Chapter

Changes in the Agro-Climatic Conditions in Bulgaria at the End of the 20th and the Beginning of the 21st Century

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Abstract

Agriculture is one of the most sensitive sectors of the economy. Therefore, climate change has the greatest impact on agricultural production. Despite the achievements of modern agricultural science and the development of agrotechnologies, the importance of meteorological conditions for the size and quality of agricultural products cannot be compensated. Agriculture in Bulgaria is carried out under conditions of limited and insufficient moisture. By the end of the last century, the studied trends of climate change in the area of agricultural production have led to a deterioration of agro-climatic conditions. The temperatures increase and decreasing rainfall and the uneven nature of their distribution cause short-term manifestations of this impact consisting of high variability, including extreme weather events and long-term manifestations consisting of changes in the agro-climatic characteristics of an agricultural area. Since the beginning of the 21st century, we have witnessed annual weather and climate records, both globally and nationally. The frequency and amplitude of extreme weather events is increasing every year. The World Meteorological Organization (WMO) is emphasizing 2019 as the fifth warmest year since the beginning of the 21st century. This paper presents the results of the changes study in agro-climatic conditions in the period 1986-2015 compared to the reference period 1961-1990, as a result of changes in the values of main meteorological elements at the end of the last and the beginning of the present century. The results of the research are necessary for decision-making, both at scientific and management level, in risk assessment and preparation of measures for adaptation to climate change, and directly in agricultural practice - for the choice of crops, varieties and hybrids and in the choice of technological solutions.

Keywords: climate change, deviation, temperatures, rainfalls, vegetative season duration, degree days

1. Introduction

Agriculture, as a branch of our national economy, operates entirely under the open sky. For this reason, climate change and fluctuations and climate anomalies have a very significant impact on the growth, development and productivity of agricultural crops. Climate change affects not only the quantitative but also the qualitative indicators of agricultural production. The development of agricultural practices and the application of precision and organic farming require in-depth knowledge of weather and climate, meteorological and climatic features and agro-climatic resources, in order to effectively and timely manage the processes to achieve maximum results.

The assessment of the influence of various factors shows that the most important for food production are the hydrothermal conditions or more precisely the balance between temperature and humidity conditions. In the agricultural zone of Bulgaria the conditions of humidification are limiting, and they are determined by the balance between temperatures and precipitation. The condition of the main meteorological elements determines the quantitative indicators of the hydrothermal conditions. The established trends of their change toward the end of the last century in Bulgaria showed an increase in the average daily air temperatures, an increase in the minimum temperatures [1–3] and a decrease in precipitation [1, 4].

In order to obtain high yields of high quality agricultural products, the role of soils and their fertility, varieties and hybrids of crops, their biological potential and resistance to extreme weather fluctuations - drought, frost, over wetting and heat waves, which are a prerequisite for stress and reduced productivity. Also, the resistance of cultivated plants to diseases and pests, because when environmental conditions are optimal for plants, they are optimal for the development of weeds, diseases and pests.

The knowledge and combination of the whole complex of biotic, abiotic, economic and technological factors [5, 6] against the background of the changing climate and climatic anomalies with increasing frequency are subject to research by the National Scientific Program - "Healthy foods for strong bio economy and quality of life", and the causal links between agro-climatic and soil conditions and the biological and genetic characteristics of the main types of crops for our conditions in the last 30 years are the subject of research by the project "Agricultural ecosystems adapted to climate change", which is part of the scientific program.

The aim of this study is to discover the changes in agro-climatic resources, as a result of changes in the main meteorological elements, at the end of the last century and the beginning of the present.

2. Experimental data

For the preparation of this up-to-date development, which presents the state of the hydro-thermal conditions in the period 1986-2015 from an agro-meteorological point of view, daily data on the basic meteorological elements were used: minimum, maximum and average daily temperatures and 24-hour precipitation for the indicated period of 56 representative meteorological and agro-meteorological stations for the agricultural zone in the country, **Figure 1**.

The meteorological elements measured also include some agro-meteorological indices that more accurately define the meteorological conditions, namely: the dates of a steady transition of the average daytime air temperature at 5°C and 10°C in spring and autumn; the duration of period with temperatures above 5°C, also known as a potential vegetative season (PVP) and above 10°C - a real vegetative season (RVP); as well as the absolute minimum and maximum temperatures during the coldest and warmest months of the year - January and July, respectively, the absolute minimum temperatures in spring and autumn as an indicator of the occurrence of frost damage to agricultural production, as well as amounts of the active and effective temperatures and amounts of precipitation for the potential and real

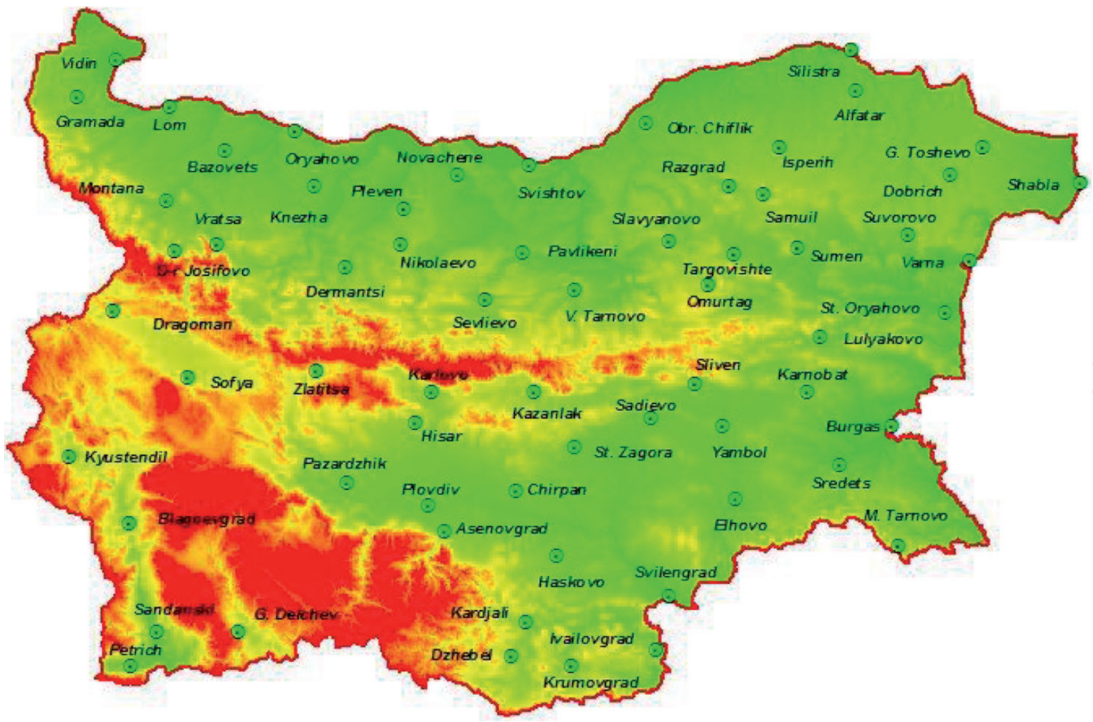

Figure 1.
Map with location of the meteorological and agrometeorological stations in the agricultural zone of Bulgaria.

growing season. In the course of this study, periods of dry spell (10-30 days without rainfall or rainfall less than 5 mm) and persistent drought (more than 30 days without rainfall or rainfall less than 5 mm) were identified. The analysis of the results obtained is a good basis to draw important conclusions, significant conclusions about the agro-climatic resources and agro-meteorological conditions in the NUTS2 administrative territorial planning zones.

3. Results and discussion

The growth, development and productivity of agricultural crops are most significantly influenced by hydrothermal conditions during the growing season. For wintering cereals - wheat, barley and rapeseed - this is the period from October of the previous year to June of the next and for spring and heat-loving from March to September, and for orchards - until October. The analysis of the average monthly long-term values of temperatures during the study period shows that they have increased, in almost all regions and months, compared to the reference period 1961-1990. In precipitation, the trends are not clearly expressed in all months and regions.

3.1 Change in basic meteorological elements during the period 1986-2015 compared to the reference period 1961-1990

3.1.1 Deviation of the average monthly temperature from the norm

The analysis of the deviations of the average multi-annual monthly temperature by months and seasons for the research period (1986-2015) was made by administrative-territorial planning zones, **Figure 2**. In all agricultural areas the temperature deviations from the reference values in December are predominantly negative. Exceptions are some of the stations located in Northwestern and North-Central Bulgaria, where the average monthly temperature for 1986-2015 is higher than the

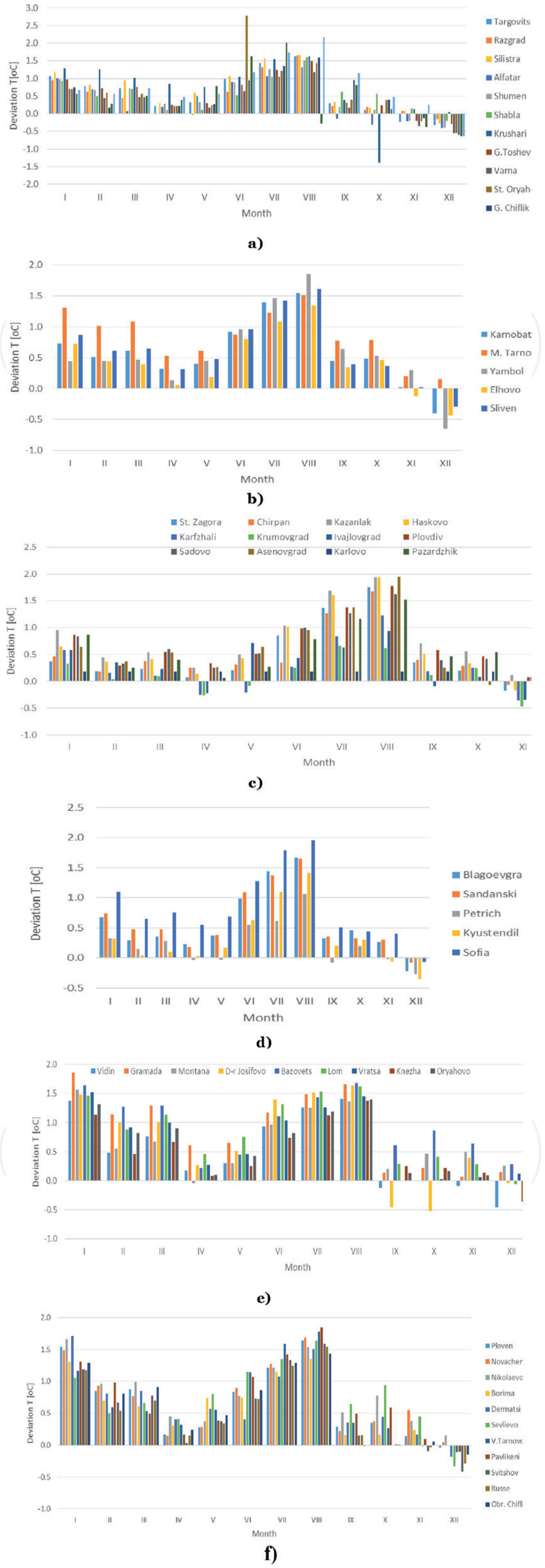

Figure 2.
Average monthly temperatures for the period 1986-2015 and deviations in comparison with 1961-1990 on different regions: (a) Northeastern Bulgaria; (b) Southeast Bulgaria; (c) Central South Bulgaria; (d) Southwestern Bulgaria; (e) Northwest Bulgaria and (f) Central North Bulgaria.

same during the reference period. The most negative temperature deviations are in Northeastern and Southern Bulgaria, reaching −0.6°C.

In January and February the trend is different from that in December. In both months during the study period it was warmer than the reference. In January in Northwestern and North-Central Bulgaria the deviations are higher than 1°C, varying from 1.0°C in Sevlievo and Knezha to 1.9°C in Gramada. In the other regions the deviations vary between 0.3°C in Krumovgrad and 1.3°C in Krushari and M. Tarnovo. In February, the positive trend of deviations is maintained, but the deviations are lower than in January. Without application of the average monthly temperatures in February it remains in Southwestern, Kyustendil and South Central Bulgaria, Krumovgrad, in the other stations the positive deviations vary between −0.1°C, Petrich and 1.3°C, Krushari. The winter in Western Bulgaria during the study period is warmer compared to the winter of the reference period. In Central Bulgaria the trend of positive deviations of the average long-term monthly temperatures is similar to that in Western Bulgaria, but the values of these deviations are lower than in the western regions of the country.

In conclusion, it should be emphasized that despite the large values of the positive deviations, which is evidence of warming, January remains the coldest month of the year in the period 1986-2015. In agro-climatic terms, winters become milder and relatively snowless.

During the spring months of March, April and May (MAM) the deviations of the average monthly temperatures remain positive compared to those for the same months during the reference period in Western, Eastern and North-Central Bulgaria. In South-Central Bulgaria - Kardzhali, Krumovgrad and Ivaylovgrad the deviations of the average monthly temperatures in April and May are negative by 0.2-0.3°C, i.e. in those places it is colder than in the period 1961-1990. In March it is warmer everywhere compared to the reference period, as in Northern Bulgaria the deviations are larger and vary between 0.4°C, Razgrad and 1.3°C in Bazovets. The average deviation in Northwestern Bulgaria is 1.0°C, in North Central 0.7°C, and in North-Eastern 0.6°C. In Southern Bulgaria the largest deviation is in Southeastern Bulgaria, 0.6°C. In South Central and Southwestern Bulgaria it is 0.4°C.

The average monthly air temperature in April has the smallest positive deviations in spring. The averages for the 6 regions vary between 0.1°C in South Central Bulgaria and 0.3°C in East and North Central Bulgaria. In May the average deviations by regions vary between 0.4°C and 0.5°C in Northern Bulgaria and 0.3°C and 0.4°C in Southern Bulgaria.

In conclusion, it can be said that the trend toward warming continues in the spring, but the values of the deviations are smaller than those in January and February.

During the summer months of the study period - June, July, August (Southeast Asia) almost all over the country the deviations of the average monthly air temperatures are positive. The smallest are the average positive deviations in June, between 0.7°C in South-Central Bulgaria and 1.1°C in North-Western Bulgaria. The largest are the positive deviations in August with average deviations by regions, 1.5-1.6°C.

In conclusion, it can be said that during the summer the highest values of positive deviations of the average monthly values of the air temperature compared to the reference period were reported. The largest increase is in August.

The autumn months of September, October and November (SON) during the study period become warmer. An exception is November, when in Northeastern, South Central and Southwestern Bulgaria, the average deviation is negative. The values of these deviations are of the order of 0.1-0.2°C, therefore it can be assumed that these deviations are of the order of the error of this meteorological element.

3.1.2 Deviation of the monthly amount of precipitation from the norm

The size and sign of the deviations of the amount of precipitation during the survey period 1986-2015 compared to 1961-1990 by months, measuring stations and agro-industrial regions of the country are presented in **Figure 3**.

In Western Bulgaria, the average value of the multiannual (1986-2015) monthly amounts of precipitation during the winter months (DJF) has weak positive and negative values of deviations, whose values are minus 10.7 mm in January in Petrich and 13 mm in December in Gramada and would not have a significant impact on the dynamics of autumn-winter moisture accumulation process.

In Central Bulgaria the deviations of the monthly amounts of precipitation during the winter months (DJF) are analogous to those of the western part of the country. The largest negative deviations were registered in January in North-Central Bulgaria and reached 13 mm in Dermantsi. In December, the positive deviations prevail.

In Southeastern Bulgaria everywhere and for all winter months we have a decrease in precipitation. Malko Tarnovo is impressive, where the winter precipitation has decreased by 76 mm for the study period compared to the reference. At the same time, in the northeastern part of the country in December and January the deviations are predominantly positive, while in February they are negative. The positive deviations in December reach 17.5 mm in St. Oryahovo and in January 10.2 mm in Alfatar.

In conclusion, it can be said that in December the precipitation in Northeastern Bulgaria increased on average by more than 10%, and in January in Southeastern Bulgaria it decreased by 18%. The average change in the other areas is insignificant. In February in Western Bulgaria the decrease of the rainfall is between 7 and 8% of the monthly norm, in North Central Bulgaria a decrease of 10%, while in South Central Bulgaria we have a slight increase. The largest decrease is in Eastern Bulgaria, where in the Northeast the decrease is by 13%, and in the Southeast by 11%.

In March, only negative deviations were reported in the stations of Northwestern Bulgaria. In the other areas there is both a decrease and an increase in precipitation. The average deviation by region is positive in the other regions. The decrease in Northwestern Bulgaria is 6% of the March norm. In the other regions the increase is between 2%, North Central and 12%, in Northeastern Bulgaria.

In April, an increase in rainfall was observed in the western regions. In Northwestern Bulgaria change is average of 5% and in Southwestern Bulgaria, by 12% of the climatic norm for April. The largest is in Petrich, where this increase is 30%. A decrease was registered in the other regions of the country. In the central regions it is on average between 4 and 8% of the norm for April. In the South-Central region the decrease is bigger, as in Krumovgrad and Ivaylovgrad, the decrease reaches 12% and 17%, respectively. The most significant is the decrease of the precipitation in South-Eastern Bulgaria, where the average value of the deviations reaches 12% of the monthly norm, and in M. Tarnovo it reaches 22%.

In May there was a clear decrease in the monthly amounts of precipitation by between 6 and 9% for the different regions of the country. An exception is Petrich, where there is a slight increase in the amount of precipitation. The largest decrease is observed in Alfatar 21% (NE) and Nikolaevo 15% (CN).

It can be said that in the spring (MAM) both negative and positive deviations of the monthly precipitation amounts during the studied period compared to the reference period are observed. The average change in the monthly amounts of precipitation by regions reached a 12% increase in March in Northeastern Bulgaria and in April in Southwestern Bulgaria and a decrease in Southwestern Bulgaria in April. By stations, the change increased to 30% of the monthly norm in Petrich in April and a decrease of 21% in Alfatar in May.

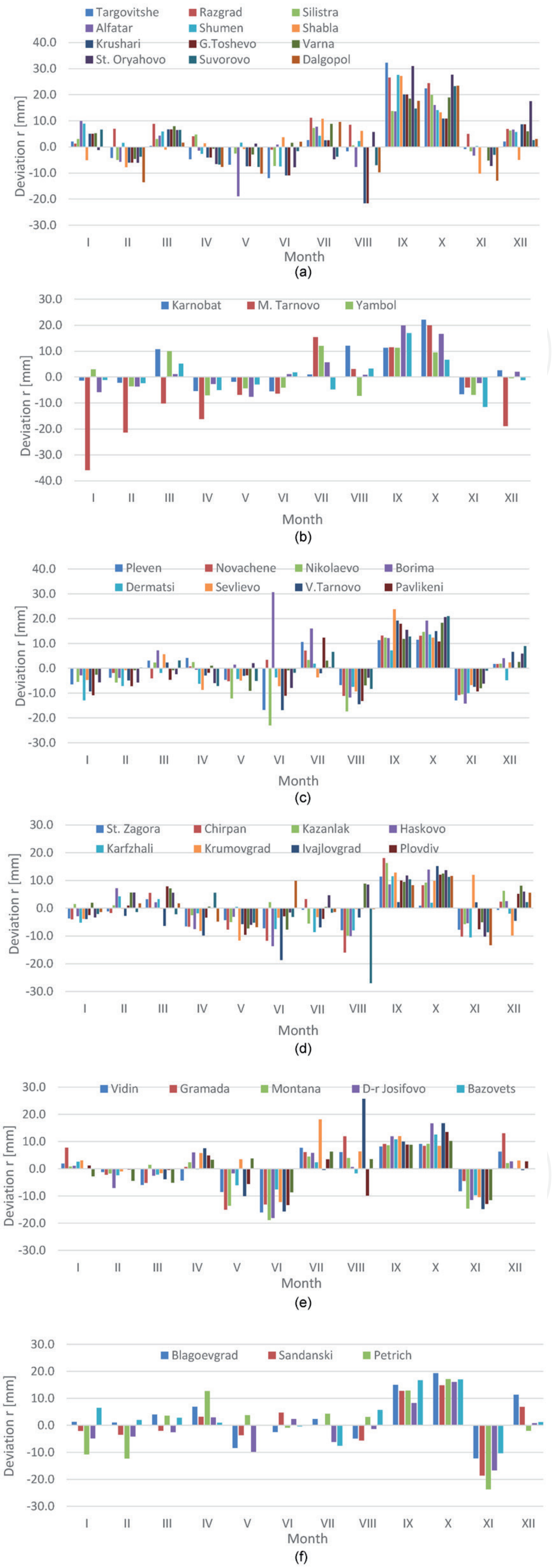

Figure 3.
Deviations in average multiannual monthly rainfalls for the period 1986-2015 compared to the reference period 1961-1990: (a) Northeast Bulgaria; (b) Northwest Bulgaria; (c) Central North Bulgaria; (d) Central South Bulgaria; (e) Southeast Bulgaria and (f) Southwest Bulgaria.

Summer (JJA) is also characterized by various changes in the monthly amounts of precipitation. In June, negative deviations were observed in all regions except Southwestern Bulgaria. They are most significant in Northwestern and North-Central Bulgaria, where the average decrease reaches 17% and 11% of the monthly norm, respectively. At stations in Northwestern Bulgaria the decrease is between 10% in Bazovets and 24% in Vidin. In North-Central Bulgaria the reduction reaches 27% in Nikolaevo. In northeastern Bulgaria the deviations are negative, except for Dalgopol, but the average value is insignificant 5% of the monthly norm. By stations, however, the reduction reaches 18% in Krushari. The decrease of the average monthly amounts of precipitation during the studied period compared to the reference one in South Central Bulgaria is by almost 10%. By stations, in Pazardzhik, Plovdiv, Kardzhali and Kazanlak the change is a slight increase, but in Krumovgrad, Sadovo, Haskovo, Chirpan and Sliven the decrease is between 13% and 21% of the monthly norm. In Southwestern Bulgaria the positive deviation is predominant, as in Sandanski the increase reaches 10% of the monthly norm. In July in Northern and Southeastern Bulgaria there is an increase in precipitation by between 9 and 12% of the monthly norm for the month. In South-Central and South-Western Bulgaria there is a slight decrease. By stations, the increase in average monthly amounts reaches 20% in Razgrad, 24% in Varna, 36% in Shabla and 44% in Lom in northern Bulgaria and 26% in Yambol and 42% in Tarnovo in southwestern Bulgaria. A significant decrease in the monthly amounts of precipitation was reported in Haskovo, 20%; Krumovgrad, 18%; Ivaylovgrad, Sofia and Kyustendil, 12% and Chirpan, 11%.

In August, everywhere, except for Northwestern Bulgaria, a decrease in the monthly amounts of precipitation is reported. It is most significant in North Central Bulgaria, where the average deviation is 19% of the monthly norm and in South Central with a deviation of 14%. In Northwestern Bulgaria there is an increase of 12% of the monthly norm, and in Southeastern Bulgaria by 6%. By stations the biggest decrease in Karlovo, Nikolaevo, and Krushari. The most significant increase in Vratsa, St. Oryahovo, Karnobat, Sadovo, and Asenovgrad.

The most significant change in the monthly precipitation amounts is observed in autumn (SON). In September and October there is an increase in precipitation everywhere, the largest being in Northeastern Bulgaria. There, in September, the increase reached 60% of the monthly value during the reference period, and in October 55%. The average deviation in the other regions fluctuates between 24% in October in South-Central and 45% also in October in South-Central Bulgaria. By stations the largest increase is observed in September in St. Oryahovo, 84%, Targovishte and Shabla 79%.

In November, the deviations are negative everywhere. The decrease in Eastern Bulgaria is insignificant, around and below 10%. But in other areas it varies between 11 and 25% of the monthly norm. In Western Bulgaria the average deviation is 21-25% of the norm, and at stations in Sandanski, 30%; in Petrich, 29%, in Montana 28%, and in Knezha, Pleven and Kyustendil 26% of the monthly norm.

The change in the average monthly precipitation amounts during the survey period 1986-2015 compared to those during the reference period is different during the months of the year. During the off-growing season, there is a predominantly insignificant decrease in the average monthly amounts of precipitation. The more significant decrease in Oryahovo, Dermantsi, Pavlikeni, Shabla, Dalgopol, M. Tarnovo, Kyustendil and Petrich is impressive, and a decrease between 13 and 19% of the norm. An increase of 13% was reported in Razgrad. The decrease in precipitation during the off-growing season is at the expense of the serious decrease in November. In the remaining months the change in precipitation is insignificant.

The average values of the deviations of the average monthly amounts of precipitation during the growing season are insignificant, but positive in all considered regions. In some stations in Eastern and Southwestern Bulgaria the increase exceeds 10% of the norm - Razgrad, Silistra, Shumen, Shabla, Varna, G, Toshevo, St. Oryahovo, Karnobat, Elhovo, Asenovgrad and Petrich. This increase is at the expense of the increase in September and October in these areas.

If analyze the average multiannual amounts of precipitation for the period 1986-2015 for all 56 representative stations for the agricultural zone of the country and their comparison with the same values for the reference period 1961-1990 shows a predominant increase of the annual amount by 20-100 mm as the largest increase of the average multiannual amount was measured in Razgrad. An increase of this indicator by 50-60 mm was registered in the stations Borima, Shumen, Varna and St. Oryahovo. During the study period there are also individual places where the measured average multiannual precipitation amount is less than the same during the reference period. The values of this decrease are 20-70 mm, the largest decrease was found in M. Tarnovo, and in Ivaylovgrad this decrease is 42, and in Kyustendil 45 mm, **Figure 4**.

3.2 Agro-climatic conditions during the period 1986-2015

3.2.1 Dates of a permanent transition of the average daytime temperatures across 5°C and 10°C in spring and autumn and temperature degree days

The steady transition of the average daytime temperature in spring and autumn at 5°C and 10°C determines the duration of the potential vegetation period (PVP) and the real vegetation period (RVP), respectively. For more accurate determination of these dates, 10 representative stations in the agricultural zone of the country were selected: in Northern Bulgaria - Knezha, Pavlikeni, Obraztsov Chiflik and General Toshevo; in southern Bulgaria - Plovdiv, Stara Zagora and Karnobat; and in Western Bulgaria - Sofia and Kyustendil. In the northern part of the country, the average date for a sustainable temperature transition across 5°C at spring is March 17th, and in the fall below 5 C is November 30th. The duration of PVP is 258 days. In Southern Bulgaria, these transitions are March 17th and December 3th respectively, and the duration of PVP is 261 days. In Western Bulgaria, represented by the high hollow fields of the Sofia, Pernik and Kyustendil fields, the transitions across 5°C in the spring on March 18th, and in the autumn on November 24th. The duration of PVP is 252 days.

The average multiannual dates of average daily temperatures transition across 10°C in spring and autumn are similarly determined and shown in **Table 1**.

The data on the average duration of the PVP and RVP during investigation period (1986-2015) and their deviations in comparison with the same values for the reference period (1961-1990) are presented graphically in **Figure 5**.

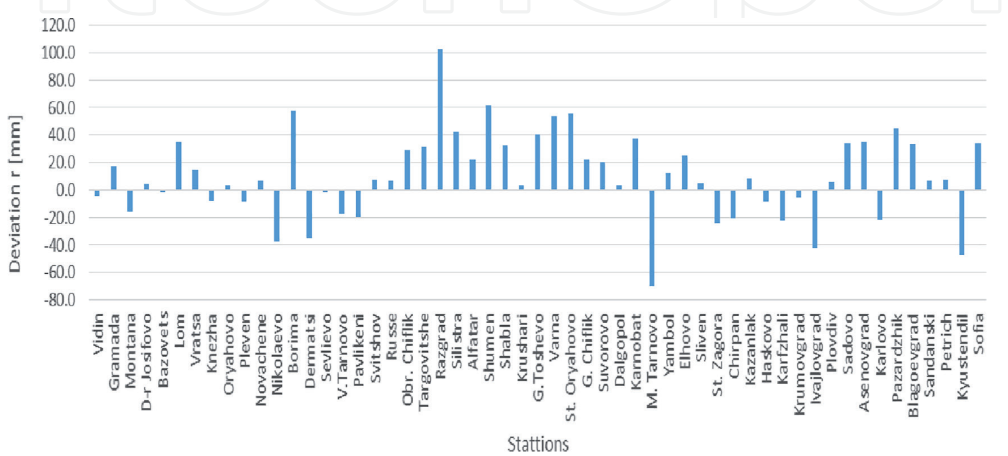

Figure 4.
Deviations between the average multiannual rainfalls for the period 1986-2015 compared to the same values in the reference period 1961-1990 for 55 representative stations located in the agricultural zone of Bulgaria.

Stations	5 °C spr [day]	5 °C spr [date]	5 °C out [day]	5 °C out [date]	Dur 5-5 °C [days]	10°C spr [day]	10 °C spr [date]	10 °C out [day]	10 °C out [date]	Dur 10-10 °C [days]
Knezha	80	21.03	334	30.11	254	105	14.04	305	1.11	201
Pavlikeni	72	13.03	332	28.11	259	99	9.04	311	7.11	212
Obr. Chiflik	74	15.03	333	29.11	259	103	12.04	309	5.11	206
G. Toshevo	78	18.03	338	4.12	261	110	20.04	310	6.11	200
Average for Nord Bulgaria	76	17.03	334	30.11	258	104	13.04	309	5.11	205
Karnobat	81	21.03	334	30.11	253	116	26.04	307	3.11	191
St. Zagora	80	21.03	339	4.12	259	104	14.03	312	5.11	208
Plovdiv	69	10.03	337	3.12	268	91	1.04	298	24.11	207
Average for South Bulgaria	76	17.03	337	3.12	260	104	14.03	306	2.11	202
Kyustendil	75	16.03	328	24.11	253	105	15.04	301	28.10	196
Sofia	79	20.03	328	24.11	252	107	17.04	306	2.11	199
Average for West Bulgaria	77	18.03	328	24.11	252	106	16.04	303	30.10	197
Average for the country	76	17.03	334	30.11	257	105	15.04	307	3.11	202

Table 1.
Average multiannual dates of continuous transition of air temperature over 5°C and 10°C in spring and autumn and duration of PVP and RVP.

The same calculations were made and for sums of active and effective temperatures above 5°C and 10°C are shown in **Figure 6**. Average multiannual sums of rainfall during PVP and RVP during investigation period and deviation in comparison with the referent period are shown in **Figure 7**.

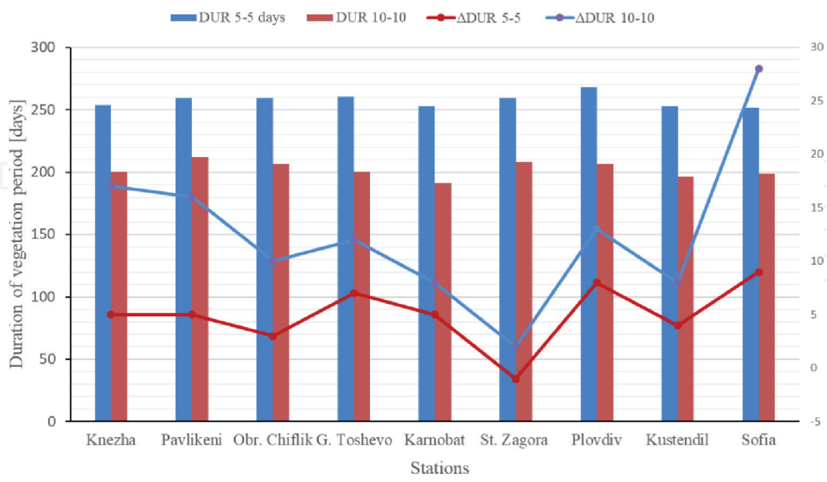

Figure 5.
Duration of vegetative season 5-5°C and 10-10°C for the period 1986-2015 and deviation of duration in comparison with 1961-1990.

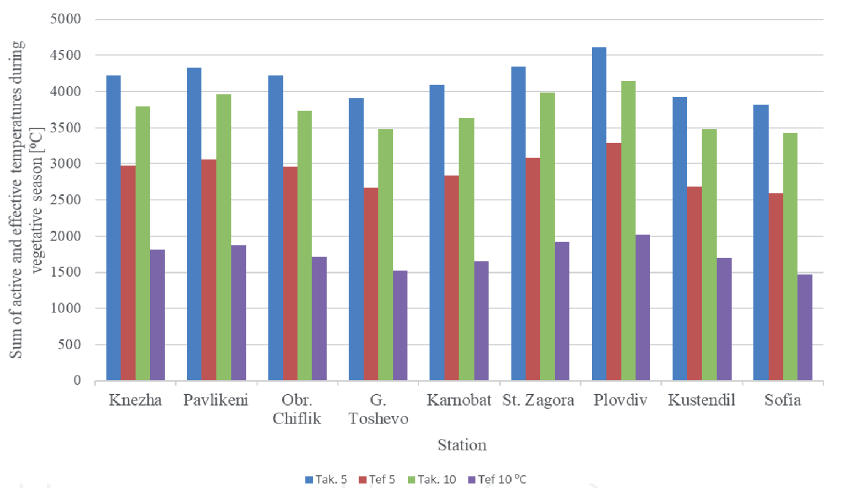

Figure 6.
Average multiannual values of accumulated active and effective temperatures over periods with a sustained transition of temperatures over 5°C and 10°C.

Figure 7.
Average multiannual rainfalls during the potential and real vegetative season in 1986-2015 and their deviation in comparison with the same seasons for the referent period 1961-1990.

4. Conclusions

The presented study is essential for a series of studies within the cited National Science Program and its project - Agricultural Ecosystems - adapted to climate change. The main results for this stage of project development are:

1. The values of the parameters of the climate change for the agricultural zone of the country during the studied period 1986-2015 for 56 meteorological and agrometeorological stations are obtained;

2. The sign and the amount of the deviations in the agricultural areas of the average multi-annual monthly values of the temperatures and the monthly amounts of the precipitation for the period 1986-2015 compared to the reference period 1961-1990 have been determined.

3. The data obtained show larger positive values of the temperature deviations in January, February, July, August and September and negative values of these deviations in December.

4. In case of precipitation - the positive and negative deviations by months are small in value, with the exception of Obraztsov Chiflik and Plovdiv. The non-uniform nature of the distribution of precipitation by seasons increases and dry winters, dry beginning of spring, rainy June and prolonged 70-90 days of summer drought, followed by wet October and November, become more frequent. These features of the climate are a serious challenge for specialists in genetics and selection in creating varieties that can withstand periods of drought;

5. The average long-term values of active and effective temperatures for the periods with t ≥ 5°C and t ≥ 10°C are obtained, which in most regions of the country are 3500-4000°C respectively and over 1500-2500°C respectively. This is a sure indication that thermal conditions are not a limiting factor and allow the cultivation of second crops, as well as the introduction of tropical crops with a short growing season;

6. The in-depth analysis of the hydrothermal conditions is a prerequisite to recommend, over the next 5 years, a gradual but large-scale increase in investments for the construction of modern irrigation systems. The results of the climate scenarios for the next 20-30 years show the tendency of the observed changes to continue, which will make impossible the efficiency of agricultural production under natural conditions of humidification of soils.

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