

Methods for long-term forecasting of water availability in spring floods (r. Arpa – p. Jermuk)

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Abstract. The article discusses the main physical and geographical factors, affecting the runoff of spring floods in the Arpa rivers catchment in the station Jermuk. Also the article discusses the development of a methodology for long-term forecasting of runoff volume of spring flood (WIV–VI) of river Arpa, station Jermuk. The study used data of water discharges of Arpa river catchment (station Jermuk), air temperature, precipitation, reserve water in snow at meteorological station Jermuk. A linear correlation was also revealed between the values of the annual runoff and runoff of spring floods in Arpa river catchment, which can be used to predict the annual runoff. To predict the volume of spring flood runoff, regression method and obtained multivariate correlation dependencies. Assessment of statistical significance and stability the proposed models showed their «satisfactory» quality and the possibility of using in the practice of engineering and hydrological forecasts.

1 Introduction

Flood water is considered extreme and becomes a flood, if maximum water flows are formed and, accordingly, high water levels are formed, at which low-lying parts of settlements, agricultural land, roads and railways are flooded, and industrial facilities are damaged [8]. Due to global climate change on the Earth, the number of catastrophic floods has increased, causing enormous damage. But floods cause both damage and great benefits, because due to flood reservoirs, electricity is generated, crops grow, and water is supplied to the population and industrial facilities [1].

Therefore, development of a methodology for long-term forecasting of flood water availability is of significant interest for water consumers and is an important task, solution thereof can help prevent economic damage and human losses, as well as regulate and manage water resources. Taking into account long-term forecasts of river flow, the most important operational decisions are made [2] related to operation of water management systems and implementation of flood control measures. Long-term hydrological forecasts are widely used

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to service many sectors of the country's economy, mainly water power engineering, agriculture and water management, timber rafting, fisheries and utilities, water, rail and road transport.

The main objective of this paper is to determine and analyze hydroclimatic conditions for formation of floods in the upper reaches of the Arpa River, and develop a methodology for long-term forecasting of flood water content (runoff volume, W_{IV-VI}) of the Arpa River – Jermuk Village.

The station of the Arpa River – Jermuk Village was chosen as a baseline for the analysis of hydroclimatic conditions of formation flood and forecasting method. It was caused by the following: a) the runoff observation period is 63 years - from 1957 to 2019; b) this station is located in the upper reaches of the Arpa River, above the Kechut Reservoir, at an altitude of 2034 m; d) exclude the influence of the anthropogenic factor as much as possible.

2 Study areas, Data and Methods

To solve the set tasks, the corresponding studies have been used as theoretical basis [3, 5–6]. Daily factual data of “Center for Hydrometeorology and Monitoring” SNCO of the Ministry of Environment of the Republic of Armenia for a period of 60 years and more were used as a source material in the paper. To analyze hydroclimatic conditions for formation of the flood runoff volume and develop a forecasting methodology, the daily water discharge in the Jermuk Station of the Arpa River, the average daily air temperatures and daily precipitation at the Jermuk meteorological station for the period from 1957 to 2019, the maximum water reserve in the snow cover at the Jermuk Weather station were used.

Forecasting methods are developed mainly on the basis of empirical dependencies arising from certain physical considerations based on observational data for the past and expressed in the form of correlative dependences of runoff on the main components of the water balance. In these dependencies, the water reserve in the snow cover and liquid precipitation are the main variables (components). As an indicator of pool moisture, losses for absorption into the soil and evaporation, their indirect characteristic – air temperature of a particular period is sometimes used [10].

When choosing one or another calculation formula, a mathematical model of runoff or flow-forming factors, one should pay special attention to the appropriateness of its use, because for the practice of forecasting and assessing the risk of hazardous spills on rivers and inland water bodies, it is its practical applicability and required reliability of the results, rather than physical validity or novelty of the approach that is of primary importance [4].

Most of the methods of long-term forecasting of spring runoff currently used in operational practice are based on physical and statistical dependencies and were developed in the 60–80s of the last century [2].

They have used a formalized approach in the paper to develop a method for forecasting flow volume of spring floods (from April to June) – obtaining a mathematical dependence that allows calculating future value of the process, namely, statistical multiple regression model, when dependence of the future value on the past is given in the form of an equation. The chosen approach for forecasting hydrological characteristics of river runoff has both a number of advantages and certain disadvantages. In this case, the disadvantage refers to extreme limitation of the available hydrometeorological information. Multivariate statistical model for forecasting the volume of runoff and maximum flow rate of the spring flood of rivers in mountainous areas was used in some papers [1, 8].

Forecasts of spring floods are usually by 25/III, when data are available to assess the hydrometeorological factors responsible for formation of spring runoff. In some anomalous years, forecasts are issued several days earlier or later than the established dates.

3 Results and discussion

Spring flood, summer-autumn flood, summer-autumn and winter low water are the phases characteristic of the water regime of the Arpa River. Spring flood is one of the main phases of the water regime of the Arpa River, which is observed annually in spring or spring-summer. In the station studied, it begins from the third decade of March and first decade of April and ends in the third decade of June and first decade of July, in some cases also in the third decade of July. On average, spring flood water is observed from April 5 to July 7 and lasts 94 days [7]. In the Jermuk section of the Arpa River during the spring flood, 44–69 % of the annual runoff takes place: on average, 57 % (fig.1). Average long-term water discharge at Jermuk Settlement is 5.15 m³/s. During this period, the absolute maximum costs that can create unfavorable or dangerous situations were recorded for the entire observed period. The maximum flow rates usually pass when rains add up to snowmelt. In Armenia, the period of snow accumulation increases with height and role of snow cover in the flood regime increases.

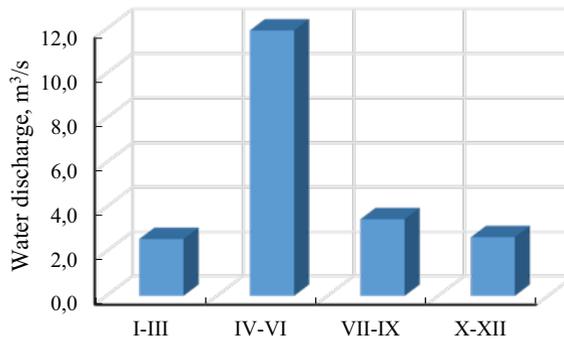


Fig. 1. Intra-annual distribution of water discharge (m³/s) in the Jermuk Station of the Arpa River

The main factors that determine the power of the spring flood are: water supply in the snow cover before the beginning of snow melting; the amount and intensity of atmospheric precipitation during the period of snow melting and the first phase of flood; autumn-winter soil moistening by the beginning of snow melting, thermal conditions of spring, affecting the intensity of snow melting [8]. With smooth development of synoptic processes, causing a significant increase in air temperature, snow reserves are melting simultaneously in several high-altitude zones and over relatively large areas. In these cases, the flood usually proceeds violently, is characterized by a high rise in the water level and passes over more or less short periods of time, having, as a rule, one wave with a sharply expressed intense rise and a smoother decline. During a protracted spring with a weak development of synoptic processes, the snow cover melts slowly, melt water flows into river beds intermittently, conditions are created for the loss of melt water, which causes a low extended flood with several waves [9].

Due to the diversity of natural conditions of the study area, the volume of runoff and other characteristics of spring floods are distributed very unevenly, but the climate in combination with the features of the relief, soil and vegetation cover, and geological and hydrogeological structure of river catchments play the leading part. Flood characteristics also vary depending on the changing hydroclimatic conditions of formation from year to year. The volume of flood runoff (W_{IV-VI}) ranges from 47.7 million m³ (1961) to 168 million m³ (1988), the average value is 94.4 million m³.

The main factor in the formation of a large volume of spring flood runoff is the amount of water storage in the seasonal snow cover formed throughout the winter, the intensity of snow melting in a friendly spring, the amount of precipitation in April – June in the catchment area, and abundance of liquid precipitation that enhances snow melting. The factor favoring the formation of such values of runoff volumes is the low air temperatures of the winter season, leading to the minimization of losses of the seasonal snow cover (thaw). Among the large volumes of runoff, the floods that took place in 1978, 1987, 1988, 2007, 1988 was the most outstanding. At Jermuk Weather Station, the hydroclimatic conditions were as follows (table 1). In 1988, the maximum values of the total precipitation (570 mm) of the pre-winter and winter periods were recorded, and at this time almost no thaws were observed and the air temperature was - 4.3 °C. Among the small volumes of flood runoff that took place in 1961, 1962, 2015, 2018, the flood of 1961 is the opposite - very low water. In the fall of the previous 1960, the weather was hot and dry; therefore, the moisture content of the basin was significantly below average. The winter was warm, the air temperature exceeded the norm, the amount of snow reserves for the winter of 1960/61 was below the norm.

Table 1. Climatic indicators – factors in the formation of volume runoff flood on the Arpa River at the Jermuk Station

Climatic factors	Years characteristic for water content		
	low water	average	abounding
	1961 г.	1972 г.	1988 г.
Pre-winter and winter precipitation, mm	161	329	570
The amount of precipitation from April to June, mm	185	343	294
Average winter air temperature for pre-winter and winter periods, °C	-3,9	-6,9	-4,3
Air temperature in April, °C	3,7	5,0	3,4

The spring flood looks like a well-defined wave, formed by melted snows, rain and underground waters. Therefore, it is usually of mixed origin. The ascent is intense and is accompanied by individual significant peaks. The duration of the flood rise period is associated with the feeding of the rivers, the passage of the maximum flood discharge. The duration of the flood rise period in the studied section is on average 45 days. The decline in flood as a result of rainfall and groundwater inflow is characterized by the presence of a long plume. And the decline in high water, as in other mountainous regions, in the absence of rain is more prolonged, extended and occurs very slowly and smoothly. The duration of the period of decline in high water compared to the rise is longer and averages 49 days. The decline in high water is mainly determined by the type of feeding, altitude position and the peculiarities of the geological and hydrological conditions of the catchments.

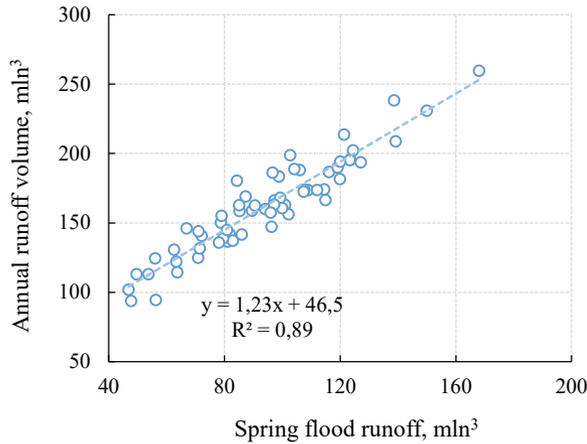


Fig. 2. Correlation between the volumes of spring runoff floods and annual runoff on the Arpa River – Jermuk Station

In the study area, the annual water content of the rivers is closely related to the runoff of the spring flood (fig. 2). As a result of the study, a close correlation was obtained between the actual values of the annual runoff and the runoff of the spring flood on the Arpa River – Jermuk Station. This relationship can be used to forecast annual runoff in the Jermuk Station of the Arpa River.

After researching, analyzing and evaluating the physical and geographical conditions of the basin, available literature sources and initial materials, we obtained dependencies, some of which can be applied when making forecasts.

To forecast the volume of runoff during the flood period, a multifactorial regression method was used, that is, multifactorial correlations between the forecast value and hydrometeorological elements causing it. To obtain these relationships, the volumes of spring flood runoff (W_{IV-VI}) were used as a predictor, and the average monthly discharge in March (\bar{Q}_{III}) in the Jermuk Station of the Arpa River, the average air temperature of the Jermuk meteorological station for November-February months (\bar{t}_{XI-II}), for March (\bar{t}_{III}), for April (\bar{t}_{IV}), as well as the amount of atmospheric precipitation from December to March ($\sum X_{XII-III}$), from April to May ($\sum X_{IV-V}$), for November ($\sum X_{XI}$). Regression analysis made it possible to obtain the following formulas for calculating the volume of spring flood runoff:

$$W_{IV-VI} = -4,67\bar{t}_{XI-II} - 2,19\bar{t}_{III} - 2,84\bar{t}_{IV} + 3,75\bar{Q}_{III} + 0,13\sum X_{XII-III} + 0,14\sum X_{IV-V} + 0,08\sum X_{XI} + 1,0 \quad (1)$$

We also tried to use maximum reserves of water in snow (P_{max}) from 1993 to 2019 for the Jermuk weather station as a predictor. In this case, a much better result is obtained. The disadvantage is that the data series for snow stocks is short (1993–2019). The obtained multifactorial correlations for predicting the maximum costs are as follows

$$W_{IV-VI} = -5,00\bar{t}_{XI-II} + 0,88\bar{t}_{III} - 6,35\bar{t}_{IV} + 6,30\bar{Q}_{III} + 0,24P_{max} + 30,5 \quad (2)$$

Indicators of the quality of the forecasting methodology are given in table. 2, where S is the mean square error of the test predictions, σ is the mean square deviation from the norm of the predicted value, R is the correlation coefficient, S/σ is the parameter for evaluating quality of the multiple linear regression model. The development of the method has shown

that the obtained dependencies can be used for operational forecasts of the volume of spring floods.

Table 2 Method quality indicators

Formula	Quality indicators		
	S/σ	R	Method type
(1)	0,71	0,71	satisfactory
(2)	0,67	0,75	satisfactory

A relationship is noted between the maximum flow rates on snow-fed rivers and the runoff volume during the flood period, and the closest relationship is characteristic of the maximum flow rates with the runoff volume for a pentad or decade, in which the maximum is observed. The closest relationship between the volume and the maximum flow rate of high water takes place on rivers with a predominantly snow supply, with the greatest amplitude of fluctuations in the altitudinal zonality of the catchment area and a relatively short period of snow melting. The least close connection is observed in rivers with mixed feeding. In such cases, the formation of several peaks usually takes place [10]. This pattern is also inherent in the study area. The obtained correlation between the volume (W_{IV-VI}) and the runoff of the maximum flow rates (Q_{max}) for the flood period can be represented by the equation - $W_{IV-VI} = 11,2Q_{max} + 39,9$. This dependence can be used to predict the volume of flood runoff on the Arpa River – Jermuk Station.

4. Conclusions

Thus, in the Jermuk Station of the Arpa River during the spring flood, 44–69 % of the annual runoff occurs: on average, 57 %.

The volume of the spring flood runoff varies from 47.7 million m³ (1961) to 168 million m³ (1988), the average value is 94.4 million m³.

The obtained multivariate dependencies can be used to forecast the volume of spring floods for the Arpa River – Jermuk Station. Individual climatic characteristics of the Jermuk weather station are the main predictors of predictive multiple regression equations.

The proposed methods need improvement by replacing the identified predictors with better ones, with an annual verification of the proposed equations associated with lengthening the predictive series and, accordingly, refining the coefficients.

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