ECOLOGICAL IMPACTS OF ROAD NETWORK DENSITY ON LANDSCAPES IN NIZHEGORODSKOE POVOLZH'E NATIONAL PARK

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ABSTRACT

The article presents the results of the correlation between the indicator of the density of the road network, reflecting the degree of anthropogenic pressure, and natural features, that determine the economic attractiveness of landscapes and the possibility of laying roads on their territory. The density of the road network serves as an integral indicator of the intensity of development of the territory and generally reflects the degree of their preservation. Being a product of historically established relationships between the features of the relief, hydrographic network, soil and vegetation cover and the nature and intensity of economic development, the indicator of the density of the road network on the one hand is formed under the influence of the landscape features of the territory, on the other hand, it can be considered as one of the economic properties of the landscape, allowing it to outline and characterize. The object of the research is the territory of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park (Russia). In the course of the research, the results were obtained: a comprehensive assessment of the state of landscapes in the territory of the Nizhegorodskoe Povolzh'e National Park was carried out, indicators of landscape determinism of anthropogenic pressure on the territory were calculated through an analysis of the density of the road network.

Keywords: Sustainable national park management, Ecosystem vulnerability, Landscape fragmentation, Anthropogenic pressure, Karst ecosystems.

INTRODUCTION

At the end of the XX – beginning of the XXI century in Russia was actively forming a system of national parks, which is due, on the one hand, to the need to fulfill international obligations in the field of nature protection, and on the other hand, to the increasing demand of society for recreational services, related to natural landscapes (Asadulagi et al., 2024; Mirzagitova et al., 2023). The multifunctional model of national parks, which assumes both the conservation of natural complexes and regulated recreational use, has been widely recognized as optimal. At the same time, the implementation of this model requires a detailed analysis and assessment of the territory in terms of

its natural resources and recreational capacity (Fitzsimmons, 1979; Michalowska and Glowienka, 2008; Okayama and Okano, 2016; Shu et al., 2021). In this context the landscape approach is the most effective basis for the organization of rational nature management in the territory of national parks (Dukenov et al., 2023; Suryandari et al., 2024). In the present work the correlation between anthropogenic impact (Ilyushin and Afanaseva, 2020), including recreational pressure, and landscape differentiation of the territory is investigated. As a comprehensive indicator of the economic, including recreational pressure, the authors use the indicator of the density of the road network. While recognizing the versatility of roads, the authors nevertheless believe that recreationists are their active users, which makes it possible to indirectly assess the attendance of landscapes by this indicator (Abdullayev et al., 2023; Akhmetshin et al., 2023). The analysis of the density of the road network allows not only to judge the degree of recreational pressure, but also to identify types of landscapes (Xiaoyi and Boonyanmethaporn, 2024) vulnerable to anthropogenic impact, exposed, for example, to the risk of fires, the main cause of which is human activity (Salaimeh SA, 2024). The approach proposed by the authors to the spatial analysis of the relationship between recreational pressure and landscape structure can form the basis for the development of differentiated measures for the conservation of natural complexes in the national park. The use of a landscape approach in territorial design (Borodina et al., 2023), including the design of specially protected natural areas, is traditionally considered an effective technique and is widely used to preserve and restore populations of rare plant and animal species (Bakka et al., 2021b, 2023; Sambuaga et al., 2024).

MATERIALS AND METHODS

Research Design. In this study, the researchers aimed to assess the density of the road network as an indicator of anthropogenic pressure on the landscapes of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park (Russia). The study was conducted between 2017 and 2024 using a combination of field research, thematic maps, and remote sensing data. Authors used following research methods: expeditionary, geoinformation, cartographic, comparative geographical, literature analysis, correlation, mathematical. The density of the road network was taken as an integral indicator of landscape traffic. Using field research data, as well as data from remote sensing of the Earth, the existing roads on the territory of the Pustynsky section of the national park were digitized, followed by the calculation of their length and density in each landscape. The calculation of the density of the road network was carried out separately for each of the 7 landscapes of the Pustynsky section of the national park, allocated earlier (Astashin et al., 2023b).

Characteristics of the Researched Territory. The territory of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park is located in the southern part of the Nizhny Novgorod Region in the Seryozha River basin in the Nizhny Novgorod Region in Arzamasskij and Sosnovskij districts (Figure 1).

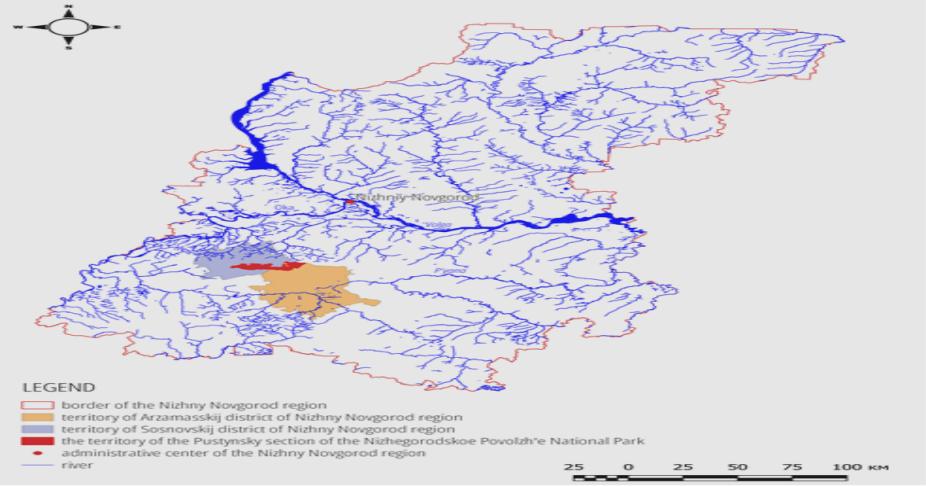

Figure 1. The position of the research area in the Nizhny Novgorod region in Arzamasskij and Sosnovskij districts.

The pre-quaternary formations of the Pustynsky section of the Nizhny Novgorod Volga National Park are represented by sediments of the Permian system in which gypsum, limestone, anhydrite and dolomite are widely represented, which created prerequisites for the development of karst (Tolstikhina 1970a; Ulyanov, 1980). Neopleistocene and Holocene formations are distinguished as part of the Quaternary system, which are genetically subdivided into deluvial, alluvial, proluvial, aeolian and biogenic (Tolstikhina 1970b).

Since sands of water-glacial origin are widely represented in the quaternary formations (Kuz'min et al., 2019), the relief of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park is often shallow-hilly, maned, with sand dunes up to 10 m high. Due to the presence of gypsum and limestone deposits in the pre-quaternary deposits, karst landforms are common in the researched territory - karst funnels, wells, logs, polje. Many large sinkholes and karst poljes are flooded with water and are lakes. Fluvial landforms are widely represented – river valleys, ravines, gullies.

The climate of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park is temperate continental, with moderately cold winters and warm summers. The annual precipitation is 450-500 mm, the moisture coefficient is 1. The hydrological framework of the Pustynsky section of the national park is a complex of karst and alluvial-karst lakes (Astashin et al., 2023a), through some of which the main drainage of this territory flows – the Seryozha River. The soil cover is mainly represented by sod-podzolic sandy soils, alluvial-sod soils are common on floodplains, and peat-swamp soils are replaced in waterlogged areas (Asadulagi et al., 2024; Ilyushin and Afanaseva, 2020; Ilyushin and Martirosyan, 2024). The structure of the vegetation cover is dominated by pine forests, on the floodplains of rivers – oak forests, turning into black alders and willows in waterlogged places.

The territory of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park lies in a broad-leaved subzone of forest-steppe zone within the Privolzhskaya landscape region (Isachenko, 1991) in the central part of the Oksko-Tyoshskoe poles'e landscape area (Bakanina et al., 2003). In the course of complex landscape researches of the territory of the Pustynsky section, a landscape map was created (Astashin et al., 2023b), the length of the network of dirt roads and their density were calculated for each landscape (Table 1, Figures 2, 3).

Table 1. The density of the network of dirt roads in the landscapes of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park.

Landscape type	**Area, km^2**	**Length of dirt roads, km**	**Density of the network of dirt roads, km/km^2**
1. Floodplain palustrine landscape of lowland swamps	20,17	0,79	0,039
2. Floodplain wet forest landscape under black alder community, oak forests, spruce forests and pine forests on alluvial-turf often gleying soils of various mechanical composition	39,95	6,1	0,152
3. Wet lowland forest landscape of the first above-floodplain terrace under pine and spruce forests on sod-podzolic sandy loam soils	19,45	16,3	0,83
4. Well-drained dune-karst forest landscape of the third above-floodplain terrace under pine forests on sod-podzolic sandy soils	9,96	18,36	1,84
5. Slightly moistened slope alluvial-fluvioglacial forest landscape under the linden-pine forests on sod-podzolic sandy soils	45,03	56,74	1,2
6. Slightly moistened watershed fluvioglacial forest landscape under pine forests on sod-podzolic sandy loam soils	3,83	4,64	1,21
7. Slightly moistened slope moraine agroforest landscape under linden-pine forests on sod-podzolic loamy soils	0,24	0	0

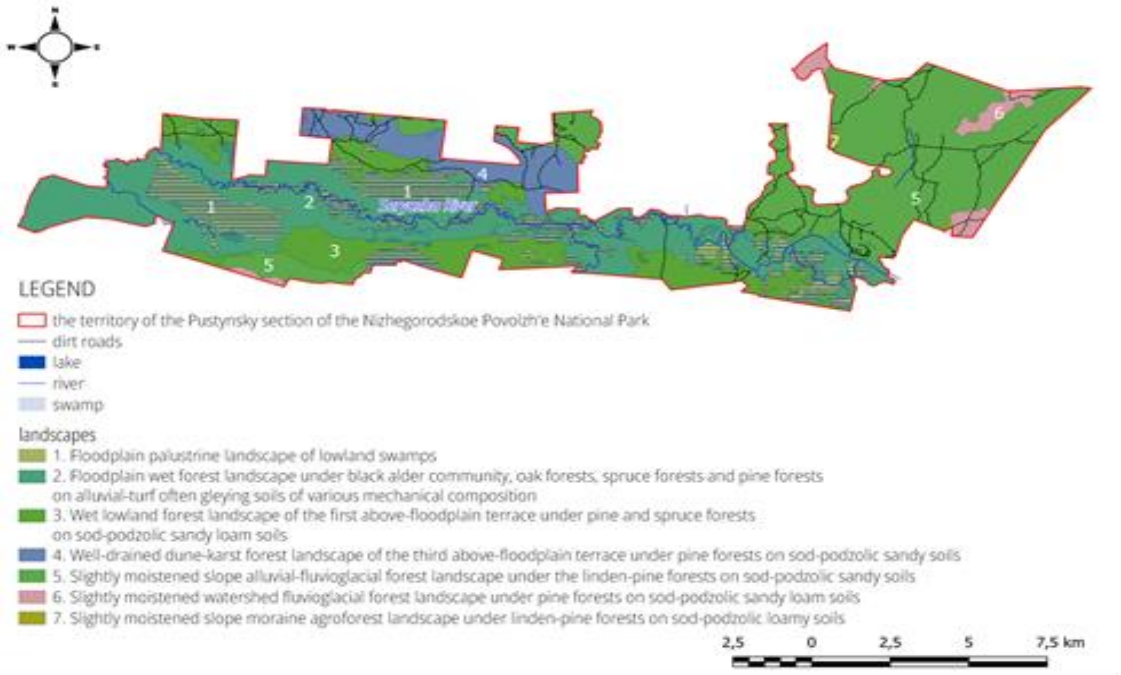

Figure 2. A network of dirt roads in the landscapes of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park.

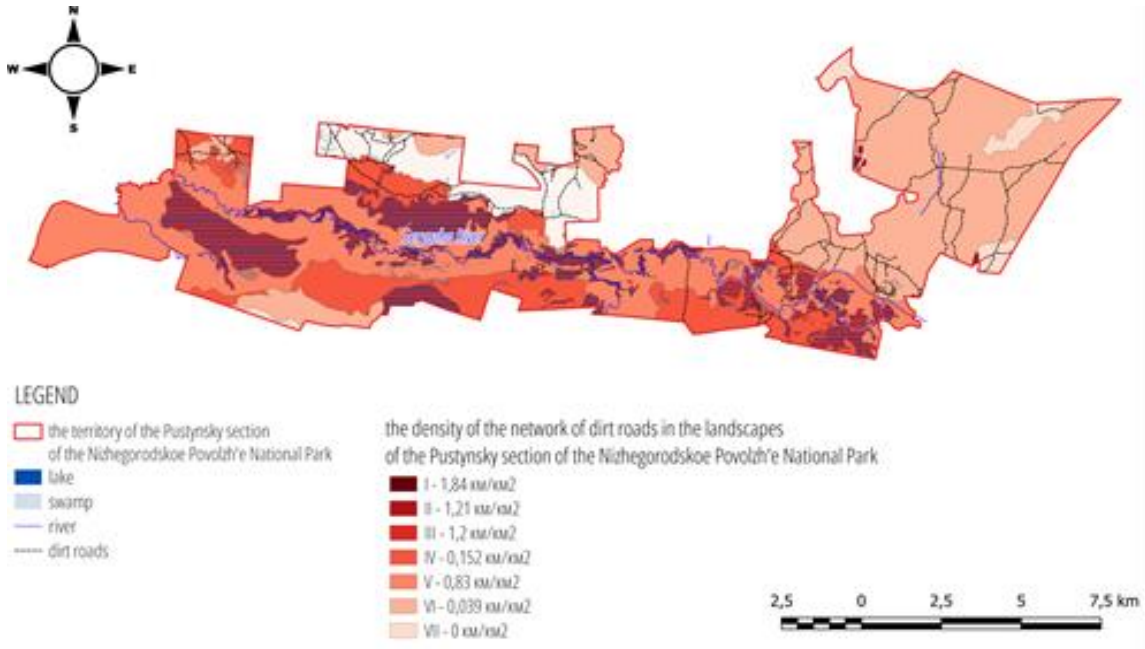

Figure 3. The density of the network of dirt roads in the landscapes of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park.

The total length of the network of dirt roads on the territory of the Pustynsky section is 102 km. The values of the density of the dirt road network vary significantly in different landscapes and are determined by the landscape situation – drainage, the presence of attractive objects (lakes, picturesque landscapes, rivers, etc.) (Table 1).

RESULTS AND DISCUSSION

Despite the nature protection regime in force on this territory for about a century (from 1934 to 2024 there was a Pustynsky reserve (Government of the Nizhny Novgorod Region, 2013), in 2024 the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park was established on its basis (Government of the Russian Federation, 2024)), natural complexes were subjected to anthropogenic influence in various forms – from recreation and tourism to harvesting forests. Any economic use of the territory presupposes the presence of a person, which means the inevitable emergence of a network of roads (Bazhina, 2023; Belousova et al., 2021). In general, the more often and intensively environmental management tasks are implemented, the more extensive the road network becomes (Grigorieva and Nikulshin, 2022; Rzabay et al., 2018; Zhyrgalova et al., 2024).

Anthropogenic activity – its content and intensity – is determined by the properties of the landscape (Baidalina et al., 2024), thus, the indicator of the development of the road network is both a consequence of the influence of the landscape basis on anthropogenic activity, and a kind of landscape indicator, a property of the modern landscape, that has significant quantitative differences between neighboring landscapes (Polovchenko, 2021). The most obvious and easy-to-calculate quantitative characteristic of the development of the road network is the density of roads, expressed in the total length of roads per unit area. We have chosen km/km2 as the unit of measurement.

Being an integral indicator of the current state of the landscape, the development of the road network is also a significant factor in its transformation (Atasheva et al., 2024). The issues of anthropogenic fragmentation of the landscape and its impact on the landscape are deeply developed in the works of Jochen A. G. Jaeger and his colleagues (Jaeger, 2000; Jaeger et al., 2005; Spanowicz and Jaeger, 2019). Some experience in researching this issue has been accumulated in the Nizhny Novgorod region, on the territory of which the Pustynsky section of the National Park is located (Bakka and Kiseleva, 2017; Bakka et al., 2021a).

This paper presents the results of a comparative assessment of the density of the road network in the landscapes of the Pustynsky section of the National Park. We consider the quantitative indicator of the density of the road network as a property of the natural-economic landscape, generically characterizing the degree of its involvement in economic activity and indirectly – the degree of anthropogenic transformation.

There are 7 landscapes within the researched territory (Figure 3), indicators of the density of the road network have significant differences in landscapes: from the complete absence of roads to high indicators – 1.84 km/km2 (Table 1). Almost all roads within the researched territory are dirt.

The lowest indicators of the density of the road network are inherent in floodplains: the floodplain palustrine landscape of lowland swamps (0.039 km/km2) and the floodplain wet forest landscape under black alder community, oak forests, spruce forests and pine forests on alluvial-turf often gleying soils of various mechanical composition (0.152 km/km2). Due to the constant waterlogging, floodplain landscapes are inconvenient both for conducting economic activities and for laying roads, in which, moreover, there is no economic need inside the landscape. The same roads, which are only partially present, are mainly transit in nature.

The slightly moistened slope moraine agroforest landscape under linden-pine forests on sod-podzolic loamy soils within the Pustynsky section of the national park has no roads at all, but this circumstance is determined not so much by the specifics of the natural basis of this landscape – surface slopes, that complicate the economic development of the territory, as by the extremely small area of this landscape within the national park – only 0.24 km2. Most of the landscape, which has relatively fertile loamy soils, was not included in the national park precisely because of the high economic demand and significant transformation of landscapes, characterized, among other things, by a high density of the road network.

The wet lowland forest landscape of the first above-floodplain terrace under pine and spruce forests on sod-podzolic sandy loam soils has an average density index of the road network for the Pustynsky section: 0.83 km/km2. Due to small elevation differences, significant areas are swamped, which reduces its economic demand, including recreational and limits the possibilities of laying roads.

The maximum values of the density of the road network for the Pustynsky section are landscapes of sandy slopes and watersheds. Slightly moistened slope alluvial-fluvioglacial forest landscape under the linden-pine forests on sod-podzolic sandy soils (1.21 km/km2) and slightly moistened watershed fluvioglacial forest landscape under pine

forests on sod-podzolic sandy loam soils (1.2 km/km2), well-drained dune-karst forest landscape of the third above-floodplain terrace under pine forests on sod-podzolic sandy soils (1.84 km/km2), due to the good drainage and wide distribution of pine forests, have traditionally attracted both loggers and recreationists, including hunters, mushroom and berry pickers, tourists. Landscape features make it relatively easy to pierce dirt roads and keep them in working order.

CONCLUSION

The landscapes of the Pustynsky section of the Nizhegorodskoe Povolzh'e National Park have a pronounced heterogeneity of values of the density of the road network, which indicates a high landscape determinism of this characteristic. Being an integral reflection of economic interest, the value of the density of the road network in each landscape is formed under the influence of the characteristics of this landscape, which determine its economic relevance – as a source of raw materials (logging) or satisfaction of recreational needs.

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