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## Extreme precipitation in the Amur River basin: formation factors and methods of estimation

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# Extreme precipitation in the Amur River basin: formation factors and methods of estimation

M D Trubetskova, I A Filippova and N V Osypova

Water Problems Institute of the Russian Academy of Sciences, 3, Gubkin str., 119333, Moscow, Russia

irinafil@yandex.ru

**Abstract.** The values of maximal daily precipitation in the Amur River basin obtained using two different methods are considered. The first one is based on the hydro-meteorological approach to calculate the probable maximum precipitation. The second one is developed by the authors; it combines several statistical methods for calculating the values of the hydro-meteorological characteristics of low probability. Comparison of the results obtained by the two methods is made.

## 1. Introduction

Limited hydro-meteorological information on rare hydrological events makes the problem of analyzing the conditions of extreme floods formation and estimating their characteristics rather difficult. To predict inundation caused by rain floods, it is important to have a reliable tool for estimating maximal runoff of low probability, extreme precipitation being the main factor of its formation. Short series of hydro-meteorological observations makes it impossible to reliably approximate the distribution functions of runoff and precipitation in the range of rare frequency using statistical methods and, all the more, to extrapolate them into the zone of very low probabilities. In such cases, it is possible to use methods that obtain estimates of probable maximum values of the characteristics under consideration basing on genetic (deterministic) conceptions. The idea of estimating maximal runoff value in the form of probable maximum flood (PMF) first appeared in the works of American hydrologists [1, 2]. In general, both methods for estimating PMF give their values that do not contradict with the observational data [3]. A number of authors [4] propose simulating a flood hydrograph and obtaining PMF basing on the so-called probable maximum precipitation (PMP). The PMP values can be estimated using the available hydro-meteorological information.

The article discusses the results of applying two approaches to the problem of estimating maximal values of precipitation which form maximal flood runoff. The first approach is the hydro-meteorological method for determining PMP according to WMO method [5]. The second one is developed by the authors, it is based on a complex of several known statistical methods. Both approaches have advantages and disadvantages. Unlike the hydro-meteorological approach, the statistical method is easy to use and indispensable in case of limited hydro-meteorological information. At the same time, the hydro-meteorological approach has undoubted advantages: it involves the data on atmospheric factors, such as dew point temperature, air temperature, wind speed, humidity, giving more reliable results for large river basins. In addition, it is possible to use the method by analyzing satellite information [6].



A number of studies indicate that both methods give similar results of the PMP [7, 8]. However, it is noted that in some cases, the PMP values obtained by statistical methods are twice as high as those obtained by physical methods [9-11]. The main conclusions made in these works suggest that statistical approaches give overestimated PMP values, but the method is preferable for poorly studied regions. A number of authors showed that the choice of a method for calculating PMP depends not only on the availability of precipitation data, but also on the physiographic features of the study region. Therefore, further research is needed to compare the results of these two approaches for a particular region. The study is carried out on the example of the Amur River basin. In 2013 a catastrophic flash flood caused enormous damage to the population and the economy of the whole region.

## 2. Materials and methods

### 2.1. Study area

According to the character of the water regime, the rivers of the Amur Basin belong to the Far Eastern type with a pronounced rain feeding. Rain feeding makes 47–85, snow feeding – 2–26, underground feeding – 9–31% of the annual flow volume. The main phase of the water regime of these rivers is rain floods observed in the warm season (mainly in July–September). The greater part of the annual flow passes during this period. Annually, from 5–10 to 15 floods occur in the summer–autumn period.

The greater part of the precipitation falls in the basin during the warm period, several times exceeding the winter sum. The average annual precipitation varies within 450–670 mm, monthly maximum is observed in July – August (100–150 mm), making on average 20–25% of the annual amount.

High intensity of summer precipitation combined with significant antecedent wetness of the soil in the basin leads to the formation of strong rain floods on many rivers of the basin which give rise to inundation in the middle and lower reaches of the Amur River.

### 2.2. Data

For estimating PMP, we used the data on the dew point temperature and precipitation sums on 43 synoptic stations in the Russian part of the Amur basin. The information is taken from an array of eight-term observations data on the main meteorological characteristics [12]. The length of the time-series is 51 years (1966–2016). Time-series of daily precipitation from the same source were also used [13]. The length of these time series is different; the maximal observation period is 1910–2013.

### 2.3 Methods

**2.3.1. The PMP method.** The term “probable maximum precipitation” is defined as the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends [5]. In this study, the hydro-meteorological approach was applied to obtain the PMP values. It consists in the assumption that on a given territory an upper limit of maximal precipitation depth exists, which cannot be exceeded for physical reasons. The essence of the method is that for the study area the maximum possible water vapor content of the air is determined using observation series of dew point temperature, and all the moisture is assumed to fall down in the form of precipitation. In reality such a situation is almost impossible. Further, a real rainstorm with maximal precipitation sum (“maximized rainfall”) for the chosen period (24 hours in this study) is distinguished from a long-term series of observations. The actual moisture content of the atmosphere during this rainfall is determined from the actual dew point temperature observed. PMP is calculated by the formula:

$$P_m = P_s \frac{W_m}{W_s},$$

where  $P_m$  is PMP;  $P_s$  – is the precipitation sum of the rain shower being maximized;  $W_m$  is the maximum possible moisture content of the atmospheric column at this point;  $W_s$  is the moisture content of the atmospheric column during a rain shower being maximized.

The estimation of PMP to a considerable degree depends on the interpretation of the dew point temperature data. In [14] it was shown that the accuracy of the PMP calculations can be roughly estimated as 20 mm. However, the described method has a number of shortcomings: first of all, the need for long series of meteorological observations data, complex and time consuming calculations, as well as the fact that new observational data can significantly change the result.

**2.3.2. The statistical method.** We propose a procedure based on the complex of known statistical methods for calculating inverse distribution of rare occurrence precipitation. It consists of the following steps:

1. First, the study area should be divided into homogeneous regions basing on the conditions of the precipitation formation [15]. When aggregating hydro-meteorological data within a homogeneous region, one can proceed from the hypothesis of its statistical homogeneity. This assumes the common type of the probability distribution curve and the common range of parameter values within a region. For zoning, we used the principle of physiographic homogeneity [15].

2. The problem of lack of hydro-meteorological information needed for statistical analysis should be solved by aggregating the data within a homogeneous region. In [16] it is shown that in the Amur River basin it is impossible to select stable clusters basing on synchronization of long-term fluctuations of precipitation in summer-autumn months, which is the necessary condition for using a number of methods for data aggregation. Therefore, the POT-method (Peaks Over Thresholds) was used for this. The POT method allows to increase the sample of extreme values by including hydro-meteorological phenomena repeated several times a year at different observation stations within a homogeneous region. All the values within a sample that exceed a certain threshold can serve as the basis for fitting the model, therefore with continuous series of observations at our disposal, the threshold approach is more efficient [17].

3. For each region, the one common time-series should be formed consisting of three (and more) characteristics of maximal precipitation for each year. Then the threshold values of maximal precipitation are to be assigned, and the time-series of values lying above the threshold are to be formed. Statistical parameters ( $C_v$ ,  $C_s$ ) are to be calculated for the obtained series using the L-moment method and GEV-distribution parameters. According to the conclusions made in [18], for the Amur Basin the GEV-distribution was used as a theoretical distribution satisfactorily describing the observations in the low-probability area.

4. Then the threshold value which leads to the best compliance with the empirical material should be estimated, and quantiles of a given probability of exceeding obtained. These values can be considered as the maximum possible precipitation in the region and used as an input parameter in modeling maximum water discharge (for example, in the HEC program).

### 3. Results

1. For each synoptic station in the Amur basin, PMP values were calculated using the method [8] for the summer period (from May to September). In [5], the maximal daily precipitation amount is presented for each meteorological station which is adopted as real in the procedure of the automated monitoring of observational data. This values range in the interval of 250–350 mm in different parts of the Amur basin. The PMP values obtained by us for all the synoptic stations except for six of them do not exceed this value.

2. Regionalization of the Amur River basin has been carried out. The basin has been divided into 5 homogeneous regions. Region 1 is located in the southeast of the basin, on the Sikhote-Alin raises, and covers the Russian part of the Ussuri basin. Region 2 includes the Bureya basin and the lower reaches of the Amur River. Region 3 occupies the middle and lower reaches of the Zeja River, Region 4 – its upper course. Region 5 occupies the basins of Shilka and Argun. The joined analysis was carried out

for the data on the long-term fluctuations of maximal precipitation sums in the regions. It proved that the hypothesis of statistical homogeneity is possible to be used when aggregating the precipitation data within each of the regions.

3. For each region, the threshold for maximum precipitation was empirically chosen, and the samples of maxima exceeding the thresholds were formed. For calculation, the data from the part of the time-series having values above the threshold were used. For Region 1 the threshold is 100 mm (or 22% of the total length of the time-series), for Region 2 – 70 mm (45%), for Region 3 – 60 mm (38%), for Region 4 – 50 mm (42%), for Region 5 – 50 mm (60%).

4. The quantiles of maximum precipitation of various probabilities has been obtained for each of the regions.

#### 4. Discussion

Table 1 presents the results of calculations done by the two methods. PMP values were determined for each synoptic station, while the statistical method gave the characteristics of the maximal precipitation for the whole region. Therefore, to compare the results, for each homogeneous region the average values of PMP were obtained – as the arithmetic average of the PMP values of all synoptic stations within the region, and the maximum of these values as well (table 1).

**Table 1.** Values of daily precipitation of different probability of excess and PMP values.

Region	The number of synoptic stations within the region	The precipitation sum of the fixed probability calculated by the statistical method (mm)					PMP (mm)	
		0.01%	0.1%	1%	10%	20%	Maximal	Average
1	8	365	223	170	125	112	359	211
2	13	1090	299	167	102	89	266	188
3	5	326	167	119	85	76	265	178
4	4	730	213	121	73	63	279	165
5	10	369	154	103	71	63	214	140

For all regions, the obtained average and maximum values of PMP were found to be lower than the precipitation sums of 0.01% probability. The average PMP values are comparable with precipitation values of 1% probability, the maximum ones exceed them. In accordance with the definition, the value of the PMP cannot be exceeded for physical reasons and should be more than precipitation sum of any probability, even 0.01%. Therefore, the question arises: does the PMP method underestimate the maximum possible precipitation, or does the statistical method overestimate it? Values of daily precipitation amounts of 1090 and 730 mm (table 1, regions 2, 4), of course, are absolutely unrealistic for the area of the Amur Basin.

#### 5. Conclusion

The maximal precipitation values are estimated for the synoptic stations in the Amur River basin using 2 methods: PMP method according to [8] and the statistical method for the selected homogeneous regions. The comparison of the results proved the methods to give similar results for the values of PMP and maximum precipitation of 1% probability in the Amur River basin.

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