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# The Climatic Water Deficit in South Oltenia Using the Thornthwaite Method

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**Abstract**

Understanding the dryness and drought phenomena is fundamental in explaining the landscape features and the rational use of water resources in a region. The authors aim to assess the climatic water deficit (WD) in one of the most sensitive regions in Romania in terms of aridity: Southern Oltenia. Defining and characterizing the intense aridity was done based on the Thornthwaite method under a multi-annual regime (1961-2007) and during the growing season (April-October) in order to reveal the climate suitability for human activity and the optimum conditions for the main crops. In southern Oltenia the Thornthwaite aridity index values (Iar-TH) (%) defines an arid area, increasing from north to south and south-west from 40-45% to 50%. The highest values displaying a pronounced aridity (Iar-TH ≥ 50%) cover a significant part of the Blahniţa Plain, Desnăţui Plain, Southern Romanaţi Plain (Dăbuleni Field), the Jiu Valley and the entire Danube Plain (about 65% of the entire surface).

**Keywords:** *climatic water deficit (WD), Thornthwaite Aridity Index ($I_{ar}$-TH), PET, South Oltenia, aridity and drought*

**Rezumat. Deficitul de apă climatic în sudul Olteniei folosind Metoda Thornthwaite**

Cunoaşterea fenomenelor de ariditate şi secetă sunt esenţiale atât în explicarea caracteristicilor peisajului cât şi în utilizarea raţională a resurselor de apă dintr-o regiune. Autorii îşi propun evaluarea deficitului de apă climatic (DEF) în unul dintre cele mai sensibile regiuni ale ţării în ceea ce priveşte ariditatea: sudul Olteniei. Definirea şi caracterizarea aridităţii ca intensitate s-a realizat pe baza valorilor obţinute prin metoda Thornthwaite atât în regim anual multianual (1961-2007), cât şi în perioada de vegetaţie (aprilie-octombrie) pentru a evidenţia favorabilitatea climatului pentru dezvoltarea în condiţii optime a culturilor agricole. În sudul Olteniei valorile indicelui de ariditate Thornthwaite ($I_{ar}$-TH) (%) definesc un domeniu arid, crescând dinspre nord spre sud şi sud-vest, de la 40-45% la 50%. Cele mai mari valori, exprimând o ariditate pronunţată ($I_{ar}$-TH ≥ 50%) acoperă o parte însemnată a Câmpiilor Blahniţei şi Desnăţuiului, sudul Câmpiei Romanaţiului (Câmpul Dăbuleni), luncile Jiului şi Oltului şi toată Lunca Dunării (cca. 65%).

**Cuvinte cheie:** *deficitul de apă climatic (DEF), Indicele de Ariditate Thornthwaite ($I_{ar}$-TH), ETP, sudul Olteniei, aridizare şi secetă*

## INTRODUCTION

Water resources and quality are declining, thus representing a severely limiting factor, particularly jointly with the increasing aridity due to global warming predicted by climatic models and scenarios. These scenarios estimate that the drought will persist and increase in intensity in critical agricultural regions of Europe (especially in the southern and south-eastern regions) as well as in Asia, Africa and North America, regions that will suffer pronounced dryness, heat, water shortage and an increasingly reduced agricultural production (Păltineanu et al., 2007a, Păltineanu et al., 2009).

Current climate changes accepted by the international scientific community are supported by the analysis of already conducted long term observational data, which started in the late twentieth century. They are individualized through *significant thermal contrasts* and *increased precipitations* as well as by the *emergence in the probability of the occurrence of extreme events* such as: expanded intervals with temperatures characteristic for the warm and cold seasons, prolonged droughts, extreme heat and aridity phenomena, heavy rainfall, increased frequency of thunderstorms, etc. All of this induces discontinuities in the variability of climatic parameters in areas more or less extended, creating a large negative impact on the environment.

The latest IPCC Report on the change of key climatic parameters, based on observational data on a global scale and on various scenarios of possible future changes, reveals an accelerated transition to a warmer climate characterized by situations with extreme temperatures and frequent heat waves, excessive droughts, in some regions and heavy rainfall, in others etc. (IPCC, 2007).

Studies conducted in Romania, highlighting the drivers of global climate change, shows as major outcomes: increased air temperature, decreased precipitation, reduced access to drinking water, and ultimately the extended aridity during the crop growing season in the southern regions of Romania, having a great impact on agricultural production. Most arid regions of Romania (considered on a global scale under the Köppen climate classification) are generally in the south, southeast and east of the country (Marica and Busuioc, 2004; Păltineanu et al., 2007a, 2007b, 2009; Busuioc et al. 2010, Sandu et al., 2010).

Along with the general climate changes, climatic water deficit develop drought, aridity or even desertification phenomena which, according to the hierarchy of natural hazards conducted by Bryant, 1991, is ranked first, based on the territory it currently occupies, the evolution trend as well as human victims and material damages it causes. In our country, some regions were individualized, in terms of landscape features, as undergoing desertification: Dobrogea, Southern Oltenia, and Southern Moldova.

According to the climatic regionalization, Southern Oltenia falls in the climatic sector with Mediterranean influences developing thermal characteristics (> $10^{o}$C) and precipitation (500-600 mm/year) specific for the plain areas in the south of the country.

## DATA AND METHODS

The paper aims to determine the **climatic water deficit (WD)** in southern Oltenia using the ***Thornthwaite Method*** in order to reflect the climate suitability for human activity and for the optimal development of spontaneous vegetation and reference crops (wheat and maize).

When preparing the paper, climate data from the meteorological stations in the analysed area (Craiova, Caracal, Calafat, Băileşti) has been used, as well as from meteorological stations of Turnu Măgurele and Drobeta Turnu Severin, the adjacent area, seen as support stations. The observation period was 1961 - 2007. In order to define and characterize the aridity and the climatic water deficit in the analysed area the Thornthwaite Aridity Index values for the growing season (April-October) were depicted as it is considered the most affected by these restrictive climate characteristics. For identifying them the following have been analysed: air and soil temperature, relative humidity, saturation deficit, rainfall (annual amounts of precipitation, half-year period, seasonal, monthly, the maximum amount fallen in 24 hours, liquid and solid precipitation frequency), direction and wind speed (Fig. 1).

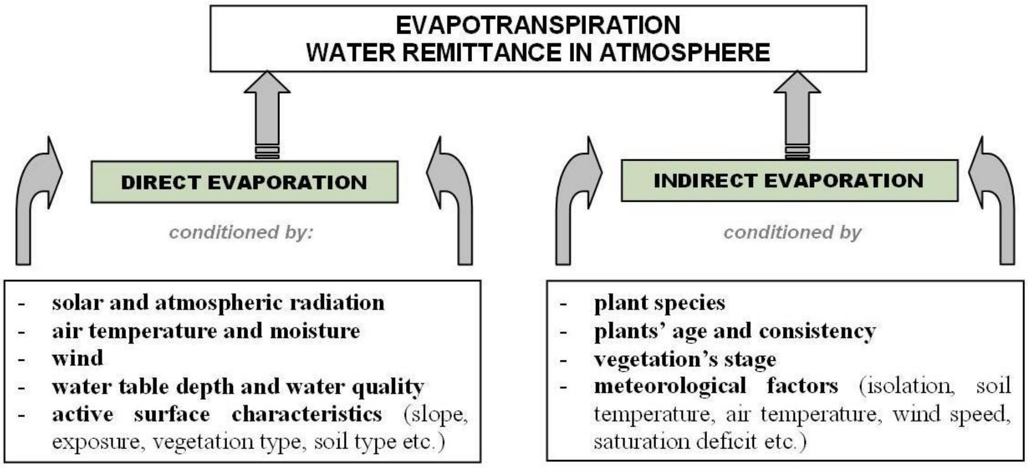


**Fig. 1. The scheme of water remittance in atmosphere through evapotranspiration**

When talking about climatic water deficit triggering aridity and drought, several factors are used, often based on air temperature, precipitation, potential evapotranspiration (PET), dominant wind direction and speed, solar radiation, vegetation type, soil water reserves, groundwater depth, etc. (Şerban, 2010). It is also the case of aridity indexes, which are taking into consideration one or more of these climatic parameters. In this relationship, a critical element is **precipitation** on which the parameter values and spatial distribution of drought and dryness largely depend. In the southern Oltenia, the annual mean precipitation values varies between 500-600 mm (Fig. 2), with a close variability ecart, having the mean annual amplitude of only 62.5 mm (the highest quantities being registered at Craiova meteorological station, and the lowest at Calafat).

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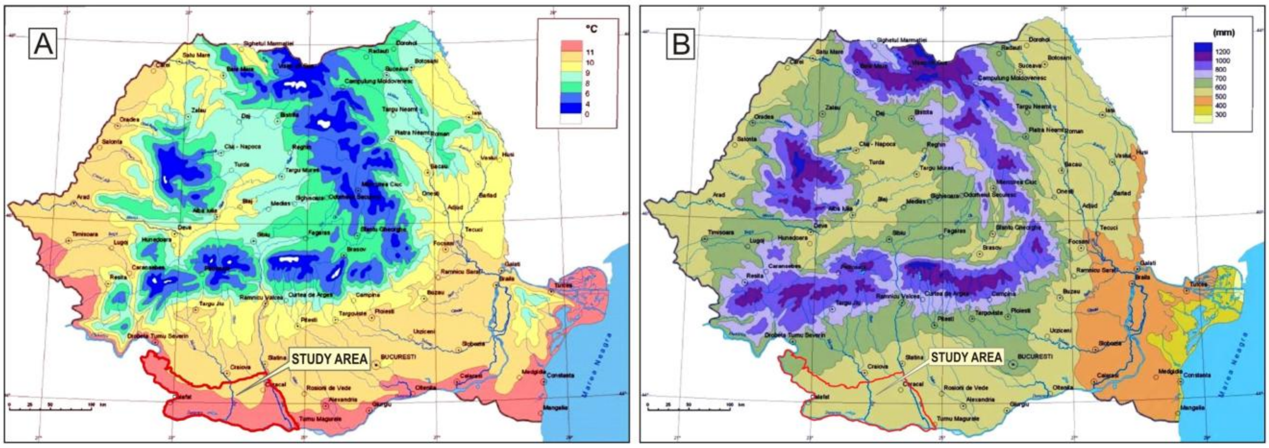


**Fig. 2. Mean annual temperatures (A) and annual precipitation amounts (B) in Romania (1961-2000) (Sandu et al., 2009)**

In the study-area, at all time scales (1961-2007), precipitation quantities generally increase westwards, so that at Drobeta Turnu Severin (located in the surrounding area) 667.2 mm are registered. During the growing season the mean monthly precipitation amounts are roughly similar in all the weather stations taken into consideration (Table 1), while May and June are the months when the maximum precipitation values are registered and October when the minimum rainfall is recorded (Dragotă, 2006).

The second meteorological element of interest in analyzing the soil water deficit and hence of the dryness degree specific for the Oltenia Plain, is the **air temperature** which oscillates around the 11°C on an annual regime. During the growing season it reaches around 17.5°C, scoring the maximum values in July when (22-23 °C) (Table 2). High temperatures and especially prolonged and intense heat waves may change dramatically the water balance by increasing the evapotranspiration thus favouring the intensity of drought. In addition, heat waves, which are increasing in the past 30 years, produce thermal stress to plants both in duration and intensity, inducing negative effects on crop development and production (Sandu et al., 2010).

**Evapotranspiration** is considered another key element in analysing climatic water deficit. It appears as a complex phenomenon, which represents the amount of water evaporated from the soil and that eliminated through transpiration by plants, registering different levels from one region to another, depending on different factors (Fig. 3).

This climatic parameter defines precisely the assembly of water losses through the two mentioned processes (evaporation and transpiration) initially determined empirically, based on climate data.

**Table 1. Mean monthly and annual precipitation amounts in the South Oltenia (1961 - 2007)**

| Meteorological stations | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference meteorological stations** | | | | | | | | | | | | | |
| Craiova | 36.0 | 34.2 | 38.6 | 50.8 | 65.1 | 72.8 | 61.8 | 51.2 | 43.8 | 39.0 | 51.5 | 46.8 | 591.5 |
| Caracal | 34.4 | 33.0 | 38.3 | 46.6 | 58.9 | 68.1 | 62.8 | 52.2 | 38.9 | 36.3 | 45.0 | 41.7 | 555.1 |
| Calafat | 33.5 | 34.0 | 37.4 | 48.9 | 58.3 | 56.3 | 49.7 | 39.3 | 39.9 | 39.1 | 47.4 | 45.1 | 529.0 |
| Băileşti | 37.9 | 37.0 | 39.7 | 50.3 | 60.4 | 58.1 | 53.0 | 43.1 | 40.2 | 39.4 | 50.7 | 48.3 | 558.1 |
| **Support meteorological stations** | | | | | | | | | | | | | |
| Turnu Măgurele | 36.2 | 32.9 | 35.7 | 40.1 | 57.2 | 58.6 | 57.1 | 48.8 | 42.3 | 34.3 | 43.9 | 40.8 | 527.80 |
| Drobeta Turnu Severin | 46.9 | 44.6 | 46.6 | 61.5 | 71.7 | 67.6 | 60.5 | 44.2 | 47.8 | 50.8 | 59.3 | 65.6 | 667.2 |

*Source: National Meteorological Administration database*

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**Table 2. Mean monthly and annual temperature in the south Oltenia (1961 - 2007)**

| Meteorological stations | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reference meteorological stations** | | | | | | | | | | | | | |
| Craiova | -1.8 | 0.4 | 5.1 | 11.3 | 16.8 | 20.3 | 22.4 | 21.8 | 17.2 | 11.3 | 5.1 | -0.1 | 10.8 |
| Caracal | -1.8 | 0.4 | 5.4 | 11.6 | 17.3 | 21.0 | 23.0 | 22.2 | 17.7 | 11.5 | 5.2 | 0.0 | 11.1 |
| Calafat | -0.7 | 1.3 | 6.1 | 12.2 | 17.7 | 21.3 | 23.3 | 22.6 | 18.0 | 11.9 | 5.7 | 0.8 | 11.7 |
| Băileşti | -1.4 | 0.7 | 5.7 | 12.0 | 17.7 | 21.1 | 22.9 | 22.2 | 17.5 | 11.3 | 5.1 | 0.2 | 11.3 |
| **Support meteorological stations** | | | | | | | | | | | | | |
| Turnu Măgurele | -1.7 | 0.6 | 5.8 | 12.2 | 17.8 | 21.4 | 23.3 | 22.5 | 17.8 | 11.6 | 5.3 | 0.2 | 11.4 |
| Drobeta Turnu Severin | -0.2 | 1.7 | 6.2 | 12.1 | 17.4 | 21.0 | 23.1 | 22.6 | 18.0 | 12.1 | 6.1 | 1.2 | 11.8 |

*Source: National Meteorological Administration database*

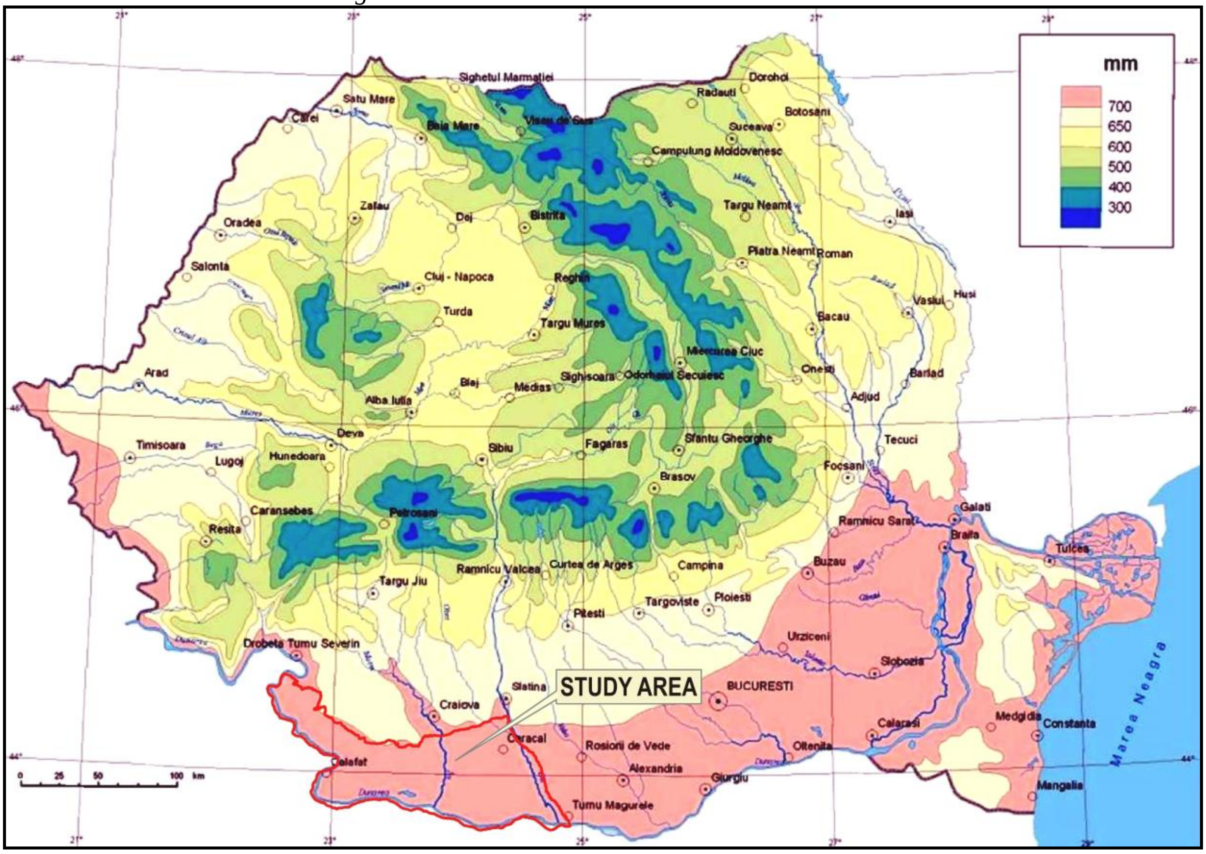


**Fig. 3. Mean annual evapotranspiration (Thornthwaite) values in Romania (Sandu et al., 2009)**

Subsequently, while the diversification of the application domains, different ways of calculating the potential evapotranspiration, have resulted.

Thus, at international level, many methods and formulas for calculating the potential evapotranspiration have been developed, based on one or more climatic factors aimed at being applicable in several areas: air temperature (Thornthwaite, Blaney-Criddle, Klatt, Holdrige), air saturation deficit (Aplatiev, Ivanov, Papadakis), several climatic factors (Turc) energy balance (Pennman, Bouchet), etc. (Păltineanu et al., 2007a; Sandu et al., 2009). The most broadly used method of calculating potential evapotranspiration in Romania is considered to be that of Thornthwaite (Păltineanu et al., 2009).

This parameter measures total water losses through evaporation and transpiration of a reference plant layer (generally grass), having a uniform height of several inches and supplied with plenty of water during the high growing season. It is calculated using the formula:

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

where:

t = mean temperature (ºC) for the considered period (month, decade);

I = annual thermal index

$$I = \sum_{n=1}^{12} i_n \; , \; i_n = \left( \frac{t}{5} \right)^{1.514} \quad = \textit{monthly thermal index}$$

$$a = 6.75 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.79 \cdot 10^{-2} \cdot I + 0.49$$

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F(λ) = correction term according to latitude and month.

In the present paper, the authors also considered the Thornthwaite aridity index (1948) with the aim of highlighting the climatic water deficit in the South Oltenia, defining and characterizing the aridity extent. The index could be used both on an annual basis as well as for the growing season (April-October), using the formula:

$$Iar\text{-}TH\ (\%) = 100 \times \Sigma\ (P - PET)/\Sigma\ PET$$

Initially, on a global scale, the Thornthwaite humidity index was defined by the humidity classes (*description*) segmented by units (*criterion*) (Table 3).

**Table 3. Thornthwaite aridity index classes and units on a global scale**

| Type | Description | Criterion |
|---|---|---|
| A | Perhumid | $I_{Th} > 100$ |
| $B_4$ | Very humid | $80 < I_{Th} \leq 100$ |
| $B_3$ | Highly humid | $60 < I_{Th} \leq 80$ |
| $B_2$ | Moderate humid | $40 < I_{Th} \leq 60$ |
| $B_1$ | Low humid | $20 < I_{Th} \leq 40$ |
| $C_2$ | Moist subhumid | $0 < I_{Th} \leq 20$ |
| $C_1$ | Dry subhumid | $-20 < I_{Th} \leq 0$ |
| D | Semiarid | $-40 < I_{Th} \leq -20$ |
| E | Arid | $-60 < I_{Th} \leq -40$ |

*Source: Păltineanu et al., 2007a.*

Compared to temperate latitudes and climatic conditions specific for Romania in terms of vegetation period (April-October) Iar-TH registers reformulated and adapted aridity classes (Monteith, 1965, Allen 1986, Allen et al., 1989, 1997, 1998, Jensen at al., 1990, Hargreaves, 1989, 1994, Hargreaves et al., 1985; Hattfield and Allen, 1996; Păltineanu et al., 2007b), as follows (Păltineanu et al., 2007a) (Table 4):

**Table 4. Thornthwaite aridity index classes and units on a regional scale**

| Description | Criterion |
|---|---|
| Semitemperate | 0-10 |
| Semiarid | 20-40 |
| Arid | > 40 |

## RESULTS AND DISCUSSIONS

In the south of Oltenia, the mean value of the Thornthwaite Aridity Index calculated for all meteorological stations taken into account expresses sharp changes regarding the generating climatic conditions for the period 1961-2007. On an annual regime, the Thornthwaite Aridity Index, ranked in the aridity classes, shows that 28.3% of the analyzed years fell in the *C1 Dry subhumid* class, with 1985, 1989, 1999, 2001, especially the consecutive years 1992-1994, standing out. Only two years 1983 and 2000 (4.3%) show annual values that fit in the *D semi-arid* class. Given that these values represent the average of the whole southern area of Oltenia, the result of the application of the Thornthwaite Aridity Index is significant (Fig. 4, A).

Regarding the vegetation period (April-October) the *D semi-arid* class feature is more pronounced (58.7%), highlighting drier summers in southern Romania. In this context, the moisture deficit highlighted by the Thornthwaite index is more relevant, as this feature is more dominant after 1983. Zero cases of aridity or hyper-aridity were registered, since the Thornthwaite index values for southern Oltenia are averaged (Fig. 4, B).

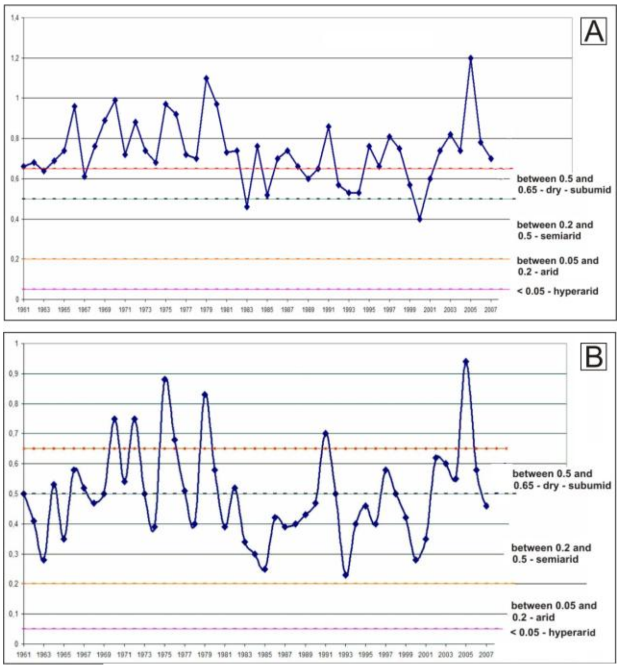


**Fig. 4. Thornthwaite Aridity Index values on an annual basis (A) and for the vegetation period (April-October) (B) in South Oltenia**

In southern Oltenia the Iar-Th delimits **arid** areas covered by an increase in the degree of aridity from north to south and south-west. In terms of subscribing to vegetation zones characteristic to the Romanian territory, the index values reveal an area with a humidity deficit at the contact between the steppe and forest steppe zone (Dumitraşcu, 2006).

The highest practical applicability of calculating the climatic water deficit and hence of the Thornthwaite aridity index in this predominantly agricultural region is linked to water consumption by crop plants. Thus, the distribution maps for both their growing season (April-October) and the main crops (wheat and maize) were developed.



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In the study-area, the ***maximum intensity of the Iar-TH*** ranges between 50-55 units covering most of Blahniţa, Desnăţui and Romanaţi Plains (Dăbuleni Field) extending to the floodplains and terraces of the Danube, Olt and Jiu Rivers (approx. 550,000 ha, making up 67.57% of the Oltenia Plain). Over 27% of the analysed area displays an Iar-TH of 45-50 units describing an intermediary step of vulnerability to dryness, covering about 230,000 ha in the northern Romanian Plain (Caracal Plain and the Leu-Rotunda Field), North of Segarcea, Blahniţa and Băileşti Plains. The lowest values of Iar-TH (40-45 units) are found at the contact area between the Getic and Mehedinţi Plateaus, only 5.27% of the studied area (Fig. 5).

Irrigation water requirements for the main crops is determined by direct experimental methods (some of which applied in the Oltenia Plain: Maglavit, Caracal, Gogoşu, etc.) and indirect experimental methods in relation to water requirements of plants that are in different phenological phases. Amid the broadly used indirect methods is the Thornthwaite method which defines the correction factors for different crops in soil and climate conditions spatially differentiated. Depending on each plant's phenophase specific for the vegetation period, these factors are essential in the irrigation process for estimating the actual water consumption. Thus, the **maximum real evapotranspiration** (ETC-est) value of major crops in South Oltenia (wheat and maize) is the main and most practical way of valorisation the Thornthwaite aridity index.

For ***wheat*** crops, during the growing season (May-June), ETC-est registers low variations for Romania, from 320-360 mm (Dobrogea, The Romanian Plain, the Moldova Plateau and Banat and Crişana Plains) decreasing to 300 mm in the Transylvania Plateau.

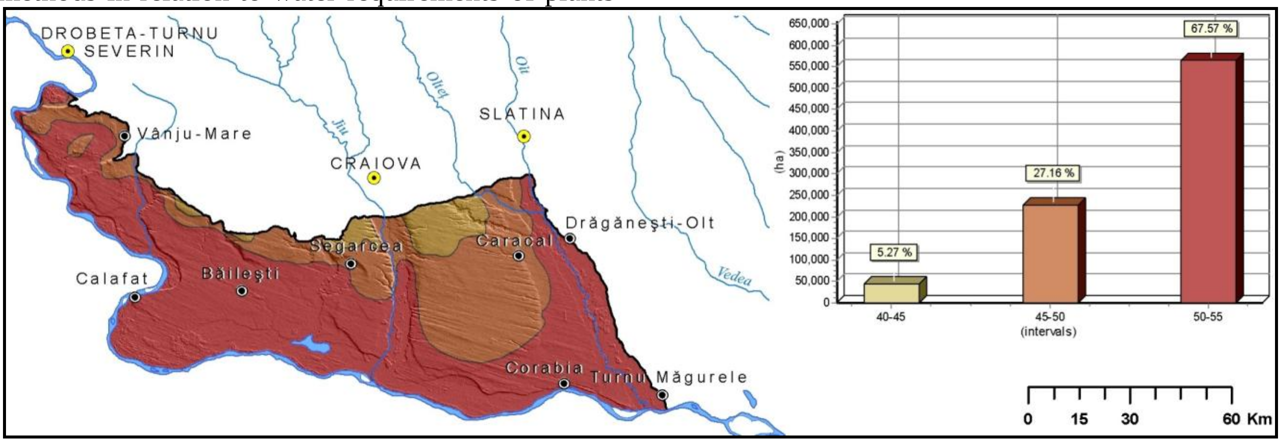


**Fig. 5. Spatial distribution of the Thornthwaite (Iar – TH, % mm/mm) aridity index during the vegetation period (April – October) for the main crops in South Oltenia (processed after Păltineanu et al., 2007a)**

In Oltenia Plain maximum water consumption values for the entire growing season reaches the highest values in the Danube Plain and in the southern Romanaţi (Dăbuleni Field) and Desnăţui Plains (Segarcea and Băileştiului Plains), reaching 360-370 mm. The values of this parameters decrease from the south, south-west to north, north-east, where in the northern area of Caracal and Desnăţui Plains they reach the lowest level (340-350 mm) (Fig. 6, A). On a national level, for ***corn***, ETC-est values fall in a relatively homogenous field in June, July and August with a maximum of 480-500 mm in Dobrogea and in the south-western extremity of the country, reaching high values (470-490 mm) in the southern Romanian Plain and Bărăgan Plain and increasingly low values (450-480 mm) in the rest of the Romanian Plain, south-east of Moldova and the Crişana and Banat Plains. Minimum values (400-450 mm) are found in Getic Piedmont, the Subcarpathians, the northwest of Moldavian Plateau and Transylvania Plateau.

In the Oltenia Plain, the highest values of ETC-east (500-520 mm) ware registered in the south-western part of the area largely overlapping the southern Desnăţui Plain and the Danube Floodplain. These values decrease to the north and north-east, where they reach 460-480 mm (northern part of Caracal and Desnăţui Plains) (Fig. 6, B).

For characterizing drought-related phenomena, estimating the **climatic water deficit (WD)** in southern Oltenia is compulsory for framing the study-area into a region with different degrees of aridity. The index is based on the relationship between precipitation (P) and potential evapotranspiration (Thornthwaite PET) under a formula agreed by the United Nations Environment Programme (UNEP). Unlike some drought indicators such as SPI (standardized precipitation

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index), climatic water deficit has the advantage of a more accurate quantification of the water supply needed for a reference crop (Păltineanu et al., 2009).

The largest area of southern Oltenia is characterized by a climatic water deficit between -150 and -200 mm (approx. 60%) particularly noted for the most part of the Romanaţi and Desnăţui Plains. In their southern sectors, especially in the Danube Floodplain, the values of the deficit increase, reaching -200 up to -250 mm (about 20% of the entire analysed territory) and the intake of water required by crops is provided from the underground. In the northern part of the study-area the climatic water deficit is lower (from -100 to -150 mm) covering more than 20% of the territory (Fig. 7).

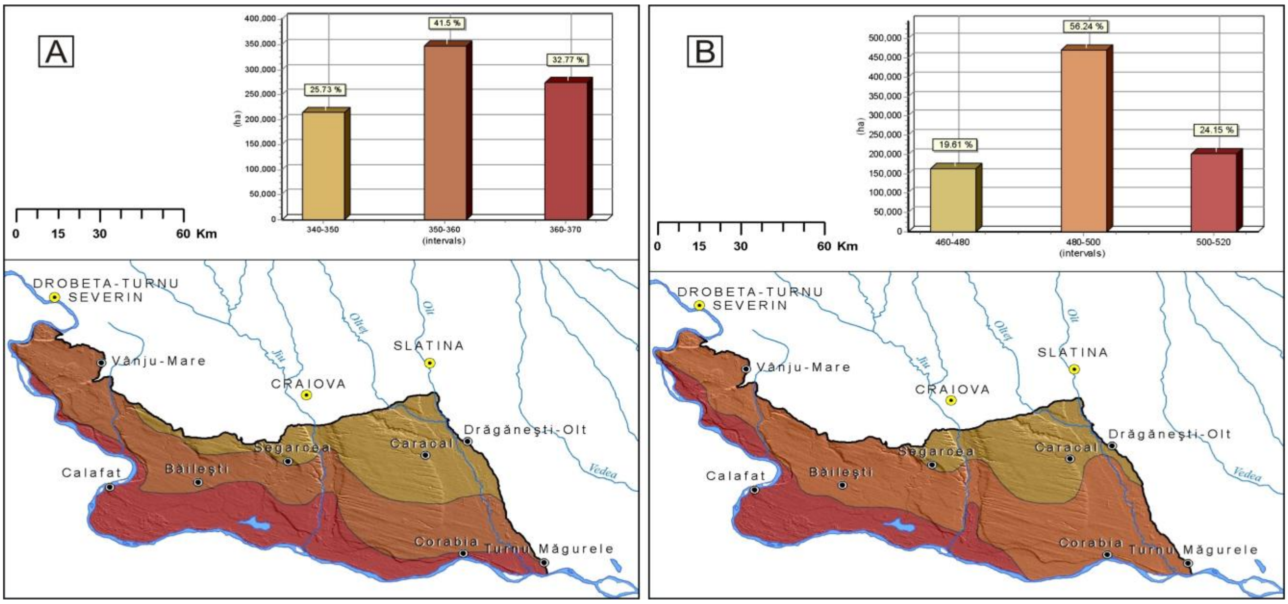


**Fig. 6. ETc-est (mm) distribution for wheat (A) and maize (B) during the growing season in South Oltenia (processed after Păltineanu et al., 2007a)**

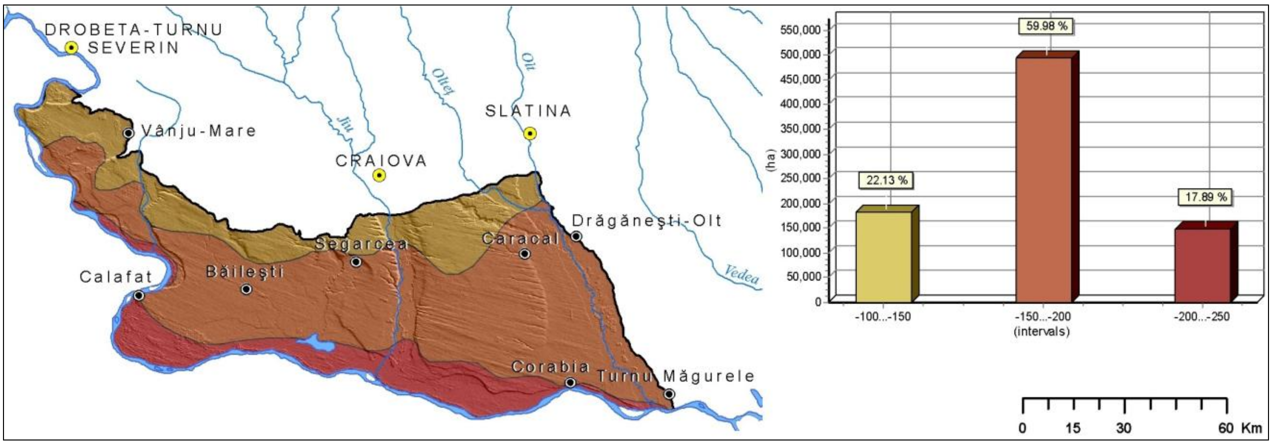


**Fig. 7. Spatial distribution of mean annual climatic water deficit versus $ET_0$ – TH in South Oltenia (processed after Păltineanu et al., 2007a)**

The analysis carried out on the climatic water deficit correlated with precipitation amounts for the main crops (wheat and maize) during the high growing season reveals several spatial and quantitative differences. Thus, one can notice that water deficit for wheat registers moderate values in June, since is also the month with maximum rainfall in southern Romania. For maize, however, the values of this agroclimatic parameter are higher, as they are calculated for the month of July, the month with maximum biological activity of this plant, overlapped on its thermal characteristics (maximum values during the year) (Table 5).

In terms of territorial distribution of climatic water deficit, the area best represented in southern Oltenia is the Danube Floodplain, while the northern and central parts of Desnăţuiului and Romanaţi Plains have mean or low values for both crops.

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**Table 5. Water requirements and consumption parameters for the main crops during the high growing season in South Oltenia**

| Main crops | PP (mm) | WD (mm) | Spatial distribution |
|---|---|---|---|
| Wheat (June) | 55-70 | -50…-60 | *Northern Blahniţa, Desnăţui and Romanaţi Plains* |
| | | -60…-70 | *Danube Floodplain (Calafat-Corabia Sector)* |
| Corn (July) | 50-65 | -70…-80 | *Northern and Center Desnăţui and Romanaţi Plains* |
| | | -80…-90 | *Danube Floodplain (Drobeta Turnu Severin- Rast Sector)* |

*Source: National Meteorological Administration*

## CONCLUSION

The processing of *Thornthwaite aridity index* (annual and for the growing season) and *potential evapotranspiration (Thornthwaite method)* and its components were used in underling the climatic water deficit parameters in southern Oltenia. Based on these values one could frame the study-area into the category of regions most affected by restrictive climatic phenomena, especially aridity and drought, ranking it as second in this regard across the country (Table 6). Therefore, as main outcome, both the extent of natural vegetation and agricultural crops for the area under analysis depends primarily on the climatic water deficit, but also on the main environmental features of a certain region (Fig. 8).

Assessing drought-related indexes and indicators is fundamental in evaluating water deficit and water resources on local and regional scale in order to predict practical measures to control aridity and drought phenomena.

**Table 6. Framing the study-area into the agricultural regions of Romania according to the climatic water deficit values (mm) in the growing season**

| Group | Regions |
|---|---|
| 1 | *Eastern Dobrogea* |
| 2 | *Western Dobrogea, Bărăgan and the South-Western part of Oltenia Plain* |
| 3 | *The South and East of the Romanian Plain and the South-East of Moldova* |
| 4 | *The Banato-Crişană Plain* |
| 5 | *The hilly extra-Carpathian regions* |
| 6 | *Transylvanian Plateau* |

*Processed after Păltineanu et al., 2007a.*

**Fig. 8. Aridity and drought related phenomena on sandy-soils in the Leu-Rotunda Field**

The importance of estimating climatic water deficit would help forecasting its key components, improving agricultural decision making at the farm or policy level and ultimately assuming specific measures for adapting to climate variability and change (including extreme events).

## ACKNOWLEDGEMENTS

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