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The impact of the climate changes during the period 1971-2010 on the reference evapotranspiration in North Bulgaria

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Резюме. Данните за варирането на евапотранспирацията в пространството и времето са необходима информационна основа за определяне на регионалното разпределение на водните ресурси. Анализите на исторически климатични данни позволяват да се установят настоящите и бъдещите потребности от вода и да се изработят стратегии за адаптация към климатичните промени. Настоящата работа е фокусирана върху тенденциите на климатичните промени на територията на Северна България през периода 1971-2010 г. и тяхното влияние върху еталонната евапотранспирация. Обработени са ежедневни метеорологични данни – минимална, максимална и средноденонощна температура на въздуха, валежи, относителна влажност на въздуха и средноденонощна скорост на вятъра от 19 агрометеорологични станции на територията на земеделско производство в Северна България за посочения период. Изчислени са ежедневните, месечните и сезонните стойности на еталонната евапотранспирация по метода на FAO 56. Към темпратурата на въздуха, дефицита на насищане на въздуха с водни пари, валежите и еталонната евапотранспирация за периода април-септември е приложен тестът на Mann-Kendall, в резултат на което са открити и доказани тенденции на затопляне на климата. Представено е в графичен вид временно-пространственото разпределение на еталонната евапотранспирация за месеците от април до септември, за характерни по отношение на земеделската дейност годишни периоди – април-юни и юли-август и април-септември и за характерни във влажностно отношение години – средно влажна, средна и средно суха година, в рамките на последния 30-годишен период 1981-2010 г. Интерполацията е извършена чрез Invert Distance Weighting. Картите са изработени в среда на ArcGIS 9.3. Съставени са хистограми на разликите между климатичните стойности на еталонната евапотранспирация на двата 30-годишни периода – 1981-2010 и 1971-2000. Установено е, че сумарната евапотранспирация за периода април-юни се е повишила основно с 5-10 mm и 10-20 mm. За периода юли-август преобладават увеличенията с 10-20 mm. Сезонното увеличение за периода април-септември е преобладаващо 10-20 mm и 30-40 mm. Най-големи са месечните увеличения за юли и август - до 8.8 mm. През средно влажна година, еталонната евапотранспирация варира между 570 и 700 mm, през средна – между 580 и 790 mm и през средно суха – между 670 и 850 mm. Евапотранспирацията е най-висока в Централна Северна България и части от Северозападна

България, а най-ниска – по Черноморското крайбрежие.

Ключови думи: еталонна евапотранспирация, тенденции, пространствено разпределение, затопляне на климата, Северна България

Abstract. The temporal and spatial variation of crop evapotranspiration is a good basis for estimation of the regional water allocation. This research is focused on revealing the trends of climate change within the territory of North Bulgaria in the period 1971-2010 and its effect on the reference evapotranspiration. Meteorological data of the forty-year period 1971-2010 from 19 climatological and synoptic stations were processed. FAO reference evapotranspiration was calculated. Mann-Kendall test was used to detect 1971-2010 trends in the air temperature, rainfall, vapor pressure deficit and reference evapotranspiration as indicators of climate change. The spatio-temporal distribution of the reference evapotranspiration for different periods and wetness year types is presented. A significant tendency to climate warming was established in North Bulgaria. The evapotranspiration trend keeps positive since 1971 till now. The reference evapotranspiration totals of the periods April-June and July-August have increased mostly with 10-20 mm, while of the period April-September – with 20 and 40 mm.

Keywords: reference evapotranspiraion, trends, spatio-temporal distribution, climate warming, North Bulgaria

Introduction

The economic growth nowadays causes considerable ecological losses. One of the negative consequences of man activities concerns the stability of climate. The uncontrolled use of water resources, the agricultural practices, which have soil pollution effect and cause intensive release of carbon dioxide, the deforestation for the purpose of a new farmland establishment, the urban sprawl, etc., enable climate warming and take control on the global hydrological cycle (Sivakumar, Motha, 2007; Millán, 2014). The EU Adaptation Strategy and the national adaptation strategies cover a wide range of adaptation measures. The analyses of historical climate data are a contribution to the elaboration of policies and measures against the negative ecological and economy effect of climate change. The knowledge of the current, near and far future crop water requirements, of their temporal and spatial variation, is important for the estimation of the regional water allocation and for elaboration of irrigation technologies of high water use efficiency (Tong et al., 2007; Lingu et al., 2011).

The presented research focuses on detecting trends of climate change and establishing the spatio-temporal distribution pattern of the reference evapotranspiration over the territory of North Bulgaria for the period 1971-2010.

Material and methods

The area of the study is the agricultural territory of North Bulgaria. It comprises two climatic zones – temperate-continental and Black Sea zone. The climate of the first one is shaped under the influence of the continental air masses from the temperate latitudes, the air masses of a local origin, the transformed oceanic air masses from North-West, and also under tropic and arctic air masses. Its yearly rainfall is 500-600 mm.

The climate of the second zone is mild. It is under the influence of the Black Sea basin, of the local atmospheric circulation and bears the temperate-continental climatic influence. The rainfall is low – less than 500 mm (Geography of Bulgaria, 2002).

Meteorological data of the forty-year period 1971-2010, originally from 19 climatological and synoptic stations, have been processed. Since the reference evapotranspiration and the open water evaporation have same physical nature, we consider the chosen stations with good spatial coverage (Kyuchukova, 1974; Slavov, Moteva, 2007). Seventeen of the stations are representative for the temperate-continental climate, and two – for the Black-Sea climate. The daily reference evapotranspiration was calculated in an Excel environment on the basis of the daily sunshine duration, maximum and minimum air temperature, relative air humidity and mean wind speed (Allen et al., 1998). The monthly and seasonally ET_o values were estimated by cumulating the daily ones.

Mann-Kendall test was used for detection of 1971-2010 trends of air temperature, rainfalls, vapor pressure deficit and reference evapotranspiration (Salmi et al., 2002; Croitoru et al., 2013). ArcGIS 9.3 software was used to illustrate the spatio-temporal distribution of the reference evapotranspiration. Interpolation was done by Invert Distance Weighting method.

Results

Detection of climate change

The detected trends of the air temperature and vapor pressure deficit (VPD) for the potential vegetation period April-September within 1971-2010 (Fig. 1) are positive. The increase of the seasonally air temperature totals in the temperate-continental zone is at the rate of 10.1 $^oC\ yr^{-1}$, while in the Black Sea zone it is at the rate of 8.1 $^oC\ yr^{-1}$. Totally, the increase in the first zone is 402.6^{o}C (10.1%) and in the second - 326.0^{o}C (8.2%)

Vapor pressure deficit in the temperate-continental zone performs an increasing trend at a rate of 8.1 hPa yr^{-1} and in the Black Sea zone – at the rate of 9.1 hPa yr^{-1}, totally - 323.5 hPa (25.0%) and 365.4 hPa (42.7%) for the period 1971-2010.

These trends reveal an apparent significant tendency of climate warming in North Bulgaria.

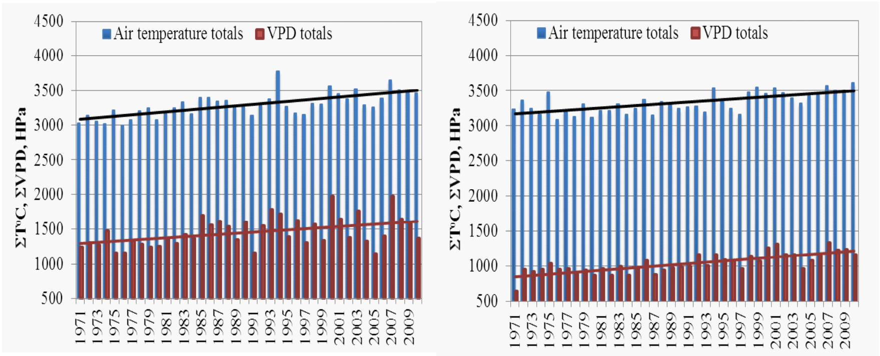

Fig. 1. Long-term (1971-2010) tendencies of air temperature totals and Vapour Pressure Deficit totals of the period April-September per climatic zones: a) temperate continental; b) Black Sea
Фиг. 1. Многогодишни (1971-2010 г.) тенденции на температурните суми и на сумите на дефицита на насищане на въздуха с водни пари за периода април-септември по климатични области: а) умерено-континентална; b) Черноморска

The monthly data (Table 1) show that the increase of both climate elements for July and August - the hottest and driest months of the year, is highly significant. The increase of air temperature in the temperate-continental zone is significant in June too. No significant changes in air temperature, i.e. no warming tendencies, have been established for September in both climate zones. VPD reveals significant positive tendencies in July and August, i.e. the evapotranspiration will be more intensive in future. In the Black Sea region, the positive trends of VPD are significant for all months. These results are relevant to those of different scenarios, which have forecasted future warming and drought in our country (Alexandrov, 1997, 2008, 2011ab; Alexandrov et al., 2011; Popova, 2012). Bartoli et al. (2013) also proved that the climate of the Carpathian Basin is becoming drier with a summer drying trend in the 21st century.

Table 1. Significance of 1971-2010 monthly air temperature and VPD trends per climatic zones by Mann-Kendall test (Z values)
Таблица 1. Статистическа значимост на трендовете на месечните стойности на температура на въздуха и дефицита на насищане на въздуха с водни пари за периода 1971-2000 г., доказана чрез теста на Mann-Kendall (стойности Z)

Climate zones	April	May	June	July	August	Sept.	Apr.-Sept.
Air Temperature							
Temperate continental	1.55	2.55*	3.74***	4.63***	4.39***	1.94	4.74***
Black Sea region	1.20	2.57*	3.27**	3.81***	4.30***	1.46	4.37***
Vapor Pressure Deficit							
Temperate continental	0.87	1.62	0.45	2.48*	2.41*	1.15	3.11**
Black Sea region	3.93***	4.09***	3.41***	3.27**	3.83***	2.78**	5.46***

*† significance at α=0.1 level; * significance at α=0.05 level; ** significance at α=0.01 level; *** significance at α=0.001 level*

No 1971-2010 trends were detected in the precipitation data - neither monthly nor totally for the potential vegetation period.

FAO reference evapotranspiration, as a climate change indicator, also shows a positive April-September trend. It is seen on Fig. 2 that ET_o in the temperate-continental zone increases with 2.6 mm yr^{-1} and in the Black Sea zone – with 3.7 mm yr^{-1}, totally for the period 1971-2010 with 103.6 mm (16.2%) and 148.7 mm (25.4%). This increase of the trend in the temperate-continental zone is from 639.8 mm to 743.47 mm and in the Black Sea zone - from 584.9 mm to 733.6 mm. The monthly estimates of the trends, which are presented in Table 2, confirm the significant positive trends for all months in the Black Sea zone, while in the temperate continental zone the trends are positive for July, August and September. The trends are all significant at the 0.01 level of significance.

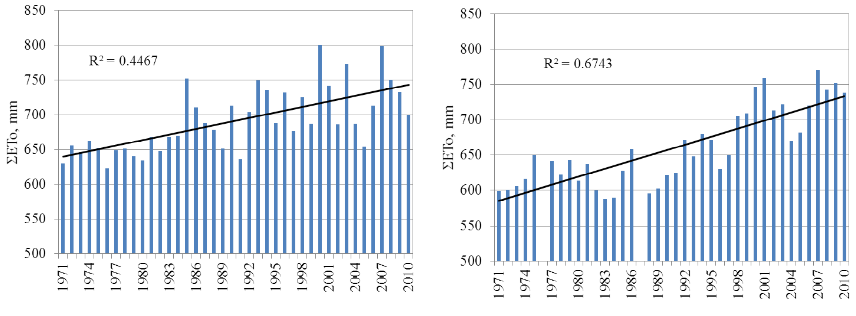

Fig. 2. Long-term (1971-2010) tendencies of ETo totals of the period April-September per climatic zones: a) temperate continental; b) Black Sea
Фиг. 2. Многогодишни (1971-2010 г.) тенденции на сумата на еталонната евапотранспирация за периода април-септември по климатични области: a) умерено-континентална; b) Черноморска

Table 2. Significance of monthly ETo data trends per climatic zones by Mann-Kendall test in the period 1971-2010 (Z values)
Таблица 2. Статистическа значимост на трендовете на месечните стойности на еталонната евапотранспирация по месеци и климатични области за периода 1971-2000 г., доказана чрез теста на Mann-Kendall (стойности Z)

Climate zones	April	May	June	July	August	Sept.	April-Sept.
Temperate continental	1.39	2.62**	2.88**	3.41***	3.62***	1.15	4.87***
Black sea	4.84***	4.42***	3.81***	5.88***	5.44***	4.37***	6.14***

*† significance at α=0.1 level; * significance at α=0.05 level; ** significance at α=0.01 level; *** significance at α=0.001 level*

ET_o of the contemporary climate

The daily ET_o data comprises the potential vegetation period April-September of the period 1971-2010 for all agrometeorological stations. Mean 1981-2010 climatological values were obtained according to WMO concept for a climatological normal (WMO, 2009). The maximum daily evapotranspiration in both climate zones occurs on 25 July and is 5.2 mm d^{-1} (Fig. 3). It should be noted that in the first part of the growing season, the daily values of the temperate-continental zone are up to 0.3 mm higher, while in the second part of the growing season they tally or are lower than those of the Black Sea zone.

The strongest evapotranspiration demand in all months occurs generally in Central North Bulgaria (in Pleven region), the weakest – in Eastern North Bulgaria (Dobrich, Varna and Shabla regions). The monthly values of ET_o vary within the territory of North Bulgaria in the following ranges: in April – from 65.3 mm (Shabla) to 86.0 mm (Pleven); in May – from 90.9 mm (Shabla) to 124.6 mm (Obr. Chiflik); in June – from 107.8 mm (Shabla) to 145.5 mm (Pleven); in July – from 127.6 mm (Shabla) to 163.0 mm (Montana); in August – from 110.0 mm (Shabla) to 144.2 mm (Montana); and in September – from 70.8 mm (Shabla) to 90.4 mm (Pavlikeni) (Fig. 4).

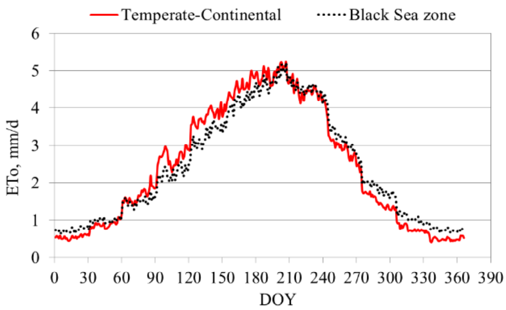

Fig. 3. Daily reference evapotranspiration in the period 1981-2010 per climate zones
Фиг. 3. Ежедневна еталонна евапотранспирация за периода 1981-2010 г. по климатични области

The seasonal April-September ET_o is highest in Central and Western North Bulgaria (Fig. 5). The reference evapotranspiration in the temperate-continental climate zone varies from 669.1 mm (Dobrich) to 745.8 mm (Pleven). In the Black Sea climate zone, under the impact of the higher air humidity there, it varies within lower values – from 572.4 to 585.3 mm (Fig. 5).

The increase of the ET_o climatic values of from 1971-2000 period to 1981-2010 period per stations is shown on Figs 6, 7 and 8. This increase is established for the three important water consumption periods in our country – April-June, July-August and the potential vegetation period April-September.

The increase of April-June ET_o totals in seven locations is from 5 to 10 mm, in three of them it is from 10 to 15 mm and in four of them – from 15 to 20 mm. Totally, one third of the territory of North Bulgaria is affected by less than 10 mm increase of the evapotranspiration demand and another third of the territory – by 10-20 mm (Fig. 6).

The July-August ET_o totals have increased with 5-10 mm in four locations, in another four locations - with 10-15 mm, and in eight locations - with 15-20 mm. Overall the two third of the territory is affected by 10-20 mm increase in the evapotranspiration demand (Fig. 7).

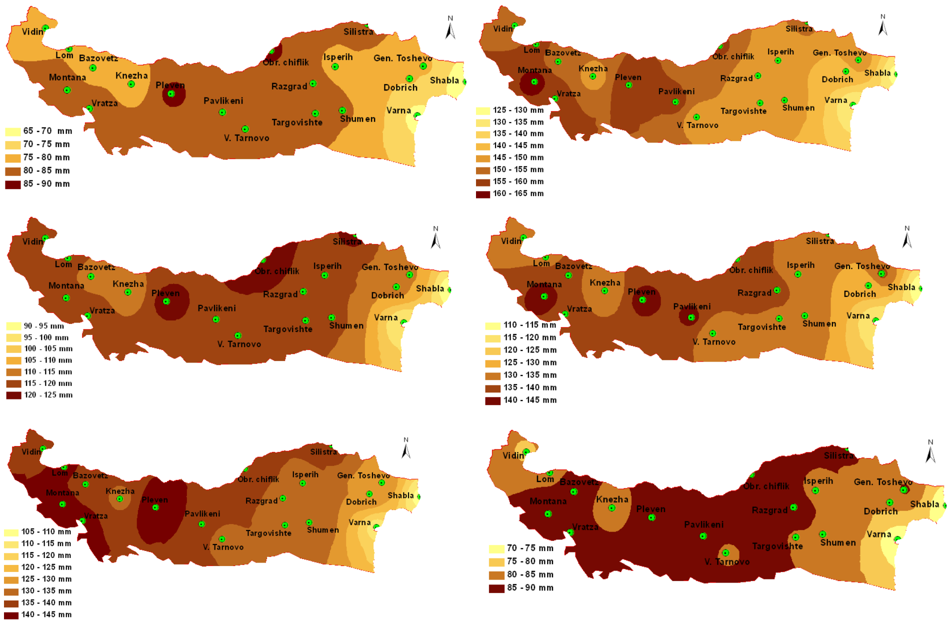

Fig. 4. Zoning of the seasonal reference evapotranspiration normals in 1981-2010: a) April; b) May; c) June; d) July; e) August; f) September

Фиг. 4. Пространствено разпределение на климатичните стойности (1981-2010 г.)на еталонната евапотранспирация по месеци: a) април; b) май; c) юни; d) юли; e) август; f) септември

Fig. 5. Zoning of 1981-2010 normals of April-September reference

Фиг. 5. Пространствено разпределение на климатичните стойности (1981-2010 г.) на еталонната евапотранспирация за периода април-септември

Seasonally (April-September) ET_o has increased with up to one design irrigation application depth (60 mm): in six locations the values of 10-20 mm prevail and in another six locations – prevail the values of 30-40 mm (Fig. 8).

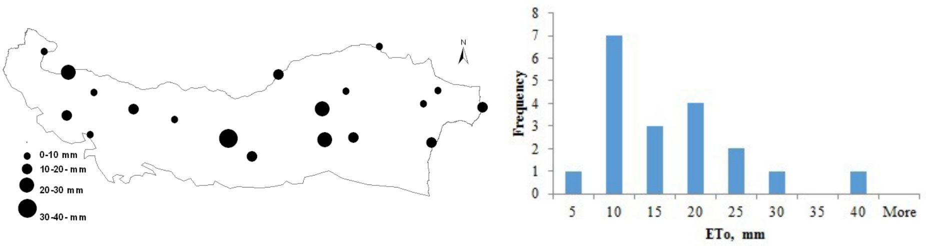

Fig. 6. Differences between 1981-2010 and 1971-2000 ET_o normals (a) and histogram (b) for April-June
Фиг. 6. Разлики между климатичните стойности на еталонната евапотранспирация за периодите 1981-2010 г. и 1971-2000 г. (a) и хистограми на разпределението им (b). Период април-юни

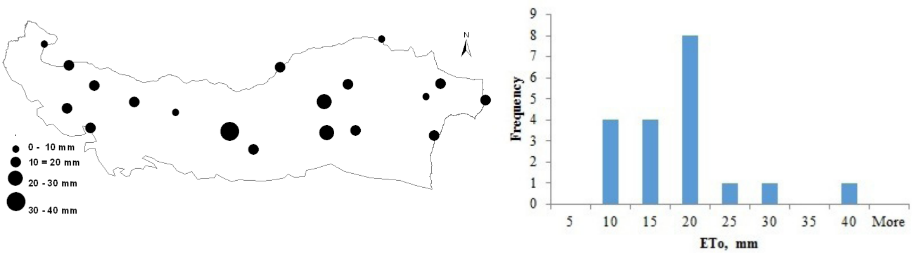

Fig. 7. Differences between 1981-2010 and 1971-2000 ET_o normal (a) and histogram (b) for July-August
Фиг. 7. Разлики между климатичните стойности на еталонната евапотранспирация за периодите 1981-2010 г. и 1971-2000 г. (a) и хистограми на разпределението им (b). Период юли-август.

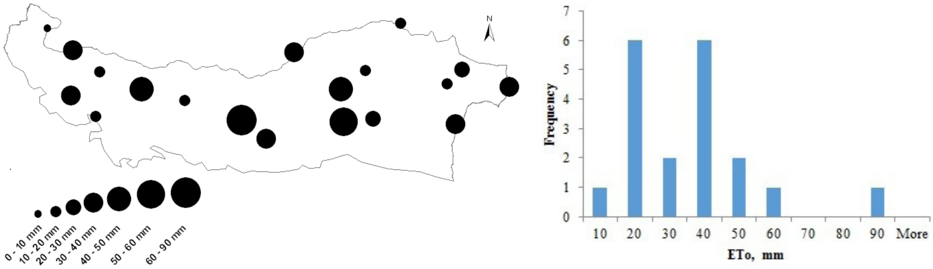

Fig. 8. Differences between 1981-2010 and 1971-2000 ETo normal (a) and histogram (b) for April-September
Фиг. 8. Разлики между климатичните стойности на еталонната евапотранспирация за периодите 1981-2010 г. и 1971-2000 г. (a) и хистограми на разпределението им (b). Период април-септември

The average increase of ET_o per months is shown in Table 3. The highest average increase over the territory of North Bulgaria is detected for July (7.3-8.8 mm) and August (8.7 mm). The monthly increase in the Black Sea zone is higher than that in the temperate-continental zone for all months.

The zoning of ET_o in years of different wetness type is illustrated on Fig. 9. In a dry growing season, in which ET_o has 25% probability of exceedance (2009), it varies from 668.2 mm (Shabla) to 851.0 mm (Pleven), in the average growing season

Table 3. Differences between 1981-2010 and 1971-2000 normals of the reference evapotranspiration totals per climate zones and months, mm
Таблица 3. Разлики между климатичните стойности на еталонната евапотранспирация за периодите 1981-2010 и 1971-2000 г. по месеци и климатични области

Climate zones	April	May	June	July	August	Sept.	April-Sept.
Temperate continental	2.4	5.8	5.6	7.3	8.7	2.1	31.9
Black sea	3.7	5.7	6.0	8.8	8.7	4.2	37.3

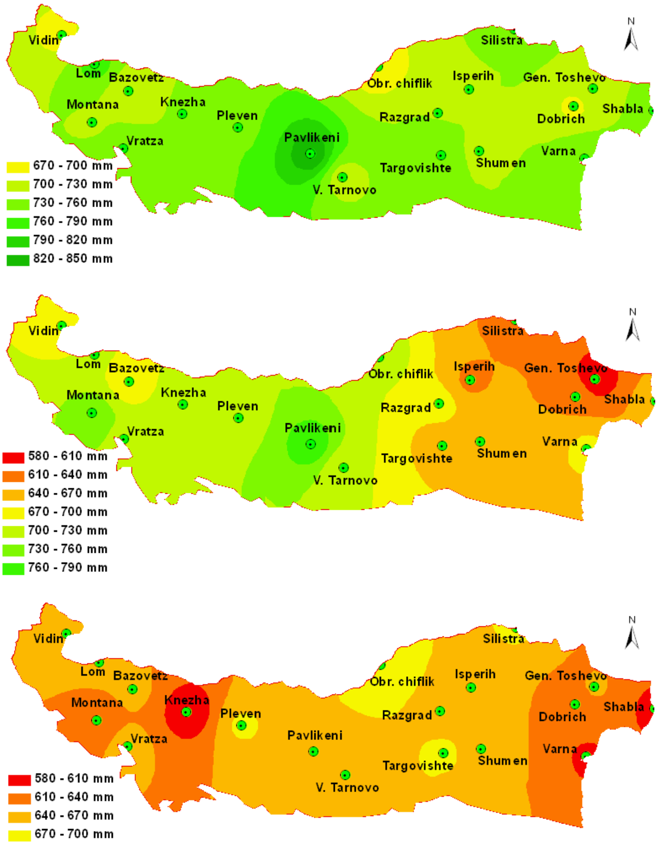

Fig. 9: Zoning of the seasonal reference evapotranspiration in: (a) a dry growing season, (b) average growing season, (c) wet growing season
Фиг. 9. Пространствено разпределение на сезонната еталонна евапотранспирация през: суха (а), средна (b)и влажна (c) година

(50% probability of exceedance of ET_o) (2004) – from 581.7 mm (Gen. Toshevo) to 789.7 mm (Pavlikeni) and in a wet growing season (75% probability of exceedance of ET_o) (1989) – from 575.4 mm (Knezha) to 703.2 mm (Obr. Chiflik) (Fig. 9). The average values of ET_o in these years are 734.9, 684.4, and 646.2 mm respectively, with lowest territorial variation for the wet conditions. ET_o has the greatest variation over the country in an year of average moisture conditions.

Conclusions

The strongest evapotranspiration demand within the period 1981-2010 in North Bulgaria occurs in its central parts – around 750 mm in Pleven region, the weakest – in the eastern parts 580 mm in Varna and Shabla regions.

The trend of the reference evapotranspiration of the period April-September keeps positive for 40 years (1971-2010), which is an indication for climate warming.

The mean April-June and July-August values of the reference evapotranspiration has increased from the period 1971-2000 to the period 1981-2010 mostly with 10-20 mm, and the mean April-September values – mostly with 20 mm and 40 mm.

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