
REGIONAL PROBLEMS OF ENVIRONMENTAL STUDIES AND NATURAL RESOURCES UTILIZATION

Development of the Informal Road Network and Its Impact on the Transformation of Taiga Geosystems in the North of Irkutsk Oblast

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Abstract—We examine the impact of roads on geosystems in territories of new development, where the extraction of hydrocarbons motivates especially intensive improvement of the infrastructure. In this study, we consider motor roads beyond the official network, which have been informally constructed, maintained, or used by various organizations or individuals. We represent types of roads with different forms and regimes of management schematically. As the model area for studying the impact of roads on taiga geosystems, we selected a territory in the north of Irkutsk oblast, in the interfluvium of the Kirenga and Khanda rivers; field investigations of the transformation of geosystems were carried out along the informal road from the Vershina Khandy village to the Magistral'nyi settlement. Particular attention was paid to the possible intensification of geomorphological processes as one of the crucial factors for changes in geosystems. A comprehensive analysis of geological, geomorphological, and landscape factors using remote sensing data and field studies made it possible to compile a geomorphological map with identification of dangerous exogenous processes along these roads. Major causes for landscape disturbances were identified, namely degradation and transformation of vegetation cover and changes in the temperature regime of permafrost, which lead to waterlogging and subsidence of soils and, consequently, to the formation of multiple tracks along the roadside and intensified linear erosion.

Keywords: informal roads, road landscape, transformation of geosystems, areas of new development, geomorphological processes

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INTRODUCTION

Roads constitute a part of the complex landscape—technogenic complex, which continuously exchanges matter and energy with adjacent territories transformed during road construction [1]. The latter negatively affects the state of the landscape, damaging or destroying its natural elements, and therefore disturbs the balance in nature. Examples of such interference in nature include forest partitioning, disrupted groundwater flow, destruction of habitats, and cutting off migration routes of animals, and deterioration of the microclimate. As well, road landscapes have their own set of associated hazardous exogenous processes and emerging new landforms, such as landslides, ravines, thermokarst sinkholes, and quarries. Road construction also negatively affects the appearance of the landscape. It can disrupt the harmony of the scenery and weaken the external attractiveness of the landscape. Thus, road landscapes belong to direct anthro-

pogenic complexes formed as a result of purposeful human activity in nature [2].

According to some studies, certain forms of traditional mobility are disrupted due to the development of new infrastructure. There are many examples that illustrate the undesirability of roads for the local society and their negative impact on both the environment and people [3]. In environmental sciences, the development of road networks is associated with fragmentation and changes in land-use, as well as deforestation, pollution, and threats to biodiversity [4].

The role of roads as places of concentration of synanthropic plant and animal species and foci of the formation of digression biocenoses, as well as migration corridors for some animal species, is well known. It takes many years for vegetation and soil cover natural for a given area to recover on the sections of abandoned roads and adjacent territories, that is, road landscapes are very stable [1].

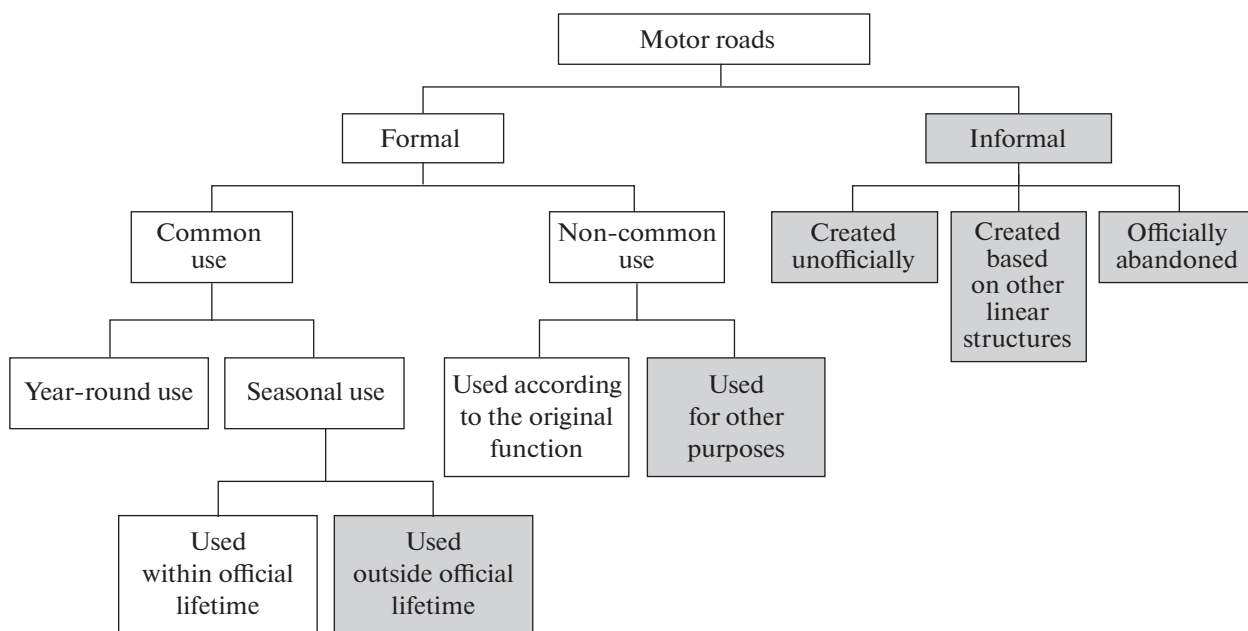


Fig. 1. Classification of formal and informal roads by forms and regimes of use. Informal roads and roads used informally are shown in grey.

The negative impact of roads on the landscape is exacerbated in areas with permafrost. Researchers note deeper thawing of permafrost near the roads [5] and the development of thermokarst [6]. In tundra landscapes, it was observed that almost every trace of heavy equipment persists for many years and the long-term use of such machines completely destroys the vegetation cover [7, 8]. The density of the road transport network in steppe landscapes can increase by 44% during the operation of a single oil field [9].

The impact of infrastructure development on the environment remains poorly understood. This applies not only to official roads but also to other linear objects created for the initial exploration, construction, and maintenance of infrastructure and mining facilities, but used for transportation. These roads, as well as other private and forest ones, are not reflected on the maps of the transport network. There is no generally accepted term for their designation in the scientific literature. Researchers of these roads in the forests of the Amazon call them “unofficial,” although they refer to both illegally formed and private forest roads [10, 11]. Describing the same objects, A. Hughes employs the term “hidden roads” [12]. In the Russian literature, O.A. Molyarenko [13] uses the term unowned for roads that do not have a clearly approved status. V.V. Vasil’eva [14] employs the term “wild” to denote winter roads created without involvement of any authorities.

In this work, we use the term “informal roads,” borrowed from Ch. Trombold [15], who proposed it to distinguish informal roads from planned and con-

structed official routes. As informal roads, we considered both unofficially created and uncommon roads, which, despite the fact that they were built and maintained in accordance with existing standards, are operated by organizations and individuals other than those envisaged in the construction and operation. We also include seasonal common roads, which are operated not only within the official lease term (Fig. 1). The boundary between formal and informal roads is flexible: once built, official roads can become informal if not maintained, while informal roads often precede the creation of formal ones [16].

Informal roads are of greatest importance in the regions of new development, which include the north of Irkutsk oblast [17], where the official transport network is sporadic. Despite the active development of the oil and gas and forestry industries in this region, there has been no research on the accompanying infrastructure development and its impact on the environment. Therefore, studying the impact of the development of the informal network on the transformation of taiga geosystems in the northern regions of Irkutsk oblast is particularly relevant.

TERRITORY AND RESEARCH METHODS

For the inventory, we used a territory with arbitrary borders, which has various types of economic activities and, accordingly, regimes of organizing the road network; at the same time, this is an area that had a long period of traditional nature management (Fig. 2a).

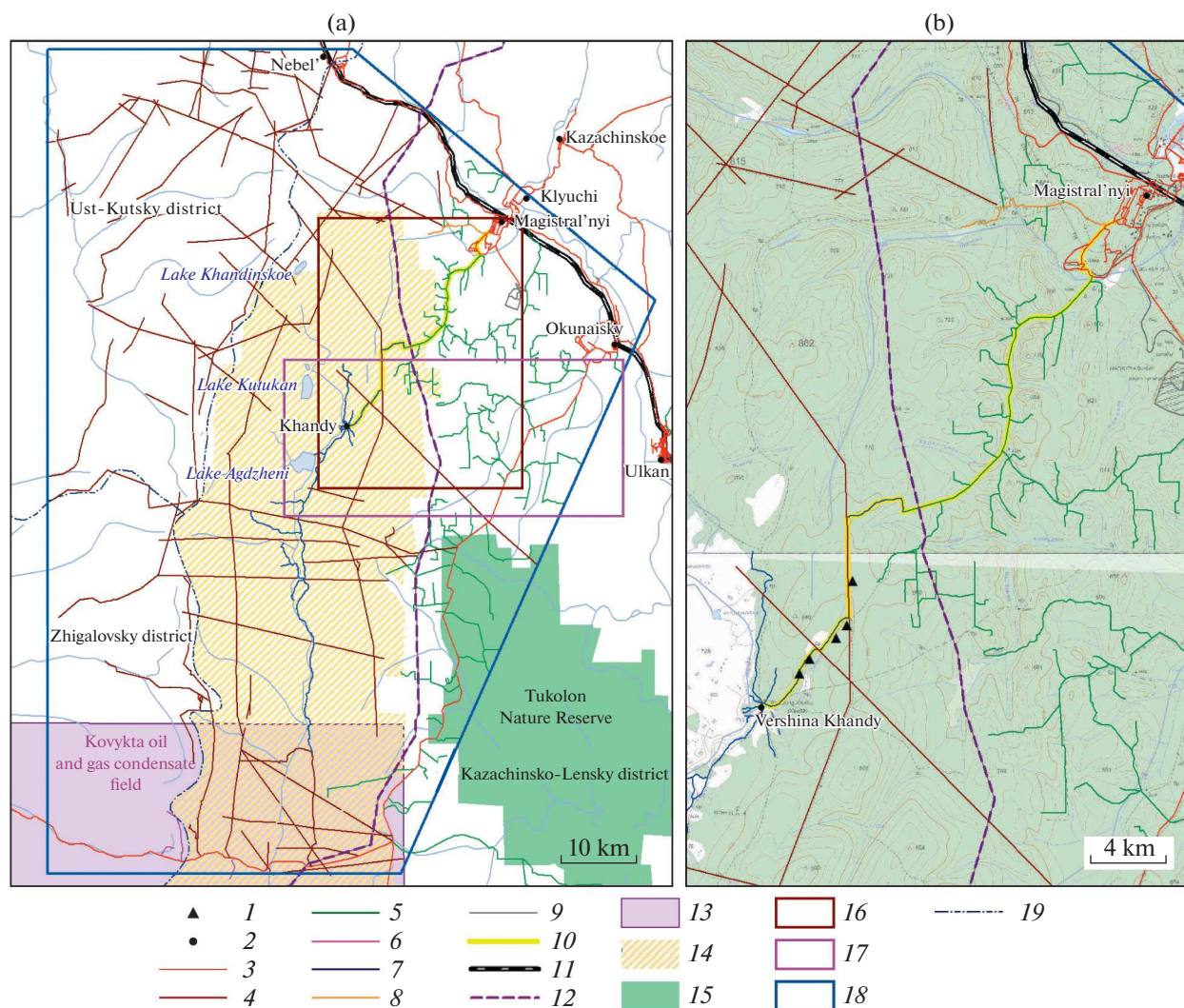


Fig. 2. The study area (a) and a blown up map (b). 1, photographing sites, 2, settlements. Motor roads: 3, common use; non-common (departmental) use: 4, geological, 5, timber-carrying, 6, oil and gas, 7, commercial, 8, agricultural, 9, other roads. 10, road between Vershina Khandy and Magistral'nyi villages, 11, railways, 12, gas pipeline (under construction), 13, oil and gas fields, 14, territories of traditional nature management, 15, specially protected natural areas. Borders of: 16, blow-up, 17, geomorphological scheme, 18, study area, 19, administrative regions.

The study area with an arbitrary center in the national Evenk village Vershina Khandy is located within three administrative districts of Irkutsk oblast: Ust-Kutsky, Kazachinskoe, and Zhigalovsky. This is the territory of historical residence and traditional economic activities of the Evenks, representatives of the indigenous peoples of the North, Siberia, and the Far East of the Russian Federation. Their traditional use of natural resources included reindeer husbandry, hunting, fishing, as well as gathering pine nuts, berries, and herbs [18]. In 1776, on the Kirenga River, 57 km from the current location of the Vershina Khandy village, the Kazachinskoe settlement was formed [19]. Numerous interethnic marriages between residents of these two settlements led to the relocation of some Evenks to the Kazachinskoe village [18]. The

industrial development of the territory was initiated by the construction of the Baikal-Amur Mainline (1975–1986), during which, in 1975, 36 km from the Vershina Khandy village, a railway was laid and the Magistral'nyi settlement was established. Currently, the study area is at the stage of active economic development due to the extraction of hydrocarbons and use of forest resources, as well as the prospects for the construction of the Power of Siberia pipeline, which implies further development of infrastructure, including the road network.

To study the impact of motor roads on geosystems, we selected a part of the study area corresponding to the Khandinsky depression, in the interfluvium of the Kirenga and Khandy rivers. According to the map [20], this territory belongs to the Kudinsko-Khandinsky steppe-

taiga piedmont province, which represents the western marginal part of the Baikal-Dzhugdzhur mountain-taiga region. The height of the bottom of the Khandinsky boggy depression is 700–750 m. This is a flood-plain-terrace complex; the territory is characterized by low ridges (100–300 m) with gentle slopes. The average height of the plateau bordering the depression is 900–1000 m above sea level. The region is flat with rounded flat peaks.

The climate in the study area is extremely continental. The average temperature in January is $-20...-21^{\circ}\text{C}$ and in July it is $+16^{\circ}\text{C}$, annual precipitation is 360–440 mm. This is an area of ubiquitous seasonally frozen grounds and permafrost, which is the reason that long-term seasonally frozen soils are formed here [21]. The Khandinsky depression is dominated by sparse larch and spruce–larch dwarf-birch moss forests with peaty soils. The plateau is covered with sloping larch–cedar–spruce small-grass–green moss forests on sod-podzolic soils.

Field studies were carried out along the informal road from the Vershina Khandy village to the Magistral'nyi settlement, which is a model for studying the impact of roads on various types of geosystems, since it consists of different economic areas (see Fig. 2b).

This work employed an integrated approach, including various research methods (route, comparative-analytical, and geoinformation ones). For the inventory of roads, modern high-resolution satellite imagery (Landsat 8, Sentinel), multi-temporal topographic maps, and materials on the development of oil and gas transportation infrastructure were used. Positions of common roads were determined according to open data from the governments of the constituent entities of the Russian Federation. The rest of the roads of various types were divided into several subtypes, depending on the economic characteristics.

The construction of motor roads disturbs the vegetation cover and the geological environment, including the relief. Disruption of the relief carries the threat of dangerous exogenous processes, this is the reason that our work considers road construction conditions in terms of geomorphological hazards.

Comprehensive analysis of geological, geomorphological, and landscape factors, as well as data of remote sensing of the Earth and field studies, made it possible to make a map of the manifestation of hazardous exogenous processes.

RESULTS AND DISCUSSION

Permanent transport connection with the Vershina Khandy village exists only during the cold season. For the rest of the time, it is very difficult to use the road; in some places, depending on the amount of precipitation, it becomes almost impassable, so local residents

are forced to use heavy all-terrain vehicles or new types of light vehicles (swamp vehicles or karakats).

According to surveys, residents of the Vershina Khandy village do not want a high quality road: they fear that hunters and fishermen might use it to intrude into the lands of the Evenk community. However, the area and its informal roads are already been widely used for geological exploration, the needs of the forest industry, as well as for recreational use (hunting and fishing) by residents of neighboring areas and settlements.

As a result of the inventory, we subdivided the entire road network of the study area into two main types of roads, for common and non-common (departmental) use. Among the roads of non-common use, depending on the type of activity, there are timber-carrying, oil and gas, geological, agricultural, and trade roads. Based on the results of the inventory, a map of the road network was compiled, which additionally included railways, a gas pipeline under construction, specially protected natural areas, and lands of traditional use by the Khandinsky community (see Fig. 2a). As an inset map, it additionally includes the investigated informal road between the Vershina Khandy and Magistral'nyi villages with sites of photographing (see Fig. 2b).

Analysis of the inventory of the road network showed that common roads span over 317 km, or 15.2% of the total length of roads. The length of non-common roads is 1763 km, or 84.8%, including geological, 1146 km; timber-carrying, 469; commercial, 111; oil and gas, 13; agricultural, 10; and other roads, 13 km. The density of the common road network is $45.5 \text{ km}/1000 \text{ km}^2$, which is slightly higher than the average value for Irkutsk oblast ($40.7 \text{ km}/1000 \text{ km}^2$). At the same time, the density of the road network of all types is $298 \text{ km}/1000 \text{ km}^2$, which is significantly higher than the average for the region and is similar to the density of the road network of the Volga Federal District ($338 \text{ km}/1000 \text{ km}^2$).

The beginning of the roadway of the investigated road from the Vershina Khandy village is an old trade route (7.2 km), followed by a section of an unused geological profile (5.3 km), a section of the road that was unofficially created by local residents (4 km), and a section of a forest road currently leased by OOO Rusforest Magistral'nyi (18.4 km), which is turning into a common motor way to the Magistral'nyi village (4.7 km). Officially, the Vershina Khandy village has no roads connecting it with other settlements or major common roads. The existing road is an informal inter-settlement road and is not supported by the local municipality.

Thus, a significant part of the non-common roads in the study area can be operated unofficially as informal roads.

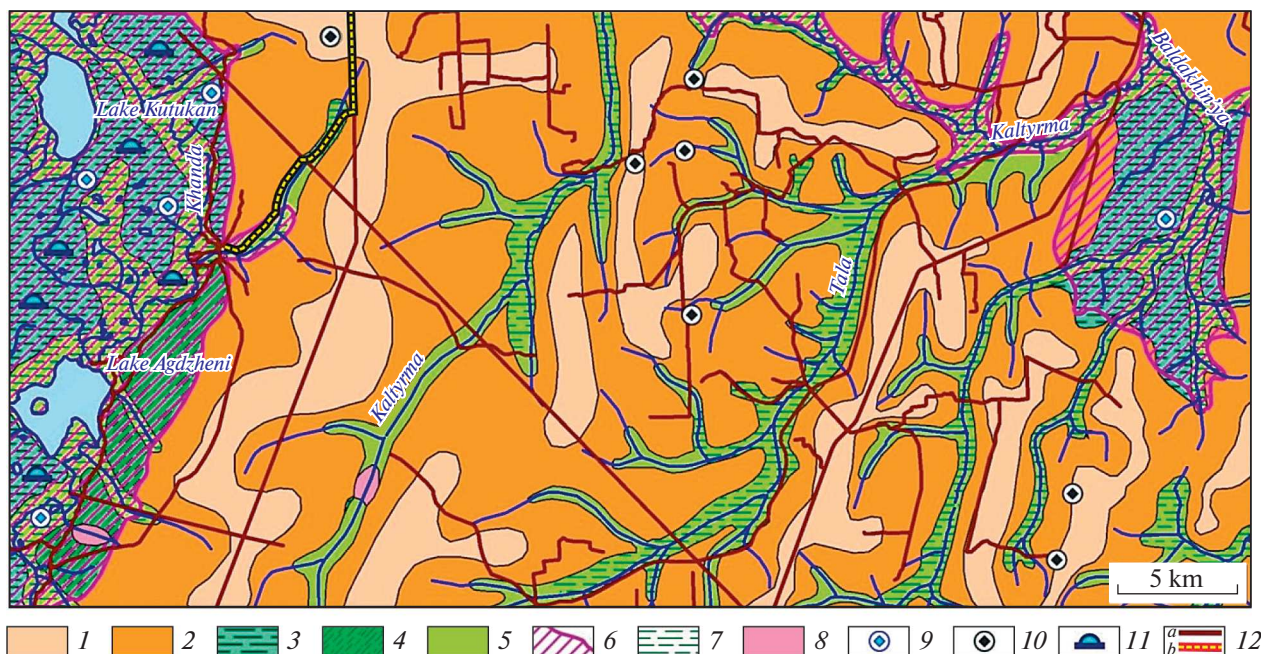


Fig. 3. The geomorphological scheme of the Khanda-Kirenga interfluvium. 1, wavy watersheds; 2, slopes of different steepness; 3, bottoms of depressions with low-lying bogs; 4, bottoms of basins with raised bogs; 5, river valleys with a complex of undifferentiated floodplains and terraces; 6, spread of permafrost; 7, wetlands of river valleys; 8, icy areas of river valleys; 9, thermokarst; 10, karst; 11, heaving of soils; 12a, road network; 12b, road between Vershina Khandy and Magistral'nyi villages.

If we take the fact into account that the width of the roadway of informal roads is 6 m on average, the area of the modified landscapes will be approximately 1000 ha, excluding the indirect impact. These figures will increase with the development of multiple tracks in swampy and difficult-to-pass areas.

According to A.G. Smirnykh [2], road landscapes, depending on the thickness and nature of the technogenic cover, are divided into four categories. Informal roads in the study area can be attributed to country-road landscapes without a raised subgrade with an unpaved surface. It is such landscapes (local roads, which are badly organized and unpaved) that are characterized by advancing road erosion.

Motor roads are a special type of anthropogenic geomorphological system; one of their distinctive features is the intersection of territories with a particular structure of exomorphogenesis processes [22]. The study area has a network of roads that were created in various geomorphological conditions. The morpho-structural plan is represented by the positive dome-shaped upland of the Khanda-Kirenga interfluvium that separates elements of the Cis-Baikal depression: the Khandinsky and Baldakhinsky depressions.

This area is characterized by three types of surfaces with different reliefs. The denudation relief is represented by wavy watersheds, the structural-erosion-denudation relief is developed on the slopes of river valleys, the erosion-accumulative relief is typical of

floodplains and river terraces, and the lake-accumulative and biogenic relief is widespread in the bottoms of the basins [21]. According to the zoning of Irkutsk oblast in terms of hazardous exogenous processes [23], the study area is characterized by a medium geomorphological hazard level with high probability of karst processes, cryogenesis, and planar and linear erosion. The occurrence of dangerous processes is also due to the spread of insular permafrost.

Based on the data on the geological and geomorphological structure of the study area, a geomorphological map was compiled (Fig. 3). The legend reflects landforms and their inherent exogenous processes. Permafrost with geomorphological processes characteristic of the regions of its distribution, permafrost cracking and heaving of soils, thermokarst, and ice formation, is developed in the bottoms of the basins and in some parts of the river valleys.

Analysis of the obtained data showed that the operation of motor roads transforms taiga geosystems, primarily through the activation of geomorphological processes. For roads on slopes and watersheds, there is a risk of flat and linear erosion. Depending on the steepness and exposure of the slopes, the geomorphological system can be complicated by creep, solifluction, screes, landslides, and emerging karst.

When examining a section of the road from the Vershina Khandy village to the timber-carrying road, the following landscape disturbances were observed.

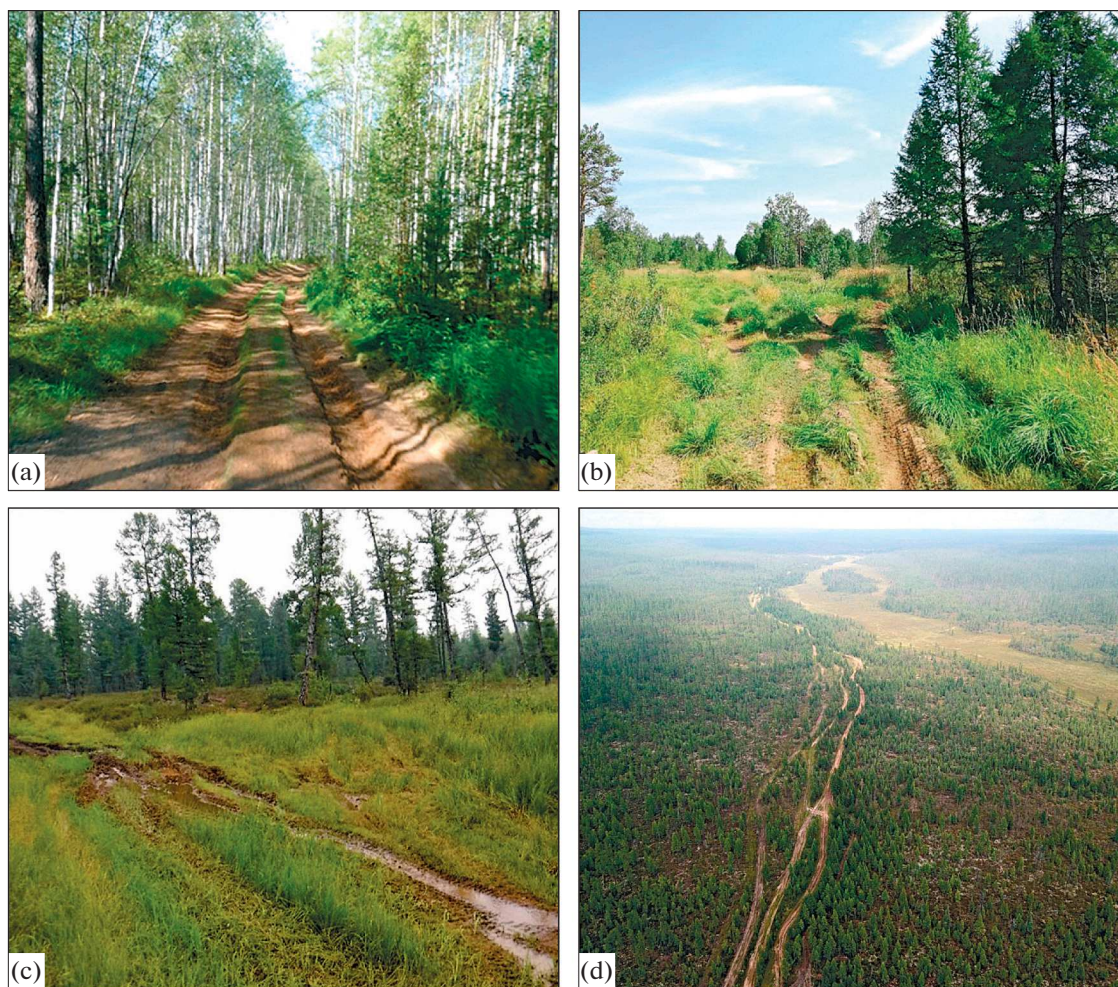


Fig. 4. Landscape disturbances revealed during the examination of the road section between the Vershina Khandy village and the timber-carrying road. (a) roadside secondary forest, (b) the most disturbed section of the road to the Vershina Khandy village, (c, d) multiple tracks, waterlogging (thawing of permafrost).

Along almost two-thirds of the road, there is a roadside secondary birch mixed-herbs forest, while larch and spruce-larch dwarf-birch moss forests are in the background here (Fig. 4a).

Approximately 8 km from the village, a swampy area begins, where local residents can drive in the summer only using heavy or light all-terrain vehicles. There is an area of close occurrence of permafrost here; therefore, the road is accompanied by thawing, watering, and subsidence of soils. The moss cover perishes here and is replaced by sedges and reed grass (see Fig. 4b and 4c).

Difficult-to-pass swampy sections of the road are characterized by the emergence of multiple tracks, which is due to the impossibility of driving along the main road bed. This gives rise to a significant number of parallel roads, which disrupt the landscape (see Fig. 4d).

The road section with a steepness of 10° is characterized by ravines (erosion ruts) (Fig. 5). In general,

erosion plays a significant role in the formation of road landscapes. It is most intensively expressed on roads of local importance, which are badly organized and unpaved. Traces left by heavy equipment destroy vegetation for many years, which leads to ravine formation, often complicated by thermokarst.

Based on the results of analyzing the location of forest fires within 5 km from the investigated road using satellite images since the early 2000s it was revealed that the road did not affect their occurrence, although there are a significant number of large burned areas around the Vershina Khandy village. These are mainly fires that spread to the south of the village in 2012–2013 and to the northwest in 2017.

Thus, informal roads, like the road from the Vershina Khandy village to the Magistral'nyi settlement, have a great impact on natural landscapes. Primary disturbances of the natural landscape during the development of the road network are mainly associated with changes in the structure of vegetation and



Fig. 5. Ravines (erosional ditches) in the study area.

soil cover, drainage conditions, emerging flooding areas, waterlogging, karst phenomena, and advancing linear erosion, depending on the geological and geomorphological structure of a particular area.

The data presented in this work indicate the need to take the effect of informal roads on natural landscapes into account when designing infrastructure projects in areas of new development.

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