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Nadezda N. Vinogradova

THE IMPACT OF ACTIVE DEBRIS-FLOWS FROM TRIBUTARY VALLEYS ON CHANNEL DEVELOPMENT IN MOUNTAIN RIVERS (EXAMPLE OF THE RIVER BAKSAN)[1]

Abstract: The impact of valley debris-flows (*siela*[2] in Russian) on the main channel development and fluvial processes involves a direct influence on the channel itself and an indirect influence of a modified pattern of water and bedload discharge. Taking into account the mutual influences of the main river and the valley debris-flows four main types of debris-flow impact nodes (DIN) were identified in the Baksan valley. The most evident impact of valley debris flows on the main river channel and its longitudinal profile can be seen in the type one impact zone. It characteristically features torrential cones and evident nick-points of the longitudinal profile. Three types of reaches can be identified in the main river channel in this zone: headwater reach, direct impact reach and a reach with active transformation of the supplied debris. This DIN tends to evolve at the confluences with tributaries with highly frequent debris-flows containing large volumes of material.

Key words: mountain river, channel, longitudinal profile, torrential cone, valley debris-flows, debris-flow impact nodes.

1. Introduction

Mountain fluvial processes involving the active impact of valley debris-flows have scarcely been dealt with by fluvial-geomorphology. Only a very few studies devoted to the topic have been published (Talmaza, Kroshkin 1968, Kuznetsov, Chalov 1988, Bogomolov et al. 2002, Chalov 2002). However the assessment of the impact of valley

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[2] In Russian siela is a broader term covering: debris-flows, mud flows, torrential flows and valley debris-flows. For the purpose of this paper it shall mean debris-flows.

debris-flows on river channels and the forecasting of their aftermath has a practical use especially for economically managed valleys, as large volume debris-flows can change the morphology and regimen of the main rivers radically and very rapidly. The Soil Erosion and Fluvial Channel Research Laboratory, Faculty of Geography, Moscow State University, has been conducting a research project into the channel dynamics along the upper course of the River Baksan on the Caucasian Mt. Elbrus since 2000. The project aims to understand the patterns of fluvial processes on a large mountain river exposed to active debris-flows in its tributaries.

2. Study area

The River Baksan, taking its source at the glaciers on Mt. Elbrus and the Main Caucasian Ridge, has a drainage area of 6900 km^2, including 6.8% covered by glaciers. It is 173 kilometres in length and has an average gradient of 12‰. Its numerous tributaries are a scene of debris-flow activity. In its upper course the River Baksan runs in a deep valley with a number of broader and narrower spots in the form of v-shaped ravines. The contemporary channel is deeply incised and 'squeezed' between rocks and the torrential cones of its tributaries. The discharge regimens of the main river and its tributaries are highly influenced by glacial ablation and snowmelt, which extends the spring and summertime flood flow season which overlaps with that caused by rainfall. Table 1 summarises basic data on the water and bedload discharge from the upper Baksan.

The rapid current (flood flows peaking at 3.5 m·s^{-1}) and relatively small depth (>2 m) provide conditions for a large scale movement of bedload originated from the channel bed and bank erosion, as well as from valley debris-flows. Deposits building valley debris-flow cones and accumulation landforms within the Baksan river channel feature various granularities from boulder to sand to silt. The upper River Baksan has more than 30 tributaries with active debris-flows of various origins (rainfall, glacier and rainfall, human-induced), frequency and volume (Perov 2003). Valley debris-flows mostly occur in June and August and partly overlap with the Baksan flood flow season. The key reaches of the Baksan, where the research was conducted, are typified by an active impact of valley debris-flows on channel development. The highest research stretch, eight kilometres

Table 1. Main parameters of water discharge and material transport in the Baksan drainage area

Water gauge	Distance from source [km]	Drainage area [km^2]	Long-term averages				Average daily concentration of suspended matter [g·m^{-3}]
			Discharge [m^3·s^{-1}]		Transport [kg·s^{-1}]		
			Annual	Maximum	Suspended matter	Bedload	
Tegenekli	12	180	10.0	51.9	-	-	-
Tyrnyauz	45	838	23.7	134.0	23.2	9.5	980
Zayukovo	91	2100	33.8	148.0	33.3	13.3	980

in length, starts at km 16 from the source. It consists mainly of reaches without alluvial landforms interspersed with such featuring alluvial landforms and rocky steps (according to a classification by R.S. Chalov 1997). Here the greatest impact on the channel regimen is exerted by valley debris-flows of the River Kubasanty. The lower stretch (14 km), begins at km 42 from the source and includes both reaches featuring well developed and weakly developed alluvial landforms, rocky steps, non-dissected debris-flow cones and canalized channels. The debris-flows of the River Gerkhozhansu have made the greatest impact on the development of this stretch of the River Baksan (Figure 1).

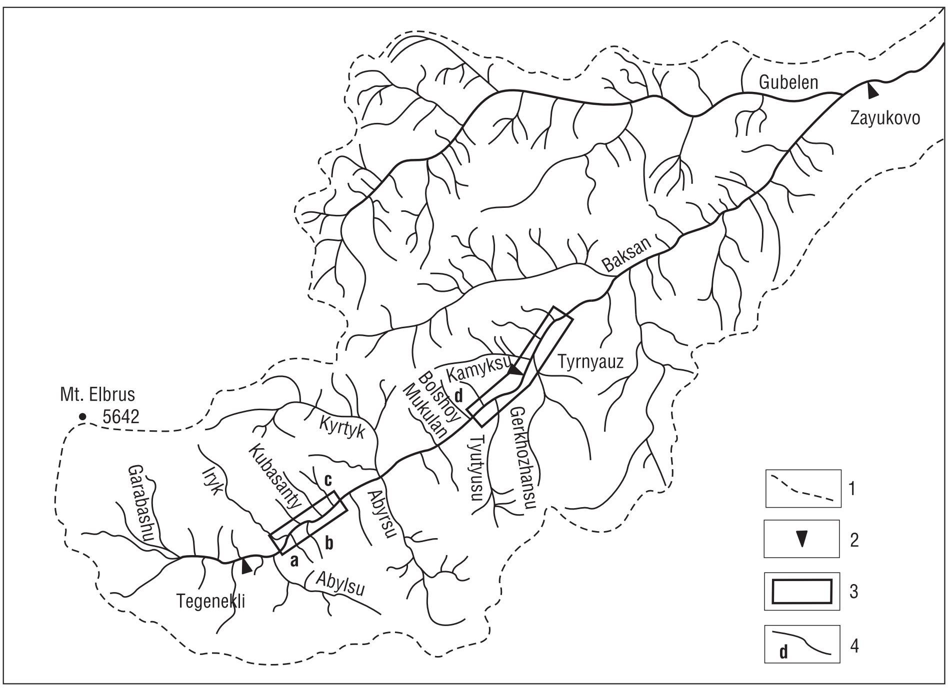


Figure 1. The upper River Baksan drainage basin

Explanations: 1 – drainage basin boundary, 2 – hydrological posts, 3 – study reaches, 4 – tributary valley debris-flows: a – Sagayevskiy, b – Dzhapyrtala, c – Kyzgen, d – Malyi Mukulan.

3. Methodology

The research involved fieldwork, as well as the analysis of aerial photos, large scale topographic maps and long-term hydro-meteorological data including water levels and discharges of water and bedload at hydrometric posts. The fieldwork conducted along the two main study stretches included the levelling of the channel cross-sections and longitudinal profiles, geodetic pictures of selected sections, identification of the granulometric composition of the channel and valley debris-flow deposits, surveying valley debris-flow basins, repeated pictures from constant points, etc. The granulometry of the channel deposits was always determined from the same surfaces located within various components of the channel landforms.

4. Results

The impact of the valley debris-flows on the development of the channel and the fluvial processes in the River Baksan depends on the frequency of the valley debris--flows, the volume of material carried with them, the valley debris-flow vs. channel bedload granularity ratio, the river transporting capacity, and the types of mutual relationship between the valley debris-flows and the river channel. This impact is manifested in the form of a direct influence of the valley debris-flows on the Baksan channel and of an indirect influence on the water and bedload discharge regimen, as well as on the conditions of channel development.

The direct impact involves the changing of the elevation of the main river channel and its horizontal transformation. Channels undergo a radical reworking along those reaches where there is a direct impact, which at a time of catastrophic valley debris-flows can mean their complete destruction. Much of this material is deposited at the confluence due to the large volume of material supplied by a single valley debris-flow (more than 30-50 thousand m^3 every time). This often blocks the channel, partly or completely, in the form of a barrage, which is then quickly washed down. The other bank of the channel is then subject to intensive erosion.

The length of a channel reach exposed to the direct impact of valley debris-flows depends mainly on the volume of the material supplied, but also on the morphology of the valley and of the main river channel at the confluence. Generally, the greater the volume of the material, the longer is the distance of its accumulation along the main river channel and the length of river along which the debris-flow waves that spread downstream from the valley debris-flow mouth take to calm down. During the catastrophic debris-flows of 2000, a combined total of five million m^3 of debris from the River Gerkhozhansu directly affected two kilometres of the River Baksan channel. In 1998, debris-flows along the River Kubasanty totalled 150-200 thousand m^3 of material causing an impact along 0.3-0.4 kilometres. Regular debris-flows on the Sagayevskiy and the Bolshoy Mukulan tributaries at 50 thousand m^3 affect the Baksan channel along more than 100 metres.

Modification of the channel development conditions as a result of valley debris-flows include changes to the gradient and the longitudinal profile, valley and channel morphology, and the composition and formation of the channel sediments. The changed conditions are particularly evident at the entry points of the most active valley debris-flows. A long--term valley debris-flow activity builds up a torrential cone and produces convex shapes in the longitudinal profile of the main river. Upstream of the cone the longitudinal profile gradient diminishes towards the cone, and grows again on reaching the cone and downstream from it. The reduced gradient causes deposition in the main river channel, while the increase of the gradient causes a gradual washing down of the valley debris-flow deposits at increasing rates downstream from the cone.

Valley debris-flows only cause short-lived modifications to the discharge regimen involving a flood wave on the main river below the direct debris-flow impact nodes (DIN) i.e. contact zones of the valley debris-flows and the main river channel. Water levels rise briefly (1-5 days), but abruptly while daily average water levels rise by more than one metre; the daily average discharges can even exceed 150 $m^3 \cdot s^{-1}$ at 75 m^3 per 24 hours. Flood flows caused by valley debris-flows cause increased rates of erosion below the mouth.

The impact of valley debris-flows on bedload discharge is much greater. Concentration of the suspended matter in the main river below the confluence of the valley debris-flows can grow by up to four times (by a level of magnitude or more), which is caused by the washing away of small particles from the rubble delivered. Large valley debris-flow events can increase a monthly average concentration of suspended material by up to two times from the long-term average. Such a dramatic increase in the concentration of suspended material increases the water density and reduces the washing down flow rate for the coarse particles (Rossinsky, Debolsky 1980). The washing down of the valley debris-flow material, the related activation of the slope processes and the increase in bank erosion contribute to an increased concentration of suspended material and discharge of bedload both on the tributaries and the main river. On the River Baksan the increase of suspended material after the valley debris-flow events is traceable down to the confluence. Also the floodplain tends to be transformed with some channels being filled in and new ones being created. In this way the spatial pattern of currents is changed.

Upstream from the cone, a headwater lake forms that collects all of the main river's bedload and part of its suspended matter. In the Baksan drainage basin where the valley debris-flow season coincides with the maximum volumes of water and bedload on the main river, the volume of the deposition within the dammed lakes can be very large.

At the end of the valley debris-flow season, the river may either gradually return to its former channel parameters (relaxation) or start developing a new channel type that corresponds to the modified conditions (new gradients and the type and nature of deposits), depending on the degree to which the channel has been changed.

Four main types of DIN were identified taking into account the discharge, valley morphology, frequency and volume of valley debris-flows, valley debris-flow rubble and bedload composition (Table 2).

The type one DIN is characterised by the build-up of debris-flows cones in the confluences of the tributaries and a related evident 'bump' in the longitudinal profile of the Baksan, as well as the development of three characteristic reaches along its channel: a – headwater reach, b – direct impact reach, c – reach of active transformation of debris-flow material transported downstream. This type occurs at the confluences of the River Baksan with the rivers Kubasanty and Gerkhozhansu which relatively frequently supply some of the volumetrically largest valley debris-flows.

The second type zone stands out with its poorly defined contemporary torrential cone, or lack of it, as well as with the development in the main river channel of a reach where the valley debris-flow material is actively transformed. It is found at the confluences of tributaries: a) with frequent debris-flows of small or medium volumes (less than 100 thousand m^3) and low granularity (tributaries: Bolshoy and Malyi Mukulan); b) cutting deeply into old cones, but with relatively infrequent valley debris-flows (tributaries: Kyrtyk, Kamyksu, Garabashy).

Table 2. Parameters of debris-flows on the tributaries of the River Baksan

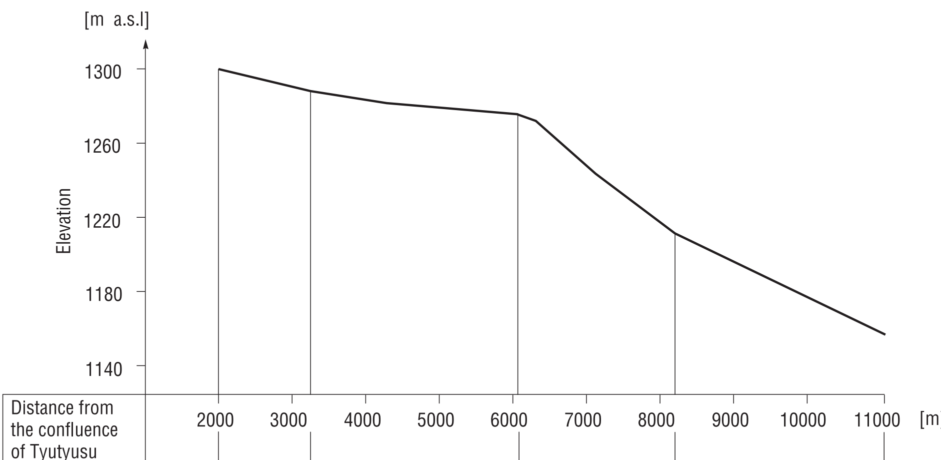
Tributary confluence distance from Baksan sources, km	Type of debris - flow impact nodes (DIN)	Average debris flow occurrence [years]	Unitary volume of material [thousand m^3]		Date of maximum volume debris flow
			Long-term average	Maximum	
Kubasanty, 20	I	5	100	972	5 Aug. 1967
Gerkhozhansu, 45	I	10	500	5000	18-25 Jul. 2000
Bol. Mukulan, 34	II	2	40	100	24-25 Jul. 1984
Mal. Mukulan, 36	II	up to 4/year	10	30	20 Jul. 1970
Kamyksu, 45	II	15	30	70	25 Jun. 1972
Sagayevskiy, 16	III	5	100	330	5 Aug. 1967
Tyutyusu, 36.5	III	20	50	500	5 Jul. 1934
Kyzgen, 21.5	IV	20	20	100	5 Aug. 1967
Dzhapyrtala, 19	IV	50	50	1000	1943

Source: expert assessment by I.B. Seymova and V.F. Perova.

The third type is typified by the development of a torrential cone pushing the river to the other side of the valley and only a minor 'bump' in the main river longitudinal profile. It can be found in the confluences of the Baksan tributaries: a – with frequent debris-flows supplying medium or large volumes of fine material (the river Sagayevskiy), b – with rare debris-flows supplying medium or large volumes of material (River Tyutyusu).

The fourth type is characterised by a lack of visible modifications to either the longitudinal or cross-profiles in the Baksan channel. It is typical of the impact zones of the Baksan with its tributaries: a – with low valley debris-flow activity, or b – with a medium to low valley debris-flow frequency, low and medium volumes, unloaded on old cones and high river terraces (rivers Kyzghen, Dzhapyrtala).

The most pronounced impact of valley debris-flows on the channel morphology and on the main river longitudinal profile is found with the DIN of the first type, where the main river is regularly blocked by the large quantities of debris. A reach upstream of the cone is typified by a flat longitudinal profile, accumulation of deposits and the emergence of a braided channel. The reach downstream of the barrage point, but still coinciding with the cone, is characterised by a sudden gradient increase (between two and five times greater than regular). Downstream of the cone, the gradient gradually reaches a regular value (Figure 2). What sets this reach apart from others is the presence of accumulation landforms and their transformation by the river. Landforms located higher up, such as debris walls, lateral and median bars form exactly at the time of mass supply of material, i.e. during the arrival of the valley debris-flow and during floods induced by debris-flows. Accumulation landforms emerge downstream during the transformation of the cone by the main river. The length of the Baksan reaches exposed to an evident influence of valley debris-flows on the Kubasanty River is four kilometres and on the Gerkhozhansu – more than eight.



Reach	Regular	Headwater				Direct impact			Processing
Water level gradient [‰]	10.5	5.7	3.8	1.7	0.0	14.8	36.1	30.4	18.3

Figure 2. Baksan longitudinal profile near the town of Tyrnyauz after catastrophic valley debris-flows on the Gerkhozhansu, 18-25 July 2000

After the catastrophic debris-flows from the Gerkhozhansu valley on 18-25 July 2000, the Baksan valley floor was entirely blocked. The river rose to more than six metres upstream of the barrage point, building up a two kilometres long lake that flooded a road and much of the local town of Tyrnyauz. During the subsequent summer season the lake was almost completely filled in with the main river's sand and gravel. The channel bed rose by more than four metres and the overall volume of bedload deposited along this reach was one and a half times more than the Baksan's annual average bedload discharge (Figure 3A). As the channel gradient diminished along the three-kilometre headwater reach above the barrage the average diameter of the deposits was halved (from 6 cm to 3 cm). The elevation of the Baksan channel rose by five to 15 metres along the reach where the valley debris-flow material was accumulated, as compared to prior to the event. Direct impacts of the valley debris-flow included the washing down of a left-bank terrace across the river from the cone, the filling in of the old channel and the cutting of a new

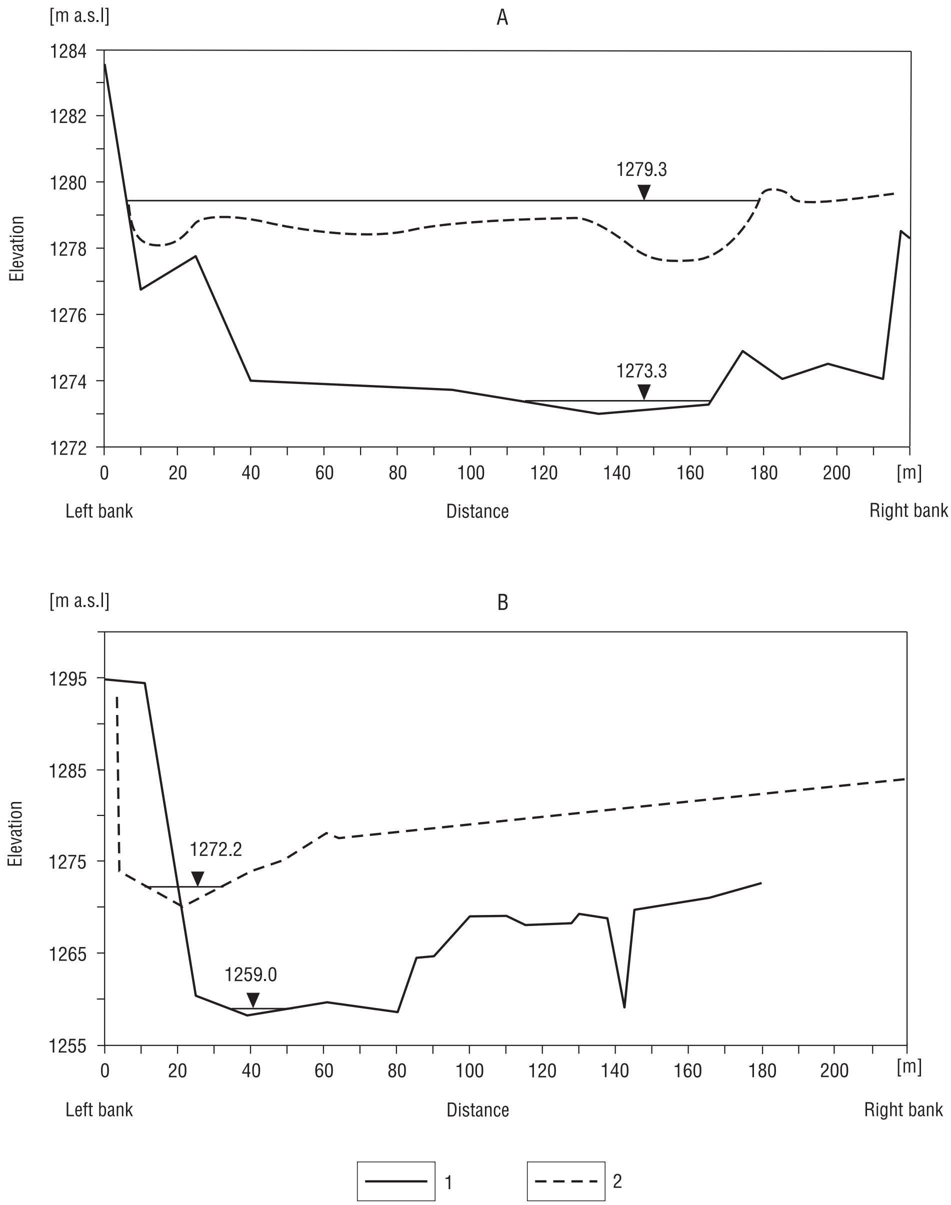


Figure 3. Near-channel cross-sections of the Baksan valley

Explanations: 1 – before 1975, 2 – after the valley debris-flows of the Gerkhozhansu of 25 August 2000, A – headwater reaches, B – direct impact reaches.

braided and uneven channel whose elevation and location did not match the old channel (Figure 3B). The cone consists of various unsorted material, mostly poorly rounded boulder and gravel fractions. After the breaching of the barrage and during flood flows, the formations are washed and carried away. Downstream of the cone the bedload granularity diminishes and its sorting improves.

Debris accumulation reaches were found in the DIN of the second type downstream of the tributary confluences. High 'stuck on' terraces developed up to 4-5 metres high and 200-300 metres long along the downcut channels (such as below the Bolshoy Mukulan confluence), while vast accumulation zones emerged on broad floodplains (downstream of the Kyrtyk confluence). During flood flows these deposits are subject to intensive washing down and carried away into the Baksan channel and downstream. As an example of this process, material from a spat of debris-flows in the Bolshoy Mukulan valley in July 2002 was found in the river Baksan 4.5 kilometres downstream of the confluence. It differed from the river's own bedload by a lower degree of sorting.

The third type of DIN is typified by large torrential cones within which the bulk of the valley debris-flows is unloaded. This means that only minor quantities of the debris reach the main river channel. The impact of valley debris-flows in this case is manifested indirectly in the pushing of the channel towards the far bank and in the addition of the supplied debris to the channel alluvia, i.e. with a marked increase in the proportion of a rougher fraction at the confluence of the tributary. In 2003, when debris flowed down the Sagayevskiy stream channel, the average diameter of the Baksan's bed pavement directly below the cone more than doubled (from 11 to 21 cm), as compared with 2002.

The fourth type of impact zone does not display any direct impact of the valley debris-flows on the Baksan channel.

The impact of valley debris-flows on the granularity of the Baksan channel bedload is manifested by an increase of the dragged bedload diameter near the tributary confluences. This impact is particularly evident in terms of active valley debris-flows and those that supply coarse material when the longitudinal profile of the main river channel is clearly bent upwards. Indeed, downstream of the river Kubasanta the average bedload granularity of 2002 increased more than five times as compared with an upstream reach (from 6 to 35 cm). Along the headwater reaches and where the debris supplied is processed the channel gradient diminishes and so does the bedload granularity. Material differences were found, however, in the nature of the relationship between gradient and granularity along these reaches. It was linked with the reduction of the critical initial washdown flow rates at high gradients (Makkaveyev 1955), that were observed in the debris processing reaches (Figure 4).

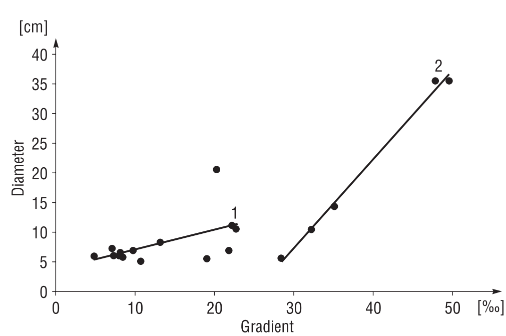


Figure 4. Average bedload diameter and the Baksan channel gradient

Explanations: 1 – in the headwater reaches, 2 – in the reaches where the valley debris-flow material is processed.

5. Conclusion

The impact of valley debris-flows on mountain fluvial processes depends mainly on the morphology of the valley at the confluence, the frequency of valley debris-flows, the volume of the material supplied and on the main river water and bedload discharge volume. A variety of influences exerted by these factors produces certain types of impact zones in the process of development of the main river channel at the confluences of valley debris-flows. The identified impacts could be utilised in the building of models of channel development after valley debris-flows, but also to work out methods of space and time forecasting of river channel development under the influence of valley debris-flows.

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Nadezda N. Vinogradova
Faculty of Geography
M.V. Lomonosov Moscow State University
Leninskie Gory
119992 Moscow
Russia