Spring flood frequency analysis in the Southern Buh River Basin, Ukraine

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Abstract. The river floods are among the most dangerous natural disasters in the world. Each year, the spring floods cause the significant material damage in the different countries, including Ukraine. Knowledge of trends in such floods, as well as their probabilistic forecast, is of great scientific and practical importance. In last decades, the decreasing phase of cyclical fluctuations of the maximum runoff of spring floods has been observed on the plain rivers of Ukraine, including the Southern Bug River. In addition, there is an increase in air temperature. So, the actual task is to determine the modern probable maximum discharges estimates of spring floods in the Southern Buh River Basin as well as their comparison with the estimates that were computed earlier. It gives an opportunity to reveal possible changes of the statistical characteristics and values of the probable maximum discharges, to analyze and to discuss the reasons for these changes. For the investigation, we used the time series of the maximum discharges of spring floods for 21 gauging stations in the Southern Buh River Basin since the beginning of the observations and till 2015. The method of the regression on the variable that is based on the data of analogues rivers was used to bring up the duration of the time series and restoration of the gaps. In the study, the hydro-genetic methods for estimation of the homogeneity and stationarity of hydrological series, namely the mass curve, the residual mass curve and the combined graphs. The distributions of Kritskyi & Menkel and Pearson type III for the frequency analysis were used. It has been shown in this study that the maximum discharges of spring floods of time series are quasi-homogeneous and quasi-stationary. It is explained the presence in the observation series of only increasing and decreasing phases of cyclical fluctuations, their considerable duration, as well as the significant variability of the maximal flow. The series of maximal runoff of spring floods are very asymmetric, which significantly complicates the selection of analytical distribution curves. The updated current parameters of the maximal spring flood runoff have not changed significantly. It can be assumed that such characteristics have already become stable over time, as the series of maximal runoff of spring floods already have phases of increasing and decreasing of long-term cyclic fluctuations.

Keywords: spring floods, stationarity, homogeneity, frequency analyses, cyclical fluctuations
Introduction

In the world, the extreme floods on the rivers cause considerable and prolonged flooding of the densely populated territories, which cause to damage a myriad of infrastructures such as buildings, roads, bridges, and barrages and sometimes also losses of human lives. The extreme floods are among the costliest natural hazards (Doe, 2006; Razmi et al., 2017; Blöschl et al., 2019). Since the natural disaster as extreme floods is the basis for planning and design of various hydraulic structures, hydrological forecasting, flood risk reflection characteristics such as trends of extreme floods and its changes, and its formation conditions, the probable maximal flood and its characteristics have a great practical importance. The determining of the probable maximal flood is the practical importance, especially for the planning, design, and operation of hydrotechnical structures (Apel et al., 2004; Blöschl et al., 2013; Okoli et al., 2019).

During the 20th century, many scientists developed the methodological approaches to the definition of flood estimates, which remain relevant today. Therefore, the statistical approaches, hydrometeorological methods, empirical formulas, different regionalization methods are usually used to flood estimates (Blöschl et al., 2013; Saghafian, 2014; Odry and Arnaud, 2017). At the same time, such research may have the related difficulties due to low precision of extreme flood discharge measurements and estimates, using comparatively short time series of observed flood data, limited data availability, as well as temporal variation in the data series due to variability in climate and to environmental changes, etc. Hence, the important task is obtaining reliable flood estimates. This can be achieved by using appropriate methodological approaches (McKerchar and Macky, 2001; Kjeldsen, 2015; Okoli et al., 2019).

In Ukraine, on the plain rivers the dangerous floods are observed during the spring period (Grebin, 2010; Gorbachova, 2015; Shakirzanova, 2015; Khrystyuk et al., 2017). In this paper, the spring flood estimates was carried out for the Southern Buh River Basin. The research for this river is actual because the river has significant importance for hydro-energy sector and agriculture. Thus, Southern Buh River Basin has 6929 ponds and 200 water reservoirs (Palamurchuk and Zakorchevna, 2006). In the different years, these reservoirs can accumulate from 20 to 70% of the local flow. Water river is widely used for irrigation, especially in drought years (Vyshnevskyi, 2000). The frequency approach is widely used for flood estimates in Ukraine. Typically, the statistic estimates are the updated every 5 years. This approach allows the use of modern data and, accordingly, to receive more reliable and accurate flood estimates.

The aim of this study is to determine the modern probable maximal discharges estimates of spring floods in the Southern Buh River Basin as well as their comparison with the estimates that were computed earlier. It gives an opportunity to reveal possible changes of the statistical characteristics and values of the probable maximal discharges, to analyze and to discuss the reasons for these changes.

The tasks of the research include:

– the use of the method of linear regression for the restoration of the data of observations in different years;

– the investigation of the homogeneity and stationarity of the observation series on based the graphical methods;

– the determination of 1% maximum discharges of spring flood of the rivers.

Materials and Methods

Southern Buh River is the second-longest river after the Dnipro River in Ukraine. It is the longest river that flowing exclusively through the territory of Ukraine – its length is 806 km. The basin river is on the Volyn-Podillia and Dnipro Uplands, as well as in the Black Sea lowland for the lower part of the basin. Its crosses three natural zones: forest, forest-steppe, and steppe. Catchment covers 10.6% of the territory of Ukraine. Southern Buh River Basin has the pear-shaped form: at the top part it is narrowed; in the middle and lower parts the basin is sharply asymmetrical (Fig. 1). Southern Buh River is plain river, because the average height of its catchment in the upper part is 300-320 m, in the lower part is 5-20 m, the average slope of water surface is 0.40% (Kaganer, 1969).

The atmosphere circulation is carrying out an important role for the formation of the basin climate. It is associated with the movement of an air masses from the Atlantic, Arctic, and Mediterranean. Moderate
Continental climate is typical for the river basin. Precipitation gradually decreases from the source to the mouth of the river. (Bauzha and Gorbachova, 2017). The summer rains (except for the strong) do not form a surface runoff at some catchments of steppe zone due to the intensive infiltration of rainwater into the soil and significant evaporation from river catchment. Furthermore, such rivers almost do not have an underground supply and in the summer-autumn period it dries up. In winter period, such rivers are usually frozen (Gorbachova and Khrystyuk, 2018). Southern Buh River basin is characterized by a clearly pronounced spring flood, during which it is forming from 35 to 60% of annual streamflow (Shakirzanova, 2015).

The Southern Buh Basin has extremely high anthropogenic loads. Hence, more than 8 000 artificial reservoirs were created in the basin, their total volume is close to 1.5 km³, which is almost equal to the runoff in the dry year of probability 95%. Its water is widely used for hydro-energy sector, industrial and municipal water supply, agriculture, irrigation, shipping, tourism, etc. (Bauzha and Gorbachova, 2017).

In this study we used the series of observations of 21 gauging stations of the Southern Buh River Basin (Fig. 1). The catchment areas are changing in the greater limits – from 92.5 to 46200 km². The period of observation on these rivers is from 14 (Southern Buh River – Selythse village) to 102 (Southern Buh River – Oleksandrivka village) years (since the beginning of the observations and till 2015) (Table 1).

To verify the reliability of observations data on the maximum discharges of the spring flood it was used the historical information. On several rivers, the observations were not conducted for some years. Some data series were with errors or have short duration of observed flood data.

The method of the regression on the variable that is based on the data of analogues rivers was used to bringing up the duration of the time series and restoration of the gaps. This method recommended for using as by «Guide to Hydrological Practices» WMO (2009), as and by the national guideline of Ukraine (BNR, 1983). It is carrying out provided that:

\[ R \geq 0.7, l \geq 10, k/\sigma_k \geq 2 \]  

where \( R \) is the correlation coefficient between discharge values of the corrected and analogue gauging stations; \( l \) is a number of joint observation years of corrected and analogue gauging stations; \( k \) is the regression coefficient; \( \sigma_k \) is the standard deviation of regression coefficient.

The determining probable characteristics of time series can be carried out only based on the homogeneous and stationary data. Nowadays, two methodi-
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cal approaches detecting changes in the hydrological series of observations that are widely used world-wide: deterministic and statistical (Kundzewicz and Robson, 2004; WMO-No. 168, 2009; Gorbachova, 2014). In the paper, Kundzewicz and Robson (2004) it is showed that the hydrological series are characterized by some features (they are non-normal, seasonal, and serially correlated). Therefore, the statistical criteria to analyze changes of hydrological series of observations should be used only after their transformation, particularly resampling methods should be made. The graphical method and historical data are used to confirm the results of the statistical criteria.

In this paper, the deterministic approach based on graphical methods for estimation of the homogeneity and stationarity of hydrological series are used. These methods include correlation graphs, frequency of values, histograms, mass curves, double mass curves, residual mass curves, chronological charts, and etc. (Chow et al., 1988). During the 20th century the methodical approaches of using graphical methods were developed. Thus, Rippl (1883) invented and proposed to use the mass curve and residual mass curve for the design of the reservoirs and Merriam (1937) is the author of the double mass curve that he used for a research of hydrometeorological series change. In the papers, Gorbachova (2014, 2016) showed that with the complex use of certain graphical (hydro-genetic) methods can successfully carry out the assessment of homogeneity and stationarity of hydrological series. The mass and residual mass curves, and combined graphs of hydrological characteristics were proposed for the complex analysis of observation data. This methodological approach has already been used to investigation the homogeneity and stationarity of streamflow of Ukrainian rivers (Gorbachova et al., 2013; Gorbachova, 2015; Zabolotnia et al., 2019).

The mass curve is used to detect the influence of anthropogenic factors (hydraulic structures, canals) and of climate change (the presence of trends in the data series). The generation of runoff in the study area is homogeneous, and vice versa when the mass curve is not detected “hopping”, “outliers” or unidirectional deviation. The mass curve is defined with the following formula:

$$Q = \sum_{t=1}^{T} Q(t)$$

where $Q$ is the total discharge of river for time period $T$; $Q(t)$ is the discharge of $t$th year.

The residual mass curve was used for the assessment of the observation series stationarity. The analysis allows the definition of the stationarity of data series, the sustainability of the mean value of

| No | River       | Location of the gauging station | Catchment area (km²) | Study period and its duration, years |
|----|-------------|---------------------------------|----------------------|--------------------------------------|
| 1  | Southern Buh| Pyrohivtsi village             | 827                  | 1964-2015 / 52                       |
| 2  | Southern Buh| Lelitka village                 | 4000                 | 1926-43, 1945-46, 1964-2015 / 72      |
| 3  | Southern Buh| Selyshche village              | 9100                 | 2002-2015 / 14                       |
| 4  | Southern Buh| Trostyanchyk village            | 17400                | 1930-41, 1946-94, 1996-2015 / 81      |
| 5  | Southern Buh| Pidhir’ya village              | 24600                | 1926-43, 1958-2015 / 76               |
| 6  | Southern Buh| Oleksandrivka village          | 46200                | 1914-2015 / 102                      |
| 7  | Southern Buh| Stara Synyava village          | 439                  | 1946-93, 1996-2015 / 68               |
| 8  | Zhar        | Lityn village                   | 692                  | 1931-88, 1990-94, 1996-2015 / 82      |
| 9  | Riv         | Demydivka village              | 1130                 | 1916-18, 1922-41,1945-88, 1990-94, 1996-2015 / 91 |
| 10 | Sob         | Zoziv village                   | 92.5                 | 1945-88, 1990-94, 1996-2006, 2008, 2010-13, 2015 / 66 |
| 11 | Savranika   | Osychky village                 | 1740                 | 1936-39, 1945-2015 / 75               |
| 12 | Kodyma      | Katernyka village               | 2390                 | 1931, 1933-41, 1945-88, 1990-2015 / 80 |
| 13 | Synuha      | Synyahyn Brid village           | 16700                | 1925-31, 1933-89, 1991-2015 / 89      |
| 14 | Hnylyy Tikych| Lysyanka village               | 1450                 | 1945-2015 / 71                        |
| 15 | Velyka Vys  | Yampil village                  | 2820                 | 1925-1941, 1943, 1945-91, 1993-2015 / 87 |
| 16 | Yatran’     | Pokoyleove village             | 2140                 | 1955-2010 / 61                        |
| 17 | Chorny Tashlyh | Tarasivka village           | 2230                 | 1933-43, 1945-88, 1990-2015 / 81      |
| 18 | Mertvooid   | Kryva Pustosh village          | 252                  | 1949-88, 1991-94, 1996-2015 / 64      |
| 19 | Inhul       | Kropynytskyi city              | 840                  | 1945-81, 1983-88, 1992-2006, 2008-12, 2014-15 / 65 |
| 20 | Inhul       | Sednivka village               | 4770                 | 1954-2015 / 62                        |
| 21 | Inhul       | Novogorozhene village          | 6670                 | 1931-1941, 1945-2015 / 82             |
the hydrological characteristic over a long period of time. The mean value of the time series is stable in the presence of at least one dry and wet phase of a long-term cyclical fluctuations of time series. The residual mass curve is defined by Andreyanov’s formula (1959):

\[
f(t) = \frac{\sum_{i=1}^{T} (k(t) - 1)}{C_V}
\]

where \( C_V \) is the variation coefficient of time series; \( k(t) = Q(t)/Q_0 \) is the modular coefficient; \( Q(t) \) and \( Q_0 \) is the discharge of \( t \)th year and mean discharge for the period \( T \).

Combined graphs of hydrological characteristics allow the definition of the synchrony/asynchrony of long-term fluctuations in different rivers within the one hydrological homogeneous area. In turn, the synchronous fluctuations are indicated on the homogeneous climatic conditions of runoff formation.

The Kritskyi & Menkel, Pearson type III and Gumbel distributions for the frequency analysis were used (Kritskyi & Menkel, 1940; WMO, 2009; BNR, 1983; Chow et al., 1988). The empirical probability distribution is defined by the formula (BNR, 1983):

\[
P_m = \frac{(m|n + 1)100\%}{n}
\]

where \( m \) is ordinal number of hydrological series members that arranged in the decreasing order; \( n \) is the total number of hydrological series members.

Statistical parameters of the analytical probability distribution, namely the mean discharge of the data series, the variation, and skewness coefficients are defined by the method of moment and method of maximal likelihood according to methodical approaches that were showed in the WMO (2009).

The fitting criterion \( \chi^2 \) to check the results of analytical curve approximation of empirical points was used (Chow et al., 1988).

**Results and their analysis**

In accordance with formula (2), in the Southern Bug River basin for the 21 gauging stations the graphs of the mass curve of maximal discharges of spring floods were created. Examples of such curves for some rivers are shown in the Fig. 2.

The analysis of these graphs shows that the observations series are inhomogeneous, because a point of inflection is on them, after which the tendency of maximal discharges changes. At the same time, this type curves indicates the absence of unidirectional stable trends of maximal discharges of spring floods of the Southern Bug River basin. Such tendencies are typical also for other plain rivers of Ukraine (Shakirzanova, 2015; Gorbachova et al., 2016; Zabolotnia et al., 2019). Such observations series have the mass curve of convex type. The residual mass curves were created to identify the reasons for such a tendency of maximal discharges of spring flood of the rivers (Fig. 3). Their analysis showed that for the period 1970-1980 for all rivers was the transition from the increasing to decreasing phases of the long-term cyclical fluctuation. The decreasing phase continues to this day and its completion cannot be predicted. The different phases of cyclic fluctuations are observed in the

![Fig. 2. Some mass curves of the maximal discharges of spring floods of the Southern Buh River Basin](image-url)
various directional changes of streamflow (Pekarova et al., 2003; Gorbachova, 2015). Also, these phases have a significant difference in the mean values (Gorbachova, 2015). Furthermore, the maximum flow of rivers has considerable variability (its values are several times higher than the values of average annual and minimum flow). The feature of the maximum flow of spring flood of plain rivers is the long duration of cyclical fluctuations phases. For example, at the Southern Buh River hydrological station on Oleksandrivka village the data series of maximal spring flood (the observations have been carried out since 1914), have not yet completed a decreasing phase that began in 1970 (Fig. 3). This series of observations also do not have the complete increasing phase of fluctuations since observations began at a time when the increasing phase was already in progress. Consequently, at the Southern Buh River hydrological station on Oleksandrivka village the maximal flow of spring floods with the duration of observation at 102 years (1914-2015), does not have a full cycle of long-term fluctuations.

Therefore, the presence in the observation series of maximal flow of spring floods of plain rivers in only increasing and decreasing phases of cyclical fluctuations, their considerable duration, as well as the significant variability of maximal flow are forming the convex type of mass curves. Also, a mass curve type has a temporary character and occurs when a combined analysis of different phases of long-term cyclical fluctuations, namely only increasing and decreasing phases. The observation series can be classified as quasi-homogeneous. The conclusions are indirectly confirmed by the analysis of the maximal flow of spring floods of mountain rivers. Such studies (Gorbachova and Barandich, 2016; Zabolotnia et al., 2019) is shown that the phases of cyclic fluctuations of mountain rivers have a much shorter duration than

plain rivers. For mountain rivers, the mass curves have the sinuous type. In the study (Shakirzanova, 2015) it is shown that in the Southern Buh River Basin the climatic factors of spring floods have long-term cyclical fluctuations. The cyclical fluctuations of climatic factors of the formation of spring floods of rivers are also shown in the papers (Khrystiuk, 2013; Khrystyuk et al., 2017). The classification of hydrographs by similar shapes in them was carried out and it was shown that the presence of similar in shape hydrographs in the time series of classes indicates that from time to time the similar formation conditions of water flow at the catchment area repeats due to cyclicity of climatic and, as a consequence, of hydrological processes. In the study (Khrystiuk et al., 2020) the cyclicity of spring floods based on the classification of hydrographs by the facet method in the Southern Buh River Basin is showed.

The absence of a full cycle of long-term fluctuations in the observation series of the maximal flow of spring floods of rivers makes such data an unrep-
floods are homogeneous, because at all hydrological stations the fluctuations of the maximal flow of spring floods are synchronous and syn-phase (Fig. 3). It also shows that the anthropogenic impact does not have a significant effect on the maximal flow of spring floods because rivers with natural flow have the same tendency as the rivers with the hydraulic structures. It also facilitates the selection of rivers of analogues. For short series of observations, it is necessary (if possible) to carry out them the increase duration. This will allow such series to have the information about extreme floods that were observed in the increasing phase of long-term cyclical fluctuations in the Southern Buh River Basin. For example, these are the same data series as for Southern Buh River – Pyrohivtsi village (Fig. 3a) and for Southern Buh River – Selyshche village (Table 1).

In accordance with the requirements to calculations (1), the increased duration and restoration of the gaps in the time series by the method of regression on the variable based on the data of analogue rivers were carried out. An analysis of the results shown that in the time series remained some gaps, but their percentage was significantly decreased (Table 2). In the Southern Buh River Basin there are difficulties with the choice of analogue rivers because observations do not cover small rivers and some tributaries (Gorbachova and Khrystuik, 2018).

Hence, at the Southern Buh River water gauging station on the Oleksandrivka village, the time series has the longest duration without gaps (102 years). This station is the closing water gauging station on the Southern Buh River, consequently, its catchment area is the largest in basin (Fig. 1, Table 1). However, it cannot be an analogue for the time series that were obtained from catchments with small areas. All other time series have gaps in observations due to military actions, reconstruction, etc. The restored time series allows obtaining the more reliable calculated statistical characteristics of the maximal discharges of spring floods in the Southern Buh river basin, which are shown in the Table 2. However, we have some difficulties with the selection of the analytical curves when approximating the empirical points of spring floods in the Southern Buh river basin. We found that the distributions Kritskyi & Menkel and Pearson type III can be used for plotting analytical curves (Fig. 4 and Table 3).

The Gumbel distribution is generalized extreme value distribution. However, in the Southern Buh River Basin the Gumbel distribution cannot be used to generate analytical curves, because the lower part of such curves is in the range of negative values. The Pearson type III distribution also could not be used for some series of observations for a similar reason. Therefore, basically the analytical curves of Kritskyi & Menkel distribution to determine the values of maximal discharges of spring floods with 1% probability were used. Although, these curves also do not correspond very well the empirical points according to the analysis by fitting criterion $\chi^2$ (Table 3). This situation can be explained by the fact that the observation series of spring floods are very asymmetric, because it has only a few extreme discharges. For short series (for example, it has only one extreme discharge), it is generally impossible to select the analytical curve without restoring the historical discharges. These are such series of observations as for water gauging stations of the Southern Buh – Pyrohivtsi village and the Sob – Zoziv village.

**Discussion**

The last frequency analysis of observation data for the maximal discharges of spring floods of the Southern Buh River Basin was carried out in the paper of Gorbachova and Khrystuik, 2018. In this paper, the calculation was carried out for the data to 2010 and were shown that values of maximal discharges of spring floods with 1% probability have the tendency to decrease in relation to the calculations which was completed according to the data to 1980. A comparative analysis of the results of this study with the results introduced in the paper of Gorbachova et al. (2018) showed that the values of maximal discharges of spring floods with 1% probability as well as its statistical characteristics not significantly changed (Table 3, columns 6, 7, 8, and 10). Consequently, such a parameter as the mean values of maximal discharges of spring floods already became stable over time. It is ensured by the presence in the time series of the increase and decrease phases of long-term cyclical fluctuations (Fig. 3). Thus, the analysis of cyclic fluctuations of the maximal flow is especially important when the frequency analyses are carried out.

**Conclusions**

The research presents the results of the spring floods estimates of the Southern Buh River Basin. The analysis of the homogeneity and stationarity of the maximal discharges of spring floods showed that time series are quasi-homogeneous and quasi-stationary. It is explained by the features of the maximal flow of spring floods of plain rivers, namely presence in the observation series only increasing and decreasing phases of cyclical fluctuations, their considerable duration, as well as the significant variability of maximal flow.
| №  | River                              | Location of the gauging station | Calculated period, years | Percentage of preserved data | Statistical parameters | Parameter definition method | $Q_{1\%}$, m$^3$/s | $Q_{\text{mean}}$, m$^3$/s | $C_v$ | $C_s$ | $C_r/C_v$ |
|----|-----------------------------------|----------------------------------|--------------------------|------------------------------|------------------------|---------------------------|---------------------|------------------------|-------|-------|-----------|
| 1  | Southern Buh                       | Pyrohivtsi village               | 1916-2015                | 36/12                        | 24.3/25.5              | MLE                       | 93.4/92.7           | 0.80/0.85              | 0.80/0.76 | 2.31/2.30 |
| 2  | Southern Buh                       | Letkiha village                  | 1915-2015                | 14/13                        | 1.40/1.22              | MLE                       | 763/687             | 3.11/3.37              | 2.51/2.51 | 1.12/1.12 |
| 3  | Southern Buh                       | Shlyshche village                | 1916-2015                | 85/12                        | 0.418/0.42             | MLE                       | 103/94              | 2.49/2.42              | 1.18/1.18 | 2.89/2.89 |
| 4  | Southern Buh                       | Troyatsyky village               | 1915-2015                | 118                           | 4.70/4.27             | MLE                       | 206/187             | 3.11/3.37              | 2.51/2.51 | 1.12/1.12 |
| 5  | Southern Buh                       | Pidhir'ya village                | 1917-2015                | 17/8                          | 6.97/6.18             | MLE                       | 226/216             | 0.97/0.81              | 0.97/0.81 | 1.18/1.18 |
| 6  | Southern Buh                       | Obskyndyuka village              | 1915-2015                | 18/10                        | 7.37/7.67             | MLE                       | 440/340             | 2.92/3.33              | 2.18/2.18 | 1.50/1.50 |
| 7  | Southern Buh                       | Talava village                   | 1917-2015                | 16/11                        | 21.6/22.11            | MLE                       | 115/105             | 2.31/2.29              | 1.47/1.47 | 1.47/1.47 |
| 8  | Southern Buh                       | Lypnyanka village                | 1916-2015                | 34/24                        | 0.413/0.42             | MLE                       | 226/216             | 1.12/1.12              | 1.12/1.12 | 2.31/2.30 |
| 9  | Southern Buh                       | Os'kivka village                 | 1916-2015                | 17/7                          | 8.38/8.56             | MLE                       | 577/522             | 1.82/1.82              | 1.82/1.82 | 2.50/2.50 |
| 10 | Southern Buh                       | Zaporizhzhya village             | 1928-2015                | 17/7                          | 8.07/8.56             | MLE                       | 218/217             | 1.69/1.70              | 1.69/1.70 | 2.50/2.50 |
| 11 | Southern Buh                       | Oleksandrivka village            | 1915-2015                | 12/9                         | 0.413/0.42            | MOM                       | 1479/141             | 1.12/1.00              | 1.12/1.12 | 2.31/2.30 |
| 12 | Southern Buh                       | Oleksandrivka village            | 1916-2015                | 16/13                        | 21.6/22.11            | MLE                       | 121/110             | 2.31/2.29              | 1.47/1.47 | 1.47/1.47 |
| 13 | Southern Buh                       | Oleksandrivka village            | 1915-2015                | 34/24                        | 0.413/0.42             | MLE                       | 226/216             | 1.12/1.12              | 1.12/1.12 | 2.31/2.30 |
| 14 | Southern Buh                       | Syryntsi village                 | 1917-2015                | 34/24                         | 1.74/1.56             | MOM                       | 285/280             | 2.30/2.00              | 2.30/2.00 | 2.30/2.00 |
| 15 | Southern Buh                       | Karpenko village                 | 1915-2015                | 17/11                        | 8.38/8.56             | MLE                       | 218/217             | 1.82/1.82              | 1.82/1.82 | 2.50/2.50 |
| 16 | Southern Buh                       | Korytno village                  | 1915-2015                | 17/11                        | 8.38/8.56             | MLE                       | 218/217             | 1.82/1.82              | 1.82/1.82 | 2.50/2.50 |
| 17 | Southern Buh                       | Cheremny Tyshyky village         | 1916-2015                | 25/13                        | 7.54/6.80             | MLE                       | 91/800              | 1.60/1.58              | 1.60/1.58 | 2.36/2.36 |
| 18 | Southern Buh                       | Kryva Pustoh village             | 1917-2015                | 25/13                        | 7.54/6.80             | MLE                       | 91/800              | 1.60/1.58              | 1.60/1.58 | 2.36/2.36 |
| 19 | Inhul                              | Kropyvnytsky city                | 1917-2015                | 25/13                        | 7.54/6.80             | MLE                       | 91/800              | 1.60/1.58              | 1.60/1.58 | 2.36/2.36 |
| 20 | Inhul                              | Kropyvnytsky city                | 1917-2015                | 25/13                        | 7.54/6.80             | MLE                       | 91/800              | 1.60/1.58              | 1.60/1.58 | 2.36/2.36 |
| 21 | Inhul                              | Novopozyvtsya village            | 1915-2015                | 17/7                          | 5.23/5.15             | MLE                       | 215/212             | 1.51/1.50              | 1.51/1.50 | 2.50/2.50 |
| 22 | Inhul                              | Novopozyvtsya village            | 1915-2015                | 24/13                        | 1.36/1.38             | MOM                       | 230/230             | 2.30/2.00              | 2.30/2.00 | 2.30/2.00 |
| 23 | Inhul                              | Novopozyvtsya village            | 1915-2015                | 24/13                        | 1.36/1.38             | MOM                       | 230/230             | 2.30/2.00              | 2.30/2.00 | 2.30/2.00 |

Note: MLE – Maximum likelihood estimation method, MOM – Method of moments; in columns 6, 7, 8, and 10, the numerator shows the values that were calculated for the data to 2010 (Gorbachova et al., 2018), the denominator shows the values that were calculated for the data to 2015; the
The restoring of the gaps in the time series is especially important step in the investigation because it allowed obtaining information about extreme floods that were observed in the increasing phase of long-term cyclical fluctuations of the Southern Buh River Basin. It contributes to obtaining more reliable and stable over time of the statistical characteristics of time series.

In the Southern Buh river basin, we have some difficulties with the selection of the analytical curves when approximating the empirical points of spring floods. Such empirical distributions are very asymmetric due to the presence of only a few extreme discharges. The calculation characteristics of the

Table 3. Check of spring flood series for compliance distribution laws in the Southern Buh River Basin

| №  | River - gauging station                  | $\chi^2(a, v)$ | $\chi^2$  | Compliance | Distribution low        |
|----|----------------------------------------|----------------|-----------|------------|-------------------------|
| 1  | Southern Buh – Pyrohivtsi village      | 12.6           | 7.91      | compliant  | Krytsky & Menkel        |
| 2  | Southern Buh – Lelitka village         | 12.6           | 18.9      | not compliant | Krytsky & Menkel    |
| 3  | Southern Buh – Selyshche village       | 12.6           | 11.2      | compliant  | Pearson type III       |
| 4  | Southern Buh – Trostyanchyk village    | 12.6           | 21.0      | not compliant | Krytsky & Menkel    |
| 5  | Southern Buh – Pidhir’ya village      | 12.6           | 9.04      | compliant  | Pearson type III       |
| 6  | Southern Buh – Oleksandrivka village   | 12.6           | 48.5      | not compliant | Krytsky & Menkel    |
| 7  | Ikva – Stara Synyava village           | 12.6           | 6.56      | compliant  | Pearson type III       |
| 8  | Zhar – Lityn village                   | 12.6           | 9.31      | compliant  | Krytsky & Menkel        |
| 9  | Riv – Demydivka village               | 12.6           | 11.2      | compliant  | Krytsky & Menkel        |
| 10 | Sob – Zoziv village                   | 12.6           | 29.6      | not compliant | Krytsky & Menkel    |
| 11 | Savranka – Osychky village             | 12.6           | 37.1      | not compliant | Krytsky & Menkel    |
| 12 | Kodymya – Katerynka village            | 12.6           | 40.4      | not compliant | Krytsky & Menkel    |
| 13 | Synyuha – Synuhyyn Brid village        | 12.6           | 10.5      | compliant  | Pearson type III       |
| 14 | Hnylyy Tikyech – Lysyanka village      | 12.6           | 44.7      | not compliant | Krytsky & Menkel    |
| 15 | Velyka Vys – Yampil village            | 12.6           | 24.5      | not compliant | Krytsky & Menkel    |
| 16 | Yatran – Pokotylove village            | 12.6           | 47.5      | not compliant | Krytsky & Menkel    |
| 17 | Chornyi Tashlyk – Tarasivka village    | 12.6           | 27.8      | not compliant | Krytsky & Menkel    |
| 18 | Mertvovid – Kryva Pustosh village      | 12.6           | 37.2      | not compliant | Krytsky & Menkel    |
| 19 | Inhul – Kropyvnytskyi city             | 12.6           | 12.1      | compliant  | Krytsky & Menkel        |
| 20 | Inhul – Sednivka village               | 12.6           | 30.3      | not compliant | Krytsky & Menkel    |
| 21 | Inhul – Novogorozhene village          | 12.6           | 34.6      | not compliant | Krytsky & Menkel    |
maximal discharges of spring floods already became stable over time. It is ensured by the presence in the time series of the increase and decrease phases of long-term cyclical fluctuations.

The research results can be used by scientific and project organizations for getting more reliable estimations of time series and to plan and design of different hydraulic structures, as well as for regional planning and management of water resources of the Southern Buh River Basin.

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