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Hydrology

Simplified Empirical-Formula Dependence for Calculating Maximum Water Discharge in a River Catchment

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Abstract. In recent years, the occurrence of natural disasters has significantly increased on our planet, particularly floods and debris flows. Georgia given its complex physical and geographical conditions, is no exception. Improving methods for forecasting the magnitude of expected natural disasters has become a key issue. Current methods used for calculating the forecasted quantitative magnitude of a debris flow event, it is essential to determine the maximum water discharge. Although there are many empirical methods for calculating maximum discharge, they still need to improve the reliability of calculation accuracy and simplify the process. The methodology proposed in this work for reliable flood forecasting is based on a classical empirical formula which we have modified based on the main factors that generate regional runoff and analyzing the corresponding mathematical transformations. The empirical relationship presented by us, enhances the accuracy of maximum discharge calculations and improves the reliability of flood forecasts. *© 2025 Bull. Georg. Natl. Acad. Sci.*

Keywords: hydrosection, debris flow, atmospheric precipitation, maximum water flow, forecast

Introduction

As far as the catchment basins of mountain rivers, mudslide-generating foci are mainly developed on the surface of steep slopes covered with erosive cracks, due to rock disintegration and erosion, sediments accumulate in these cracks. Once they become saturated with water, they start to move as a result of gravitational forces. The moved flow is characterized by significant speed and energy. To increase the effectiveness and reliability of mudslide control structures, the design and construction of such structures should be carried out locally, directly on small rivers or their tributaries. Therefore, the maximum effect of determining reporting hydrological values and the reliability of the prediction for the catchments of these small rivers can only be achieved if the hydrological calculations of the maximum flood flows are carried out directly at the site of the process occurrence – the studied hydrointersection. However, this approach requires a long series of hydrological observations, which is practically non-existent on small mountain rivers and tributaries [1-3].

For the calculations of reliable forecasting of flood events, the basis of the proposed methodology is the model of classical, empirical formulas, which we have modified based on the specification and analysis of the main factors that generate regional runoff. The above-mentioned allows us to increase the accuracy of maximum water flow calculations and the reliability of prediction.

The general form of the formula proposed by us is the same as the adaptation of the classical volumetric (genetic) formula model, and the main emphasis is shifted to the accuracy of determining the calculation values of the parameters included in it. For their determination, empirical reporting relationships were developed based on the processing, analysis, and evaluation of numerous materials of local factors affecting runoff [4].

The proposed water flow formula appears identical to the genetic formulas, however, the catchment area in it is recorded with the following interpretation – F = tv.b, where the catchment area is expressed as F = Lb and L = tv, respectively, we get the following relation:

$$Q_t = \frac{P}{T} tvb\, \alpha\varphi \text{ m}^3\text{/sec}, \quad (1)$$

where P is the report providing precipitation (mm), T – the duration of precipitation (h), t – the current time – from the start of runoff (h), v – the flow speed (m/s), b – the width of the catchment area (km), α – the runoff coefficient, φ – the runoff hydrograph adjustment coefficient.

Let us consider the methods for determining the parameters given in the expression separately.

As it is known, one of the most important factors determining the amount of runoff for reporting is atmospheric precipitation.

In general, if we know the amount of rain in mm, we can calculate the volume of water coming to the catchment area – W (m^3) according to the territorial spread of rain

$$W = 1000\, H \cdot F \text{ m}^3,$$

where H is the amount of rain in mm, F – basin area km^2.

It is known that precipitation is unevenly distributed in time and area, further complicating the individual natural conditions of the catchment area.

The total amount of atmospheric precipitation does not participate in the formation of floods, some of it in the form of losses goes to evaporation, infiltration, filling the micro-relief of the catchment area, etc.

Therefore, it is more reasonable to determine the effective precipitation that creates runoff based on the difference between precipitation and infiltration intensity.However, the difficulty of practically determining the effective precipitation according to the infiltration curve, especially for less studied basins, has resulted in the fact that it is mainly determined as the runoff coefficient (a) given in formula (1) and is the ratio of the actual runoff volume to the total precipitation volume – for the same rain, and which is obtained by calculating the maximum of flood flows caused by rains [5]:

$$\alpha = \frac{\sum Q_t}{HF},$$

where $\sum Q_t$ is the amount of runoff (flow) – (m^3/sec), H – rainfall (mm), F – catchment area (km^2).

The analysis of the studies showed that the contribution of runoff regulation by the catchment area in the mountainous region in the formation of atmospheric precipitation maximum water flow is about 35%. Accordingly, the calculated runoff coefficient is equal to 0.65.

In order to determine the values of the estimated duration (T) and the estimated amount of precipitation (P), when getting our proposed analytic expressions the genetic composition of similar expressions existing in many methods of runoff determination was taken into account [6].

The calculation formulas have the following form:

$$T = 2\ell^{0.4} + \frac{0.28\ell}{V}, \text{ hr,} \quad (2)$$

$$P = 7 \cdot \tau^{0.2} \cdot (60T)^{0.26}, \text{ mm,} \quad (3)$$

where T is the estimated duration of precipitation (hr); ℓ – distance passed by water flow till the estimated intersection (km); V – water flow average speed (m/sec); P – the estimated amount of precipitation (mm); τ – ensuring repetitions of estimated water flow (by years).

In other specific cases, the given expressions should be adjusted after obtaining the latest hydrometeorological observation materials for the study basin, to clarify the values of the coefficients and quality indicators included in the formula.

As for the determination of the water flow speed (V m^3/sec) in the river bed and slopes, based on the practical study of the observation materials and analysis, the empirical calculation formula obtained by us has the following general form:

$$V = a\, i^m h^n, \text{ m/sec,} \quad (4)$$

where i is the slope of the bottom of the water stream; h – water flow depth (m); a – coefficient, m and n quality indicators, which are specified on the basis of data obtained from observations of research territories; for a given specific case (river: Rioni, Khobi): $a = 9$; $m = 0.4$; $n = 0.25$ [4].

Determining the morphometric parameters of the river catchment area is also an important factor in determining the magnitude of runoff for reporting.

In the early period, there were very few, if any, specific studies on the areas of a network of small mountain rivers, and the vast majority of observations belonged to studies of runoff generative factors from large catchments. As mentioned above, mudslides generative hotbeds in mountain river basins are small, steeped areas, therefore the calculated values for large river basins are less suitable for areas that are much smaller and are more branched (that significantly increases the runoff).

Determination of the length of the catchment area till studied intersection (L, km), average width (b, km) and river slope (I) is facilitated by using modern maps (Arc View GIS).

But, in this case, we must take into account the fact that the width of the catchment (b), which is generally equal to $b = (\ell_1 + \ell_2)$, where $(\ell_1)$and (ℓ_2) are the lengths of the right and left slopes, when measured on a map (direct summing of these values), will give a big error if the tilt values of slopes are not taken into account (especially in mountain river conditions).

Based on the numeric calculations and analysis performed by us considering these conditions [7], the estimated width of the catchment area (b) was obtained:

$$b = b_1 + 2Hi^{0.07}, \quad (5)$$

where b_1 is the width of the catchment area measured on the map (distance between the watersheds); H – depth of the valley (heights difference of the bottom of the river to the slope pick); i – slope tilt (difference of the mentioned heights divided by the length of the slope).

As given in formula (1), the runoff hydrograph regulation coefficient φ, in the case of a mountainous region, mainly depends on the catchment area forestation coefficient and approximately equals 0.9.

Finally, according to formula (1), we calculate the maximum water discharge, where the necessary condition for predicting the maximum water discharge for reporting provision is that the duration of precipitation (T) has to be greater than or equal to the time (-t), needed for the maximum water discharge from the onset of flooding caused by this precipitation: $T \geq t$.

The calculation is carried out in the following order: we calculate the speed of the water flow using formula (4); by formula (2) we determine the duration of atmospheric precipitation, by formula (3) the amount of precipitation to be calculated; (5) by formula we define the width of the catchment basin. The distance covered by the water flow is calculated based on the map data.

Conclusion

According to the proposed methodology, formula (1) can be used to calculate the predicted maximum water discharge for rivers with small catchment areas that lack hydrological studies or observational data. This is applicable when the duration of precipitation, denoted as *T*, is greater than or equal to the time taken from the onset of flooding due to precipitation to the occurrence of the maximum discharge, represented by the relationship $t - T \geq t$. The calculations should be performed by sequentially calculating the hydrological characteristics included in formula (1), utilizing the empirical relationships specified in equations (4), (2), (3) and (5) within the article, and employing a topographic map.

ჰიდროლოგია

მდინარის წყალშემკრებ აუზში წყლის მაქსიმალური ჩამონადენის საანგარიშო გამარტივებული ემპირიული დამოკიდებულება

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საყოველთაოდ ცნობილია, რომ ბოლო წლებში, ჩვენს პლანეტაზე მნიშვნელოვნად გაიზარდა ბუნებრივი კატასტროფების შემთხვევები, განსაკუთრებით აღსანიშნავია წყალმოვარდნები და ღვარცოფული მოვლენები. მეტად რთული ფიზიკურ-გეოგრაფიული პირობებიდან გამომდინარე, გამონაკლისი არც საქართველოა. დღის წესრიგში დადგა მოსალოდნელი ბუნებრივი სტიქიების პროგნოზული სიდიდეების საანგარიშო მეთოდიკების გაუმჯობესების საკითხი. აღსანიშნავია ისიც, რომ ღვარცოფული მოვლენის პროგნოზული რაოდენობრივი სიდიდის საანგარიშოდ არსებულ დამოკიდებულებებში, პირველ რიგში, აუცილებელია დადგინდეს წყლის მაქსიმალური ხარჯები. მიუხედავად იმისა, რომ დღეისათვის არსებობს მაქსიმალური ხარჯების საანგარიშო მრავალი ემპირიული დამოკიდებულება, ისინი მაინც მოითხოვს საანგარიშო სიზუსტის საიმედოობის გაზრდას და ანგარიშის გამარტივებას. წარმოდგენილ ნაშრომში წყალმოვარდნების საიმედო პროგნოზირებისთვის შემოთავაზებული მეთოდიკის საფუძველს წარმოადგენს კლასიკური, ემპირიული ფორმულების მოდელი, რომელიც ჩვენ

მიერ მოდიფიცირებულია რეგიონული ჩამონადენის წარმომქმნელი ძირითადი ფაქტორების დაზუსტების და შესაბამისი მათემატიკური გარდაქმნების ანალიზის საფუძველზე. წინამდებარე ნაშრომში წარმოდგენილი ემპირიული დამოკიდებულება საშუალებას გვაძლევს გავზარდოთ მაქსიმალური ხარჯის გაანგარიშების სიზუსტე და პროგნოზირების საიმედოობა.

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