10.2478/v10066-012-0042-3

ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN – POLONIA

VOL. LXIX, 1 SECTIO B 2014

* Laboratory of Engineering Geology and Geoecology, Russian Academy of Sciences
Siberian Branch, ** Faculty of Earth Sciences and Spatial Management
Maria Curie-Skłodowska University

OKSANA MAZAEVA*, VADIM PELINEN*, GRZEGORZ JANICKI**

Development of bank gullies on the shore zone of the Bratsk Reservoir (Russia)

Rozwój wąwozów krawędziowych w strefie brzegowej Zbiornika Brackiego (Rosja)

Keywords: exogenic processes, gully erosion, bank gully, Brack Reservoir, Siberia
Słowa kluczowe: procesy egzogeniczne, erozja wąwozowa, wąwozy krawędziowe, Zbiornik Bracki, Syberia

INTRODUCTION

Erosional landforms of the gully type include among others V-shaped dissections in high shores of water bodies or steep slopes of large river valleys in various morphoclimatic zones (Drozdowski 1977; Gawrysiak 1994; Burkard, Kostaschuk 1997; Smolska 2007; Leyland, Darby 2008; Superson, Zagórski 2008; Repelewska-Pękalowa et al. 2013). Such erosional dissections, known as bank gullies, develop as a result of concentrated overland flow caused by intensive precipitation or snowmelt. They are usually ephemeral landforms reaching insignificant sizes in natural conditions. They can exceptionally develop during one event and as a result of increased rate of erosion caused by agricultural activities (Rodzik et. al. 2004, 2011; Rodzik, Terpiłowski 2005). An accelerated development of bank gullies is also observed in the zone of artificial dam reservoirs (Pecherkin 1969; Ovchinnikov et al. 1999). In the area of the Kamsk Reservoir, an increase in the volume of gullies developed in loess-like sediments is 2–3 times higher than shore degradation by abrasion processes (Pecherkin 1969). Gully erosion is also an important source of material deposited in the slope zone and in water bodies (Vandekerckhove et al. 2001; Poesen et al. 2003; Foster et al. 2007).

The high number and various stages of development of bank gullies dissecting the southern shores of the Bratsk Reservoir encouraged undertaking studies on the rate of development and evolution of these landforms (Ovchinnikov et al. 1999; Mazaeva et al. 2006, 2014; Grobelska et al. 2007; Kaczmarek et al. 2012). High seasonal and annual water level fluctuations in dam reservoirs provide conditions for development of the described gully landforms substantially different than those occurring in the zone of marine shores, lakes, or river valleys. The primary objective of the study was the determination of the current conditions and the identification of factors responsible for the development of gullies in the coastal zone of the Bratsk Reservoir. Another task was to prepare the morphological description of the resulting landforms and their classification.

STUDY AREA

In the region of southern Siberia, gully landforms are not concentrated in compact areas, and are particularly related to areas under intensive agricultural use (Ryzhov, Kobylkin 2011). As an exception, in the zone of the mouth of the Unga and Osa Rivers, in the southern part of the Bratsk Reservoir, high density and variety of those erosional forms is observed (Fig. 1). The reservoir's shore area, composed of susceptible to erosion Quaternary unconsolidated (loose) sediments, constitutes 38% of the entire length of the reservoir's shore line, i.e. approx. 2,277 km (Ovchinnikov et al. 1999). Degradation particularly concerns silty sands, locally loess-like silts, and silts with laminae of detrital material, particularly where the bedrock (argillites, aleurolites, marles, and Cambrian sandstones) is located below the groundwater surface level. The occurring moderate continental climate (Dwc following Köppen Climate Classification System) with severe and dry winters and cool summers also favours erosional processes. They are particularly intensive in spring, after the degradation of the snow cover and defrosting of the ground, the seasonal freezing of which reaches a depth of 2.5 m–3.0 m (Leshchikov, Shats 1983). The mean annual air temperature in the cold season varies from -1.1ºC to -3.2ºC, and the number of days with negative temperature exceeds 122 (Hydrometeorological regime, 1978). January is the coldest month, with temperatures from -22.9°C to -26.8°C. Also during short summer, an increase in the rate of erosion processes is observed following downpours.

The area of detailed research is located in the middle part of the Lena-Angara Plateau (600 m–750 m a.s.l.) with denivelations of 150 m –200 m, covered with forest-steppe assemblages (Fig. 1). Erosional dissections and gullies develop in loose fluvial-slope or wash-slope sediments forming slightly inclined abrasive shores of the reservoir. The storage reservoir, second largest in the world in terms of volume (170 km^3), was established in 1967 in the zone of the mouth of the Oka and Iya rivers to the upper Angara river, flowing out of Lake Baikal (Fig. 1). Its management resulted in violent changes in the environment, and activated karst and erosion processes. The elevation of the erosional base line after filling the reservoir radically changed the network of erosional landforms occurring in slopes of the river valleys. The mouth zones of gullies were flooded, and erosion processes were activated on the retreating shore scarp of the reservoir. Catchments of gullies were reduced, and their range was changed. The size reduction and watershed reshaping, the rise of erosion base level were observed. Denivelations were also locally reduced. Moreover, the area was deforested as a result of expansion of the economy, and new infrastructure was established. Water level fluctuations in the reservoir currently amount to 3 m–4 m, and reach up to 10 m in a multi-annual (Ovchinnikov et al. 1999).

The Rassvet study site includes the coastal zone of a bay of the Osa river (Fig. 1). It is located in an inclined accumulative-denudational terrace (2º–8º) composed of alluvial silty and silty-sandy sediments, and fine and medium-grained sands. Numerous aeolian, karst, and erosional landforms occur there (Fig. 1). The largest gullies in the analysed shore section have a length of a dozen metres each, and their depth does not exceed 1.5 m. In the years 1967–1999, the shore of the reservoir in the vicinity of the Rassvet site retreated by approximately from 40 m to 95 m on the average, by a maximum of 130 m (Ovchinnikov et al. 1999).

The laboratory analyses of the composition, structure, and physical and mechanical parameters of the soil showed that the features affect the development of bank gullies (Grobelska et al. 2007; Kaczmarek et al. 2012). It was particularly evidenced that important factors include: the lithological sequence in the vertical profile of unconsolidated silty-sandy (loess-like) sediments covering sandy layers; high content of silty particles in loess-like sediments; the original skeleton-aggregate microstructure of the sediment; sulphate salinity; low physical and chemical activity, and low cohesion, facilitating hydration of the sediment, and causing a decrease in its density and increase in retractility, and then facilitating its deposition. Moreover, interlayered sands are salinated with sulphates, little humid, and loose. In the conditions of high hydration, the soils are unstable and flow naturally already at an inclination of 26.5º–33º. Fig. 2 presents a typical system of layers in the deposit profile, composed of loose silty-sandy sediments and sand layers, subject to seasonal freezing.

STUDY MATERIALS AND METHODS

The field research was conducted along a 2 km section of the shore line of the Bratsk Reservoir in the vicinity of the Rassvet site. The study area includes numerous erosional landforms dissecting the high shore of the reservoir (Fig. 1C).

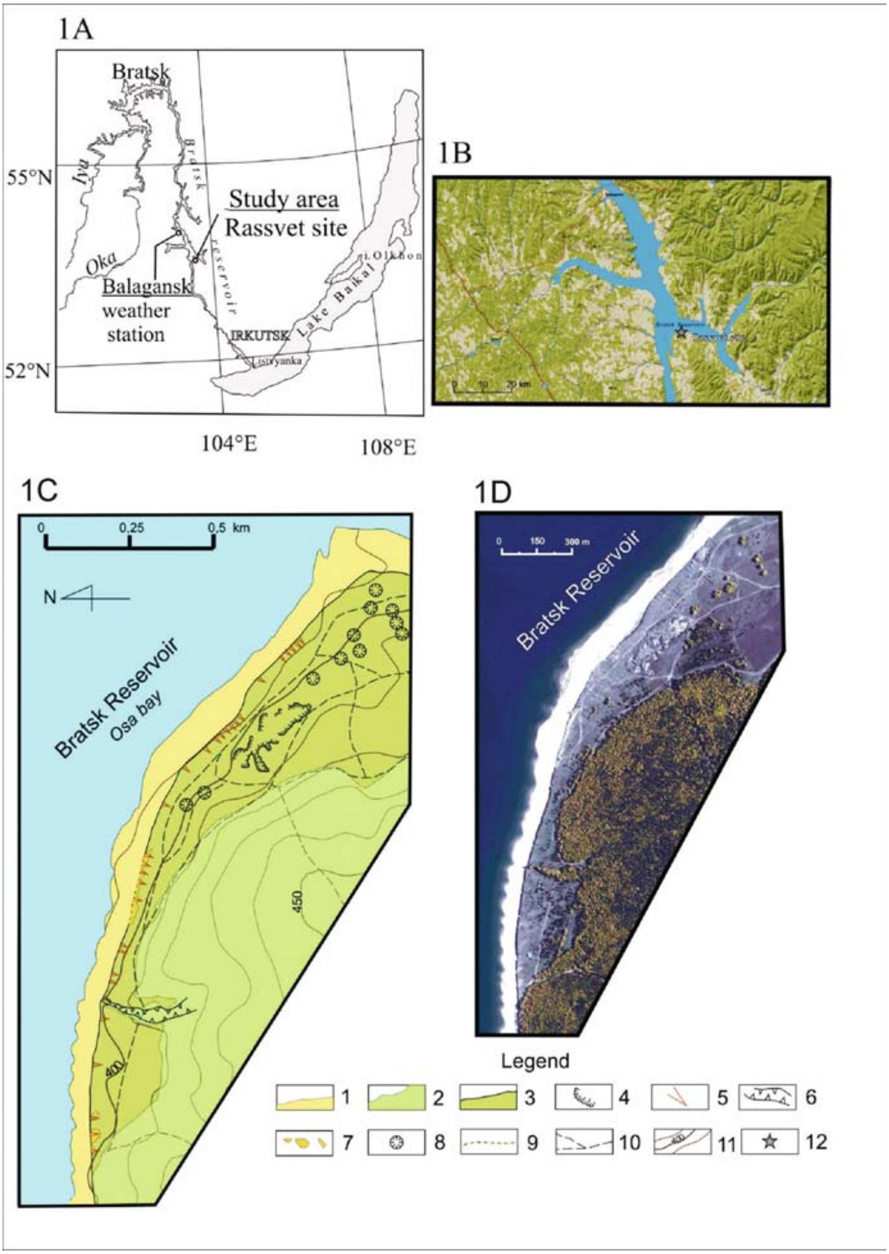

Fig. 1. Location of the Rassvet study site on the map of the Bratsk Reservoir (A) and on the topographic map (B); Geomorphological map of the study site (C): 1 – beach, 2 – forests, 3 – pastures, 4 – quarry boundaries, 5 – gully landforms, 6 – old gullies (in Russian: *bal'ka*), 7– aeolian deposits areas, 8 – karst funnels, 9 – slopes of the reservoir with active aeolian phenomena, 10 – dirt roads, 11 – contour lines with height, 12 – location of the study area; (D) satellite image of the Rassvet site (http://www.bing.com/maps/)

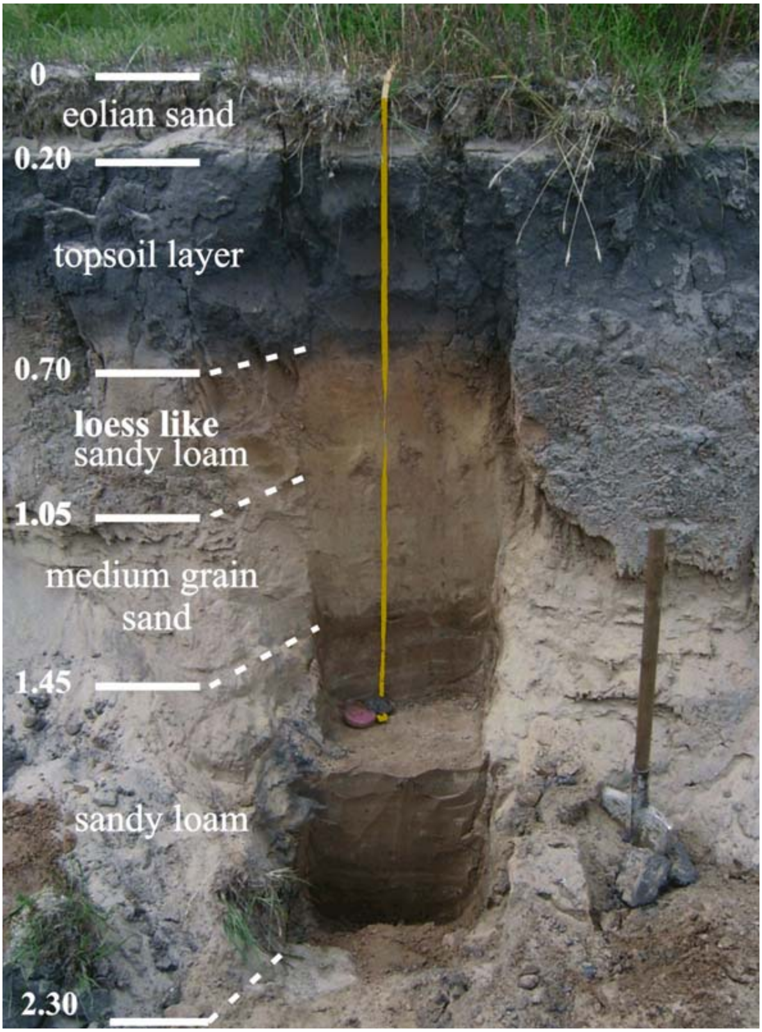

Fig. 2. Exposure of a gully sidewall with the lithological section

Detailed morphometric measurements of the described erosional landforms were conducted in the following years: 2004, 2007–2009, and 2011. The location of the erosional landforms was identified by means of a GPS satellite navigation receiver. The basic spatial dimensions of the gully landforms, such as: width of the bottom of the dissection, width, depth, and length of the gully along its axis, were determined by means of a laser rangefinder (Leica disto A8) with a measurement accuracy of ±1.5 mm along a section of 30 m, and ±1.0 mm along shorter sections. Moreover, cross profiles were developed, and the circumference of the gully was calculated. The following heights were also determined: gully head, and the dissected shore of the reservoir. The volume of each of the gullies was calculated according to the following formula:

$$V_0 = \sum \left(\frac{S_i + S_{i+1}}{2} \times L_{i\text{-}i+1} \right)$$

where:
V_0 – gully volume;
$L_{i\text{-}i+1}$ – distance between two adjacent profiles;
$S_i + S_{i+1}$ – cross-sectional area of the measured i and i+1 profile.

The monitoring of the abrasive shore edge retreat and the range of aeolian covers was performed with the application of a two-phase GPS receiver (Ashtech Z-Xtreme) by the kinematic method. The postprocessing of GPS measurement data was performed in the Ashtech Solution v.27 software with an accuracy of 0.01+1 ppm. In the period from 2006 to 2007, also a series of measurements of the basic morphological elements in the shore zone of the reservoir was performed. The measurements permitted the determination of the rate of retreat of the shore edge, and the boundaries of occurrence of active aeolian fields along the reservoir's shore (Khak et al. 2009; Mazaeva et al. 2014). The lithological analysis of the cover sediments of the study site was conducted in a natural excavation in a sidewall of an erosional dissection with a depth of 1.6–2.3 m (Grobelska et al. 2007).

STUDY RESULTS

Conditions of bank gully erosion

Annual precipitation totals in the period 2004–2011 were varied, and amounted to 350 mm on the average. Lower annual totals (213.9 mm) were recorded in 2011, and the highest (413 mm) in 2006. The highest contribution of rainfall (60%–70%) was recorded in the warm season from May to September (Fig. 3). Daily precipitation totals did not exceed 35 mm–40 mm, and the highest number of days (5) with precipitation ≥ 30 mm/day occurred in 2006. Only in 2006 and 2007, heavy rainfall was observed with the highest precipitation intensity reaching 1 mm–2.12 mm/min. This type of chance rainfalls caused violent overland flow, and activated the processes of soil and gully erosion.

Low temperatures (< -10ºC) occurring in the cold season resulted in deep seasonal freezing of the soils (2.5 m–3.0 m). Snow precipitation occurred from October to April, and its totals reached 45 mm–78 mm/year. The thickness of the snow cover was also varied (from 10 cm to 25 cm), similarly as the content of water

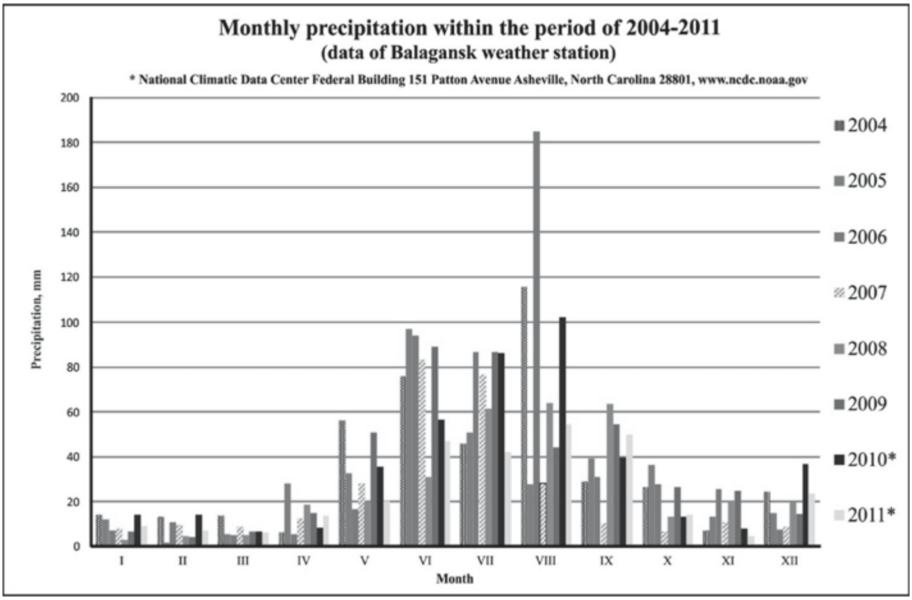

Fig. 3. Monthly precipitation totals in the Balagansk weather station in the period from 2004 to 2011; * data for years 2010 and 2011 from the North Carolina National Climatic Data Center

(39 m–67 mm) before the melt season (March). Snowmelt began in the first decade of April, and usually ended on the 26th–27th day of the month. During that period, the soil surface was devoid of the vegetation cover, because vegetation commenced between 15 and 25 May. Moreover, deep freezing of the soils made the infiltration of precipitation waters impossible, and facilitated the organisation of overland flow. In spring, occasional pronival flows were observed, with their intensity limited by the occurrence of low temperatures by night.

The study period was dominated by W and NW winds. Their velocity and changes in direction determined the wave height and intensity of abrasion, as well as the rate of aeolian processes in the coastal zone of the Bratsk Reservoir. The thickness of current aeolian deposition amounts to 0.2 m–0.4 m (Fig. 2).

The water level in the reservoir in the period 2004–2007 was quite high, and reached a state approximate to normal in August 2006 (Fig. 4). The maximum annual water level in the reservoir was recorded in the autumn season, and minimum in April (Fig. 4). Maximum water level amplitudes (4.5 m–5.0 m) were recorded in the summer–autumn season in 2004 and 2006, and minimum amplitudes (~1 m) in 2007 (Fig. 4).

In the period from July 2007 to June 2008, a continuous decrease in the water level in the reservoir was observed (Fig. 4). In 2007, in the period of active water exchange, the water level was lower by approx. 2.0 m–2.5 m than in the analogi-

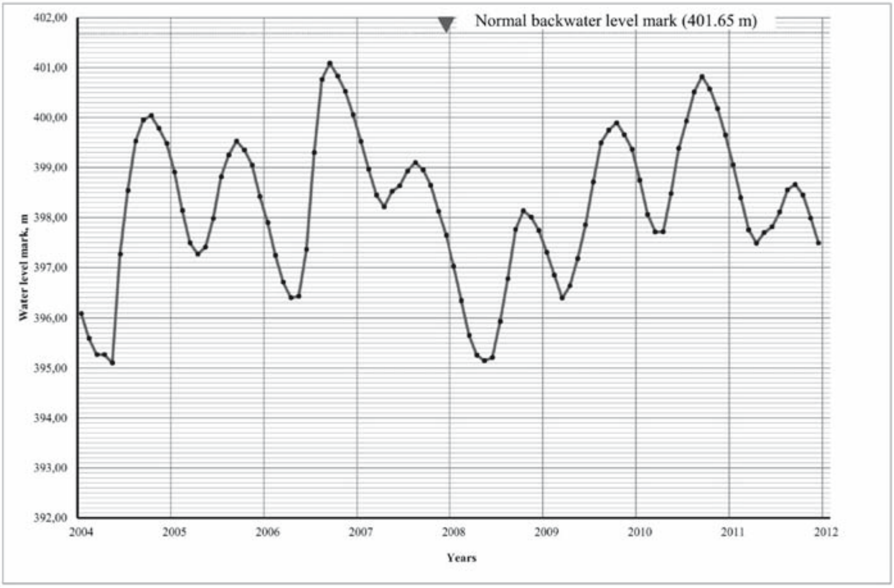

Fig. 4. Mean monthly water levels in the Bratsk Reservoir (data from the Balagansk weather station)

cal period of 2006. The variability of mean monthly water levels in the period 2004–2011 was low (398.5 m–399.0 m). The lowest water levels in the spring-summer season 2008 slightly exceeded 395 m, and were lower than in 2007 by approximately 4 m. From July 2008 to May 2009, an increasing tendency was observed, and mean water levels amounted to approximately 397.5 m (Fig. 4). Changes in the water level in the reservoir affected the dynamics of groundwaters in the backwater zone, and the intensity of geomorphological processes in the coastal zone of the reservoir.

Types of bank gullies

Aerial photographs from 1969 and 1980 show 13 gullies with a length from 2 to 30 m, distributed along a 2 km section of the coastal zone after filling of the reservoir. The research conducted in the period 2004–2009 showed a continuous increase in the number of erosional landforms and their volume, although exceptions also occurred. In the study area in 2004, spatial development of 16 landforms was observed. In 2007, 21 landforms were active, in 2008 already 38, and in 2009, field research confirmed the activity of 47 landforms. The mean depth of the gullies varied from 0.5 m to 3.5 m.

Table 1. Morphological characteristics of bank gully landforms at the Rassvet site (data from 2008).

Geometrical parameters of gully							
Gullies	**Height of abrasive scarp [m]**	**Height of gully head-cut [m]**	**Width [m]**	**Depth [m]**	**Shape idex (mean) [w/d]**	**Length of gully [m]**	**Volume [m³]**
Group 1	4.8÷6.6	1÷1.2	1.9÷9.8	1.3÷4.9	1.1÷4 (2.5)	10÷30	75÷150
Group 2	1.6÷3.7	0.2÷0.4	2.1÷6.8	0.5÷1.9	1.9÷4.2 (3.1)	4÷6	20÷40
Group 3	4	0.4÷0.7	1.9÷8	0.8÷1.8	2.3÷6.4 (4.3)	6÷15	10÷30

The erosional gully landforms which developed after 1969, dissecting the shores of the Bratsk Reservoir at the Rassvet site, can be initially categorised into three groups (Table 1). Group 1 includes large-size active gully landforms, developing in the western part of the active abrasion scarp (Fig. 5). Their long profile is uneven with two deflections, and the mean inclination of the bottom amounts to 0.5 m m^{-1}. They have a V-shaped cross profile, and a shallow and erosional bottom (Fig. 5).

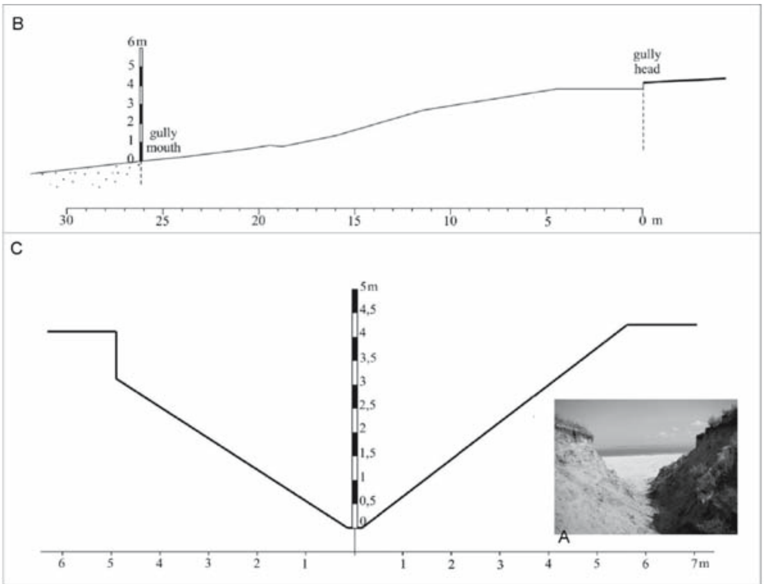

Fig. 5. View of the mouth section of a gully from group 1 (A). Long profile (B) and cross profile through the mouth section (C)

Heavy rainfalls in 2004 and 2006 caused the development of erosional kettles and distribution channels in the bottom of the head of this group of gullies, and alluvial fans (with a radius of approximately 100 m) encroaching on the beach at their mouths. As a result of a downpour (11.8 mm) on 11.06.2007, the described gullies were elongated from approx. 1 m to 8.0 m. The total volume of the removed material, particularly soil, was estimated at a level from 16.6 m^3 to 77 m^3. It was deposited outside the gully causing aggradation of the beach.

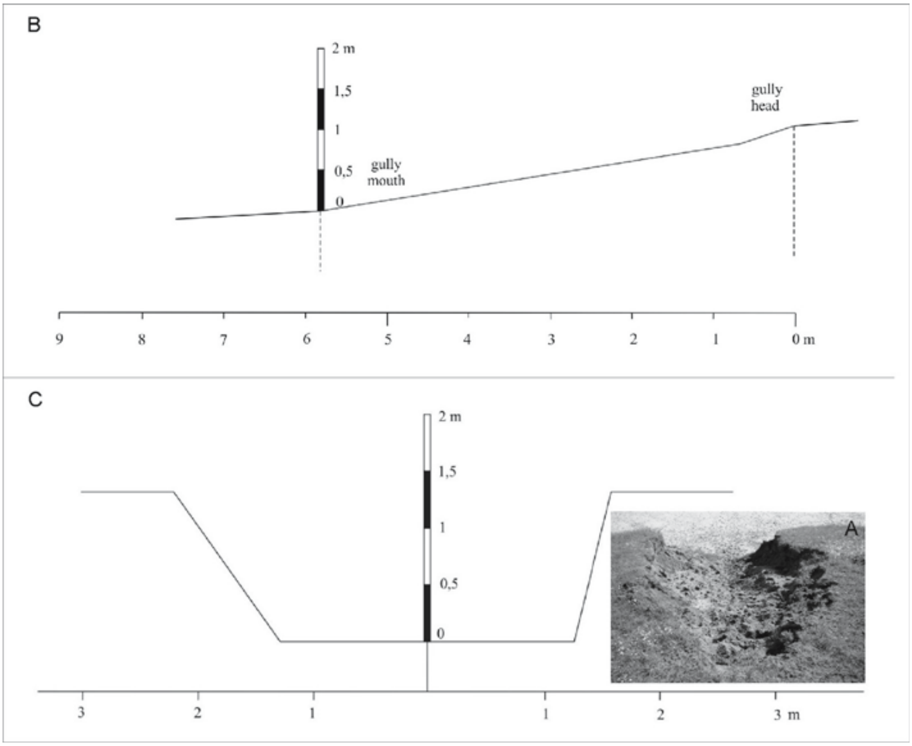

Fig. 6. View of a gully from group 2 (A). Long profile (B) and cross profile through the mouth section (C)

Gullies from group 2 (Table 1) have smaller dimensions and less distinctive boundaries (h = 0.2 m–0.4 m) at the gully head, and lower depths in the mouth zone (Fig. 6). The long profile of those landforms is even, and the mean inclination of the bottom amounts to 0.16 m m^{-1}. Their cross profile resembles the letter U. The bottom is flat, rather wide (> 2 m), and accumulative (Fig. 6). Beach sands are deposited in their bottoms, developing fans with a radius of up to 9 m.

In contrast to group 1, the dissected abrasion scarp is stable, and its height is lower (1.6 m–3.7 m). The scarp in this part of the shore is composed of hydrated alluvial-slope sediments with grass vegetation and bushes stabilising it.

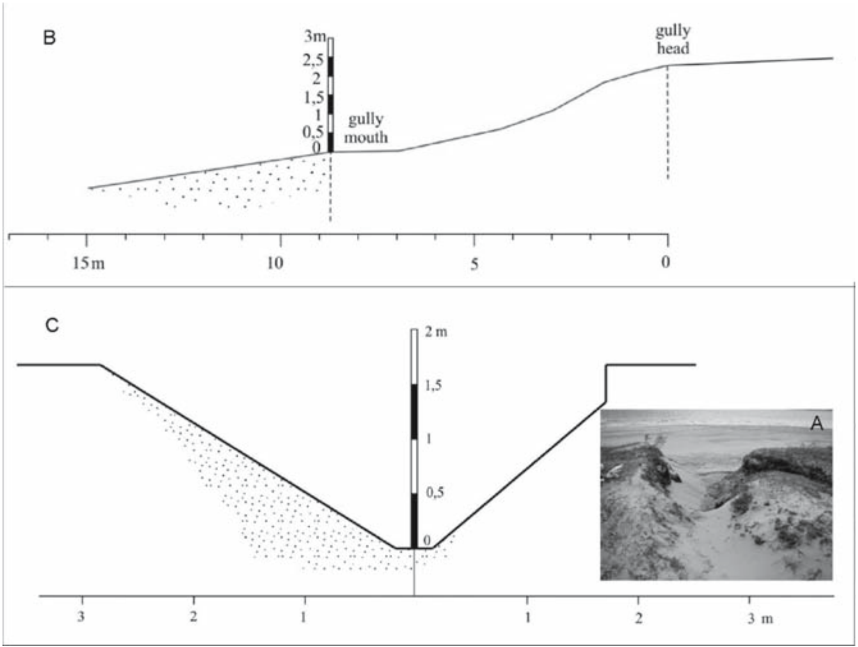

Fig. 7. View of a gully from group 3 (A). Long profile (B) and cross profile through the mouth section (C)

Gullies from group 3 occupy smaller areas within the coastal zone of the reservoir, and are distinguished by active aeolian phenomena. Aeolian sediments are deposited in the zone of the scarps, in the gully bottom, and they reach outside of its boundaries (Fig. 7 and 8). The height of the upper edge of the gullies varies from 0.4 m to 0.7 m (Table 1). The long profile is varied, usually uneven, and the bottom inclination amounts to > 0.2 m/m. The cross profile can be either V-shaped or box-shaped. The recorded downpours caused no changes in the volume of the landforms. The runoff precipitation waters were accumulated in the sandy aeolian deposits and retained in the vegetation cover.

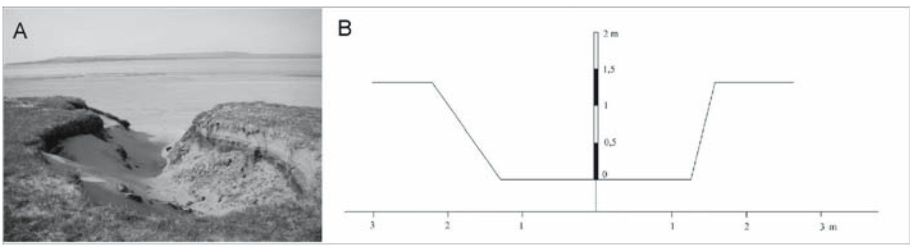

Fig. 8. View on a gully from group 3 (A). Cross profile through the mouth area (B)

Bank gully development model

The initial forms of gully erosion at the Rassvet study site are small dissections or splits resulting from intensive abrasion of the reservoir's shore (Fig. 9). In the autumn season 2006, at high water levels (401.2 m), the occurring processes caused the development of 5 new erosional landforms. Abrasion processes also undercut the mouth zones of well developed bank gullies, and resulted in the occurrence of discontinuities in their long profiles (Fig 10). As a consequence, the hanging of the mouth sections of gullies over the beach is observed, as well as increased supply of slope material to the tidal plain, and therefore its shallowing.

Fig. 9. View of the active scarp shore with initial forms of bank gullies at the Rassvet site (2006, photo by O. Mazaeva)

A decrease in the water level in the reservoir results in an increase in the discharge of infiltrating waters, and activation of piping and subsidence processes. The piping channels and wells, as well as subsidence basins concentrate surface runoff and increase the rate of erosion processes in the coastal zone. The activity of animals (burrows of ground squirrels, cattle trails) also activates erosion processes.

The mechanism of development of erosional forms in the zone of abrasive shore is determined by changes in the water level in the retention reservoir (Fig. 11). The development of bank gullies at the study site confirms the model developed for such landforms by I.A. Pecherkin for the Kamsk Reservoir (Pecherkin

Fig. 10. View from the abrasive shore with the hanging mouth of an old gully (*bal'ka*; photo by O. Mazaeva)

et al. 1969). In periods of high water levels, mouths of bank gullies are flooded. This results in the dissection of the gully bottom and development of regression dissections. Convex sections of the bottom in the long profile of gullies are subject to dissection to the highest degree.

The next stage of development of bank gullies is related to weather conditions, and particularly to the occurrence of summer downpours and spring snowmelts. Intensive propluvial and pronival runoffs further cut the initial erosional forms, and cause their spatial development. The process of the greatest importance is headcut erosion, resulting in the development of the upper deflection, and changes in the long profile. This results in narrow and uneven bottoms and V-shaped cross profiles of the landforms (Fig. 11).

Further development of bank gullies depends on the area of the drained catchment. A small catchment usually restricts the development of gully landforms. This results in smoothing of the edges of gullies, deposition in the bottom, and the development of a U-shaped or box-shaped cross profile. The landforms are modified by subsidence processes and other shallow mass movements. A larger gully catchment sometimes makes it impossible to deepen or dissect the gully bottom, or its spatial development through lateral branches (Fig. 12).

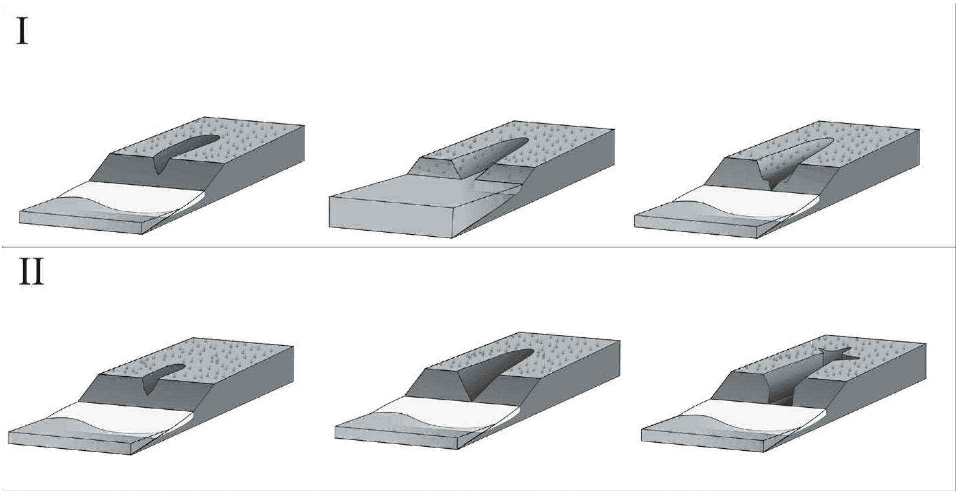

Fig. 11. Model of development of bank gullies: I. secondary gully erosion in inactive gullies after a cycle of shore erosion; II. normal cycle of gully development from a small V-shaped gully to a U-shaped landform or *bal'ka*

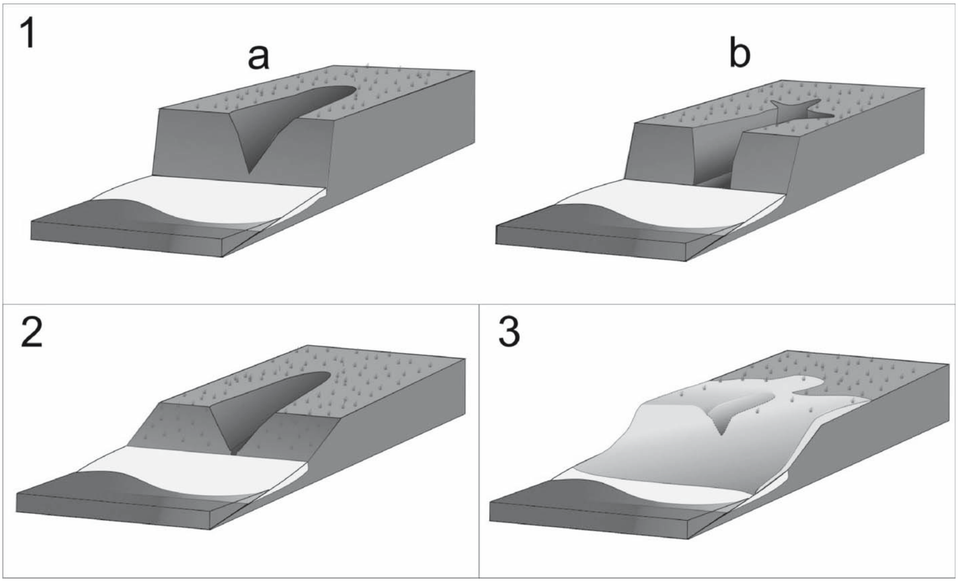

Fig. 12. Bank gully development at the Rassvet site: 1 – V-shaped initial landform (a), secondary dissection of gully bottom (b), 2 – secondary cutting of gully bottom, 3 – gully buried under aeolian deposits

At the final stage of development, bank gullies are inactive or "buried" as a result of aeolian deposition. Gullies are sometimes activated again after a cycle of shore erosion. In such a case, gully bottoms are further cut, and their long and cross profiles become more complex (Fig. 10). Large inactive gullies can be potentially transformed into dry valleys with accumulative bottoms and gentle slopes with grassy vegetation (in Russian: *bal'ka*). Such a gully, presented in Figure 2, is included in maps from before the period of development of the reservoir. The genesis of the landform is more complex, however, because it dissects a shallow valley, and its course suggests that the gully was used as a road (Fig. 1).

DISCUSSION AND CONCLUSIONS

The development of erosional gullies at the Rassvet site is particularly determined by abrasion processes. They cause the degradation of the shore scarp, and lead to an increase in the height, and hanging of the mouth sections of gullies, and discontinuations in their long profile. This results in an increase in the volume of the main erosional forms. In the period 2007–2008, a decrease in the water level in the reservoir activated processes of erosion of infiltration waters, gully bottom dissection, and headcutting. Low water stages also enable an increase in the dynamics of aeolian processes within the shore area, and deposition of sands in the coastal zone and in gully bottoms. The presence of aeolian sediments in the gully head effectively restricted headcut erosion processes during a downpour on 25/26.07.2008.

The initiation and development of erosional landforms in the coastal zone of the retention reservoir shows a seasonal character related to water level fluctuations in the reservoir. The hydrological regime of water level fluctuations becomes the primary factor responsible for the development of the coastal zone of artificial lakes. In the period from 2004 to 2007, intensive precipitation and abrasion resulted in an increase in the volume of erosional landforms at a mean rate estimated for 5.04 m^3 yr^{-1}. In the period from July 2007 to June 2008, the total mass of material removed from the gullies amounted to 627.66 m^3, and the mean rate of their headcutting equalled 16.5 m^3 yr^{-1}. An increase in the number of erosional dissections was also observed as a result of the occurring abrasion and subsidence processes along the active shore scarp in the years 2006–2007.

In the period from 2007 to 2008, the development of new erosional landforms was observed, particularly responsible for the negative balance and transport of material from the slope to the flood area (group 1). A high amount of material was also removed from well-developed erosional landforms (group 2). These results are in accordance with research conducted on Lake Huron (Burkard, Kostaschuk 1997). It should be emphasised, however, that the presence of aeolian sediments in gullies from group 2 and 3 provides different conditions and mechanism of development of erosion (e.g. lithological parameters of eroded sediments). In comparison to bank gullies in the Mediterranean zone (Vanderckhove et al. 2001), the Rassvet site is distinguished by higher dynamics of development of such landforms, although at a degree incomparable to that in the case of gullies developing in the black earth zone in north-eastern China (Hu et al. 2007). In the period from June 2008 to May 2009, numerous gullies were distinguished by low activity. In this period, the removed gully material was estimated for 418.59 m^3, and the mean rate of development of gullies for 16.05 m^3 yr^{-1}.

Bank gullies in the vicinity of the Bratsk Reservoir represent various development stages. Their initial forms are accompanied by mature and old forms. The model of development of such landforms is complex, and depends on a number of factors. The gullies are generally ephemeral and subject to "burying". They are rarely transformed into dry valleys.

REFERENCES

Burkard M.B., Kostaschuk, R.A., 1997: *Patterns and controls of gully growth along the shoreline of Lake Huron*, Earth Surface Processes and Landforms, 22, 901–911.

Drozdowski, E., 1977: *Dynamika inicjalnych faz rozwoju wąwozu,* Przegląd Geograficzny, 49, 67–86.

Foster I.D.L., Poesen J., Boardman J., Keay-Bright J., 2007: *Sediment tracing and environmental history for two small catchments, Karoo Uplands, South Africa*, Geomorphology, 90 (1–2), 126–143.

Gawrysiak L., 1994: *Geological and morphological conditions of erosions forms development in the region of Southern Bellsund (Spitsbergen)*. In: (ed.) M.S. Zalewski*, 60 years of Polish research of Spitsbergen*, XXI Polar Symposium, Warszawa, 93–106.

Grobelska H., Mazaeva O.A., Khak V., 2007: *Uwarunkowania rozwoju dolinek erozyjnych w strefie brzegowej Zbiornika Brackiego (rz. Angara, Rosja)*. In: *Funkcjonowanie geoekosystemow zlewni rzecznych, 4. Procesy ekstremalne w srodowisku geograficznym*: 275–285 (in Polish).

Khak V.A., Mazaeva O.A., Kozyreva E.A., 2009: *Primeneniye tsifrovykh modeley rel'yefa dlya monitoringa ekzogennykh geologicheskikh protsessov*. In: *Sergeyevskiye chteniya, Modelirovaniye pri reshenii geoekologicheskikh zadach*, Materialy godichnoy sessii Nauchnogo soveta RAN po problemach geoekologii, inzenernoy geologii i gidrogeologii (23–24 marca 2009 r.), GIEOS, 11, 140–145.

Hu Gang, Wu Yongqiu, Liu Baoyuan, Yu Zhangtao, You Zhimin, Zhang Yongguang, 2007: *Short-term gully retreat rates over rolling hill areas in black soil of Northeast China*, Catena, 71, 321–329.

Leyland J., Darby S.E., 2008: *An empirical-conceptual gully evolution model for channelled sea cliffs*, Geomorphology, 102, (3–4), 419–434. doi:10.1016/j.geomorph.2008.04.017.

Leshchikov F.N., Shats M.M., 1983: *Merzlye porody juga Srednej Sibiri,* Novosibirsk, Nauka.

Kaczmarek H., Mazaeva O.A., Kozyreva E.A., Khak V.A., 2012: *Stacjonarne badania procesów egzogenicznych w strefie brzegowej Zbiornika Brackiego (południe Syberii Wschodniej*), Landform Analysis, 20, 47–59.

Maruszczak H., 1973: *Erozja wąwozowa we wschodniej części pasa wyżyn południowopolskich*, Zeszyty Problemowe Postępów Nauk Rolniczych, 151, 15–30.

Mazaeva O.A., Khak V.A., Kozyreva E.A., 2014: *Monitoring loka'lnykh beregovyh geosistemow Bratskoe vodohranilise*, Geomorfologija, 75–78.

Mazaeva O.A., Grobelska H., Khak V.A., 2006*: Rozwój dolinek erozyjnych w strefie brzegowej sztucznego zbiornika wodnego (Zbiornik Bracki, Rosja*), Dokumentacja Geograficzna, 32, 195–199.

Ovchinnikov G.I., Pavlov S.Kh., Trzhtsinsky Yu.B., 1999: *Izmienienie geologiceskoj sredy v zonah vliâniâ Angaro-Jenisejskih vodohranilis*, Nauka, Novosibirsk, 1–254.

Pecherkin I.A., 1969: *Geodinamika poberežij Kamskih vodochranilis*. *Geologiceskie procesy*, Perm, 1–308.

Repelewska-Pękalowa J., Pękala K., Zagórski P., Superson J., 2013: *Relief. Permafrost and periglacial processes*. In: (eds.) P. Zagórski, M. Harasimiuk, J. Rodzik, *The Geographical Environment of NW Part of Wedel Jarlsberg Land (Spitsbergen, Svalbard)*, Faculty of Earth Sciences and Spatial Management Maria Curie-Skłodowska University, Lublin, 166–191.

Rodzik J., Górnikowska M., Terpiłowski S., 2004: *Młode rozcięcia erozyjne w rezerwacie „Szwajcaria Podlaska".* In: (eds.) R. Dobrowolski, S. Terpiłowski, *Stan i zmiany środowiska geograficznego wybranych regionów wschodniej Polski*, Maria Curie-Skłodowska University Press, Lublin, 275–280.

Rodzik J., Terpiłowski S., 2005: *Human influence on gully erosion in a sandy side of the Bug River valley (E Poland)*. In: (eds.) W. Zgłobicki, J. Rejman, *Human impact on sensitive geosystems*, Maria Curie-Skłodowska University Press, Lublin, 95–104.

Ryzhov Y.V., Kobylkin D.V., 2011: *Distribution and development of gullies in Southern East Siberia (Russia)*. In: (eds.) G. Janicki, J. Rejman, W. Zgłobicki, *Human impact on gully erosion*, Landform Analysis, 17, 151–155.

Poesen J., Nachtergaele J., Verstraeten G., Valentin C., 2003: *Gully erosion and environmental change: importance and research needs*, Catena, 50, 91–133.

Popov I.V., 1951: *Inziniernaâ geologiâ*, Geolizdat, Moscow, 1–444.

Vandekerckhove L., Poesen J., Oostwoud Wijdenes D., Gyssels G., 2001: *Short-term bank gully retreat rates in Mediterranean environments*, Catena, 44 (2), 133–161.

Smolska E., 2007: *Development of gullies and sediment fans in last-glacial areas on the example of the Suwałki Lakeland (NE Poland*), Catena, 71, 122–131.

Superson J., Zagórski P., 2008: *Uwarunkowania procesów erozyjnych na krawędzi podniesionej terasy morskiej w okolicy Calypsobyen (NW Ziemia Wedela Jarlsberga, Spitsbergen)*. In: *(*eds.) A. Kowalska, A. Latocha, H. Marszałek, J. Pereyma*, Środowisko przyrodnicze obszarów polarnych*, Wrocław, 71–78.

STRESZCZENIE

Na krawędziach morfologicznych, w strefie wysokiego brzegu zbiorników wodnych oraz na stromych zboczach dolin rzecznych w różnych dziedzinach morfoklimatycznych obserwuje się rozwój form erozyjnych zbliżonych pod względem genetycznym i morfologicznym do wąwozów. Niekiedy formy tego typu zaliczane są do wąwozów efemerycznych. Dobrym poligonem badawczym do obserwacji tego typu wąwozów są brzegi Zbiornika Brackiego (Rosja), gdzie doszło do przyspieszenia procesów erozyjnych w wyniku budowy zbiornika. W rejonie Zatoki Osy (południowa część zbiornika) występują sprzyjające warunki do rozwoju tzw. wąwozów krawędziowych. Występują one w różnych stadiach rozwojowych, a ich ewolucja jest złożona i wielokierunkowa, uwarunkowana przez procesy abrazyjne i eoliczne. Finalnie ulegają one degradacji lub subfosylizacji, rzadko rozwijają się w kierunku form dolinnych.