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# PREDICTING THE VULNERABLE AREAS OF THE MOUNTAIN RIVERBEDS BY CONSIDERING FIELD AND LABORATORY EXPERIMENTS

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Abstract: An experiment to evaluate the vulnerable areas of the mountain riverbeds was accomplished by using a special hydraulic channel installed at the hydraulic engineering laboratory of Ts. Mirtskhulava Water Management Institute of Georgian Technical University, and the initial study value was the identification of the sediment transportability of the water current ( $q_t$ ). During the experiment, the following conditions of similarity for the model were considered: dynamic (Froude number) - $Fr = iden$ geometric (bed gradient) - $i = iden$ sediment movement - $V_{wat} / V_{sed} = iden$ , and similarity of the bed resistance coefficient (Chézy coefficient) - $C_n = iden$ . Based on the field-experimental studies accomplished by the author of the present work in 2005-2014 in the catchment basin of the river Tetri Aragvi, along the Georgian military road, to evaluate the vulnerable areas of the mountain riverbeds, the sensitive areas of the riverbed were evaluated by considering the major typical characteristics.
By using the theory of reliability and risk, it was established that the dynamics of the erosive processes of the riverbed was described by an exponential distribution, and the process of sediment accumulation in the riverbed could be described by Cauchy distribution law. Gained results were compared to the natural data and it was established that the error between them was within the accessible range.

KEY WORDS: current transportability, vulnerable areas of the river, erosion, sediment accumulation.

## 1. INTRODUCTION

During the formation of the mountain river debris flow one of the key importance is the average diameter of the factions (*d*), river bed roughness(*c*), river slope (*i*), flow speed (*V*) and the debris flow discharge (*Q*).

The recent field research of the mountain river landscape (where the debris flows are usually formed) is proved, that it is necessary to define set of the main hydrological and hydraulic characteristics of the erosion and accumulated areas, which can be used later for construction of river bed regulating hydraulic engineering structures.

The above-mentioned issue can be resolved using the theoretical and field monitoring researches conducted in the hydraulic engineering laboratory of the Water Management Institute of Georgian Technical University and in the river basin of White Aragvi. (See Fig.1).

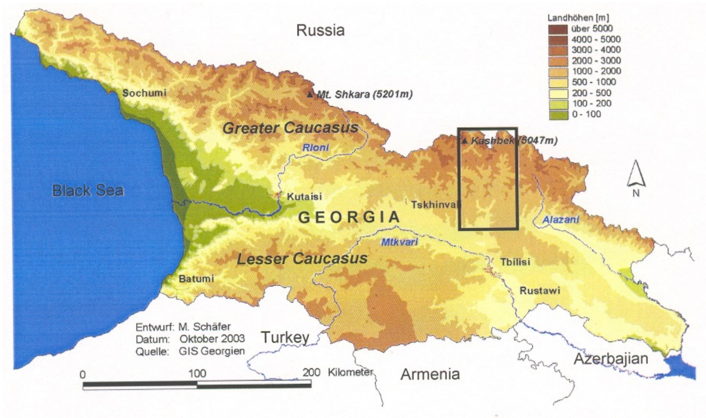


Fig.1 The study object

## 2. THE EXPENDITURE OF THE SEDIMENT TRANSPORTED BY THE TURBULENT DEBRIS FLOW

For determining the allocation of the sediment transported by the turbulent debris flow, the laboratory experiments were provided by the Ts. Mirtskhulava Water Management Institute of Georgian Technical University.

The laboratory equipment is the hydraulic groove with the cross section 0,60x0,50 m$^2$, length 18,0 m, the groove inclination was changing within $i$=0,01-0,05.
For purpose to get the experiment closer to nature, the fractions with the average diameter of: 0,75; 2,25; 3,75; 5,25; 6,75 mm. were considered [2].

There was made the roughness on the bottom of the hydraulic groove with the attached fractions of average diameter 3,75 mm.

Geometric and dynamic similarity of the general terms and conditions were kept during the laboratory experiments. In particular, dynamic similarity: $F_r$=*iden*; sediment movement $V_{wat}/V_{sed}$=*iden*; the flow resistance $C$=*iden*. The river bed inclination was chosen as one of the determining factors in the open, natural river bed during the sediment movement of the turbulent debris flow ($i$). According to data from laboratory experiments (see Table 1), the solid fractions of five values, the slope of the hydraulic groove and the relative value, the functional relationship will be [3]:

$$q_{sed}/q_{wat} = A[i^x,(d/k_{sed})^y] \qquad (1)$$

Table 1

Data for computing the qualitative indices (y)

| $q_{sed} / q_{wat}$ | River slope | | $\frac{q_{sed} / q_{wat}}{i^{0,63}}$ | $q_{sed} / k_{sed}$ | $(\frac{q_{sed} / q_{wat}}{i^{0,63}})_{average}$ |
|---|---|---|---|---|---|
| | i | $i^{0,63}$ | | | |
| 0,0132 | 0,01 | 0,0549 | 0,2404 | 0,40 | 0,2239 |
| 0,0180 | 0,02 | 0,6851 | 0,2115 | | |
| 0,0240 | 0,03 | 0,1098 | 0,2186 | | |
| 0,0296 | 0,04 | 0,1316 | 0,2249 | | |
| 0,0340 | 0,05 | 0,1515 | 0,2244 | | |
| 0,0100 | 0,01 | 0,0549 | 0,1822 | 1,20 | 0,1932 |
| 0,0152 | 0,02 | 0,0851 | 0,1786 | | |
| 0,0216 | 0,03 | 0,1098 | 0,1971 | | |
| 0,0264 | 0,04 | 0,1316 | 0,2006 | | |
| 0,0314 | 0,05 | 0,1515 | 0,2073 | | |
| 0,0072 | 0,01 | 0,0549 | 0,1312 | 2,00 | 0,1705 |
| 0,0138 | 0,02 | 0,0851 | 0,1622 | | |
| 0,0190 | 0,03 | 0,1098 | 0,1730 | | |
| 0,0256 | 0,04 | 0,1316 | 0,1945 | | |
| 0,0290 | 0,05 | 0,1515 | 0,1914 | | |
| 0,0060 | 0,01 | 0,0549 | 0,1093 | 2,80 | 0,1440 |
| 0,0114 | 0,02 | 0,0851 | 0,1339 | | |
| 0,0160 | 0,03 | 0,1098 | 0,1457 | | |
| 0,0210 | 0,04 | 0,1316 | 0,1596 | | |
| 0,0260 | 0,05 | 0,1515 | 0,1716 | | |
| 0,0048 | 0,01 | 0,0549 | 0,0874 | 3,60 | 0,1196 |
| 0,0088 | 0,02 | 0,0851 | 0,1034 | | |
| 0,0143 | 0,03 | 0,1098 | 0,1302 | | |
| 0,0143 | 0,04 | 0,1316 | 0,1489 | | |
| 0,0194 | 0,05 | 0,1515 | 0,1281 | | |

Where $k_{sed}$ is the height of the hydraulic groove (mm) roughness. Laboratory data values have been marked on the logarithmic net (see Fig. 1)

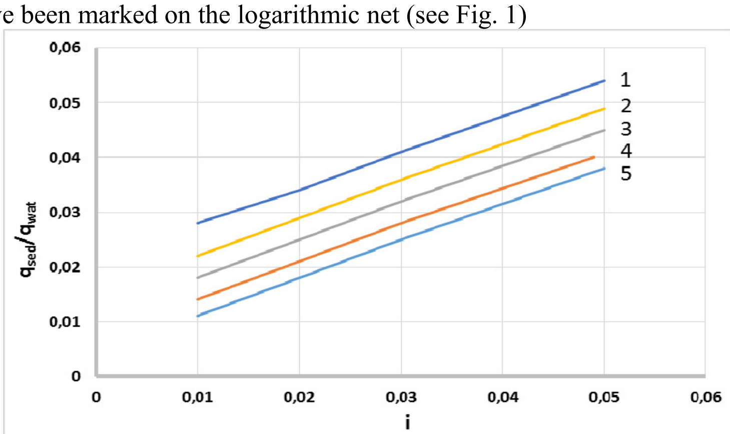

Fig. 2 ($q_{sed}/q_{wat}$)=$f$($i$, $d$) attitudes chart where: 1. $d$=0,75 mm; 2. $d$=2,25 mm; 3. $d$=3,75 mm; 4. $d$= 5,25 mm; 5. $d$=6,75 mm

According to the graphics of the logarithmic net (see Fig. 2) we set that $x$=0.63, and in order to identify the coefficient of proportionality and quality indicators, we conducted conversion. According to the computations we get, that $A$=0,2 and $y$=-0, 35. Finally equation (1) will be:

$$q_{sed} / q_{wat} = 0{,}20 \cdot i^{0,63} \left(k_{sed} / d\right)^{0,35} \tag{2}$$

Taking into account the well-known hydraulic equations $V = q_{wat} / h$ and $V = C\sqrt{hi}$ than (2) equation will be:

$$q_{sed} = 0{,}20 \cdot C \cdot i^{1,13} \cdot h^{1,15} \left(k_{sed} / d\right)^{0,35} \qquad m^2 / c^2 \tag{3}$$

In order to determine the reliability of the equation we get (3), it was compared to the theoretical and empirical equations and natural data fixed in the river basin of White Aragvi (see Fig.1). 1 - According to the equation (3), when the average diameter of the sediment equals to $d$=6,75 mm; 2 – R. Asatrian $d$=6,25 mm; 3 – R. Pedroli $d$=5,20 mm; and A. Kuprin $d$=6,00 mm. The laboratory experiment analysis showed, that the regularity of the fractions, transported by the turbulent debris flows can be described by the 3-rd equation. This proved by the field researches as well.

## DEBRIS FLOW TYPE RIVER BED DEFORMATION SURVEY USING RELIABILITY AND RISK THEORY

The main issue for the prediction of the debris flow type rivers deformation is the exact determination of the river erosion and accumulation areas and the sediment amount. Certainly, we have to take into the account the geometric dimensions of the river bed.

The field – monitoring researches provided by the author in the river basin of White Aragvi, along the Georgian military road (Fig. 1) in 1981- 2015, are dedicated to the resolution of the problem.

The objects of the study were the left active mudflow tributaries of the White Aragvi River. It may be possible exact determination of the deformation processes - erosion and accumulation areas in these tributaries beds.

River Chadistsikhis-Khevi was chosen because of active, erosion, accumulated areas, which is determined by length of the river (332,8 m) and its slope $i$=0,105 (see Fig. 3)

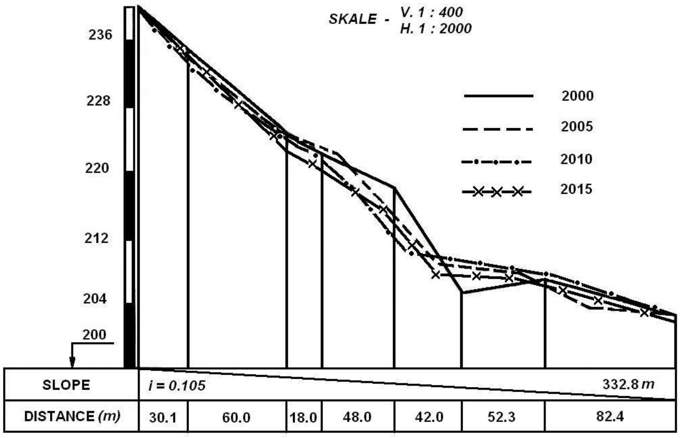


Fig. 3 Longitudinal profile of river Chadistsikhis-Khevi

The geometric dimensions of the river, depths of washed and accumulated area and other characteristics number equals to 202 points,

Longitudinal profile of the river erosion, geometric dimensions of accumulated areas, depths of washed and accumulated areas and other characteristics were observed using digital theodolite and Global Positioning System. In case of erosion, the number was equal to 202 points, and 110 points were in case of accumulated areas.

Statistical data of erosion and accumulated areas are presented in the appropriate intervals in the 3-rd and 4-th tables.

Table 3

The statistical data of the river erosion areas

| Intervals ($m$) | 0-0,3 | 0-0,6 | 0,6-0,9 | 0,9-1,2 | 1,2-1,5 | 1,5-1,8 | 1,8-2,1 |
|---|---|---|---|---|---|---|---|
| frequency $m_i$ | 72 | 62 | 29 | 17 | 3 | 11 | 8 |
| $f(h)$ | 0,3564 | 0,3069 | 0,1436 | 0,0842 | 0,0149 | 0,0545 | 0,0396 |

Table 4

The statistical data of the river accumulated areas

| Intervals $h_1$(m) | 0-0,4 | 0,4-0,8 | 0,8-1,2 | 1,2-1,6 | 1,6-2,0 | 2,0-2,4 | 2,4-2,8 | 2,8-3,2 |
|---|---|---|---|---|---|---|---|---|
| frequency $m_i^*$ | 36 | 34 | 17 | 13 | 5 | 2 | 2 | 1 |
| $f(h_1)$ | 0,327 | 0,309 | 0,155 | 0,118 | 0,045 | 0,018 | 0,018 | 0,009 |

The mathematical expectation (m) is equal to the depth of erosion m=0.575

The magnitude of the erosion depth (see Table 3) is the subject to the following distribution [1]:

$$f(h) = \frac{A}{e^h} \tag{4}$$

Where A=0, 3564

Taking into account the values of the coefficient A, the equation (5) gets the form:

$$f(h) = \frac{0{,}3564}{e^h} \tag{5}$$

The probability of the state of the environmental situation of the longitudinal profile of sediment riverbed erosion in the watercourse, after the passage of debris flow, is as follows:

$$f(h) = \int_0^{2{,}1} \frac{0{,}3564}{e^h} dh = 0{,}264 \tag{6}$$

The risk of an imbalance of the ecological situation of the longitudinal profile of sediment river bed is:

$$R(h) = 1 - P(h) = 1 - 0{,}264 = 0{,}736 \tag{7}$$

Obtained result suggests that to preserve the ecological situation of the longitudinal profile of the channel sediment of the river bed, it is necessary to construct erosion control or mudflow blocking structures.

The mathematical expectation of height of accumulation of debris sediments in the bed is equal to $m_i^* = 0{,}7657$.

The theoretical curve, with the accumulation of sediment corresponds to the law of the Cauchy distribution [4], the formula of which is as follows:

$$f(h_1) = \frac{1}{\pi(1 + h_1^2)} \tag{8}$$

Probability of stability of the longitudinal profile in the area of sediment bed, where the accumulation of sediments is take place, is equal to:

$$P_1(h_1) = \int_0^{3{,}2} \frac{dh_1}{\pi(1 + h_1^2)} \tag{9}$$

Integral, which is given according to (9) was solved by the method proposed by the French mathematician Jean-Victor Poncelet [5]:

$$P_1(h_1) = 0{,}5095 \approx 0{,}51 \tag{10}$$

The risk of the destruction of the stability of the longitudinal profile of the bed taking into consideration the accumulation of sediment in the area of stability is:

$$R_1(h_1) = 1 - \int_0^{3{,}2} \frac{dh_1}{\pi(1 + h_1^2)} = 1 - 0{,}51 = 0{,}49 \tag{11}$$

The analysis shows that the probability of stability of the longitudinal profile of the erosion of the bed after passing the debris less than in the case of accumulation of sediment carried into the mainstream (0.264<0.51).

Naturally, the risk of deformation of the sediment bed longitudinal profile in a case of erosion process is greater than in the case of accumulation of sediments

0.736>0.490, which corresponds to the pattern of river bed deformations in natural conditions.

In the practice of river bed deformations, including flows originating from sediment, erosion and accumulation in the river bed occur together.

In this case, the total probability of the stability of the sediment river bed longitudinal profile (during joint pass of erosion and accumulation) will be equal to:

$$P_0 = P(h) \cdot P_1(h_1) = \left( \int_0^{2,1} \frac{0,3564}{e^h} dh \right) x \left( \int_0^{3,2} \frac{1}{\pi(1+h_1^2)} dh_1 \right) = 0,264 \cdot 0,51 = 0,14 \qquad (12)$$

Risk preservation of stability of the sediment river bed longitudinal profile at a joint event of erosion and accumulation in line will be:

$$R_0 = 1 - P_0 = 1 - 0,14 = 0,86 \qquad (13)$$

The result $R_0$=0,86 indicates a high risk of violation of stability of the longitudinal profile of the natural watercourse of the river Chadistsikhis-Khevi.

Therefore, to achieve the ecological balance of the river, construction of erosion control and mudflows control river bed regulating structures [1] is necessary.

## CONCLUSIONS

- Received empirical equation, taking into account its basic factors, is used for computing the specific discharge of solid fractions transported by the debris flow.
- Applying Theorem of probability density distribution function set the depth of erosion and accumulation of debris height outputs when passing catastrophic mudflow.
- The estimation of the ecological balance in the watercourse of river White Aragvi (for example river Chadistsikhis-Khevi) using reliability theory and risk theory. The quantitative indicators to preserve the stability of the longitudinal profile of the natural river bed have been received and in a case of the erosion river bed are the following: reliability of the longitudinal profile - $P(h)$=0,264; risk of an imbalance of the ecological situation of the longitudinal profile - $R(h)$=0,736; case of accumulation of debris flow carried into the channel, accordingly reliability of the longitudinal profile $P_1(h_1)$=0,51, and risk $R(h_1)$=0,49.
- Total reliability of maintaining the ecological integrity of debris flow type rivers, such as river Chadistsikhis-Khevi in the case of joint events of erosion and accumulation of debris sediments is equal to $P_0$=0,14, and the risk of loss of river bed stability - $R_0$=0,86, which indicates the active deformation of the longitudinal profile of the river. The developed method is acceptable to other mountain streams originating from debris flows in the basin of river White Aragvi to assess and predict the ecological balance of the longitudinal profile of the channel.

- The research has given the basis to recommend the proposed methodology. This allows to carry out effective engineering and environmental activities, not only in the basin of river White Aragvi, but also on other debris flow watercourses of Georgia.

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