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Chapter

Evapotranspiration and Drought in Different Agricultural Zones of Bulgaria

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Abstract

Bulgaria is located in an area with insufficient humidification and is characterized by periods of the drought of varying duration and intensity. From the last 15 to 20 years, the limiting factor in agro-meteorological conditions was the drought. Agro-meteorological drought consists of the depletion of available soil water reserves in the root zone. Ultimately, the results of droughts affect the size of yields and the quality of production. The consequences of this extreme condition from a meteorological and agro-meteorological point-of-view phenomenon can be mitigated only by expanding the irrigated areas. The aim of this work was to present the tendencies in the change of the potential evapotranspiration during the studied period 1986–2015 as a result of the climate changes and also the tendencies of the conditions for occurrence of agricultural drought in the future, and also to propose an approach where using certain indicators controls the process of accumulation and consumption of water in the soil. Such approach could find application in adapting agriculture to climate change and the updation of agro-environmental zoning relevant to climatic changes.

Keywords: potential evapotranspiration (ETP), soil moisture index (SMI), drought index (AI), annual and seasonal amounts of precipitations and temperatures (Σt and Σr)

1. Introduction

Droughts have a significant impact on agriculture to limit crop productivity and lead to reduced yields and have caused significant economic losses in a number of areas in Europe and the world. According to research by the Institute for Environment and Sustainable Development from the Joint Research Center in Ispra, Italy, drought is one of the biggest related to meteorological disasters. Continuing over months or years, it can affect large areas and can have serious environmental, social and economic impacts. These impacts depend on the duration, severity, and spatial extent of the absence of precipitation, but also on the environment and the socio-economic vulnerability of the affected regions. Europe has rich freshwater resources, but there is

a strong regional imbalance across the continent. Water scarcity, for example, is a significant problem in many European regions, particularly in semi-desert and continental climate zones.

A recent study conducted jointly by the European Commission and the Member States estimates the cost of droughts in Europe over the last 30 years at least € 100 billion. The same study estimated the economic damage from drought and heatwaves in 2003 in Central and Western Europe at more than € 12 billion. Other examples of this are the drought that developed in late 2004 in southern Portugal and Spain; the 2006 spring drought in France and the southeast of the United Kingdom and the spring 2011 drought in the enlarged parts of Western Europe, with severe economic consequences, mainly in the agricultural sector. In addition, April 2007 was the driest April according to the meteorological services of Germany, the Netherlands, and Austria, and November 2011 was the driest November in history for large parts of Europe, and Bulgaria. More facts - in the last 5 years in Bulgaria and many countries in the region there is a permanent summer drought, which usually begins in the second half of July and turns into an autumn drought by October and sometimes November.

Climate change, according to the Intergovernmental Panel on Climate Change for Europe, shows significant changes in the water balance across Europe, with an increased likelihood of summer droughts in the Mediterranean, as well as in Central and South-Eastern Europe. However, changes in the annual distribution of precipitation, as well as in energy and water balances, are likely to occur in other regions of Europe, leading to an increased likelihood of declining water levels and an increased likelihood of extreme weather events.

The European Commission published a Communication on “Meeting the Challenges of Water Scarcity and Droughts in the European Union” in December 2007, requesting a wider range of activities to adapt and mitigate the effects of drought and the changing climate in Europe. The measures requested include the development of a European Drought Observatory (EDO), the provision of consistent and timely drought information from the continental to the regional and local scales.

In order to detect, monitor, and forecast droughts on a continental scale, the Joint Research Center (JRC) of the European Commission (EC) is developing a prototype of the European Drought Observatory (EDO). A multidisciplinary set of indicators has been introduced, which is used within EDO to continuously monitor the various components of the environment potentially affected by this hazard (soil, vegetation, etc.) in order to obtain a comprehensive and up-to-date picture of the situation. Two indicators produced under EDO compare yield statistics to assess the effects of drought events on agricultural production. The test area is Spain, which is often suffered from a severe and prolonged drought. The results show that yields are significantly reduced in line with the drought events found by the indicators.

As drought is a slow-growing phenomenon affecting the whole water cycle (e.g. soil moisture, river basins, water levels in lakes, reservoirs, and groundwater) and has direct effects on vegetation, all these components must be monitored continuously throughout a long period of time. Other important aspects of adequate drought management are drought risk analysis (i.e. the likelihood of drought occurring to a certain degree, severity, and duration) and social vulnerability to drought. They are the basis of a detailed risk assessment. Finally, in the short and medium-term, forecasting the occurrence and likely development of droughts, as well as forecasting and analyzing the likely effects of climate change on drought hazards in different regions, are important to support the development of effective management plans on land.

At the beginning of the last century, attempts began to define the concept of drought, especially agrometeorological drought, and ways to identify it. Based on the common for all types of drought - precipitation deficit, almost all indices are related to them - a different number of days without precipitation, and later they refer to the consumption of water from soil and vegetation - evapotranspiration. In 1965, Palmer published its model for determining three types of drought - meteorological (PDSI), hydrological (PDHI), and agricultural (Z-index). A historical review and analysis of the indices used in the United States for different types of drought by [1] shows that the Crop Moisture Index (CMI), the Palmer Moisture Anomaly Index, is the most widely used to study the agricultural type of drought.

In relation to significant a problem with identifying drought – duration and intensity in 2013, World Meteorological Organization (WMO) and the Global Water Partnership (GWP) started an Integrated Drought Management Programme (IDMP), Integrated Drought Management Programme. The first step of drought management is Monitoring and Early Warning Systems. The most commonly used drought indicators/indices for detecting the drought are shown in the Handbook of Drought Indicators and Indices [2]. Experience has shown that it is difficult to establish common indicators. Due to the complexity and variability of drought depending on climatic and geographical conditions, it is appropriate to work on different indicators to be included in drought monitoring and warning systems. Selecting of the indicators has to consider timely detection of drought to realize appropriate communication with users and coordination to mitigate of effect. The characteristics of climate in space and time also have to have in mind to determine drought onset and termination. One of the most important things in the selection of indicators is the availability of information.

Every year, huge financial resources are invested in agriculture to maintain a plant-friendly water and nutrition regime. Many of them are lost due to the low level or lack of scientific management of activities in every production field in our country and in most countries of the world. The losses are due to inefficient use of energy, water, fuel, and human labor, as well as data from the meteorological network. As a result, agricultural fields are an intensive source of pollutants that damage ecosystems.

2. Drought monitoring in Bulgaria

The studies on the frequency of dry periods with different duration in Bulgaria have a special interest in view of the dry character of climatic conditions in the agricultural regions. An in-depth study of the conditions for the occurrence of drought and drought periods in Bulgaria during 1983–1994 was made by Kincaid and Heermann [3]. There is defined that the driest time during the year occurs most frequently in the period from August to October, and the areas with the highest number of droughts are the Seaside and Southern parts of the lowland of Tundja, Maritsa, and Struma [3, 4]. A similar trend is observed in the last 20 years - increased frequency and the dry period compared to the modern climate, especially in the Thracian Lowland and Northeastern Bulgaria [5, 6]. The most used agroclimatic indices in historical scale are Selianinov's HTK, De Martone Index, Thornthwaite Index, the balance of atmospheric humidity, aridity index, and so on. They are used for a comprehensive assessment of temperature and humidity conditions in the area under consideration. The most commonly used is aridity index because it gives an idea of the real water deficit for a certain period. Dilkov [7] found that in the period of spring, wheat growth evaporation-precipitation balance values are exceeding

–200 mm in each 2 to 4 years of 10 years. More recent studies [8, 9] that the evaporation-precipitation balance in the spring growing season for the period 1971–2000, the range between –223 mm and + 15 mm, the largest deficit of water resources is observed in some areas of the Thracian lowland and especially agricultural lands around Svilengrad, Ivailo, Plovdiv (–180 mm). The values of De Martone in agricultural areas ranged from 20 to 40 - mm/°C, [10–12] which defines the terms as moderately moist, HTK Selyaninov of about 1, and wheat yields are obtained when values of the De Martone than 30 mm/°C. Comprehensive assessment of conditions in the areas of agricultural production shows that in the region of Thracian lowland and Dobroudja to obtain high yields of wheat is necessary to compensate for the water deficit, is to conduct additional irrigation at critical growth and yield formation of cultivations. The change in the deficit in the root zone of the specific soil sown with a certain crop during the current growing season differs significantly from that calculated by climatic methods, which are based on average multi-year data. Estimates of the impact of climate change during the period 1961–2000–2010 on the soil moisture in wheat cultivation on six soil types were made and results were obtained for 24 agricultural stations in the country [13].

To characterize the hydrothermal conditions for growing autumn and spring crops in the country, the Selyaninov Hydrothermal Coefficient (SHC), De Matron (AI_{DM}), and the potential evapotranspiration on Thornthwaite (ETP) were used by processing data from 42 climatic and agrometeorological stations [10–12].

The influence of climatic changes on the atmospheric humidity, the evaporation from a free water surface, and the reference evapotranspiration on the territory of Bulgaria have been studied. The most unfavorable changes in the evaporating conditions have occurred in the Petrich-Sandanski climate region, as well as in the Central and Eastern part of the Danube Plain [10–12]. 30-year FAO reference evapotranspiration rates were obtained using the Penman-Monteith (ET_o) equation for 30 agrometeorological stations. A summary is made by climatic regions [14].

The single and combined effect of the meteorological parameters of the FAO Penman-Monteith equation on the estimates for the reference evapotranspiration during different sub-periods of the potential vegetation period (PVP) related to the physiological development of crops and their sensitivity to moisture is analyzed. One-factor and two-factor correlation analysis was conducted for 30 agrometeorological stations on the territory of agricultural production in Bulgaria [15].

Maps for the average annual spatial distribution of the atmospheric moisture balance ($BAO = \text{sum of precipitation minus reference evapotranspiration}$) are presented, as well as for the 30-year change of this deficit, and the areas with the most unfavorable conditions for agricultural crops are indicated. The need to update the irrigation regime of crops is justified [16, 17].

Maize in Bulgaria is a crop that suffers from water deficiency during its most sensitive phases in terms of water - sweeping-squeezing and squeezing-milk maturity. Data from the period 1971–2000 from 9 representative agrometeorological stations were processed. The climatic moisture supply of corn for grain, grown on four types of chernozems in Northern Bulgaria - typical, leached, carbonate, and degraded, is analyzed [8].

Comparative study of drought use monitoring of 3 indices is made in National Institute of meteorology and hydrology (NIMH). For detection of meteorological drought during 2009 WMO recommended the Standardized Precipitation Index (SPI) as a main meteorological index for observing and analyzing the drought conditions [18]. *SPI transform the precipitation totals for a certain period in a standard normal distribution.* In the intensity scale of SPI, the positive and negative values correlate

with the up normal rainfall and drought. McKee et al. [19] determined that the drought started at values of $SPI \leq -1$, but in many cases are used different values between 0 and -1 or below -1 [20]. In many countries, including and these in Southern and South-Eastern Europe, classifications are used, including the category “normal” for SPI values in the range of ± 0.5 .

The Soil Drought Index (SMI) developed by the HPRCC (High Plains Regional Climate Center) determines the intensity of drought by assessing the available water available to plants in the soil [21] relative to its maximum quantity for a given soil type. To calculate it, the measured soil moisture in agricultural crops is used, which allows to determine the degree of drought for a particular crop. It characterizes soil drought from normal to extreme, with the degree of drought increasing with decreasing index.

The monitoring is made with monthly data which means that the information has a diagnostic character.

Fundamental research is needed to gain knowledge about the root causes of the processes taking place in agroecosystems.

Inefficient management of activities in each field stems from the inability to easily and cheaply obtain current data on water supply (or deficit) in the soil by applying local (point) methods for measuring soil moisture and the climatic and remote methods used requiring highly qualified specialists [22]. This difficulty is related to the huge number of agricultural fields. It was found that when measuring 2 places in 10 depths for an area of 50.0 ha, the error was 79.6%. In order to reduce the error to 7.0%, it is necessary to make 50 measurements of the soil moisture profile, including 10 points in depth [23]. These results show that the representativeness of the experimental data obtained using these methods is a serious problem. Their application is limited within experimental stations, as well as for instrument calibration, regardless of the developed methodologies to reduce the number of measurements. This is confirmed by [3], who showed that for each field it is necessary to obtain representative data on water deficit over three days for the entire growing season. For example, for only one cornfield with an area of 50 ha, we need on average about 25,000 point measurements for a vegetation period lasting 150 days.

3. Material and methods

Solving various global tasks, such as the improvement of irrigation systems is related to determining the agroclimatic resources for growing cereals under irrigated and non-irrigated conditions requires the processing of data from meteorological and agrometeorological observations in all parts of the country. Observations from two or three climate and agroclimatic stations were taken in some larger regional centers. Thus, the territory of the country, which consists of 28 districts, was covered with 70 stations from the meteorological and agrometeorological networks of NIMH. The location of the stations is chosen so that the distance between them is approximately 20–30 km. Such a distance between the measuring points ensures the correctness and representativeness of the field of the measured elements related to the temperature conditions and their derivative characteristics. These include the maximum, minimum, and average daily temperatures and the 24-hour amount of precipitation, and the derived characteristics include active and effective temperatures reported above a certain biological threshold. Most hydrothermal indices reflecting the conditions of moisture and the characteristics of evaporation from the soil and crops were included here, i.e. evapotranspiration.

Under these conditions, there are suspicions about the interpretation of the precipitation field, but its structure is not the subject of this study. The latter is measured with sufficient accuracy, where the error due to the slightly greater distance between the measurement points is largely compensated by the number of measurements of water reserves in soil layers to a depth of 1 m.

In addition to the temperature and precipitation to characterize the conditions of drought and drought in any part of the country, the working database included data on the average daily values of agility of water vapor, the relative humidity of 2 m in the weather cell, wind speed and the duration of sunshine.

The working database is created with the data for the average daily values of maximum (Tmax), minimum (Tmin), average daily (Tav) temperatures, the agility of water vapor (E), relative humidity (F), wind speed (w), the duration of sunshine (s), and the sum of precipitation (r) for all 70 stations, **Figure 1**.

With the mentioned data, Excel spreadsheets were formed, as a separate file was created for each station, and the data cover a 30-year measurement period - from 1986 to 2015 inclusive. In this form, the control of the data, the marking of missing data, and their recovery were carried out. Statistical data processing was also performed - mean of each of the series, standard deviation, variance, standard deviation, median, mode, and type of data distribution.

In addition, a single database was created with the Excell® files. In the middle of the database are performed all calculations and selective data processing - the climatic value of meteorological elements, calculation of coefficients and indices reflecting the hydrothermal conditions and their spatial distribution throughout the country.

The methodology of the Joint Research Center in Ispra, Italy, and the General Directorate of Agriculture of the European Commission was used to characterize the drought conditions. According to her, the Aridity Index (AI) has recently been widely

Figure 1.
Spatial distribution of meteorological stations on the territory of the country.

used to assess the conditions of drought and drought in agriculture. The calculation of the dryness index is applied by formula (1), recommended by [24], in the Methodology for identifying areas with natural constraints, described in the JRC Technical by calculating the dryness index:

$$AI_{UNEP} = \sum r/ETP, \quad (1)$$

where AI - drought index, $\sum r$ - annual amount of precipitation; and ETP - the sum of the annual potential evapotranspiration. All values of the drought index.

Potential evapotranspiration - ETR, as defined by FAO-56, is the evapotranspiration from a grass surface with a standard height of 8–15 cm of plants that are actively growing, completely shading the soil surface and not experiencing water shortages [25, 26]. In recent years, a new calibrated method for calculating potential evapotranspiration has emerged worldwide - the FAO Penman-Monteith method [27, 28].

Potential evapotranspiration (ETP) by this method is determined by the equation:

$$ET_o = \frac{0,408\Delta(R_n - G) + \frac{\gamma 900 U_2 (e_a - e_d)}{T+273}}{\Delta + \gamma(1 + 0,34U_2)} \quad (2)$$

where.

ETP potential evapotranspiration [mm d^{-1}],

R_n и G net radiation and heat flow in the soil [$\text{MJ m}^{-2} \text{d}^{-1}$],

T the average daily air temperature в [$^{\circ}\text{C}$],

Δ water vapor pressure gradient [$\text{kPa } ^{\circ}\text{C}^{-1}$],

γ psychrometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$],

e_a и e_d deficit of air saturation with water vapor at standard altitude (at the level at which the meteorological measurements are performed) - 2 m [kPa],

U_2 wind speed at a reference height of 2 m [m s^{-1}].

Potential evapotranspiration (ETP) was used to assess the saturation of the atmosphere with water vapor, and real evapotranspiration (ETR) was used to assess the behavior of the plants concerned under certain evaporative conditions in the atmosphere.

4. Results and discussion

The annual course of potential evapotranspiration in certain meteorological conditions is determined by the biological characteristics and physiological development of crops, their water needs at each stage of their development. Physical conditions have the effect of increasing or decreasing evapotranspiration, while physiological conditions associated with aging have the effect of limiting the influence of external factors and regulating the evaporation process.

The study used daily data, which were mentioned above for the period 1961–2015. The study performed the following:

- With the given data calculations have been made with the Penman-Monteith Eq. (2) FAO56 and the CropWat® model. Daily values of the potential evapotranspiration for each station for the 30-year period were obtained;
- The amounts of ETR for each station are calculated for three important periods for agricultural production and irrigation in our country: 1) the period from sowing to

emergence vegetative development and overwintering of autumn crops from October of the previous to March of the following year; 2) the period of ripening of winter cereals April-June and 3) the period of irrigation of spring crops – July-August;

- The trends of the potential evapotranspiration for the research period by representative stations and administrative regions have been obtained. The results for both the potential vegetation and the traditional period of irrigation in our country – June-August are presented.

The differences between the final and initial values of the trends representing the change in the potential evapotranspiration over the 30-year period have been calculated. The obtained results for the potential evapotranspiration by years were averaged for the study period, the minimum and maximum values, standard deviation, coefficient of variation, steepness, and median for each point of the agricultural territory of the country were determined, **Table 1**.

Station/Statistics	Long-term Average	St. deviation	Min. value	Max. value	Var. coefficient	Kurtosis	Median
Knezha	935.87	72.35	793.17	1171.97	59.85	0.60	921.22
Pleven	979.75	78.62	841.43	1225.10	59.37	0.91	982.17
Pavlikeni	976.44	155.83	773.34	1321.79	135.88	−0.87	923.22
Russe	1102.42	112.36	928.83	1353.54	92.28	−0.54	1113.00
Targovishte	925.91	91.62	735.78	1147.28	73.89	−0.21	930.00
Ispeih	912.57	73.15	795.81	1073.52	61.16	−0.75	907.60
Shumen	955.58	63.76	832.77	1146.72	51.55	0.11	951.28
G.Toshevo	923.00	79.69	805.44	1112.34	64.77	−0.09	913.33
Montana	963.01	132.49	760.36	1278.14	117.33	−0.88	910.44
Vidin	895.78	57.81	675.95	1013.36	40.84	4.33	901.75
Average North Bulgaria	957.03	91.77			75.69	0.26	945.40
Karnobat	945.62	53.63	1186.18	1186.18	42.96	0.04	944.92
Elhovo	977.44	63.15	1084.43	1084.43	47.79	1.54	980.96
Sliven	1029.60	71.63	1253.60	1253.60	56.96	0.03	1026.75
Chirpan	990.31	60.72	1301.45	1301.45	48.51	0.84	988.93
Kazanlak	932.96	63.66	1005.92	1005.92	51.36	−0.30	934.53
Plovdiv	1016.31	76.27	997.63	997.63	60.15	0.45	1014.55
Sandanski	1115.16	78.78	1074.23	1074.23	64.49	−0.45	1109.64
Kyustendil	903.10	53.10	1093.01	1093.01	43.23	−0.82	905.92
Sofia	894.76	48.30	1168.99	1168.99	40.25	−0.56	893.63
M.Tarnovo	914.19	61.95	1213.74	1213.74	48.63	0.02	908.51
Average South Bulgaria	971.94	63.12			50.43	0.08	970.83

Table 1.
Statistical characteristics for 20 representative stations in northern and southern Bulgaria.

Figure 2.
Average long-term values of the potential evapotranspiration by stations and periods of crop development for the period 1961–2015.

The graphic materials and simulations cover 18 representative stations to describe in the most plausible way the conditions in the six regions into which we have divided the country.

The values of the potential evapotranspiration by stations and periods of crop development were also calculated, as already noted. During the period October–March the predominant value of ETP is above 800 mm–850 mm, higher than 900 mm is the potential evapotranspiration in Gramada, Nikolaevo, Pavlikeni, Hisar,

Figure 3.
Trends of potential evapotranspiration in northern Bulgaria.

Sandanski, Svishtov, and Burgas. The lowest values of ETP were obtained in Lovetch, Borima, Dermantsi, Sevlievo, and Ivaylovgrad, a less than 800 mm, **Figure 2**.

The values of the potential evapotranspiration by stations and periods of crop development were also calculated, as already noted. During the period October–March, the predominant value of ETP is close to 800 mm.

The dynamics and the trend of change of the potential evapotranspiration in Northern and Southern Bulgaria during the investigation period are presented in **Figures 3** and **4**. It can be seen that in almost all representative stations there is a tendency to increase the potential evapotranspiration. While in the northern regions this process is clearly visible, in the southern regions there is diversity, and in the northwestern and north-eastern parts of the country, the increase in ETP is well expressed, in the central regions this process oscillates around an average and only in Kazanlak, Kyustendil, and Sofia to a slight reduction in ETP. Precise analysis shows that this is due to an increase in the amount of precipitation. These results are also confirmed by the data of the conducted significance test by the Mann-Kendall method, **Table 2**.

The values of the long-term average monthly potential evapotranspiration for 18 representative stations from Northern and Southern Bulgaria, which correspond to the transitional-Continental and transitional-Mediterranean type of climate are presented in tabular and graphical form in **Table 2** and in **Figure 5**.

Figure 4.
Trends of potential evapotranspiration in southern Bulgaria.

III-X	Z criteria	Sign	IV-VI	Z criteria	Sign	VI-VIII	Z criteria	Sign
Vidin	1.2	+	Vidin	0.5		Vidin	2.6	**
Montana	6.4	***	Montana	6.5	***	Montana	6.4	***
Knezha	5.2	***	Knezha	3.5	***	Knezha	4.0	***
Pleven	3.7	***	Pleven	2.9	**	Pleven	3.1	**
Novachene	-1.1	+	Novachene	-1.1		Novachene	-0.3	
Nikolaevo	-0.3	+	Nikolaevo	-0.3		Nikolaevo	0.6	
Pavlikeni	5.5	***	Pavlikeni	4.6	***	Pavlikeni	5.5	***
Obr. Chiflik	3.9	***	Obr. Chiflik	3.8	***	Obr. Chiflik	3.1	**
Targovishte	4.1	***	Targovishte	3.2	**	Targovishte	3.8	***
Ispcrih	2.4	*	Ispcrih	2.3	*	Ispcrih	3.2	**
Shumen	1.2	+	Shumen	1.6		Shumen	1.4	
Krushary	2.0	*	Krushary	2.0	*	Krushary	1.0	
G. Toshevo	3.9	***	G. Toshevo	2.6	**	G. Toshevo	3.5	***
Karnobat	0.68	+	Karnobat	1.8	+	Karnobat	2.0	*
M Tarnovo	1.80	+	M Tarnovo	1.4		M Tarnovo	2.0	*
Elhovo	-0.63	+	Elhovo	0.3		Elhovo	0.1	+
Sliven	2.84	**	Sliven	2.5	*	Sliven	2.5	*
Chirpan	0.38	+	Chirpan	0.8		Chirpan	1.2	+
Kazanlak	-0.66	+	Kazanlak	-0.3		Kazanlak	0.1	+
Plovdiv	2.12	*	Plovdiv	1.4		Plovdiv	2.6	**
Blagoevgrad	-2.85	**	Blagoevgrad	-1.7	+	Blagoevgrad	-1.6	
Sandanski	5.74	***	Sandanski	4.0	***	Sandanski	5.1	***
Petrich	-2.42	*	Petrich	-2.3	*	Petrich	-2.1	*
Kyustendil	-0.94	+	Kyustendil	-0.7		Kyustendil	0.9	+
Sofia	-2.48	*	Sofia	-0.2		Sofia	-0.2	
Levels of significance *** - $\alpha = 0.001$; ** - $\alpha = 0.01$; * - $\alpha = 0.05$ and + - $\alpha = 0.1$.								

Table 2.
Levels of significance of the trends determined by the Mann-Kendall test for change of ETP by agricultural crops and periods of development.

The average multi-year monthly values of the potential evapotranspiration were calculated, which are shown in **Table 3**. The highest monthly values of ETP were reported in the stations Sandanski-198 mm and Sliven-182 mm. These values were reported in July, the warmest month of the year, and the lowest values of this indicator for the same period of the year are in the Krushari – 148 and Sofia-152 mm.

The average long-term values of soil water consumption through evapotranspiration in the period 1961–2015 in Northern Bulgaria are increasing, compared to the reference period. This increase is most noticeable in the northeastern region during the autumn-winter period October–March - 117 mm,

Figure 5.
Average multiannual values of ETP (mm) for northern and southern Bulgaria, which correspond to the transitional-continental and transitional Mediterranean types of climates and for 1986–2015.

Months/Stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Vidin	18	26	55	83	121	143	160	138	86	45	21	15
Montana	24	34	67	93	129	156	175	160	103	57	31	22
Knezha	19	28	60	90	126	150	166	149	95	51	27	17
Pleven	21	30	63	95	130	154	171	154	98	55	28	19
Novachene	14	23	52	84	120	142	154	138	84	45	20	12
Nikolaevo	15	25	52	81	113	134	148	132	81	44	21	13
Pavlikeni	22	33	63	97	132	157	178	164	106	61	32	20
Obr. Chiflik	20	29	63	97	134	150	171	153	102	55	28	19
Targovishte	21	30	61	90	124	146	168	147	96	53	28	19
Ispcrih	20	26	56	87	124	141	159	142	92	50	27	18
Shumen	22	31	59	89	124	144	163	145	93	53	29	21
Krushary	18	26	55	88	123	137	155	141	92	51	27	17
G. Toshevo	20	27	54	85	120	139	165	152	97	55	28	20
Karnobat	19	28	54	83	118	144	167	150	93	49	24	17
M Tarnovo	23	30	54	86	119	138	155	138	90	53	31	23
Elhovo	19	31	58	89	124	145	167	153	97	55	27	18
Sliven	23	33	60	90	128	156	182	162	105	58	29	22
Chirpan	17	29	59	90	126	152	171	157	103	52	24	14
Kazanlak	21	30	56	81	113	134	157	142	94	53	27	18
Plovdiv	23	34	63	94	128	157	177	158	103	56	30	20
Blagoevgrad	17	29	57	86	115	137	157	136	86	49	25	16
Sandanski	25	40	75	103	140	174	198	174	115	63	31	22
Petrich	20	32	64	92	130	154	177	158	103	58	26	17

Months/Stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Kyustendil	17	28	58	85	114	135	156	137	84	45	22	15
Sofia	17	27	55	82	112	134	152	137	86	46	23	15

Table 3.
Average long-term values of potential evapotranspiration (ETP) for some representative agrometeorological stations by months for the period 1961–2015.

after it is the northwest - 114 mm, followed by the north-central region - 102 mm. An increase in evapotranspiration is also present in the other two periods, as in the first of them the values of the increase are 27 mm–44 mm, and in the period June–August these values are 48 mm–68 mm, as the higher values refer to the northwest, and the lower ones for the northeastern region. On average for Northern Bulgaria, the increase in evapotranspiration for the entire growing season is 201 mm, **Table 3**.

Soil water consumption by evapotranspiration in Southern Bulgaria for the study period is similar and a bit lower to this in Northern Bulgaria, **Table 3**. Summarizing the results of the comparative study we should note an overall increase in potential evapotranspiration throughout the country compared to the reference period 1961–1990. The most noticeable is the decrease of ETP during the autumn-winter period in the high valley fields of Western Bulgaria –61 mm; an Increase of ETP is observed in the southwestern region - 108 mm. During the period April–June the decrease is observed in the high valley fields of Western Bulgaria –22 mm, followed by the south-central region - 36 mm. An increase in ETP is also observed in the period June–August, as again the highest values belong to the high valley fields in Western Bulgaria with 122 mm and the southwestern region - 59 mm. The average values of increase in soil water consumption through evapotranspiration in Southern Bulgaria in the three periods is 117 mm in the autumn-winter period; 36 mm in spring and summer and 62 mm in summer.

Obtained values of the AI index are analyzed in time and space, as a result the dry and wet years during the studied period are determined (criterion - the number of stations with $AI \leq 0.6$ for the agricultural zone of the country is more than half), and also regions in which $AI \leq 0.6$ by years (criteria - the number of years with $AI \leq 0.6$ to be greater than or equal to 7, which is in accordance with the cited above methodology. By applying the criteria $AI \leq 0.6$ dry year; $0.6 \leq AI \leq 1.0$ normal year and $AI \geq 1.0$ wet year we are defined the last 30 years as dry, wet, and normal years according to the values of the drought index as follows:

Dry years are - 1985, 1986, 1988, 1989, 1990, 1992, 1993, 1994, 2000, 2001, 2006, 2008, 2013, and 2015.

Wet years are - 2002 and 2005, 2012, and 2014.

Normal years are - 1987, 1989, 1991, 1992, 1995, 1996, 1997, 1998, 2003, 2004, 2007, 2009, 2010, and 2011.

As a result of the simulations, the average multi-year dates of the beginning of the depletion of water reserves below the lower limit of optimal moisture (70% of AWC) were obtained, which requires the first irrigation of corn crops. For Northern Bulgaria, the deadlines are from May 31 to June 17, and the increase of the date is from west to east, **Table 4**.

In Southern Bulgaria, the average dates of depletion of water reserves occur one week earlier - May 24, and in the sub-Balkan fields and high valley fields of Western Bulgaria, this happens in the period June 20–26, **Table 5**.

Production areas	October–March 1961– 1990/1986–2015/trend	April–June 1961– 1990/1986–2015/trend	June–August 1961– 1990/1986–2015/trend
North Bulgaria			
Northwest	736/850/+114	306/351/+44	378/445/+68
North Central	750/852/+102	320/353/+32	394/446/+52
Northeast	695/812/+117	310/337/+27	383/431/+48
Average for Northern Bulgaria	727/838/+111	312/347/+34	385/441/+56
South Bulgaria			
Southwest	805/913/+108	329/358/+29	419/478/+59
South Central	790/875/+86	324/359/+36	396/443/+47
Southeast	791/878/+88	325/354/+29	415/464/+49
High fields of Western Bulgaria	908/847/–61	369/347/–22	388/367/–22
Sub-Balkan fields	791/847/+56	317/350/+33	411/445/+35
Average for Southern Bulgaria	775/892/+51	323/358/+21	401/464/+34

Table 4.
Sums of potential evapotranspiration (ETP) (mm) for character periods by agroindustrial regions of the country.

Station	Date of sowing	Date of first watering
Vidin	20.04	31 V
Montana	27.04	11 VI
Knezha	25.04	11 VI
Pavlikeni	25.04	14 VI
Razgrad	29.04	17 VI
Shumen	29.04	17 VI
Karnobat	26.04	12 VI
M. Tyrnovo	20.04	7 VI
Sliven	20.04	30 V
Kazanlyk	30.04	20 VI
Chirpan	15.04	26 V
Plovdiv	15.04	24 V
Sofia	28.04	26 VI
Sandanski	15.04	25 V

Table 5.
Average long-term dates of depletion of water in the soil below 70% of AWC and determination of the need for irrigation in maize-grain crops, FAO group 400–500.

5. Conclusions

This study presents part of the results related to the need for continuous monitoring of potential evapotranspiration (ETP) and monitoring of trends in its change. Within this study, the parameters of ETP for the period 1961–2015 were obtained for 72 stations from the agricultural territory of Bulgaria, and also the results for some

stations representative for the agricultural production are shown. The more important conclusions are the following:

1. The values of average mean temperatures, amounts of precipitation, and amounts of potential evapotranspiration representative for agricultural production during the study period 1986–2015 have a positive trend compared to the same values during the reference period 1961–1990;
2. The data obtained for the period 1986–2015 show positive values of deviations and an increase in evapotranspiration throughout the country with a tendency for this process to continue to increase;
3. The uneven nature of the distribution of precipitation by seasons is intensifying and the dry winters, dry beginning of spring, rainy June, and prolonged 70–90 day summer drought, which more and more often turns into autumn drought, become more frequent. These features of humidification conditions are a serious challenge for selection specialists in creating varieties that can withstand periods of drought and drought;
4. The analysis of the results obtained at this stage is reason to recommend in the coming years a gradual but large-scale increase in investment for the construction of modern irrigation systems. The results of the climate scenarios for the next 20–30 years show that the trend of the observed changes will continue, which will greatly hinder and reduce the efficiency of individual branches of agricultural production under natural conditions of humidification;
5. Need for solid support and rapid development of precision and organic farming through digitalization, but with the leading participation of experts in agrometeorology, climate change, and agronomy.

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