and Mangalia (Figure 1a); while these meteorological stations were selected so that they cover the analyzed region uniformly (although three stations, Galați, Brăila and Călărași, are located in the immediate vicinity of Dobrogea's western outer limit, they can be considered as representative for the study area, given the nature of the climatic parameters and their extensive spatial influence), the selection was also determined by climate data availability. The data were obtained and processed from European ECA&D database (European Climate Assessment & Dataset) (Klein Tank *et al.*, 2002), for Galați, Tulcea, Sulina, Călărași and Constanța, while the National Meteorology Administration (NMA) provided the information for Medgidia, Mangalia and partly for Brăila (NMA, 2012). For the Brăila station, the data were processed after Vişinescu *et al.* (2003) (period: 1961–2002), and supplemented with data provided by the National Meteorology Administration (period: 2003–2009) (NMA, 2012).

2.3 Methodology

In order to analyze the seasonal and annual climatic water balance (CWB), based on the relationship between precipitation (P) and potential evapotranspiration (CWB = P – PET), the annual and monthly potential evapotranspiration (PET) data were extracted using temperature data, through the Thornthwaite method (Thornthwaite, 1948) which is considered to be the most appropriate for Romanian territory (Păltineanu *et al.*, 2007). Therefore, computing the potential evapotranspiration was based on the following formula (The climate of Romania, 2008):

$$PET = 16 \cdot \left(\frac{10t}{I} \right)^{\alpha} F(\lambda),$$

where t is mean monthly temperature (°C),

I–annual thermal index based on the relation: $I = \sum_{n=1}^{12} i_n$, $i_n = \left(\frac{t}{5} \right)^{1.514}$,

$$\alpha = 6.75 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.49 \quad \text{and}$$

where $F(\lambda)$ is adjustment term depending on latitude and month.

Although the Thornthwaite methodology has certain drawbacks with regard to evapotranspiration–summer underestimation and winter overestimation (Carrega, 1994)–, due to the fact that certain parameters which influence the evapotranspiration mechanism are not taken into account (e.g. wind speed), the Thornthwaite methodology presents the major advantage of requiring minimal data and providing satisfactory results. Thus, although the Penmann-Monteith method, recommended by FAO (Allen *et al.*, 1998), is not used in this study due to the unavailability of detailed climatic data, the Thornthwaite method is considered to be representative for Romania, and it is the most widely used method in the country for estimating PET values (Păltineanu *et al.*, 2007; Bandoc, 2012a; Bandoc *et al.*, 2014).

After obtaining the PET values, the CWB (mm) dynamics analysis was divided into two major phases–trend analysis and probabilistic distribution type analysis, both performed for annual and seasonal values, namely for winter (December – February), spring (March – May), summer (June – August) and autumn (September – November). For the CWB temporal trend analysis for the 1961–2009 time frame, GIS and statistical data processing methods were used in seasonal and annual regimes. Thus, the monthly and annual data were processed using the grid vector representation method (Cheval *et al.*, 2003), adapted for the present study using the *Spline* point grid data interpolation method (Prăvălie *et al.*, 2014c).

Additionally, the Mann-Kendall nonparametric test and the Sen's slope method were used for trend statistical analysis (Salmi *et al.*, 2002), as these are among the most widely employed statistical methods for climatic parameter trend analysis (Xu *et al.*, 2006; Zhao *et al.*, 2007; Yang *et al.*, 2010; Fan *et al.*, 2012; Jiang *et al.*, 2012; Liu *et al.*, 2012; Piticar and Ristoiu, 2012; Xia *et al.*, 2012; Fan *et al.*, 2013; Shifteh Some'e *et al.*, 2013). The trend analysis was performed using the Excel MAKESENS application, developed by the Finnish Meteorological Institute (Salmi *et al.*, 2002), which operates with two types of statistical analyses (used in this study in their basic form), namely monotonic increase/decrease trend analysis (Mann-Kendall test), and linear trend slope analysis (Sen's slope estimate method – Q) (Salmi *et al.*, 2012). The test operates with four thresholds of trend statistical significance, i.e. $\alpha = 0.001$, $\alpha = 0.01$, $\alpha = 0.05$ and $\alpha = 0.1$.

In order to complete this systemic approach related to water balance temporal dynamics, the annual and seasonal probability distributions were identified (second phase of the study). Moreover, the equations describing the probability density were mentioned, using the *Pearson, Gamma, Chi-Squared* and *Wakeby* mathematical models, which are based on the following relations:

1) the *Pearson* distribution is described by the function

$$f(CWB) = \frac{\exp\left(-\beta/(CWB-\gamma)\right)}{\beta\cdot\Gamma(\alpha)\left((CWB-\gamma)/\beta\right)^{\alpha+1}},$$

where α is continuous shape parameter ($\alpha > 0$), β is continuous scale parameter ($\beta > 0$), and γ is continuous location parameter ($\gamma \equiv 0$ yields of the two-parameter Pearson 5 distribution). Domain $\gamma \leqslant CWB < \infty$;

2) the *Gamma* distribution is described by the function

$$f(CWB) = \frac{CWB^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp\left(-\frac{CWB}{\beta}\right),$$

where α is continuous shape parameter ($\alpha > 0$), β is continuous scale parameter ($\beta > 0$), γ is continuous location parameter ($\gamma \equiv 0$ yields of the two-parameter Gamma distribution), and Γ is Gamma Function. Domain $\gamma \leqslant CWB < \infty$;

3) the *Chi-Squared* distribution is described by the function

$$f(CWB) = \frac{CWB^{\frac{\upsilon}{2}-1}\exp\left(-\frac{CWB}{2}\right)}{2^{\frac{\upsilon}{2}}\Gamma\left(\frac{\upsilon}{2}\right)},$$

where υ is degree of freedom (positive integer), and Γ is Gamma Function;

4) the *Wakeby* distribution is described by the function

$$CWB(F) = \zeta + \frac{\alpha}{\beta}\left(1-(1-F)^{\beta}\right) - \frac{\gamma}{\partial}\left(1-(1-F)^{\delta}\right),$$

where α, β, γ, ∂ and ζ are all continuous. The following conditions are imposed:

$\alpha \neq 0$ or $\gamma \neq 0$, $\beta+\delta > 0$ or $\beta=\gamma=\delta=0$, if $\alpha=0$, then $\beta=0$, if $\gamma=0$, then $\delta=0$, $\gamma \geqslant 0$ and $\alpha+\gamma \geqslant 0$.

Domain: $\zeta \leqslant CWB < \infty$ if $\delta \geqslant 0$ and $\gamma > 0$; $\zeta \leqslant CWB \leqslant \zeta + \frac{\alpha}{\beta} - \frac{\gamma}{\delta}$ if $\delta < 0$ or $\gamma = 0$.

Finally, the correctness of the chosen theoretical distributions was verified using the PP Plot and Q-Q Plot curves, and also the Probability Difference Graph (PDG) (Wilk and Gnanadesikan, 1968; Michael, 1983; Parzen, 1993).

It should also be noted that, prior to completing the two stages of the study, the multivariate functional relationship between CWB and the constituting parameters (rainfall and PET) was analysed, through the smoothing loess technique (Wen, 2011; Hancock and Hutchinson, 2006), which is necessary in order to verify the existence of a high functional dependence between the three variables at all analysed stations. This nonparametric method is used for estimating local regression surfaces which remove roughness caused by the conflicting influence of random factors. The smoothing level series would represent the result of major continuity factors, decisive for the water balance evolution of the analyzed series for each station (Cleveland, 1979; Craven and Wahba, 1979; Hurvich, 1988). The chosen smoothing model is bivariate quadratic, and only the best characteristics of each data set are kept. The method is based on the closest neighbor algorithm, where the bigger the number, the higher the smoothing level. The surface smoothing is performed using the Renka I procedure (Renka, 1996).

3 Results

The multivariate modeling method (smoothing loess technique), used in order to highlight the functional relationship (from 1961 to 2009) between the climatic water balance (CWB), atmospheric precipitation (P) and potential evapotranspiration (PET), demonstrated that there is a high functional dependence between the three variables at all analysed stations, with one exception (Figure 2).

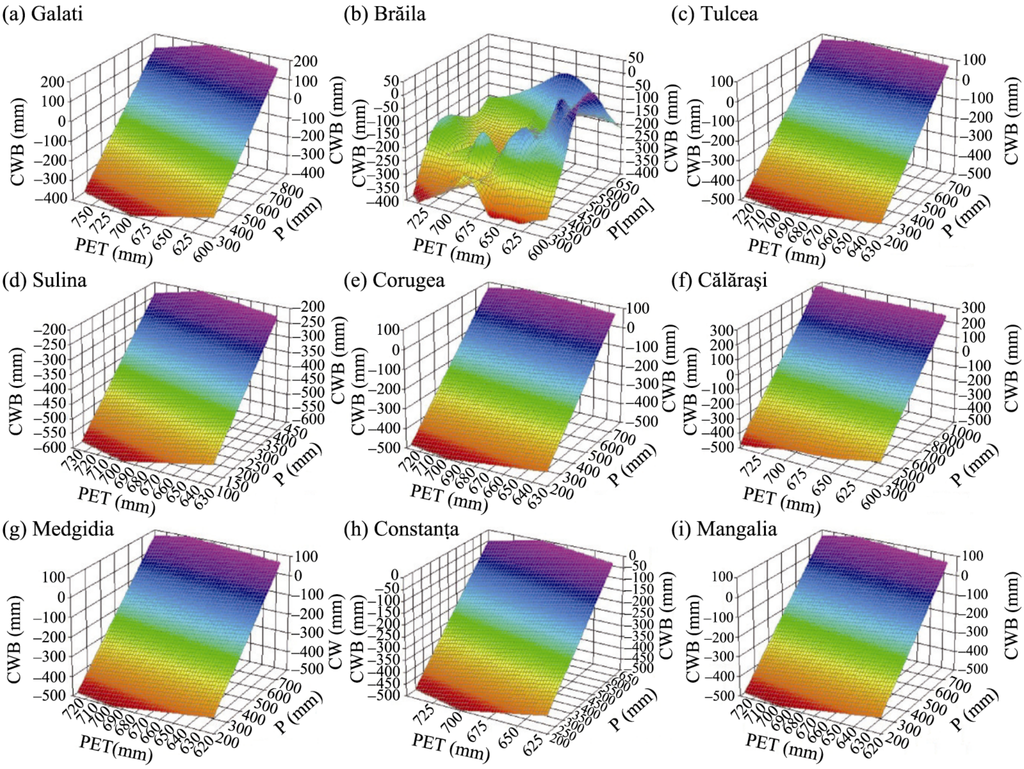
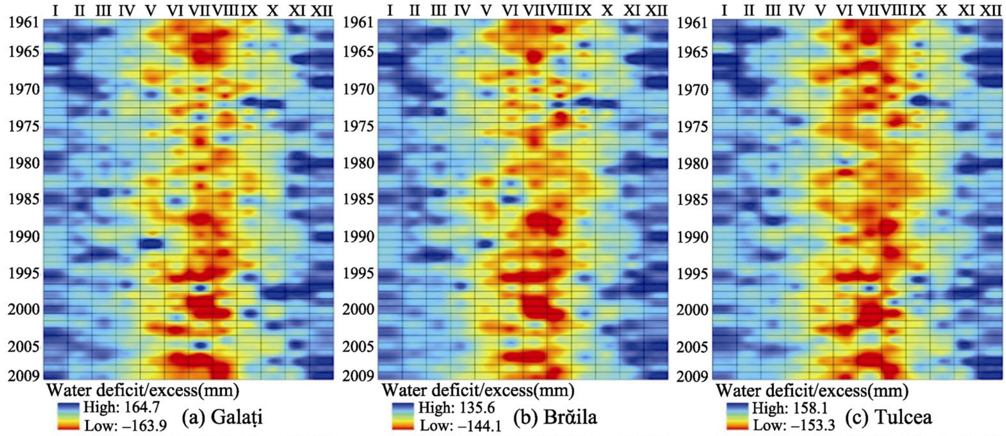


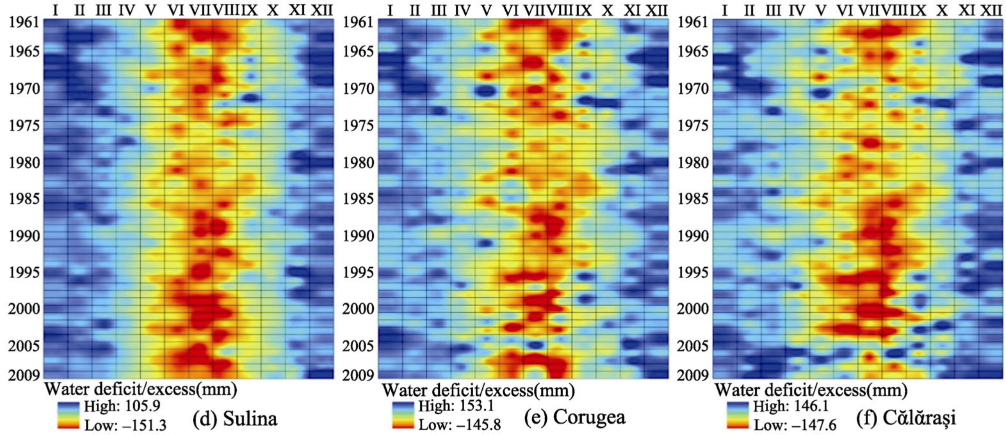
Figure 2 Multivariate smoothing loess surface summarizing the functional dependence between atmospheric precipitations (P) and the climatic water balance (CWB), in connection with the potential evapotranspiration (PET) variation for the 1961–2009 time-frame, at all analyzed weather stations

Therefore, it was noticed that the variation coefficient value (r^2) for the three variables is 1 (or very close to 1) for all weather stations, except for Brăila station, where the r^2 value is 0.6 (in this case, there may be some discrepancies between the data sets recorded by two different sources). Also, the relational matrix illustrates the manner in which humidity deficit flow for each of the analyzed stations evolves in close connection with atmospheric precipitation and PET variations (the humidity deficit increase is generally determined by rainfall decrease and PET increase) (Figure 2).

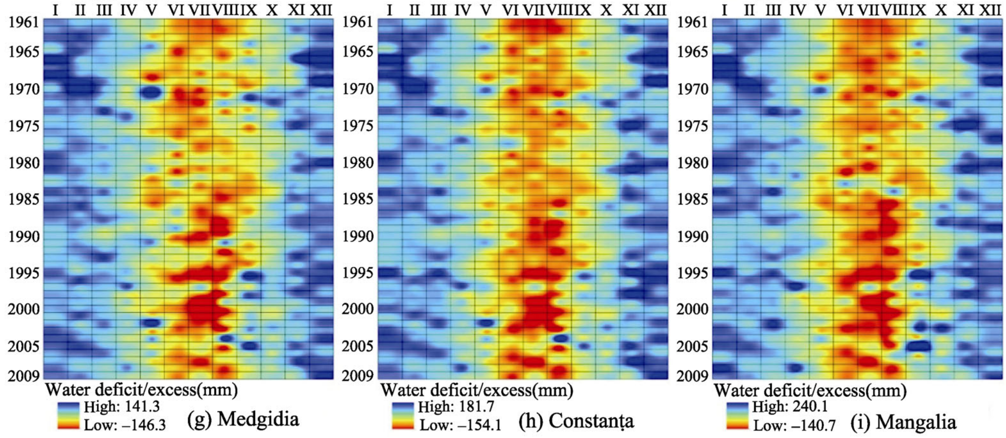
Regarding the assessment of the overall CWB index dynamics, the vectorized grid analysis of monthly values reveals an apparent increase climatic water deficit, especially during the summer months, as evidenced by the more nuanced colours mainly corresponding to the months of June, July and August (Figure 3).



(a) Galați (b) Brăila (c) Tulcea



(d) Sulina (e) Corugea (f) Călărași



(g) Medgidia (h) Constanța (i) Mangalia

Figure 3 Climatic water balance monthly value dynamics between 1961 and 2009, at the nine weather stations

This becomes highly noticeable after 1985 at all nine weather stations, and remains constant up to the year 2009, with the exception of a short time interval (around the year 2005), characterized by low deficit levels (or even surplus) during the summer season (Figure 3).

Upon analysis of the graphic representation of annual and seasonal CWB variations and trends, particular cases can be noticed for each station and for each time scale. Annually, while the vectorized grid results reveal a clear deficit increase only at Sulina station (Figure 4), the Mann-Kendall test results indicate decreases at four (Galați, Brăila, Tulcea and Sulina) of the nine analysed stations, of which only one was statistically significant (Sulina) (Table 2).

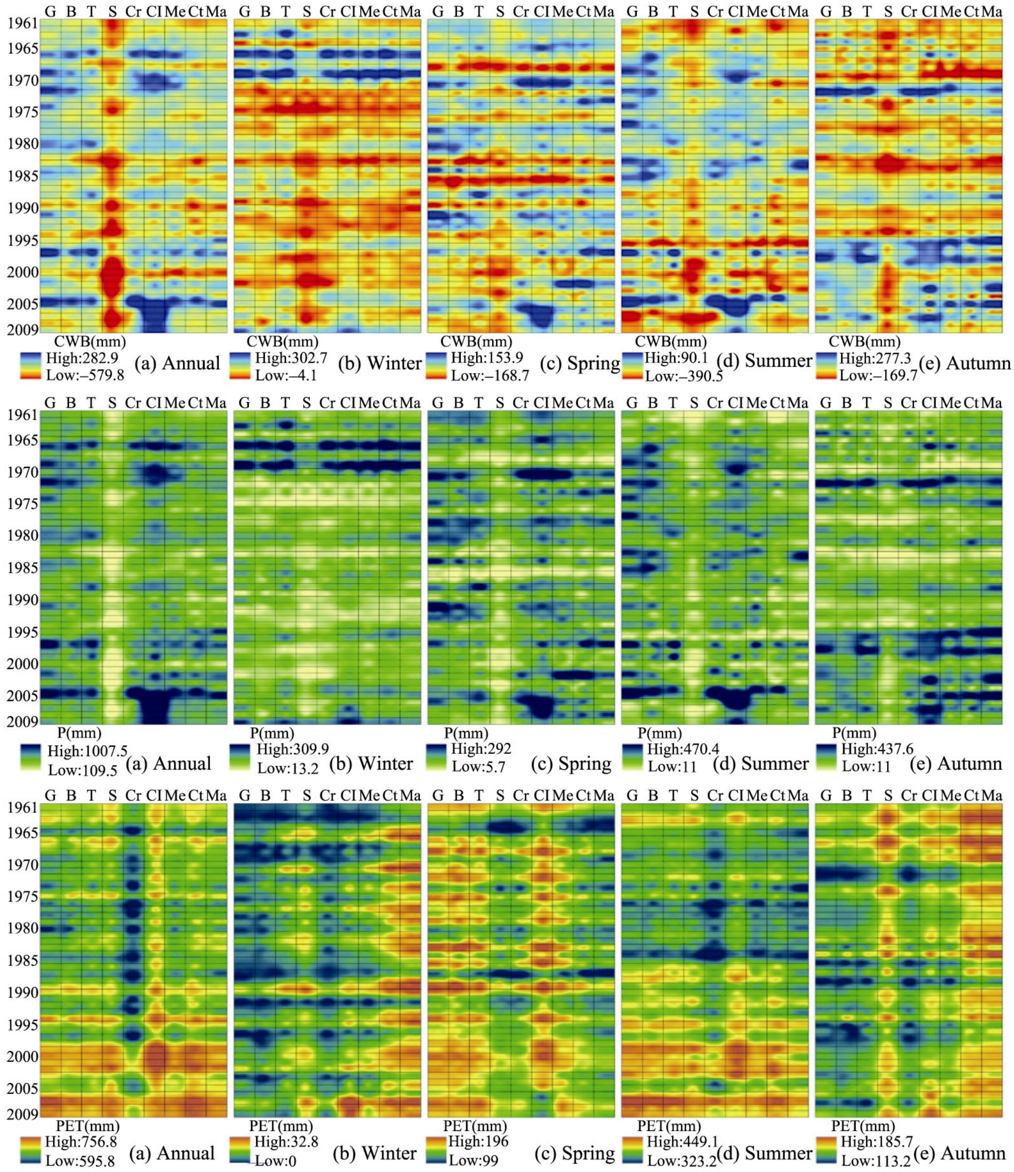


Figure 4 Climatic water balance (CWB)/precipitation (P)/potential evapotranspiration (PET) annual and seasonal value dynamics (1961–2009 period), at the Galați (G), Brăila (B), Tulcea (T), Sulina (S), Corugea (Cr), Călărași (Cl), Medgidia (Me), Constanța (Ct) and Mangalia (Ma) weather stations

Table 2 Trends characteristics (1961–2009 period), resulting from the Mann-Kendall test / Sen's slope method, in annual (A) and seasonal (W – winter, Sp – spring, Su – summer, Au – autumn) climatic water balance (CWB), precipitation and potential evapotranspiration (PET) values at the nine weather stations (G–Galați, B – Brăila, T – Tulcea, S – Sulina, Cr – Corugea, Cl – Călărași, Me – Medgidia, Ct – Constanța, Ma – Mangalia)

		Weather stations	G	B	T	S	Cr	Cl	Me	Ct	Ma
CWB (mm)	A	Test Z	–0.99	–1.80+	–0.04	–3.37***	0.16	0.82	0.35	0.39	0.44
		Sen's slope (yr)	–1.00	–1.74	–0.06	–3.22	0.11	1.67	0.38	0.47	0.33
		Sen's slope (49 yrs)	–49.12	–85.23	–2.73	–157.57	5.22	81.82	18.69	23.06	16.36
	W	Test Z	–0.01	–0.59	–1.28	–3.03**	–1.28	0.49	–0.92	–0.39	–1.44
		Sen's slope (yr)	–0.04	–0.26	–0.79	–0.86	–0.55	0.18	–0.46	–0.13	–0.47
		Sen's slope (49 yrs)	–1.88	–12.54	-38.52	–41.91	–26.94	8.81	–22.38	–6.49	–23.18
	Sp	Test Z	–0.84	–1.49	–0.78	–2.44*	0.56	0.56	–0.03	0.42	–0.18
		Sen's slope (yr)	–0.39	–0.85	–0.43	–0.79	0.24	0.39	–0.02	0.18	–0.08
		Sen's slope (49 yrs)	-19.00	–41.61	-21.17	–38.77	11.88	18.95	–0.78	8.92	–3.99
	Su	Test Z	–1.11	–1.49	0.20	–2.22*	–0.06	–0.51	–0.27	–0.80	–0.58
		Sen's slope (yr)	–0.97	–1.37	0.15	–1.16	–0.07	–0.45	–0.17	–0.46	–0.35
		Sen's slope (49 yrs)	–47.37	–67.04	7.30	–56.88	–3.63	–22.04	–8.3	–22.71	–16.95
	Au	Test Z	1.18	2.44*	1.75+	–0.80	1.47	2.70**	1.53	1.41	1.72+
		Sen's slope (yr)	0.90	1.41	1.14	–0.35	0.95	2.26	0.97	0.82	0.98
		Sen's slope (49 yrs)	43.89	69.20	55.82	–16.93	46.47	110.79	47.34	40.30	47.99
Precipitation (mm)	A	Test Z	–0.09	–0.95	0.53	–3.15**	1.09	1.47	1.42	1.42	1.22
		Sen's slope (yr)	–0.16	–0.82	0.57	–2.32	0.90	2.21	1.44	1.43	1.08
		Sen's slope (49 yrs)	–7.90	–40.26	27.82	–113.76	43.93	108.37	70.62	70.22	53.00
	W	Test Z	0.10	–0.65	–1.16	–2.58**	–1.12	1.01	–0.76	–0.30	–1.12
		Sen's slope (yr)	0.04	–0.22	–0.70	–0.80	–0.51	0.46	–0.33	–0.11	–0.42
		Sen's slope (49 yrs)	2.10	–11.00	-34.31	–39.03	–25.11	22.61	–15.96	–5.62	–20.51
	Sp	Test Z	–0.22	–1.12	–0.29	–2.24*	0.87	0.59	0.44	0.95	0.09
		Sen's slope (yr)	–0.11	–0.41	–0.18	–0.54	0.44	0.36	0.29	0.38	0.05
		Sen's slope (49 yrs)	–5.39	–19.93	–8.78	–26.65	21.34	17.56	14.36	18.56	2.35
	Su	Test Z	–0.51	–0.82	1.41	–1.26	1.22	0.16	0.99	0.64	1.03
		Sen's slope (yr)	–0.35	–0.62	0.61	–0.49	0.55	0.13	0.56	0.35	0.49
		Sen's slope (49 yrs)	-17.15	–30.48	30.04	–24.11	26.86	6.41	27.36	16.99	23.84
	Au	Test Z	1.39	2.32*	1.46	–1.14	1.25	2.97**	1.39	1.21	1.59
		Sen's slope (yr)	0.82	1.21	1.02	–0.39	0.75	2.40	0.83	0.74	0.78
		Sen's slope (49 yrs)	40.36	59.22	49.99	–19.33	36.58	117.55	40.61	36.10	38.16
PET (mm)	A	Test Z	3.23**	2.58**	3.04**	2.58**	2.32*	3.09**	3.09**	3.61***	3.30***
		Sen's slope (yr)	1.01	0.70	0.64	0.70	0.70	0.67	0.90	1.04	0.86
		Sen's slope (49 yrs)	49.50	34.47	31.22	34.34	34.54	33.07	43.86	50.80	42.12
	W	Test Z	2.34*	1.10	0.78	1.87+	1.88+	3.15**	1.63	1.41	0.96
		Sen's slope (yr)	0.11	0.03	0.04	0.11	0.07	0.23	0.11	0.09	0.07
		Sen's slope (49 yrs)	5.22	1.23	2.02	5.59	3.28	11.07	5.52	4.39	3.58
	Sp	Test Z	1.75+	1.18	1.30	1.35	0.91	–0.51	1.72+	2.32*	1.94+
		Sen's slope (yr)	0.30	0.21	0.20	0.18	0.14	–0.11	0.29	0.29	0.23
		Sen's slope (49 yrs)	14.61	10.12	9.86	8.63	6.97	–5.54	14.30	14.30	11.51
	Su	Test Z	3.70***	3.85***	3.99***	3.09**	3.34***	3.78***	4.32***	4.32***	4.16***
		Sen's slope (yr)	0.80	0.68	0.67	0.59	0.67	0.60	0.77	0.88	0.76
		Sen's slope (49 yrs)	39.21	33.43	33.04	28.67	32.59	29.60	37.88	43.03	37.38
	Au	Test Z	–0.99	–1.65+	-1.66+	–0.85	–1.27	–0.22	–1.18	–1.15	–1.32
		Sen's slope (yr)	–0.15	–0.20	–0.20	–0.11	–0.16	–0.03	–0.15	–0.14	–0.14
		Sen's slope (49 yrs)	–7.17	–10.01	–9.96	–5.33	–7.67	–1.27	–7.15	–6.82	–7.03

Note: "+", "*", "**" and "***" indicate significance at α = 0.1, 0.05, 0.01 and 0.001 level, respectively; the values without these symbols indicate lack of statistical significance

While these decreases are characterized by annual rates reaching –3.2 mm/yr (which generates a total deficit of –157.6 mm when considering the entire 49-year period) at the Sulina station, only two cases are statistically significant (Sulina and Brăila). For the other five stations, slight CWB increase trends were detected (more evident in Călărași), with no statistical significance, and annual rates ranging between 0.1 and 1.7 mm/yr; in addition, an overall CWB increase can be noticed throughout the entire period (49 years), which falls in the interval 5...82 mm (Table 2). For the most part, these positive trends are due to CWB value dynamics after 2000, as up to this year balance variations generally indicated an increase of deficit values both annually and seasonally (Figure 4).

For a thorough understanding of CWB dynamics, an analysis of the two constituting parameters, rainfall and PET, is necessary. The graphical and statistical analyses of annual values revealed that CWB variations were primarily influenced by rainfall dynamics (general decrease/increase similarities at the same stations as the CWB), while evapotranspiration recorded increase trends at all nine analysed cases (Figure 4 and Table 2). In addition, considering the differences between precipitation and evapotranspiration rates, rainfall's prevalent influence on CWB variation becomes apparent. Thus, rainfall variability rate intervals could be identified, with values ranging between –2.3 and 2.2 mm/yr, while PET increase rates fall in the 0.6...1 mm/yr interval (Table 2). However, even though rainfall variations constituted the main influence on CWB annual trends, it must be noted that rainfall trends do not generally have statistical confidence, and this parameter's variation is not uniform throughout the study time frame (last decade's increases, opposing the general decreasing trends observed until 2000, reduced/stopped CWB deficit trends) (Figure 4).

Seasonally, during the winter season (December-February), CWB decreasing trends (towards deficit) are apparent all throughout the Dobrogea region, except for the south-western sector (Călărași station), where slight surplus values can be noticed (0.2 mm/yr). Thus, CWB decreasing trends range between –0.04 mm/yr in Galati (about –2 mm in the entire period) and –0.86 mm/yr (42 mm/49 yrs) at the Sulina station (Table 2). A separate analysis of the constituting parameters showed an overall decrease (with two exceptions, of which one is particularly evident at the Călărași station) of rainfall in this season (generally with no statistical significance), ranging from –0.1 to –0.8 mm when considering annual rates, or between –6 and –39 mm for the entire period 1961–2009 (Table 2).

PET trends, positive in all cases (with statistical confidence in less than half of the cases), indicate low value increase rates, with a peak of 0.23 mm/yr (or 11.1 mm/49 yrs) at the Călărași station (Table 2). In this season, a lower PET influence in CWB dynamics can be noticed, due to the low rates (as a result of the season's typical low temperatures), although they have a higher statistical significance than the precipitation amounts' trends (the latter, however, show significantly higher trend values).

In spring (March – May), general trends decrease (Figure 4), as the Mann-Kendall test results indicate six stations with negative CWB trends (Table 2). While trend rates range between –0.02 and –0.85 mm/yr, the values of a single station (Sulina) are statistically significant. The increase rates identified at three stations (Corugea, Călărași, Constanța) have relatively low values, which reach the maximum value of 0.39 mm/yr (Table 2).

The separate analysis of the constituting parameters reveals variability rate ranges of –0.5...0.4 mm/yr (–26.7...21.3 mm/49 yrs) for precipitation, and of –0.1...0.3 mm/yr

(–5.5...14.6 mm/49 yrs) for PET (Table 2), with both parameters generally lacking trend statistical significance (excepting four stations for PET). In this season, a relatively equal influence of the two parameters in CWB dynamics can be identified, given the differences between precipitation and evapotranspiration rates (in four of the analysed cases – Galați, Tulcea, Medgidia, Mangalia –, PET rates are higher than those of precipitation, which explains the negative CWB trends, while for the other five cases, CWB trends can be explained by precipitation rate values).

While summer (June – August) is the season with the most apparent decreasing CWB trends (deficit) –8 out of 9 stations –, ranging between –0.1 and –1.4 mm/yr (or between –4 and –67 mm/49 yrs), the results feature the same uncertainty problem, due to the general lack of statistical significance (Table 2). The separate parameter analysis revealed precipitation decreases in only three cases (with a peak of –0.6 mm/yr, Brăila station), and increases at six weather stations (with a maximum value of 0.61 mm/yr at Tulcea), although both lack statistical significance. Upon PET rate variability analysis (positive, ranging from 0.59 to 0.88 mm/yr, and statistically significant in 100% of cases), this parameter's exclusive influence on CWB dynamics can be noticed in the summer season (Table 2).

The last analysed season, autumn (September – November), has positive CWB trends at eight of the nine analysed stations (statistically significant in only 50% of cases), which range between 0.8 and 2.3 mm/yr, or from 40.3 to 110.8 mm/49 yrs (Table 2). At the eight stations, although both precipitation dynamics, with positive trends (between 0.7...2.4 mm/yr), and PET dynamics, with negative trends (maximum decrease rate of 0.2 mm/yr), explain the CWB evolution in this season, a higher influence of precipitation can be noticed, given the obvious differences between this parameter's rates and those of PET.

In addition to the results prompted by the Mann-Kendall method on climate trends and their quantification, it was considered useful for the present study to also feature a data series distribution analysis (in the form of histograms), which allows the extraction of additional statistical information on the intervals of prevailing values between 1961 and 2009, for each analysed station and time scale. To this end, four types of distribution were identified for the annual and seasonal regimes, i.e. *Pearson*, *Gamma*, *Chi-Squared* and *Wakeby* (Figure 5).

Therefore, the applied methodology demonstrates that, based on nonparametric tests, the annual and seasonal distribution types can be estimated probabilistically for each station (Figure 5) (Parzen, 1960; Griffiths, 1989; Aksoy, 2000; Deni and Jemain, 2009; Nunez *et al.*, 2011; Owolawi, 2011; Öztekin, 2011; Bandoc, 2012; Alzaatreh *et al.*, 2014). Subsequently, P-P Plot, Q-Q Plot and Probability Difference Graph (PDG) type tests were used to check the extent to which the theoretical distribution proposed for the CWB matched the recorded data, which confirmed the viability of the four mathematical models.

Thus, annually, the distribution types which were identified are *Pearson* for Galați, Brăila and Tulcea, *Gamma* for the stations at Sulina, Corugea, Călărași, Medgidia and Mangalia, and *Chi-Squared* for Constanța (Figure 5). Graphic representations show that, in this temporal case, the probability density reveals positive asymmetry, with high humidity deficit frequency throughout the entire time frame, at all stations. Quantitatively, at the nine weather stations, the deficit intervals with the highest frequency (f) ranged between –461 and –401 mm (Sulina, the value frequency in this range, of the entire analysed data series over the 1961–2009 period, was of ~26%) and –240…–156 mm (Medgidia, f ~ 30%) (Figure 5).

For the winter season, *Gamma* distributions were used for Galați, Călărași, Medgidia and Mangalia, and *Chi-Squared* for the other five stations. In this season, while the probability density shows positive asymmetry at all analysed stations, there are mainly surplus values (present in this season alone), which do however have evident value intervals (of higher

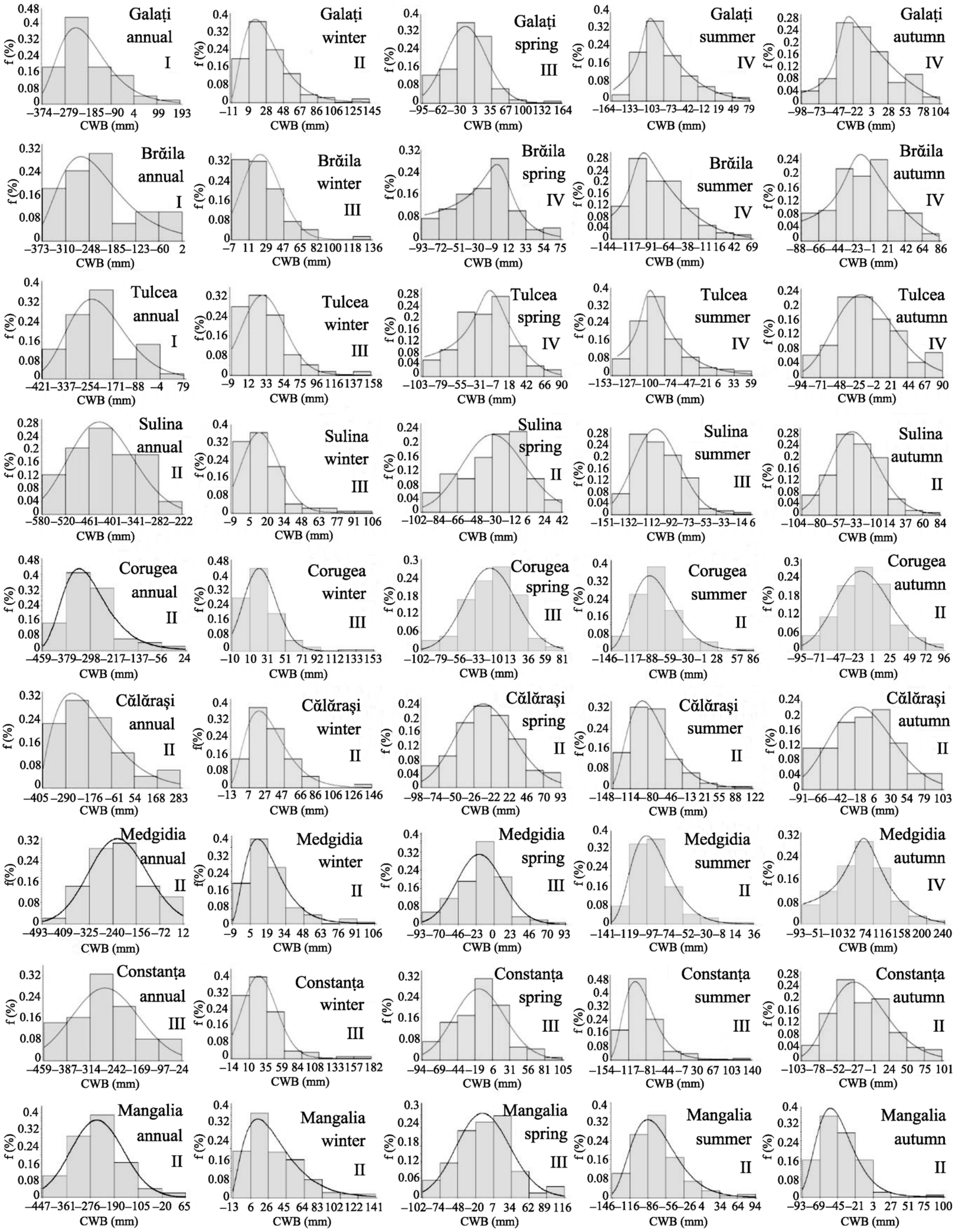


Figure 5 Annual and seasonal climatic water balance (CWB) frequency (f) distributions (I – *Pearson*, II – *Gamma*, III – *Chi-Squared*, IV – *Wakeby*) in the 1961–2009 period, at the nine analyzed weather stations

frequency) generally not exceeding the 50 mm threshold. The intervals with the highest frequencies ranged between –7...11 mm (Brăila, f ~ 33%), and 12...33 mm (Tulcea, f ~ 32%) (Figure 5).

In spring, *Chi-Squared* (Galați, Corugea, Medgidia, Constanța and Mangalia), *Wakeby* (Brăila, Tulcea) and *Gamma* (Sulina, Călărași) distributions were identified. The distribution analysis indicated positive asymmetry for the Galați station, negative asymmetry for the stations in Brăila, Tulcea, Sulina, Corugea, Medgidia si Mangalia and Constanța, and symmetric density for the Călărași station. It was found that the intervals with the highest frequencies ranged from –26…–22 mm (Călărași, f ~ 23%) to 7...34 mm (Mangalia, f ~ 26%) (Figure 5).

During the warm season, summer, distributions such as *Wakeby* (Galați, Brăila, Tulcea), *Chi-Squared* (Sulina, Constanța) and *Gamma* (Corugea, Călărași, Medgidia, Mangalia) were used. They indicated positive asymmetries at all stations, with a very high predominance of deficit values (existing particularity of this season). In this case, the intervals with the highest frequencies ranged from –132... –112 mm (Sulina, f ~ 28%) to –86... –56 mm (Mangalia, f ~ 35%) (Figure 5).

In the remaining season, *Wakeby* (Galați, Brăila, Tulcea, Medgidia) and *Gamma* (the other five remaining stations) distributions were used. For this season, a probability density with positive asymmetry was found at the stations in Galați, Tulcea, Sulina, Corugea, Medgidia, Constanța and Mangalia, while for the stations in Brăila and Călărași the negative distribution prevailed. In terms of the highest frequency value intervals identified at the nine stations, they ranged between –69...–45 mm (Mangalia, f ~ 36%) and 32...74 mm (Medgidia f ~ 29%) (Figure 5).

4 Discussion

Considering the entire evolution of the climatic water balance, both in terms of trends, as well as through value distribution, a connection can be established between its dynamics and the spatial data status of the UNEP aridity index. The spatialized index values indicate semi-arid features in northern Dobrogea (where four stations particularly showed high climatic water deficit values), and dry sub-humid climate features in the south, characterized by values greater than 0.5 mm/mm (situated in the 0.5–0.65 mm/mm interval, which typically describes a dry sub-humid climate, according to the index classification) (Trabucco and Zomer, 2009), where the weather stations generally showed lower deficit values. This situation is due to the high precipitation amounts recorded over the last decade in southern Dobrogea (where the evapotranspiration regime maintained its uniform upward trend), in the context of growing cyclonic activity in the region (Busuioc *et al.*, 2010).

The fact that one of the environmental components which are most heavily affected by climatic water balance variability is agricultural area which is of utmost importance. Such is the case of our study area, which contains large agricultural areas of wheat, corn and sunflower crops, mostly present in the central-southern Dobrogea plateau. Crop yields were influenced by water balance variations especially over the past two decades, since the nationwide collapse of irrigation systems (Grumeza and Klepș, 2005). Therefore, the deterioration of irrigation systems following the political transition in 1990, in conjunction with a humidity deficit increase especially in the northern part of the region, created the prerequisites for humidity climatic stress growth, with possible implications for reducing crop yields. However, considering the three types of crops, the climatic water balance oscillations' influence on agricultural yields may differ temporally and spatially.

Considering the case of wheat crops, which have an October-June vegetation period, it is apparent that, over the past few decades, they have undergone a high humidity-related stress, due to general increase in the humidity deficit during winter and even spring (considering the negative trends at six weather stations), fully overlapping the vegetation period. Spatially, it is very likely that the climatic water deficit-related stress may have had an influence almost throughout Dobrogea's entire agricultural region (plateau region), given the general negative trends characteristic of the two seasons.

Regarding the other two types of crops, corn and sunflower, they could have an even greater importance, given that the growth stages of these crops depend largely on summertime climatic conditions (corn crops' vegetation period lasts from April to September and sunflower crops' from March to August). Upon analysis of the negative CWB trends recorded in the summer season (the most apparent in the entire seasonal context, both spatially and in terms of magnitude), and of distribution types (with the highest deficit values on a seasonal scale), a high vulnerability of the two crop types to water deficit can be brought into question, generally for the entire spatial scale.

Interestingly, although during autumn, from a trend-oriented point of view, almost all stations recorded humidity surplus increases, and the deficit is much lower in terms of distributions, this season is not of particular interest for crops cereal. While winter crops (wheat) could be an exception, their growth and productivity depend to a lesser extent on climatic humidity conditions during this particular time frame.

It should however be noted that, besides climatic factors, regional agricultural system productivity has also been influenced over the past decades by several additional factors. Considering the relationship between climatic water deficit and corn yields in the Dobrogea Plateau, a recent study (Prăvălie *et al.*, 2014b), conducted on the post-socialist period 1990–2003, showed that water deficit in the warm season influenced corn yield dynamics especially in the central southern region (in some cases, even as high as 50%, causing losses of up to 11 kg/ha/year, for a deficit increase of 1 mm), although in the present study CWB trends and distributions indicate deficit summer values for the entire study area. This is due to other factors affecting agricultural system dynamics in central-northern Dobrogea (soil and groundwater characteristics, anthropogenic management conditions), which is emphasized in the analysed time interval 1990–2003 (Prăvălie *et al.*, 2014b). Moreover, it must be borne in mind that the analysed period in the present study (49 years) is different from the corresponding agro-climatic analysis (14 years), which means that for a complete assessment of the climate – crops relationship, it is necessary to analyse data series (climatic and agricultural) on the longest possible time intervals.

It is important to note that, apart from agricultural systems, the CWB dynamics recorded over the past five decades are likely to have influenced the ecological component as well to a certain extent. In this eventuality, the following are worth mentioning: the forest ecosystems in northern Dobrogea, possibly degraded (Prăvălie and Bandoc, 2015), similarly to certain analysed cases in southern Romania, where withering was detected, against the background of decreasing precipitation and increasing temperatures in the warm season

(Prăvălie *et al.*, 2014c; Prăvălie *et al.*, 2014a).

Also, Danube Delta's wetland ecosystems are among the most important ecologic components of the analysed region, most likely affected by the CWB dynamics in the past half century. These ecosystems are of particular importance to the environment and society, as they provide a wide range of ecosystem functions and services such as biodiversity and soil conservation, ensuring the nutrients' circuit, protection against disease and land degradation etc. Thus, similarly to other wetlands of global importance, this wetland provides several main categories of ecosystem services (provisioning, regulating, supporting and cultural services) (MEA, 2005); however, the Danube Delta is, at the same time, of universal value in that it is the largest reed bed area on Earth, it is the largest continuous marshland in Europe, and has one of the highest levels of biodiversity in the world (e.g., it totals more than 300 species of birds) (PRDD, 2014).

Thus, upon analysis of the CWB dynamics in north-eastern Dobrogea, it was found that in this region the climate deficit had the highest values. In terms of CWB trends recorded at the Sulina station in the past 50 years, they have shown the highest water deficit acceleration rates throughout the study area, statistically significant in almost all cases; the trends remained valid even during the autumn season (exceptional season for all the other stations). This particularity has therefore caused a continuous amplification of the climatic stress on ecosystems, with highly probable adverse consequences on the region's flora and fauna species.

5 Conclusions

This paper highlights the climatic water balance (CWB) dynamics in Romania's most arid region, Dobrogea, which is considered to be an essential quantifying indicator of atmospheric water variation, in the context of the climate change affecting the region over the past half century. Therefore, an analysis of CWB temporal characteristics over the past five decades (1961–2009 period), through statistical and GIS techniques, showed that the predominant element is moisture deficit, both in terms of trends, and occurence frequency in the full data series of the nine weather stations.

In terms of trends, the nonparametric Mann-Kendall test results showed temporal (annual and seasonal) and spatial differences. Annually, a deficit increase was found mainly in northern Dobrogea (with a maximum rate of –3.2 mm/yr, or a humidity loss of ~ –160 mm over the entire period, in the northeast). Seasonally, an overall water deficit increase was observed in winter, summer and, partly, in spring, with the most apparent decrease rates in the northern region as well (the maximum value of –1.4 mm/yr, or –67 mm/49 yrs, was recorded in summer, in the northwest). However, the general lack of statistical significance should be noted, although there are certain exceptions (the most prominent is the Sulina station, the trends of which having had statistical confidence in almost all cases).

The separate analysis of the CWB constituting parameters' trends, precipitation (P) and potential evapotranspiration (PET), indicated a greater influence of P in CWB dynamics annually, in winter and autumn, a greater importance of PET in summer, and an approximately equal influence of the two parameters in spring. In addition, the trend analysis of the two parameters also showed an overall increase of PET values, both annually and seasonally (except for autumn), largely based on statistical significance, and more dynamic annual and seasonal rainfall regimes, marked however by uncertainty due to the general lack of statistical significance of trends.

The probabilistic distribution type analysis, using four mathematical models (*Pearson*, *Gamma*, *Chi-Squared* and *Wakeby*), highlighted the fact that all weather stations were generally characterized by deficit value intervals, both annually (generally high frequency of deficit values found below the –200 mm threshold) and seasonally (maximum deficit values in summer), except for winter, generally characterized by slight surplus values (high frequency surplus intervals were generally below the 50 mm threshold).

Therefore, amid the spatial identification and dynamics quantification of the climatic water balance, the results can contribute to a better management of water resources and, consequently, of farming systems, as well as to a better understanding of the regional ecological potential, which is indispensable for ecosystem adaptability to future climate change in the region.

Acknowledgements

The authors are thankful for the valuable comments coming from anonymous referees who had the patience to review earlier versions and thus considerably helped revise this paper.

This work was performed as a part of research supported by the UEFISCDI PN-II-PT-PCCA-2011-3.2 1427 (Project ECOMAGIS/No. 69/2012) and project COSMOMAR No. 58/2013 financed by STAR Program of ROSA.

Also, the article has enjoyed the support of the Pluri and interdisciplinarity in doctoral and postdoctoral program cofinanced by Ministry of National Education – OIR POSDRU, contract no. POSDRU/159/1.5/S/141086.

References

Allen R G, Pereira L S, Raes D *et al.*, 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome: FAO.

Alzaatreh A, Famoye F, Lee C, 2014. The gamma-normal distribution: Properties and applications. *Computational Statistics and Data Analysis*, 69: 67–80.

Aksoy H, 2000. Use of Gamma Distribution in Hydrological Analysis. *Turk. J. Engin. Environ. Sci.*, 24: 419–428.

Bandoc G, 2012a. Estimation of the Annual and Interannual Variation of Potential Evapotranspiration. Evapotranspiration: Remote Sensing and Modeling. InTech., 251–272.

Bandoc G, 2012b. Statistical analysis of seasonal and interannual variability of precipitation in the coastal region Sfantu Gheorghe. *Journal of Environmental Protection and Ecology*, 13: 1656–1663.

Bandoc G, Golumbeanu M, 2010. Climate variability influence to the potential evapotranspiration regime of Sfantu Gheorghe Delta Shore. *Journal of Environmental Protection and Ecology*, 10(1): 172–181.

Bandoc G, Dragomir E, Mateescu R, 2013. Spatial analysis of potential evapotranspiration in Danube Delta. 3rd International Conference on Social Sciences and Society (ICSSS), December 27–28, 2013, Jeju Island, Korea.

Bandoc G, Mateescu R, Dragomir E, *et al.*, 2014. Systemic approach of the impact induced by climate changes on hydrothermic factors at the Romanian Black Sea Coast. *Journal of Environmental Protection and Ecology* 15(2): 455–467.

Bogdan O, 2005. Dobrogea Plateau. In: Geografia Romaniei V ed. The Climate. Bucharest, Romania: Romanian Academy Publishing House. (in Romanian)

Bouma J, Varallyay G, Batjes N H, 1998. Principal land use changes anticipated in Europe. *Agric. Ecosyst. Environ.*, 67: 103–119.

Breshears D D, López-Hoffman L, Graumlich L J, 2011. When ecosystem services crash: Preparing for big, fast, patchy climate change. *AMBIO*, 40: 256–263.

Busuioc A, Caian M, Cheval S *et al.*, 2010. Variability and Climate Change in Romania. Bucharest, Romania: Pro

Universitaria Press. (in Romanian)

Carrega P, 1994. Topoclimatologie et habitat. France: Nice-Sophia Antipolis University.

Cheval S, Baciu M, Breza T, 2003. An investigation into the precipitation conditions in Romania using a GIS-based method. *Theoretical and Applied Climatology*, 76: 77–88.

CLC 2006. Corine Land Cover (raster data). European Environment Agency. www.eea.europa.eu.

Cleveland W S, 1979. Robust locally-weighted regression and smoothing scatterplots. *Journal of the American Statistical Association*, 74: 829–836.

Cohen S, Ianetz A, Stanhill G, 2002. Evaporative climate changes at Bet Dagan, Israel, 1964 – 1988. *Agricultural and Forest Meteorology*, 111(2): 83–91.

Craven P, Wahba G, 1979. Smoothing noisy data with spline functions. *Numer. Math*., 31: 377–403.

Croitoru A E, Pițicar A, Imbroane A M *et al*., 2013. Spatiotemporal distribution of aridity indices based on temperature and precipitation in the extra-Carpathian regions of Romania. *Theoretical and Applied Climatology*, 112: 597–607.

Cuculeanu V, Marica A, Simota C, 1999. Climate change impact on agricultural crops and adaptation options in Romania. *Climate Research*, 12: 153–160.

Cuculeanu V, Țuinea P, Bălteanu D, 2002. Climate change impacts in Romania: Vulnerability and adaptation options. *GeoJurnal*, 57 (3): 203–209.

Deni S M, Jemain A A, 2009. Fitting the distribution of dry and wet spells with alternative probability models. *Meteorol. Atmosphere Phys*., 104: 13–27.

Drăghici I, 1988. Atmospheric Dynamics. Tehnica Press, Bucharest, Romania. (in Romanian)

Dregne H E, 2002. Land degradation in the drylands. *Arid Land Research and Management*, 16: 99–132.

Eitzinger J, Stastna M, Zalud Z *et al*., 2003. A simulation study of the effect of soil water balance and water stress on winter wheat production under different climate change scenarios. *Agricultural Water Management,* 61: 195–217.

Fan L, Lu C, Yang B *et al*., 2012. Long-term trends of precipitation in the North China Plain. *J. Geogr. Sci*., 22(6): 989–1001.

Fan H, Hu J, He D, 2013. Trends in precipitation over the low latitude highlands of Yunnan, China. *J. Geogr. Sci*., 23(6): 1107–1122.

Feng S, Fu Q, 2013. Expansion of global drylands under a warming climate. *Atmos. Chem. Phys*., 13: 10081–10094.

Fisher J B, Tu K P, Baldocchi D D, 2008. Global estimates of the land–atmosphere water flux based on monthly AVHRR and ISLSCP-II data, validated at 16 FLUXNET sites. *Remote Sensing of Environment*, 112(3): 901–919.

Gâștescu P, Posea G, 2005. Danube Delta and Razim-Sinoe Lagoon Complex. Bucharest V ed. Geografia Romaniei. Romania: Romanian Academy Publishing House. (in Romanian)

Glazer A N, Likens G E, 2012. The water table: The shifting foundation of life on land. *AMBIO*, 41: 657–669.

Griffiths G A, 1989. A theoretically based Wakeby distribution for annual flood series. *Hydrological Sciences – Journal – des Sciences Hydrologiques*, 34: 231–248.

Grumeza N, Klepș C, 2005. Irrigation Facilities in Romania. Bucharest, Romania: Ceres Publishing House. (in Romanian)

Hancock P A, Hutchinson M F, 2006. Spatial interpolation of large climate data sets using bivariate thin plate smoothing splines. *Environmental Modelling & Software*, 21: 1684–1694.

Hurvich C M, Simonoff J S, 1998. Smoothing parameter selection in nonparametric regression using an improved Akaike information criterion. *Journal of the Royal Statistical Society*, 60: 271–293.

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press.

Jhajharia D, Shrivastava S K, Sarkar D *et al*., 2009. Temporal characteristics of pan evaporation trends under the humid conditions of northeast India. *Agricultural and Forest Meteorology*, 149: 763–770.

Jiang D, Li Z, Wang Q, 2012. Trends in temperature and precipitation extremes over circum-Bohai-Sea region, China. *Chinese Geographical Science*, 22(1): 75–87.

Jiang J, Huo Z, Feng S *et al*., 2013. Effects of deficit irrigation with saline water on spring wheat growth and yield in arid Northwest China. *J Arid Land*, 5(2): 143−154.

Klein Tank, A M G., Wijngaard J B, Konnen G P *et al*., 2002. Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *Int. J. of Climatol*., 22: 1441–1453.

Le Houérou H N, 2002. Man-made deserts: Desertization processes and threats. *Arid Land Research and Management*, 16: 1–36.

Liu C, Zhang D, Liu X *et al*., 2012. Spatial and temporal change in the potential evapotranspiration sensitivity to meteorological factors in China (1960−2007). *Journal Geographical Sciences*, 22(1): 3–14.

Liu X, Zhang S, Shan L, 2013. Heterosis for water uptake by maize (*Zea mays L.*) roots under water deficit: Responses at cellular, single-root and whole-root system levels. *J Arid Land*, 5(2): 255−265.

Lungu M, Panaitescu L, Niță S, 2011. Aridity, climatic risk phenomenon in Dobrudja. *Present Environment and Sustainable Development*, 5(1): 179–180.

Maftei C, Bărbulescu A, 2008. Statistical Analysis of Climate Evolution in Dobrudja Region. Proceedings of the World Congress on Engineering, Vol II, July 2–4, 2008, London, UK (accessed on http://www.iaeng.org/publication/WCE2008/WCE2008_pp1082-1087.pdf).

Marica A C, Busuioc A, 2004. The potential of climate change on the main components of water balance relating to maize crop. *Romanian J. Meteorol*., 6(1/2): 50–57.

Marin L, Bîrsan M V, Bojariu R *et al*., 2014. An overview of annual climatic changes in Romania: Trends in air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed during the 1961–2013 period. *Carpathian Journal of Earth and Environmental Sciences*, 9(4): 253–258.

Marinică I, Văduva I, 2010. Comparison between the Oltenia Plain and the Southern Dobroudja Plateau in terms of pluviometric deficit. *Forum geografic. Studii şi Cercetări de Geografie şi Protecţia Mediului*, 9: 57–64.

McDonald R I, Douglas I, Revenga C *et al*., 2011. Global urban growth and the geography of water availability, quality, and delivery. *AMBIO*, 40: 437–446.

MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute, Washington, DC, United States.

Mertz O, D'haen S, Maiga A *et al*., 2012. Climate variability and environmental stress in the Sudan-Sahel zone of West Africa. *AMBIO*, 41: 380–392.

Michael R J, 1983. The stabilized probability plot. *Biometrika*, 70(1): 11–17.

Murărescu O, Murătoreanu G, Frînculeasca M, 2014. Agrometeorological drought in the Romanian plain within the sector delimited by the valleys of the Olt and Buzău Rivers. *Journal of Environmental Health Science and Engineering*, 12: 152.

National Meteorology Administration (NMA), 2012. Climatic data on temperature and precipitation parameters at Brăila (2003–2009 period), Corugea, Medgidia and Mangalia (1961–2009 period) weather stations.

Nunez J H, Verbist K, Wallis J R *et al*., 2011. Regional frequency analysis for mapping drought events in north-central Chile. *Journal of Hydrology*, 405: 352–366.

Olesen J E, Bindi M, 2002. Consequences of climate change for European agricultural productivity, land use and policy. *Eur. J. Agron*., 16: 239–262.

Olesen J E, Trnka M, Kersebaum K C *et al*., 2011. Impacts and adaptation of European crop production systems to climate change. *Europ. J. Agronomy*, 34: 96–112.

Owolawi P A, 2011. Rainfall rate probability density evaluation and mapping for the estimation of rain attenuation in South Africa and surround- Ing Islands. *Progress in Electromagnetics Research*, 112: 155–181.

Öztekin T, 2011. Estimation of the parameters of Wakeby distribution by numerical least squares method and applying in to the annual peak flows of Turkish rivers. *Water Resources Management*, 25: 1299–1313.

Parzen E, 1960. Modem Probability Theory and Its Applications. J. Wiley & Sons Inc., New York, USA.

Parzen E, 1993. Change P-P plot and continous sample quatile function. *Communications in Statistics: Theory and Methods*, 22(12): 3287–3304.

Păltineanu C, Mihăilescu I F, Seceleanu I, 2000. Dobrogea, Soil and Climate Conditions, Crop Evapotranspiration and IrrigationWater Requirements for the Main Crops. Constanta, Romania EX PONTO Press. (in Romanian)

Păltineanu C, Mihăilescu I F, Seceleanu I *et al*., 2007. Using aridity indexes to describe some climate and soil features in Eastern Europe: A Romanian case study. *Theoretical and Applied Climatology*, 90: 263–274.

Păltineanu C, Mihăilescu I F, Prefac Z *et al*., 2009. Combining the standardised precipitation index and climatic water deficit in characterising droughts: a case study in Romania. *Theoretical and Applied Climatology*, 97: 219–233.

Peptenatu D, Sîrodoev I, Prăvălie R, 2013. Quantification of the aridity process in south-western Romania. *Journal of Environmental Health Science and Engineering*, 11: 3.

Piticar A, Ristoiu D, 2012. Analysis of air temperature evolution in northeastern Romania and evidence of warming trend. *Carpathian Journal of Earth and Environmental Sciences*, 7(4): 97–106.

Prăvălie R, Bandoc G, 2015. Aridity variability in the last five decades in the Dobrogea region, Romania. *Arid Land Research and Management*, 29: 265–287.

Prăvălie R, Peptenatu D, Sîrodoev I, 2013. The impact of climate change on the dynamics of agricultural systems in South-Western Romania. *Carpathian Journal of Earth and Environmental Sciences*, 8(3): 175–186.

Prăvălie R, Peptenatu D, Sîrodoev I, 2014a. Changes in the forest ecosystems in areas impacted by aridization in South-Western Romania. *Journal of Environmental Health Science and Engineering*, 12: 2.

Prăvălie R, Sîrodoev I, Patriche C V *et al*., 2014b. The analysis of the relationship between climatic water deficit and corn agricultural productivity in the Dobrogea plateau. *Carpathian Journal of Earth and Environmental Sciences*, 9(4): 201–214.

Prăvălie R, Sîrodoev I, Peptenatu D, 2014c. Detecting climate change effects on forest ecosystems in South-Western Romania using Landsat TM NDVI data. *J. Geogr. Sci*., 24(5): 815–832.

PRDD (Periodic Report Danube Delta), 2014. Statement of outstanding universal value of Danube Delta. World Heritage Centre, UNESCO.

Reidsma P, Ewert F, Lansink A O *et al*., 2010. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. *Eur. J. Agron*., 32: 91–102.

Renka R, 1996. Algorithm 752: Software for Scattered Data Fitting with a Constrained Surface under Tension. *ACM Transactions on Mathematical Software*, 22: 9–17.

Reynolds J F, Stafford Smith D M, Lambin E F *et al*., 2007. Global desertification: Building a science for dryland development. *Science*, 316: 847–851.

Rockström J, Karlberg L, 2010. The Quadruple Squeeze: Defining the safe operating space for freshwater use to achieve a triply green revolution in the Anthropocene. *AMBIO*, 39: 257–265.

Salmi T, Määttä A, Anttila P *et al*., 2002. Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates: The Excel Template Application MAKESENS. Helsinki, Finlanda: Finnish Meteorological Institute.

Sellers P J, Dickinson R E, Randall D A *et al*., 1997. Modeling the exchanges of energy, water, and carbon between continents and the atmosphere. *Science*, 275: 502–509.

Shifteh Some'e B, Ezani A, Tabari H, 2012. Spatiotemporal trends of aridity index in arid and semi-arid regions of Iran. *Theoretical and Applied Climatology*, 111: 149–160.

The Climate of Romania, 2008. National Meteorology Administration, Romanian Academy Publishing House, Bucharest, Romania.

Thomas A, 2000. Spatial and temporal characteristics of potential evapotranspiration trends over China. *Int. J. Climatol*., 20: 381–396.

Thornthwaite C W, 1948. An approach toward a rational classification of climate. *The Geographical Rev*., 38(1): 55–94.

Trabucco A, Zomer R J, 2009. Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIAR-CSI GeoPortal at: http://www.csi.cgiar.org.

Vespremeanu E, 2000. The Danube Delta tourist maps 1: 200.000. Amco Publishing House, Bucharest, Romania.

Vişinescu I, Les G M, Zamfirache V *et al*., 2003. Drought: Features, characteristics and cyclicity in the agro-climatic setting of the North-Eastern Romanian Plain. Brăila, Romania: VHL Publishing House. (in Romanian)

Wen L, Rogers K, Ling J *et al*., 2011. The impacts of river regulation and water diversion on the hydrological drought characteristics in the Lower Murrumbidgee River, Australia. *Journal of Hydrology*, 405: 382–391.

Wilk M B, Gnanadesikan R, 1968. Probability plotting methods for the analysis for the analysis of data. *Biometrika*, 55(1): 1–17.

Xia J, She D, Zhang Y *et al*., 2012. Spatio-temporal trend and statistical distribution of extreme precipitation events in Huaihe River Basin during 1960–2009. *J. Geogr. Sci*., 22(2): 195–208.

Xu C Y, Gong L B, Jiang T *et al*., 2006. Analysis of spatial distribution and temporal trend of reference evapotranspiration and pan evaporation in Changjiang (Yangtze River) catchment. *J. Hydrol*., 327: 81–93.

Xu M, Ye B, Zhao Q *et al*., 2013. Estimation of water balance in the source region of the Yellow River based on GRACE satellite data. *J. Arid Land*, 5(3): 384–395.

Yang Y, Chen Y, Li W *et al*., 2010. Impacts of climatic change on river runoff in northern Xinjiang of China over last fifty years. *Chinese Geographical Science*, 20(3): 193–201.

Yang Y, Feng Z, Huang H Q *et al*., 2008. Climate-induced changes in crop water balance during 1960–2001 in Northwest China. *Agriculture, Ecosystems and Environment*, 127: 107–118.

Zhao D, Zheng D, Wu S *et al*., 2007. Climate changes in northeastern China during last four decades. *Chinese Geographical Science*, 17(4): 317–324.

Zhao L, Zhao W, 2014. Evapotranspiration of an oasis-desert transition zone in the middle stream of Heihe River, Northwest China. *Journal of Arid Land*, 6(5): 529–539.