The assessment of extremal precipitation as part of flood runoff calculations

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Abstract. The goal of the study is to assess the extremal precipitation within the territory of the Urals with the use of the Hershfield’s statistical method. This method is not used in Russia but it is recommended for use by the World Meteorological Organization. The processing of data for 25,000 single storms observed at 233 weather stations in the Urals was carried out (in the basins of Kama and Tobol rivers), the statistical characteristics of various precipitations were evaluated, and extremal precipitation maximums were assessed. The said calculations could significantly increase the precision of measurement of extremal runoff in the rivers of the region.

1. Introduction
The methods of probability maximum precipitation (PMP) which define the extremal runoff in small watersheds are exhaustively covered in modern research, and are even brought up to practical recommendations [1]. For the most part, the input parameters of calculation models are empirical data of ground and radiosonde observations. This article describes the PMP calculation methods based on statistical methods built on the analysis of many years of multifaceted precipitation observations. This group includes the widely recognized Hershfield’s method [2-9], which has not been practically applied in Russia until now. The relevance of the study is emphasized by the implementation of modern methods that allow determining the probability maximums of hydrometeorological values.

2. Materials and methods
The present paper examines the results of combined analysis of extremal rainfall observation materials gathered from the weather stations of the Ural Territorial Administration for Hydrometeorological and Environmental Monitoring with a series of 20 years of observations gathered with precipitation gauges (data from 192 weather stations within the period from 1890 to 2015) and rain-recording gauges (data from 41 weather stations within the period from 1936 to 2015). In total more than 25,000 single storms were analyzed.

The Hershfield’s method allows estimating the probable maximum precipitation by conjugating the statistical value \( K_m \) of a rainstorm in extensive area and its adjustment with the use of an average value \( \bar{X}_{m-1} \) and coefficient of variation \( C_{vn-1} \) for the watershed under consideration. Instead of a rainfall maximum an abstract statistical value \( K_m \) is used.
\[
K_m = \frac{(X_m - \bar{X}_{n-1}) \cdot \bar{X}_{n-1}}{C_{m-1}}
\]  

(1)

where \(X_m\) is the first component in the ordered series of \(n\)-years of observations, i.e., having the maximum value, \(\bar{X}_{n-1}\) is the \(n-1\) series average, except for the maximum value \(m\); \(C_{m-1}\) is the coefficient of variation of \(n-1\) series. Obviously, the higher the density of weather stations, the closer will be the value \(K_m\) to the value corresponding to the probable maximum precipitation.

3. Results

Most foreign published research papers use values estimated by Hershfield as reference values. Due to this fact, the assessment of maximums was carried out using this method. The observation data from weather stations previously used in [10] for the whole observation period were used to trace the curve (figure 1).

![Figure 1. Dependence of coefficient \(K_m\) from ratio \(1/C_{v_n}\) (for a rainfall lasting 1,440 min).](image_url)

The Hershfield’s method allows estimating the maximum precipitation by conjugating the statistical value \(K_m\) of a rainstorm in extensive area and its adjustment with the use of an average value \(\bar{X}_{n-1}\) and coefficient of variation \(C_{v_{n-1}}\) for the watershed under consideration. Values \(K_m\) were calculated for all weather stations listed in [10, 11, 12] based on many years of series of maximum annual precipitation. During the analysis of series of intensive rainfall in the Urals for various periods,
it was possible to determine the dependence of type $K_m = f \left(1/C_{v_n-1}\right)$ characterized by good quality (correlation coefficient 0.86) (Figure) for the first time within the territory of Russia. Based on this dependence, an estimation of PMP using the Hershfield’s method was carried out (by multiplying the average precipitation sums, calculated for selected weather stations, and value $K_m$ estimated from $C_{v_n-1}$, the coefficient of variation of series n-1) (table 1).

Table 1. Comparison of maximum permissible precipitation during 24 hours

| Weather station | Observation period n, years | Height H, meters | Characteristics of maximum precipitation based on observation data and reliability value of 0.001% ($H_{0.001\%}$, mm) | Estimated maximum daily precipitation (PMP, mm) using the Hershfield’s method |
|-----------------|-----------------------------|-----------------|-------------------------------------------------|--------------------------------------------------|
| Verkhneye Dubrovo | 62                         | 287             | Reference                                      | CV          | $C_s/C_v$ | $H_{0.001\%}$ | Estimated maximum daily precipitation (PMP, mm) using the Hershfield’s method |
| Yekaterinburg    | 63                         | 281             | 39.0                                            | 0.39       | 3.2       | 232             | 185                  |
| Zlatoust         | 62                         | 532             | 36.8                                            | 0.45       | 2.3       | 203             | 264                  |
| Ivdel            | 64                         | 93              | 36.4                                            | 0.37       | 1.3       | 154             | 202                  |
| Krasnoufimsk     | 65                         | 205             | 32.8                                            | 0.41       | 2.2       | 225             | 179                  |

4. Discussion

The comparison of results of estimation of maximum daily precipitation based on actual observation data and with the use of the Hershfield’s method shows that the daily maximums differ significantly, by 4 to 30%. However, it is impossible to opt for either of the methods, since the deviations are multidirectional. Considering that, according to G A Alekseev ratio (2), the obtained values correspond to reliability of 0.001% within the set rainfall parameters, the comparison between the obtained maximum daily precipitation with the estimated values based on the observation data specified by the authors Klimenko et al [10] was carried out. Log normal distribution (Captain) was used to estimate the values with reliability higher than 0.001%. It was previously established by the authors for a series of precipitation sums as the best [10, 12].

Transition to the precipitation sums for rain of any duration was carried out with the use of results of the study conducted by the authors with regard to maximum duration of rainfall and coefficient of rainfall reduction in space. As established by the authors [13] there is an inverse dependence between the intensity of rainfall in different periods and its duration:

$$I(t)_{p,\%} = S_{p,\%}/(t+1)^n,$$  

where $S_{p,\%}$ is the maximum (immediate) intensity of precipitation during a period of time $t \to 0$ which depends on the probability of increase once every N years (the N value is related to reliability P in the following ratio: N=100/P); n is the coefficient of reduction of rainfall intensity to its duration.

Based on the research conducted by the authors, n equals to 0.56 to 0.72 for Sverdlovsk Oblast (in the vicinity of Yekaterinburg). Value S equals to 13.0 to 30.0 mm/min. Considering that $S_{p,\%} = A + B \cdot \lg(N)$ where A and B are constant for estimated weather station rain parameters; N is the estimated frequency of rainfall under the set rain parameters (for example, $A = -1.55$ and $B = 3.58$ for Yekaterinburg), the probability of exceedance P% corresponding to maximum intensity is estimated from (3):
\[ P_s = \frac{100}{s_{\text{max}} - A}, \]  

(3)

**Conclusion**

The values of maximum intensity of precipitation and daily sums of precipitation in this case correspond to the probability of exceedance one time every 1,000-100,000 (0.1-0.001%). This is also confirmed by the calculation estimates.

Thus, it is justifiable to assess the probable maximum precipitation with statistical methods, one of which is the Hershfield's method, when assessing the probable maximum runoff. The estimates carried out with the use of this method are related to the statistical methods of research of runoffs and probable maximums might be approximated by the completely determined value of probability of exceedance.

**References**

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