Sediment Budget Change in the Fluvial System at the Central Part of the Russian Plain Due to Human Impact

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Introduction

The fluvial system can be defined as a system of continuous flowlines and reservoirs on the surface of the Earth, associated with the erosion, transport and deposition of the sediments. One of the main characteristics of the fluvial system is its sediment budget. There are two main types of the fluvial systems: erosion type, with general positive sign of sediment budget; and sedimentation type, with general negative sign of sediment budget. The fluvial system can change their type and sign of sediment budget in time due to human impact and climatic change.

The main tool to estimate in details the erosion and sedimentation pattern change through the fluvial system is solving of the sediment budget equation for the real river net (Sidorchuk, 1996). The empirical coefficients in this equation have to be calibrated with the contemporary and/or past erosion-sedimentation data. The calibrated equation can be used for reconstruction of the sediment budget in the fluvial systems for climatic and land use conditions in the past, and for prognosis of erosion and sedimentation for different scenarios of future development of climate and human impact.

The case study for Zusha River basin.

The basin of River Zusha (the tributary of the upper Oka River, Fig.1) is situated at the Central Russian Upland with the altitudes in the range of 140-280 m.

The mean temperature of January is -9°C, of July is +19°C . The annual precipitation is 570-580 mm, and about 70% comes as rainfall. The catchment is covered by grey forest soils on the loess substratum. A fluvial system of Zusha River basin consists of: slopes; rills; lozhbina's (an elongate trough); gullies and its fans; balka's (aggradated gully or creek); creeks; small and median sized rivers (with channel and floodplain parts). The erosion takes place at the upper parts of the slopes, and sedimentation occur at the lower parts, with the predominance of erosion in the whole. There are mostly erosion processes in the gullies. The balka and creek valleys are the main places of the sediment deposition. Sedimentation prevails also on the river floodplains. A complicated process of sediment exchange between the bed and flow takes place in the small and medium rivers. The contemporary rate of sheet and rill erosion for agricultural lands was calculated by Belotserkovskiy et al. (1991) with two main Soil Loss models, which were verified for the Russian Plain conditions: State Hydrological Institute Model for estimation of erosion during the spring snow melting; and Universal Soil Loss equation for the period of the rainfall. The calculated soil loss rate varies from 3.0 to 10.0 t/ha per year within the basin. The volume of gully erosion (the volume of gullies more than 50 m long) for the period of intensive agriculture was calculated by Kosov et al. (1989), the mean value is 640 t/ha. The annual precipitation for the central part of the Russian Plain during the last 500 years was reconstructed by Zlatokrilin et al. (1986). The history of land use and crop's rotation was investigated by Krokhalev (1960). The information about changes of the area under cultivation, was taken from the compilation by Tsvetkov (1957) and after year 1914 was obtained directly from the statistical yearbooks. The change of the relative intensity of gully erosion was calculated by the ages of 500 gullies, estimated by the soil profile depth measurements (Kosov et al,1989, Sidorchuk,1995). The structure of the net of main channels (more than 10 km long) and the main morphometrical and hydrological parameters, used in calculations, were derived from Hydrological Survey data.

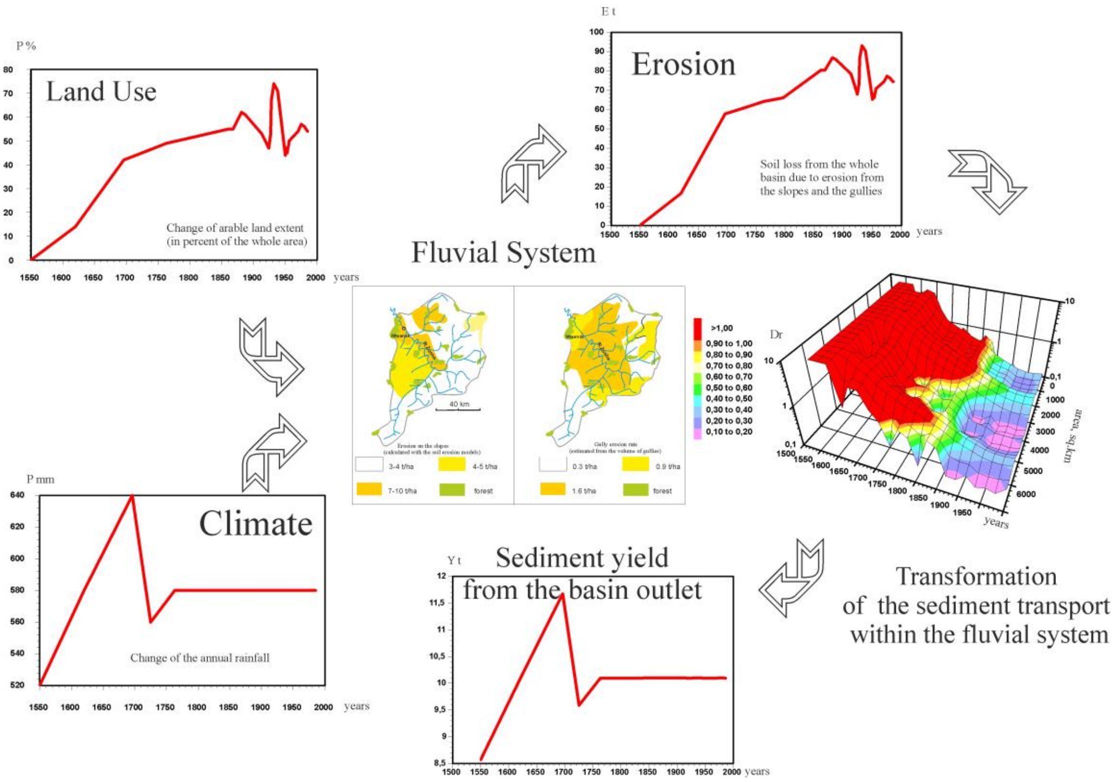

Fig.1 Land use and climate change cause the erosion at the Zusha River channel net, which is transformed to the sediment yield.

Results

Delivery ratio and sediment yield variations at the Zusha River catchment were calculated trough the time and space (fig.1) for the different levels of human impact using the method, described in (Sidorchuk, 1996). At 16th century, in natural condition with a very low level of slope and gully erosion Dr was higher than 1.0 for all the basin (conditions of channel erosion). The sediment yield was equal to transport capacity of the river channel, and it was more than input of the sediments from the slopes and from the gullies. In the conditions of increase of human impact at the beginning of 17th century, when 14 % of the river basin were tilled, the value of Dr became less than 1.0 for the main part of the basin, because the transport capacity of the river flow (highest for the last 500 years due to maximum precipitation) was nevertheless smaller than the input of the sediments from the slopes and from the gullies. This input was not very high, and the rate of sedimentation in the upper reaches of the channel was also not very high in these conditions (about 20-50% of eroded sediments were washed out of the system). In the conditions of high level of human impact in 1930th, when the river basin was tilled on 71 % of its territory, the value of Dr became less than 0.2 for the whole basin. Only 10% of eroded sediments were delivered to the end the system.

Conclusions

The main factor of temporal change of the erosion rate from the slopes was an arable land area variation. The same factor was of the main importance for the gully erosion rate, but rather significant time lag between fallow tillage and formation of mature gullies occur. The level of land protection by vegetation cover varied within the range ±20% and was the second important factor (with the exception of the period of natural vegetation cover in the 16th century, when vegetation cover completely protected the slopes of erosion damage). So the time variability of the whole erosion on the Zusha River basin was rather large and mean annual transport of sediments from slopes and the gullies changed from 0.2 kg/s in 16th century to 70-90 kg/s at the beginning of 20th century to 50-70 kg/s at the end of century.

The precipitation amount varied within the range ±10%, and flow transport capacity and sediment outflow from the fluvial system varied within the same range. The mean annual sediment outflow from the median sized channels in the Zusha River basin was more or less constant during the last 500 years, and varied within 8.6-11.7 kg/s.

The influence of sediment inflow to channels from the river basin on the sediment outflow from the river mouth is extremely low. All the sediments, eroded from the slopes and in the gullies, are accumulated within the fluvial system (mainly, at the upper reaches of the channels), and the sediment yield is controlled mainly by river flow transport capacity.

The fluvial system of the Zusha River, typical for the central part of the Russian Plain, is very sensitive to the level of human impact. The maximum mean annual transport capacity of this system is about 8-12 kg/s. The system was of an erosion type only in natural conditions with dense forest -- steppe vegetation cover and low erosion on the slopes. When the natural vegetation was destroyed by tillage on more than 18-20% of basin area, the sediment flow from the basin become more than flow transport capacity and the system transformed to a sedimentation type. Delivery ratio at the lower cross-section rapidly decreased with arable land area grows from Dr =60% in 17^{th} century to Dr =10-15% in 20^{th} . Dr value increased at the period of lower intensity of agriculture and with increase of precipitation. The transport capacity in the fluvial systems of the Zusha type is regulated mainly by deposition of additional sediment at the upper parts of the fluvial net (in balka's and creeks) and by reduction of the fluvial system whole length.

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