WATER RESOURCES IN BULGARIA UNDER CLIMATE VARIABILITY AND CHANGE

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Abstract: Variability of air temperature, precipitation and river runoff during the 20th century in Bulgaria was investigated. According to the GCMs used in the study air temperature is expected to increase between 2 to 5^{o}C till the end of the 21st century. In general, precipitation is expected to increase during the winter and to decrease during the warm half-year. It is obviously that there would be some changes in the water resources. Possible scenarios for air temperature, precipitation and annual runoff in Bulgaria assuming the current trends and also the last severe drought period were created, as well. On the first hand total precipitation during the potential crop-growing season will increase due to projected increase of the duration of the potential crop-growing season caused by warming. On the second hand however, the total precipitation amount during the actual crop-growing season is projected to decrease due to the GCM simulated decrease of precipitation and because of shortening the actual crop-growing season caused also by expected warming. The Decision Support System for Agrotechnology Transfer DSSAT was used to simulate the impact of climate variability and climate change scenarios on the parameters of the soil water balance during the maize growing season. Parameters of the water balance such as seasonal evapotranspiration, runoff and drainage and moisture at maturity were included within the analysis. Adaptation strategies and options in respect to water resources including irrigation under climate change are also listed at the end of the study.
Keywords: climate variability and change, river runoff, soil water balance, maize, DSSAT

WASSERBETRIEBSMITTEL IN BULGARIEN UNTER KLIMAVERÄNDERLICHKEIT UND KLIMAÄNDERUNG

Zusammenfassung: Änderungen in der Lufttemperatur, des Niederschlags und des Flussabflusses während des 20. Jahrhunderts in Bulgarien wurden analysiert. Entsprechend den GCM's, die in der Studie verwendet werden, wird erwartet, dass sich die Lufttemperatur zwischen 2 und 5^{o}C bis zum Ende des 21. Jahrhunderts erhöhen könnte. Im allgemeinen wird erwartet, dass sich der Niederschlag während des Winters erhöht und sich während des warmen Halbjahres verringert. Es ist offensichtlich, daß es dadurch zu Änderungen in den Wasserbilanzen (verschiedener Skales) geben wird. Mögliche Szenarios für Lufttemperatur, Niederschlag und den jährlichen Abfluss in Bulgarien, entsprechend dem gegenwärtigen Trend und den zuletzt aufgetretenen Trockenheiten, wurden zusätzlich erstellt. Erstens wird der Gesamtniederschlag während der potentiellen Vegetationsdauer wegen der verlängerten Vegetationsdauer durch die erwartete Erwärmung erhöht. Zweitens jedoch wird der Gesamtniederschlag in der aktuellen Vegetationsdauer der einjährigen Kulturpflanzen abnehmen, verursacht durch die in dieser Zeit erwartete Abnahme des Niederschlags und durch die wegen der Erwärmung verkürzte Wachstumsperiode (beschleunigte phänologische Entwicklung). Das Simulationsmodell für Kulturpflanzen DSSAT (Decision Support System for Agrotechnology Transfer) wurde benutzt, um die Auswirkungen der Szenarien der Klimaänderung auf die Wasserbilanz bei Mais zu simulieren. Die Parameter der Wasserbilanz wie saisonale Evapotranspiration, Abfluß, Drainage und Bodenfeuchtigkeit sind in der Analyse enthalten. Anpassungsoptionen und Strategien in Bezug auf Wasserressourcen einschließlich der Bewässerung unter Klimaänderung werden ebenfalls berücksichtigt.
Schluesselworte: Klimavariabilität und Klimaänderung, Abfluss, Bodenwasserbilanz, Mais, DSSAT.

1. Introduction

The Earth's climate has exhibited marked "natural" variations and changes, with time scales ranging from millions of years down to one or two years. The global average surface temperature increased over the 20th century by 0.6±0.2°C. Globally it is likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record since 1861 (e.g. IPCC WG1 TAR, 2001). The concentration of greenhouse gases in the atmosphere has continued to increase. This is largely due to human activities, mostly fossil fuel use, land-use change, and agriculture. Emissions of greenhouse gases and aerosols continue to alter the atmosphere in ways that are expected to affect the climate. The atmospheric concentration of CO_2 has increased by 31% since 1750 (e.g. IPCC WG1 TAR, 2001).

Europe has a very diverse hydrological background, reflecting its varied climate and topography. In the south, including Bulgaria, there is very significant variation in flow through the year, with long, dry summers (e.g. IPCC WG2 TAR, 2001). Major European rivers such as the Rhine, Rhone, Po, and Danube distribute water from the “water tower” of the Alps. Superimposed on this varied hydrological base is a wide variety of water uses, pressures, and management approaches. A succession of droughts has illustrated southern Europe’s vulnerability to hydrological extremes. There are many other water-related pressures on Europe’s environment, however (e.g. Stanners and Bourdeau, 1995), such as increasing demand for water, particularly in the south, and subsequent increases in abstractions (e.g. IPCC WG2 TAR, 2001).

The objective of this study was to assess some aspects of water resources (precipitation, river runoff, components of the soil water balance under maize growth and development) in Bulgaria under climate variability during the 20th century and projected climate change for the 21st century.

2. Material and Method

Daily data for mean air temperature and precipitation from 16 weather stations across the country with elevations below 800 m were gathered for the period 1901-2000 (Figure 1). Weather data had been previously evaluated for erroneous and missing values. All observed meteorological data that were used in this study were provided by the weather network of the Bulgarian National Institute of Meteorology and Hydrology. The obtained time series of air temperature and precipitation anomalies were smoothed by a 5-year running average. Two non-parametric tests were used in most cases in order to determine the possible existence of statistically significant trends of air temperature and precipitation assuming a 5% probability level – the Mann-Kendall and Spearman rank statistics (e.g. WMO, 1990).

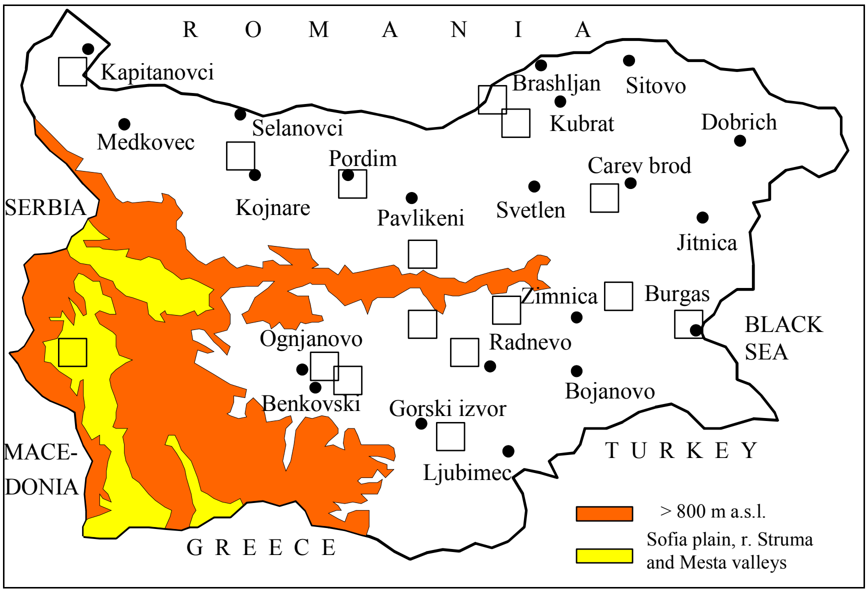

Figure 1. Spatial distribution of weather (the squares) and experimental crop variety (the points) stations, used in the study

Three hydro-climatic regions are detached in Bulgaria: Danubian catchment basin (North Bulgaria), Black Sea catchment basin (East Bulgaria) and Mediterranean catchment basin (South Bulgaria). The river runoff was investigated for the period 1935-1997 on the base of 152 hydrological stations, situated in the major river valleys of the separate catchments. Subsequently in the final stage of the treatment, only the last basin hydrological stations (on their base can be obtained conclusions about the chronological flow changes) were used. It can be pointed out that from 1910 till 1939 about 50 operating hydrological stations were created in Bulgaria. After that period a gradual establishment of new hydrological stations started, so their number was highest for the period 1950 – 1959: 59 stations. The time series of the existing stations were prolonged on the base of complex information and respective calculations.

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project has developed a computerized Decision Support System for Agrotechnology Transfer (DSSAT) which integrates soil, weather and crop data bases with dynamic crop simulation models (e.g. Tsuji et al., 1998). System analysis and validated crop simulation models provide an alternative method for representing the crop production problem. Using models, crop growth and development can be evaluated under a wide range of management and environmental conditions. A validated crop model may be used to evaluate alternative strategies for improving farm performance using computer programs especially designed for this purpose. These programs facilitate running crop models for different soil types, planting dates, planting densities, varieties, irrigation amounts and dates, strategies, fertilizing timing, depth, and type, over several seasons to determine the most promising and least risky combinations of site management (e.g. IBSNAT, 1993; Tsuji et al., 1994). Climate variability and change impacts including evaluation of crop water use are among the most helpful DSSAT applications.

The greatest part of the national maize production is concentrated in the areas with elevation below 800 m. The DSSAT CERES model for maize was previously (e.g. Alexandrov and Eitzinger, 2001) calibrated and validated for the agrometeorological conditions of 21 experimental crop variety stations across the country (Figure 1). Generally, the results, which had been obtained in a previous study, indicated relatively satisfactory performance of the CERES maize model in a fully specified environment (e.g. Alexandrov and Eitzinger, 2001). In this simulation study a maize hybrid with a medium crop-growing season was used. Standard agrotechnological data such as planting date, depth and density as well as fertilizing amounts were averaged for the last years and applied as input within the CERES model. The automatic irrigation option of the CERES maize model was selected for irrigation applications, so that water would not be a limiting factor in the simulation. Respective soil profiles, applicable for the locations used in this study, were also applied as required model input.

Thirty years of current climatic data are normally used in developing a baseline climate scenario. A 30-year period is considered adequate to include a good representation of wet, dry, warm, or cool periods. The so called "current climate" was therefore based on the period 1961-1990, according to the recommendations by the World Meteorological Organization (WMO). Daily weather data of maximum and minimum air temperature, precipitation and simulated (e.g. Georgiev and Slavov, 1993) solar radiation for the period 1961-1990 were gathered from the weather stations, nearest to the selected experimental crop variety stations.

Most climate change studies use estimates of regional climate change from global circulation models (GCMs) (e.g. IPCC, 1997; Watson et al., 1996). The major advantage of using GCMs as the basis for creating climate change scenarios is that they are the main tool that estimates changes in climate due to increased greenhouse gases for a large number of climate variables in a physically consistent manner. At least three GCMs should be used for creating regional climate change scenarios to highlight related uncertainties. Using one GCM scenario can create the impression of a prediction, and using two GCMs sometimes shows only minor variance among scenarios (e.g. ANL, 1994).

The 30-year averaged transient GCM monthly meteorological outputs were provided for this study by the IPCC DDC (Intergovernmental Panel on Climate Change Data Distribution Center) for the periods: 1961-1990, 2010-2039, 2040-2069 and 2070-2099 (the last 3 periods are referred to as 2020s, 2050s and 2080s). The GCMs, which are used in the study, include the models from the Max-Planck Institute for Meteorology (ECHAM4), UK Hadley Center for Climate Prediction and Research (HadCM2), Canadian Center for Climate Modeling and Analysis (CGCM1), Australian Commonwealth Scientific and Industrial Research Organization (CSIRO-Mk2b) and Geophysical Fluid Dynamics Laboratory (GFDL-R15). The simulated results from the "business as usual" scenario, greenhouse gas and sulphate aerosol forced GCM experiments are used in the current study (e.g. IPCC DDC, 1999). The outputs for air temperature, precipitation, and solar radiation of the GFDL-R15 model for the 2080s were not available and the ECHAM4 outputs for the 2050s and 2080s do not account the cooling aerosol effect. In order to interpolate GCM model output data to a specific weather station, linear averaging based on the inverse distances between the specific point and the GCM grid points from the four nearest grid points was used. Without interpolation, sudden changes in climate could occur in impacts at the boundaries of GCM grid boxes (e.g. ANL, 1994).

3. Results and discussion

3.1. Climate and river runoff long-term variability during the 20th century

A minimum of annual temperature in the country appeared in the 1900s. In the earlier 1940s there was also a cold spell. There were no significant air temperature fluctuations in the 1970s and 1980s. A slightly warming has been observed since the middle of 1980s. Generally, there is no significant overall trend of mean annual air temperature in Bulgaria for the 20th century. (Figure 2). There has been an obvious increasing trend in air temperature during the period April-September since the end of the 1970s. An insignificant increase in air temperature during the cold-half of the year (October-March) is observed. The direction to a slight increase in air temperature is most obvious in winter (January-March) due to significant warming in January and February. Spring (April-June) is also tending to be warmer at the end of the 20th century. Summer air temperatures (July-September) were lower in the 1970s.

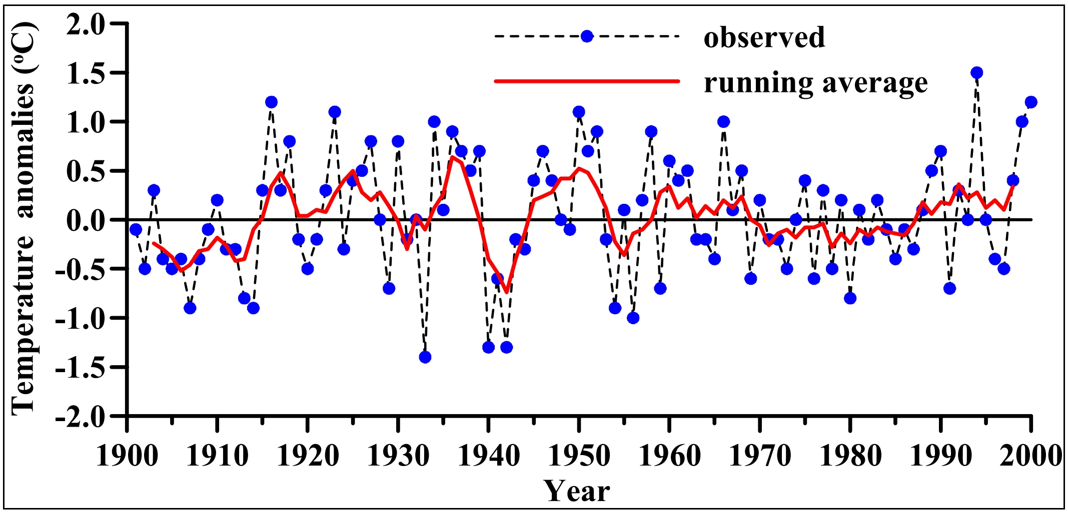

Figure 2. Long-term anomalies of annual air temperature, relative to 1961-1990

Water resources are related to most meteorological elements, however the highest correlation is of course between water resources and precipitation. Dropped down on a respective area, precipitation is transformed into runoff through the influence of the nature-landscape, hydrological and antropogenic complexes. Annual precipitation in Bulgaria varied considerably from year to year during the 20th century (Figure 3). In some years, very low annual precipitation caused droughts of different intensities. The country has experienced several drought episodes during the 20th century, most notably in the 1940s and 1980s.

Drought spells in the 1940s and 1980s were observed everywhere across the country. Drought in Bulgaria was most severe in 1945 and especially in 2000 with precipitation less than 30% of current climatic values (Figure 3). The most significant wet spell occurred in the 1950s. It was followed also by relatively high precipitation values in the 1960s and 1970s. Generally, the variations of mean annul precipitation in Bulgaria showed an overall decrease.

There was a decreasing trend in precipitation during the period from April to September from the end of 1970s. 1985, 1988, 1993 and 2000 are among the driest warm-half years. Precipitation was below the 1961-1990 average for 14 of the last 20 years of investigation (Figure 4a). There is no statistically significant overall trend in precipitation during the cold half of the year despite of the decreasing trend, which was observed from the end of 1960s till 1995 (Figure 4b). Winter precipitation deficit was observed during the last decade. Both spring and summer as well as autumn precipitation had a tendency to decrease during the 20th century. February, April and December had an increase direction in precipitation, while January, June, July and October have had precipitation reductions.

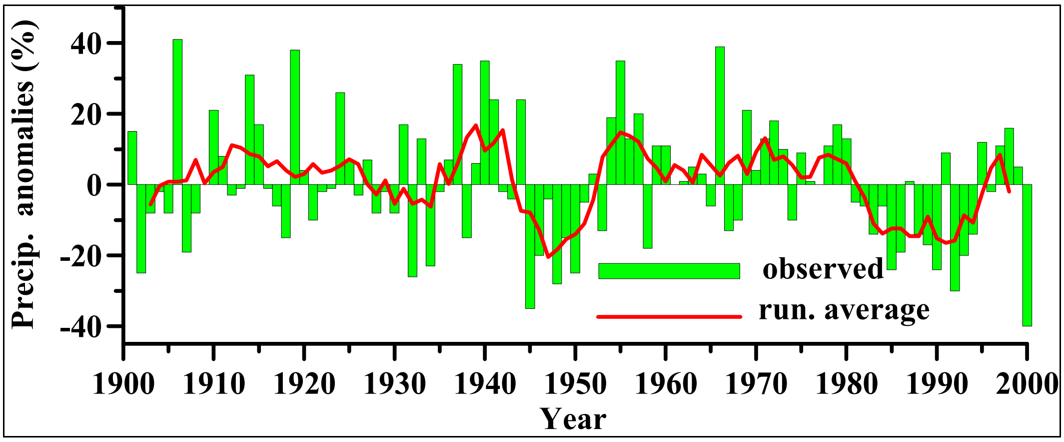

Figure 3. Long-term anomalies of annual precipitation, relative to 1961-1990

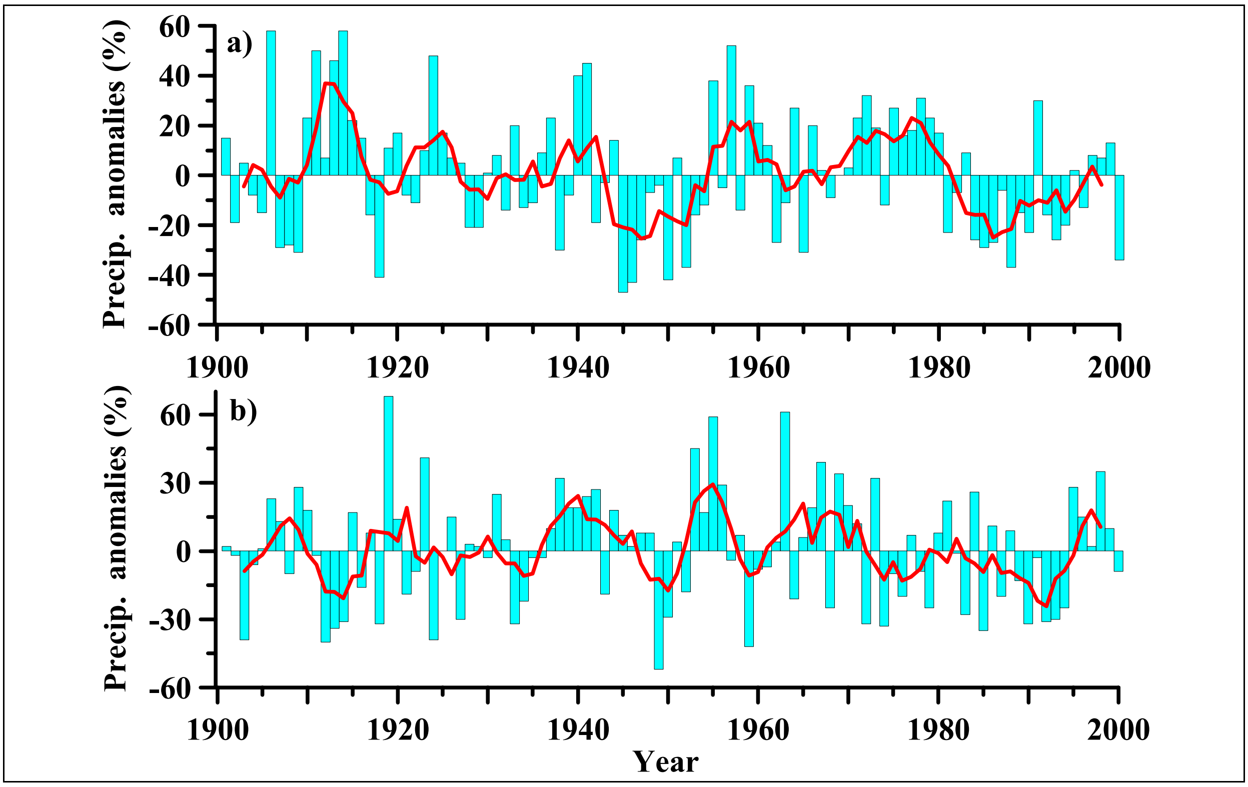

Figure 4. Long-term anomalies of precipitation during the periods: April-September (a) and October-March (b), relative to 1961-1990

Figure 5 represents anomalies and 5-year running average of the annual river runoff in North Bulgaria from 1935 to 1997. The running averages for the runoff in East Bulgaria and South Bulgaria are also shown. It could be seen that the runoff anomalies are following the anomalies of annual precipitation shown in Figure 3. There were significant runoff reductions at the end of the 1940s and especially during the last two decades (1980s and 1990s). According to the obtained results the runoff status was worst in South Bulgaria (Figure 5).

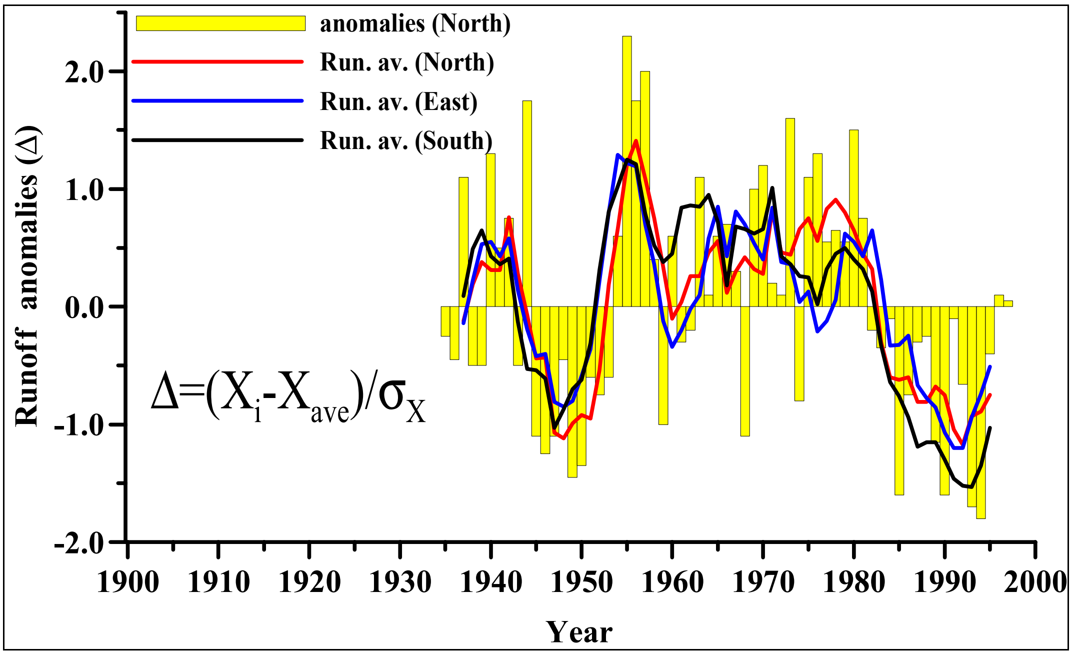

Figure 5. Anomalies of annual river runoff in Bulgaria, relative to 1961-1990

The period in which runoff and precipitation in Bulgaria were below the norm is 1982-1994. It is characterized with 31% lowering of the runoff in Bulgaria towards the norm from the period 1980-1996 (with -26% compared to the trend) and corresponds to rarely return. The relative lowering toward the trend by absolute values is highest in North Bulgaria (-31%) and lowest in East Bulgaria (-29%). The depressions in the dry spell are most strongly expressed in 1990, 1993 and 1994 when an absolute minimum of the period 1980-1995 occurred: from 0.31 till 0.43 relative to the norm, with very low return probability. The tendencies of the annual runoff variability in North Bulgaria, East Bulgaria and South Bulgaria, were determined on the basis of linear trend analysis: $Grad_Q$ (North Bulgaria) = -0.0480; $Grad_Q$ (East Bulgaria) = - 0.0400; $Grad_Q$ (South Bulgaria) = - 0.2525. The characteristics of the examined generalized series in relation to their outlined secondary and basic phases as well as cycles are given in Table 1. The evaluations of the grade of revealing in respect to the relevant phases are shown in Table 2.

The last drought period (1982-1994) affected also considerably groundwater in Bulgaria (e.g. Bojilova and Orehova, 2000). Most of springs were with reduced discharge and wells showed lower water levels. The reduction of spring discharge was determined to be up to 20-30%. The chronological structure of the drought was similar to this of the river discharge. Generally, the groundwater anomalies were following the river runoff anomalies. For North Bulgaria and South Bulgaria the groundwater decrease was most severe in 1994 as well as in 1992 and 1993. The highest observed decrease in East Bulgaria occurred in 1989 and 1994, respectively.

The above findings are consistent with the results obtained in previous studies (e.g. Alexandrov, 2000; Koleva, 1993; Koleva and Iotova, 1994. Genev, 1998, 1999, 2000a,b).

Table 1. Characteristics of runoff Q (m^3/s) time series in Bulgaria

Region	Secondary phases (number)	Basic phases (number)	Number of cycles (periods)	t_r	Significant cycles determined by $S(\lambda)$
North Bulgaria	7	4	[(-) 9, (+) 28] (1945 - 1981)	6.7	60 ; 30; 20 ; 15
East Bulgaria	8	3	[(-) 17, (+) 30] (1935 - 1981)	12.0	60 ; 30; 20; 15; 12
South Bulgaria	6	4	[(-) 9, (+) 31] (1942 - 1981)	6.0	60; 30; 20

Legend: t_r - average period of the correlation function; $S(\lambda)$- spectral function

Table 2. Deviations (in %) of runoff Q (m^3/s) time series from the norm of manifested phases

Region	Period										
	1935 1944	1945 1953	1954 1958	1959 1962	1963 1967	1969 1973	1975 1981	1982 1984	1985 1995		
	max	min	Max	const	max	max	max	const	min		
North Bulgaria (%)	9.8	32.9	45.6	8.9	18.6	26.1	30.2	6.7	31.3		
Region	Period										
	1935 1936	1937 1942	1943 1951	1952 1958	1959 1962	1963 1967	1969 1973	1974 1979	1980 1981	1982 1984	1985 1995
	min	max	min	max	min	max	max	min	max	const	min
East Bulgaria (%)	26.5	25.9	36.5	47.8	26.9	40.4	40.5	10.2	101.1	2.6	45.1
Region	Period										
	1935 1941	1942 1950	1951 1952	1953 1958	1960 1963	1965 1967	1969 1973	1975 1981	1982 1984	1985 1995	
	max	min	const	max	max	max	max	max	const	min	
South Bulgaria (%)	11.6	19.4	0.6	29.7	33.5	16.9	28.3	11.8	7.6	36.7	

3.2. Simulation of soil water balance components for the period 1961-1997

The DSSAT Seasonal Analysis program was used to simulate different components of the soil water balance during the crop-growing season of maize from 1961 to 1997. Variations of seasonal number of irrigation applications and totals, precipitation, evapotranspiration, surface runoff and water drainage were analyzed for every experimental crop variety station across the country (Figure 6). The numbers of irrigation applications vary around their averages (between 8 to 11 in North Bulgaria and from 9 to 12 in South Bulgaria). There were 14 irrigation applications at experimental crop variety station Kubrat in 1996 due to very low maize-growing seasonal precipitation (Figure 6a,c). The minimum of irrigation applications, for example at experimental crop variety station Ognjanovo (South Bulgaria) was 6 in 1961 and 1983 because of significant precipitation totals (400 mm). Naturally, there is strong correlation between irrigation and precipitation amounts – seasons with lower precipitation were characterized with higher irrigation totals. The total irrigation amount in 1996 which was necessary for normal maize growth, development and yield formation in the country was around 350 mm.

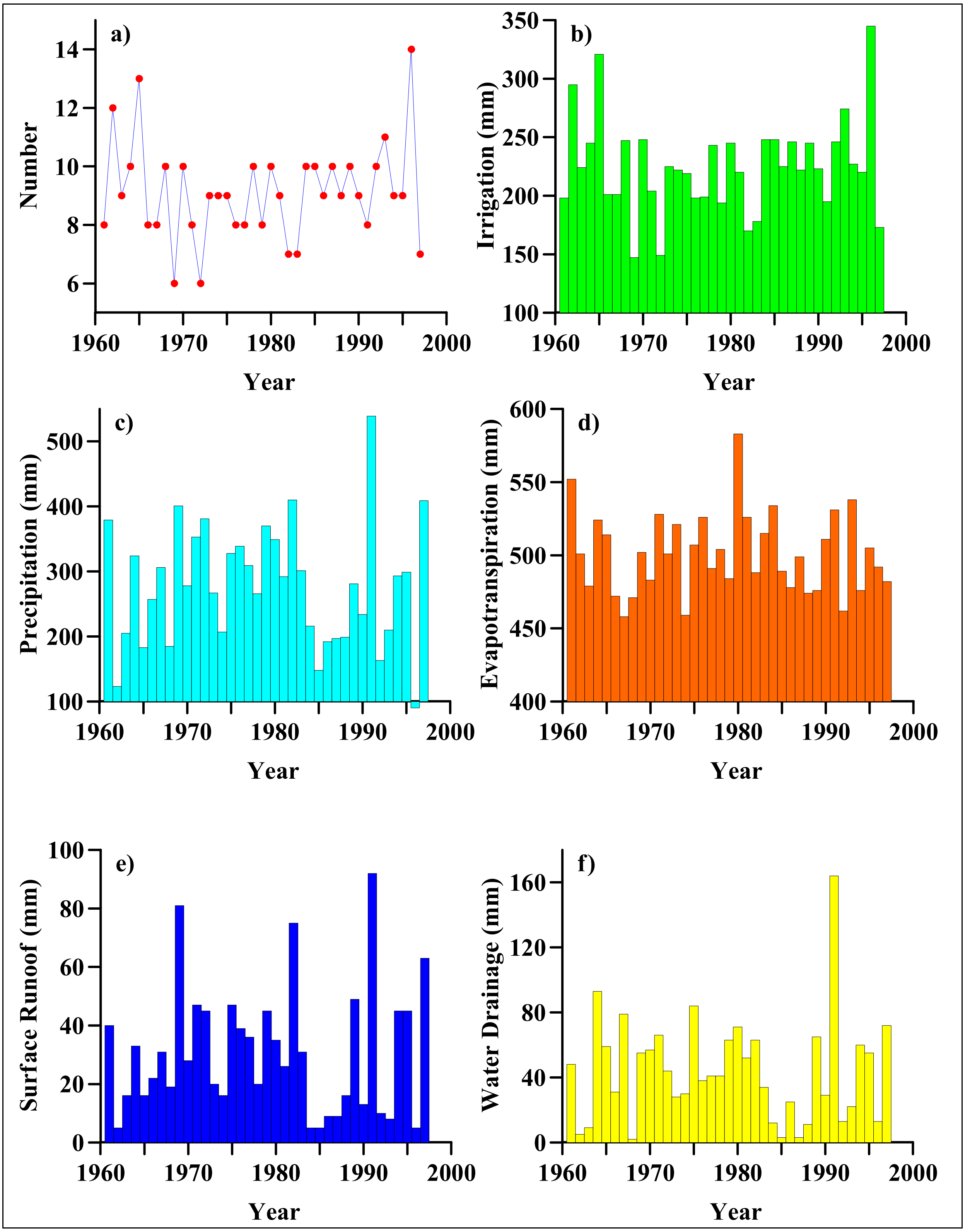

Figure 6. Variations of maize-growing seasonal number of irrigation applications (a), irrigation total (b), precipitation (c), evapotranspiration (d), surface runoff (e) and water drainage (f) at experimental crop variety station Kubrat (North Bulgaria, 1961-1997)

The water demands for irrigation applied in South Bulgaria were higher than the irrigation amounts in North Bulgaria due to less precipitation and higher air temperatures. Seasonal precipitation varied considerably during the investigated period – from less than 100 mm to more than 500 mm. The variations of evapotranspiration are a function of precipitation and irrigation variations. The evapotranspiration variations were higher in North Bulgaria than in South Bulgaria. The variations of surface runoff were following precipitation variations (Figure 6c,e). Seasonal water drainage was above 160 mm in 1991 at experimental crop variety station Kubrat due to higher seasonal precipitation, followed by significant seasonal runoff. However in some years, water drainage was very low, for example in 1968, 1985 and 1985 (Figure 6f).

The anomalies of the water balance components during the maize-growing season were compared to the 1961-1990 normals. There is an obvious increasing trend in the number of irrigation applications during the last two decades. For example, there have been only positive anomalies at experimental crop variety station Zimnica (South Bulgaria) since 1983. Most of the irrigation totals anomalies were also positive during the last considered years due to significant precipitation reductions across the country. Most of the seasonal surface runoff anomalies during the period 1961-1997 were negative because of some significant positive anomalies and especially lower precipitation in the 1980s and 1990s. There is no tendency in evapotranspiration anomalies – they varied above or below the normals for the period 1961-1990. The same behavior had the anomalies of seasonal water drainage.

3.3. Trend scenarios for air temperature, precipitation and runoff

The results obtained for the 20th century show there would be some changes in the water resources in the country. Table 3 represents five scenarios for future air temperature, precipitation and annual runoff in Bulgaria assuming the current trends and also the last severe drought period. Annual river runoff is expected to decrease up to 14% in 50 years and to be 20% less at the end of the century in respect to the current climate. In case that a severe drought period is also assumed within the study, the expected decrease of annual runoff in Bulgaria is between 39 and 45%. Some studies applying directly GCMs outputs are also projected a runoff decrease in the country between 15 and 50% (e.g. *Strzepek and Yates, 1997*).

Table 3. (Pessimistic) scenarios for future development of hydrological process in Bulgaria

Element	Model 1 Trend 2050 T1	Model 2 Trend 2100 T2	Model 3 Drought 1982-1994 D	Model 4 T1+D	Model 5 T2+D
Air temperature	+0.5°C	0.7°C	0.2°C	0.5°C	0.7°C
Precipitation	-4%	-6%	-12%	-15%	-17%
Runoff	-14%	-20%	-31%	-39%	-45%

3.4. GCM climate change scenarios for the 21st century

The transient GCMs predicted that annual temperatures in Bulgaria are to rise between 0.7° (HadCM2) and 1.8°C (GFDL-R15) in the 2020s. However, the HadCM2 model simulated a slight decrease in air temperature for November in the 2020s. A warmer climate is also predicted for the 2050s and 2080s, with an annual temperature increase ranging from 1.6° (HadCM2) to 3.1°C (GFDL-R15) in the 2050s, and 2.9° (HadCM2 and CGCM1 models) to 4.1°C (ECHAM4) in the 2080s. Warming is projected to be higher during the summer in the 2080s.

The CGCM1 model predicted an increase in annual precipitation in the 2020s and 2050s. The GFDL-R15 model projected a decrease in precipitation in May, June and July in the 2020s and 2050s. The ECHAM4, HadCM2, and CSIRO-Mk2b models simulated a decrease in monthly, seasonal and annual precipitation in the 2080s. The changes in monthly solar radiation are expected to vary between –10 and 10% during the next century. An increase of solar radiation is expected during the cold half of the year, based on the ECHAM4 model runs.

3.4. Impact of GCM climate change scenarios on crop (maize) water use

On the first hand, total precipitation during the potential crop-growing season will increase due to projected increase of the duration of the potential crop-growing season caused by warming. On the second hand however, the total precipitation amount during the actual crop-growing season is projected to decrease due to the GCM simulated decrease of precipitation and because of shortening the actual crop-growing season caused also by expected warming. In the middle of the 21st century the ECHAM model simulates a decrease of the above growing season between weeks and a month. As a result of projected warming and precipitation deficit the simulated irrigation demands increased, however the total water amount for irrigation decreased due to considerable shortening of the maize crop-growing duration (Table 4). As a result of the irrigation decreasing and shortening of the growing season, seasonal evapotranspiration is also expecting to decrease at the ECHAM4 2050s up to about 20% (Figure 7).

Table 4. Changes (in %) of seasonal irrigation of maize under the GCM climate scenarios

Station	EC	Ha	CC	CS	GF	EC	Ha	CC	CS	GF	EC	Ha	CC	CS
	2020s					2050s					2080s			
Benkovski	-12	-8	-20	-17	-4	-22	-23	-32	-26	-15	-32	-39	-35	-35
Bojanovo	-16	-8	-23	-19	-12	-25	-19	-35	-29	-18	-35	-38	-37	-40
Brashljan	-14	-13	-20	-17	-11	-25	-26	-33	-29	-17	-34	-45	-38	-40
Burgas	-14	-9	-21	-16	-11	-24	-17	-32	-28	-22	-35	-38	-38	-40
Carev brod	-17	-14	-25	-21	-14	-26	-26	-37	-31	-22	-38	-47	-41	-45
Dobrich	-16	-19	-20	-18	-18	-23	-27	-33	-28	-24	-37	-48	-41	-41
Gor. Izvor	-15	-7	-23	-19	-6	-24	-24	-36	-29	-15	-34	-42	-36	-37
Jitnica	-14	-16	-21	-16	-16	-23	-25	-34	-29	-24	-36	-47	-40	-42
Kapitanovci	-15	-13	-21	-21	-7	-26	-33	-36	-31	-17	-35	-46	-36	-40
Kojnare	-17	-14	-23	-21	-9	-29	-32	-36	-32	-20	-37	-51	-42	-44
Kubrat	-16	-13	-21	-19	-12	-26	-27	-34	-31	-17	-35	-47	-39	-41
Ljubimec	-15	-8	-21	-17	-12	-26	-18	-33	-28	-20	-35	-34	-37	-39
Medkovec	-15	-14	-21	-21	-11	-27	-30	-34	-30	-20	-36	-48	-38	-38
Ognjanovo	-12	-8	-20	-17	-4	-22	-23	-32	-26	-15	-32	-39	-35	-35
Pavlikeni	-12	-11	-18	-19	-4	-24	-26	-30	-29	-11	-29	-43	-34	-36
Pordim	-12	-11	-18	-19	-4	-21	-26	-30	-29	-11	-29	-43	-34	-36
Radnevo	-15	-7	-24	-18	-6	-26	-24	-37	-28	-14	-35	-42	-37	-38
Selanovci	-16	-13	-22	-22	-9	-28	-31	-37	-33	-18	-37	-49	-41	-43
Sitovo	-13	-11	-16	-16	-7	-22	-22	-28	-26	-15	-32	-40	-32	-37
Svetlen	-18	-15	-26	-21	-15	-28	-28	-38	-34	-24	-38	-48	-42	-46
Zimnica	-18	-11	-26	-20	-15	-28	-22	-38	-32	-23	-39	-45	-42	-44

Legend: EC – ECHAM4; Ha – HadCM2, CC – CGCM1, CS- CSIRO-Mk2b, GF - GFDL-R15

4. Conclusions

The study results show the currently observed decreasing trend of water resources in Bulgaria is expected to continue into the future due to warming and especially precipitation reductions. As a result of the current and expected water shortage conditions in Bulgaria, general and specific strategies can be recommended (e.g. *Vodno delo, 2001*): saving water resources; overcoming water-supply crisis; securing water for irrigation and related efficiency; formation of knowledge and sense of water resources saving.

The save of water resources could include, for example, providing water resources management based on reservoir principle, allowing maximum and effective utilization of water resources; additional runoff regulation; providing minimum runoff into rivers; conserving or liquidation of drillings, regarding not utilized groundwater; providing waste water purification; etc.

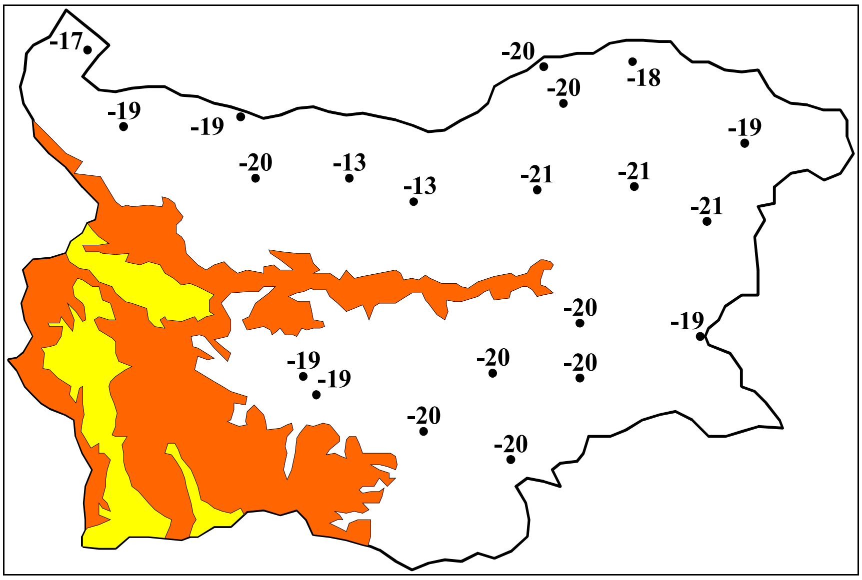

Figure 7. Changes (in %) of total evapotranspiration during maize growing season under ECHAM4 climate change scenarios for the 2050s

To overcome the water-supply crisis the following could be implemented: building water reservoirs to catch spring high water; reconstruction of water-supply networks; appropriate water-supply zoning and provision of necessary equipment providing utilization of the whole water input; completing buildings/equipment/etc. of local importance for solving the problems of water-supply for drinking and daily wants; etc.

As a result of expected warming and precipitation deficit, changes in water use of maize in Bulgaria are projected. The simulated irrigation demands increased, however the total water amount for irrigation decreased due to considerable shortening of the maize crop-growing duration. That result does not mean avoiding the expected problem with water scarcity. It should be noted that decreasing the growing season leads to decrease of maize yield, that is why maize hybrids with longer growing duration should be grown under expected warming. Therefore, the problem concerning the water applied for crop irrigation definitely exists. The adaptation options for an increase of the irrigation effectiveness should include: introduction of irrigation technologies with decreased water charges and without losses under water transport and spreading; restoring and reconstruction of the already constructed hydromeliorative fund; reconstruction and building of new test-pits for utilization of groundwater; utilization of river water and precipitation for moisture storing irrigation during the winter season; utilization of waste water and drainage system water.

Finally, the formation of knowledge and sense of water resources saving may include active media policy; development of a new attitude of population to water; development of regular rubrics informing population about current status of water resources; public control on water thefts and waste; involving non governmental organizations in the problems of water saving and waste.

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