Erosion and sediment yield on the Earth

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Abstract The paper is based on suspended sediment yield data from 3763 stations and bed load data from 295 stations. Within plain regions a distinct maximum of erosion and sediment yield occurs in the tropical and subtropical zones. Statistical analysis indicates that the principal factors controlling the zonal distribution of erosion are runoff amount and land cultivation. The latter varies considerably in different natural zones. Topographic and geologic controls on the erosion rates are discussed. For small streams, the influence of zonal factors is less pronounced, and azonal factors (topography, geology) are more important. Taking into consideration all the available data, two principal models of erosion may be suggested: natural and natural-anthropogenic.

INTRODUCTION

Analysis of sediment discharge information affords one of the most objective methods of evaluating the intensity of erosion (Makkaveev, 1955). The sediment discharge of a river is not, however, a precise measure of all erosion occurring within the drainage basin. A considerable portion of load is not transported out of the basin. This portion accumulates on the slopes and valley bottoms. Many researchers have concluded that in plain regions this represents over half of all the products of erosion within the river basin. Nevertheless, the river sediment load is directly related to the erosion rate, including mechanical denudation, over the whole drainage basin area. Therefore, sediment discharge data can be used to estimate the relative rate of erosion and mechanical denudation in different regions and under different conditions.

The present paper reports a global scale analysis of erosion processes, based on data on suspended sediment loads from 3763 stations and bed load from 293 stations. The bed load percentage of the total sediment load varies from 6% in plain regions to 23% in mountain regions, depending on topography and landscape-climatic conditions. For each drainage basin the main characteristics were determined, including drainage basin area, landscape zone, relief type, lithology, specific rate of flow, degree of man-induced change to the landscape and percentage area of forest, arable soils, marshes and lakes. The sediment yield data were assembled from published sources. The data on drainage basin characteristics have been published elsewhere (Dedkov & Mozzherin, 1984). Large and small river catchments were analysed separately, the threshold between then being 5000 km^2.

LANDSCAPE ZONALITY CONTROL

In plains regions, two maxima of erosion and sediment discharge were distinguished. The primary one is the subtropical-tropical maximum, in comparison with which subarctic and temperate belts evidence lower values (Fig. 1). This confirms the conclusion concerning a tropical erosion maximum first advanced by Strakhov (1960). Within the temperate belt, a pronounced maximum occurs in the forest-steppe and broad-leaved forest zones and a minimum in the semidesert zone (Fig. 1). The Langbein-Schumm rule (1958) which proposes an erosion maximum in semidesert areas

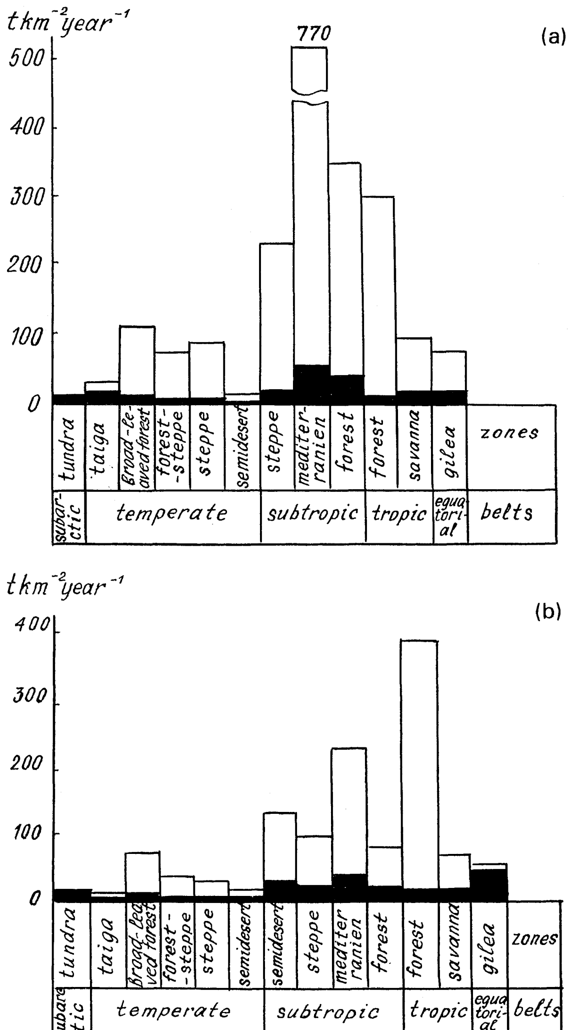

Fig. 1 The suspended sediment yields (t km^{-2} year^{-1}) of different landscape zones and belts of the plain regions of the world. (a) small rivers (basin areas < 5000 km^2); (b) large rivers (basin area 5000-100 000 km^2); ■ natural component (basins of Category I of economic use); □ anthropogenic component of suspended sediment yield.

was based on data from only one region. It is not confirmed by global erosion models, which are based on large data sets of sediment loads (Walling & Kleo, 1979; Dedkov & Mozzherin, 1984; Jansson, 1988; Lvovich *et al.*, 1991).

Statistical analysis reveals that the main factors controlling the zonal distribution of erosion and sediment load are land cultivation and runoff (Fig. 2). For large rivers, correlation coefficients between sediment suspended yield and the above variables are 0.63 and 0.61 respectively.

The anthropogenic factor shows some zonal regularity, due to the fact that different geographical zones differ in their degree of cultivation because of their special environmental features (Fig. 1). Human economic activities result in an increase in suspended sediment load by a factor of 3.5 for large rivers and by a factor of 8 for small rivers. The maximum found in the broad-leaved forest and forest-steppe zones of the temperate belt reflects this anthropogenic influence.

When various large river basins with similar levels of cultivation are compared, a significant influence of stream discharge over the magnitude of erosion and sediment discharge is apparent. The greater the stream discharge value, the more pronounced is the increase in erosion resulting from deforestation and land cultivation. Analysis of suspended load data from drainage basins with the lowest (1) level of cultivation indicates that before the development of agriculture, erosion rates were primarily controlled by the volume and intensity of runoff. The zonal character of erosion is also influenced by soils and weathering products. Within each landscape zone, large sectors which differ in the erosion rate can be identified. The are influenced by various factors, including (climate, stream discharge, degree of cultivation, topography and geology).

In mountain regions, the tropical and subtropical maxima are also pronounced, but the most intense denudation, based on sediment yield evidence, occurs in the glacial zone (Dedkov & Mozzerin, 1992). The zonal pattern of erosion is also controlled by the degree of cultivation and runoff magnitude. Sediment loads in mountain regions increase by factor of 1.4 due to cultivation. In natural landscapes runoff magnitude is of primary

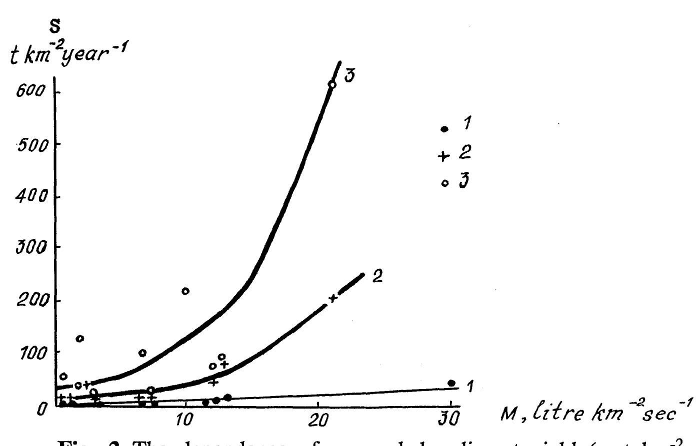

Fig. 2 The dependence of suspended sediment yield (s, t km^{-2} year^{-1}) on runoff (m, l km^{-2} s^{-1}) in plains regions. Categories of economic development: • low (forest > 70%, cultivation < 30%); + medium (forest and cultivation 30-70%); o high (forest < 30%, cultivation > 70%). The relationships are based on mean zonal values for large rivers.

importance in influencing erosion rates, although its influence is not so pronounced in the mountains as compared to the plains. The latter feature may be accounted for by the stronger influence of azonal factors in mountain areas.

The intensity of mechanical denudation increases with altitude and relief and also with proximity to the equator. Both erosion and mechanical denudation are greater within the oceanic sectors than within continental ones.

TOPOGRAPHIC CONTROL

Under natural conditions, sediment yields in mountain areas are 28 times greater than in plain areas. Human–induced acceleration of erosion, which is more pronounced in plain areas) reduces the ratio to 3.2.

In natural landscapes the mechanical erosion rate directly depends on the altitude and relief (Dedkov & Mozzherin, 1992). However, anthropogenic influence distorts the simple relationship. Due to the economic activity of man, primarily through agriculture, erosion is particularly high in elevated areas of the plains and in low mountains. Some mountainous regions are subjected to less erosion and denudation than adjacent cultivated highlands (e.g. the Urals and the right-bank regions of the Volga). Earthquakes play an important role, for they can cause a short-term, but very marked increase in the processes of mechanical denudation and erosion.

ROCK COMPOSITION CONTROL

Taking the Earth as a whole, suspended sediment loads from areas underlain by sedimentary rocks exceed those from areas of crystalline rocks by a factor of 2.4 and from areas of mixed rocks by a factor of 1.4. The ratios are even higher in mountains regions. The most intense erosion is characteristic of loess and loess loams and many of the clays (including weathering crust clays) found in the tropics and subtropics, whereas the weakest erosion is characteristic of igneous and metamorphic rocks, sands, gravels and limestones. The reduced erosion found on these rocks is explained not only by the mechanical properties of the rocks and the soils developed on them, but also by the fact that land underlain by these rocks is usually not extensively cultivated due to the same properties. In contrast, land underlain by loess and clays commonly has fertile soils and is therefore extensively cultivated and strongly eroded. Thus the different degrees of agricultural cultivation of areas underlain by different rocks increases the contrasts in erosion and sediment yield. For the Earth in general, the average degree of cultivation of river basins underlain by crystalline, mixed and sedimentary rocks is 1.5, 1.7 and 2.1, respectively.

The selective nature of erosion is more pronounced in mountain areas than on the plains, especially in the semi–humid subtropics, subarctic and semideserts. Hence, in the above mentioned zones, structurally–controlled relief, caused by differential erosion of rocks of different resistance is particularly common.

GENERAL REGULARITIES

Within all the landscape zones of plain regions and in the forest zones of mountain regions, channel erosion plays an important role in influencing sediment discharge under natural conditions. Erosion over the whole drainage basin area will be weak where vegetation protects the surface from gully and soil erosion. Under such conditions, specific sediment suspended yields increase or remain constant as the basin area increases. According to Makkaveev (1955), river sediment loads are related to water discharge to the second power in plains rivers and to the third power in mountain rivers.

When human activity disturbs the natural vegetation, basin erosion (including soil erosion and gullies) increases markedly. The products of erosion move initially to small streams. While flowing towards larger rivers, part of the load will be deposited. This accounts for the distinct inverse relationship between basin area and specific sediment suspended yield. This pattern resembles the natural situation typical of treeless mountain landscapes, where natural mechanical denudation and erosion are highly pronounced (subnival and semidesert zones).

As a result of anthropogenic increases in basin erosion and increased accumulation in valleys on flood-plains, new deposits of river sediment are formed. Radiocarbon dating and other dating evidence demonstrate that such deposits are synchronous with the agricultural development of these areas.

REFERENCES

Dedkov, A. P. & Mozzherin, V. I. (1984) *Erosia i Stok Nanosov na Zemle* (Erosion and sediment yield on the Earth) (in Russian with an English summary). Izdatelstvo Kazanskogo Universiteta.

Dedkov, A. P. & Mozzherin, V. I. (1992) Erosion and sediment yield in mountain region of the World. In: *Erosion, Debris Flows and Environment in Mountain Regions* (ed. by D. E. Walling, T. R. Davies & B. Hasholt) (Proc. Chengdu Symp., July 1992), 29-36. IAHS Publ. no. 209.

Jansson, M. B. (1988) A global survey of sediment yield. *Geogr. Ann.* **70**, Ser. A, 81-98.

Langbein, W. B. & Schumm, S. A. (1958) Yield of sediment in relation to mean annual precipitation. *Trans. AGU* **39**, 1076-1084.

Lvovich, M. I., Karasik, G. Ya, Bratseva, N. L., Medvedeva, G. P. & Meleschko, A. V. (1991) *Sowremennaja Intensivnost Vnutrikontinentalnoj Erosii na Eusche Zemli* (Contemporary intensity of the world and intracontinental erosion). Meshduvedomstv. Geophisich. Comitet pri Prisedeume Akad. Nauk SSSR, Moskva.

Makkaveev, N. I. (1955) *Ruslo Reki i Erosia v ego Basseine* (Channel of the river and erosion in its basin). Izdatelstvo Akad. Nauk SSSR.

Strakhov, N. M. (1960) *Osnowy Teorii Lithogenesa* (The principles of the theory of lithogenesis), vol. 1. Izdatelstvo Akad. Nauk SSSR.

Walling, D. E. & Kleo, A. N. (1979) Sediment yields of rivers in areas of low precipitation: a global view. In: *The Hydrology of Areas of Low Precipitation* (Proc. Canberra Symp., December 1979), 479-493. IAHS Publ. no. 128.