Some peculiarities of spring snowmelt floods’ beginning, peak and end times at watercourses of the river Belaya basin

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Abstract. The article investigates the specific features of spring snowmelt floods’ typical beginning, peak and end times at watercourses of the river Belaya basin. The correlation between the mean multiannual values, the standard deviation of high water typical beginning, peak and end times as well as the morphometric characteristics of water-producing areas was estimated. Based on the regression analysis of the surveyed data from the analyzed watercourses of the area, correspondences for the dates are revealed, map charts for the standard deviations are designed. The results obtained are of the empirical nature, yet allowing making tentative calculations of the mean multiannual calendar values of high water extreme points at the unexplored watercourses of the studied area.

1. Introduction
In the current practice of hydrological calculations and forecasts a special importance is attributed to determining the characteristics of the spring run-off. The most elaborated features of high water include the parameters applied for calculating the observed values – the maximum throughflow for the period and the aggregate runoff depth. The temporal characteristics of the high water period are used for constructing hydrographs, drawing up analytical models based on volumetric methods, making forecasts of different temporal nature and at the same time haven’t been thoroughly explored. The described situation is also typical for the area studied by the authors – the river Belaya basin. The maximum throughflow and the aggregate runoff depth for the region have been considered in detail by the authors [1, 2, 3], while the temporal characteristics have received coverage only in several papers. The basin within the territory of the Republic of Bashkortostan is supplied with a map of the dates for the beginning of the flooding at a scale of 1:7 500 000 [4] which is drawn up taking into account the survey data up till the year 2000. The map is of indisputable value and yet isn’t devoid of several shortcomings, including low accuracy (a contour interval of 5 days) and incomplete spatial coverage (the northeastern part of the catchment area administratively related to the Chelyabinsk and Sverdlovsk regions is not included). Furthermore, forecasts have been made for individual river stations of the river Belaya as to the occurrence of the distinctive hydrological phenomena, including high water beginning, peak and end times. The authors in their works [5, 6, 7] provide forecasts as to the extremes of high water times. The results obtained are of clear value in terms of the application of new methods in operational forecasts of the spring runoff characteristics; however, they do not allow estimating the extremes’ occurrence times in unexplored areas. Thus, overall the typical high water periods for the analysed area call for further investigation, while the data...
available are fragmentary and do not comply with the basin principle. Given the above-mentioned the author of this work seeks to investigate the peculiarities of high water beginning, peak and end times at watercourses of the river Belaya basin.

2. Research data and methods
The object of analysis is represented by the basin of the river Belaya. The watercourses’ recharge is mixed, with snow and groundwater predominating, the water regime being marked by the presence of a characteristic high-water phase – the spring snowmelt floods, observed mainly in April-May, as well as a stable low-water phase with occasional floods in the mountainous area and an intermittent low-water phase in the flatland area. Within the framework of hydrology the spring runoff period has been well elaborated.

The initial data are constituted by observations from 86 hydrological stations featuring the longest observation duration. The weather dates of the beginning, the peak and the end of the floods were systematized for selecting the stations. The total number of annual points reached 3185 for the beginning, 3171 for the peak, and 3175 for the end. All the stations are located within the study area and the location of survey points is relatively even.

The main parameter analysed is represented by the mean dates of the beginning, the peak and end of the floods which are defined by means of conventional methods for selecting the stations by series reduced to the multiannual period. To assess the temporal variability in accordance with the recommendations [8] the standard deviation (SD or mean square deviation) was applied.

At the preliminary stage the resulting arrays of mean values and deviations were mapped in order to identify spatial patterns. The preliminary mapping of the array was exercised using the geostatistic operations software wizard (Geostratical Wizard) ArcGIS 10.3.

At the main stage the data underwent the regression analysis procedure, wherein the dates and their standard deviations were treated as dependent variables. The following morphometric characteristics of the catchment areas were used as predictors: the area, the average height, the latitude and the longitude of the center of gravity, the average incline. The reliability and accuracy of the equations obtained were evaluated using the standard methods.

In order to assess the contribution of individual morphometric characteristics of the catchment areas in terms of the time of extremes at the final stage of the research the authors have calculated standardized regression coefficients allowing to exclude the multiscale character of predictors by taking into account their standard deviation.

3. Results
The preliminary mapping of the arrays reveals that due to the great variability in the duration of the spring throughflow growth as well as to this parameter’s dependence on the lag time and, consequently, on the water catchment’s area a direct construction of maps for the peak and the end dates is impossible.

The map charts designed for the phenomenon’s beginning evinced the presence of a clear-cut negative anomaly of unknown genesis up to 5-6 days in length in the central part of the river Belaya catchment, viz. in the interfluves of the rivers Ay and Yuryuzan.

To this end, regressive dependencies on morphometric factors were established for the beginning, the peak and the end mean dates. In the spatial distribution of the standard deviations a number of distinctive trends have been identified, which makes it possible to map and subsequently determine standard deviations in direct accordance with the obtained map chart (figure 1).

The next stage features the performing of regression analysis. The resulting regression dependencies obtained by the authors are provided below:

\[
\begin{align*}
D_B &= 12.03 \text{ (March 12)} + 0.006H + 0.293I_B + 0.211\ln(F) + 0.004X + 0.017Y - 5.74 \text{ for the beginning}; \\
D_p &= 16.03 + 0.017H + 1.101I_B + 1.193\ln(F) - 0.002X - 0.016Y - 5.74 \text{ for the peak}; \\
D_k &= 14.04 - 0.004H + 2.580I_B + 3.795\ln(F) + 0.034X - 0.012Y - 5.74 \text{ for the end}; \\
\delta_B &= 6.74 - 0.002H - 0.176I_B - 0.143\ln(F) - 0.0009X - 0.002Y - 5.74 \text{ for the beginning’s standard deviation};
\end{align*}
\]
\[ \delta p = 1.31 + 0.013H + 0.039I_B + 0.098\ln(F) - 0.009X - 0.006Y \] for the peak’s standard deviation;
\[ \delta k = 16.68 - 0.003H + 0.275I_B + 0.103\ln(F) - 0.0004X - 0.003Y \] for the end’s standard deviation.

In formulae:

- \( F \) – catchment basin area, km\(^2\);
- \( H \) – mean catchment altitude, m. Due to the insufficient character of the published data concerning the morphometric characteristics of the stations and with a view to ensuring the uniformity of the initial data the elevations were determined according to the SRTM materials [9] using the ArcGIS 10.3 toolkit under the algorithm [10, 11, 12];
- \( X \) – the longitude of the catchment’s centre of gravity, km;
- \( Y \) – the latitude of the catchment’s centre of gravity, km. The grid reference was obtained using the project’s frame of reference (Pulkovo-42) by truncating the value 10 000 000 for the longitude and 5 800 000 for the latitude with subsequent rounding off the result to integer values in kilometers.
- \( I_B \) – the mean incline of the catchment basin slope, degrees. The incline is determined by analogy with the mean catchment elevation.

The characteristics of the obtained equations, the assessment of their accuracy and integrity are supplied in table 1.

**Table 1. The equations’ features.**

| Parameter     | multiple correlation coefficient | approximation accuracy | mean-square error | correlation type |
|---------------|---------------------------------|-------------------------|-------------------|-------------------|
| mean multiannual dates |                                 |                         |                   |                   |
| beginning     | 0.79                            | 0.62                    | 2.14              | distinctive       |
| peak          | 0.85                            | 0.71                    | 3.32              | high              |
| end           | 0.85                            | 0.72                    | 5.69              | high              |
| standard deviation of dates |                             |                         |                   |                   |
| beginning     | 0.37                            | 0.14                    | 1.03              | moderate          |
| peak          | 0.62                            | 0.38                    | 2.41              | noticeable        |
| end           | 0.26                            | 0.07                    | 2.45              | weak              |

The results of standardized coefficient calculations are supplied in table 2.

**Table 2. Standardized regression coefficients.**

| Parameter     | H     | I_B   | ln(F)  | X     | Y     |
|---------------|-------|-------|--------|-------|-------|
| mean multiannual dates |       |       |        |       |       |
| beginning     | 0.32  | 0.20  | 0.11   | 0.13  | 0.54  |
| peak          | 0.55  | 0.41  | 0.34   | -0.04 | 0.29  |
| end           | -0.07 | 0.56  | 0.62   | 0.38  | -0.13 |
| standard deviation of dates |       |       |        |       |       |
| beginning     | 0.40  | -0.37 | -0.23  | -0.10 | 0.19  |
| peak          | 0.87  | 0.03  | 0.06   | -0.39 | 0.23  |
| end           | -0.26 | 0.25  | 0.07   | -0.02 | -0.15 |
Figure 1. Standard deviation of the mean multiannual dates of the beginning (a), the peak (b) and the end (c) of spring snowmelt floods, the river Belaya basin.

4. Discussion
With reference to analysing the mean multiannual dates of the beginning, the peak and the end of spring snowmelt of the river Belaya basin it has been detected that the extreme points’ occurrence dates feature statistically significant correlation with morphometric characteristics.

The implemented standardized coefficient analysis of the center of gravity coordinates testifies to the presence of distinctive spatial trends. Thus, when moving from the north to the south the beginning and the peak are shifted to an earlier time, the given offset value amounting to 5 days within the study
area. The end, on the contrary, is marked by the sectoral component – in the eastern part of the basin the snowmelt flooding comes to an end at a later date. The sectoral character of the end dates is less conspicuous, the difference for the extreme western and eastern points of the territory not exceeding 4 days.

Yet, despite the observed spatial trends the direct mapping of multiannual mean periods regardless of the square areas, the elevations and the inclines of the catchment slope is impossible and produces incorrect results. This is accounted for by the fact that the selected spatial trends are complicated due to the influence of non-geographic morphometric factors: the square areas, the elevations and the inclines of the catchment slope. The assessment of standardized regression coefficients (Table 2) indicates that various non-geographical morphometric factors come to be of key importance for different extreme points. Thus, the increasing inclines and square areas produce shifts to later dates with all of the given phenomena. The given offset tends to be of a logarithmic character with the increasing square area and can be explained by an increase in the lag time owing to the growing size of the catchment. Determining the implications of the shift in view of the increasing incline of the slope hasn’t been accomplished yet.

Due to the mountainous nature of the eastern part of the basin the time of occurrence of the extremes depends on the elevation of the catchment basin. For the beginning and the peak dates the relationship is represented as a distinctive straight line while for the end it is reverse and weaker. The direct relationship reflects a shift to a later date as a consequence of the observed thermal gradient predetermining a delay in melting and the subsequent water in-flow into the channel network of the watercourses of the mountainous zone. The mean elevation impact towards the time of the end of high water is ambiguous and calls for further investigation.

The standard deviations’ regression dependencies on morphometric factors are of insignificant relevance and cannot be recommended for usage. The preliminary mapping revealed the fact that the dates’ standard deviations feature the presence of distinctive multidirectional nonlinear spatial trends. The weak statistical significance disclosed in the subsequent regression analysis is believed to originate from the parabolic nature of the standard deviations’ dependencies on the of the center of gravity coordinates. The described phenomenon is vividly expressed in the given map charts (see Fig. 1) which are recommended for usage in determining the standard deviation.

Overall the revealed regular patterns are in line with the current conceptions of the maximum formation of snowmelt runoff [1, 2, 3] as well as the spring high water duration dependencies on morphometric factors obtained earlier for the territory [13]. It should be noted that despite the substantially high accuracy of the designed equations one of the drawbacks of the given research lies in the empirical nature of the revealed dependencies.

5. Conclusion
The dates of spring high water beginning, peak and end at watercourses of the river Belaya basin have been analyzed. For the mean values of the given characteristics statistically significant correspondences with the morphometric characteristics of the catchment areas have been identified, the maps charts of standard deviations have been drawn up. The results obtained may be used for the approximate calculating of the mean multiannual values and standard deviations of extreme point dates of the previously unexplored watercourses of the territory.

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