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Cause-Factor Relations of Modern Denudation Development (According to the Caucasus Region Example)

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Abstract: The studies carried out on the basis of the Caucasus Mountains, support the concept of modern denudation multifactorial processes. As might be expected, the presence or absence of links between the rate of denudation and natural anthropogenic factors, determining these rates, depends mainly on the degree of data detail concerning the spatial variability of different factors. The results suggest that the Caucasus region has a reliable set of data that allowed to establish certain relationship between the individual factors and denudation rates for each of the high-altitude zones. In terms of Caucasus among all factors the greatest impact on the Annual Layer Flush index, characterizing the total removal of loose fragmental material beyond the River Basin is performed by lithology and terrain elevation. The contribution of other factors such as slope and slope exposures, water reserves in a snow cover, the layer of atmospheric precipitation, temperature fluctuations, forest coverage, soil type and population density is clearly manifested only in certain regions.

Key words: Denudation, a layer of annual flushing, suspended river sediment discharge, the Caucasus mountains, factor analysis

INTRODUCTION

The quantitative approach is used more widely during the study of geomorphological and geo-ecological process. One of important geomorphology tasks is the assessment of the denudation spatial variability which is best seen in mountainous countries. The intensity of denudation to some extent may be judged by the volume of sediment produced by rivers. This denudation is called a transit one and shows the amount of material displaced along the balance portion by all exogenous processes, reached the river bed and located beyond by the river flow. The study of general or total, denudation, taking into account besides the transit denudation the amount of destroyed material not displaced by exogenous processes is a complex task and therefore it is not considered in this study. Lopatin (1952) pointed out in particular, the share of transit denudation for some watersheds at the amount of 8-20% from the total volume of loose material, displaced within the basin. Dumitrashko (1973), Voskresensky (1968) and Rastvorova (1973) also noted that the inclusion of River Sediment Denudation is not accurate enough. However, it generally reflects the spatial differences in the rate of denudation within the mountainous countries and may be used as an indicator that reflects the differences in the intensity of mountain countries destruction by the complex of exogenous and endogenous processes.

MATERIALS AND METHODS

The intensity of denudation, the emergence and development of modern exogenous processes is influenced by relief, tectonic movements, structural and lithological conditions, climate, land cover and a man (Lave and Avouac, 2001; Dedkov and Mozzherin, 1984).

In this study to analyze the impact of natural and anthropogenic factors, the following parameters are used: precipitation volume, the number of days with a temperature transition at 0°C and the days with snow cover, the average height of a watershed, the steepness and the exposure of the slope, lithology, the mechanical structure and the type of soil, forest coverage and population density. The source of information on climate factors is the observations at meteorological stations published in year books (climate references), about soil and geological factors geological and Soil maps and the works on geology, Topography factors the digital Model of relief (SRTM), about anthropogenic factors-the reference and statistical data. All information collected on various factors that determine the denudation process development is entered into the program ArcGis where their processing is performed.

The information on climatic factors is introduced into the program ArcGis as point objects and then the obtained data are used for the interpolation and

extrapolation of the values on the entire territory of the studied mountainous countries. Similar data on the types of soils and geological characteristics are entered in the program ArcGis as the area objects (polygons) with the determination of soil type and its mechanical content, density, rock lithology and topography data are presented as a raster which is handled by the tools "slope" and "aspect" for the steep layers and slope exposure obtaining.

Further for each selected River Basin of the study area by factors obtained as the result of information processing in the program ArcGis, the average height of the terrain, the steepness of slopes, sediment layer, the number of days with a transition temperature at 0°C and the days with snow cover, population density are calculated and the predominant soil types, lithologies and slope exposures are determined.

The routine observations data at hydrological stations according to the annual flushing layer and individual factors are entered in the general table separately for each of the studied mountainous countries for the correlation analysis and linear regression model.

In the process of data analysis, the null hypothesis about the importance of this or that factor influence on the denudation in mountain countries. The factor influences with the probability of 95% if the level of significance is <0.05, otherwise the distinction between factors is deemed to be insignificant and the null hypothesis is accepted.

Using the abovementioned methods and approaches, the spatial analysis of the distribution of denudation along the Caucasus will be performed. The indicator of the denudation is the annual demolition of material, calculated according to the runoff of suspended sediment and secondly, the assessment of the development cause-factors for modern denudation in various altitude zones of the mountains will be performed.

Thus, the purpose of this research is to study by the example of the Caucasus region, the intensity of denudation in the mountains, associated to a large extent with a significant overall erosional dissection of the mountains and as a rule with a modern high tectonic activity and to confirm the concept of the modern denudation multifactor processes.

The Caucasus is a vast mountainous country located South of the East European Plain. In the West, it is washed by the Black and Azov seas and in the east it is washed by the Caspian Sea. The Caucasian region includes the Greater Caucasus, Lesser Caucasus, the Caucasus foothills and plains and lowlands. The Caucasus relief is characterized by a combination of powerful mountain elevations, hills and lowlands. The mountains of the Great Caucasus and Transcaucasia are sharply dissected by gorges the result of powerful young uplifts is observed along with highly elevated aligned planar surfaces which witnessed the earliest stages of the relief development. The upper high tiers are taken by a young alpine terrain which was formed with the participation of glacial-nival processes during the Late Quaternary and modern era. The lowlands are mainly accumulative plain: alluvial, proluvial alluvial and marine ones (Milkov and Gvozdetsky, 1976). The areas to the North of the Greater Caucasus axial zone have the features of a temperate climate, the Caucasus has subtropical climate features. But, there are significant climatic differences within these areas. The annual amount of precipitation with the rise in the mountains increases at all levels, significantly decreases from West to East and eventually decreases in high zones.

RESULTS AND DISCUSSION

The mountains are exposed to intensive mechanical denudation, the part of the products of which referred to as "local" is redeposited in a variety of sediments and not be imposed beyond the mountainous area and the other part of the sediment the "transit" one is removed beyond mountainous area by the rivers (rarely by glaciers, mudslides and wind) and directly depends on the intensity of denudation in the mountainous area. According to it one may judge about the volume of material making up mountains and denudation reduction of their average height (Mozzherin and Sharifullin, 2014).

The assessment of a factor impact may be controlled by dispersion, regression and correlation analysis, the essence of which is to test the hypothesis about the importance of these factors influence on the studied sign for dispersion and regression analysis and the fact that the change in one trait is usually accompanied by certain changes in the other if the correlation analysis is used.

Spatially, the main burden of denudation in the Caucasus region (Fig. 1) is imposed on most populated territory folded by limestone and marl territory Southeast of the Greater Caucasus (the basin of the River Kura, near the station Surra). The total demolition at the site makes >10 mm year^{-1}. The Caspian, Kuransky and Colchis lowlands with loose fragmental rocks the accumulation dominates denudation in the Kuban lowland and the total

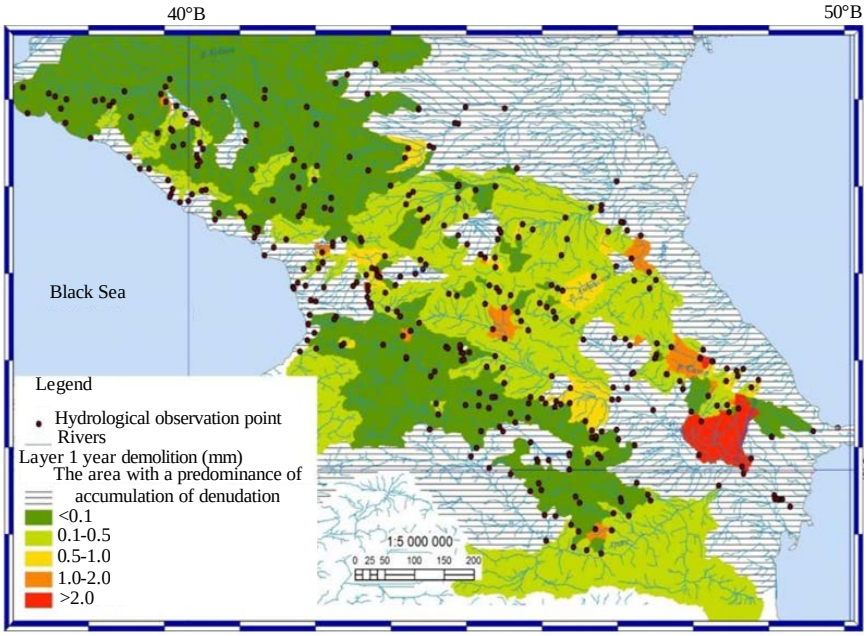

Fig. 1: The value of the annual flushing layer in the Caucasus

demolition of the Stavropol Upland varies on average from 0.1-0.5 mm year^{-1}. Some basins are dominated by the accumulation and in some basins due to the strong anthropogenic influence denudation reaches up to 2 mm year^{-1} (Pshish River). Several areas of the most intense erosion are revealed:

- Within the Greater Caucasus the middle flow of Rioni, Inguri and Landzhanauri River and also the middle flow of the River Kury and Genaldona River
- Within the Lesser Caucasus-Voghchi River and the headwaters of the River Kury where the average annual runoff makes >1 mm year^{-1} (Fig. 1)

There are the parts with the predominance of accumulation over denudation in the Greater and Lesser Caucasus areas (the Inguri River Basins Andean Coysu, the Terek and others). The appearance of such areas is primarily related to the situation of hydrological stations in reservoirs and River Basins abutment to the tectonic faults (Terek River, the headwaters of Rioni, Inguri, Ahindzha and Araks River).

In the Caucasus, the pools, folded with sedimentary rocks are eroded to a greater extent than crystalline ones. Thus in the River Basins on the igneous, metamorphic rocks of the Greater and Lesser Caucasus the flushing

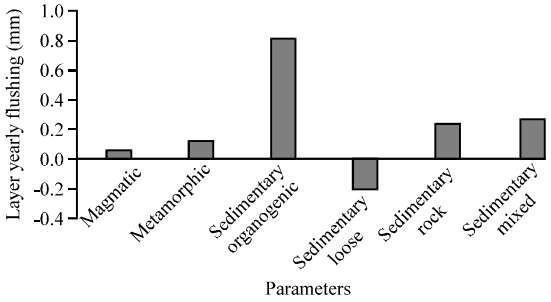

Fig. 2: Changes in the average value of the annual flushing layer depending on lithology

layer does not exceed 0.1-0.2 mm year^{-1} while in the pools composed of limestone the denudation rates make about 1 mm year^{-1} (Fig. 2).

Besides, the areas composed of sedimentary loose rocks (clay, sand, loam) due to small altitudes are exposed to denudation in a lesser extent than mountain areas and these are the areas of mountain degradation products accumulation prevalence. For the mountains of the Greater and the central part of the Lesser Caucasus the decline in the overall rate of denudation is observed with the growth of precipitation layer (Fig. 3). Thus in the Colchis lowland, despite the enormous amount of precipitation (over 1.200 mm), the layer of a year flushing makes no >0.05 mm year^{-1} while for the foothills of the Caucasus Araks lowland, the peripheral

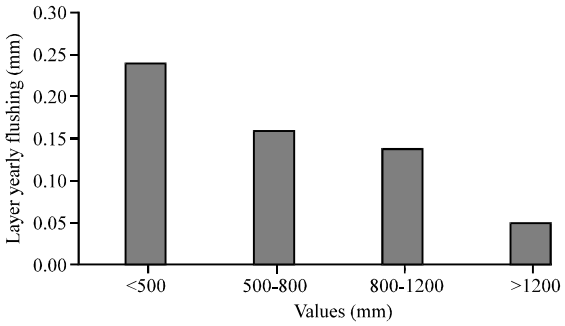

Fig. 3: Changes in the average values of the annual drift layer, depending on the annual precipitation layer

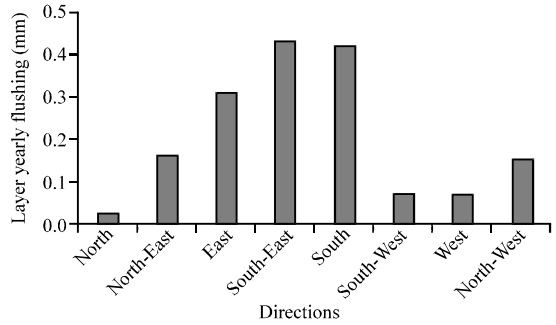

Fig. 4: The distribution of the annual flush layer mean values on the slopes of different exposures

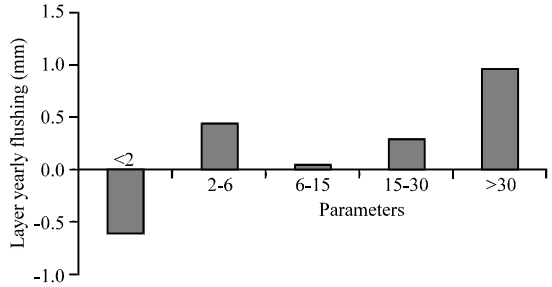

Fig. 5: Changes in the average values of the annual demolition on the slopes of varying steepness

part of the Lesser Caucasus where the rainfall amount is <500 mm year^{-1} is characterized by higher values of denudation due to the high economic development of the territory and the presence of easily eroded rocks.

The development of denudation processes is also influenced by the exposure and the steepness of slopes. In the Caucasus, the greatest value of demolition accounts for the Southern, South-Eastern and steep slopes (Fig. 4 and 5) with a significant heat flow during the day, the smallest value of demolition is in the north and gentle slopes. On the plains, as mentioned above, the bottoms of river valleys are dominated by the processes of sediment accumulation.

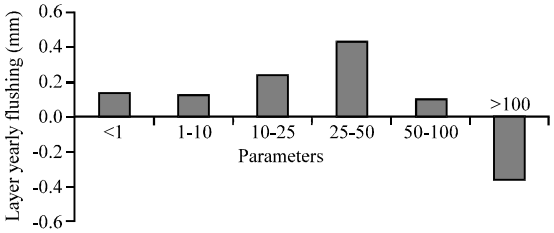

Fig. 6: Change in the average values of the annual drift layer, depending on the population density

The most densely populated (>100 people km^{-2}) plains of the Caucasus region are the areas of demolition material to a lesser extent and vice versa, in the foothills and the plains along the river valleys the processes of mountain demolition products accumulation prevail.

The rest of the territory with the population density increase from <1-50 men km^{-2} the value of the annual layer of flushing also increases, due to increased load on the slope soils as the growth of areas for plowing and pasture areas which stimulates the slope flushing processes (Fig. 6).

Table 1 shows the results of dispersion and regression analysis, measured by the value ratio. Thus in the midlands and highlands of the Caucasus region there is a significant influence of lithology, temperature variations, deviations (Table 1). The impact of relief height is high in the foothills, temperature variations and forest coverage of the lowlands is highly influenced by economic development. The intensity of denudation is influenced by the reduction of forest coverage area from the foothills to the high mountains. High in the mountains the sharp differences of diurnal temperatures and the presence of snow before summer contribute to intense frost weathering, especially in the periglacial zone (Table 1).

The influence of soil type on the denudation rates throughout the Caucasus region was not essentially manifested within this scale of research.

Table 2 shows the correlation analysis results for different altitudinal zones of the Caucasus region, indicating the lack of a strong connection between the rates of denudation and the factors influencing these rates. However in the lowlands, hills and highlands a year-long drift layer is moderately and poorly correlated with the height of a watershed, slope steepness, temperature variations, rainfall amount, snow cover and forest coverage.

The main denudation load (>1 mm year^{-1}) is observed at the altitudes >500 m (Table 3). There is an unload of river flows on the plains, carrying the sediments from

Table 1: Dependence of various factors influence on the denudation rate in the Caucasus Mountains

Factors	Foothills up to 500 m	Low mountains 500-1000 m	Average mountains 1000-2000 m	High mountains, >2000 m
Height above sea level	0.02	0.70	0.93	0.11
Lithology	0.22	0.07	0.01	0.00
Precipitation layer	0.06	0.31	0.18	0.02
Number of days when the temperature is not 0°C	0.05	0.46	0.01	0.00
Slope angle	0.20	0.66	0.00	0.00
Snow cover	0.41	0.18	0.67	0.00
Forest coverage	0.03	0.28	0.40	0.01
Slope exposition	0.69	0.18	0.34	0.06
Soil type	0.17	0.37	0.27	0.13
Mechanical content of soil	0.07	0.16	0.55	0.15
Population density	0.13	0.03	0.13	0.00

Table 2: Correlation between the layer of annual runoff and factors at different heights

Parameters	Lowland	Highland	Low mountains	Average mountains	High mountains
Average height of a basin	0.53	-0.02	0.11	0.07	0.27
Steepness of slopes	0.10	0.20	0.16	0.17	0.43
Temperature fluctuations	0.38	0.04	-0.02	-0.17	-0.03
Precipitation volume	-0.48	0.31	0.14	-0.13	-0.11
Period of snow layer coverage	0.26	0.10	0.11	-0.19	-0.39
Forest coverage	-0.04	0.27	0.15	-0.18	-0.02
Population density	0.09	-0.03	0.22	-0.04	-0.04

Table 3: Statistical data according to a year runoff layer at different altitudes

Values	Plain	Low mountains	Average mountains	High mountains
Average value	-0.2	0.08	0.28	0.19
Minimum value	-9.45	-8.60	0	0
Maximum value	0.58	5.99	7.77	1.74
Standard deviation	1.30	1.62	0.85	0.32
Variation ratio (%)	-500	1800	294	165

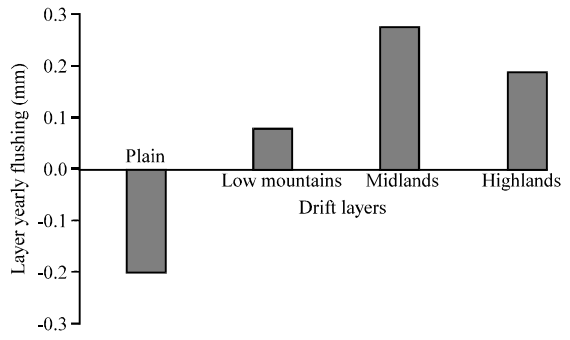

Fig. 7: Average values of annual drift layer at different altitudes

mountain areas (Fig. 7). In middle mountains the annual average value of the flush is higher than in the highlands as the swimming pools located within this high-rise zone are composed of limestone in most cases (Table 3 and Fig. 2). The variation coefficient value by heights shows a clear heterogeneity. The factor of above sea level is dominant only in the highlands (with lithology) whereas in the foothills, lowlands and midlands a number of other factors influences on denudation rates (Table 1). Thus, along the entire studied area lithology makes a strong impact as was mentioned above. In addition to the type of rocks at the altitudes between 200 and 500 m the denudation is influenced by a snow cover at the altitudes above 1,000 m it is influenced by frost weathering, up to 500 m, it is influenced by precipitation and afforestation (Table 1). The strong correlation between the layer of an annual runoff and climatic factors is absent (Table 2) but there is a weak link with the fluctuation in temperature and the duration of snow cover at the altitude of 200 m and with the amount of precipitation and afforestation at the altitudes of 200-500 m as well as a weak feedback with the amount of precipitation at the altitudes up to 200 m and the duration of snow cover at the altitudes above 2,000 m. In the Nival Zone the role of an anthropogenic factor is insignificant (Table 1) but in the foothills and lowlands its role may be very significant which is evidenced by the maximum values of denudation at these altitudes (Table 3). Statistical data according to a year runoff layer at different altitudes.

This is due to a high load on pastures adjacent to settlements. The correlation analysis between population density and the layer of the annual demolition shows that on the most part of Caucasus the increase of population density is not accompanied by denudation increase (Table 2). The steepness of a slope in the Caucasus mountains plays a subordinate role at all altitudes except highlands where a moderate influence of this factor is observed. The impact of relief height is significant only on the plains. The influence of a soil type on the denudation intensity at different heights is not strong (Table 1).

Summary: In general, lithology makes profound effect in the Caucasus on the rate of denudation and in combination with other factors (height and amount of precipitation) a slight increase of exposure occurs. The role of other factors is significant only for certain high-altitude zones or separate areas within the Caucasus region. The obtained results may not reflect the full picture of various factors impact, since, first of all, the denudation is influenced by other factors not accounted for in this study for example, earthquakes, vegetation and secondly, a sufficiently small array of data with the averaged values was used during calculations which does not allow to reject the null hypothesis of any factor influence in some cases.

CONCLUSION

The maximum rates of denudation reduction in the Caucasus is observed at mid-mountain sites that are composed of easily washed carbonate rocks, the lowest values a year flush layer are marked on the piedmont plains.

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