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Climate change impact on seasonality of flood in the Desna river catchment, North Ukraine

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SUMMARY

The modern climate of Ukraine is characterized by asymmetric warming (more significant in the north than in the south), expressed in the winter and summer months. This may affect the seasonality of the flood. The time of flooding or its seasonality is an excellent indicator for studying the processes of flood formation under climate change conditions. The results of this study show that frequency of winter floods in the Desna river catchment, located in the north of Ukraine, is increase and frequency of spring floods is decrease. It is the result of changes in the current climatic regime in the North of Ukraine. In the second period of observations (1998-2015) the process of flood formation began almost two weeks earlier than in the first (1960-1987). The most probable moment of the peak of the flood according to the frequency distribution curves of the annual maximal floods in the second period shifted significantly relative to the first period and occurred earlier by 7 days. The value of the density distribution of Q max annual dates in the spring flood peak area decreased significantly. Since 1988, the dates of the beginning of spring floods have shifted to earlier dates (February-March), which indicates warmer winters with thaws, which leads to a decrease in water reserves in the snow and, consequently, the early beginning of spring floods.

Introduction

In the last report of the IPCC predicts that climate-related extreme events will become even more frequent around the world (*IPCC. Climate Change,2021).* 2020 was Europe's and Ukraine's hottest year on record, at 2.8°C above average, and each of the last 20 years in Ukraine were warmer than the long-term average (*Wilson et al., 2021*). As a result, Ukraine is experiencing a number of climatic consequences, including large-scale floods, which lead to the loss of people and livelihoods and negatively affect GDP (*Snizhko et al., 2021*). The current climate of Ukraine is characterized by asymmetric warming (more significant in the north than in the south), pronounced in the winter and summer months. The most important meteorological parameters that determine the climatic and agroclimatic resources of each territory are air temperature and precipitation (*Snizhko et al., 2020a, 2020b*).
In Ukraine, the highest warming rate for the period 1981–2010 was observed for the northern and northeastern parts with the rates of annual mean temperature 0.58–0.66 °C/10 years (*Balabukh & Malitskaya, 2017*). The most evident of these changes include changes in air temperature and the phenomena associated with it (*Shevchenko et al, 2020*). As a result of such changes, the number of thaws, heavy precipitation in the form of both snow and rain increases in Ukraine in winter due to warming, and the number and intensity of heavy rains, hail, squalls, tornadoes and days with thunderstorms increased in summer. Such changes can clearly affect the hydrological regime of rivers, causing extreme hydrological situations (floods or droughts).
The increase in the frequency of river floods in many regions is often attributed to climate change. However, recent studies (*Blöschl et al., 2019*) show that climate change can lead to both an increase and a decrease in the flood frequency. The timing of the flood or its seasonality may also change due to climate impact (*Blöschl et al., 2017*). The determination of flood seasonality is important for many applications in hydrology. In general, seasonality is regarded as an excellent indicator for the investigation of flood generation processes.
The task of these studies is to identify the impact of climate change on the flood regime of the Desna River located in the north of Ukraine by analysing the shift in flood timing during 1960-2015.

Short Description of the Desna river catchment.

The Desna River is the largest catchment area (88,900 km^2) and the second-longest left tributary of the Dnieper (1130 km), the runoff of which forms up to 20% of its water runoff. Most of the Desna sub-basin is located within the mixed forest zone in the northeast part of Ukraine, and the southeastern part of the sub-basin is located within the forest-steppe zone of Ukraine. The nature of the water regime of rivers is largely determined by the characteristics of the spring flood, its duration, and the partial participation of meltwater in the annual runoff, which in turn is determined by the type of river feeding.
In the Desna sub-basin, spring flooding begins on its tributaries, which are located in the lower part of the basin. As the snowmelt front advances to the north (on average 3 to 5 days), snowmelt begins to cover the entire river basin. On small and medium-sized rivers of the basin in the upper and middle reaches of the river (Seimas), the average dates of the beginning of spring floods fall in the second decade of March, in general, the average duration of floods is 55-65 days, but in some years, duration is 40-45 days, during intermittent snowmelt can reach from 80 to 100 days. Catastrophically high spring floods were last observed in the Desna sub-basin in 1932 and 1970 (*Ovcharuk et al., 2019*).

Data and Methods of Research

The hydrological date was obtained from daily runoff observations carried out by the Central Geophysical Observatory named after Boris Sreznevsky in Ukraine for the period 1960-2015 were selected for analysis of floods in the Desna River Catchment. The annual maximum river flow (Q max annual) and annual maximum daily flow timing (T Qmax annual) were chosen as the main indicators for research. The Q max annual series were extracted from the daily discharge data set, as the

maximum value in a hydrological year for each of the gauges. The flood time indicator (T Qmax annual) was defined as the number of the day of occurrence of Q max annual each year.
The research used available observational data on the characteristics of the maximum flow for 10 gauges in the basins of Desna within Ukrainian border.
The research methodology is built in such a way to reveal the influence of climatic factors on the formation of floods and to analyse the causes of the detected. The approach consists of the analysis of the timing of annual maximum discharges.

To investigate a possible shift in the time of flood occurrence, the distribution of the timing of floods is estimated and for pooled flood series within catchment and compared for two sub-periods of equal length, i.e., 1960-1997 and 1998-2015. The comparison of the distribution of the days of occurrence of floods for these periods aims at identifying changes in flood seasonality, possibly related to changes in flood generation processes due to climate change and warming. The non-parametric distribution density function KDE "Kernel density estimation" was used to estimate the distribution of days of occurrence of Q max annual during the calendar year (*Kernel Density Estimation, 2022*).

Results and Discussion

Analysis of the kernel density histograms for the dates of occurrence of the values of Qmax annual summarized for 10 gauges in the Desna river catchment for the two observation periods (1960-1987 and 1988-2015) indicates (Fig. 1) the significant differences in the processes of flood formation in these comparison time periods.
The distribution of the dates of occurrence of the Qmax annual in the first period of observations (1960-1987) is characterized by a pronounced acute peak distribution with the center, which falls on April 6. The highest probability of passing Qmax annual for this time period is 90 days and lasts from January 30 to May 30).
The histogram of the distribution of kernel density dates of Qmax annual for the second period of observations has a more flattened form, compared with a similar graph for the first period. The most probable moment of the peak of the flood according to the averaged data on Qmax annual dates for a set of 10 gauges in the basin falls on March 30. This means that in the second period (1998-2015) the most probable date of the flood peak is reached 7 days earlier than in the first period.

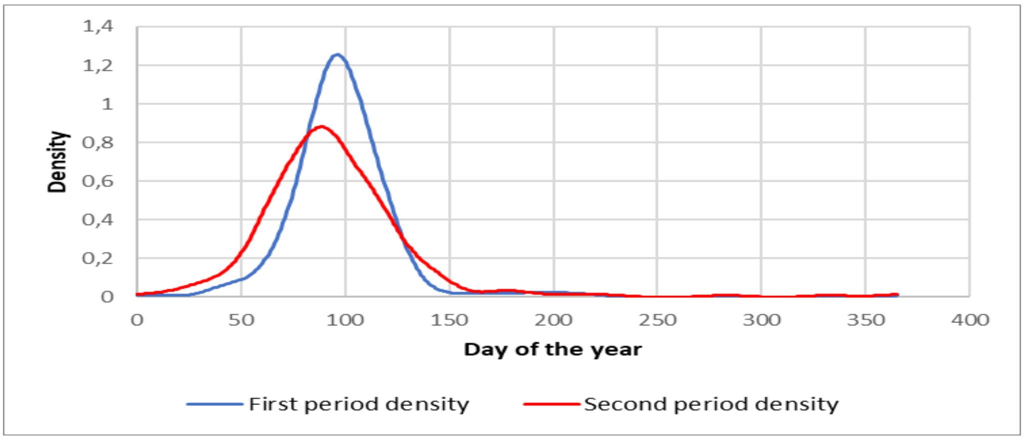

Figure 1 *Seasonality of floods in Desna river basins. The lines show the distribution (circular kernel density) of the day of occurrence of floods in two periods (1960-1987 and 1987-2015)*

Our research shows that in the current period due to climate change, the processes of flood formation have intensified significantly. In the second period of observations (1998-2015) the process of flood formation began almost two weeks earlier than in the first (1960-1987). The increase in the density distribution of Qmax annual dates in the area of the histogram from January 17 to March 20 was 9-13 days ahead of a similar increase in the histogram of the first period (1960-1987).

Frequency of cases (in terms of kernel density) of Qmax annual in the second period on each date was about twice as high as in the first period. However, the value of the density distribution of Qmax annual dates in the flood peak area decreased significantly from 1,26 (first period) to 0.88, ie 1.43 times. These facts, obtained from the statistical processing of observations, are evidence of global warming in the region, which has led to frequent thaws since January, increase in rain on snow cases. Due to this, Qmax annuals were often formed in the second observation period, even in January-February. The increase in the frequency of warm winters with thaws also affected the reduction of Qmax annual during flooding (*Gorbachova and Koshkina, 2013*).

Since 1988, the dates of the beginning of spring floods have shifted to earlier dates (February-March), which indicates warmer winters with thaws, which leads to a decrease in water reserves in the snow and, consequently, the early beginning of spring floods (*Gorbachova and Koshkina, 2013*).The most probable end dates of the period with the highest density of distribution the cases of Qmax annual in the first period are May 30, and in the second - June 12. That is, under the influence of climate change (temperature and precipitation) in the modern period, spring floods lasted 13 days longer. Usually the end of the flood is observed on average in the basin in the third decade of May. The reason for the increase in the frequency of Qmax annual in January-February is the increase in cases of advection-influenced thaws during climate warming, which occur during the movement of cyclones from the Atlantic, Mediterranean and Black Seas. The increase in the frequency of winter floods and a significant increase in the number of Qmax annual cases during this period is the result of changes in the current climatic regime in the Desna River basin.

The results obtained by Didovets et al. (*Didovets et al.,2019*) confirm the projected increasing of the river discharge in the Desna basin during the 21st century from January to March up to 28 % under RCP 2.6 and up to 42 % under RCP 8.5. During the rest of the months, river discharge is projected to decrease from -3 % to -16 %.

A comparison of histograms of the distribution of Qmax annual dates of the I and II periods shows an increase in the recurrence of Qmax annual cases in the II period from May 8 to June 12. This is explained, first of all, by the intensification of the warming of the underlying surface, which affects the formation of powerful convective air currents, thunderstorms and showers.

Occurrence of floods in the summer-autumn low water period in the Desna basin in both comparative periods has a low probability. In December, the probability of Qmax annual increases slightly.

Conclusions

The results of this study show that frequency of winter floods in the Desna river catchment is increase and frequency of spring floods is decrease. It is the result of changes in the current climatic regime in the North of Ukraine. In the second period of observations (1998-2015) the process of flood formation began almost two weeks earlier than in the first period (1960-1987). The most probable moment of the peak of the flood according to the frequency distribution curves of the annual maximal floods in the second period shifted significantly relative to the first period and occurred earlier by 7 days. The value of the density distribution of Q max annual dates in the spring flood peak area decreased significantly. Since 1988, the dates of the beginning of spring floods have shifted to earlier dates (February-March), which indicates warmer winters with thaws, which leads to a decrease in water reserves in the snow and, consequently, the early beginning of spring floods. The increase in the frequency of Q max annual cases in warm period of year is explained, first of all, by the intensification of the warming of the underlying surface, which affects the formation of powerful convective air currents, thunderstorms and showers.

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