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Drought in the Bulgarian low regions during the 20th century

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With 7 Figures

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Summary

In this study, the long-term variations in precipitation in the Bulgarian low regions: the Danube Plain in north Bulgaria and the Thracian Lowland in south Bulgaria, were analysed. Some quantitative criteria were also used to compare drought frequency and intensity between the two regions and between different years. Analyses of the rainy conditions in the selected regions during the 20th century were carried out. The last century can be split into several wet and dry sub-periods with duration of 10–15 years. The long-term variations of the Ped and PAI drought indices are also considered in the paper. In addition, the drought conditions in the Danube Plain and the Thracian Lowland were estimated using the de Marton aridity index. The results obtained show that the latter index can also be applied for the detection of drought periods in the regions considered.

1. Introduction

Drought is undoubtedly one of the worst natural hazards (e.g. Wilhite, 2000). Not only does it affect the social and economic life of millions of people every year, but from time to time the existence of a whole nation is endangered. Its beginning is subtle, its progress is insidious and its effects can be devastating. Drought may start at any time, last indefinitely and may attain many degrees of severity (e.g. WMO, 1975).

Investigations of drought are carried out all over the world. However, because of the complexity of this natural phenomenon, a uniform methodology for implementing drought studies has not yet been developed, although some indices of drought are widely used. Drought classification is one basic reason for this dearth of methodologies. Typically, there are five types of drought: soil drought, atmospheric drought, soil-atmospheric drought, hydrological drought and socio-economic drought (e.g. AMS, 1997; Farago et al., 1989; Maracchi, 2000; Ped, 1975; Wilhite, 1993, 2000; Wilhite and Glantz, 1985; WMO, 1975). Soil drought occurs during long periods without precipitation. When this type of drought occurs, soil moisture decreases considerably, and crops and natural plant communities suffer. Reduced precipitation and high air temperatures are observed during atmospheric droughts when hot, dry winds are frequent. The high rates of evapotranspiration during these atmospheric conditions, disrupts the water balance of plants. However, crop damage is most extensive during soil-atmospheric droughts. Long-term droughts that reduce river runoff, underground sources of water, and moisture are categorised as hydrological droughts. Common to all types of drought is a lack of precipitation (e.g. WMO, 1993).

At any given time, at least one nation in the world is being adversely affected by drought. Although drought is a natural component of the climate in arid and semi-arid areas, it can occur in areas which normally receive adequate precipitation (e.g. Li and Makarau, 1994; WMO, 1975). Hydrometeorological data indicates that droughts have occurred frequently through the last century in Europe and that they are part of the climatic cycle, particularly in southern Europe (e.g. Klein and Wijngaard, 2000; Schuurmans, 1995). An analysis of moisture extremes over Europe shows strong decadal-scale variability in drought frequency, with the 1940s and early 1950s experiencing widespread and severe droughts, a pattern repeated in 1989 and 1990 (e.g. Briffa et al., 1994). The summer of 1992 was extremely hot and dry in central and eastern Europe (e.g. Schellnhuber et al., 1994), as was the summer of 1995 throughout much of western Europe (e.g. Palutikof et al., 1997). More recently, in the summer of 2003 many parts of Europe were affected by heat waves and severe drought.

One of the first comprehensive investigations of the drought in Bulgaria was carried out by Ganev and Krastanov (1949, 1951). They used data derived from various times within the period 1887–1949 from 47 weather stations, agro-meteorological newsletters, and synoptic maps. According to Ganev and Krastanov (1951), drought in Bulgaria occurred most frequently in autumn. Sabeva et al. (1968) investigated droughts between 1896 and 1960. Recently some results on drought analysis are given by Koleva et al. (2004). In this paper the frequency and intensity of the drought periods in the Bulgarian low regions: the Danube Plain (north Bulgaria) and the Thracian Lowland (south Bulgaria), are studied.

2. Data and methods

2.1 The Bulgarian climate

Bulgaria is situated on the Balkan Peninsula in southeast Europe. The country has an area of about 111,000 km^2 and consists of very diverse relief. Lowlands (0 to 200 m) cover 31.45% of the country, hills (200 to 600 m) 40.90%, highlands (600 to 1600 m) 25.13%, and mountains over 1600 m 2.52%. The local and regional climate is highly influenced by latitude, altitude, topography, proximity to the Black Sea and the dominant atmospheric circulation. Bulgaria is located on the transition between two climatic zones – moderate continental and Mediterranean. The annual course of precipitation is different in these two zones. There are significant differences in the radiation balance in winter and summer, caused by latitudinal insolation. As a result, the thermal conditions are characterised by well-pronounced seasonality. The summer is warmer and the winter is relatively cold. The autumn is slightly warmer and drier than the spring. This seasonality is modified, to some extent, by the circulation conditions and by orographic influences. The zonal extension of the Balkan Mountains and Rila-Rhodope Mountain Massif is a natural barrier to invasions of cold air masses towards the southern part of the country. These mountains are also obstacles to warm air masses which overflow the mountains, and the foehn effect is observed over their northern slopes. Bulgaria is split into north and south regions by the Balkan Mountains, which have a strong effect on the temperature regime.

Annual precipitation in Bulgaria ranges from 550–600 mm in the lowest elevations of the country to 1000–1100 mm in the highest elevations. The precipitation distribution across Bulgaria is mainly caused by synoptic atmospheric conditions, which are influenced considerably by topography. Insufficient precipitation is climatically common in some parts of Bulgaria, leading some scientists to speculate that the country has a tendency toward drought. According to the Budyko drought coefficient, the country is characterised by insufficient moisture. This coefficient is calculated using data from the annual radiation balance and total annual precipitation (e.g. Budyko, 1974). The Budyko drought coefficient is between 1.5 and 1.8 for Bulgaria.

Drought in Bulgaria is usually a result of long periods with low precipitation under anticyclonic weather conditions. It can occur in any month of the year. The weather conditions during drought are characterised by decreased precipitation, high air temperatures, low humidity, and warm, strong winds. Long-term drought can negatively impact the water balance of plants, causing unstable crop physiological conditions and low crop yields, as well as threaten natural ecosystems and water supplies (e.g. Slavov et al., 2004).

2.2 Experimental data

Monthly precipitation data from 36 weather stations as well as monthly average air temperature data from 17 weather stations were used in the

Fig. 1. Weather stations in Bulgaria used in the study; Δ – precipitation, • – air temperature

study. These stations are located in the Danube Plain and the Thracian Lowland (Fig. 1). The altitude of these weather stations does not exceed 300 m a.s.l. The majority of the stations have meteorological data for the period 1901 to 2000. All data used in this study belong to the weather database of the Bulgarian National Institute of Meteorology and Hydrology. The data were previously controlled for errors and homogeneity (e.g. Alexandrov et al., 2004). Missing monthly values of precipitation and average air temperature were replaced by interpolating information from neighbouring weather stations.

2.3 Methods

Precipitation distribution is one of the basic identifiers of drought occurrence in a given region. However, the distribution of additional meteorological elements should also be taken into account in order to describe the degree of drought. For example, the distribution of air temperature is an especially important characteristic for drought classification. Usually, average precipitation for a given region is calculated from long-term variations in precipitation data. In this study the long-term variations of precipitation in the Danube Plain and the Thracian Lowland are analysed. Accordingly, the index of anomaly P is calculated as (e.g. Koleva, 1988):

$$P_j = \frac{1}{n}\sum_{i=1}^{n}\frac{x_{ij}}{\overline{x_i}} \qquad (1)$$

where $j = 1, \ldots, N$ years, x_i – total annual precipitation in the ith station, $\overline{x_i}$ – averaged annual precipitation for the same station, n – station number.

Statistical methods were used to analyse the long-term variations in precipitation. The long-term data series were smoothed by moving averages. These methods eliminate the random and short periodic fluctuations of the time series. Visual evaluation of the smoothed time series is subjective, therefore the Spearman coefficient r and the Mann-Kendall coefficient r_1 were also used in this study in order to investigate the existence of lasting trends (e.g. WMO, 1966, 1990).

The frequency distribution of annual precipitation is calculated in the range (e.g. WMO, 1975):

$$\begin{array}{ll} P<\overline{P}-2\sigma_P & \text{– extreme dry} \\ \overline{P}-2\sigma_P<P<\overline{P}-\sigma_P & \text{– dry} \\ \overline{P}-\sigma_P<P<\overline{P}+\sigma_P & \text{– normal} \\ P>\overline{P}+\sigma_P & \text{– wet} \end{array} \qquad (2)$$

where P is precipitation in a particular year, $\overline{P}$ the average precipitation during the period 1961–1990, σ the standard deviation.

There are many indices which characterise drought severity with a single value derived only from a few meteorological parameters (e.g. Dunkel, 2000; Farago et al., 1989; Svoboda et al., 2002). The significant advantage of such drought indices is that they can produce long-term data series. For example, the aridity index, introduced by Palfai et al. (1995) is presented as follows:

$$\mathrm{PAI} = \frac{T_{\mathrm{IV-VIII}}}{q_i P_{\mathrm{X-VIII}}} 100 \qquad (3)$$

where PAI is the aridity index (°C/100 mm), $T_{\mathrm{IV-VIII}}$ is average air temperature during the period April–August (°C), $P_{\mathrm{X-VIII}}$ is weighted precipitation during the period October–August (mm). The monthly weights q_i of precipitation are based on the conditions of the soil moisture storage capacity and crop water demands. The estimated weighing factors are as follow: 0.1 in October, 0.4 in November, 0.5 from December to April, 0.8 in May, 1.2 in June, 1.8 in July and 0.9 in August. It is evident that July is the most critical month from the water supply perspective. A significant correlation value between the PAI index and the well-known Palmer's drought index was found (e.g. Palfai et al., 1995). The threshold PAI value should be equal to 6. The lower values are for the wet years. Drought can be categorised as moderate dryness when the PAI index is between 6 and 8, medium dryness from 8 to 10, heavy dryness from 10 to 12 and extremely heavy dryness when PAI exceeds 12 (e.g. Palfai et al., 1995).

Other drought indices were also used for a comparison of the drought frequency and intensity between different regions and years. For example, the Ped index (e.g. Ped, 1975):

$$\mathrm{Ped} = \frac{\Delta T}{\sigma_T} - \frac{\Delta P}{\sigma_P} \tag{4}$$

where ΔT and ΔP are anomalies of air temperature and precipitation, relative to a given time period; σ_T, σ_P are standard deviations of air temperature and precipitation, respectively. Values of the Ped index that are between 1 and 2 indicate the existence of an insignificant drought, values of $2 < \mathrm{Ped} < 3$ indicate moderate drought, and values $\mathrm{Ped} > 3$ indicate severe drought. Negative index values characterise wet periods.

The de Martonne index J (mm/°C) for monthly values can be presented as follows (e.g. de Martonne, 1926):

$$J = \frac{12p}{(t + 10)} \tag{5}$$

where p and t are monthly total precipitation (mm) and air temperature (°C), respectively. This index was developed as an aridity index, although it can be used to detect drought episodes (WMO, 1975). When the J index is less than 30, drought conditions may be observed. A value of less than 20 is typical of severe drought.

3. Results and discussion

The long-term variations of annual precipitation anomaly index and 10-years moving average in the considered regions of the Danube Plain and the Thracian Lowland are shown in Fig. 2. Generally, the trend is negative for the 20th century, but it is statistically insignificant. A well-presented decreasing trend in precipitation is observed during the last two decades of the previous century. This trend is significant in the Thracian Lowland according to the Spearman and Mann-Kendall coefficients.

The driest years in Bulgaria during the 20th century were 1945 and 2000. Other considerable dry years were 1902, 1907, 1932, 1934, 1946, 1948, 1950, 1953, 1985, 1986, 1990, 1992 and 1993. It is important to note that there are some differences in the classification of dry years between the regions of the Danube Plain and the Thracian Lowland.

Particular years, months or successive months with insignificant precipitation, i.e., periods of atmospheric drought, are not uncommon events in the country and can even be considered as the normal climatic characteristics of Bulgaria. Climatically, two successive dry months usually occur in the lower areas of the country annually. However, there are some years with six and more successive dry months. Long dry periods during the cold-half of the year were observed in 1913, 1934, 1967, 1976 and 1983. Extended dry periods during the warm-half of the year occurred in 1928, 1945, 1965, 1985 and 2000.

Climatically, there are three successive months during the year with below normal precipitation. The number of months with below normal precipitation throughout the year is about five. Usually, precipitation is less than 50% of the average in two to three months of the year. In some years, 5 to 6 or even more successive months with less precipitation than the average can be observed. This occurred in about 25–30% of the years during the 20th century. In 1945, precipitation amounts were especially low from January to November across most of the country. The 1944 autumn was also dry, resulting in a total drought duration of approximately 12–15 months. Several successive dry months (from January to August and even until October in

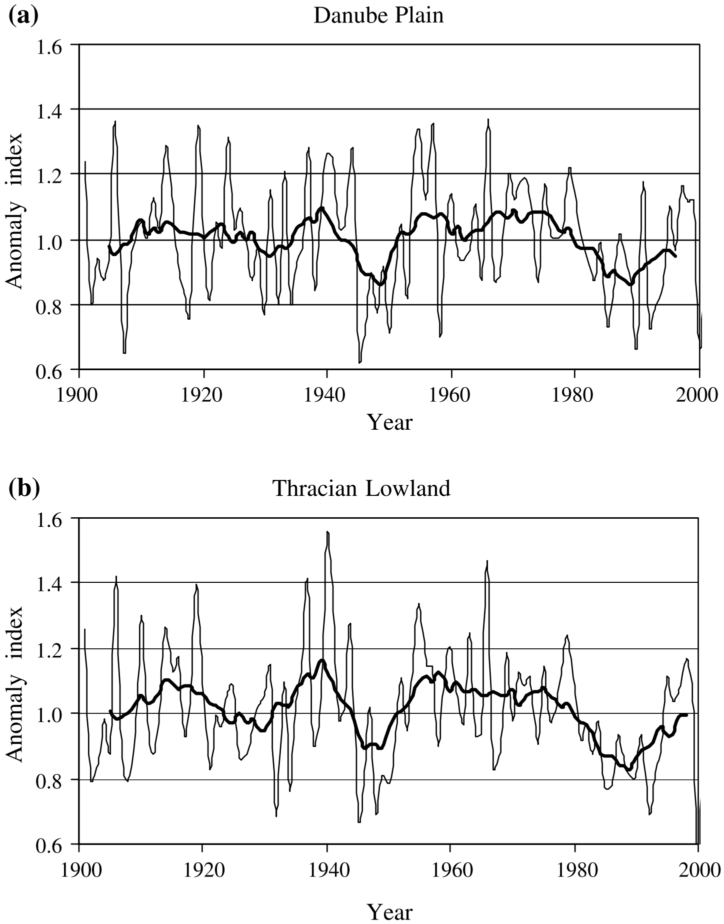

Fig. 2. Long-term variations of the area-averaged precipitation anomaly index and 10-years moving average for Danube Plain (**a**) and Thracian Lowland (**b**), relative to the reference period 1961–1990

some places) were also observed in 1938, 1959 and 1968. Precipitation in some months was 20–30% lower than the norm. These drought episodes, however, were not observed in all regions of Bulgaria. There were four to six successive months with reduced precipitation in 1985, 1990, 1992, 1993 and 1994. The total months with lower precipitation than the average at some weather stations were about nine or ten. In these years precipitation was less than 50% of the average for four, five, or sometimes six months. Even in some weather stations such as Lom (Danube Plain), Stara Zagora and Sliven (Thracian Lowland) dry months lasted for seven to nine months. During 2000 the monthly precipitation was below normal in 9–11 months. In July, August and October, at most of the weather stations, precipitation was only 4–7% of the normal.

It is necessary to emphasise that during the 20th century there was no year with above-average monthly precipitation. In Bulgaria, there was always at least one month or successive wet months during the most severe drought years. The previous century is divided into several wet and dry sub-periods with duration of 10–15 years. In Fig. 3 the percentage distribution of the years in separate sub-periods according to the drought criteria (2) is given. The distribution of these sub-periods is compared with that of the reference period 1961–1990. Three chief periods during the 20th century are characterised by long and severe droughts, namely 1902–1913, 1942–1953 and 1982–1994. During the first period, the drought years were approximately 20% of the total years. However, they increased to 40% of the second period and even approximated 50% of the last period 1982–1994. Another characteristic of the last period is that years with above normal precipitation were not observed in the Thracian Lowland. The above results are consistent with results obtained from neighbouring Balkan and other countries (e.g. Komuscu, 1999; Madjar et al., 1995; Stanescu et al., 1994; Szinell et al., 1998).

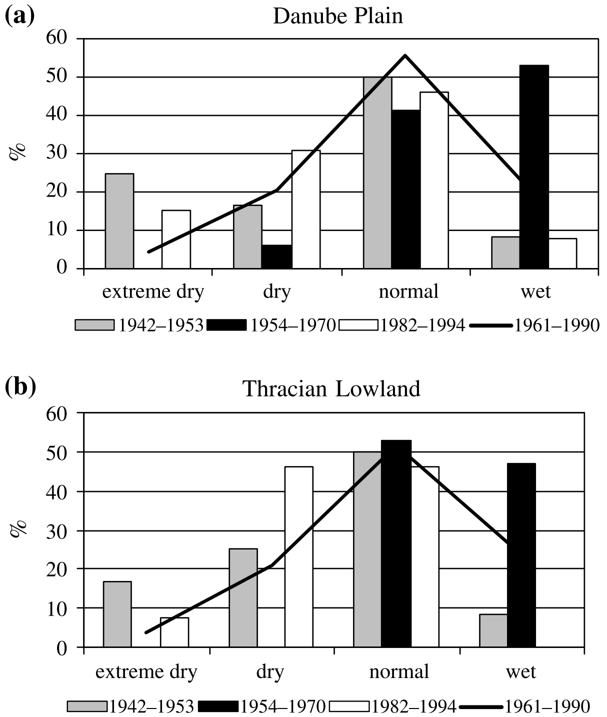

Fig. 3. Distribution (in %) of extremely dry, dry, normal and wet years in Danube Plain (**a**) and Thracian Lowland (**b**) for various periods during the 20th century including the reference period 1961–1990

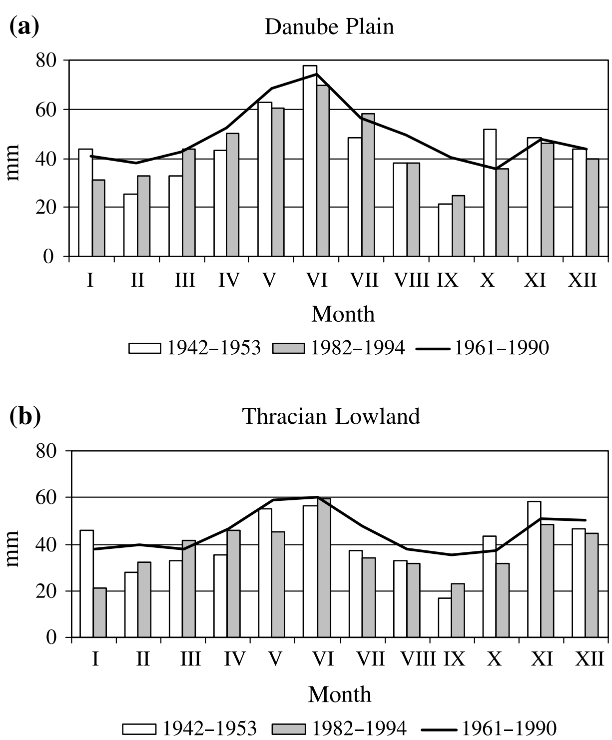

Fig. 4. Annual course of area-averaged precipitation in Danube Plain (**a**) and Thracian Lowland (**b**) for the two driest periods during the 20th century as well as the reference period 1961–1990

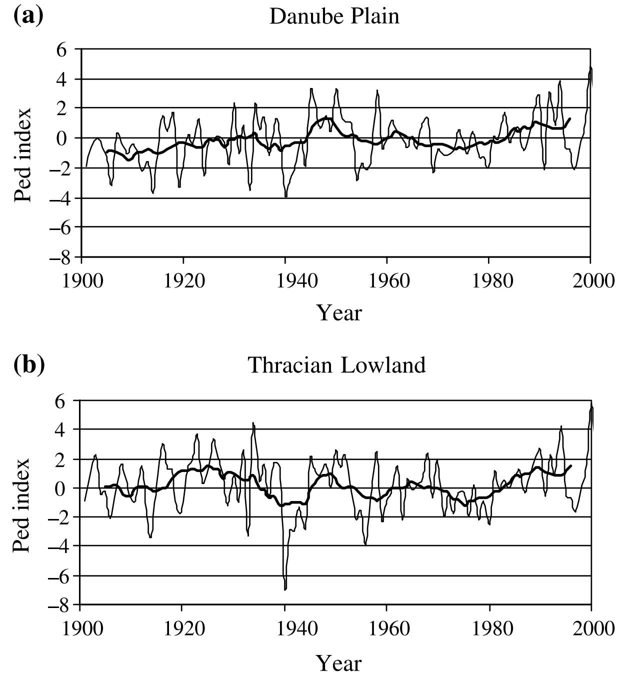

Fig. 5. Long-term variations of the area-averaged annual Ped index and its 10-years moving average for Danube Plain (**a**) and Thracian Lowland (**b**)

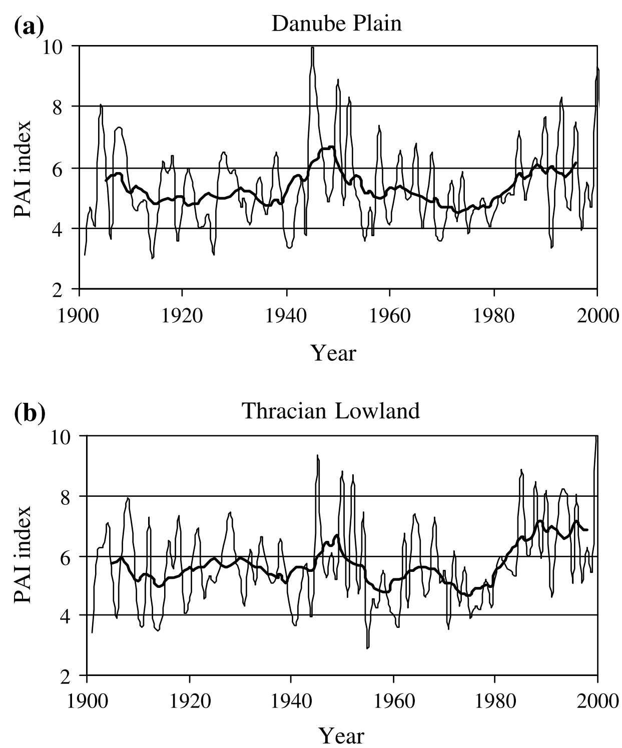

Fig. 6. Long-term variations of the area-averaged annual PAI aridity index (in °C/100 mm) and its 10-years moving average for Danube Plain (**a**) and Thracian Lowland (**b**)

Figure 4 represents the interannual distribution of precipitation during the periods 1961–1990, 1942–1953 and 1982–1994. It can be seen that during the period 1942–1953 drought conditions were observed at the end of summer and at the beginning of autumn when precipitation was 10–20 mm less than the average. The precipitation amounts were especially low during the winters of 1982–1994. The characteristics of the precipitation distribution during the above time periods were similar to the characteristics of the moderate-continental distribution of precipitation.

The yearly variations of the Ped drought index are shown in Fig. 5. Droughts occur more frequently in the Thracian Lowland, when the values of this index are higher than 2. Drought years during the last twelve years of the 20th century were 1989, 1990, 1992, 1994, 1999 and 2000. Especially dry were 1994 and 2000, when the Ped index values were higher than 3 and even 4. In general, this index has shown an increasing trend at the end of the last century. However, this trend is significant only for the Danube Plain according to the Spearman and the Mann-Kendall coefficients.

The results obtained are almost the same when the variations in the PAI index are analysed (Fig. 6). Drought conditions (PAI > 6) in the Thracian Lowland were observed in 40% of the years during the last century, and 29% of the years in the Danube Plain. More severe droughts occurred in 6–8% of the years during the previous century with 1945 and 2000 being extremely dry years. Only in these years was the PAI index higher than 9, even above 11 in the Thracian Lowland in 2000. A tendency towards dryness during the last two decades has been observed.

The annual values of the de Martonne index were equal to about 25 in the selected regions during the period 1961–1990. It decreased down to 19–23 during the period 1982–1994. Figure 7 shows the variations of the monthly de Martonne index, regarding these two periods. July, August and September are the driest months during 1982–1994 with index values of about 10.

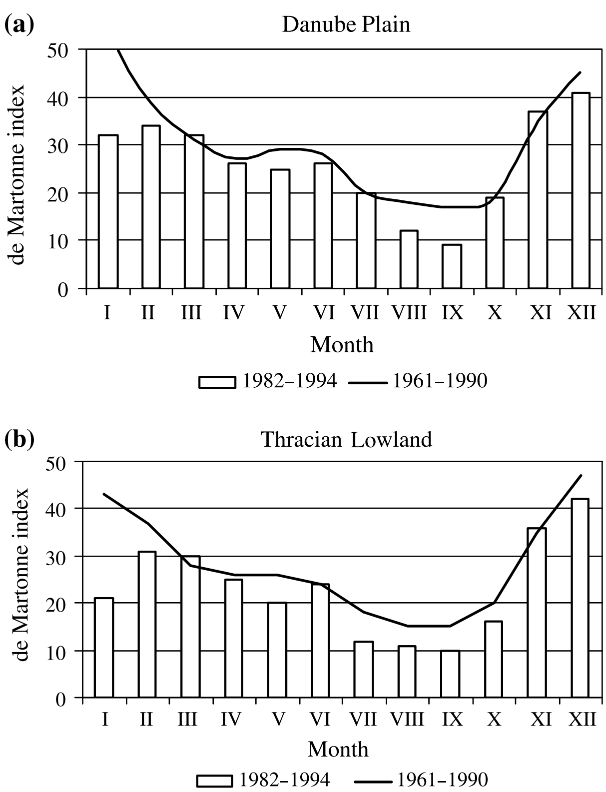

Fig. 7. Annual course of area-averaged de Martonne index (in mm/°C) in Danube Plain (**a**) and Thracian Lowland (**b**) for the dry period 1982–1994 as well as the reference period 1961–1990

4. Conclusion

In the last few decades it became more and more evident that in all countries in the Balkan subregion and in the surrounding countries drought has had a major impact on many forms and areas of life and the economy, on the whole society and on the environment. Drought is a natural, recurrent feature of the climate of Bulgaria. For the Danube Plain and the Thracian Lowland, the previous century experienced both wet and dry subperiods with duration of 10–15 years. The driest periods were 1942–1953 and especially 1982–1994. A general tendency towards drying during the last two decades has been observed. The frequency of dry years, registered in the Danube Plain and the Thracian Lowland, increased while rainy years practically did not occur. The analysis of the rainy conditions during the 20th century at 36 Bulgarian weather stations showed a decreasing tendency in annual precipitation. However, this tendency is not statistically significant at the 95% confidence level, because of climate change. This could alter climate variability including precipitation patterns, and extreme weather events such as drought which are likely to occur more frequently in the future.

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