FLOODS AND SOIL EROSION

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Contents

Summary

Water erosion is a part of the complex denudation of the earth's surface. It is a phase in the weathering of rocks by running water, removing eroded material, and accumulating it in a new place. The basic feature of the erosion–transportation–accumulation process is the pronounced spatial and temporal organization in the hierarchy of hydro-geomorphologic systems. The trend toward the dynamic equilibrium between topography, soil, rocks, and hydraulic parameters of surface running water—self-regulation operating under natural laws—are characteristic features of such systems, ranging from a rill network on an elementary slope to the fluvial system of a large river basin. Running water works as a sculptor to transform the earth's surface. Water-formed rills, trenches, gullies, ravines, valleys of small and large rivers, and peculiarly meandering networks of river channels, greatly change and often determine the structure of the earth's landscapes. Rain and meltwater floods, while acting for a comparatively short time, much disturb the normal functioning of hydro-geomorphologic systems at any scale. This kind of erosion and the amount of transported loose material are greater by orders of magnitude than the erosion done by water flows at moderate or low flows. This is why the annual sediment load of most rivers predominantly occurs over a short period, such as two to three months, or even ten to twenty days. The high irregularity of run-off with time has an influence on the temporal variation of erosion intensity. This can be considered irregularly pulsative. It manifests itself in all temporal scales, ranging from an erosion event caused by a single rainstorm to seasonal, yearly, or geological timescales.

1. Introduction

The earth's surface where human beings live is an arena of two antagonistic groups of forces whose interaction mostly determines the appearance of our planet. The energy of the processes within the Earth causes uplifting of the earth's crust, formation of ranges, volcanic cones and plateaus, and deformation of the earth's surface during earthquakes in many areas of the world. The processes within the earth, which are called endogenous, constantly tend to maintain and enhance topographic contrasts on the earth's surface. On the other hand, the solar energy and gravitation drive continuous mechanical and chemical weathering of rocks and leveling the earth's surface in a futile attempt to attain equilibrium. These processes, called exogenous, break down rocks, transport them by water or moving ice, accumulate rocky material at lower elevations, transport fine particles by air, wear away and build up the shores of seas, oceans and other large water bodies.

While the two groups of processes are permanently in conflict, the domination of exogenous processes results in gradual reduction of absolute and relative heights of terrain, and general leveling the land. The exogenous processes are able to change mountains into rolling lowland—a peneplain. On the other hand, in wet areas with intensive uplifting and high carrying capacity of running water, highly dissected topography with contrasting relative heights is created. All processes of breaking down and washing out of bedrock, and removal of loose material to lower places, are called denudation (from the Latin *denudatio*). The main driving force of most denudational processes is gravity, which manifests itself directly (e.g. by rockfall and landslides in mountains) or through the movement of other media (water, ice, air). The driving process of denudation is water erosion, which greatly transforms the earth's surface.

2. Water Erosion

Water running over the land surface breaks rocks down, carries away loose material, and transports it downstream. At lower levels, where the carrying capacity of streams is reduced or where a stream flows into a lake or the ocean, loose material deposits or re-deposits. Every year streams carry about 17.0 billion tons of eroded material from the land to the oceans, seas, or large deep lakes. Rivers and groundwater that directly discharge into the oceans carry about 3.5 billion tons more. Other denudational processes, such as wind and glaciers, in total carry only about 3 billion tons from the land to the oceans. Rivers are of particular importance in the drainage network. These long-lived flows of water cross the greater parts of the continents. As they run, they cut into the earth's surface, creating valleys, and transporting a large amount of eroded material from the drainage basin. By deepening valleys they enhance topographic contrasts, making slopes steeper and thereby stimulating erosion on the slopes.

Water erosion is controlled by many physiographic, geologic, climatic, and other factors, such as topography, types and distribution of soils, vegetation cover, lithology, land use, etc. However, the intensity, duration, and ultimate effects of erosion are determined by the organization and energy of running water. Depending on these factors, all streams of the land can be classified into three basic hierarchically interacting groups:

- Overland or sheet flows of snowmelt or rainwater, running over slopes and removing topsoil
- Ephemeral streams, running in gullies and removing soil
- Perennial rivers, flowing in definite channels, sometimes deeply cut into bedrock.

Overland or sheet flows are formed on slopes while water runs as a film, combined with water streams flowing in small channels. Running water carries away small particles of loose material, detaching them from soil aggregates and the packed upper layer of the soil.

If soil is bare or covered by sparse vegetation, raindrops facilitate the removal of mineral soil particles by run-off waters. While falling onto wet soil, a raindrop is reflected from it as a crown-like splash. Soil particles trapped by the splash are spattered from the place of the raindrop's landing. Soil particles are spattered downhill further than they are uphill. This difference is nearly threefold on a 10% slope.

Rainsplash or splash erosion prevails if soil-infiltrating capacity is high, being unfavorable for overland flow. The most intensive erosion occurs when thin sheet flow combines with falling raindrops. The depth of overland flow has to be less than approximately three raindrop diameters.

The arena of erosion caused by overland flow is a whole slope. The eroded material moves down the slope.

Gullies can form in the middle or lower parts of a slope if the topography favors the concentration of overland flow and small streams. Their formation is preceded by the appearance of small depressions, rills, and trenches, which expand and join together while eroding. A gully is a comparatively deep and narrow channel typically eroded by ephemeral streams or sometimes small perennial streams. Steep or even almost vertical slopes, V- or U-shaped cross-sections, and high branching are characteristic of gullies. They range from hundreds of meters to several kilometers long, and from several meters to some tens of meters wide, and are typically several meters deep.

Water-erosional landforms vary greatly. Thus slope rills are only a few centimeters deep and wide, while large river valleys reach well into the tens of meters deep and are several hundreds of meters wide (Figure 1).

Water-erosional landforms are generated under different conditions as a result of different driving processes. These are the criteria for the classification of spatial hydro-geomorphologic systems, which differ in geomorphologic structure and hydrologic functions (see Table 1). The generic types of water-erosional landforms do not strictly pertain to the appropriate types and hierarchic levels of hydro-geomorphologic systems. Hence typical sizes of water-erosional landforms (see Figure 1) are simply estimated to classify erosional landforms into a generic series.

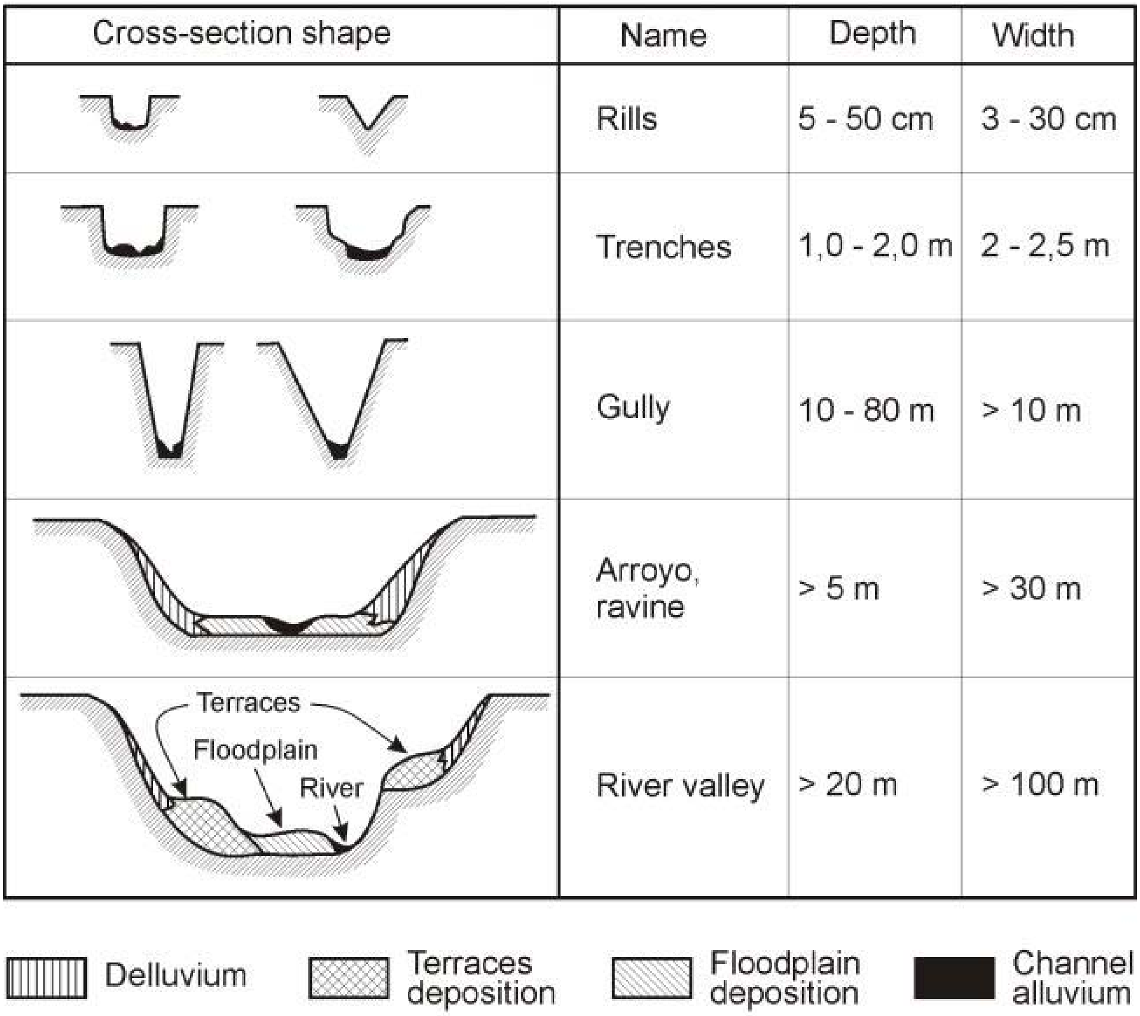

Figure 1. Water-erosional landforms in lowlands

Level	System name	Conditions and driving processes of erosion	Key factors of erosion	Water-erosion forms
I	Slope site	Infiltration, evapotranspiration and inflow from adjacent sites	Weathering rate of parent rocks	Rill, trench
			Soil texture	
			Vegetation type	
II	Slope	Generation of water flow on slope	Slope shape	Trench, gully, ravine
			Change of slope angle along slope	
			Change of water holding capacity of soil and sediment deposit along slope	

III	Unit watershed	Stream flow in channel (temporary or permanent)	Combination of watershed slopes (aspect, area, length, gradient)	Gully, ravine, arroyo, small watershed
			Runoff regime	
			Rate of loose material delivery from slopes	
			Channel deposits	
IV	River watershed	Runoff	Structure of river network	Arroyo, river valley
			Runoff regime	
			Rate of sediment delivery from watershed into river network	

Table 1. Hierarchy of hydro-geomorphologic systems and generic types of water-erosional landforms

3. Watershed Erosion

Water erosion on watershed slopes is a complex process that brings together the impact of raindrops, removal of slope deposits, and transportation of loose material by overland flow. Although the erosion activities of rain and overland flow are convenient to study separately, both these phenomena are closely interacting parts of the integrated process of water erosion. In general, water erosion on slopes is a result of interactions in the atmosphere–vegetation–soil–water system.

The intensity of water erosion naturally depends on two basic factors, i.e., the erodibility of surface deposits and the energy of water flows over the surface. These causes are controlled by a great number of factors, which together determine the readiness of surface deposits to be eroded and the ability of water flows to originate on slopes and to scour and transport loose material. There are very many combinations of these factors, which can induce or hinder erosion. In most settings, erosion in a watershed depends on the formation of overland flow.

3.1. Uniform Slope Site Erosion

Inclination, vegetation and soil within a small slope site can be considered uniform with the accuracy admissible for analyzing erosion. The driving processes of the hydrological cycle of a site are vertical water flows such as atmospheric precipitation, infiltration, and evapotranspiration. A uniform slope site interacts with adjoining sites in a common water flow along the slope.

Under given climatic conditions, the formation of water flow in a uniform slope site depends on the infiltration rate of rainfall and the processes that affect the water-holding capacity of soil. High infiltrating capacity of soil decreases overland flow, and evapotranspiration between rains discharges soil capacity to hold more infiltrated rainwater. A slope site of low infiltration and low soil water-holding capacity is more suitable for the formation of water flow and hence erosion.

The rate of erosion, i.e., the amount of loose material removed from a slope site per unit of time, depends on the site slope, rate of weathering, grain size and petrographic composition of the deposition, and vegetation type, if other conditions are equal.

The role of any factor in erosion is not constant. Moreover, the interaction between the factors of erosion rate is clearly nonlinear. This is generally illustrated in Figure 2.

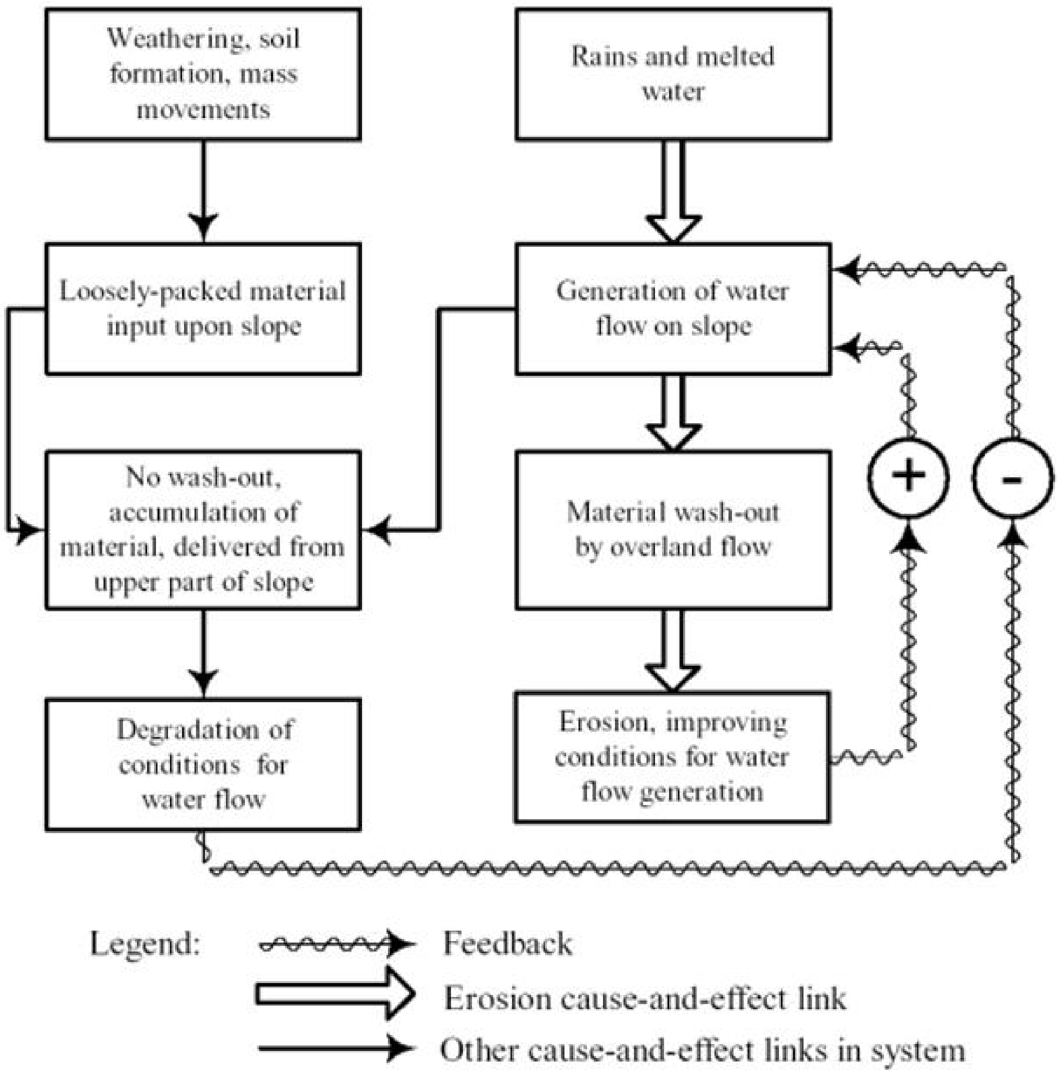

Figure 2. Feedback between overland flow and loose material wash-out in a uniform slope site

Bedrock weathering, soil formation, mass movement, and the input of material with overland flow from upper sites all contribute to the generation of loose material, which is subject to water erosion. Figure 2 shows the situation when the amount of erosion-prone loose material decreases in a given site, i.e., the site is subject to erosion. It results in a reduction of the water-controlling capacity of the soil. This, in turn, intensifies run-off during rain, and increases the amount and energy of water flows. Hence positive feedback forms in the slope site system, reinforcing the input impulse, i.e. in this case the slope water flow.

When the balance of loose material on the slope becomes positive, it accumulates on the slope site. This results in an increase in rainwater held by the soil, and reduction of slope run-off and flow energy. This forms negative feedback in the hydro-geomorphologic system of a slope site (Figure 2), which reduces the erosivity of run-off and hence intensifies the accumulation of loose material.

The preceding only describes the most general relations of water and loose material in a uniform slope site. This pattern in nature is supplemented by the effects of many other factors, which may be short-term, seasonal, annual, or permanent. For instance, the active erosion phase can be changed into the stable phase, or even an accumulation phase, by the seasonal reduction of rainfall or gradual climate change toward aridity. Erosion is heavily controlled by vegetation, which protects topsoil from erosion, and prevents the impact of raindrops and formation of overland flow, and the density of vegetation varies through the seasons.

3.2. Slope Erosion

A slope can be a combination of two or more uniform sites combined by water flow parallel to the earth's surface. The hydro-erosion system of a slope is characterized by changing the inclination and the features of soil.

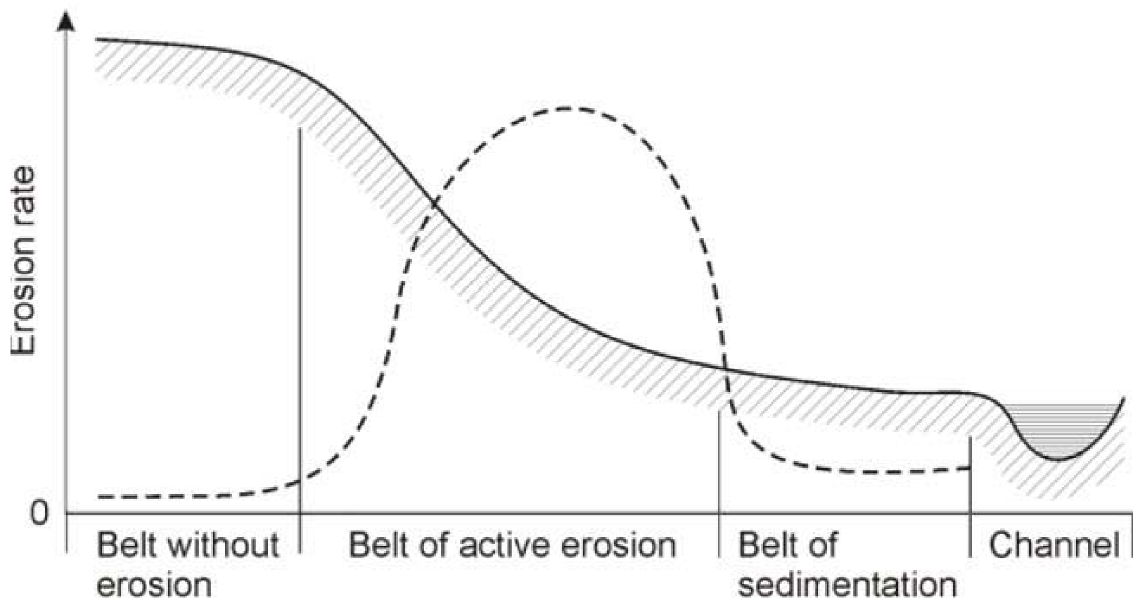

Figure 3. Erosion rate on a typical slope

If we consider a slope as a whole, erosion at any point depends on the ratio between soil erodibility and the energy of water flow. Soil erodibility is controlled by factors, such as soil moisture, clay mineralogy, organic matter, and permeability. Soil erosion resistance is enhanced by vegetation and build-up of compacted organic material. Soil erodibility depends more on the physical features and biological material (roots, soil colloids, organic and mineral aggregates, etc.) of topsoil than the structure of the lower layers of the soil profile. The erosivity of a slope water flow depends on its flow energy, which is proportional to the volume of water and the speed of run-off. These values are controlled by the location of a site on the slope and its inclination. Hence the upper, middle, and lower parts of a typical slope of a watershed are characterized by different erosion rates (Figure 3).

Water erosion is not common in the upper part of a slope because of the low energy of water flow. This is why the upper part of a slope is sometimes called the belt without erosion. The water-holding capacity of soil and loose material depends on chance combination of factors such as parent rocks, their weathering, and soil formation.

The middle part of a slope is characterized by higher propensity to generate powerful water flow, and water erosion and the removal of loose material is most active here. This part of a slope is usually called the belt of active erosion.

The gentler inclination in the lower part of the slope causes accumulation of loose material, coming from the upper parts. The negative feedback of the water–loose material system (see Figure 2) is mostly pronounced there.

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Biographical Sketch

Anatoliy Fedorovitch Mandych was born in November 1936 in Ukraine. His initial professional education in hydrology was received in the Hydrometeorological College in Kharkov (Ukraine, 1951-1955). He graduated in the Geographical Faculty of Moscow State University (1955-1960), and later took a post-graduated course there (1963-1967). His specialty is that of geographer-hydrologist (science degree – Candidate of Science).

His professional experience was obtained through participation in hydrology related research at the Institute of Forest and Timber, Siberian Branch of USSR Academy of Sciences (Krasnoyarsk, 1960-1963), in Moscow State University, Geographical Faculty (1963-1967; 1972), in the USSR Research Institute of Hydrometeorological Information, World Data Center (1967-1972), in the Pacific Institute of Geography, Far Eastern Center of the USSR Academy of Sciences (Vladivostok, 1973-1978), in the Institute of Multidisciplinary Research (Khabarovsk, 1978-1984), and in the Institute of Geography, Russian Academy of Sciences (Moscow, from 1984 to the present). His key qualifications are as a hydrologist and landscape ecologist. His main fields of scientific interest are landscape hydrology, the hydrological cycle on the landscape scale, sediment transport by rivers, water resources and their transformation by human impact.

His current position is Head of the Center for Coastal and Barrier Geographic System Studies in the Institute of Geography. He has published over 80 scientific works and made over 60 presentations at scientific meetings.