Features of technogenic morphogenesis on the territory of south-western Belarus

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Abstract. The classification of modern technogenic relief with the identification of its types, subtypes and forms is substantiated for the territory of southwestern Belarus. Information about the types of impact on the geological environment in the process of technomorph formation is given. Based on the generalization of field research materials, topographic maps and published literature, a diagram of the technogenic relief of the region under study was constructed which shows the largest artificial forms of its various types. Using information from technical documentation, special measurements and calculations, the averaged parameters of technomorphs were determined and their main morphological features were characterized.

Keywords: technogenic geological processes, technogenic relief, technogenesis, geomorphology.

Introduction

A directed effect on the earth's surface of the territory of southwestern Belarus occurs as a result of human economic activity and it leads to its significant transformation and the emergence of technomorphs. The transformation of the relief is associated with the construction of residential and industrial buildings, highways and railways, hydraulic structures, drainage reclamation, mining, land use in agriculture and other activities.

Purposeful study and mapping of technogenic geological processes and the artificial morphogenesis (technomorphs) formed by them are currently being actively pursued in various regions of the world as evidenced by the solid published literature [1–7]. The study of the processes of technogenic morphogenesis in the territory of south-western Belarus was carried out by A.V. Matveyev, S.F. Savchik, M.F. Hrachanik and others. Much attention in the works of these authors was paid to the creation of a classification of technogenic geological processes and the resulting technomorphs. So, A.V. Matveyev et al. [8, 9] proposed a rubrication of the relief of the south of Belarus in which technogenic formations were identified in the rank of a group. Accumulative and depleted forms, channels of technogenic watercourses, basins of artificial reservoirs and technogenic-mediated taluses, landslides, etc. were distinguished in the group. M.F. Hrachanik [10], in relation to the territory of the eastern part of the Podlaska-Brest depression, compiled a classification with

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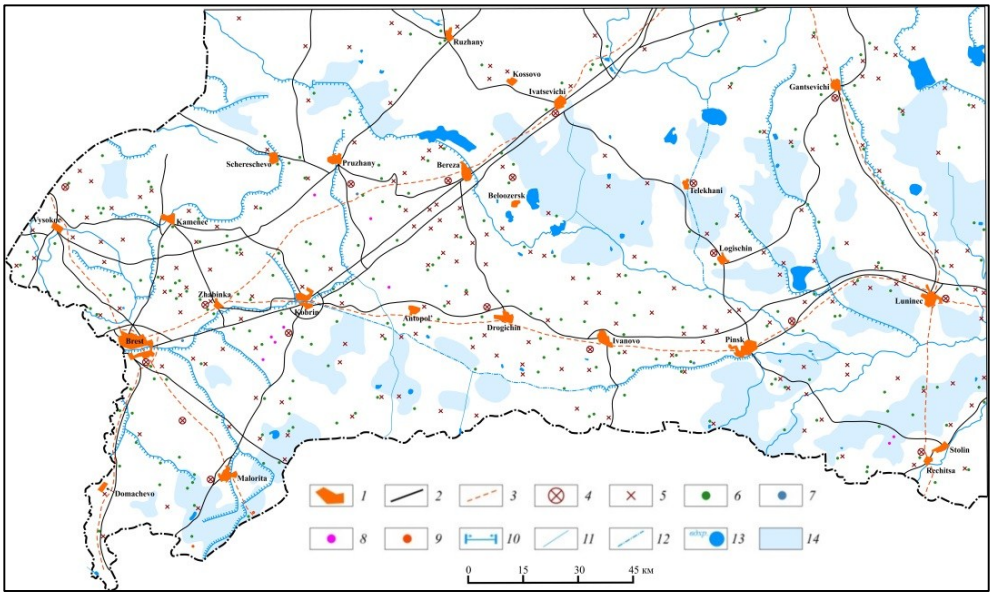
the allocation of an anthropogenic class including a technogenic group which is divided into several types and subtypes.

Methods. Based on the generalization of the materials of the mentioned authors, a classification of the technogenic relief supplemented by the results of their own research was developed reflecting its diversity, genesis and the most general features of morphology. The allocated classification units will be discussed in detail below. The territorial distribution of the technogenic relief is shown in a specially drawn up diagram (figure).



Legend: 1 – complexes of forms of residential spaces; 2 – large road technomorphs; 3 – large railway technomorphs; 4 – solid waste landfills; 5 – mini-landfills for solid waste; 6 – open pit for sand extraction; 7 – quarries for the extraction of clay; 8 – quarries for the extraction of peat; 9 – quarries for the extraction of chalk; 10 – straightened river sections; 11 – large reclamation canals; 12 – large hydraulic structures (canals); 13 – bowls of reservoirs; 14 – large reclamation systems

Fig. Scheme of technogenic relief of the territory of south-western Belarus.

The main source of factual material was the data of field observations, medium-scale topographic maps of the territory of southwestern Belarus, scientific publications. Cartographic measurements were made within the squares of a kilometer grid having a side length of 2 km on a scale and an actual area of 4 km^2 in order to determine the length of the formed road and irrigation technomorphs. All obtained values were entered into the table. Further, the obtained materials were generalized and reduced to a single scheme at a scale of 1 : 500,000. For this, a transparent cartographic base with a grid of squares with an area of 100 km^2 was compiled. The territory of the region under study was divided into 322 squares for which the volumes of technogenically displaced soils were calculated. Additionally, using online cartography tools (Google Earth) and Landsat-8 satellite images the location of solid waste landfills was determined and applied to a cartographic base accompanied by calculations of accumulation volumes.

Results and Discussion. *Mining type*. Among the negative forms of relief that arise during the extraction of minerals the most common are quarries which are divided into 2 groups: industrial and intraeconomic. There were 266 open-pit mines (of which 63 were industrial, and 203 were on-farm) on the territory of south-western Belarus, as of October 22, 2018 according to the data of the Brest Regional Committee for Natural

Resources and Environmental Protection. Clay, sands, sand and gravel mixtures, gravel, peat, sapropel, chalk are mined by quarrying in the region.

Industrial quarries are wider and deeper due to the greater volume of mining operations. Thus, the largest in southwestern Belarus are the peat quarries (Perelumye (145.27 ha), Zavidnyuvka (254.41 ha), Zubkovo (180.2 ha), etc.). The area of the quarries for the extraction of sand and clay is much smaller and usually does not exceed 10 hectares. The depth of excavations ranges from 1–1.5 to 12 m (Rechitsa sand pit). The area intra economic quarries usually does not exceed 1 hectare, the depth can reach 5 m.

The transformation of the relief of the territory during the development of minerals by quarrying occurs in several stages. At the first stage, an excavation starts at the quarry location based on the parameters specified in the design documentation. The fertile soil layer is removed and stored, later it can be used in the reclamation of the quarry. Thus, already at the stage of laying a quarry positive (dumps of the fertile soil layer) and negative (quarry excavations and other depressions) technomorphs are formed. At the second stage, with the beginning of the development of a mineral, the depth and area of the excavation grows, collapse-talus processes are actively manifested on its walls [11, 12] which are activated under the influence of atmospheric precipitation, melted snow and ground waters and wind.

There are many unauthorized places for mining in the region in addition to industrial and intra economic quarries which are registered with the state. They have a small width and depth and are measured by the first meters.

Accumulative technogenic forms created in the process of mining are embankments and dumps usually located near industrial facilities that process natural raw materials or in areas of its production.

Selitebny type. There are significant differences in the topography of cities and rural areas. By definition E.A. Likhacheva, “the relief of the urban area is a complex combination of natural, technogenic and architectural forms that create specific geomorphological conditions – a special type of polygenetic surface” [13, p. 176]. According to L.L. Rozanov [14, 15], an integral geotechnomorphic surface is formed in cities – a conjugate set of primary (natural) and secondary (technogenically determined) landforms. According to the author of the article, the relief of urbanized territories is part of the forms of the selitebny type since the geological impact on the earth's surface and the emerging technomorphs during the construction of settlements are monotonous.

The general background of urbanized areas is significantly influenced by complexes of one- and multi-storied artificial structures for various purposes. They are complex engineering structures consisting of natural and man-made materials. Usually, their height does not exceed 10 m, however, in large cities of the region, such as Brest, Pinsk, Kobrin, etc., there are multi-storied buildings several tens of meters high. The area of buildings is measured in tens by the first hundred square meters.

Relief planning, filling or cutting of natural forms is carried out in the process of building buildings. Significant masses of rocks are moved at various distances. According to the author's estimates, during the construction of ditches for buildings in the cities of the territory of south-western Belarus about 267 million m^3 of solids were displaced. Urban engineering structures create large static loads on the foundation soils, changing the conditions of their occurrence and physical and mechanical properties. According to data [12], static pressures from multi-storied buildings reach 0.5 MPa and from separate industrial structures – up to 2 MPa as a result of which the base soils are compacted and their moisture content decreases. Deformations occur from the arising stresses in the solid mass which can cause a violation of structural bonds, the development of subsidence phenomena that create a risk of destruction of buildings.

An important part of a settlement is its transport infrastructure which includes embankments and road surfaces, bridges, crossings, sidewalks and other engineering solutions. Highways within settlements are most often two- and four-lane paved which is important to ensure the speed of traffic.

The number of railway lines in cities which are not junction is greater than outside them. The railways form a complicated complex in the settlements where the junction stations are located (the cities of Brest, Zhabinka, Luninets) which ensures the movement of transport in several directions. The construction of embankments and excavations for roads and railways changes the appearance of the relief, creates additional loads on the foundation soils. The risk of destruction of embankments and road surfaces becomes real under the influence of dynamic loads created by transport, unfavorable geological processes (landslide phenomena, activation of erosion processes) can develop.

Movable-motionless technogenic morphogenesis [14] play an important role in the formation of urban relief and its change. These include road, rail, river, air vehicles as well as industrial, agricultural, construction mining machines and mechanisms, military self-propelled units, etc. They have a direct impact on the geological environment in the process of using them for construction and mining, etc.

Hydrological objects located on the territory of cities are subject to significant transformation. Thus, many rivers in the region within the urbanized territories have straightened channels which prevent the development of lateral erosion and meandering processes, high water during floods. Fortified embankments are being built as a result of hydrotechnical measures. The banks are subject to embankments and the accumulation of solid sediments in the riverbed is regulated. Lakes are also affected by the process of technogenic transformation, as drainage areas, the feeding regime of the reservoir and the processes of sedimentation change significantly. Small reservoirs and ponds are being created to regulate the water regime of the territory. Sediments are accumulated in the bowls of reservoirs depending on the mode of their use and processes typical for the bank zones of reservoirs develop.

Places for storage and processing of solid waste industrial waste mounds and waste rock dumps formed as a result of the activities of processing enterprises are formed in the relative proximity to cities and outside them and sometimes in the city limits. The accumulation of significant volumes of waste and dumps creates loads on the underlying rocks. In addition, material is eroded and transported over considerable distances under the influence of wind and atmospheric precipitation. Landfalls and taluses, suffusion can develop within the dump technomorphs.

Fortified settlements and mounds form a special group of residential type objects. The fortified settlements are represented by leveled forms and are the remains of ancient inhabited territories (cities, fortresses, etc.), their cultural layer is often buried under modern sediments. Mounds are hills of various sizes that were created by man in the historical past.

Road type. Ridge and ridge-like embankments of roads and railways are widely developed in the territory of south-western Belarus. Highways are divided into 4 classes – trunk roads, highways with improved coverage, roads with and without coverage. Country and forest roads and trails were not specially considered during the research as they do not make a big contribution to changing the topography of the territory. Highways cover the territory of south-western Belarus with a dense network. The parameters of road technomorphs are determined using technical documentation for their construction, field studies and are presented in Table 1.

Table 1. Average parameters of road technomorphs [by 16, 17]

Road class / number of paths	Subgrade width, m	Subgrade height, m	Volume of 1 running meter of subgrade, m^3
Highways			
Motorways	28,5	1	28,5
Highways with improved coverage	27,5	0,7	19,25
Coated roads	12	0,5	6
Unpaved roads	10	0,25	2,5
Railways			
Double Track	6,4	1	6,4
Single Track	2,3	1	2,3

The total length of embankments and excavations of all highways on the territory of the studied region is 11,300 km of which technomorphs are highways – 198 km, highways with improved coverage – 1700 km, with coverage – 6300 km, without coverage – 3050 km. According to the calculations carried out on the territory of south-western Belarus, as a result of road construction, about 84 million m^3 of rocks have been displaced at various distances.

A motor road is a complex engineering structure, the embankment (subgrade) of which is constructed in a shape close to trapezoidal from natural and / or man-made soils, local or imported [16]. Pavement is laid on the upper part of the roadbed it is a multi-layer structure designed to redistribute the pressure on the ground from the action of the load of a moving vehicle. Work is carried out to plan and level the territory when preparing the area for the construction of the road. Embankments are compacted during construction, especially if the underlying soils are weak (peat, sapropel, etc.). The construction of the roadbed and pavement leads to the formation of extended linear technomorphs, which in the conditions of the Belarusian Polesie significantly alter the earth's surface. The higher the class of the road, the higher the degree of relief transformation as for the construction of a multi-lane highway the construction of a larger subgrade is required and large volumes of rocks are moved.

Crossings and bridges are constructed at intersections of roads as well as when a road crosses a river or canal. A subgrade is erected during the construction of crossings and it in height and width exceeds the usual embankments and has a complex configuration. During the construction of bridges, special reinforced concrete or metal structures are used. Embankments are erected adjacent to the two banks of the reservoir.

In some cases, excavation is carried out most often when crossing local elevated sections to build a road, huge volumes of sediments are moved which are later used for the construction of subgrade and road pavements or a cavalier is arranged in which soils that are not used for one reason or another are stored. The greatest transformative impact on natural systems occurs during the construction of roads within areas with weak soils at the base, for example, in swamps. In such cases, soft soil is extracted which leads to the destruction of natural landforms, displacement of cover deposits and their replacement with imported soils. In the areas of road construction, the relief acquires a leveled appearance with extended positive rampart and ridge-shaped technomorphs that stand out against its background.

During the construction of the roadbed of highways, engineering and technical solutions are necessarily applied, aimed at preventing the development of negative manifestations of exogenous processes, however, during the exploitation of the road under the influence of natural factors (precipitation, air temperature, etc.) and man-made (dynamic effects of moving vehicles) impacts, the subgrade can lose stability. This leads to the emergence of

the danger of the development of erosion and landslide processes, destruction of the subgrade and disruption of movement or failure of certain sections of the roads.

The railways of south-western Belarus are represented by 6 large branches. The total length of technomorph railways in the region is 770 km of which double-track – 280 km, single-track – 495 km. About 2.9 million m^3 of solids were moved over various distances during the construction of railways.

The subgrade of the region's railways is arranged in the form of a trapezoid. Technomorphs can be arranged both on leveled surfaces and in recesses. Natural and technogenic soils, local or imported are used [17] during the construction of embankments. After the erection of the embankment and before laying the track, the roadbed is covered with a layer of rocky, weakly weathered rocks, which prevent the development of processes of erosion and destruction by the wind and also redistribute the load during the operation of the railway.

The greatest impact on the natural environment occurs when laying paths in areas with damp and damp foundations (in swamps). In addition to the actual construction of excavations and embankments, replacing part of the natural soils with imported ones, additional drainage ditches, drainages, etc. are constructed.

Hydraulic engineering type. The largest hydraulic structures on the territory of south-western Belarus are the Dnieper-Bug and Oginsky canals. Of these two objects, the Dnieper-Bug waterway is navigable. It stretches across the study area from west to east for 243.2 km connecting the rivers Mukhavets and Pina. The guaranteed channel width and depth are 40 and 2 m, respectively. Based on this, the volume of displaced material during the construction of 1 running meter of the canal is 80 m^3 and the total volume of displaced soil is 19.45 million m^3. The Oginsky canal connects the rivers Shchara and Yaselda, however, do not fulfill their functions at the present stage, they are a historical monument.

A significant transformation of the relief occurs during the construction of hydraulic structures. The formed technomorphs are significantly superior in parameters to other types of channels in the region. Cavaliers are constructed from the excavated and unused soils, which reach 5 m in height.

After excavation of the canal to ensure a long service life and to prevent water erosion in the channel and meandering processes, sections of the banks of hydraulic structures are often doned or straightened using engineering and technical methods.

A large number of dams and bunds have been built on the territory of the region which are extended positive forms of relief, they are built mainly from natural soils. Sluice gates and waterworks which are designed to regulate water flow are built of artificial materials and rising significantly above the water surface.

Bowls of reservoirs and ponds also belong to negative hydrotechnical technomorphs. In total, there are 44 reservoirs on the territory of the territory of south-western Belarus which are of 3 types: bulk, lake and channel. Small reservoirs with a water surface area of up to 1–2 km^2 and a total volume of up to 5 million m^3 prevail. Ponds are much smaller in comparison with reservoirs; therefore, their number was not specially counted.

According to V.M. Shirokov et al. [18], the Polesie reservoirs have low and gentle shores composed mainly of sands of various granulometric composition. Reservoirs of Belarus are divided into 5 hydromorphological types: small shallow water; small non-deep; medium complex (valley type); medium-deep and deep (lake and lake-river). The morphometric parameters of the Polesie reservoirs are predetermined by the flat relief, the parameters of the lake basins and the structure of the river valleys.

Small shallow water reservoirs have depths less than 2 m. This type includes the Papernya reservoir on the river Zelvyanka, the average depth of which is 1.13 m, the mirror area is 1.8 km^2 and the total volume is 2.0 million m^3. Small non-deep reservoirs have average depths up to 2–3 m. A reservoir of this type can be the Gornovo-2 reservoir, the

average depth of which is 2.7 m, the surface area is 0.38 km^2 and the total volume is 1.04 million m^3. Medium complex (valley type) and medium-deep reservoirs have depths of more than 3 m. The Pogost reservoir belongs to the medium complex type, the average depth is 3.4 m, the surface area is 16.2 km^2 and the total volume is 54.5 million m^3. Deep (lake and lake-river) reservoirs are created on the basis of natural lakes or in river valleys they have a large area, depth (more than 5 m) and volume, a complex configuration. An example of such a reservoir is the Bereza-1 reservoir, created on the basis of the lake Black.

During the construction of reservoirs, the adjacent area is planned, its leveling is carried out, water canals, gateways-regulators, dams, enclosing dams and other hydraulic structures are constructed which significantly alter the natural appearance of the relief. At the final stage of construction, the banks of reservoirs, canals and feeding rivers are embanked and the territory adjacent to the lakes is slightly flooded. Reservoirs activate many exogenous processes, primarily abrasion. Slope processes develop in the coastal zones of reservoirs. Reservoirs affect the groundwater regime which leads to the activation of suffusion and subsidence processes.

Irrigation and drainage type. Open drainage channels of various classes prevail among the destructive irrigation and drainage technomorphs. The averaged parameters of irrigation and drainage technomorphs are shown in Table 2. The set of interconnected drainage canals which are a complicated complex of engineering and technical structures is called a drainage system.

Table 2. Averaged parameters of reclamation canals and canalized river sections [by 19–20]

Type of construction	Width, m	Depth, m	The volume of soils during the excavation of 1 running meter, m^3
Trunk	6	2	12
Open drainage	3	1,2	3,6
Canalized section of the river	10	2	20

According to the drainage method, drainage systems prevail on the territory of south-western Belarus they are represented mainly by open drainage channels which are built in trapezoidal recesses. When laying channels, the excavated soil is used for road construction or is stored in the near-edge parts, forming a cavalier. The depth of the canals is set based on the conditions for ensuring the required drainage rate: the minimum for mineral soils is 1 m, for peat soils – 1.2 m after peat settling, the maximum for shallow canals-dehydrators is 1.4–1.5 m. The distance between the open drainage canals the network is calculated according to various formulas (depending on engineering-geological, geomorphological and other conditions). According to V.S. Anoshko [21], the distance between channels on low-lying peat soils is from 60 to 110 m, on transitional – 50–70 m, on upper – 30–40 m. According to the author's calculations, as a result of irrigation and drainage construction, 115 million m^3 of rocks were moved.

The largest in terms of parameters are the main canals. Their depth can reach several meters, width up to 10 m or more. An example is the Orekhovsky channel. After reconstruction in 1973, its width was 12 m, in the middle of 2018 – 8.2 m. This canal is part of the large reclamation system “Orekhovskaya” located to the north of the agro-town Povitie of the Kobrin region, which, in addition to it includes the Orekhovskoye reservoir, catching and supplying channels and open drainage channels.

The largest number of channels falls on small drainage channels. Their width rarely exceeds 5 m, the initial depth is equal to the minimum design depth (1–1.2 m), however, during operation and the action of natural factors, their depth significantly decreases without additional maintenance measures the channels silt up, overgrow and fail. To ensure

observation of the level of groundwater and its composition, observation wells of various depths are being constructed on the territory of the reclamation system.

When laying canals, the extracted soils can be used to fill dams that enclose polder systems or reservoirs, road embankments and can also be stored along the canal in the form of a cavalier which is a shaft up to several meters high. Sometimes the cavaliers are leveled and in such cases have a height 0.15–0.5 m. For the further use of reclaimed land as agricultural land, the earth's surface flattens out and leveled areas of reclamation systems are formed.

Belligerative type. A special type of technomorph for various purposes is emerging in territories that are occupied by military units or set aside for military training grounds,. Barracks and other residential and command premises may correspond in parameters to residential buildings of the residential type but there is a small number of multi-storied buildings among them. The sizes of these buildings are different. Garages and hangars are used for storage of military equipment and can reach significant sizes and occupy large areas. To ensure takeoff and landing of helicopters and airplanes, runways of various configurations with hard surfaces are being built. The warehouses of fuels and lubricants, in addition to the surface part, have large underground reservoirs in which oil products are stored.

A special type of technomorph is formed by various fortifications and long-term defensive points. They are widespread in the vicinity of the cities of Brest and Pinsk and in the Kamenets region between the villages of Stavy and Orlya. From the soils extracted during the construction process, defensive embankments (parapets) are arranged, which have a height of up to 1 m.

During the military exercise, weapons are tested and it is accompanied by blasting operations. The explosion of a projectile leaves an explosive funnel on the earth's surface – the dimensions of which depend on the power of the explosion of the projectile.

Communal type. This type includes all technomorphs that arose in the process of equipping territories for landfills and mini-landfills for solid household and municipal waste as well as during waste storage. Landfills are the largest waste storage areas. There are a total of them on the territory of the studied region 18. An example of a large solid waste accumulator is the landfill located to the south of the village of Vulka-Gorodishchenskaya, Pinsk district, Brest region. Its area is about 78.7 thousand m^2. As waste accumulates with a capacity of several meters, the surface of the landfill is leveled with the help of heavy special equipment, poured over with a layer of soil and compacted. The height of the accumulated waste layer currently reaches 20 m and the volume is approximately 2.66 million m^3. The composition of waste is different: metal, paper, cardboard, plastic, reinforced concrete structures, construction waste, glass, etc. Poorly fixed waste is often carried by the wind over considerable distances.

A moat up to 2 m wide was laid around the storage areas it is intended for the accumulation of liquid waste components. Control wells are installed along the perimeter of the landfill with the help of which the quality control of groundwater is ensured.

Mini-landfills for solid domestic waste occupy a much smaller area – usually no more than 0.1 km^2. There were 196 such objects on the territory of south-western Belarus in total, as of October 1, 2018.

The main area of the mini-landfill is the production zone which can occupy up to 95 % of its entire area [22]. Within its limits, solid waste is stored, in most cases in 1, less often up to 3 layers with each compaction according to technologies used at larger landfills. At the bottom of the stored waste is usually a pit, the soil from which is used for intermediate or final isolation of waste or is placed in cavaliers around the perimeter. The equipped cavalier is a shaft made of local soil up to 3 m high which encloses the landfill area and

prevents waste from being transported outside of it. Also on the territory of the landfill outbuildings, bowls of ponds and disinfecting baths, drainage ditches, etc.

There are a large number of unauthorized dumps in the region in addition to landfills and mini-landfills for storage and disposal of solid municipal and domestic waste they are most often located in open pit mining sites or in the forest.

Conclusions. A diverse complex of technogenic landforms arose on the territory of south-western Belarus as a result of intensive human economic activity. Technomorphs are formed as a result of a targeted impact on the geological environment during the construction of various buildings and structures, the movement of huge volumes of soil, the transformation of positive and negative landforms. This led to a significant change in the natural appearance of the earth's surface in the region. A classification of the technogenic relief was made on the base of generalization of field research data and published materials. The highest unit of classification is a group (technogenic). All technomorphs of the region are combined into 7 types: mining, road, residential (selitebny), hydrotechnical, irrigation and drainage, belligerative and communal. Each type includes 2 subtypes of forms – accumulative and destructive. The types of impact on the earth's surface are shown as a result of which technomorphs arise.

Bibliography

1. Osipov V. I. Tekhnogenez i sovremennye zadachi nauk o Zemle [*Technogenesis and Current Tasks in the Earth Sciences*]. Ecology and Industry of Russia, 2016, 20 (3), pp. 4–12. (In Russian). DOI: 10.18412/1816-0395-2016-3-4-12.

2. Szabó J. Anthropogenic Geomorphology: Subject and System. In: Szabó J., Dávid L., Lóczy D. (eds). Anthropogenic Geomorphology. Springer, Dordrecht, 2010, pp. 3–10. DOI: 10.1007/978-90-481-3058-0_1.

3. Peloggia A. U. G. Geological classification and mapping of technogenic (artificial) ground: a comparative analysis. Revista do Instituto Geológico, 2018, 39 (2), pp. 1–15. DOI: 10.5935/0100-929X.20180005.

4. Uraskulov M. R., Bogush I. A., Cherkashin V. I., Gazaliev I. M., Yusupov A. R. Geoecological Problems of Zones of Ore Mining Technogenesis in the North Caucasus. Arid Ecosyst, 2018, 8, pp. 47–52. DOI: 10.1134/S2079096118010110.

5. Mzia K., Tkemaladze S. The Classification Imereti's Landscapes and Its Anthropogenic Transformation. Earth Sciences, 2017, 6 (6), pp. 111–116. DOI: 10.11648/-j.earth.20170606.12.

6. Tsermegas I. Anthropogenic transformation of the relief of the Aegean Islands. Miscellanea Geographica, 2015, 19 (2), pp. 40 – 49. DOI: 10.1515/mgrsd-2015-0009.

7. Nelson F., Outcalt S. I. Anthropogenic geomorphology in northern Alaska. Physical Geography, 1982, 3 (1), pp. 17–48. DOI: 10.1080/02723646.1982.10642216.

8. Matveyev A. V. Istoriya formirovaniya rel'efa Belorussii [*History of the formation of the relief of Belarus*]. Minsk, Navuka i tekhnika Publ., 1990, 144 p. (In Russian).

9. Matveyev A. V. et al. Rel'ef Belorusskogo Poles'ya [*Relief of Belarusian Polesie*]. Minsk, Nauka i tekhnika Publ., 1982, 131 p. (In Russian).

10. Hrachanik M. F., Matveyev A. V., Bogdasarov M. A. Rel'ef territorii Podlyassko-Brestskoy vpadiny [*Relief of the territory of the Podlaska-Brest Depression*]. Brest, BrGU Publ., 2013, 154 p. (In Russian).

11. Galkin A. N. et al. Inzhenernaya geologiya Belarusi (3 t.) [*Engineering geology of Belarus (3 vol.)*]. Vitebsk, VGU Publ., 2016–2018. (In Russian).

12. Trofimov V. T. et al. Inzhenernaya geologiya Rossii. Inzhenernaya geodinamika territorii Rossii [*Engineering geology of Russia. Engineering geodynamics of the territory of Russia*]. Moscow, KDU Publ. House, 2013, 816 p. (In Russian).

13. Likhacheva E. A. Antropogenno-geomorfologicheskie sistemy [*Anthropogenic-geomorphological systems*]. Geomorfologicheskie sistemy: svoystva, ierarkhiya, organizovannost' [*Geomorphological systems: properties, hierarchy, organization*]. Moscow, Media-PRESS Publ., 2010, pp. 176–181. (In Russian).

14. Rozanov L. L. Teoretiko-metodologicheskie osnovy geotekhnomorfologiches-kogo issledovaniya prirodopol'zovaniya. Diss. dokt. geogr. nauk [*Theoretical and methodological foundations of geotechnological and morphological studies of environmental management. Dr. geogr. sci. diss. abstr.*]. Moscow, 1997, 47 p. (In Russian).

15. Rozanov L. L. Geotekhnomorfogenez i organizovannost' geotekhnomorfosistem [*Geotechnomorphogenesis and organization of geotechnomorphosystems*]. Geomorfologiya, 2008, 2, pp. 90 – 96. (In Russian). DOI: 10.15356/0435-4281-2008-2-90-96.

16. Minin A. V. et al. Avtomobil'nye dorogi Belarusi [*Highways of Belarus*]. Minsk, BelEn Publ., 2002, 672 p. (In Russian).

17. TKP 45-3.03-163-2009 (02250) Zheleznye dorogi. Zemlyanoe polotno. Pravila proektirovaniya [*State Standard 45-3.03-163-2009 (02250). Railways. Subgrade. Design rules*]. Minsk, M-vo arkhit-ry i stroit-va Belarusi Publ., 2010, 99 p. (In Russian).

18. Shirokov V. M. et al. Vodokhranilishcha Belorussii: prirodnye osobennosti i vzaimodeystvie s okruzhayushchey sredoy [*Reservoirs of Belarus: natural features and interaction with the environment*]. Minsk, Universitetskoe Publ., 1991, 207 p. (In Russian).

19. Murashko A. I. et al. Melioratsiya [*Land Reclamation*]. Minsk, BelEn Publ., 1984, 567 p. (In Russian).

20. Lagun T. D. Melioratsiya i rekul'tivatsiya zemel' [*Land Reclamation and Recultivation*]. Minsk, IVTs Minfina Publ., 2017, 376 p. (In Russian).

21. Anoshko V. S. Geograficheskie osnovy melioratsii [*Geographical Basics of Land Reclamation*]. Minsk, Vysheyshaya shkola Publ., 1974, 176 p. (In Russian).

22. Sokolov L. I. et al. Sbor i pererabotka tverdykh kommunal'nykh otkhodov [*Collection and processing of municipal solid waste*]. Moscow, Infra-Inzheneriya Publ., 2017, 176 p. (In Russian).