

Altitudinal Zonation of Exomorphogenesis in Northern Tien Shan

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ABSTRACT

The structure of the morphogenesis processes is justified at the altitude mountain systems of the Northern Tien Shan, which is naturally determined not only for the mountain ridges, but also for the intermontane basins. According to the structure, the following exomorphodynamic zones are clearly distinguished: submontane-lowland, low-mountain, mid-mountain and high-mountain. In the intermontane basins, the differentiation of fluvial geomorphogenesis processes is well expressed and five high-rise fluvial zones are developed. Among geomorphological processes in the structure of Northern Tien Shan exomorphogenesis, special hazard could be caused by mudflow, avalanche, landslide-crumbling conditions, dike breaking and mudflow storage reservoirs' or water tanks' jetties. The relevance of adverse geomorphological phenomena studying is determined by the need in health and safety and development of measures to manage the possible geomorphological risks.

KEYWORDS

Mountain morphogenesis; intermontane basins;
morphodynamic processes; Tien Shan; mountain
mudflows

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Introduction

The history of scientific research of the Tien Shan is associated with the name of P.P. Semenov-Tyan-Shansky (1985), who in 1856 was the first to establish a landscape zoning and determined the height of the snow line in Zailiyskiy Alatau. Further studies have continued to examine the issues of the orography, geological structure, soil and vegetation cover of the ridge (Abuziarova, 1967). The landscape zones allocation by P.P. Semenov-Tyan-Shansky (1985) was based on the nature of vegetation and climate characteristics of each zone (Krestnikov & Nersesov, 1964). Scheme of the vertical zonation of Zailiyskiy Alatau was the first of Central Asian Mountains and became the basis for further studies of mountain landscapes, including geomorphological conditions of their formation (Belyaevsky et al., 1973).

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Considering the climate influence on the prominence, the researchers note that the topography, in turn, creates a climatic differentiation both horizontally and vertically (Gulnura, Abuduwaili, & Richard, 2013; Gutiérrez & Gutiérrez, 2013). In the mountain systems of the Northern Tien Shan differentiation processes of prominence formation in height (altitudinal zonation) are natural not only for the mountain ridges, but also for the intermontane basins (Bulanov, 2008). Altitudinal zonation of exomorphogenesis processes due to the stratification of the prominence and landscape-climatic conditions of each of the stages (Zhang et al., 2015).

Within the altitude zone, differentiation of exomorphogenesis processes depends not only on morphometric characteristics of the relief, but also on the rocks' lithology, slopes' exposure, influencing the distribution of heat and moisture on the slope, which is manifested in the characteristics of surface discharge, soil and vegetation cover (Makarov, 2012). Altitudinal zonation of exomorphogenesis processes is characteristic not only for the entire complex processes of prominence formation, but also for individual genetic types. This is most clearly seen in intermontane basins located at different hypsometric levels of the Northern Tien Shan (from 1000-1200 up to 2600-2800 m), the area of which ranges from 10-20 up to 2500 m² (Selander et al., 2012). In a tectonic respect, they represent neotectonic sunken blocks, formed by the neogene-quaternary deposits: clays, sands, loams, sandy loams, conglomerates, boulder-gravels (Novikov et al., 2014). Basins are limited to the regional sublatitudinal splits. Modern tectonic movements are manifested in the uplift of the basin surface by 3-5 mm/year, which increases the intensity of the exomorphogenesis processes (Jolivet et al., 2013).

Northern Tien-Shan is an integral part of the sublatitudinal Central Asian mountain zone (Bullen et al., 2001). The comfort degree of the population activity and the various branches of material production development within the mountain countries is determined by the characteristics of the natural environment, first of all, a geomorphologic component of mountain geosystems (Golosoov et al., 2012). Basic morphometric parameters of the prominence are the absolute and relative height, depth and density of differentiation, steepness of slopes, high-altitude differentiation of all natural ingredients and high seismicity constitute the basis for development of modern and sometimes unfavorable exomorphogenesis processes (Bekseitova et al., 2014a; Ufimtsev, 2009). These prominence features greatly limit the development of mountain areas (Bao & Zhang, 2010). According to available data, 56.2 per cent of the world's population are concentrated within the lowlands (below 200 m), with the increase in altitude there is a sharp change in the population distribution by altitudinal zones: from 200 to 500 m – 24,0 %; from 500 to 1000 m – 11,6 %; from 1000 to 1500 m and 4.4 %; from 1500 to 2000 m and 2.3 %; above 2000 m – 1.5 % (Grossman & Krueger, 1995).

This regularity of population distribution on tall stages of the prominence in general is typical for the mountains of South-Eastern Kazakhstan, including the Northern Tien Shan (Atakulov et al., 2013). With the exception of intermontane basins such as Zaisan, Alakol and Ili. Territorial organization of settlements in their boundaries is marked by individual peculiarities, due to the situation in the arid zone and similar to it natural and environmental conditions (Sizov et al., 2015).

In the Northern Tien Shan the wide range of natural resources is accommodated (Bekseitova et al., 2014b; Sydnev & Ho, 2015). Their exploration requires a comprehensive geographical research, especially unfavorable, often catastrophic processes of exomorphogenesis (Fonstad et al., 2013). Their relevance is due to revealing the main regularities of these processes' manifestation in the areas of mountain water tanks (Bartogai on the Shilik river, Bestobinsk on the Charyn river) (Havenith et al., 2013), construction of ski resort "Kokzhailau" (Li et al., 2016), ski routes for the Winter Universiade-2017 (Zakifyanov, Andruschishin & Makogonov, 2013).

Among geomorphological processes in the structure of the Northern Tien Shan exomorphogenesis, of particular danger are mudflow phenomena (Hagg et al., 2013). The basins of the rivers Kishi and Ulken Almaty, Talgar and Issyk are characterized with the most intense mudflow formation and powerful mudflow phenomena of rainfall and glacial origin (Khromova et al., 2014). Over the last 150 years in the mountains of Ile Alatau 12 catastrophic mudflows were observed: three seismogenic (1841, 1887, 1889), four rainfalls (1921, 1947, 1950, 1953), five glacial (1963, 1973, 1977, 1980, 1981 years) (Shangguan et al., 2015). A catastrophic mudflow of 1963 destroyed and filled with deposits the lake Issyk, which for many years was a natural mudflow storage reservoir (Havenith et al., 2013). It stressed the potential danger of high-mountain mudflows of the lake basin. The catastrophic mudflow of 1973 to its power surpassed all mudflows on the Kishi Almaty river, and mudflow of 1977 (Ulken Almaty) was the most dramatically powerful in the mountains of Kazakhstan (Strom, Havenith, & Korup, 2006).

The issues of altitudinal zonation of natural systems' individual elements (landscapes) have a certain history; however, the works on patterns identification of exomorphogenesis zones' development were not conducted. In this regard, increases the necessity to study the regularities of exomorphological zones' development in the Northern Tien Shan, to study the prominence-formation processes of mountain ridges and intermontane basins. The obtained findings will help in the development of measures to manage the possible geomorphological risks and to ensure public safety.

Materials and Methods

The study was performed in the framework of the state grant of the Kazakhstan Republic 0362/GF2; 0382/GF on the evaluation of natural-ecological potential of Kazakhstan mountain regions.

In the study of the exomorphogenesis processes of epiplatform orogenesis territories in the Northern Tien Shan, a complex of methods was used, including field geomorphological and landscape measurements (Hillier, 2011), analysis of remote Earth sensing materials (Kromuszczyńska et al., 2016), geological and geomorphological profiling (Robb et al., 2015), systematic analysis of the obtained data (Payo et al., 2016).

To monitor the glacial areas of the mountain ridges of the Northern Tien Shan, the satellite imagery (LANDSAT-5) was used. To interpret the remote sensing materials, the digital topographic base (scale 1: 200 000) and a computer program ArchGIS 9.2 were used (Argyriou et al., 2016; Wang et al., 2006).

Results

In this work, a model of altitudinal zonation processes of modern exomorphogenesis is first developed taking into account the anthropogenic component in terms of the research area Zailiyskiy Alatau (Figure 1).



Figure 1. Map of the modern exomorphogenesis processes manifestations on the high-mountain zone of the Ile Alatau

Space images occupy a unique position in monitoring of glacial zones of the ridge, which is a "repository" of glaciers (Argyriou et al., 2016; Selvarani, Maheswaran, & Elangovan, 2016), which are important in water supply (drinking water, hydropower, irrigation) of South-East Kazakhstan, especially for such a large conurbation as Almaty (Labonté et al., 2014). The results (space images from 2008) of remote sensing were interpreted based on the use of digital topographical basis of scale 1:200 000 and ArcGIS 9.2. They helped to compile the maps of the modern glaciation in a number of river basins (Figure 1) and the map of high-altitude climate zones (in 3D) (Figure 2), reflecting the current state of climate morphogenesis mountain ridge.

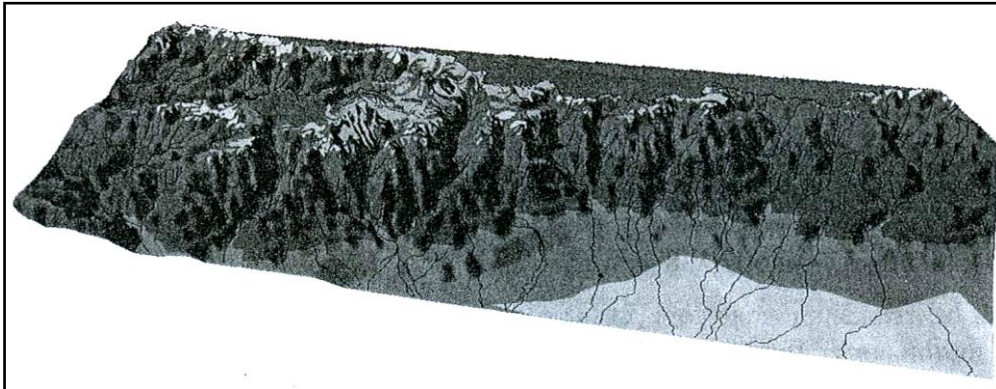


Figure 2. 3D-model of Ile Alatau climate zonation in ArcScene

In relation to the differentiation of contemporary processes of mountain areas' exomorphogenesis vertically, taking into account the dynamics of the process in the current conditions, we have identified not morphological but exomorphogenesis zonation. According to the structure of the exomorphogenesis processes in the mountain systems of the Northern Tien Shan, there are clearly distinguished lowland, low-mountain, mid-mountain and high-mountain exomorphogenesis zones. A typical example of the zone structure of modern exogenous processes is the Ile Alatau.

Submontane-plain zone - 600-1000 m, horizontal differentiation 1.5-2.0 km/km², vertical - 5-10 m, the processes of alluvial-proluvial aggradation and clough erosion dominate.

Low-mountain zone - 1000-2000 m, the differentiation density is up to 2.5 km/km², the differentiation depth ranges from 150-200 to 250-300 m, with the exception of island mountains' surfaces to the Neogene peneplain. Main processes: river erosion, gravitational slope processes (landslides, devolutions, screes) (Figure 3).



Figure 3. Differentiation of contemporary processes of ecomorphogenesis in Kungey Alatau (photo by Veselova L. K.)

Mid-mountain zone - 2000-3200 m, the differentiation density is up to 3.0-3.5 km/km², the differentiation depth ranges from 300-500 to 500-700 m, fluvial processes dominate: linear erosion, surface discharge. Among the unfavorable prominence-forming processes there are torrential mudflows, avalanches, devolutions, and rockfalls.

High-mountain zone - 3000-3600 m and above (Figure 4), differentiation depth is about 800-1500 m, modern Nival-glacial and cryogenic processes dominate: exaration, ice aggradation, glacial mudflows, solifluction, frost heave, thermokarst.

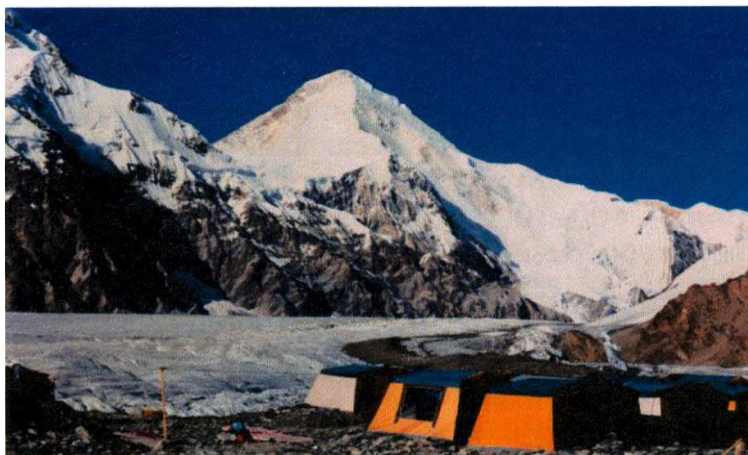


Figure 4. Nival-glacial exomorphogenesis zone of Tien Shan, Khan-Tengri peak (photo by Veselova L. K.)

Research has shown that the morphometric parameters of the prominence provide the main influence on the exomorphogenesis development (Zhenyu et al., 2014). Among the complex of morphometric parameters, to identify the geodynamic activity the following were used: the absolute altitude, values of the horizontal and vertical differentiation, slopes' exposure (Blomdin et al., 2016).

In the studied Sogety, Zhalanash, Kegen and Tekes basins, the main geomorphogenesis processes in intermontane basins are fluvial processes. The predominance of disjunctive violations of different amplitude created a landscape zonation: epihercynian platform blocks were at different hypsometric levels. Depending on the regional and local tectonic movements' manifestations, the intermontane basins has become an integral part of low-mountain, mid-mountain and high-mountain prominence stages with a significant landscape-climatic and exomorphogenesis zonation.

Each basin's surface, depending on altitude, is subjected and exposed to exogenous processes of prominence formation in accordance with the regulations in a particular landscape-climatic zone: desert, steppe, meadow - forest, subalpine, Alpine, Nival-glacial.

Intermontane basin are very diverse in physiographic aspect (Giano, 2016). There are several types of them: straightforward, isometric, granose, rectangular, latitude-oriented, and others (Hewitt, 2013). For intermontane basins of the Northern Tien Shan, the latitude-oriented (Figure 5A) and rectangular (Figure 5B) basins are typical.

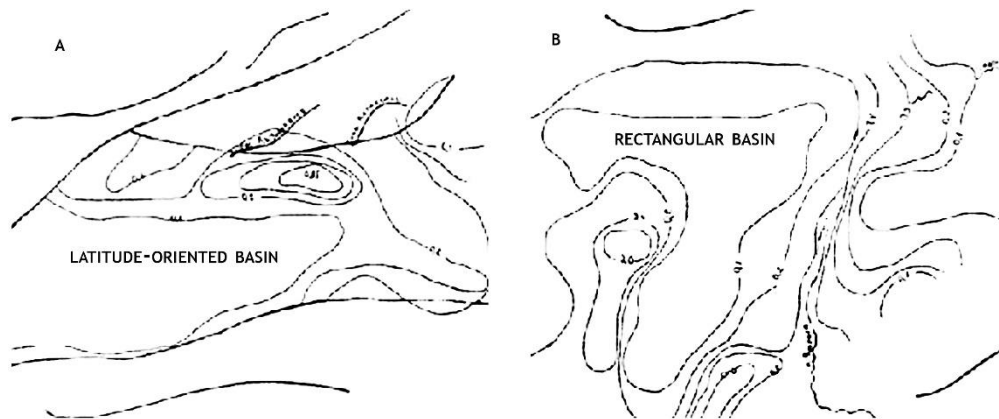


Figure 5. Physiographic types of intermontane basins of the Northern Tien Shan

Despite a number of common patterns of intermontane basins' geomorphological structure, each of them is peculiar and has individual manifestation of exomorphogenesis (Blomdin et al., 2016).

Studies of ecological and geomorphological processes with different degree of detail were held in Sogety, Zhalanash, Kegen and Tekes valleys. The exomorphogenesis processes in Sogety basin and, in particular, in the Bartogay tract were studied in details. Sogety intermontane basin is located between the Toraigyr ridge in the South, and the Sogety and Bogety mountains in the North at an altitude from 800 to 1200-1300 m.

Structural basis of the prominence is formed by latitude-oriented sunken block, consisting of individual blocks separated by submeridional splits. The central part surface of the basin is almost devoid of linear flow. The soil cover is presented by submontane gray-brown soils. Among vegetation, desert plants dominate: sagebrush, anabasis-salsa, saltwort. For this part of the basin, the predominant process of prominence formation is a sheet erosion.

Processes of prominence-formation in the Western part of the Sogety basin near the Bartogai water tank differ with diversity and complexity. Reservoir is located 15 km far from the Kokpek village in the Shilik river valley. It was introduced in 1983 and together with the Big Almaty channel was intended to irrigate the submontane flatland between the rivers Shilik and Chemolgan.

The efficiency of the reservoir depends largely on the characteristics of the development of modern exogenous prominence formation processes, the intensity of which is determined by geomorphological, geological, tectonic, bioclimatic and anthropogenic factors (Zhong et al., 2014).

Morphogenesis of the tract Bartogay is presented in Table 1.

Despite the aridity of the climate in this tract, the fluvial processes are key in the exogenous prominence formation, they make up 60% (Sizov et al., 2015). Especially significant in this regard, is the role of erosion and aggradation processes of temporary stream flows (Kurbanova, Gasanov, & Denmukhametov, 2015). It is represented by an extensive network of narrow-valleys of temporary streams, which in these conditions are the main arteries transporting loose material (Agalareva, 2013). The differentiation density on the right bank is 6.35 km/km², and on the left bank - 4.23 km/km². Physiographic characteristics of

narrows are different: the depth varies from 5-6 m in the middle part to 50 m in the entry; the width reaches 200 m; the steepness of the slopes is up to 200-250. At the bottom of the narrows from one to 3-4 channels of temporary streams are observed with the shut-in depth up to 1.0 m.

Table 1. Modern exogenous processes of the Bartogay tract

Process and its appearance forms	Prominence	Lithogenic basis of the prominence	The distribution on area, %	Created forms and elements of prominence
Erosion of temporary streams	The slopes of the intermontane flatlands, low-mountains, mid-mountains	Clays, loams, sandy loams, boulder-gravels, granites, tuff sandstones	9,8	Washouts, trails, shallows, cloughs, narrows
Stream erosion of the Shilik river	Flood areas, haughlands, benches, terraces	Sands, gravels, boulder-gravels, pulps	0,9	Benches, anabranches, channels
Channel aggradation	Haughland of high and low levels, channel	Loams, sandy loams, sands, boulder-gravels	0,4	Channel banks, islands
Diluvial-proluvial aggradation	Outflows of narrows and cloughs, foot of ridges' shoulders, low-mountains, surfaces of high terraces	Loams, breakstone-loam deposits, breakstone, boulder-gravels	4,4	Alluvial cones, alluvial cone's blankets
Devolution-scrree processes	The slopes of the low-mountains, mid-mountains	Breakstone, chippings, chumps	10,5	Scree, devolutions, straight shoulders
Diluvial-scrree processes	The slopes of the low-mountains, mid-mountains	Loams, breakstone loams, breakstone	10,1	Scree blankets, washouts, shallows
Colluvial-diluvial aggradation	The slopes of the low-mountains, surfaces of steeply-sloping flatland	Loams, breakstone loams, breakstone, chippings	4,6	Scree, scree blankets, cones
Deterioration processes	Surfaces of low-mountains and mid-mountains' interstream areas	Porphyrites, calc sinters, granites, granodiorites	13,8	Residual deposit segregation
Wind erosion	Terraces' surfaces	Loams, sandy loams, sands	2,7	Blowing holes
Sheet erosion	The slopes of the intermontane flatlands' ridges, terraces, slopes of the low-mountains	Loams, breakstone-loam deposits	42,8	The slopes of ravinements, cavitations of different physiography

Thick alluvial cones at the foot of the Turaigyr slopes are sources of sediments and loose material, which is streamed to the water tank by temporary water flows.

On the right bank, the alluvial cones form a loop with length up to 4 km, on the left bank - about 5 km, their width varies from 100 to 400 m. The central narrow has the thickest alluvial cone. The volume of loose material accumulated in it is about 33750 m³ - a potential source of sediment filling for the water tank.

The processes of sheet erosion on the mountains' slopes are intensive, forming a diluvial blanket at the foot. Sheet erosion dominates on 42% of the Bartogay tract area, the surface of the alluvial-lakustrine flatlands and terraces

of Shilik river are exposed to it. The presence of a thick aleurite layer up to 3-5 m, contributes to the development of channel erosion. A dense network of furrows and washouts with a depth from 12-14 to 20-25 cm is observed on the slopes of the ridges.

It should be noted that there are some differences in the intensity of erosion-accumulation processes of temporary streams in the system of Toraygyr ridge and Ortinau Mountains. The valleys of the southern part have a greater length, in their mouths a vast alluvial cones are formed that is caused primarily by the rocks' lithology and slopes' exposure.

A sparse herbaceous cover favors erosive activity of temporary stream flows. Not only the bottom, but also the slopes of the narrow are affected by intensive erosion. Processes of lateral erosion destroy them. In a separate narrows, steep slopes were formed and at the present time they are affected by rapid destruction.

In the Northern part of the tract on the surface of the terrace II clough erosion develops, individual cloughs reach depths of 6-7 m. The erosion sediments are accumulated at the terrace I. Thus, as the result of channel and slope erosion of temporary stream flows, the removal of erosion products in the water tank increases.

Erosion processes are developed not only within the intermontane flatland, but also on the slopes of mid-mountains and low-mountains. They are most intense in the areas of Bartogai and Toraigyrova splits, where there is a strong fragmentation of paleozoic rocks. Breakstone-loamy deposits with thickness up to 1.0-1.5 m are easily susceptible to erosion and form on the slopes a network of washouts with a depth of 0.7-1.2 m and width 0.5 m. The sections of these slopes are also regular suppliers of loose material to fill the bowl of the water tank.

Gravity-slope processes dominate in the mid-mountains and high-mountains. In the areas of Toraigy and Bartogai splits, the landslides and rockfalls are widespread. On the left bank of Shilik river, the surface of the terrace I is complicated by landslides deposits. The separate chumps reach a diameter of 26.5 m, the volume of 4-5 m³, weight reaches 10-12, sometimes 25 t. The slopes are covered with breakstone screes, often movable. On average, scree are developed at the 10.5% of the area. Their deposits are the source of replenishment of bottom sediments in the water tank.

The weathering processes contribute to the formation of screes. They can be seen everywhere, but the greatest role they play is the modeling of surfaces of the water partings (Brantley, Lebedeva, & Hausrath, 2012). The role of the processes of eolian deflation and accumulation, salinization and waterlogging in the modern prominence formation of the Bartogay tract is insignificant. Deflation develops on sand and loamy soils I and II of terraces as a result of strong mountain - valley winds.

The construction and operation of the reservoir have violated the natural and created new conditions for the development of prominence formation processes (Romanova et al., 2011). Riverbed, slope processes were replaced by a lake, resulting in the rearrangement of the coast, intensive development of abrasion processes. At the exit of Shilik river from the Toraigy canon in the southern part of the water tank, the internal (underwater) delta is formed. Both transgressive and regressive deposit accumulation contributes to it. Within the

reservoir from 30 to 80% of the sediments is deposited. According to reports, the average annual sediment load (gauging station the Shilik river in the Malibay village) during the period of reservoir operation decreased 9-fold, from 23.6 kg/s (1928-1982) to 2.6 kg/sec (from 1983 to 2000). The trend in the development of the given processes is ongoing. The average annual accumulation of sediments on the river Shilik river in Bartogai water tank is 21,0 kg/s.

The formation, structure and stability of the intermountain depressions are determined by landscape-climatic and lithological-structural conditions of the valleys and surrounding mountain ridges (Spencer et al., 2014). Therefore, in the Bartogay tract in the structure of exomorphogenesis, fluvial processes take up to 60 %. The remaining 40 % comes from the following processes: sheet erosion - 15 %, deluvial - 12 %, landslide-scrree - 10 %, colluvial-deluvial aggradation - about 3 % (Figure 6).

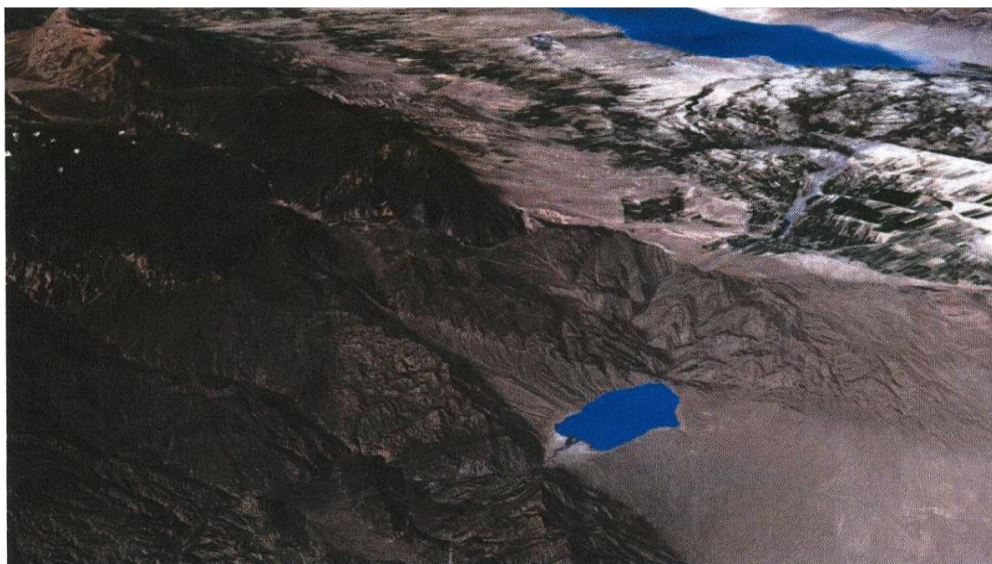


Figure 6. Bartogay water tank (Terrain Model from Google Planet Earth 7.1.1.1988)

With the increase of the absolute height of the intermontane basins' surfaces and surrounding ridges, the complexity of the structure of fluvial processes and landforms takes place (Robb et al., 2015). Most clearly, this pattern is seen in the Tekes basin, situated between high mountains of Khan – Tengri on the South and Ketmen on the North, at the absolute elevation from 1,700 to 2,400 m. At these altitudes, five altitudinal zones of fluvial geomorphogenesis are developed:

1700-1800 m - advanced persistent fluvial system of the Tekes river with tributaries Orta Kokpak, Ulken Kokpak, Bayankol, Narynkol. River valleys are distinguished by well-developed floodplains of high and low levels, a complex of four terraces above the floodplains, inland deltas.

1800-1900 m - a relatively stable system of temporary rivers (by hand. Daraty, Escartcan, Omeke) with a predominance of formation processes of accumulative forms of prominence – alluvial cones (tracts Astyngy, Jabyr, the foot of the Adyrgan mountains). On the slopes, a system of erosional landforms is developed: potholes, washouts, cloughs, the badland is formed.

1900-2000 m - a relatively simple dynamic system with the domination of the erosion processes of temporary stream flows and sheet erosion. The thickness of the horizontal differentiation reaches 10-12 km/km² (mountains Jabyr, Adyrgan).

2000-2200 m - a predominance of fluvial systems, the temporary course flows with the formation of erosional-accumulative forms of prominence (mountains, Jabyrthaw, Ustyngi Jabyr tract).

2200-2400 m – water parting surfaces of the mountains Aygyrjal and Birucas in the Tekes basin with fluvial landforms of seasonal sheet erosion.

Discussions

In this work, we first developed a model of altitudinal zonation processes of modern exomorphogenesis taking into account the anthropogenic component. The issues of altitudinal zonation of natural systems' individual elements (landscapes) have a certain history; however, the works on patterns identification of exomorphogenesis zones' development were not conducted.

The identification of the nature and laws of exomorphogenesis processes' development in mountain areas of inland deserts, which is a benchmark of the Northern Tien-Shan, is necessary to solve many problems of national economy and well-being of the local population. This requires the development of research methods using new technologies for exomorphogenesis processes' mapping. The analysis of research data to substantiate the model of altitudinal zonation of exomorphogenesis should be not only descriptive, but also should include the forecasting of possible risks.

For each exomorphological zone, prominence formation processes are unique: the destructive and aggradational transformation of glaciers is characteristic for high-altitude zones, fluvial processes dominate in the mid-mountain zone, in lowland and foothill zones the combined processes of alluvial-proluvial accumulation and gravitational-slope erosion dominate.

The influence of the tectonic movements in the Northern Tien Shan is not significant (on average 3-5 mm/year), but it increases the overall intensity of the exomorphogenesis processes. Morphometric parameters of the prominence provide the main influence on the development of exomorphogenesis. The study of prominence formation of intermontane basins in the region is of important economic value, as it could help to improve the operational efficiency of the Bartogai water tank in the Sogety valley. The efficiency of the water tank depends largely on the characteristics of modern exogenous processes of prominence formation, the intensity of which is determined by geomorphological, geological, tectonic, bioclimatic and anthropogenic factors. A further objective of the research is the development and implementation of measures to control sedimentation, not only in the Shilik river, but also in coastal zones – coast erosion, and removal of deluvial-proluvial sediments of many valleys of temporary streams in the water tank. The role of fluvial processes in Tekes, Zhalanash and Kegen basins is predominant, because unlike Sogety basin, they are not limited from West and East by the Shilik river (Bartogai water tank) and

Charyn river respectively, which do not have a significant impact on prominence-forming processes of the basin.

Conclusion

Thus, the morphological features of the topography in the intermontane basins determine the leading processes of prominence formation in each high-mountain exomorphogenesis zone structure (Fonstad et al., 2013). Forecast for development of exomorphogenesis processes is based on the results of a study of changes in natural conditions in each of the geomorphological (exomorphogenesis) altitudinal zones (Payo et al., 2016).

The most significant changes occur in the nival-glacial zone as a result of the degradation of modern glaciation. The growing degradation of glaciers provides an opportunity to assess the direction of changes in the structure of the geomorphological processes in high-altitude zones and in the mountain system as a whole. The glaciation of the Ile Alatau area during 1955-2008 decreased by 117,77 km² (41 %), which is about 0.8% per year. When keeping the detected rate of glaciers' decline, glaciers of Ile Alatau may disappear by the end of the twenty-first century.

Obtained research findings indicate significant changes in geomorphological processes not only vertically, but also in every exomorphogenesis zone. In high-mountain zones, dynamics of the processes is due to changes in climatic conditions; and in the foothills, the low-mountains and mid-mountains, the proportion of the influence of anthropogenic factors of prominence formation increases along with natural factors.

Disclosure statement

No potential conflict of interest was reported by the authors.

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