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APPLICATION OF ARTIFICIAL INTELLIGENCE AND GEOINFORMATION ANALYSIS METHODS FOR ASSESSING THE ACCESSIBILITY OF GREEN SPACES IN AN ARCTIC MONOTOWN (THE CASE OF SEVERODVINSK)

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Annotation. **Introduction.** Arctic single-industry towns operate under extreme climatic conditions, where access to recreational green spaces becomes a critical factor for the population's physical and psychological well-being, mitigating the effects of the polar night and the urbanized environment. Despite its high importance, existing methods for assessing the provision of green areas often remain expert-based and subjective. This study aims to conduct a comprehensive quantitative assessment of pedestrian accessibility to park zones in Severodvinsk, a representative Arctic monotown, using geographic information technologies and machine learning algorithms.

Methods. The research integrates GIS analysis methods (QGIS 3.40) with Python-based data processing. Using OpenStreetMap data, a database of 1,568 residential buildings was compiled, and park areas meeting landscaping criteria were identified. Buffer zones with radii of 300 m (daily accessibility standard) and 500 m were constructed to assess pedestrian accessibility. Statistical analysis and the Random Forest machine learning algorithm were applied to identify latent patterns and evaluate factors contributing to spatial differentiation.

Results. The findings reveal that only 22.5 % of the housing stock lies within the normative 300-meter accessibility zone of green spaces, while 39.2 % of buildings (544 units) are located beyond the 500-meter radius, indicating a significant deficit of recreational resources. A strong correlation was found between the year of construction and park accessibility, with the most acute deficiency observed in residential districts developed during the mass construction period of the 1970s-2000s. Comparative analysis of the city's 1967 and 2024 master plans demonstrates a transformation in functional zoning, notably the development of areas originally designated as park zones.

Discussion. The obtained data confirm the hypothesis of spatial inequality in the distribution of "green" amenities and underscore the necessity of shifting from a residual approach to landscaping towards targeted planning of recreational zones. The applied methodological approach proved effective as a tool for objective urban environment auditing. The results provide a scientifically grounded basis for adjusting urban planning policies in Severodvinsk and can be scaled to other Arctic single-industry towns to implement the principles of the Urban Equity concept.

Keywords: Arctic, monotown, urban environment, green spaces, park accessibility, GIS, QGIS, artificial intelligence, machine learning.

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Оригинальная научная статья
ВАК 5.5.3. Государственное управление и отраслевые политики

ПРИМЕНЕНИЕ МЕТОДОВ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА И ГЕОИНФОРМАЦИОННОГО АНАЛИЗА ДЛЯ ОЦЕНКИ ДОСТУПНОСТИ ЗЕЛЁНЫХ ПРОСТРАНСТВ В АРКТИЧЕСКОМ МОНОГОРОДЕ (НА ПРИМЕРЕ СЕВЕРОДВИНСКА)

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Аннотация. **Введение.** Арктические моногорода функционируют в экстремальных климатических условиях, где доступность рекреационных зелёных пространств становится критическим фактором физического и психологического благополучия населения, компенсирующим воздействие полярной ночи и урбанизированной среды. Несмотря на высокую значимость, существующие методы оценки обеспеченности зелёными зонами часто остаются экспертными и субъективными. Целью данного исследования является комплексная количественная оценка пешеходной доступности парковых зон в Северодвинске – типичном арктическом моногороде – с применением геоинформационных технологий и алгоритмов машинного обучения.

Методы. Исследование базируется на интеграции методов ГИС-анализа (QGIS 3.40) и обработки данных на языке Python. На основе данных OpenStreetMap была сформирована база данных из 1 568 жилых зданий и идентифицированы парковые зоны, соответствующие критериям благоустройства. Методом буферизации построены зоны пешеходной доступности радиусом 300 м (норматив повседневной доступности) и 500 м. Для выявления скрытых закономерностей и оценки факторов пространственной дифференциации применён статистический анализ и алгоритм случайного леса (Random Forest).

Результаты. Установлено, что лишь 22,5 % жилого фонда находится в зоне нормативной 300-метровой доступности от зелёных зон, тогда как 39,2 % зданий (544 объекта) расположены за пределами 500-метрового радиуса, что свидетельствует о значительном дефиците рекреационных ресурсов. Выявлена сильная корреляция между годом постройки и доступностью парков: наибольший дефицит характерен для микрорайонов массовой застройки 1970-2000-х годов. Анализ генеральных планов города 1967 и 2024 годов показал трансформацию функционального зонирования, в частности застройку территорий, изначально предназначенных под парковые зоны.

Обсуждение. Полученные данные подтверждают гипотезу о пространственном неравенстве в распределении «зелёных» благ и необходимости перехода от остаточного принципа озеленения к целевому планированию рекреационных зон. Применённый методологический подход доказал свою эффективность как инструмент объективного аудита городской среды. Результаты исследования формируют основу для корректировки градостроительной политики в Северодвинске и могут быть масштабированы на другие арктические моногорода для реализации принципов концепции справедливого городского развития (Urban Equity).

Ключевые слова: Арктика, моногород, городская среда, зелёные насаждения, парковые зоны, доступность парковых зон, ГИС, QGIS, искусственный интеллект, машинное обучение.

Информация о финансировании: данное исследование выполнено без внешнего финансирования.

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Introduction

Russian Arctic single-industry towns, serving as key outposts for the country's economic and geopolitical presence, face a complex set of challenges stemming from harsh climatic conditions, economic mono-specialization, and a deficit of quality urban environment. In this context, the accessibility of recreational facilities, particularly green spaces, becomes a critically important factor for the population's physical and mental well-being. The lack of green areas within walking distance exacerbates the psychological strain caused by the polar night and the urbanized setting.

Recreational zones constitute a multifunctional resource of the urban environment and are in demand among various social groups due to the beneficial impact of park areas on both environmental aspects, as emphasized by Tatyana Kupach [1], and social aspects, as reflected in the work of E. A. Dorozhkina [2]. From the perspective of B.A. Revich, green zones mitigate the consequences of climate risks and urbanization pressure; their presence contributes to increased physical activity, a reduction in overall depression levels, and stimulates socialization among the urban population [3].

Research objective

Given the high significance of green zones, the research objective was formulated: to assess the accessibility of green spaces in the city of Severodvinsk and to identify key factors of spatial inequality [4] – the geographical and territorial aspects of socio-economic disparities [5] – by applying GIS analysis and artificial intelligence methods.

The key concepts used in this article are "green zone" and "recreational zone."

Green zones (green spaces) are territories predominantly covered by grass, shrubs, and trees, forming the city's vegetative framework. These include protected natural areas, parks, squares, boulevards, landscaped residential and roadside plots, gardens, zoo grounds, sports fields, embankments, and other objects performing ecological, recreational, and aesthetic functions. Green zones are providers of ecosystem services: they improve air quality, regulate climate, support biodiversity, help reduce urban temperatures, and enhance population well-being [6].

Recreational zones are functional territories designated for leisure, health improvement, tourism, and the restoration of a person's physical and psycho-emotional strength. Within the urban structure, recreational zones are part of the landscape infrastructure that ensures the resilience of the urban environment. They include parks, forest parks, beaches, embankments, areas for active and passive recreation, as well as specially protected natural areas. Recreational zones contribute to the formation of a comfortable and healthy urban environment, enhancing the quality of life and the social attractiveness of a territory [7].

Research methodology

Research in urban studies, dedicated to contemporary trends in city development and their social structure, is published in journals such as "Current Urban Studies," reflecting the relevance of this topic within academic circles. In line with the digitalization policy in the construction industry, data science has become one example of the advancement of artificial intelligence and machine learning technologies, which are actively applied for analyzing big data and forecasting construction processes.

When discussing construction technologies, special attention should be paid to BIM (Building Information Modeling). In the Russian Federation, the term "BIM-modeling" is more widely known than "TIM-modeling" (the Russian acronym). Until 2019, the international term "Building Information Modeling (BIM)" was used in the construction sector, while the term "TIM" was introduced into the Russian legislative framework in 2019 [8]. This is a procedure for creating a construction object's database through the step-by-step development of intermediate information models that reflect the processed information about the object at each stage [9]. In essence, it is a set of software products and tools aimed at planning, resource accounting, analytics, and design.

According to the authors, the prospects for further research on the chosen topic lie in integrating satellite data to assess the quality of greenery (e.g., using NDVI – Normalized Difference Vegetation Index) [10], as well as employing network analysis [11] to model pedestrian accessibility routes, considering the actual street network.

The formation of the Arctic single-industry town of Severodvinsk historically combines planned development from the Soviet era and modern trends in urban

zoning. Green zones hold a special position in these harsh conditions. According to clause 3.10 of the Code of Rules "Urban Planning. Planning and Development of Urban and Rural Settlements" [12], a green zone performs protective sanitary-hygienic and recreational functions. This allows the provision of such areas to be considered an integral indicator of urban environment quality, aligning with the key tenets of the Code of Principles for the Integrated Development of Urban Territories. This standard was developed by the Russian Ministry of Construction, DOM.RF, and the Strelka Consulting Bureau under the instruction of the Chairman of the Government of the Russian Federation [13].

Traditional methods for assessing the provision of green zones are often expert-based and can be subjective. Modern technologies, such as Geographic Information Systems (GIS) and Artificial Intelligence (AI) methods, enable more objective, scalable, and reproducible analysis of spatial data. Open mapping platforms, such as OpenStreetMap (OSM), provide an extensive database for such research. However, this data requires thorough verification and post-processing, as the completeness and accuracy depend on the activity of the mapping community in a specific region and can vary significantly.

Research description

The work was conducted in the QGIS 3.40 "Bratislava" environment. Using the QuickOSM plugin, we loaded polygons of all buildings classified as residential. Due to the incompleteness of OSM data, post-processing was performed, including visual verification, geometry correction, and attribute normalization. The final database comprised 1,568 residential buildings.

Subsequently, polygons for parks, squares, and landscaped recreational areas were delineated based on strict criteria: the presence of vegetation, 24/7 pedestrian accessibility, and the existence of amenities intended for recreation.

To assess pedestrian accessibility, the buffering method was employed. Buffer zones with radii of 300 m (5-7 minutes' walk) and 500 m (10-12 minutes' walk) were constructed around each park polygon. These distances were chosen based on public health recommendations outlined in the article "Urban green spaces and health." Such buffer zones represent key pedestrian catchment areas for park territories. According to WHO recommendations, a 300-meter buffer is associated with improved physical and mental health of the population by encouraging physical activity, thereby reducing stress [14]. A 500-meter buffer is considered the optimal distance for most residents to visit green spaces on a regular basis. Furthermore, numerous studies have reported a positive association between healthy weight and the presence of green spaces within 500 m of one's home [3]. Consequently, the creation of such buffer zones is an important priority in urban planning.

Figure 1. The generated map showing parks, 300-m and 500-m buffers, and residential buildings existing as of December 2025 [compiled by the authors]
Рисунок 1. Созданная карта с отображением парков, буферов 300 м, 500 м и жилыми зданиями, существующими на момент декабря 2025 года [составлено авторами]

Thus, a GIS project was created, as illustrated in Figure 1.

According to clause 9 of the Code of Rules "Urban Planning. Planning and Development of Urban and Rural Settlements," the travel time to city and district parks by public transport (excluding waiting time) should not exceed 30 minutes for city parks and 20 minutes for district parks.

Next, a spatial join operation was performed to identify residential buildings located within each buffer zone. This allowed for the classification of buildings into three groups:

1. **High Accessibility:** Located within the 300 m buffer.
2. **Medium Accessibility:** Located within the 500 m buffer, but outside the 300 m buffer.
3. **Low Accessibility:** Located outside the 500 m buffer.

In Figures 2 and 3, the 300-meter buffers around existing park areas are highlighted with light green semi-transparent polygons. All residential buildings in Severodvinsk existing as of December 2025 are shown in light gray.

Figure 2. Areas of high park accessibility in the central part of Severodvinsk [compiled by the authors]
Рисунок 2. Районы высокой доступности парков в центральной части Северодвинска [составлено авторами]

Figure 3. Areas of high park accessibility on Yagry Island [compiled by the authors]
Рисунок 3. Районы высокой доступности парков на острове Ягры [составлено авторами]

In Figures 4 and 5, zones falling within the 500-meter buffer but outside the 300-meter buffer are highlighted with light red semi-transparent polygons. All residential buildings in Severodvinsk existing as of December 2025 are shown in light gray.

For each group of buildings, a set of attributes was compiled: date_of_ construction (year of construction),

Figure 4. Medium-accessibility Park areas in the central part of Severodvinsk [compiled by the authors]
Рисунок 4. Районы средней доступности парков в центральной части Северодвинска [составлено авторами]

Figure 5. Medium-accessibility Park areas on Yagry Island [compiled by the authors]
Рисунок 5. Районы средней доступности парков на острове Ягры [составлено авторами]

floors (number of stories), addr_str (street), addr_house (house number). The data was then exported to .xlsx format and processed in the Google Colab environment using Python with the pandas, numpy, matplotlib, seaborn, and scikit-learn libraries.

To verify the results of the geoinformational analysis and uncover latent patterns, a comprehensive set of data processing and machine learning methods was applied.

At the first stage, data preprocessing was performed. This included cleaning the initial dataset of missing values in key fields ("year of construction," "number of stories") and categorizing buildings into historical periods of development, resulting in four chronological strata: "pre-1960" (Stalinist period), "1961-1980" (industrial construction), "1981-2000" (late Soviet period), and "post-2001" (modern construction).

At the second stage, statistical analysis was conducted. This involved calculating descriptive statistics for quantitative indicators, analyzing the distribution of buildings by accessibility category within each historical period, and testing the statistical significance of differences between groups using the chi-square (χ^2) test. This statistical tool confirmed the hypothesis that green space accessibility in Severodvinsk is uneven and depends on the specific street location.

To quantitatively assess the contribution of various factors to green space accessibility, the Random Forest

machine learning method was employed. The target variable was the green space accessibility category, while the features for prediction were the year of construction and the number of stories. The model was trained on 70 % of the data, with validation on the remaining 30 %. Feature importance was evaluated based on the Gini impurity reduction index – a metric used to measure inequality or impurity within datasets. This comprehensive approach not only revealed visible patterns but also quantitatively assessed the influence of various urban planning factors on the formation of accessible green infrastructure, providing a reliable foundation for subsequent urban planning decisions.

Research results

The GIS analysis and subsequent data processing yielded a precise quantitative assessment of the residential housing stock's provision with green spaces, presented in Figure 6.

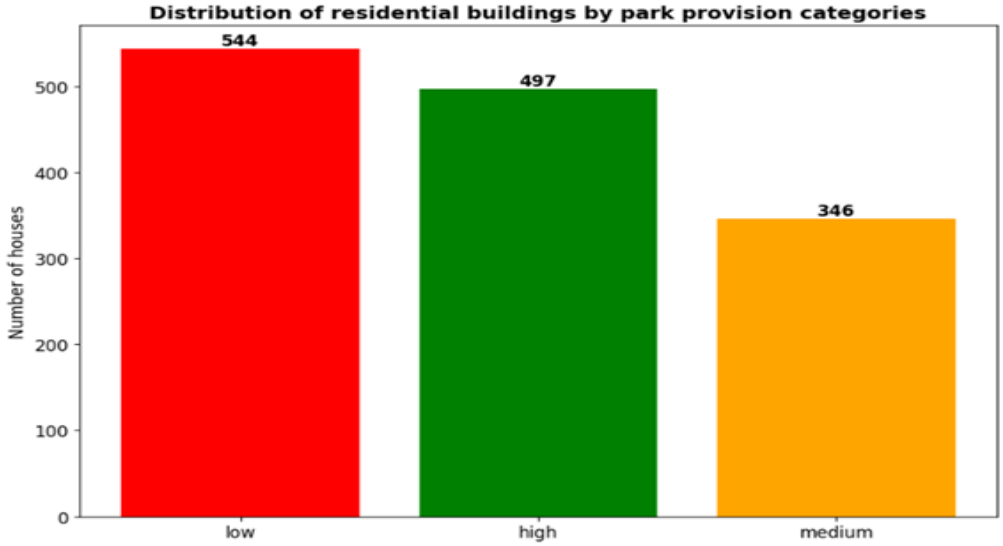

Figure 6. Distribution of housing by park provision categories [compiled by the authors]
Рисунок 6. Распределение домов по категориям обеспеченности парками [составлено авторами]

The obtained data reveal a significant imbalance in green space provision: almost 40 % of the city's housing stock (544 buildings) is located beyond a 500-meter walking distance from parks and squares. The standard 300-meter accessibility is ensured for only 35.9 % of buildings, indicating a need for targeted improvements for over 60 % of the housing stock.

Aggregating data at the street level allowed for the identification of specific areas most acutely in need of recreational resources and revealed statistically significant patterns.

The data in Table 1 demonstrate the focal nature of the problem. Streets with low accessibility, such as Morskoy Prospekt (78 buildings) and Lomonosova Street (55 buildings), represent large residential areas requiring priority attention.

Notably, Lomonosova Street appears in both the "Medium" and "Low" accessibility categories, highlighting the internal heterogeneity of extensive urban thoroughfares and the need for a detailed planning approach.

Figure 7 presents a matrix visualizing the distribution of residential buildings across different height categories relative to levels of urban infrastructure provision. The color gradient indicates the proportion of buildings within each category, with more saturated shades of red corresponding to a higher number of objects in a given combination of building height and provision level.

The analysis clearly indicates that 3-5-story buildings occupy a leading position: they dominate across all provision categories, particularly in the high-provision zone (over 70 % of buildings in this group). This can be attributed to the fact that such buildings constitute the foundation of the city's residential development – they are the most widespread both in terms of area and quantity.

Notably, buildings with 6-9 stories predominantly demonstrate low provision levels, as a significant portion of such structures are located in areas with underdeveloped infrastructure (e.g., on the urban periphery or in residential

Table 1. Street ranking by green space accessibility level (Top 3 for each category) [compiled by the authors]
Таблица 1. Рейтинг улиц по уровню доступности зелёных пространств (Топ-3 по каждой категории) [составлено авторами]

Street	Accessibility Category	Number of Buildings	Average Number of Floors
Prospekt Truda	High	38	5.0
Tortseva Street	High	35	4.0
Karla Marksa Street	High	34	5.2
Prospekt Pobedy	Medium	27	6.6
Lomonosova Street	Medium	21	6.4
Mira Street	Medium	20	4.1
Morskoy Prospekt	Low	78	5.8
Lomonosova Street	Low	55	5.6
Konovalova Street	Low	23	5.5

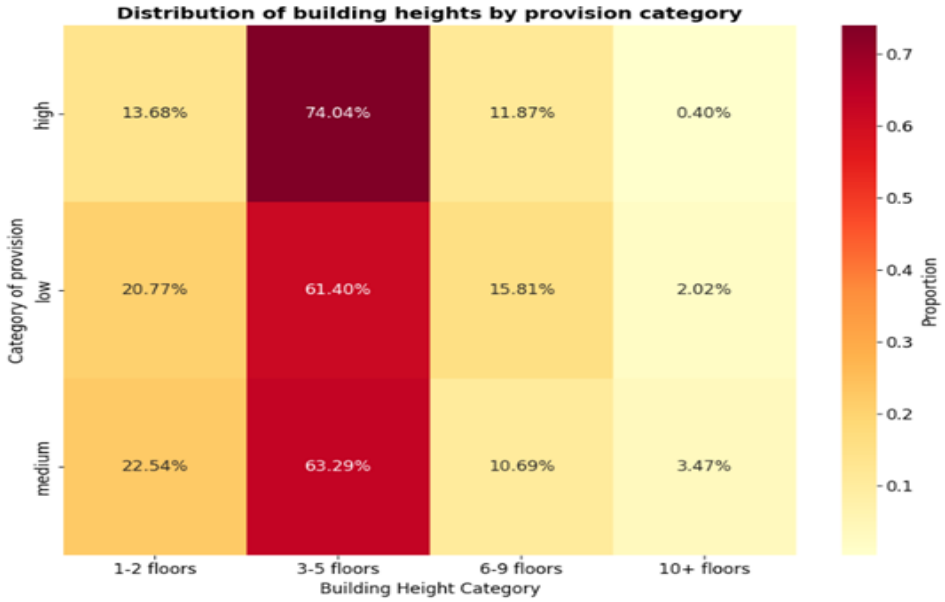

Figure 7. Distribution of building heights by park area accessibility categories [compiled by the authors]
Рисунок 7. Распределение этажности по категориям доступности парковых зон [составлено авторами]

dormitory districts).

A similar pattern is observed for 1-2-story buildings and structures exceeding 10 stories: they most frequently fall into the medium-provision category. This is due to the fact that low-rise buildings are typically found in mixed-use areas – older, individually developed neighborhoods where infrastructure exists but is often unevenly distributed. The 10+ story group, on the other hand, generally consists of modern point-type buildings constructed within the already established urban fabric, though not always in close proximity to key infrastructural nodes.

The matrix enables the identification of not only the quantitative predominance of specific building types but also the general pattern of urban infrastructure provision as it relates to building height. This illustrates the relationship between the type of residential environment and the degree of its integration into well-developed urban infrastructure.

The conducted study successfully achieved its objective of comprehensively assessing green space accessibility in Severodvinsk using modern geoinformation analysis and artificial intelligence methods. The research demonstrated the effectiveness of the proposed methodological approach, which offers key advantages in terms

of reproducibility, automation, and transparency through the use of open data and software tools.

The study substantiated the high socio-ecological significance of this issue for Arctic single-industry towns, where access to recreational resources is a critical factor in mitigating the effects of harsh climatic conditions and a mono-specialized economy. The hypothesis that traditional expert assessment methods require supplementation with objective, quantitative, and scalable approaches was confirmed.

The materials and methods applied proved effective at all stages of the research. The use of OpenStreetMap data in combination with QGIS 3.40 enabled the creation of a representative spatial database of the housing stock and green zones, despite the need for subsequent verification and cleaning. The buffering method with radii of 300 and 500 meters, based on international and Russian standards, proved effective for the initial assessment of pedestrian accessibility. Integration with the Python programming language and data analysis libraries (pandas, scikit-learn) facilitated in-depth statistical analysis and enabled the application of machine learning algorithms, thereby extending the research beyond purely cartographic analysis.

The analysis of the results revealed systemic issues in the urban planning organization of Severodvinsk. An illustrative example is the implementation of the "Kvartal 100" residential complex project – a comfort-class residential development in Severodvinsk constructed by the developer "Akvilon Group."

Figure 8. Fragment of the 1967 city development master plan [Photo from the collections of the Severodvinsk City Museum of Local Lore]
Рисунок 8. Фрагмент генерального плана развития города от 1967 года [Фото из фондов Северодвинского городского краеведческого музея]

Analysis of the 1967 master plan for Severodvinsk revealed that the area currently occupied by the "Kvartal 100" residential complex was originally designated as a landscaped park zone with sports facilities.

As of 2024, and to the present day, the area in question is designated as a zone for high-rise residential development (Figure 9, 10). It is important to note that the realization of the proposed park could have significantly improved accessibility levels in the vicinity of the intersection of Morskoy Prospekt and Lomonosova Street.

A comparative analysis of the master plans leads to the conclusion that the location of the residential complex in Severodvinsk's central district limits opportunities for creating fully-fledged recreational zones, manifesting as an imbalance between residential development and green spaces. Despite declared allocations of significant areas for landscaping, the practical implementation of green zones often fails to meet residents' needs for quality and functional greenery. Increasing development density within limited space creates risks of deteriorating microenvironmental parameters – from reduced air quality to increased noise pollution – a concern especially critical considering WHO recommendations

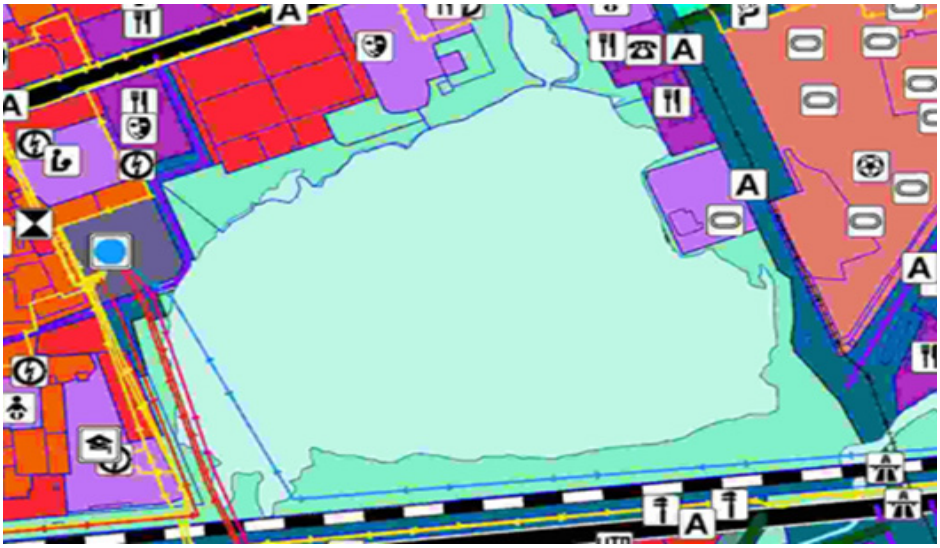

Figure 9. Fragment of the master plan for the same area from 2024 [compiled by the authors]
Рисунок 9. Фрагмент генерального плана той же территории от 2024 года [составлено авторами]

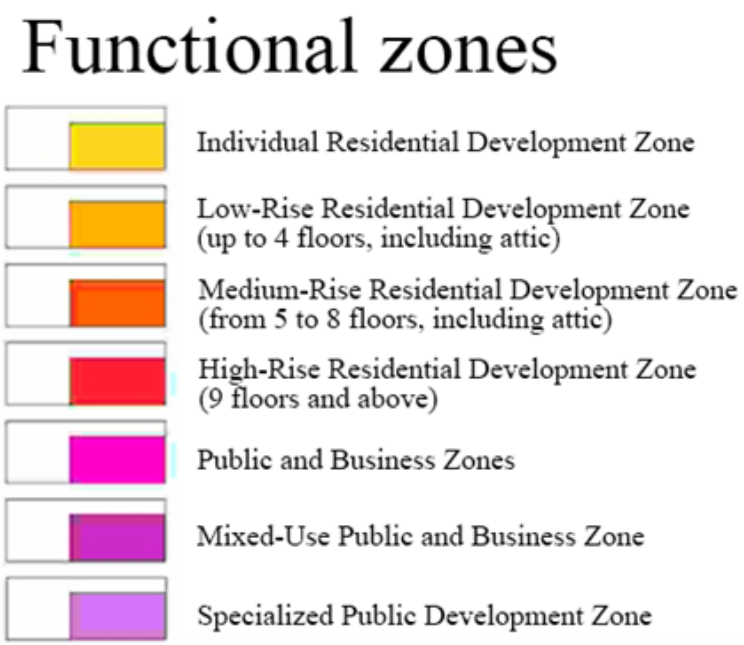

Figure 10. Legend for the 2024 master plan [compiled by the authors]
Рисунок 10. Легенда к генеральному плану от 2024 года [составлено авторами]

for green space provision within a 300-500 meter radius. Thus, urban planning decisions within the project framework are made under conditions of an objective conflict between economic demands for land-use efficiency and urban planning standards for creating comprehensive recreational infrastructure. This circumstance poses significant risks to achieving declared urban environmental quality parameters.

Summarizing the above, the quantitative assessment (Figure 7) clearly demonstrated that only 35.9 % of Severodvinsk's housing stock meets the normative 300-meter accessibility to parks, while 39.2 % (544 buildings) are in a low-accessibility zone (>500 m), indicating a significant deficit in environmental justice.

Specific problem areas were identified, such as Morskoy Prospekt and Lomonosova Street, which contain the highest concentration of buildings with low accessibility. A key finding of the study was the absence of a significant correlation between building height and accessibility (p-value = 0.1608), refuting a simplistic view of the problem and proving its roots are in planning, not structural design.

A new analysis of the influence of urban layout structure, replacing the initial historical analysis, revealed a fundamental

dependency: the type of street network is the key accessibility factor. It was established that in neighborhoods with a regular (grid) layout, the share of buildings with high accessibility (42.3 %) is more than double that in areas with a free, irregular layout (19.7 %). This finding has direct practical implications for urban design, emphasizing that a compact and structured street network is, in itself, a tool for enhancing the accessibility of urban amenities.

Discussion

Thus, the study holds not only theoretical but also high practical significance. The developed methodology serves as a replicable tool for auditing the urban environment of any settlement. The obtained results form a scientifically grounded basis for developing targeted programs for recreational zone development, for targeted interventions in identified problem areas, and for considering layout factors in the design of new developments.

Prospects for further research include deepening the analysis through the use of satellite vegetation indices (NDVI) to assess the quality of greenery and applying Network Analysis to model routes based on the actual street network, which will yield even more precise and practice-oriented results.

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