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USING STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX TO ASSESS LOW FLOWS IN SOUTHERN BUH RIVER

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ABSTRACT

We study a spatiotemporal variability of droughts characteristics in Ukraine at the time scales 12, 24 months separately for the periods 1951–1980 and 1981-2010. It was revealed that the maximum number of durable and severe droughts was registered in the recent 30-year period. It is also found a strong relationship between the temporal variability of drought and the annual mean water discharge in the Southern Bug River during the period 1951–2010.

Keywords: *Standardized Precipitation Evapotranspiration Index (SPEI), Droughts, Spatiotemporal Variability, Ukraine, Southern Buh River*

1. INTRODUCTION

The problem of the increasing frequency of droughts during the last decades is very acute in many countries. The drought, as the complex natural phenomenon, is conditioned by the long and sufficient shortage of precipitation accompanying by high air temperatures, which results in the decreasing soil water content due to evaporation and transpiration. The droughts impact considerably the natural environment, various ecosystems and socioeconomic activity including the agriculture, urban water supply etc.

Considering conditions of origins and duration, Wilhite and Glantz [9] (see also [10]) have proposed to separate the meteorological, agricultural and hydrological droughts. The meteorological drought results from the precipitation shortage in some area during some time period. The agricultural drought relates usually to the soil water deficits followed the crop decrease without any considerable impact on surface water resources. The hydrological drought is the period with the lack of surface and ground water resources, i.e. with the deficits of river runoff. It is generally accepted to consider the socioeconomic drought that is conditioned by the impossibility of water resources system to provide the water for the economics due to weather conditions [6]. Also, it was shown that certain time scales correspond to different types of droughts. In other words, the time scale over which water deficits accumulate becomes extremely important, and it functionally separates hydrological, environmental, agricultural, and other droughts [7].

Many scientists think that the climate change that was observed during the last decades is the most likely reason for the increase in the frequency, duration and intensity of droughts; this fact is also corroborated by the IPCC [4]. It is however must be noted that the global temperature increased twice in 20th century – about 1910-1940 (0.35°C) and from the end of 1970s to current time (0.55°C). It is therefore interesting to investigate spatiotemporal characteristics of droughts under global climate change.

This paper purposes to reveal a relationship between the droughts at the time scales of 12 and 24 months and the mean annual discharge of Southern Buh River.

2. DATA AND METHODS

In order to investigate a spatiotemporal variability of the number, duration and intensity of droughts, we use the multiscalar drought index – the standardized precipitation evapotranspiration index

SPEI. The SPEI is based on the original SPI [5] with the use of potential evapotranspiration [7], which allows combining the precipitation and temperature. The SPEI uses the difference between the monthly precipitation and the monthly potential evapotranspiration, i.e. it is simple climatic water balance for different time scales [5].

The mean value and standard deviation of the SPEI are 0 and 1, respectively. This index is the standardized value and can be compared with similar values in other sites and for other time periods. The table shows the drought category for the valued of the SPEI:

SPEI values	Drought category
0 to −0.99	mild drought
−1.0 to −1.49	moderate drought
−1.5 to −1.99	severe drought
≤ −2.0	extreme drought

Using the calculated values of SPEI, some additional drought parameters can be identified – the duration, severity and intensity. For this purpose, the truncation or threshold level can be used [7]. Figure 1 represents a plot of a drought variable denoted by X_t, which is intersected at many places by the truncation level X_0. Drackup et al. [1] defined the following major components as derived from Fig. 1: (a) drought initiation time (t_i), drought termination time (t_e), (c) drought duration (D_d), (d) drought severity (S_d) as a cumulative deficiency of a drought parameter below the critical level, and (e) drought intensity (I_d) as the average value of a drought parameter below the critical level.

In current work, we study the spatiotemporal variability of number, duration and severity of droughts in Ukraine at the 12 and 24 months time scales ($SPEI_{12}$ and $SPEI_{24}$). The $SPEI_{12}$ and $SPEI_{24}$ were calculated for the two 30-year periods – 1951-1980 and 1981-2010. The former relates to the 'stabilization' of global temperature and the latter – to the 'global warming' [4]. The analysis is carried out for the horizontal grid bounded with 44.25N and 53.75N as well as with 21.75E and 40.25E. The SPEI were calculated using the monthly temperature and precipitation [2, 3].

The hydrological regime of the Southern Buh River is investigated using the annual water discharge data in 18 sites located in the drainage area of this river. It is noteworthy that the Southern Buh River is only the large river located fully within the territory of Ukraine. Its length and drainage area are 806 km and 67,700 km^2, respectively [8]. The river has the source in Volyno-Podolskyi Plateau, then flows through Prydniprovskyi Elevation and fall into Black Sea (Fig. 2).

3. MAIN RESULTS

3.1. Spatiotemporal Variations of Droughts

First, we calculated the number, duration and severity for the all droughts (SPEI ≤ −1.0) as well as separately for the moderate, severe and extreme droughts. The time scales used are 12 and 24 months.

As an example, let us consider the spatial distribution of the droughts ($SPEI_{12}$) for two consecutive periods. Figure 3 shows that in the 1951-1980 the centers with maximal numbers of droughts (> 18 per 30 years) were located in some western and eastern regions of Ukraine as well as in the eastern coast of Black Sea; in the rest of Ukraine, from 5 to 15 droughts per 30 years were registered. During the period 1981-2010, the spatial pattern for the number of droughts was quite opposite – the number of droughts increased and the droughts spread to almost whole territory of

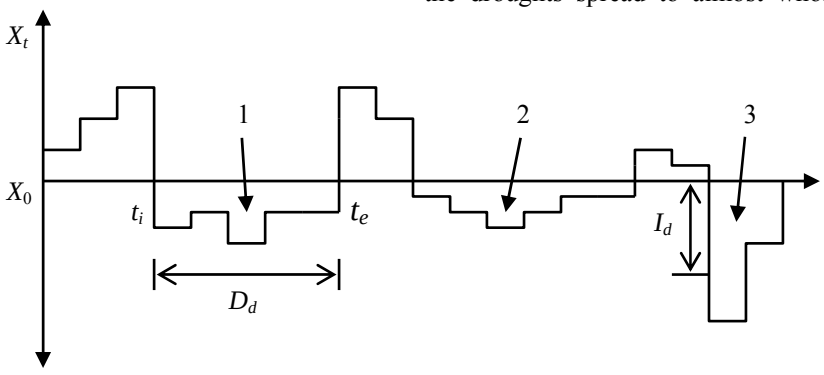

Figure 1. Drought characteristics using a given threshold level X_0.

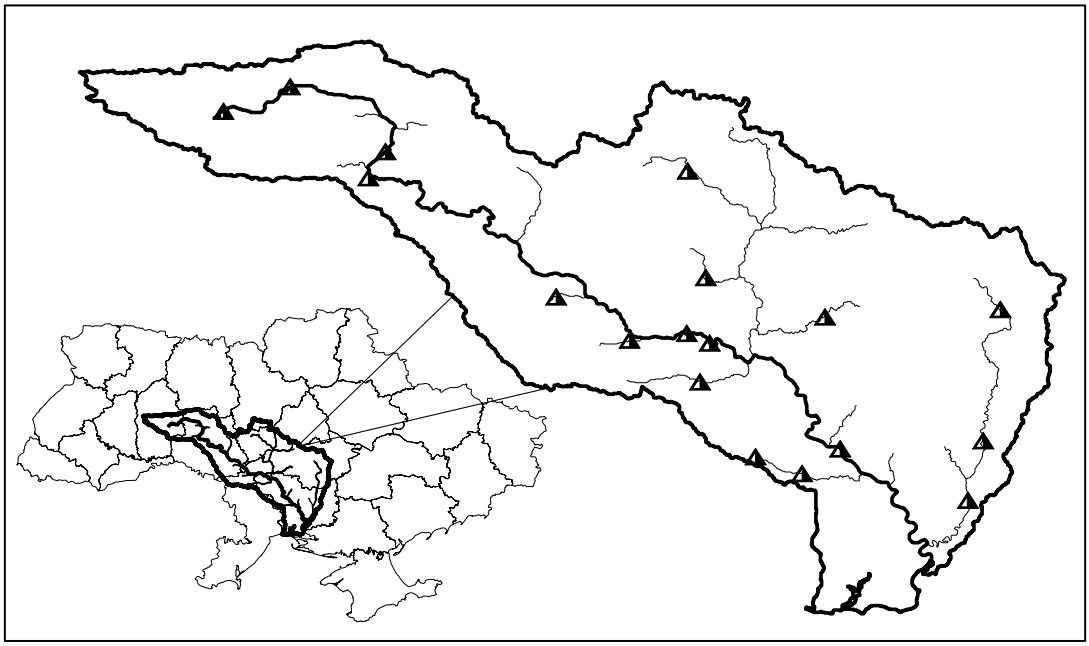

Figure 2. Scheme of Southern Buh River drainage area. The triangles denote the gauge sites.

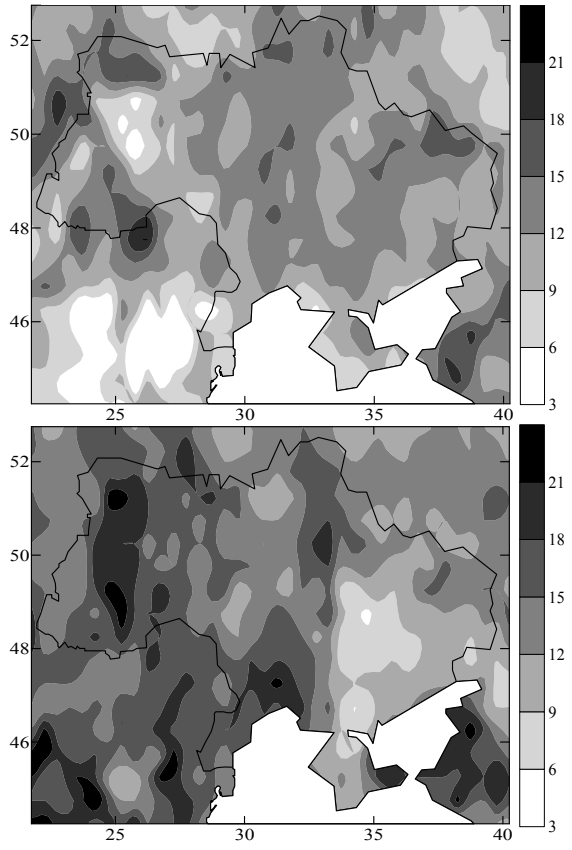

Figure 3. Number of droughts ($SPEI_{12} \leq -1.0$) during periods 1951-1980 (top panel) and 1981-2010 (bottom panel).

Ukraine. Nevertheless, the eastern and southeastern regions of Ukraine are characterized by the minimal number of droughts. On the other hand, the number of droughts enlarged mostly up to the 18-21 events per 30 years and the Southwestern Ukraine is one of regions with increasing frequency of droughts. The drainage area of Southern Buh is located just in this region. The fact of increasing number of droughts in its drainage area is the main reason to select this water body as a subject of current study.

The separate analysis of moderate, severe and extreme droughts shows that their spatiotemporal distribution is in most similar to that was considered earlier. The main difference between the categories of drought is the number of drought during the first and second periods. The number of moderate drought at the time scale 12 months is about 15-20 during the period 1951-1980. In the 1981-2010, the number has increased up to 30-35 especially in the southwestern regions. As for the $SPEI_{24}$, the maximum numbers are 15-18 and 24-27, respectively. For the severe droughts, these values are 9-12 for the 1951-1980 and 15-18 for the 1981-2010, and maximal values were registered in same regions. The number of extreme droughts is much lesser. For the period 1951-1980, just 1-3 droughts were observed in most of Ukraine with the maximum (5-7 events) in the Eastern Ukraine,

and this category of drought has not been registered in southwestern regions. The spatial pattern has reversed in the subsequent period. The maximal number of extreme droughts (> 7 events per 30 years) was observed in the Western Ukraine and Crimean Peninsula whereas the Eastern Ukraine was the zone without the extreme droughts.

As for the duration of droughts, for the $SPEI_{12}$ during the period 1951-1980 it was about 10-15 months in most of Ukraine's territory. In the 1981-2010, the duration exceeded 25-35 months in western, southwestern and southern regions. The duration of droughts that was calculated using $SPEI_{24}$ differs significantly from that is mentioned above. In the 1951-1980, the droughts with the duration more than 40 months were only registered in Vinnytsia and Chernivtsi regions. In the rest of the Ukraine's territory, the duration did not exceed 15-20 months. During the period 1981-2010, Ukraine was influenced by the droughts with duration the 20-30 months, and the duration increased up to the 40-45 month in southern and eastern regions. Most prolonged droughts (40-45 months) were registered in Volyn and Lviv regions as well as in the eastern part of Crimean Peninsula (Fig. 4). It can be noted that the maximal durations of moderate, severe and extreme droughts at the 12- and 24-months time scales have also increased. Therefore, we can conclude that the most prolonged droughts were registered during the period 1981-2010 in western and southwestern regions of Ukraine. Moreover, the duration of droughts at the 24-months time scale was greater than at the 12-months time scale.

Finally, let us consider the severity of droughts at different time scales. Similarly to the above results, the spatiotemporal distribution of severity is characterized by the maximal values in the eastern and northeastern regions of Ukraine during the period 1951-1980 and in the southern and western regions during the period 1981-2010.

So, during the first 30-years period the severity of droughts was from −40 to −20 for the $SPEI_{12}$ and from −50 to −30 for the $SPEI_{24}$ with the maximal value −50 in Western Ukraine. During the second 30-years periods the severity of droughts was $-45 \div -25$ and $-85 \div -45$, respectively.

It is interesting to analyze separately the severity of extreme droughts. In the 1951-1980, the droughts at the 12-months time scale had the maximal severity −30 in northeastern regions and rest of Ukraine was characterized by the low (−10)

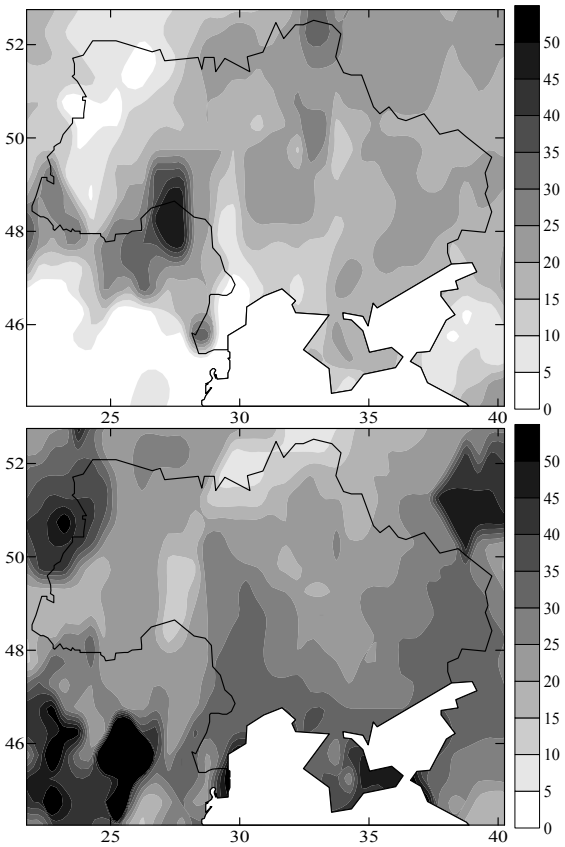

Figure 4. Duration of droughts ($SPEI_{24} \le -1.0$) during periods 1951-1980 (top panel) and 1981-2010 (bottom panel).

severity of droughts. In the 1981-2010, the severity of droughts at the 12-months time scale was usually $-20 \div -10$ and the maximal values (−60 and lesser) were registered in Volyn region. Figure 5 shows the severity of droughts that is calculated using $SPEI_{24}$. During the period 1951-1980, the plot shows that the severity was not exceed −10 in the most part of Ukraine, and eastern regions only were characterized by the severity $-30 \div -20$. As for the period 1981-2010, the severity reached the values of $-70 \div -50$ in western and southwestern regions of Ukraine. This fact testifies the significant change in spatiotemporal distribution of droughts in the last 30 years.

3.2. Southern Buh River Water Discharge

Here, we consider spatiotemporal variability of droughts together with a variability of annual mean water discharge in the Southern Buh River. The above analysis showed that the Southern Buh drainage area is located in the region with the drastic change in the frequency of droughts and in the droughts characteristics – duration and severity.

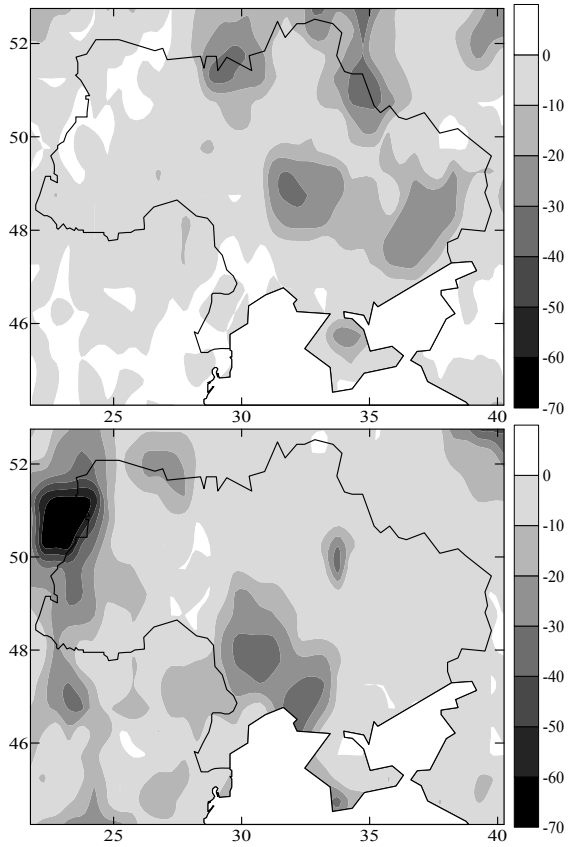

Figure 5. Severity of extreme droughts ($SPEI_{24} \leq -2.0$) during periods 1951-1980 (top panel) and 1981-2010 (bottom panel).

The comparative analysis was carried out for 18 gauge sites (see Fig. 2) along the Southern Buh River. It was revealed that the variabilities of the SPEI and water discharge are very similar for all the gauge sites. As an example, we consider the above mentioned relationship for the Katerynka site located in Pervomaisk district of Mykolaiv region.

Figure 6 represents the variation of annual mean water discharge together with the $SPEI_{12}$ and $SPEI_{24}$ in Katerynka site. It can be noted that the variations of the annual mean water discharge coincide with the variations of $SPEI_{12}$ during almost whole time period considered. For example, the most extreme and duarble droughts were accompanied by the minimal water discharge and vice versa – wet years are in good agreement with maximal water discharge in the Southern Buh River drainage area. The minimal water discharge in the 1951-1952 was registered together with $SPEI_{12} \approx -1.8$. Then, the positive values of $SPEI_{12}$ and relatively large water discharge were observed during the next subsequent years. The following sufficiently intensive drought and minimal water discharge (0.32 $m^3 s^{-1}$) were registered in the 1953-1954, and in the March-May of 1954 the drought reached the category 'extreme'. During the following several years, the wet and dry periods alternated. The next distinctive period, 1975-1976, was characterized by the durable (over 1 year) drought and the values of mean water discharge decreased to 0.58 $m^3 s^{-1}$ confirming the close relationship between the variabilities of drought and water flow.

The maximal values of mean water discharge were registered from 1976 to 1983 (up to 5.31 $m^3 s^{-1}$ in 1980). This period is also characterized by the maximal positive values of the $SPEI_{12}$. In the subsequent years, the period with high and low water discharge alternated. The next intensive drought was registered in the 2007-2008. This drought is distinguishable owing to its duration and severity; the latter is maximal among other droughts that were observed during the period 1951-2010. It was extreme during its duration and the absolute minimum of $SPEI_{12}$ was −2.7. This fact has been also revealed in the minimal water discharge.

The variability of $SPEI_{24}$ is very similar to that for the $SPEI_{12}$. As it was mentioned below, the most wet period persisted from 1976 to 1982, and the most extreme and prolonged drought was registered during the period 2006-2009.

4. CONCLUSION

During the last decades, the global climate change resulted in the increased number of droughts. Moreover, the duration, intensity and severity of droughts have also increased. The present study confirms this fact. It was revealed that the maximal values of the droughts characteristics changed significantly during the period of global temperature rise – 1981-2010. The comparative analysis showed that the time variabilities of drought indices and annual mean water discharge in the Southern Buh River are in good agreement – the minimal values of the discharge correspond to the droughts that were calculated using the $SPEI_{12}$ and $SPEI_{24}$ and vice versa.

It must be however noted that the joint analysis of drought indices and hydrological characteristics makes only sense if (i) the drainage area of river is sufficiently large, (ii) the time periods are about

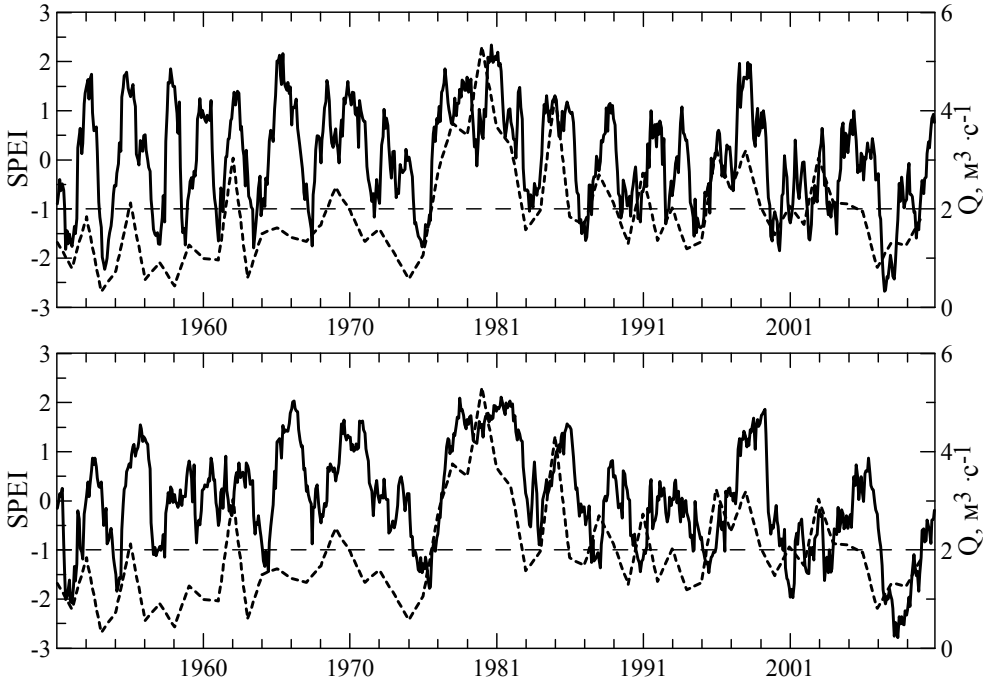

Figure 6. $SPEI_{12}$ (top panel) and $SPEI_{24}$ (bottom panel) vs. annual mean water discharge (dotted line) in Katerynka gauge site from 1951 to 2010.

decades, and (iii) the time scales that are used to calculate the indices of drought are more that 1 year.

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