

# FORMATION CONDITIONS AND DEBRIS FLOW REGIME IN JIANGJIA RAVINE, YUNNAN, CHINA – APPLICABILITY OF RUSSIAN METHODOLOGY

Mingtao Ding<sup>1</sup>, Aleksandr L. Shnyparkov<sup>2</sup>, Pavel B. Grebennikov<sup>2</sup>, Timur I. Khismatullin<sup>2</sup>, Sergey A. Sokratov<sup>2\*</sup>

<sup>1</sup>Southwest Jiaotong University, Faculty of Geosciences and Environment Engineering, The Western Park of the Hi-Tech Industrial Development Zone (Xipu Town), Chengdu, Sichuan, 611756, China

<sup>2</sup>Lomonosov Moscow State University, Faculty of Geography, Leninskie gory 1, Moscow, 119991, Russia

\*Corresponding author: sokratov@geogr.msu.ru

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**ABSTRACT.** The requirements of the debris flows' parameters assessments vary from country to country. They are based on different theoretical and empirical constructions and are validated by data from different regions. This makes difficult comparison of the reported results on estimated debris flows activity and extent. The Russian normative documents for the debris flows' parameters calculations are based on empirically-measured parameters in wide range of geological and climatic conditions at the territory of former USSR, but still not cover all the possible conditions of debris flow formation. An attempt was made to check applicability of the Russian empirical constructions for the conditions of the debris flows formation in Yunnan, China, where unique long-term dataset of debris flows characteristics is collected by the Dongchuan Debris Flow Observation and Research Station. The results show, that in general the accepted in Russia methodology of calculation of the parameters of debris flows of certain probability corresponded well to the observed in Dongchuan debris flows characteristics. Some discrepancies (in the average debris flow depth) can be explained by unknown exact return period of the actually observed debris flows. This allowed to conclude that the presently adopted empirical dependencies based on country-wide (USSR) empirical data can be extrapolated up to the monsoon climate and geological conditions of Yunnan province.

**KEY WORDS:** debris flow, probability, formation, regime, Yunnan, China, normative documents

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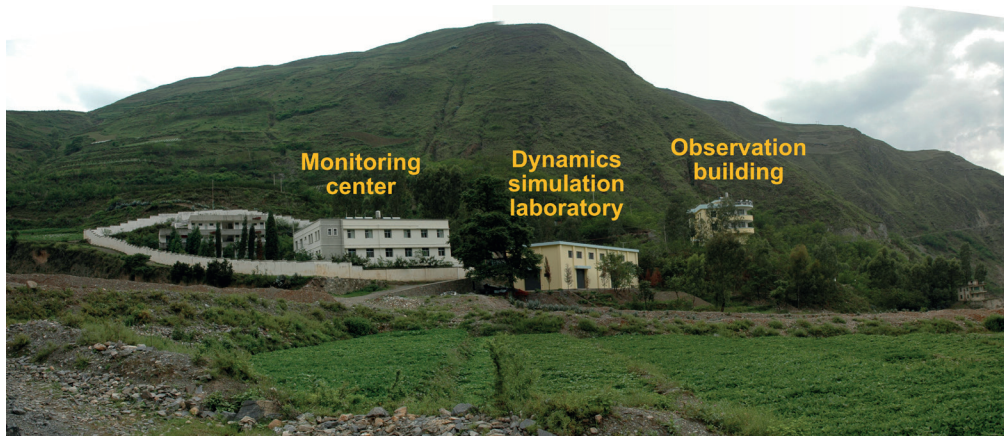
## INTRODUCTION

The study of debris flow activity in China has longstanding history. Research is actively conducted in such provinces as Sichuan, Yunnan, Gansu, Shaanxi, etc. In 1961, a unique Dongchuan Debris Flow Observation and Research Station (DDFORS) was organized in the north of Yunnan province. The station is positioned in the valley of the Jiangjia creek and is the right-hand tributary of the larger river Xiaojiang, being part of the Upper Yangtze River basin. Continuous year-round observations have been conducted at this station with automatic fixation of the main parameters of debris flows since 1987 (Fig. 1). Since 2000, the station was authorized to be the State Key Field Observation Station.

Differently from also unique Soviet (Vinogradova & Vinogradov 2017) or Swiss (Rickenmann et al. 2006) full-scale experimental sites, the station was originally focused on observing naturally-released debris flows. Such approach

was also adopted in other regions later (i.e.: Comiti et al. 2014; Hürlimann et al. 2014; Marchi et al. 2002; etc.) and should be able to provide comparable with DDFORS's one datasets with time.

The station was registering timing of the first waves of released debris flows and the ends of the events. Also, the duration of the releases and quantity of waves in each case were recorded. The velocity of the debris flows was calculated based on stopwatch timer records of a wave passing two 200-m apart positions in the torrent. The height and the width of a debris flow had expert estimation in the beginning of the observations at the station. Later they were provided by specially-installed equipment. The debris flow discharge was calculated from the height, the width and the velocity. Sampling from the moving debris flows by volume-calibrated electronic sampling instrument was used for estimation of the flow density and the bulk concentration of the flows (Guo et al. 2020).



**Fig. 1. Dongchuan Debris Flow Observation and Research Station, Institute of Mountain Hazards and Environment, Chinese Academy of Science**

The debris flows investigations at DDFORS were covering various aspects: mechanism of debris flow formation (Cui et al. 2005; Chen et al. 2017; Kang & Hu 1990), debris flow movement (Chen et al. 2007; Guo et al. 2020; Li et al. 2003; Shu et al. 2007), debris flow deposition (Wang et al. 2007), analysis of various parameters of the debris flows, such as velocity (Li et al. 2012) and relation between the dimensions of the granular material and the characteristics of the released debris flows (Li et al. 2003), effects of topography, landslides and erosion, precipitation on debris flows formation (Chen et al. 2005; Guo et al. 2013; Tian 1987; Tian et al. 2020), debris flow forecasting (Hu et al. 2011; Liu et al. 2012), debris flow mitigation engineering (Lin et al. 2007), disaster evaluation and management of debris flow (Liu et al. 2009; Liu et al. 2002), direct observations of formation of debris flow (Cui et al. 2007; Huang et al. 2015; Fu et al. 2006; Li et al. 1983; Tian et al. 2007), direct observation of debris flow dynamics (Kang & Hu 1990), statics and rheology of debris flows (Chou 2007; Li et al. 1983), hazard and risk assessment of debris flows (Cui et al. 2013; Wei et al. 2010; Zhu & Tang 1996).

Assessment of the debris flow danger and risk, as well as planning of mitigation measures and building of defense infrastructure, require quantitative estimation of height, volumes and discharge rates of the debris flows. Long-term observational data on such parameters is preferable for construction of the probability curves and calculation of these values for a required probability. However, extensive observational data is absent in 99.9% of debris flows basins. As a substitute, numerous studies are directed to finding statistical relationships between the debris flows volumes and their repeatability (Gao et al. 2019; Helsen et al. 2002; Hungr et al. 2008; Jakob & Friele 2010; Johnson et al. 1991; Liu et al. 2008; Stoffel 2010; van Steijn 1996; etc.). Another approach to statistical methods of determination of characteristics of debris flows of certain probability is mathematical modeling of such characteristics (O'Brien et al. 1993; Rickenmann et al. 2006; Shieh et al. 1996; etc.). The studies show that the dependence between frequency and magnitude of debris flows follows the power law, with strong dependence on the area of a debris flow basin. The dependencies vary from region to region and cannot be directly transferred from one region to another. Additionally, more and more common become physical models of debris flows dynamics (RAMMS; GeobruGG, FLO-2D; etc.). For any approach the large amount of collected data on debris flow activity in the Jiangjia Valley is of much use for verification of the adopted methods of estimation of the conditions of formation and regimes of the debris flow of required probability. The Russian normative documents suggest methodology and

require calculation of the parameters of debris flows for 1% probability. Extensive DDFORS dataset is much closer to such probability than most of other published empirical data. The other matter of interest is applicability of the Russian normative methodology for wider than used for construction of presently adopted in Russia dependencies range of possible conditions of debris flow formation (at least the Yunnan province, and possibly the territory of the People's Republic of China).

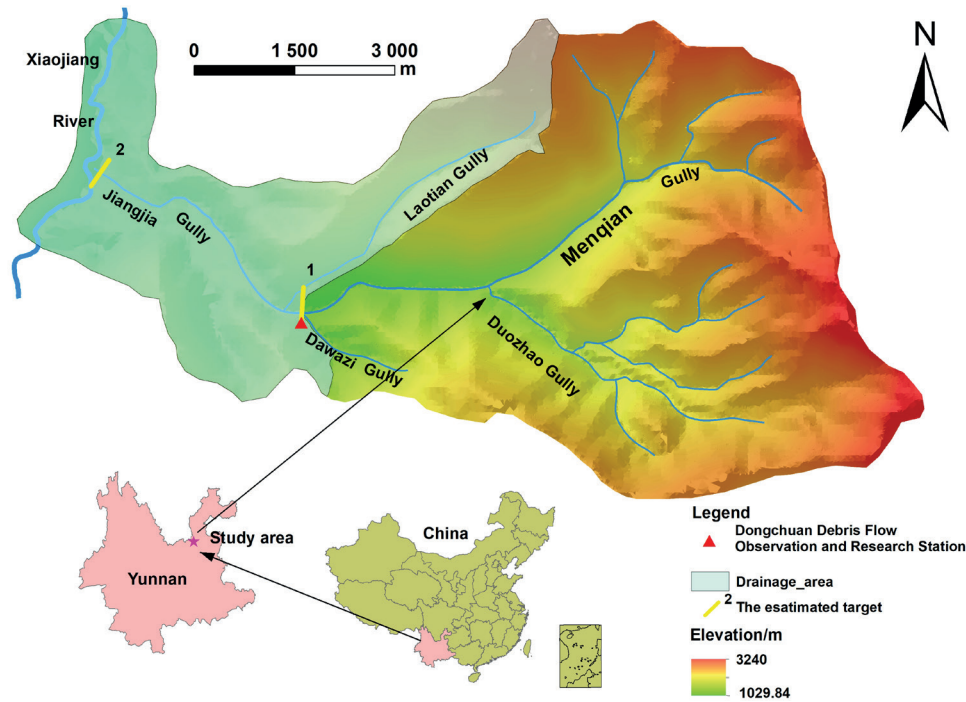
#### Area of investigation

Analysis of debris flows hazard, vulnerability and risk suggests that the regions of China with different extent of debris flow phenomena can be divided on five categories: extremely high-risk regions cover the area of 104 km<sup>2</sup>, high risk regions – 283008 km<sup>2</sup>, moderate risk regions – 3161815 km<sup>2</sup>, low risk regions – 3299604 km<sup>2</sup>, and extremely low risk regions covering the area of 2 681 709 km<sup>2</sup> (Liu et al. 2012). Maximum debris flow activity is registered in the west, south-west and north-east provinces of mainland China. More than 50 000 debris flow catchments documented there, covering around 48% of these territories (Cui et al. 2005).

The Jiangjia debris flow catchment is located in the northern part of Yunnan province, in the basin of Xiaojiang River (Fig. 2). The climate is of a monsoon type. Heavy rainfall occurs mainly from May till November. The morphology of the catchment is characterized by steep exposed slopes with intense erosion and landslide activity, which contributes to intensive debris flow activity. The catchment's area is 47.1 km<sup>2</sup>. Weighted mean slope angle of debris flow channel – 141‰. The length of the channel up to the estimated target №1 – 12.1 km, target №2 – 12.1 km.

#### Conditions of the formation of the debris flows

**Relief:** The debris flow catchment of Jiangjia is a U-shaped steeply inclined ravine. Absolute altitude varies from 2880 to 1100 m. The elevation of the slopes above the bottom of the ravine is 400–500 m. Mean absolute altitude of the catchment is 2045 m a.s.l. The inclination of the slopes varies between 600 and 700‰. The slopes are complicated by a large number of erosion-denudation funnels, in which intense erosion activity with a large number of fans occurs. This material, supplied from erosion-denudation funnels to the mainstream, is an additional potential debris flow material. The inclination of the debris flow channel in the upper part of the basin reaches 500‰, in the middle part about 110–120‰ and decrease down to 70‰ in the estuary of the catchment. The width of the bottom of the ravine varies from the first tens of meters to 170 m at the



**Fig. 2. Research area location and location of the target control points in Jiangjia**

widest point near the Dongchuan Debris Flow Observation and Research Station.

**Geology:** The Jiangjia valley lays along seismic faults and frequent earthquakes result in bedrock destruction and fragmentation. The outcrops are dominated by pre-Cambrian epimetamorphic rocks, such as slate, phyllite, and shale, all being easily weathered. Accordingly, quaternary diluvium and colluvium are widely distributed on slopes (Tian et al. 2020). About 80% of exposed bedrocks are crumbling and weakly metamorphosed. The main sources of the solid material for debris flows are landslides and debris flows' deposits at torrents' beds (Tian et al. 2020). The volume of loose deposits of landslides sites which are material for potential debris flows is estimated as  $1.23 \times 10^9 \text{ m}^3$  (Du et al. 1987) and at torrents' beds of about  $7.5 \times 10^8 \text{ m}^3$  (Yang 1997). The thickness of the loose deposits on the slopes reaches several tens of meters (Huang et al. 2015). Loose material is represented mainly by debris particles up to 10–15 cm in diameter. The filler consists of sands, loams and clay particles with the prevalence of the former. It is important that the content of the clay particles is high – 10–15% (Tian et al. 2020), which provides conditions for formation of mud-stone and mud flows.

**Climate:** The region lay in monsoon climate zone. The climatic conditions of the formation of the debris flows can be provided by the data of the closest to the Jiangjia site Huize weather station. Huize is situated 25 km NNW from the debris flow basin of interest. The absolute altitude of its position is 2114 m a.s.l., which is close to the mean absolute

altitude of the debris flow basin. The meteorological observation at Huize were started in 1957. The published rows of data start from 1980.

Throughout the year, the air temperatures are above 0°C with maximum values in the summer period (Table 1).

Precipitation falls in liquid form throughout the year. Most of the precipitation falls in the summer–autumn period – about 80–90% of the totals for year (Huang et al. 2015).

According to the Huize weather station data, the average annual precipitation is 784.4 mm (Table 2). The maximum amount is in June–August – 57% of annual precipitation.

**Vegetation:** Vegetation cover is spread over only 39.5% of the debris flow catchment area, and only 4.2% of it is occupied by forests (Cui et al. 2005; Zhuang et al. 2015; Huang et al. 2015). Currently, there is an increasing degradation of vegetation as a result of intensification of economic activity. The distribution and nature of vegetation in the Jiangjia Ravine does not prevent origination of debris flows. Most of the slopes in the ravine are not covered in forest or sod. Only on the right side of the valley, higher than 2000 m above sea level, there is forest vegetation, which sharply decreases the activity of erosion processes in place (Fig. 3).

**Seismic conditions** are favorable for the formation of solid debris material, due to the fact that the study area is located in active seismic zone. In the Yunnan province, earthquakes of magnitude higher than 5 points on the Richter scale have been repeatedly registered (Daniell 2010; Zhao et al. 2013):

**Table 1. Mean monthly and annual air temperatures, °C, Huize weather station (<https://en.tutiempo.net/climate/ws-566840.html>)**

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
12.0	14.4	19.0	21.7	23.0	23.3	23.6	23.4	21.0	18.0	14.8	12.0	18.9

**Table 2. Monthly and annual average amount of precipitation, mm, Huize weather station (<https://en.tutiempo.net/climate/ws-566840.html>)**

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual
11.8	11.2	20.7	32.5	77.6	143.3	161.8	144.4	95.9	53.8	25.8	5.6	784.4



**Fig. 3. The right side (the slope is of northern exposition) of the Jiangjia Ravine, with forest vegetation above 2000 m (Google Earth image 04.01.2020)**

1. On January 5, 1970, an earthquake occurred in Yunnan Province with a magnitude of 7.7 on the Richter scale. 15621 people were killed, 32431 were injured.
2. On July 22, 2006, an earthquake occurred in Yunnan, 90 kilometers from Zhaotong City, with a magnitude of 5.1 on the Richter scale. 13 people were killed and 41 more were injured. 56 buildings were destroyed.
3. On February 25, 2010, an earthquake occurred 90 km northwest of Anning and its suburbs Lianzhang, with a magnitude of 5.2 on the Richter scale. 35 people were injured, residential buildings were damaged. Economic damage amounted to about 52 million US dollars.
4. August 29, 2010, on the border of the provinces of Yunnan, Sichuan and Guizhou, an earthquake of 4.9 on the Richter scale occurred. The epicenter of the earthquake was located 71.6 km west of the city of Zhaotong (Yunnan Province). 14 people were injured, more than 1000 houses were destroyed. Economic damage amounted to about 13 million US dollars.

An analysis of the conditions of the relief, vegetation, seismic, climate and lithology showed that there are favorable conditions for the formation of debris flows in the Jiangjia valley.

#### Sources of data and methodology of calculations

The research involved wide list of scientific publications about the debris flow hazards and activity in Yunnan province of China, as well as on information collected from the Internet. Data collected in the Dongchuan Debris Flow Observation and Research Station in Jiangjia Ravine during years 1966–1967, 1974–1975, and 1982–2001 was used for the analysis of regime of debris flows. These data regarding registered debris flow include: date of a debris flow event, duration of event, maximum flow height, density of the solid material and density of debris flow mixture, the debris flow discharge, volume of the debris flow – overall and of its solid part, velocity of the debris flow.

Statistical processing of the data allowed to determine the period of the formation of debris flows, the duration of the debris flow hazard period, the duration of the debris flow main and maximum dangerous periods, the frequency of the debris flow events, the genetic types of debris flows, the type by the ratio of the solid and liquid components of the debris flow, the long-term average and maximal debris flow volumes, average and maximum values of debris flow velocity, debris flow depth.

The debris flow hazard period is the period between the first and the last date of debris flow occurrence during a calendar year; the debris flow main danger period is determined by a time when 90% of debris flow events occur, and the maximum danger period – when 50% of the events take place (Perov 2014). A methodology is developed in Russian Federation to determine the duration of these periods (Belaya 2005). The methodology is based on precipitation and temperature regimes over year. The research area belongs to the type № 18. This type is characterized by several dry months in a year, with excessive moisture, and a monsoon type of climate. According to this methodology, a month refers to the main debris flow danger period if the ratio of the amount of precipitation for this month is greater than or equal to 60% of the amount of precipitation for the month with the maximum value. The debris flow maximum danger period includes months with the same ratio of more than or equal to 80%.

The equations for determining the debris flow volume of 1% probability are as the following (VSN 03-76):

Maximum debris flow discharge of 1% probability in the Jiangjia Ravine is calculated by equation 1:

$$Q_{cp} = q_{1\%} m_a \lambda'_p \left( \frac{1}{W_{ofp}} \right)^{1.08} F \quad (1)$$

where  $q_{1\%}$  is a module of maximum rainfall run-off with probability of exceeding  $P=1\%$ ,  $m^3$  ( $s \times km^2$ ), determined from (VSN 03-76: Table 9). It depends on attain time of a debris flow to an estimated target and on the hydrological area. The latter was taken as № 2 in accordance ец (VSN 03-76: Table 10). The climatic conditions of the Jiangjia debris flow catchment are closest to that;

$m_a$  – coefficient depending on hydrological area, where the catchment is situated, determined according to (VSN 03-76: Table 10) and by equation:  $m_a = H_{1\%} / 250$ . The maximal daily precipitation of 1% probability is equal to 109 mm, thus:  $m_a = 109 / 250 = 0.43$ . The value of  $m_a$  should be in the range 0.75–1.25, which makes it 0.75 for presented calculations;

$\lambda'_p$  – transition coefficient from debris flow discharge with  $P^p = 1\%$  to discharge of another probability, determined according to (VSN 03-76: Table 11) and it is 1 for  $P = 1\%$ ;

$W_{ofp}$  – The coefficient of fluidity of the debris flow material for the peak phase and is determined by equations 3 and 4 below;

$F$  – debris flow catchment area above a target,  $km^2$ .

Assessment of the volumetric concentration and discharge of a debris flow requires estimation volumetric concentration of the solid constituent (So) of the debris flow. It depends on the mean bed slope and the coefficient of the debris flows activity  $\mu$ . The latter is calculated by:

$$\mu = \frac{\sum F_i \times Z_i}{F} \tag{2}$$

where  $F_i$  – areas of individual sections of the debris flow catchment, that are characterized by their specific coefficients of debris flow activity  $z_i$ , that are determined by (VSN 03-76: Table 1).

The sections with different landscape conditions in Jiangjia basin were identified at Google Earth Pro-provided image and corresponded to different debris flow activity according to (VSN 03-76: Table 1). The coefficients are varying from 0.7 to 1.0, for heavy erosion cuttings filled by thick layer of loose material, to 0.005–0.01 for forested and matted areas with no erosion. The calculations by (2) gave the following results: For target I the coefficient of the debris flows activity is 0.73, for target II – 0.66.

Debris mass fluidity factor ( $W_{otP}$ ) for the peak phase of debris flow and as average ( $\bar{W}_{otP}$ ) are, respectively:

$$W_{otP} = 1 - S_{oP} / S_{pt} \tag{3}$$

$$\bar{W}_{otP} = 1 - \bar{S}_{oP} / S_{pt} \tag{4}$$

where  $S_{oP}$  and  $\bar{S}_{oP}$  are the volumetric concentrations of the solid debris flow component for the peak phase (VSN 03-76: Table 5) and the average during the event (VSN 03-76: Table 6) respectively with a given probability of exceeding 1%;

$S_{pt}$  – the maximal volumetric concentration of solid material in a debris flow, at which it loses its fluidity properties, in this particular case assumed to be 0.705.

Debris flow volume (both solid and liquid components)  $W_{c1\%}$  corresponding to maximal discharge depending on the volume of rainfall flood  $W_{b1\%}$  and debris saturation coefficient  $\varphi_w$ :

$$W_{c1\%} = W_{b1\%} \varphi_w \tag{5}$$

where:

$$W_{b1\%} = q_{1\%} m_a \lambda'_{1\%} FC_{1\%} 10^3 \tag{6}$$

$$\varphi_w = 1 / W_{otP} \tag{7}$$

$C_{1\%}$  – debris flood coefficient, that depends on the duration of the run-up time ( $\tau$ ) and the probability of an annual excess of 1% of the maximum debris flow discharge, determined from (VSN 03-76: Table 12) by interpolation.

The volume of sediment transport of solid material (as a solid component) for calculated wave of a debris flood ( $W_{\tau 1\%}$ ) should be determined as:

$$W_{\tau 1\%} = \bar{S}_{oP} W_{c1\%} \tag{8}$$

The volume of debris flow deposit (in a friable body) at a target control point, corresponding to the estimated

discharge with 1% of exceeding probability is determined by (VSN 03-76: p. 16, Eq. 27):

$$W_{\tau 1\%} = W_{c1\%} (1 + \varepsilon_{dep}) I_y^{2/3} / (5 + I_y^{2/3}) \tag{9}$$

where:  $W_{\tau 1\%}$  – the volume of loss of solid material (in a dense body) for the calculated wave of the debris flood;  $I_y$  – average slope of the debris channel within the estimated runoff, ‰;

$\varepsilon_{dep}$  – porosity coefficient of fresh debris flow deposits (VSN 03-76: Table 8).

The velocity of debris flow  $V_{df}$  is calculated as (VSN 03-76: Equation 33):

$$V_{df} = 0.56 Q_c^{0.2} I_y^{0.3} W_{dep1\%}^{0.2} \tag{10}$$

And its average depth  $h_{av}$  (VSN 03-76: Equation 34):

$$H_{av} = 0.245 Q_{c1\%}^{0.4} / I_y^{1/15} W_{otP}^{4/15} \tag{11}$$

Maximum debris channel depth before erosion is calculated as (VSN 03-76: part 4.4, Equation 41):

$$h_{max} = 1.5 h_{av} \tag{12}$$

Conditional width  $B_y$  (m) of debris flow channel in its top corresponding to the estimated debris flow discharge rate  $Q_{c1\%}$  is calculated as (VSN 03-76: Equation 28):

$$B_y = 7.1 Q_{c1\%}^{0.4} W_{ot1\%}^{0.067} / I_y^{0.23} \tag{13}$$

RESULTS

Calculations of debris flow parameters of 1% probability were carried out for two target control points (Fig. 2).

Studies of debris flows at the Dongchuan Debris Flow Observation and Research Station have shown, that the main genetic type of debris flows in the Jiangjia Ravine are rain debris flows, the origination of which corresponds with a period of intense monsoon rains. Seismogenic debris flows can also form here, due to intense seismic activity.

Powerful earthquakes and heavy rainfall can lead to the formation of landslides that block the channels of watercourses. The formation of landslide dams and their subsequent breaching and rapid erosion can also lead to the formation of debris flows. Thus, in addition to the erosion-shear mechanism of the formation, breaching mechanism can also occur.

The average slurry density according to the observed data is 2022 kg/m<sup>3</sup>. The average density of debris/mud flow is 1680 kg/m<sup>3</sup>, varying from 1140 to 2044 kg/m<sup>3</sup> (Data... 1997; 2006; 2007).

According to the recorded data from the Dongchuan Debris Flow Observation and Research Station, the debris flow hazard period lasts from early May to the first of September, its duration – 4 months. Table 3 presents the duration of different debris flow danger periods, obtained by the methodology of N.L. Belaya and from the recorded data. According to V.F. Perov (2014) the debris flow principal danger period corresponds to the time period of 90% of all the debris flows releases, while the maximal danger period corresponds to 50% releases time period.

**Table 3. Comparison of duration of different types of debris flow danger periods according to N.L. Belaya (2005) and the actual data, months (Data... 1997; 2006; 2007)**

Type of dangerous period	Methodology	
	according to N.L. Belaya (2005)	from recorded data*
Debris flow hazard period	V–IX	V–IX
Debris flow principal danger period	VI–VIII	VI–VIII
Debris flow maximal danger period	VI–VII	VII–VIII

\* based on the data of the Dongchuan Debris Flow Observation and Research Station.

Analysis of the comparison of the obtained durations of different types of the debris flow danger period shows that the durations of the debris flow hazard period and the main danger period completely coincide. The duration of debris flow maximum danger period is 2 months in both cases, but according to the calculations this period is shifted a month earlier, which is obviously due to very large precipitation in June (see Table 1).

According to the actual long-term data, the duration of debris flow hazard period varies from 3 (1993) to 122 (1989) days, with an average value of 58 days. The earliest date of debris flow event is May 3, the latest is September (Data... 1997; 2006; 2007).

The occurrence of debris flow is observed annually, on average up to 10 times per season (Zhuang et al. 2011) In some years, with a small amount of liquid precipitation, from 2 (1993) to 4 (1988) events during the hazard period. In years of high humidity, the number of the events reaches 22 cases (1991) (Data... 1997; 2006; 2007).

The parameters of the recorded debris flows (Data... 1997; 2006; 2007) are as the following:

The flowing duration changes from half a minute to 16.5 minutes (Data... 1997; 2006; 2007);

The average debris flow discharge for all recorded events is 722 m<sup>3</sup>/s, and its maximal value reaches 4687.5 m<sup>3</sup>/s (Data... 1997; 2006; 2007).

The change in maximal daily precipitation amount from 1980 till 2020 is shown at Fig. 4. There is slight positive trend in this parameter starting from 1990<sup>th</sup>.

The registered maximal daily amount of precipitation was 98.7 mm (in 1998). To estimate the maximal daily precipitation amount of 1% probability the existent raw of data was used (Fig. 4) and provided 109 mm (Fig. 5).

The volume of debris flows averages 327 876 m<sup>3</sup>, ranging from 1 000 to 2 025 400 m<sup>3</sup>. The average volume of the slurry component in the debris flow is 215 579 m<sup>3</sup>, reaching up to a maximum of 1 266 334 m<sup>3</sup> (Data... 1997; 2006; 2007).

The average velocity of the observed debris flows is 9.5 m/s, with a maximum value of 14.4 m/s (Data... 1997; 2006; 2007).

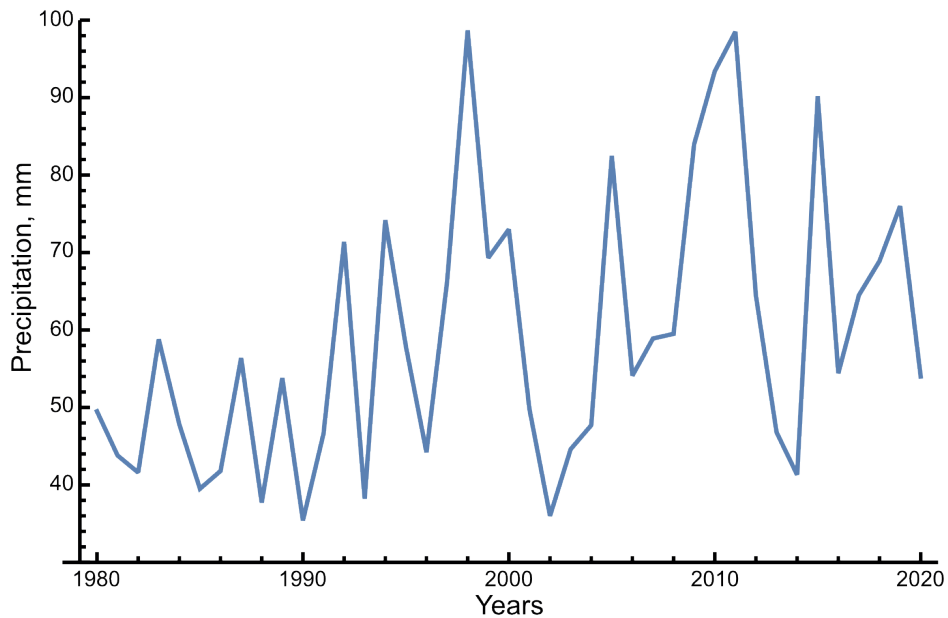


Fig. 4. Variation in maximum daily precipitation values for the time period from 1980 to 2020

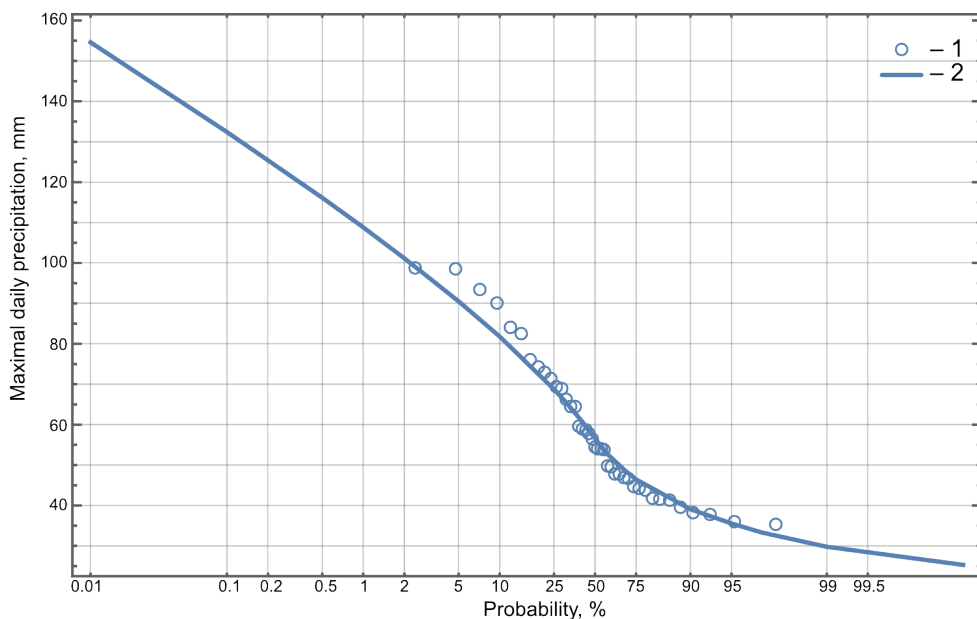


Fig. 5. The probability curve for maximum daily precipitation at the Huize weather station: 1 – the distributed registered values; 2 – the Pearson probability curve of type III,  $C_s/C_v=3$

The average flow depth of debris flows is 1.88 m, with a maximum value of 6.49 m (Data... 1997; 2006; 2007).

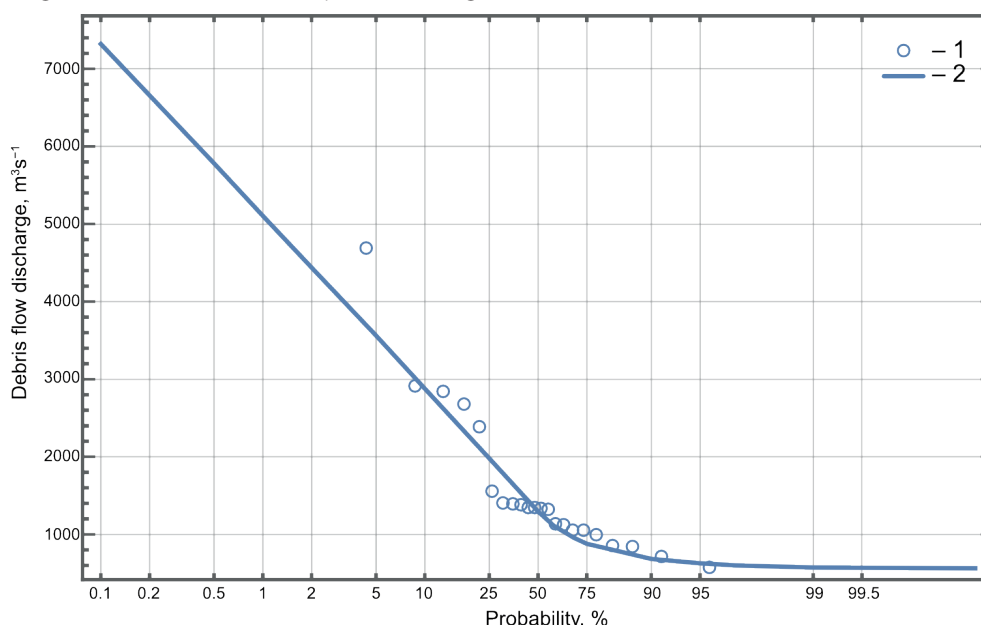
To compare the observed parameters of debris flows with the ones calculated according to (VSN 03-76), a probability curves of the debris flow parameters were constructed based on the data from the Dongchuan Debris Flow Observation and Research Station (Data... 1997; 2006; 2007). According to such calculations, the volume of a debris flow with the probability of occurrence equal to 1% at target No. 1 (Fig. 2) is 2 667 028 m<sup>3</sup>. The debris flow discharge of 1% probability was found to be 5105.5 m<sup>3</sup>/s (Fig. 6).

**DISCUSSION**

An analysis of the results of comparing the calculated and recorded parameters of the debris flows shows that the results of calculations by the method proposed in (VSN 03-76) are close enough to the actual data: For peak discharge

the error was 5.3%, for the debris flow volume it was 17.2%, for the volume of solid component the error was 1.2%, for the debris flow velocity the error was 5.6%.

Comparison of the calculated parameters of the debris flows for 1% probability with the values provided by the probability curves based on the recorded data can be interpreted as 10–15% underestimation. The exceptions are the velocity of a debris flow (56.4% lower) and the debris flow depth (7.3% overestimation). The latter has up limits. In Russia it is accepted that the maximal debris flow velocities are 15–16 m/s (Perov 2014). So, the comparison of the calculated data with the curves is not correct. Same as a construction of a probability curve for the debris flows velocities. Since the target position for the debris flow characteristics observation is not rigid, there is possibility both for underestimation and overestimation of the debris flows parameters.



**Fig. 6. The probability curve for the debris flow discharge: 1 – the distributed registered values; 2 – the Pearson probability curve of type III, C<sub>s</sub>/C<sub>v</sub>=3**

**Table 4. Calculated and observed parameters of debris flows with 1% probability of occurrence in the Jiangjia Ravine**

	Target (Fig. 2)	Q <sub>c</sub> , m <sup>3</sup> /s	W <sub>c1%</sub> , m <sup>3</sup>	W <sub>t1%</sub> , m <sup>3</sup>	V <sub>sel</sub> , m/s	h <sub>cp</sub> , m	h <sub>max</sub> , m	B <sub>y</sub> , m
Based on (VSN 03-76)	1	4429.8	2375248	1282634	8.4	7.3	11.0	56.7
	2	6072.7	3068498	1521975	8.7	7.5	11.3	71.6
	1 (probability curves)	5105.5	2667028	1602199	19.3	6.8	–	–
Actual maximal data	1	4678.0	2025400	1266324	8.9	6.5	–	–
The ratio of (VSN 03-76)-provided to the actual data, %	1	–5.3	17.2	1.2	–5.6	12.3	–	
The ratio of (VSN 03-76)-provided to the actual data for 1% probability, %	1	–13.2	–10.9	–15.7	–56.4	7.3	–	

- Q<sub>c</sub> – peak discharge debris flow, m<sup>3</sup>/s;
- W<sub>c1%</sub> – debris flow volume (both slurry and fluid components), m<sup>3</sup>;
- W<sub>t1%</sub> – the volume of sediment transport of solid material (in a slurry component) for calculated wave of the debris flood, m<sup>3</sup>;
- V<sub>sel</sub> – debris flood velocity, m/s;
- h<sub>cp</sub> – average debris flow depth, m;
- h<sub>max</sub> – maximum debris flow depth, m;
- B<sub>y</sub> – debris flow width, m.

## CONCLUSIONS

The observational data from the Dongchuan Debris Flow Observation and Research Station is suitable for testing new methodologies for debris flow parameters estimating and for testing the existent ones. Based on the long-term accepted and used in Russia methodology the parameters of debris flow regime, in particular, the duration of the debris flow hazard period and number of parameters of debris flows, could be estimated for considerably different geological and climatic conditions. The obtained

values are in good agreement with the results of actual observations. The observed maximal parameters of debris flows, required for territorial planning and engineering construction also agree well with the values calculated by the Russian normative documents, with the estimated error of 10–15%.

Considering the above, the Russian methodology for determining the parameters of debris flows with various probability of occurrence, and the methodology for determining the duration of the debris flow hazard period, can be used in the regions of People's Republic of China. ■

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