The estimation of the ecologic-geodynamical character of shores of Lake Baikal and the regulated water reservoirs

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The dynamics of exogenic geological processes with their synergetic effects is regarded as one of the criteria for the evaluation of the ecological state of regional geo-systems and the study of territories with respect to the optimum conditions for human life. The existence of man-made reservoirs is the reason of considerable changes in the environment of the territory, which have occurred within a rather short period of time from the standpoint of geological history. The subject of study is the dynamics and intensity of exogenic geological processes (such as aeolian processes, landslide, erosion and karst) in the shores of the Olkhon-island (in the Lake Baikal). Activation of these processes is largely determined by the variations of the reservoir water level. In the dynamics of the studied processes, two cycles should be mentioned: 1) development under natural (undisturbed) conditions and 2) development under technogenic conditions. In general, the extent of occurrence and the dynamics of these processes do not present any substantial natural-technogenic hazard to the human life in the territory of island; in some places of the shore area, however, the disastrous events accompanied by disturbance of the biodiversity can be observed. The landscape of the reservoir influence zones develops dynamically, in conformity with the water level variations, which can reach 10 meters (e.g. in the Bratsk reservoir).

Keywords: exogenic geological processes, man-made reservoirs, geo-ecological estimation, coast landscapes

Introduction

The dynamics, interaction and synergetic effects of exogenic geological processes serve as the criteria for ecological estimation of the local geo-systems. The quantitative indices (intensity of processes, their effects and extent of the occurrence, etc.) characterize the changes within the shore masses and ecologic-geodynamical trends of the development of the territory. The studies of geological environment and the dynamics of exogenic processes reveal the temporal transformation of the geo-system, its modern state (equilibrium or non-stable), to define and correct the most essential factors, which are the cause of the instability in geo-systems and prognosticate their development.

The comprehensive approach to the ecological estimation of the dynamics of exogenic geological processes in the natural and natural-technogenic geo-systems is one of the most important problems faced by the modern natural sciences. The increase of anthropogenic pressure upon the natural environment entailed the substantial changes in the upper area of lithosphere. The anthropogenic load (A) can be expressed by three basic factors such as population (P), demand (D) and technology (T) (Golubev et al., 1996):

\[ A = P \times D \times T \]

In the N. G. Golubev’s opinion, these factors concern both the economical and political categories. Hence, the analysis of exogenic processes and their technogenic analogues comes from particularly scientific sphere to the social-economic and political sphere due to the transformations in the upper area of lithosphere. Indeed, the convenient human life depends primarily on the stability of the regional conditions, without any eventual hazard. The state of any particular geo-system is the result of the combination of inherent potential of the territory (the so-called “factor of safety”) and the degree of technogenic influence. The problems of land use in the coastal areas of both natural and man-made reservoirs require the appropriate policy for the stable development of the territory, i.e. the compromise between the estimated load and the “natural potential” of a definite area.

In terms of the ecological influence upon the biota, all geological processes can be subdivided into two groups such as 1) hazardous, and 2) disastrous. The hazardous processes lead to the discrepancy of the lithosphere state from the optimum conditions of human life (Trofimov, 2005); these cause the loss of the geological space within the regional scale. Due to the indirect development of exogenic processes, the vast territories can be referred to the areas of hazardous or even disastrous events, because the ecological resources of the lithosphere are limited.

At present, the shores of Lake Baikal and the areas of influence of reservoirs of the Angara-Enisei cascade of hydro-electric stations are subject to increasing anthropogenic load (Fig. 1).

The methods of investigation of coast areas of the man-made reservoirs

The evaluation of ecologic-geodynamical conditions in the coastal areas of reservoirs is based on the qualitative and quantitative analysis of the exogenic geological processes, using the interpretation of the aerial photographs of
Brief survey of the geologic-geographical characteristics of the Lake Baikal influence zone and the adjacent areas

The Lake Baikal is the Globe’s unique natural water reservoir located in the central area of Asian mainland. The water area of Baikal is 31.5 thousand km², the total shore length is more than 2000 km; according to these values, the Lake Baikal ranks the world 9th and is world deepest (max. depth in the middle area is 1537 m); the lake holds ~2300 km³ of pure (almost distilled) water, which is about 20% of the world and 50% of Russia’s resources of fresh water; this exceeds the total water content in the USA Great Lakes. Within the area of Lake Baikal there are 22 islands, the area of the largest one (the Olkhon-island) exceeding 700 km² (Atlas..., 1993; Szczypka, 1995).

The geological structure of the territory of Pribaikalska includes the rock formations of different composition and age, such as the largely-dislocated and metamorphosed carbonate and silicate rocks of Archeic and Proterozoic, as well as the platform deposits primarily as narrow as folds of the NE-trend. Among the magmatogenic formations, the occurrence of granite rocks of different composition and structure can be observed in northern and north-eastern shores of Baikal. The edges of the Baikal basin are composed of Quaternary lacustrine, fluvial, proluval and glacial deposits.

The territory of Pribaikalska is located within the Baikal rift zone. The economic and industrial development of the area is impeded by high seismicity, which (according to the data of Selorenko) reaches in places MSK 11 points. In the geodynamical estimation of the local shore slopes the seismic zoning of the territory should be taken into consideration.

The pattern of development of the shore zone was noticeably attributed to variations of the water level caused by the neo-tectonic movement and transgressions, as well as periodic and rhythmic level variations occurred during the glacial and interglacial periods; these level variations were, however, of natural origin. At present, the technogenic factors interfere in the level conditions entailing numerous negative consequences.

Since August 1958, the artificial regime of water level caused by the construction and exploitation of the Irkutsk Hydro exists; the lake’s drainage has become regulated depending on both the climate of the region and the regimes of water spill from the power plant. This has entailed the more than 1.2-meter rise of the water level in the lake, which in 1962 reached the normal backwater mark of the Irkutsk reservoir. In some periods within the recent 200 years the water level reached the maximum top marks.

The rise of water level in Baikal induced the activation of exogenic geological processes, which caused the intense destruction, erosion and landslide, particularly in the south-eastern shore area. The highest degree of destruction was observed in the accumulative forms of the shore relief, such as barrier beaches and bay-mouth bars; many of them entirely disappeared: for example, the bay-bar near Kultuk, as well as the bars, detaching the Chikalovo shor (Babysa Karge islands) and the Froval Bay disappeared within the period 1962-1973. Currently, the intense destruction of the Yaki islands detaching the
Angarsky shor occurs in the northern area of Lake Baikal (Trzhitsinsky, Rzeta, 2004).

The creation of water-storage reservoirs has caused the activation of exogenic geological processes, which in the short time (from the standpoint of geological history) resulted in the substantial change of the natural environment in the region and the neighboring areas (Jagus et al., 2004; Rzeta et al., 2006). Since the mid-20th century, a number of large reservoirs of the Angara cascade of hydro-electric stations exist in East Siberia, such as the Irkutsk reservoir (1956-1962), Bratsk reservoir impounded during 1961-1967, and Ust-Ilimsk reservoir (1976); all of them are permanently regulated. 

The reservoirs are located within the Siberian platform. The peculiar feature of the Angara reservoirs is the relief pattern in the surrounding areas. The erosion is the cause of considerable ruggedness of shores, the total length of the shore line exceeding 8000 km (Ovchinnikov et al., 1999). In addition, the horizontal ruggedness of the relief on the Mid-Siberian plateau, the territory is noticeably cut by deep river valleys, therefore, the existence of high and steep slopes is typical of the area.

The variation of water level in reservoirs is a factor of detrimental influence upon the surrounding conditions. The changes of water regime of reservoirs (amplitude, rates of level variation, etc.) can intensify or impede the coastal processes (Jankowski et al., 2003). In the Bratsk reservoir, for example, the highest water levels are typical mainly of the autumn periods (stormy weather), and the lowest levels can be observed in spring (April). The amplitude of long-term level variations in the Irkutsk reservoir is 4.6 meters; in the Bratsk reservoir it can reach 10 meters.

The exogenic geological processes as the indication of ecologic-geodynamical situation in coastal areas

The Olkhon, the Baikal's largest and oldest island, is the noteworthy subject of investigation of the dynamics of exogenic processes. The aeolian processes are the most remarkable phenomena observed in the Olkhon island; their dynamics is marked by the two-cycle development: 1) prior the impounding of the Irkutsk reservoir and rise of water level, i.e. in natural conditions, and 2) post-impounding, i.e. in the technogenic conditions. Due to the disturbance of natural balance in the coastal zone, the ancient aeolian forms were affected by deflation (Agafonov et al., 2001). In the settlement Khuzhir the sand ingestion caused the removal of a streeet. The sand winnow near Khuzhir was the consequence of the vegetable soil damage. The maximum deflation of sand ridges near the undisturbed forest areas does not exceed 4 cm/year; the sand deflation in the coastal zones reaches in places 12.4-60.00 mm/year (Agafonov et al., 2001). The aeolian forms of different degrees of manifestation cover the large areas in the western coast of the Olkhon-island. The dynamics of modern aeolian processes is of differentiated character depending on the substrate properties and the rates of wind regime (Ovchinnikov et al., 2001).

The western shore of Olkhon-island is affected by the solifluction landslide. The slow plastic flow and regressive development of the seasonally freezing layers lead to origination of the swally-form cirques. The permanent solifluction process leads to the gradual flattening of shore slopes, the surface of ever-frozen rock layers follow generally the pattern of the relief and contours of slopes.

The solifluction landslides of slow-displacement type develop in the area of Kharalgan and Bayan-Shungin bay, with the total length of the landslide-affected shore exceeding 5 km. The slope is damaged by newly-originating deformation process, expressed as the brow rejuvenation, exposed landslide scars, open fissures and well-defined benches. In the area of Kharalgan-bay (the region of Kharkanty-cape), the NW-exposed fresh landslide cirques appeared in the formerly undisturbed areas.

The height of shore slopes varies from 15 to 18 m. The soil masses slid-down to the coastal area are scoured by lake water. The landslide scars expose the flat-lying clays with sand lenses. The soil creep occurs along the moist lumpy plastic clay surface. The deformation-affected slopes with the permanently active stage of displacement of clay rocks are marked by the well-defined trough-like cirques with 1.0-2.0 m-high benches; the sliding slope is covered by hummock and sink forms and numerous soil-flow fissures. The dimensions of some landslide cirques vary from 80 to 500 m along the slope, and from 70 to 360 m upslope. All slope landslides originate in the areas composed of argillaceous, sandy-argillaceous and scree-clay rocks of Neogene and Quaternary. The depth of seasonal thawing varies from 1.2 to 2.5 m, the thickness of frozen zone reaching 30-75 m. The regressive development of slope landslide will intensively proceed until the slope within cirque area becomes almost horizontal.

The erosion forms in the Olkhon-island develop primarily in the Quaternary loose rock deposits of different genesis; these are both ancient slowly-developing and technogenic, i.e. produced by the anthropogenic influence upon the area. Within a season, deep scours can originate due to the damage of soil cover. Running of the electric line to the Olkhon-island territory in 2003 can also be the cause of erosion, since the sod cover on the 20 degrees slopes was damaged during the erection of high-voltage line towers. The gully forms rapidly develop along the roads and lines of communication.

One of the technogenic gully forms of 4 m width and of 2.4 m depth originated near the settlement Kharkanty. In the area of Shambanka-cape the heavily weathered hard rock formations (marble) are cut by erosion. The fissured massif is covered by a network of erosion forms; in some places these are perpendicularly crossed by sinkholes and open fissures. The origination of geomorphological situation in the region of Shambanka-cape is contributed by karst process.

The karst process in the Olkhon region is characterized by the long history of development; as the result, the areas of thick (20-130 m) crust of weathering were formed (Trzhitsinsky et al., 2003).

In the north of the Olkhon-island the occurrence of karst funnels of 4.6 m diameter and 1.8 m depth in amphibolite and 6.6 m diameter, 1.5 m depth in crystalline limestones has been mapped; there are the inherited open karst forms of ancient origination, since the present Olkhon territory is
marked by the lack of surface water and the leaching occurs very slowly.

Since the development of karst phenomenon lasted for a long period of time, some areas of carbonate rock formations are karst affected to the depth of 350 meters, which is lower than the Baikal water level; these formations are marked by numerous hollows, caverns and broken rock mass; the hollows are confined to the areas of lithogenetic or tectonically jointing. On the eastern shore of the island, the massif of Tolgot mountain, composed of limestones with the evident signs of dissolution, tapers for 200 meters over the Baikal water level; the massif is marked by the presence of various karst forms such as caverns, sinkholes and joints filled with dolomite meal; in the southern slope the 5 m-long, 3 m-high and 1.2 m-wide grotto has been found.

**Landslides.** In the shores of Lake Baikal the origination and development of landslide is induced primarily by the abrasion and physical-chemical processes, which lead to the decrease of strength properties of sandy-arillagous rocks. The atmospheric precipitation contributes much to the intensification of landslide. During the years of extremely abundant atmospheric precipitation (exceeding the average), the numerous cases of slope deformation can be observed (Engineering geology of Priibailka, 1968).

In the western slope of Olkhon island the landslide phenomena occur in the surface deposits. The slipping processes occur in the alluvial-deluvial deposits of Neogene-Quaternary, presented by loose sandstones and clays. In the area of Sasa-cape the complex-type landslide process develops. The first landslide cirque was formed in this area after impounding of the Irkutsk reservoir; it was investigated in 1976. At present, the slope is affected to the depth of 300-350 meters by the 400-450 m-long series of cirques of sliding; the cirques are divided by well-defined crests.

Within the first cirque of landslide there are two terraces; the forested first terrace slid-down together with wooden buildings; at present the terrace is fissured and covered by wind-fallen trees, and is hollowed-out by lake water. The other terrace of smaller size tilts under the slope, the landslide scar is well-defined reaching the 44° inclination on its surface the slide blocks and liquefaction slide appear. The fresh slide deformations can be observed both in the southern and northern areas; the traces of recent liquefaction slide, which covered the slope with wind-fallen trees have been found.

The plastic soil slide of slow-displacement type also occurs at present. The mechanism of displacement of larger cirques manifests itself as quick deformation shift. The central cirque presents a deep landslide, whose glide surface is within the influence zone of the lake water backing level; in the coast area the blue clay protrusion ramps can be seen. The feathering cirques displace in the form of soil flow. The sliding activity is caused by the wind and wave load upon the slope and the specific ground conditions, the deformations were induced by technogenic variations of the reservoir water level.

Owing to the enormous water amount in the Lake Baikal and its considerable purity, as well as to small population and limited industrial and agricultural development of the territory, the changes and deformations in the area do not exert any detrimental influence upon the social and ecological situation in the region. Nevertheless, the exogenic geological processes can be marked by considerable dynamics and the extent of occurrence, and in places the disturbance of biodiversity can be observed; these phenomena can be hazardous and even disastrous for the territories with developed infrastructure.

The exogenic geological processes in the coastal areas of man-made reservoirs develop more intensively than in the natural (undisturbed) conditions. The activation, dynamics and extent of their occurrence depend upon the complex of natural-technogenic factors in the influence zone of the reservoir, which is regarded as the primary technogenic unit, marked by the specific regime of exploitation (Machowski et al., 2006).

In the territory of Karowice Province (Poland) there are numerous man-made reservoirs subject to the anthropogenic influence, which concerns the morphometric pattern of the surface, hydrographic network, and the geological structure, which are the consequence of the exploitation of mineral resources (Jankowski et al., 2001). The mining work causes the origination of soil subsidence forms, bowl-shaped sinkage pits, entailing the development of exogenic geological processes, which damage the forest and agricultural lands and the urbanized-industrial areas (Szczypek, Wiśa, 1996). In the coastal areas of small reservoirs the intense change of shores (Rzetala, 1998) and hydrochemical composition of water (Rzetala, 2000), and vegetable succession (Rahmonov, Krecia, 2004; Rahmonov et al., 2004) occur.

In the zone of influence of the Angara reservoirs, different exogenic geological processes develop (Trzhitsinsky et al., 2005; Trzhitsinsky et al., 2005); the most intense and extensive are the abrasion-accumulative processes, which considerably influence the geo-ecological situation in the territory. Almost 3 000 km-long shore line is affected by abrasion. The permanent observations have not revealed any stabilization in the abrasion process, whose intensity largely depends on variations of the water level. In the situations of low water level the emerged shoal tops are cut by water action, due to which the shoals become submerged. The rise of water level up to the normal backwater mark intensifies the hollow-out of shore slopes (Kozyr'eva et al., 2001). The maximum degree of shore hollow-out reaches 200 meters, and in some cases (in combination with landslide effect) up to 1 100 meters. The degrees of shore hollow-out amounts to 26.7% in the area of Ust-Il'minsk reservoir, and up to 54.3% in the Irkutsk reservoir; the total area of scoured coast is 6000 hectares (Ovchinikov et al., 1999).

The process of rock weathering is considered to be a preparatory phase for further exogenic processes. The joint action of weathering and abrasion processes stimulates the gravitational phenomena (Kozyr'eva et al., 2004). Major landslides displace the soil along the curved glide planes, which develop in the slackened clay deposits. The rates of weathering of different rock types vary within wide range, with one order of magnitude increase under the technogenic load.

The weathering of shore slopes in the regions of continental climate is most intensive in the periods of variable temperatures, i.e. the cases of frequent 0° crossing. The disintegration of shores of man-made reservoirs occurs more intensively than that in natural
conditions; the joint action of weathering, abrasion, solifluction and other processes stimulates the additional load upon the adjacent territories.

Almost all inherited landslides responded to the construction of reservoirs with the one order of magnitude increase of slide deformations. In most cases the abrasion process is the important factor of the initiation and dynamics of landslide in reservoir shores, for example, the Ershovskiy landslide in the area of Ust'-Ilismsk reservoir, and the Balagansky landslide in the area of Bratsk reservoir.

The southern shore area of Bratsk reservoir is marked by the extensive karst occurrence; the typical karst forms such as subsidence, sinks and tunnels occur on the day surface. Construction of the reservoir and rise of groundwater level stimulated the karst development and increased the extent of its occurrence. The karst-affected areas present definite troubles in the land use for agricultural purposes and the convenient human life. The cases of sudden disaster manifestation of karst become ever more frequent, since this is the permanently developing process, which increases the geo-ecological hazard.

The disturbance of the day surface, change of landscape etc. lead to definite troubles in the development of coastal areas; the economical development of the area will require the comprehensive estimation of the natural potential of the territory, taking into consideration the dynamics of its development and reasonable man's interference into the environment conditions.

Conclusions

The rates of anthropogenic load upon the environment of the coastal areas steadily increase. The exogenic geological processes and phenomena are the criteria of the state and development of the geo-system as a whole, concerning its proof against technogenic and other detrimental loads.

The shores of Lake Baikal are currently subject to the increasing anthropogenic influence; besides, the more than one-meter rise of water level, caused by construction of the Irkutsk Hydro, stimulates the activity of inherited geological processes. The intensity of these processes does not exert any noticeable effect on the whole geo-ecological situation in the territory; however, the tendency towards the economic development of particular areas is bound up with a certain risk. The activation of exogenic geological processes is the cause of troubles in the land use practice and the disturbance of the biodiversity.

The coastal zones of the reservoirs of the Angara-Enisei complex of hydro-power stations are the territories of difficult engineering-geological conditions due to the natural (seasonal variations of water level) and technogenic (exploitation) loads; in the case of recreational use of these areas the loads tend to increase. Therefore, the policy of zoning and estimation of the permissible technogenic influence, as well as the protection measures (if necessary) against potential deformation and disasters should be worked out, with the account of specific geologic-geomorphological conditions.

Actually, the problem of development of the territories abut on the Lake Baikal and the Angara reservoirs is topical and ever more important.

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