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Hydrology

Calculation of Sediment Runoff Using the Energy Principle: A Case Study of the Mtkvari River (Dzegvi)

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Abstract. Riverbed processes are a significant challenge in hydrology, and it is crucial to accurately estimate the amount of solid material and, consequently, obtain results that are as close to reality as possible. The calculations were performed using the so-called energy principle, and the study area encompasses the section of the Mtkvari River near the village of Dzegvi. This method of sediment runoff calculation allows not only for purely scientific research but also holds great potential for practical application, particularly for the Mtkvari River, where significant hydraulic structures, such as reservoirs and hydroelectric power plants, are planned for construction in the future. Additionally, we calculated the intra-annual distribution of water and sediment runoff, which constitutes a key component of the river's hydrological regime. *© 2026 Bull. Natl. Acad. Sci. Georg.*

Keywords: sediment runoff, energy principle, hydraulic energy, energy module

Introduction

When conducting engineering works on rivers and determining the operating conditions and performance of hydraulic structures and reservoirs, a significant hydrological aspect is the river sediment runoff, which is influenced by a complex set of physical, geographical, and hydrological factors, including the nature of its formation, volume, and intra-annual distribution. The methodology for calculating sediment runoff involves considering factors such as water discharge, average basin height and slope, underlying surface characteristics, river slope, and other factors. However, the patterns of sediment runoff formation and transport are highly complex and have not been fully understood due to the stochastic nature of geographic and hydrological conditions.

Methods

Among the methods used to measure sediment runoff, we employed the so-called "energy principle" (Svanidze et al., 1987), which states that there is a relatively close correlation between the energies associated with solid river runoff and liquid river runoff. This concept was proposed in the 1950s by Professors M. Mostkov and G. Svanidze.

The core of this concept is that a portion of precipitation that enters a basin flows downhill under the force of gravity, performing work that is expended on erosion, scouring, and transporting sediment, and subsequently on moving solid and liquid runoff to the erosional base of the riverbed, overcoming internal resistances and releasing thermal energy. This hydraulic energy can be calculated using the following formula:

$$Э_{bas.} = 86 \cdot \int_0^v mdv, \text{ kWh.} \quad (1)$$

The corresponding power $\left(N_{bas.}\right)$ is calculated using the following formula:

$$N_{bas.} = 9.81 \cdot \int_0^v mdv, \text{ kWh,} \quad (2)$$

where m is the rate of water flow (litres per second per square kilometre); dv is the elementary volume of a single part of the basin, in cubic kilometres.

Using appropriate transformations of the given formula, we can derive a formula for the energy calculation in a river basin, as proposed by G. Svanidze (Svanidze et al., 1987). This formula takes the following form:

$$Э_{bas.} = 86 \cdot F \cdot H_{ave.} \cdot m_{ave.} \cdot \rho, \text{ kWh,} \quad (3)$$

where F is the catchment area (km²); $H_{ave.}$ is the average height of the basin (m); $m_{ave.}$ is the mean value of the runoff module (litres per second per square kilometre), ρ is the coefficient that takes into account the uneven distribution of the runoff module and basin area across altitude zones, determined by a formula or by a distribution map for the territory of Georgia. For Georgia, this coefficient ranges from 1.0 to 1.6, occasionally even reaching 2.4 (for the Alazani River). In our case, based on the territorial distribution, this coefficient applies to regions III-IX with values ranging from 1.40 to 1.22 (Alaverdashvili, 1989). Therefore, we have assumed an average value of 1.31 for these regions, i.e., $\rho = 1.31$.

Results and Discussion

In the study, two sections of the Mtkvari River, namely, the village of Dzegvi and Tbilisi were selected.

The Mtkvari River is the largest in the South Caucasus, and its runoff formation is a combination of various sources. Snow, rain, groundwater, and glacial water all contribute to the annual runoff, with an average of 36.0%, 24.5%, 38.0% and 1.5% respectively. The most significant period for runoff is spring, accounting for 50-60% of the total runoff, followed by summer with 20-30%, and winter with 10-14%. The average multi-year discharge of the Mtkvari River near Tbilisi over an 87-year period from 1938 to 2024 is 210 cubic meters per second (m³/s), corresponding to a runoff module value of 9.9 liters per second per square kilometer (l/s·km²). The average multi-year discharge in Dzegvi amounts to 167.3 cubic meters per second, corresponding to a runoff module of 9.2 l/s·km² (Ezhegodnye dannye, 1988). For the Tbilisi section, the basin area (F) is 21,120 square kilometers (km²), and the average basin elevation ($H_{ave.}$) is 1,200 m. For the Dzegvi section, these values are a basin area (F) of 17,990 km² and an average,, basin elevation ($H_{ave.Dzegvi}$) of 1,360 m.

For this study, the Mtkvari River HPP near Tbilisi has been used as an analogous point for the Mtkvari HPP near Dzegvi. The Mtkvari River HPP near Tbilisi has a longer period of observation and a sediment suspension runoff rate (V_R) of 5,212 thousand tons per year based on 53 years of data. Considering that the Mtkvari is a lowland river, it is assumed that the average bottom sediment runoff is 20% of the suspended sediment load, i.e. 1,042 thousand tons per year. Therefore, the total sediment runoff for the Tbilisi section will be $V_{T,Tb}$ = 6,254 thousand tons per year.

Due to the construction of three reservoirs on the Mtkvari River in Turkey between 2010 and 2018, which have had a varying degree of impact on both the energy potential of the Mtkvari basin and the sediment runoff entering our territory, we have recalculated the relevant catchment area of 5,040 km² within their territory using Formula (3), with a reduced value that will also affect the values of existing runoff modules at both points.

Based on these results, the following practical calculations have been performed: $Э_{Tb} = 86 \cdot 18620 \cdot 1200 \cdot 11.2 \cdot 1.31 = 28193$ billion kWh.

For Dzegvi, the corresponding energy will be: $Э_{Dzegvi} = 86 \cdot 15470 \cdot 1360 \cdot 10.8 \cdot 1.31 = 25599$ billion kWh.

In the case of both sections, based on the ratio of basin energies, we can calculate the so-called conversion factor K for determining sediment. $K = Э_{Dzegvi} / Э_{Tb} = 25599/28193 = 0.91$ billion kWh.

Therefore, sediment runoff near the village of Dzegvi on the Mtkvari River is: $V_{T,Dzegvi} = K \cdot V_{T,Tb} = 0.91 \cdot 6254 = 5691$ thousand tons per year.

That is, the annual sediment runoff of the Mtkvari River in the Dzegvi area is 5,691 thousand tons per year, of which 80% (4,743 thousand tons per year) is sediment suspension and 20% (948 thousand tons per year) are bottom sediments.

A particularly important parameter is the energy module of sediment runoff or specific energy expended on transporting sediment runoff. It is expressed by the following formula:

$$\eta_T = Э_{bas.} / V_T \text{ kWh/t}, \quad (4)$$

where $Э_{bas.}$ is the basin energy V_T is the total sediment runoff.

In this instance, the energy module for both sections will be equal to: $\eta_{T,Tb} = Э_{bas.,Tb} / V_{T,Tb} = 28193/0.006254 = 4508$ thousand kWh/t, $\eta_{T,Dzegvi} = Э_{bas.,Dzegvi} / V_{T,Dzegvi} = 25599/0.005691 = 4498$ thousand kWh/t.

Based on these findings, the intra-annual distribution of water and sediment runoff for the Dzegvi section of the Mtkvari River has been carried out (the percentage distribution of water and sediment suspension within the Mtkvari River has been used).

The results obtained allow us to gain an understanding of the components required for the operation of a specified section of the Mtkvari River, such as a reservoir created near the village of Dzegvi, and consequently, a hydroelectric power plant. This includes the average multi-year discharges of both liquid materials $(Q_{ave.})$ and sediments $(T = R + G)$, and their intra-annual distribution.

Conclusion

This method has been used to determine sediment runoff for many previously unstudied rivers in Georgia, particularly those in the Black Sea coastal region. Knowledge of these rivers is essential for studying the dynamics of coastal areas and the sediment discharge of rivers into the Black Sea.

By applying the energy criterion and energy module for sediment runoff, along with data from a river analogue, it is possible to estimate the sediment runoff of previously unstudied rivers. This is crucial for studying river runoff patterns.

Table. Intra-annual distribution of water and sediments in the Mtkvari river HPP, near Tbilisi and Dzevgi

N	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average multi
$Q_{Tb.}$ m³/s	85.7	90.7	169	456	547	441	176	106	101	111	139	98	210
%	3.40	3.60	6.70	18.1	21.7	17.5	7.0	4.2	4.0	4.40	5.50	3.90	100
$V_{T,Tb}$ kg/s	9.50	28.5	92.6	670	790	437	152	61.8	31.8	42.7	42.7	16.6	198
%	0.4	1.20	3.90	28.3	33.3	18.4	6.40	2.60	1.34	1.80	1.80	0.7	100
Q_{Dzegvi} m³/s	78.9	84.7	140.5	405.5	463.8	259	128.5	80.3	77.7	96.0	104.4	88.3	167.3
%	3.93	4.21	7.00	20.2	23.1	12.9	6.40	4.00	3.87	4.78	5.20	4.40	100
$V_{T,Dzegvi}$ kg/s	10.8	25.9	90.9	794.0	731.3	240.1	103.9	39.2	26.0	34.6	47.8	19.4	180.3
%	0.5	1.2	4.2	36.7	33.8	11.1	4.8	1.81	1.20	1.60	2.21	0.9	100

ჰიდროლოგია

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