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Multipurpose studies of erosion and sedimentation in the Upper Ob basin

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ABSTRACT Information is presented on the methodology, the measurement programmes and some results relating to studies three interrelated processes associated with erosion and sedimentation, i.e. soil erosion by water, sediment discharge and river-bed deformation. The Upper Ob basin is about 216000 km^2 in area and its hydrographic network consists of about 20000 rivers. The basin is located within the Altai area. Requirements for basic information and the methods used to obtain this information are presented. The dynamics of changes in erosion and sedimentation characteristics and the factors controlling these characteristics produced by natural and anthropogenic impacts are examined. Some ideas on modelling strategies are provided.

A river basin is probably one of the most difficult features of the Earth's surface to understand. In fact, the formation of these cells of the land delimited by watershed-divides which provide the source of surface and subsurface flow and sediment discharge to the main stream, is controlled by climatic, meteorologic, tectonic, geologic, geohydrologic, geomorphologic, pedologic, ecologic and other physiographic factors, each of which is characterized by hundreds of parameters. Therefore, it is impossible to create a universal mathematical (design) or physical (experimental) model of all natural events in the basin, which are frequently syngenetic. It is only possible to analyse and describe some partial components of a uniform process with a certain approximation, and these partial components are extremely complicated themselves.

For instance, the models describing runoff formation in a basin (the priority problem in hydrology for several decades) are represented by the simplest schemes and may give only approximate results. Moreover, according to Koren (1991), it is unlikely that the situation will be subject to significant changes in the near future.

Any progress achieved in the understanding of the nature and modelling of erosion and accumulation processes over the river basin is probably much less than the progress archieved by hydrologists in understanding the hydrological cycle. This may be explained by the following reasons:

(a) insufficient coordination between erosion and accumulation processes disturbed by technogenic activity and global exogentic relief-producing processes on the Earth (weathering, transport and accumulation of mineral agents), according to Krivolutsky (1977);
(b) separate consideration and study of the three interrelated components of the erosion-accumulation process in the basin: ie. soil erosion, sediment discharge stream development (Snishchenko, 1988, 1989);
(c) the limited number of stations and periods of standard observations of basin characteristics, in small river basins in particular, and as a result, inadequate basic information for any analysis;
(d) technical and organizational difficulties which are difficult to overcome arising

from observations, measurements or organization of a field experiment, particularly in large basins.

Pragmatism on the part of scientists investigating erosion can provide at least a partial solution to the above problems. One attempt was made at the State Hydrological Institute (Department of channel processes and sediments) in 1986 during a multipurpose investigation of erosion and sedimentation prosesses in the Upper Ob basin (Altai area) in cooperation with the West-Siberia Hydrometeorological Institute (Laboratory of channel processes of the Altai rivers, Barnaul) and Moscow State University (Laboratory of erosion and channel processes).

Some initial results obtained by scientists from the State Hydrological Institute will be discussed below.

RESEARCH OBJECTIVES AND METHODOLOGY

Identification of Research Objectives

The Upper Ob basin was selected for research because of the following considerations.

(a) The research area (261700 km^2 which is 62200 km^2 less than the area of Norway -323900 km^2) occupies a range of different physiographic zones: including mountains up to 4000 m a.s.l.; piedmont zones up to 400 m and steppe zones with different conditions for river and river basin development. At the same time the majority of the rivers form part of the Upper Ob basin (Fig. 1b), and therefore any change in the characteristics of the controlling factors of the subbasins of the tributaries should in general be reflected on the main river. The rivers of the Altai area (more than 20000 rivers in total) are characterized by different types of channel processes (river-bed deformation), while the basins are characterized by various types of erosion.

(b) Anthropogenic impact on constituent basins also differs greatly in the time of occurrence and the rate, according to the type of impact and according to the presence of hydraulic structures. The economy of the Altai area favours further development and cultivation of the basin (ploughing; forest cutting; construction of power generation plants, reservoirs, ponds and protection dams; water diversions; cultivation of floodplains; agrotechnical activity in the basins, etc), and there is consequently a need for multipurpose development and protection of land and water resources.

Methods of Investigation

Although it has been accepted that the division of the single process of erosion and sedimentation into three main components was quite conventional, the vast basin area and the limited resources available to the investigators made it necessary to apply a multipurpose research methodology where the main focus was on remote-sensing methods (satellite survey, air photographs from aircraft and helicopters, air hydrometry and visual surveys from aircraft). In addition, land surveys were made along certain courses as well as detailed observations at permanent and temporary stations. Particular emphasis was given to historical data collection in the basin and to the methodology of the investigation.

A discrete understanding of erosion and sedimentation processes provided the

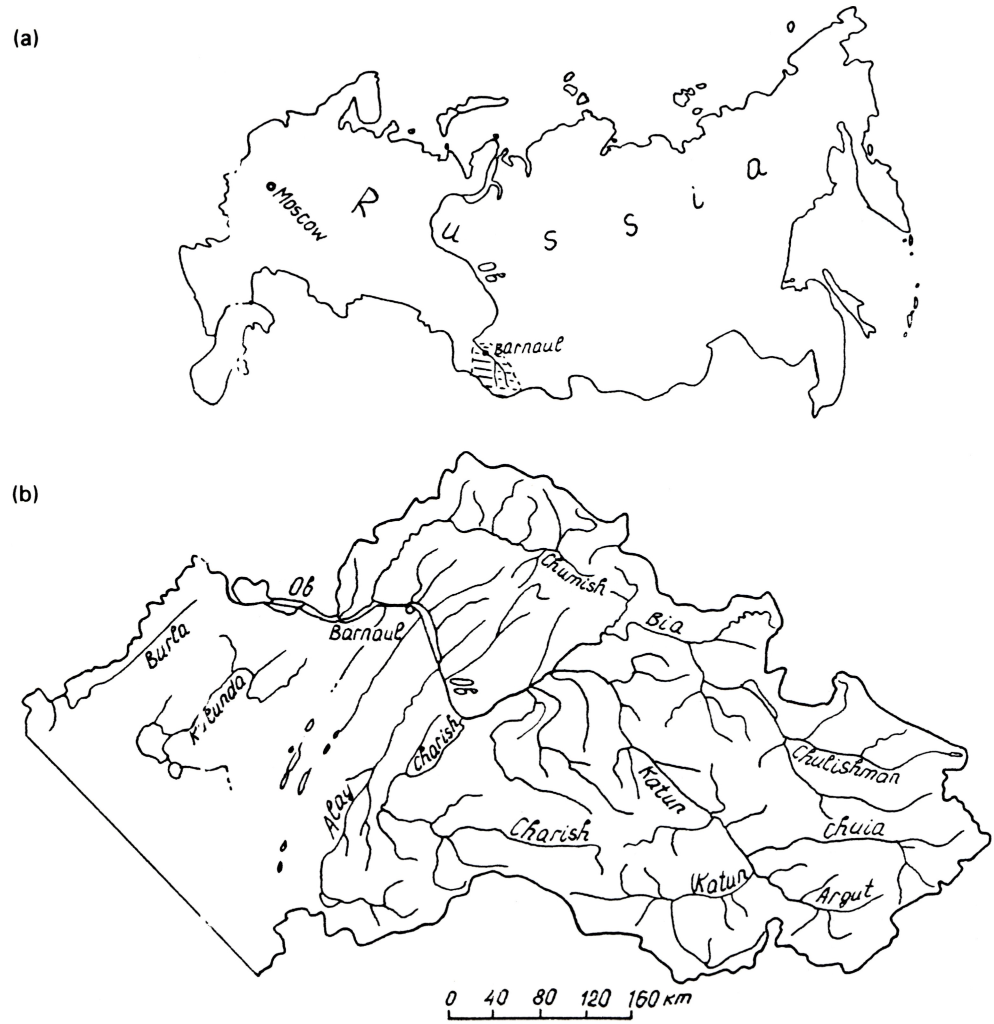

FIG. 1 (a) Location of the Altai area within the territory of Russia; (b) Schematic map of the Upper Ob basin and of the Altai area

methodological basis for the study. The essence of this understanding consists of selecting structural levels for the process and of discovering appropriate factors and laws corresponding to these levels. For example soil erosion is considered at the level of furrows, brooks, or ravines of different orders; sediment transport in rivers and river-bed deformations are considered at the level of individual particles, micro-, meso-, and macro-forms, etc.

A special consideration of these processes for a solution of practical engineering problems by physical and mathematical models was an important part of the applied aspect of the methodology.

The Research Programme

Within the subject area of erosion and sedimentation processes, investigations were made from the viewpoint of the three aspects: i.e. soil erosion within the basins, sediment transport in the erosion network components, as well as in the water courses of the hydrographic network, and channel processes in the rivers of the basin. Characteristic cycles of the processes have been selected within every aspect, as well as characteristic phases within the cycles. Hence, soil erosion characteristics were determined in spring during the period of runoff formation accompanied by selecting of phases associated with snowmelt and the thawing of frozen soils. In addition, the research programme included an assessment of the efficiency of measures taken to protect soils against erosion during different phases of the cycle. Sediment discharge was studied relative to the hydrological cycle and to long-term cycles of variations in water availability. Channel deformation was investigated at various structural levels of the process, relative to the annual hydrological cycle and to long-term cycles of variations in water availability connected with cyclic variations of climate.

Characteristics of the determining factors and indices of the dynamics of the process were used as the measured parameters.

The final part of the programme included an assessment of relationships between soil erosion, sediment discharge and channel deformation, prediction of processes and recommendations for the stabilization or control of these processes, as well as various ideas on future research.

Soil Erosion

To investigate soil erosion, the multipurpose method of Bobrovitskaya (Bobrovitskaya & Zubkova, 1991), developed at the State Hydrological Institute, was applied. This method involves visual observations from air-craft or helicopters, identification of typical areas (or reaches) characteristic of the conditions of development and rate of erosion, land surveys of erosion, land stereo-photogrammetric survey and airborne photo-graphs.

According to the results of airborne visual surveys (total length of the transects exceeded 3000 km), three groups of basins have been selected with various erosion rates and different types of sedimentation and protection measures. Air photographs have been obtained for 250000 ha at the scale of 1:25000. Interpretation of erosion incidence has been based on the available photographs.

During investigation of the selected areas (or reaches) on slopes of variable steepness and length, measurements of the morphological characteristics of the channels of brooks subject to erosion have been undertaken, soil samples have been collected, surveys of brooks and troughs where water flows down has been made, the amount of eroded soil has been evaluated, etc. All the work was undertaken at sites with measures for soil protection, eg. boardless plowing and shelter belts planted along and across the slopes.

The analysis of the information obtained made it possible to establish that soil erosion on the basin slopes of rivers of the Altai area occurred as flat (brook-like) erosion and linear (ravine-like) erosion. If the slope steepness is 1-2° and the slope length is 150-200 m, the erosion rate does not exceed 5 t/ha per year. If slopes are longer, the erosion rate tends to increase up to 20 t/ha and even higher during the period of the snow-melt floods, i.e. it exceeds the values permissible for chernozems (5 t/ha). If shelter belts are planted across the slope longer than 500 m and steeper than 1-2°, erosion from autumn-ploughed lands is up to 18 t/ha, and if shelter belts are planted along the slopes longer than 1-2 km (at the same slope steepness), erosion reaches 70 t/ha per year, i.e. a disastrous erosion rate for chernozems.

Selective erosion of fine clay and silt particles from the soil causes deteroiration of the soil structure. The eroded material is transported to permanent and temporary watercourses, - i.e. from 20% up to 100% of eroded soil during a year, - and this is reflected in the amount of sediment in the rivers.

Suspended Sediment Discharge

Sediment discharge was investigated by Zubkova (Bobrovitskaya & Zubkova, 1991). The analysis of distribution of the long-term characteristics of sediment concentration and the specific discharge of suspended sediment showed a close interrelationship between these characteristics and the erosion rate on the basin slopes.

In river basins where erosion is not intense, specific discharges of suspended sediment vary within the range 0.2-107 t/km^2 per year, and the mean long-term concentration of sediment in the rivers of this zone varies from 10 g/m^3 to 51 g/m^3. In river basins with more intense erosion on the slopes, specific discharges vary within the range 100-200 t/km^2 per year, while the concentration of sediment in the rivers of this zone varies within the range 360-1500 g/m^3. Sediment discharge of the rivers in the first region (not intense erosion) is lower by 4 or 5 times than the sediment discharge in the Upper Ob river, while sediment discharge in the second region (intense erosion) exceeds the solid discharge from the Upper Ob river by 2 or 4 times.

Sediment discharge from basin slopes always exceeds the sediment discharge from small and mid-size rivers, including the Upper Ob basin , by 6-74 times (maximum by 145 times).

Suspended sediment discharge in the rivers of the Altai area is correlated with water availability in the rivers and follows the long-term cycle of water availability.

Channel Processes in Rivers

Channel processes in the Upper Ob river, and in small or medium-size rivers of this basin were investigated by Snishchenko and Snishchenko (1991), while channel processes in small rivers was studied by Bashkov, Kopaliani and Snishchenko (1991).

The investigations undertaken resulted in the analysis of the history of river valley formation; a map was compiled of the types of channel processes (river-bed deformation scheme) in the rivers of the study area; the characteristics of the channel process intensity in these rivers were given; the laws of channel process development in the Upper Ob river were established; the evolution of channel processes in specified Upper Ob river reaches and in other rivers were predicted; the trends of changes in the types of channel processes in rivers were identified under the effect of erosion in the basins of these rivers; certain laws and peculiarities of small river evolution were discovered. Let us discuss some of the results obtained. River valley formation and some river valley components appeared to be closely connected with the phases of Holocene time, characterized by climate variations, as well as by variable humidity and river runoff and by intra-secular fluctuations of these characteristics. The 35-year cycles of dry and wet years, discovered by Shnitnikov (1957), appeared to correspond with the stages of channel deformation in the Upper Ob river, in accordance with the recommendations made at the State Hydrological Institute.

A identification of types of channel deformation (Kondratiev, Popov and Snishchenko, 1982) was made on the basis of satellite images at the scale of 1:200000 as well as on the basis of airborne surveys of greater scale. Eleven types of channel processes have been selected altogether, i.e. just as for the entire territory of Russia. The available information made it possible to establish that zones of sedimentation and zones of sediment transport corresponded to various types of channel processes, alternating along mountain, semi-mountain and plain rivers.

Reaches have been selected with completed or initiated change in the channel process type. This change in the type is explained by change in the factors which determine the channel process: i.e. runoff, sediment discharge or limiting conditions. In addition to the above variations in runoff, any change in the runoff is associated with a redistribution of maximum water discharges during a season due to forest cutting and basin ploughing during the last 200-50 years. Greater maximum water discharges produced an increase of channel widths and river bends. Satellite images and airborne surveys make it possible to assert, that the ratios between the widths of ancient channels (2500-1000 years ago), intermediate channels (1000-200 years ago) and contemporary channels (200-50 years ago) in many rivers of the study basin are as follows: 3.5:1:2. These ratios approximately correspond to water availability fluctuations (D.Snishchenko & B.Snishchenko, 1991).

An implicit connection between changes in the type of channel process and higher discharge of sediments from basins caused by erosion is clearly seen in the rivers flowing in the zones of intense erosion. Free-meandering rivers become straight, the channels of these rivers are filled by sand (middle bars) and become wider (the Aley river case-study). In cases were much sediment comes from the valley slopes and from the basin slopes to the floodplains, the floodplain surfaces become higher and it often happens that the floodplain, as the valley component, no longer exists.

In rivers where part of the flow was diverted (reduced runoff), the morphological components of the channel were reduced, and if the water discharge was reduced greatly, the river produces a new channel leaving the previous channel to be a floodplain (D.Snishchenko, & B.Snishchenko, 1991).

Intense erosion, affected subbasins and the rivers of these subbasins. It also affected the main river in the south of the Altai area (i.e. 1580 m^3/s, and a drainage area of 216000 km^2). Some increase in the width of the main river (up to 15 %) is observed on relatively straight, rectilinear reaches; on curvilinear reaches the length tends to be shorter and the channel tends to be straight, i.e. the downstream river reach about 400 km in length became shorter by about 100 km during the period from 1800 to 1986.

MAIN RESULTS AND FUTURE STUDIES

Multipurpose investigations of erosion and sedimentation in a large river basin influenced by an intense anthropogenic activity have led to definite positive methodological, cognitive, quantitative and practical results. At the same time these investigations show, that much more effort is required, and even international cooperation if possible, to archieve a more profound and comprehensive understanding of the observed processes, their computation and forecasting. We assume, that the Altai area and the Upper Ob basin would satisfy the interests of various research institutions and it could provide a specific experimental area for international cooperation to develop and verify the methodologies of various research schools.

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