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DEVELOPMENT OF LINEAR EROSION FORMS UNDER THE INFLUENCE OF TECHNOGENIC CONDITIONS

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Abstract

The activation of linear erosion forms in the south of the Irkutsk amphitheatre was stimulated by the construction and exploitation of the Bratsk water-storage reservoir in mid-XX century. In the paper, the characteristics and interaction of natural and technogenic factors influencing the erosion process are described. The construction of reservoir gave rise to new erosion mechanisms such as karst-erosion, aeolian-erosion and abrasion-erosion, which did not occur under the natural (undisturbed) conditions. The large-scale topographic maps were used for evaluation of the spatial distribution of erosion in the shore zone; the active erosion processes were observed in 16 areas of the Bratsk reservoir's shore zone; the overall erosion-affected area of the Bratsk reservoir's shore is 332.9 thousand m².

Key words: *gully, south of the Irkutsk amphitheatre, Bratsk man-made reservoir, erosion mechanisms, interaction.*

Περίληψη

Η ενεργοποίηση των γραμμικών μορφών διάβρωσης στο νότιο τμήμα του Irkutsk προκλήθηκε από την κατασκευή και την εκμετάλλευση της τεχνητής λίμνης του Bratsk κατά τα μέσα του 10ου αιώνα. Στην εργασία αυτή περιγράφονται τα χαρακτηριστικά και η αλληλεπίδραση των φυσικών και τεχνητών παραγόντων που επηρεάζουν τη διαδικασία διάβρωσης. Η κατασκευή του φράγματος προκάλεσε νέους μηχανισμούς διάβρωσης, οι οποίοι δεν εμφανίζονται υπό φυσικές (αδιατάραχτες) συνθήκες, όπως είναι η καρστική, η αιολική και η διάβρωση λόγω τριβής. Μεγάλης κλίμακας τοπογραφικοί χάρτες χρησιμοποιούνται για την αξιολόγηση της χωρικής κατανομής της διάβρωσης στη ζώνη των ακτών; οι ενεργές διαδικασίες διάβρωσης παρατηρήθηκαν σε 16 τομείς της ζώνης των ακτών της τεχνητής λίμνης του Bratsk. Η έκταση της ακτής που επηρεάστηκε από τη διάβρωση είναι 332,9 χιλιάδες m².

Λέξεις κλειδιά *gully, Irkutsk, τεχνητή λίμνη του Bratsk, μηχανισμοί διάβρωσης.*

1. Introduction

The linear erosion is the process of destruction of rocks by concentrated water streams leading to formation of rills, gullies and valleys. The linear erosion induced by temporary water streams is defined as "gully erosion". By conception of S.S. Sobolev (1948), the Russian expert in erosion phenomenon, the gully erosion is caused by the powerful flows of thawing and storm water, entailing the formation of wash-out rills, proof against the ordinary soil cultivation. Here, the "regressive", virtually presenting the incision erosion, and the "lateral" erosion types should be outlined.

In the studied territory, the following types of gully erosion develop:

- The scour channels presenting the initial form of erosion, poorly defined in the relief; it gradually smoothes-out and becomes level with the neighboring areas, generally being directed towards the gully heads and suffosional holes.
- The ravine-valley systems present the peculiar erosion forms of the relief, marked by different stages and morphology of erosion, such as secondary bottom-related gullies, primary gully-branches and small hillslope gullies. The secondary bottom-related gully is the reactivated gully in the bottom of erosion form called "balka" (Kosov *et al.* 1989). The Russian term "balka" means a linear erosion form with graded profile and stable sidewalls.
- The primary gully-branches present the head and lateral forms of valley-ravine system, whose morphology and development are almost similar to those of hillslope gullies, not confined to the valley-ravine systems. The gully forms increment due to the suffosion-subsidence phenomena, intruding in places into the areas of agricultural use and leading to their gradual reduction.

Owing to the intense human activity, the natural and technogenic factors play the increasing role in the development of erosion forms. The development of erosion forms in the studied territory due to the human activity was observed by a number of investigators (Bychkov 1964, Nikiforova and Leshchikov 1980, Nikiforova and Spesivtsev 1980, Ryzhov 1995, and others). The technogenic influence upon the development of erosion manifests itself as the disturbance of surface runoff and subsurface drainage conditions, changes of slopes morphology, as well as worsening of physical properties of soil. The economic activity, particularly in the fields of road building, timber industry, military activity, pasture -farming, irrigation and civil engineering, induce the accelerated erosion process in the context of the irrational land use.

The peculiar type of erosion forms marked by different morphology, size and stages of development, as well as the extents of occurrence and rates of expansion at the initial stage is recorded in the areas of transport communications. The primary scour channels confined to the transport communications are presented by the graded road side ditches and temporary tractor ruts (Litvin 1997).

2. Materials and Methods

The described territory occupies the south of the Irkutsk amphitheatre (south of East Siberia), within the forest-steppe zone of Priangaria (i.e. the Angara region) (Fig.1). The area is primarily forested, the steppe areas occurring as ~ 15 km-wide bands in the left shore of Angara-river, and narrower bands (~ 5 to 5 km) in the terraced valleys of Angara-river tributaries.

The subject of investigation is the technogenic erosion; the erosion-affected territories were outlined by the engineering-geological zoning according to the geologic-morphological conditions and the types of erosion forms. The erosional massif is the territory marked by combination of the relief meso-forms and the complex of loose deposits, determining the type of erosion forms, mechanism of their development and the interaction with other exogenic geological processes, with the definite extent of erosion development.

The estimation of spatial distribution of erosional forms in the shore zone has been made by the analysis of data available, published material on the activation and development of erosion processes, interpretation of the aerial photos, and using the 1:25000 scale topographic maps. The area of gully-affected shore zone was determined with the aid of the AutoCAD 2006 Program.

The comprehensive study of the interaction mechanisms of linear erosion with the suffusion, landslide, karst, abrasion and eolian processes was performed during the field works in the key sites within the period of 2000-2004 years.

The amounts of sediments transported from scours and gullies to the reservoir's shore area of the Rassvet-site were calculated by the I.V. Popov's formula (1951). For this purpose, the measurements were carried out in each gully: width in the upper and bottom areas, depths in several cross sections perpendicular to gully thalweg, as well as the total lengths of gully. Besides, the comparative analysis of air photos made in 1969 (1:7200) and 1980 (1:10000) was used.

3. Results and discussion

The forest-steppe zone of Priangaria is one of the main territories of agricultural importance in the Irkutsk region. The economical development of this region is bound up with the erosion hazard, marked by the wide area of occurrence, uneven distribution and diversity of forms. The areas of agricultural use occupying 40-65 % of the territory (the regions Bokhansky, Nukutsky and Alarsky) are subject to the mean, high and very high extents of impact of water- and wind-induced erosion, reaching in places 40-60 %.

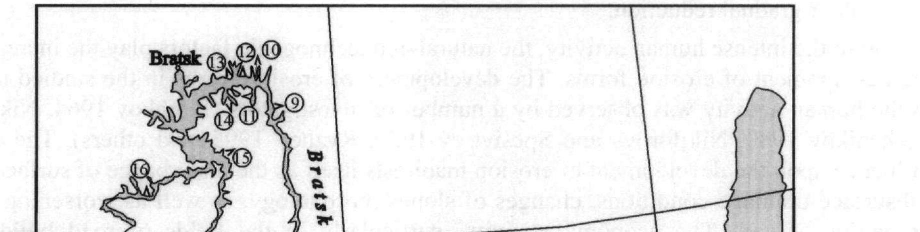

Figure 1 – Map of the studied area in Eastern Siberia, showing of the erosion-affected areas of the Bratsk reservoir's shore zone

a – sites of the erosion – affected areas: 1- Buret; 2- Kamenno-Angarsk; 3- Zakoryukovo; 4- Talkino; 5- Igzhei; 6- Zaslavskoye; 7- Ust-Uda; 8- Balagansk; 9- Shumilovo; 11- Zayarsk; 11- Chama-bay; 12- Kurgan-bay; 13- Suroptsevo;14- Torei-bay; 15- Artumei 16- Tangui; b – key sites of the field works: 17- Rassvet, 18- Khadakhan.

In mid-XX century, the flow of Angara-river became regulated by the cascade of hydro-power stations. The dam of the Bratsk Hydro has formed one of the world largest reservoirs. The construction of the Bratsk reservoir has exerted the complex influence upon the geological environment in surrounding territories, causing the changes in the topography, climate, hydrogeological conditions, properties of rock masses and the activation of gully erosion (Trzhtsinsky *et al.* 1997, 1999). Also, the economic situation in the region changed. About 240 rural settlements were removed from the flowage zone, and 90 thousands hectares (1 hectare = 10 thousands m^2) of formerly forested areas were cultivated as arable land; new motor roads as well as access roads to the resettled villages were built. The natural geosystem responded with the origination of abrasion and activation of landslide, karst-suffosion and erosion processes. The erosion of shores is determined by the factors, described below.

Despite the rise of the base level of erosion, the amount of existing erosion forms increased and new erosion forms appeared. The mouths of erosion forms in terraces and valley slopes got flooded, that reduced the range of erosion-affected area. However, the change of longitudinal profile of gully balance benefited to the activation of vertical erosion.

After the impounding, the gently sloping areas formerly used for agricultural purposes were also flooded. Zoning of the watersheds by the degree of tilting has shown that the amount of the areas of <10 degrees slope decreased from 91 % to 78 %, and the amount of 10-15 degrees slope areas increased from 7 % to 18 % (Trzhtsinsky 1994), due to which the land areas feasible for agricultural use reduced. The economic development of new territories accompanied by deforestation, road building, ploughing-up of slope areas, as well as the expansion of arable and pasture lands has entailed the origination of new erosion forms in the relief.

The subsequent land use (its irrational exploitation for pasture purposes, irrigation etc.) increased the technogenic impacts and caused the activation of existing and origination of new erosion forms. The temporary roads present the initial scour channels; the excessive irrigation of arable lands caused the development of rill erosion, which tends to develop into the gully erosion and ultimately leads to splitting of arable land.

Within the area of in-shore shoals the physical weathering and frost cleft occur, providing the specific conditions for erosional scouring by thawing water.

The determining factor of erosion activation is the variation of reservoir's water level. The reservoir design envisaged the 5 m annual drawdown of the water level (occasionally up to 10 m), with routine level variations up to 3.5-4.0 m (Bratsk reservoir 1963). During the exploitation of Bratsk reservoir, three drawdown cases of maximum 10 m were recorded, followed by the activation of exogenic geological processes.

The most enhancing conditions for the shore erosion can be attributed to the bedrock occurrence below the water level, due to which the Quaternary loose deposits (sand dust, sands, loams, in places loessial with admixture of scree-platy material) are subject to erosion. The length of shores composed of loose deposits is 2277 km (which is 38 % of the overall shore length) (Ovchinnikov *et al.* 1999); these conditions benefit to the active abrasion process and the intense erosion.

In the abrasive shore parts the mechanism of erosion development depends on the reservoir's water level stand. Development of gullies in the shores of Bratsk reservoir in the context of yearly and persistent variations of water level, conforms to the I.A. Pecherkin's scheme advanced for the Kama reservoirs (Pecherkin 1969). During the periods of high water stand, the shoals and shore-abut gully mouths get flooded, that causes the formation of regressive cut in gully bottoms. The erosion activity is observed in the convex parts of the gully's longitudinal profile. At low water stands the linear hollow-out of emerge shoals occurs in secondary abrasion beach scarp. The frost effect and shrinkage cracks serve as scour channels. Due to the erosion forms the shoal surface resembles the "combed" appearance.

The construction of Bratsk reservoir gave rise to formation of new erosion mechanisms not peculiar to the natural (undisturbed) conditions. For example, in the Rassvet-area, the aeolian processes activized after the impounding. The analysis of air photos has shown that high water level in the reservoir is the cause of considerable ruggedness of the beach scarp brows covered by eolian deposits, which induced the origination of primary scours. Comparison of the air photos of 1969 and 1980 shows that 13 gulleis of 2 to 30 meters length and 0.5 to 3.5 meters depth appeared in the 2 km-long shore zone. The erosion and aeolian processes occur in the same spatial structure under the influence of cyclic level variation (the technogenic factor). At the combination of the factors of the gullies strike and the active wind course (natural factors), numerous scour channels and gullies are filled with aeolian material, playing the role of deflation corridors. At the low water regime, the activation of vertical erosion averts the occupation of gullies with sand; 1042.88 m3 of sediments (presenting the material for aeolian process) came on the inshore shoal from the erosion forms (Mazaeva *et al.* 2006); the process is of continuous and cyclic character.

The activation of karst processes after the reservoir filling entailed the formation of numerous karst-erosional gullies; one of the recent forms of this type exists in the north-eastern right shore of the Shaloty-bay, 1.5-2.0 km north-west of the Khadakhan-settlement, right of the Khadakhan-Zakulei road. The origination of karst-erosion forms is caused by the expansion (in depth and width) of sinkholes under the influence of linear erosion. At the first stage, the erosion damages the slopes of large-size karst holes, gathering the runoff water in the holes, which promotes the activation of karst process. In the area of Khadakhan, for example, the erosion scours and rills of 4-8 m length, 0.3-1.5 m width and up to 0.5 m depth originated in the walls of karst holes. In the slopes of large sinkholes the fine scours and rills appear; the subsequent development of erosion leads to origination of larger gullies. Due to the failure and slip-down of material from the sinkhole walls, as well as washout of the convex slope, the active retrogressive head develops, making the funnel elongated and resembling the pattern of erosion forms.

The investigation of erosion forms in shore zones using the large-scale topographic maps (Mazaeva 2005) revealed that the intense erosion is typical of the left shore of the Unga-bay. The combination of long and high convex slopes of 15-30 degrees and the 2-5 m-thick eluvium-deluvium loessial deposits overlying the rocks of Verkholensk Suite of Mid-Upper Cambrian, contributes to the intensive development of slope erosion forms, such as grooves, scours, rills and small-size gullies, as well as high degree (60-90 %) of erosion affection of the area.. For example, the area of the erosion-affected shore zone near the settlement of Talkino is 37.5 thousand m^2.

Within the SE-exposed area of gently sloping shoal in the site of Zaslavsky, the erosional scours of 10-40 cm depth and 10-15 cm width develop from the 0.5-1.1 m-high brow of abrasive scarp composed of light loam; these rarely reach the morphological gully pattern due to the abrasion-accumulative processes. The overall area of the erosion-subject shore zone is 8.7 thousand m^2.

The active erosion forms are recorded near big cities and settlements with developed industrial and agricultural infrastructure; for example, wide occurrence of erosion can be observed in shore zones near the settlements of Igzhey (39.6 thousand m^2), Balagansk (25 thousand m^2) and Ust-Uda (10.35 thousand m^2). In the north area of Bratsk reservoir, the erosion-subject territories are near Zayarsk (65 thousand m^2), Suroptsevo (6.75 thousand m^2) and Artumei (6 thousand m^2). Single gullies exist in the shore zones near settlements of Kamenno-Angarsk (500 m^2), Tangui (750 m^2) and in the left shore of the Kurgan-bay (600 m^2); these are marked by small area of occurrence.

Thus, the active erosion processes were observed in 16 areas of the Bratsk reservoir's shore zone. The width of erosion-affected zone is 20-60 m, increasing up to 150 m near the settlement of Talkino; the total area of erosion-subject territory is 332.9 thousand m^2.

4. Conclusion

Owing to considerable technogenic impacts on the environment and the latter's response, the exogenic geological processes have become the factors of ecological hazard. The processes of erosion belong to those influencing negatively the conditions of human life and activity; these, however, do not present any immediate danger to human life, i.e. having the delayed ecological consequences (Krasilova 1997). In terms of the hazard degree, these belong to the group of permanent (as well as cyclic) development and spasmodic manifestation (Litvin 1999).

All kinds of erosion produce considerable harm to the farming economy, leading to the soil degradation, dividing and reducing the areas of arable and pasture land, as well as damage to buildings, roads and engineering communications. This rises the costs and decreases the efficiency of farm exploitation. The extent of damage depends on the morphology, mechanism and dynamics of erosion development.

Thus, the man-made reservoir presenting the complex natural-technical system is marked by the interaction of natural and technogenic factors. The latter, such as formation of new slopes, accumulation of runoff water in road ditches, damage to the topsoil etc. provide the conditions for natural erosion in the areas not predisposed to erosion in the natural (undisturbed) conditions. Both the technical systems and erosion process interact negatively, producing the detrimental effects upon the geo-ecological situation.

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