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Green spaces as an indicator of urban sustainability in the Arctic cities: case of Nadym

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Abstract

Green spaces have recently received wide acknowledgement for urban sustainability benefits and are mentioned in the Sustainable Development Goals SDG Target 11.7. However, the indicators used for assessment of green spaces for urban sustainability in the Arctic have not received much scholarly attention. The article aims to address this knowledge gap using an example of Nadym, Russia which is illustrative of compact cities built during the Soviet time using a system of *microrayons*. Different indicators implemented by international organizations for assessment of green spaces are compared with indicators used in Russia. Utilizing very high-resolution WorldView-3 satellite image and open source data, the quantity and quality of green spaces are estimated with high accuracy. Availability, accessibility, governance, distribution, and composition of green spaces are assessed using indicators of share of green space per capita, share of public spaces for common use within walking distance, municipal budget allocation for green space maintenance, and Normalized Difference Vegetation Index values. The results of the study

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Key words: green spaces, Arctic city, sustainability, indicators, high-resolution remote sensing

1. Introduction

Green spaces play an important role in urban sustainability, which is recognized in the United Nation Millennium Sustainable Development Goals (UN SDG). The UN SDG Target 11.7 specifies: "By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities." (Sustainable Development Goals 2020). According to the definition by UN-Habitat (2018a), the size and quality of the public spaces could be considered as a good indicator of shared prosperity. While all public spaces have to be socially inclusive, integrated, connected, and safe, the green spaces play the main role in making the city environmentally sustainable by regenerating ecological systems, restoring environmental connectivity and supporting biodiversity in urban areas (UN-Habitat, 2019). WHO has listed physical activity, social and psychological well- being, improved air quality and reduced exposure to noise among the benefits of open green spaces (WHO 2010).

Green spaces are known for provision of diverse ecosystems services (Campbell et al., 2016; Gómez-Baggethun & Barton, 2013; Haines-Young & Potschin, 2018), mitigating urban heat island effects (Aram et al., 2019; Koch et al., 2020), fulfilling human social and psychological needs (Chiesura, 2004), stress mitigation (Fan, Das & Chen 2011), and increasing life satisfaction in general (Krekel, Kolbe, & Wüstemann, 2016). The importance of green spaces is even more emphasized if counted as part of social infrastructure in the cities (Latham & Layton, 2019). Researchers found highly important effects of the spatial distribution and abundance of urban vegetation on a variety of biophysical processes of the urban environment (Yu et al., 2004). Access to parks and green space became especially appreciated during the COVID-19 (Slater et al., 2020).

While the data on green spaces is rarely available in municipalities there is growing application of remote sensing used for assessment of availability, accessibility, composition, and distribution of green spaces. Remote sensing methods and remote sensing data of various types are widely used in the analysis of vegetation cover in cities (Ciesielski and Sterenczak, 2019; Li et al., 2019), including ultra-high resolution data (QuickBird, WorldView-2, WorkdView-3) that are used to calculate vegetation indices, identify vegetation types, tree heights, evapotranspiration rates, and short-term and long-term changes (Fang et al., 2020; Li et al., 2015; Nouri et al., 2014; Vigneshwaran and Vasantha Kumar, 2019).

Meanwhile, the role of green spaces for urban sustainability has not been in the focus of the Arctic urban studies. Researchers emphasize the need to consider specific conditions for sustainability of the Arctic cities due to specific permafrost, remoteness, and rapid climate change conditions (Berman & Orttung 2020). Green spaces are the places that need more scrupulous analysis for the Arctic conditions. In comparison with cities in temperate zones, the role of green spaces may be different, which some researchers acknowledge as the need to focus rather on winter cities – planning efforts to improve well-being during the cold season than short summer season (Pressman, 1996; Chapman et al. 2017).

The question of green spaces gets even more nuanced when we follow a resilience approach to sustainability studies. Specificity of this approach is in its focus on self-organizing systems composed of independent agents interacting at local scales (Anderies, 2013). In extreme climatic conditions the question arises how resilient the green spaces are themselves before the question how they support urban sustainability. Thinking about green spaces as a green infrastructure leads to another question: how their governance is possible in a bottom-up fashion and whether the urban ecosystems are able to function in a self-regulating fashion. As many other infrastructure objects, green spaces require investment that benefits human well-being and provides diverse ecosystem services (Frischmann 2012). According to UN-Habitat (2019), maintenance of public spaces continues to be the main issue. Therefore, important questions arise about the municipal budget allocated for maintenance of green spaces and their self-regulating qualities.

This paper addresses the issues of green spaces as an indicator of urban sustainability in the Arctic cities using an example of Nadym, Russia based mostly on remotely sensed and open source data. The Russian Arctic cities are illustrative in a way that they are much more populated and compact in comparison with other Arctic cities (Orttung et al, 2020). Another unique trait of Russian Arctic cities is in popularity of dachas - individual plots of land where households grow vegetables or use for recreational purposes (Stammler, Sidorova, 2015). In addition to specific climatic conditions, researchers take into account the questions of green space development as a Soviet legacy (Dushkova, Haase, & Haase, 2016).

Researchers of Nadym found an important role that green areas play in microclimate regulation, protection from noise, wind, dust, and exhaust gases (Kirilyuk, 2006). The development of derived phytocoenosis on the territory of the city has not been specially studied, however, researchers noted increasing occurrences of invasive species, both ruderal and wild cultivated (Pismarkina, 2019). These occurrences researchers link to the general trend of Arctic greening with penetration of southern species to the north with global warming (Pismarkina & Bystrushkin, 2019). In addition, researchers note that residents of the city, who came from other, more southern regions, bring more southern plants in the urban landscape (Ezau & Miles, 2016).

The paper has the following structure. First, we give an overview of existing indicators of green spaces for urban sustainability implemented by international organizations for assessment of green spaces and compare them with indicators used in Russia. Second, we give a description of the study area and the methods used for studies of green spaces, which include analysis of very high-resolution WorldView-3 satellite image and open source data. Further we estimate the quantity and quality of green spaces: availability, accessibility, governance, distribution, and composition of green spaces. In conclusion, we discuss the specifics of the green spaces in the Arctic urban sustainability research and future implications for their understanding as sources for resilience both at the local and global levels, in comparison with other cities and across countries.

2. Methodology

2.1. Green spaces as an indicator of urban sustainability

There are several indicators developed by various organizations and countries for estimating green space availability, accessibility, and quality. The indicator utilized by UN-Habitat for Urban Sustainability Goals estimates "(a)verage share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities" where the built-up area is defined as "the contiguous area occupied by buildings and other impervious surfaces." Therefore, green spaces are taken into account indirectly, through the analysis of location, size, shape and distribution of their open public spaces and streets (UN-Habitat, 2019). The list of open public space is a mix of green and grey spaces and includes the following:

- parks with proportion of green area as the principal characteristic;
- recreational areas, including playgrounds, riverfronts, waterfronts, public beaches, etc.;
- civic parks;
- squares and plazas.

Recommendations of the UN-Habitat for city-wide public space inventory and assessment start with identifying their availability (proportion of urban surface devoted to public space); distribution (spatial balance and accessibility to the population); network (a system of public spaces); and quality (comfort, access, use, users, amenities and green) (UN-Habitat, n.d.).

Developing this indicator further, the World Health Organization (WHO) Regional Office for Europe suggested an indicator methodology to measure accessibility of urban green space (WHO 2016). According to SDG, accessibility is estimated as availability of public space within 5-10 minutes walking distance (UN-Habitat, 2019). Researchers use different distances to estimate accessibility. Some researchers estimate a 300 meters maximum linear distance to the boundary of urban green spaces of a minimum size of 1 hectare for assessing public accessibility to urban green spaces (Bosch et al., 2015). The others calculate the mean Normalized Difference Vegetation Index (NDVI) value calculated within the 0.5-mile buffer area and total acreage of parks that can be accessed within a 0.5 mile walk (Fan, Das & Chen 2011).

Among other indicators important for urban decision-makers is the International Organization for Standardization's ISO 37120 Sustainable Cities and Communities—Indicators for City Services and Quality of Life, which is an attempt to compare different cities across the world (Orttung et al. 2020). Green area (hectares) per 100 000 population serves as a core indicator for urban agriculture, food security and urban planning and is comparable with the share of green areas in urban land. The measure of square meters of public outdoor recreation space per capita serves as a supporting indicator for estimations of the recreation theme and is comparable with the share of green areas for common use.

Finally, budget allocation for maintenance of green spaces is recognized as an important measurement by WHO, and for budget reasons the organization recommends the use of low-maintenance designs for green spaces (2016). UN-Habitat lists percent of municipal budget allocated to public space and assesses changes in land values around public spaces over time as indicators of fiscal soundness of the governance of urban public space (UN-Habitat, n.d.). Budget allocation for maintenance of parkland serves as an important indicator for urban planning in Canada (Labutte, 2004).

In Russia, since the Soviet time, greening works in cities have been based on centralized state standards - GOSTs (state standards) and SNiPs (building codes and regulations). The extent of green areas in the cities is regulated by SNiP 2.07.01 - 89 "Urban planning. Planning and development of urban and rural settlements". The requirements for green space planning are quite comparable with the international standards (Table 1). However, there are some differences, especially with cities in extreme climate conditions and above 58° north. While some SNiP regulations look obsolete (such as 5 parking spaces per 100 of workers near the office buildings), they still serve as a point of reference for architects and for comparative analysis.

Table 1. Comparison of green spaces indicators by UN and SNiP

Indicators	**International standards**	**SNiP**	**SNiP for settlements above 58°**
Share of green areas in urban land	30 - 35% for streets and sidewalks 15 - 20% - for open public space*	40% for a continuous system of green areas 25% - within the residential area	In accordance with regional norms
Share of green areas for common use	9 square meters of green space per individual**	6 square meters per individual	2 square meters per individual
Accessibility of city parks	% of land accessible within 400m (5 mins walk)***	15-20 minutes walk	

*UN-Habitat 2018b; World Health Organization, 2012**; ***UN-Habitat, n.d.

Urban land improvement has been part of the Soviet system of urban planning and management, especially in the Arctic. Specific requirements are dedicated to urban land improvement with the building Code, SNiP III-10-75 (Gosudarstvennyi, 1979). Governing structure of public spaces in Russia has a significant influence from the Soviet legacy when it was implemented in a top-down manner (Dushkova, Haase, & Haase, 2016). Under the city executive committees, there were *zelenkhozy* - trusts responsible for the green economy and works in cities. As a rule, landscaping was carried out in a planned manner, in accordance with the plans for the development of the national economy, which were annually approved by regional or municipal authorities. In the northern cities, local authorities often failed to achieve the recommended landscaping standards on their territory due to the difficult natural and climactic conditions of the territories: many seedlings died or did not take root well due to sandy weak soil or destruction of the soil by the wind (Stas, 2014). In addition, the improvement of young northern cities was often an afterthought against the priorities of the accelerated construction of the industrial infrastructure.

After the collapse of the Soviet Union, management of urban green spaces has undergone significant transformations and for a while it was left as a secondary concern for the municipalities concerned with dilapidated housing and heating issues (e.g. Collier, 2011; Humphrey, 2005). New impetus for development was brought by development of the priority federal project "Forming quality urban environment" to be implemented in 2016-2021 (Passport, 2016). The green spaces were not targeted directly by the project but were considered as part of urban infrastructure. In addition, in 2019, Prime Minister D. Medvedev issued an order "On approval of the methodology for the formation of the urban environment quality index" (Rasporyazheniye, 2019). According to the Order, based on a combination of 36 indicators, the cities will be classified based on favourable and unfavourable urban environment assessment. In addition to mentioned above SNiP indicators, it included the following:

- variety of services in green areas;
- attractiveness of green areas;
- state of green spaces.

Another important regulation for Arctic cities regulation is currently under development: in 2020, the Ministry of Construction and Ministry for the Development of the Russian Far East and Arctic (Minvostokrazvitiya) started to develop specific standards for urban environment taking into account specific conditions in the Arctic cities, such as the prevalence of low temperatures, strong winds, the period of polar nights, as well as the demographic situation and rotational shift-working methods (Trubilina, 2020).

2.2. Study area

The city of Nadym is located in Yamal-Nenets Autonomous Okrug at 65◦ N with a continental subarctic climate, on territories of traditional land use of the Nentsy - nomadic indigenous people (Figure 1). The first permanent settlement in this place Stary Nadym was found in 1929 (Istoriia goroda 2020). In 1949-1956, this place accommodated camps for construction workers of the Chum - Salekhard - Igarka railway (not completed and abandoned in 1956) with a railway station in Stary Nadym (Nadymskii raion 2020). With the discovery of rich natural gas reserves in the 1960s the place was chosen as a base for shift workers and in 1972 it was transformed into a city with a permanent population. Current population of the city is 44,800 (Rosstat, 2020).

Place for Figure 1.

According to the Arctic cities database (Orttung et al., 2020), it is one of the most compact cities. The city was built according to a master plan as a typical Soviet city consisting of microrayons: residential areas were formed by the “closed contour principle” to protect people from strong winds and snow, especially in winter, with schools, kindergartens, and other social infrastructure facilities located inside of the “ring” within a walking distance (Romanov 2016; Jull 2016). The walking distance according to SNiP from housing to these objects was limited to 500 meters (SNiP 2.07.01-89, 1989). In 2001 Nadym received a status of the most comfortable (благоустроенный) small city in Russia (Nadymskii raion 2020).

The vegetation around the city is characterized by sparse Siberian larch - downy birch taiga with presence of Siberian spruce, Siberian pine and lichens on a boundary with tundra (Pechkin et al 2018). It is in the area of the occurrences of aeolian sand which necessitates extraordinary efforts for greening (Gladkov et al., 2019).

The Nadym municipal area (3,700 ha) includes the city of Nadym itself and the territories of the airport, Staryi Nadym and 107th km micro-districts. Staryi Nadym was the first permanent settlement in the study area with first houses built in 1929 (Istoriia goroda 2020). By 2015, all the residents were re-settled from the old dilapidated housing from there to the city of Nadym. Beyond the city limits, the territory is mostly occupied by industrial areas, transportation and other infrastructure, small areas of individual housing and dachas, and a significant part of the city municipality is owned by the Russian Forest Service (NII PG 2017). For the research purposes, we limit our research to studies of the city of Nadym which occupies the area of 835.9 ha and is the only area in the Nadym municipal area with the residential area. account (Rosreestr, n.d.).

2.3. Materials and methods

This article uses a variety of data sources, mostly open, and methods for analyzing them. Current city boundaries were obtained from the state land cadaster (Rosreestr, n.d.). The housing area boundaries were obtained from the latest master plan (NII PG, 2017). Within the study area, there are no privately owned green spaces, therefore, all the green areas are considered as public spaces. For the analysis of public spaces of common use we referred to the list of these places, their definition, and size given in the city master-plan (NII PG, 2017).

To analyze share of green spaces in Nadym in comparison with other Arctic cities we used a dataset compiled by the PIRE project (Orttung et al., 2020) that was based on the metrics listed in the International Organization for Standardization's ISO 37120 Sustainable Cities and Communities—Indicators for City Services and Quality of Life.

We used the boundaries of the housing zone in the master plan to estimate the public spaces of common use accessibility for the calculations of the share of population within the buffer zone of 400 meters (Ergen, 2020; Fan et al., 2016). While in these studies and UN-Habitat (2018) documents all buildings within the service area are assumed to be habitable, and the population to be evenly distributed in all buildings/ built up areas, we decided to make more detailed estimations. It is especially important for the city of Nadym which has clear functional zoning with distinguished industrial, residential, public, green, and infrastructure zones. To assess accessibility, we first estimated the share of low-, mid-, and high-rise residential buildings in the city, then calculated the share of low-, mid-, and high-rise residential buildings within the green spaces for common use buffer zones (400 m), and assumed that mid- and high-rise buildings have at least two and three times more population, respectively, than low-rise buildings. The resulting indicator of accessibility is the share of population that lives within the walking distance to the green spaces for common use and distributed in the housing according to the share of low-, mid-, and high-rise residential buildings.

For the analysis of distribution and quality of green spaces we created a map of vegetation types using remote sensing data from the WorldView-3 image from 23 August 2020 (ID 10400100604C4000). The original image was pre-processed using orthorectification and pan-sharpening procedures by Polar Geospatial Center specialists to improve the quality of decoding (Imagery Processing Options –Polar Geospatial Center, n.d.). The final image contains 4 multispectral channels (B, G, R, CIR) with a resolution of 0.35 m and is cropped along the vector border of the city. To limit the analysis area, an NDVI > 0.2 mask was calculated, which includes not only dense stands, but also areas with minimal grass cover (Hashim et al., 2019). For evaluating land cover features, we used two methods. First, we created supervised pixel-based classification using the Maximum Likelihood (ML) method (performed in ArcGIS 10.4 software). Second, we segmented space image (B, G, R, CIR bands) adding NDVI thematic channel (Cavayas et al., 2012) and created object-based classification using the support vector machine (SVM) method (segmentation was performed in Orfeo Toolbox 7.1.0, classification in SAGA GIS 7.8.0) (Iabchoon et al., 2017; Zhiyong Chen et al., 2012; Sizov et al., 2020). We referred to the previous field data collection and secondary sources to validate the vegetation types from the classification process. With a total area of the vegetation mask of 382.4 hectares, the area of the standards training sample is 26.44 hectares, the area of the control sample is 9.2 hectares, which is sufficient for automated classification (Qian et al., 2014). Evaluation of overall accuracy and construction of a confusion matrix were carried out in SAGA GIS 7.8.0.

For land cover classification, 9 types of vegetation were identified: deciduous forests, coniferous forests, shrubs, natural meadow vegetation, lawns and self-seeding meadow species with high phytomass, lawns and self-seeding meadow species with low phytomass, lichen vegetation of flat-hilly bogs, algae in swampy areas and shaded areas mainly with herbal types of vegetation. The image interpretation using pixel and object-based classification yielded similar and comparable results for all classes with the exception of lichens (Figure 2).

Place for Figure 2.

Overall classification accuracy for SVM is 89.25%, which is an acceptable indicator for this algorithm (Yan et al., 2018). The accuracy for the Maximum Likelihood method is lower (64.26%), but the classification results are highly reliable for the deciduous trees, lawn, lichen classes and, in general, can be used for comparative analysis with the SVM results. The discrepancies are related to specific classification algorithms for various types of surfaces in ultra-high resolution images. In particular, single deciduous trees are more fully distinguished in pixel classification, while in segmentation, the image is generalized and assigned to a different class. To eliminate inhomogeneities and possible errors, we used the mean values of these two results.

For an analysis of population, land use changes, and municipal programs we used data from the Russian Federal Agency for statistical services (Rosstat), municipal open access documents and local Internet sources. To understand practices of green space maintenance, the third author conducted interviews with six respondents in June-August 2020. Each of the respondents is an expert in his/her specific field related to sustaining and use of open urban spaces in Nadym. They have an experience of living in Nadym and working in the field of science and municipal administration.

3. Results and discussions:

3.1. Availability

The city pushes for greening aiming to meet national standards for public green space in the urban areas. In comparison with other Russian cities in the North, the experience of green landscaping in Nadym has been generally recognized as successful. According to the results of the remote sensing data, the share of green space within the study area is 45.75%, which conforms to the SNiP standards.

Share of green area per 100,000 population is the most important indicator for urban agriculture, food security, and urban planning. According to the dataset based on the metrics of ISO 37120 (Orttung et al. 2020), Nadym with 1046.64 ha of green space per 100,000 population (or 10.4 square meters per individual) is listed as a second to the lowest on this indicator among the Arctic cities. According to our estimates, Nadym has an even lower rate: 853.54 ha per 100,000 population (or 8.54 square meters per individual) because only the area within the city limits was taken into account. In general, we find the Russian cities have lower estimates of this indicator in comparison with other Arctic cities (with exception of Magadan) which could be explained by specifics of urban planning based on the compact *microrayon* system (Figure 3).

Place for Figure 3.

Square meters of public outdoor recreation space per capita is another important indicator for comparative analysis in the Arctic cities. In Nadym, such spaces are officially distinguished as public spaces for common use and include a relict strand known locally as Cedar Grove (23.2 ha), a park named after E.F. Kozlov (Park Kozlova) (15.9 ha), Strizhov boulevard (0.7 ha), and Remizov square (0.8 ha) (NII PG 2017) (Figure 4). We can estimate that in Nadym, this kind of green spaces account for 50.6 ha which accounts for 11.3 square meters per individual (indicator used by SNiP) or 6% of the city's residential area. The indicator is lower in comparison with median data in the USA, which is 9.3% (Karayannis, 2014), and with data available on Arctic cities, where the lowest data is available in Bodø, Norway (41.25 square meters per individual) and the highest - in Whitehorse (12017.2 square meters per individual). However, it is higher than in other cities of Western Siberia where the share was as low as 2.2 square meters per individual in Surgut in 1990 (Stas', 2017).

Place for Figure 4.

Park Kozlova is the main organizing center for the city's master plans. Most of the public institutions, such as sports palace, house of culture, registry office, school, kindergarten, are concentrated around the park, and make it attractive for public use (NII PG 2017). The Cedar Grove as a valuable relic forest receives special care from local authorities who manage and maintain its tree composition. In particular, in the 1970s, it was threatened by expansion of birch trees, supposedly caused by changes in the soil structure, moisture and microclimatic conditions after the construction of multi-storey buildings nearby (Interview with the former Deputy head of the Nadym District municipality). The unwanted trees were cut down. However, such maintenance efforts have been consumed less time and fewer budget resources than artificial planting.

In addition, other green areas of recreational importance are formed on the embankment of Lake Yantarnoye, in the Yuri Topchev park in the 3rd microdistrict, the Military Glory park in the Lesnoy village and the park located opposite the Central Regional Hospital (Pechkina, 2019).

3.2. Accessibility

Accessibility to the public spaces of common use in the city of Nadym is estimated to reach 66.52 % of population (Table 2). Considering low share of green spaces in the city, this indicator is quite high due to allocation of denser population near the parks.

Table 2. Share of buildings and population within and beyond walking distance to the public spaces for common use

Residential housing	Area (ha)		% of population	
	Beyond buffer zone	Within buffer zone	Beyond buffer zone	Within buffer zone
Low-rise housing	20.87	8.27	4.64	1.84
Mid-rise housing	5.24	9.63	2.33	4.28
High-rise housing	39.73	90.54	26.50	60.40
Total	65.84	108.44	33.48	66.52

The compact organization of the city provides shorter distance to this “wilderness” which characterizes the areas at the margins and beyond the city limits. While it is in close proximity to the city, only the areas with the systems of roads and paths are accessible for the public use. For the city, covered by snow 10 months of the year, a more important consideration is not the straight distance, but whether there are paths cleared from snow or laid over the snow. Despite the efforts of the urban planners to make the city more walkable and protected from the winter winds and snow, the abundance of snow impedes walking and road transport. In winter, in the courtyards of multi-storey buildings, only narrow spaces for cars are cleared. From another side, local residents note that in winter in Nadym there are more through passages between the districts, while in summer the passages between them are limited by relief features or specially installed curbs.

3.3. Governance

In general, most of the city's efforts follow global trends and UN Habitat calls for greening cities (UN-Habitat 2019). In the 1990s, in Nadym, the city government was responsible for the landscaping. In recent decades, the department actually carries out the functions of greening spaces of the city using the services of various organizations that work on subcontracts.

Funding for management and maintenance of the majority of public spaces is provided within the objective "Raising the level and increasing the quality of the amenities of the municipality of the city of Nadym to create a comfortable and safe living environment for the population" of the municipal program "Provision of high-quality housing and communal services" started in 2014. Funding is allocated in the budgets of the Nadym municipal district and the city municipality of Nadym the major part of which, in turn, are formed by the transfers from the Yamal-Nenets regional budget. In addition, since 2018, the city authorities have developed a program called “Comfortable Urban Environment” aimed to enhance the city’s public spaces within the national program Housing and Urban Environment. Funding sources for the project implementation include subsidies from federal, regional, and municipal budgets based on the Order from the Ministry of Construction and Utilities of Russian Federation (Pasport, n.d.).

The amount of expenses on urban amenities has an irregular character that depends on availability of different funding sources and city's priorities (Figure 5). However, we can note that funding for greening activities is usually limited and forms 1-2% of the total program budget. From one side, it might mean the green areas usually do not require expensive maintenance. For example, in the 2000s the local authorities renovated the park Kozlova with an asphalt-covered system of trails, lighting system, benches and playgrounds. Designated areas for public use protect the remaining areas from additional anthropogenic impact. Once made, investment allows the park to be home for squirrels and some bird species popular among local people. From another side, the latest master-plan acknowledges the problem of absence of specific responsible organizations and facilities and equipment for greening purposes which leads to lower rate of green spaces (NII PG, 2017). Instead of managing a specific nursery for greening purposes, most of the seedlings for planting are bought from the Forest Service, the owner of the surrounding forest (NII PG, 2017). The meagerness of the budget is evident in comparison with Canada where an average parks and recreation budget is 10.8 percent of the total urban municipal budget (Labutte, 2004). In the city of Nadym we considered only a portion of one of the city programs, in comparison with the total city budget the sum would be even smaller.

Place for Figure 5.

Beyond the budget allocation, green space maintenance includes other sources of money and labour. In particular, the Park Kozlova and Cedar Grove did not exist at the original master-plan and were a bottom-up initiative of the city builders (Museum of history and archaeology of

Nadym, 2019) that is a rather unique successful movement in the history of oil cities of Western Siberia (Stas', 2014; Stas', 2017). In contrast, a top-down initiative since the Soviet period, tree planting has been practiced by employees of state and now major enterprises during various public actions, such as *subbotniki*, etc. Currently, Gazprom Dobycha Nadym organizes annual events of tree planting where their workers participate. They have also created a public space "Ecopark" in the city for environmental education purposes (Gasprom Nadym Dobycha, 2020). In addition, there are some non-governmental organizations which are active in planting trees or cleaning public spaces. Also, there are some local informal efforts of landscape greening. Mostly they are realized at the individual houses or dachas by the residents themselves or by hired landscape architects. Finally, at the margins of the city, the natural vegetation remains intact and does not require any maintenance efforts.

In private dachas and individual housings, some people could bring single seedlings from the "mainland", but usually seedlings from the southern parts of the local Russian Forest Service. As a rule, these were the neighborhoods of the villages of Yagelny, Priozerny and Longyugan. They are located much south of Nadym and the vegetation there is completely different. There are forests there that are more like not the Far North, but the mainland. Saplings were dug in the forest in the right-of-way of gas pipelines where supposedly microclimatic conditions were warmer than in other surroundings which led to better undergrowth there.

Further development of green areas is limited by lack of space: any available bare land is most likely occupied by cars due to the lack of parking spaces. Some bare land areas serve for accumulation of snow removed from streets in the winter time, that also inhibits vegetation development during the short summer. Moreover, planting often fails due to poor soils, extreme weather, and other causes.

3.4. Distribution and composition

Green spaces of Nadym have complex composition which affects the diversity of ecosystem services these spaces have capacity to provide (Figure 6). On average, 40% of vegetation is represented by deciduous and coniferous trees and shrubs. Areas of natural herbaceous vegetation occupy a slightly smaller area - about 38%, which includes forest undergrowth, artificial plantings and grassland that is the largest class in terms of area. Lichens and algae make up no more than 5% of the city's vegetation cover. Shaded areas can be attributed equally to natural meadows and lawns with low phytomass.

Place for Figure 6.

In general, residential areas in the western and northern parts of the city are better provided with green spaces than the ones in the central part. Also, vegetation composition conforms to previous studies that found development of atypical, southern plant species in the disturbed urban landscapes (Esau & Miles, 2014). Several features can be distinguished in the spatial distribution of vegetation in the city:

The *coniferous* trees are concentrated mainly in two parks (Kozlova and Cedar Grove), as well as along the western, southern and north-eastern boundaries of the city. They consist of Siberian larch, Siberian spruce, Siberian pine, and Scots pine (Pechkin et al., 2018). Mostly they have already existed in the city area before the urban development and have limited capacity for self-reproduction.

Deciduous tree species do not form large areas and are dispersed throughout the city, dominating in adjoining territories and along pedestrian zones where they were planted within greening projects. Downy birch and willows dominate among deciduous trees (Pechkina, 2019). According to experts who took part in the city's landscaping, deciduous tree species such as birch and mountain ash adapt best, while the percentage of surviving coniferous trees is low. Moreover, birch has high potential for self-reproduction in urbanized conditions.

Shrub vegetation dominates along the periphery of the city, mainly in the drainage areas of the former swamps, partially occurring in parks. The main species are represented by willow and wild rose. Blueberries, lingonberries, and shiksha (crowberry) are also found in undisturbed areas.

Natural meadow vegetation prevails in park areas and as a background community for tree species. Among the species there are sedge, bluegrass, wormwood, chamomile, dandelions, ivan tea, and tansy prevail.

Artificially planted vegetation (mainly white downy birch, different kinds of willows and flowers) is present at the main streets, squares, and courtyards (Pechkina 2019). Artificial lawns and self-seeding grasses on man-made wastelands are ubiquitous throughout the city, including the industrial zone. The areas with low phytomass rates prevail over the areas with high phytomass rate. In recent years, flower arrangements have been planted in front of the administrative buildings in the summer.

Lichens as the most vulnerable to disturbances species occupy very limited places in the city in undisturbed areas.

Algae are detected at the local natural lakes. Often, they are indicative of the water contamination. The engineering work blocked the channels supplying it with fresh water which led to paludification and destruction of fish habitat (Krasnenko et al., 2018). In addition, most of the city does not have storm sewers so runoff from the roads get to the lake.

Shade is another important part of land cover in the Arctic city. Lower temperatures in the wintertime will make them less attractive for the public.

Green spaces provide regulating ecosystem services in various ways. First, they reduce atmospheric and noise pollution. According to the research by Kirilyuk (2006), the contribution of automobile transport to the deterioration of the atmospheric air in Nadym exceeds 75%. Siberian pine and Crack willow are found the best lead concentrators in the green spaces of the city consuming 0.6 ± 0.1 mg / kg and 1.1 ± 0.2 mg / kg respectively. Siberian pine is also found to be the most resistant representative of the northern flora to the technogenic impact in Nadym. For development of green infrastructure in the city of Nadym along automobile road planting a row of low-growing plants (common juniper) near the road, and then the row of evergreen conifers (Siberian pine) and deciduous species (talnik), are distinguished by a high capacity for accumulation of technogenic elements, the latter is the most resistant to the impact of ecotoxicants (Kirilyuk, 2006). Another regulating service of green spaces is enhancing air quality. For example, bird cherry and common juniper play an important phytoncide role (Kirilyuk, 2006). Finally, in summer, trees provide shade from the sun and in winter, coniferous trees provide wind protection by blocking wind and retaining some snow on canopies while deciduous trees allow the sun to filter through. As such, trees in the park Kozlova and Cedar Grove protect their visitors and make them attractive for attendance. Presence of lichens in the city is highly important for preservation of the natural environment and biodiversity. Algae is indicative of degrading green infrastructure. According to the local experts, foul smelling water attracts bloodsucking insects and pushes away urban dwellers.

As it was noted by numerous scholars, green spaces also provide wide variety of cultural ecosystem services, such as recreation (Campbell et al., 2016; Gómez-Baggethun & Barton, 2013; Haines-Young & Potschin, 2018). The most popular Park Kozlova and Cedar Grove are more used as white spaces with snow. People are walking, sledding, skiing and snowboarding there. The paths in the park are kept cleared of snow, so some people can even ride bikes there. Children use slides in the park, make snowmen, and play snowballs. People go skiing in Cedar Grove. Artificial plantings of flowers at the main squares and boulevards also have aesthetic value.

4. Conclusions

In addition to already existing indicators of green areas and their accessibility, we find it important to take into account the issues of historical legacy and biodiversity. Local efforts to preserve natural habitats within the city limits help to diversify ecosystem services, the benefit of natural landscapes that often remains overlooked by urban planners. Based on analysis of the soviet legacies we can learn about practices of allocating land for green spaces, SNiP regulations, and *subbotniki*. However, this knowledge needs to be combined with new emerging technologies, such as vertical greening etc.

Despite limited share of green spaces, we find it significant for the existing natural conditions and compact urban built area. It was achieved both by preserving native tree species in Park Kozlova and Cedar Grove and planting introduced species in other areas. Better embedding of natural green spaces in the cities can help with decreasing maintenance costs by using the natural ecosystem services. More community-engaged research is needed to determine ecosystem services of different types of vegetation for local communities.

High resolution imagery is instrumental for distinguishing different types of vegetation based on which better assessment of green spaces contribution to urban resilience and sustainability can be made. From one side, in-situ observations and social field studies are needed to understand existing practices of use and maintenance of green spaces, social differentiation of accessibility issues for assessing endogenous factors of resilience. From another side, analysis of global environmental and institutional drivers of change is needed for assessment of internal sources of resilience to exogenous factors. For Arctic urban sustainability research, studies of green spaces have to take into account not only their use in summertime, but also in winter. It is especially important for assessment of accessibility of public spaces to consider snow removal and lighting systems. Therefore, studies of green spaces have future implications for their understanding as sources for resilience both at the local and global levels, in comparison with other cities and across countries.

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Figure 1

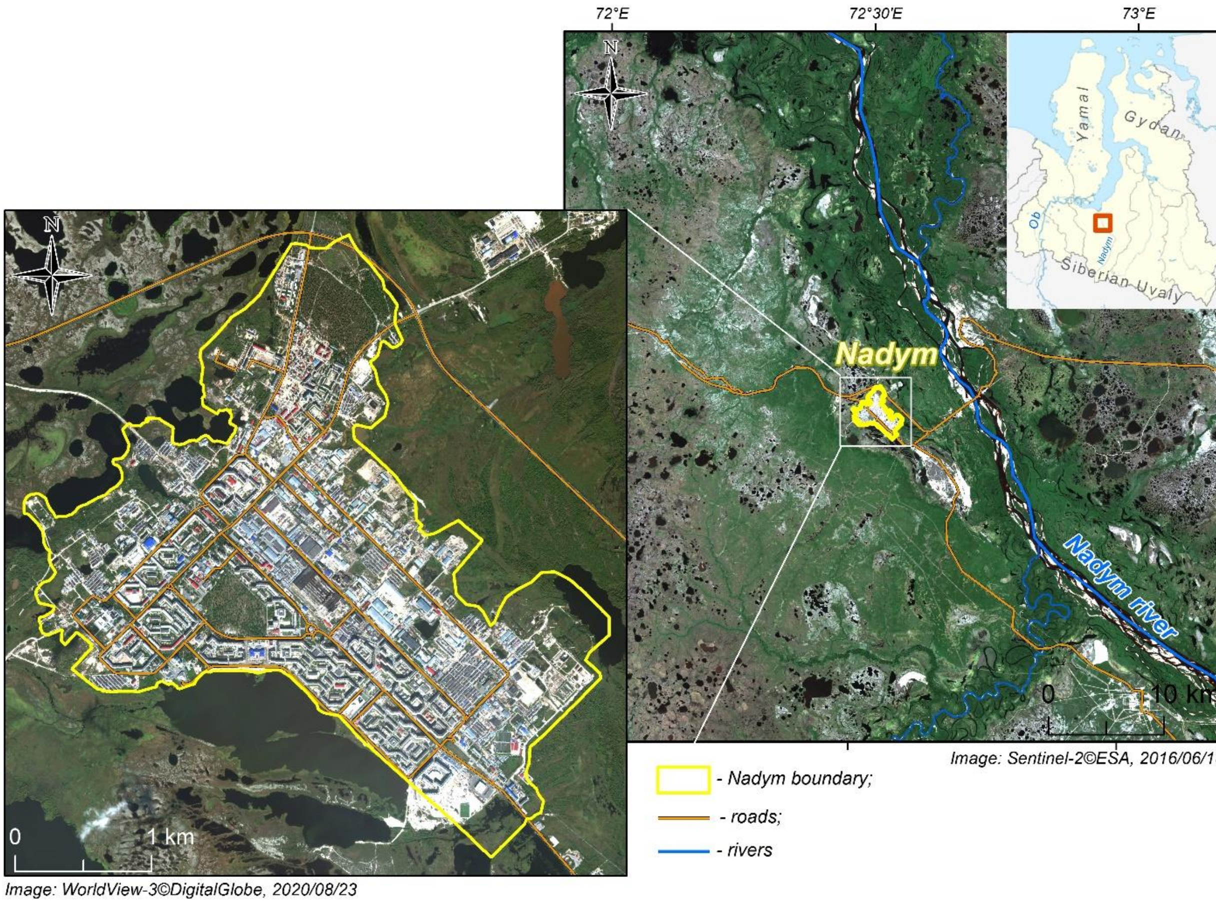

Figure 1. Study area

Figure 2

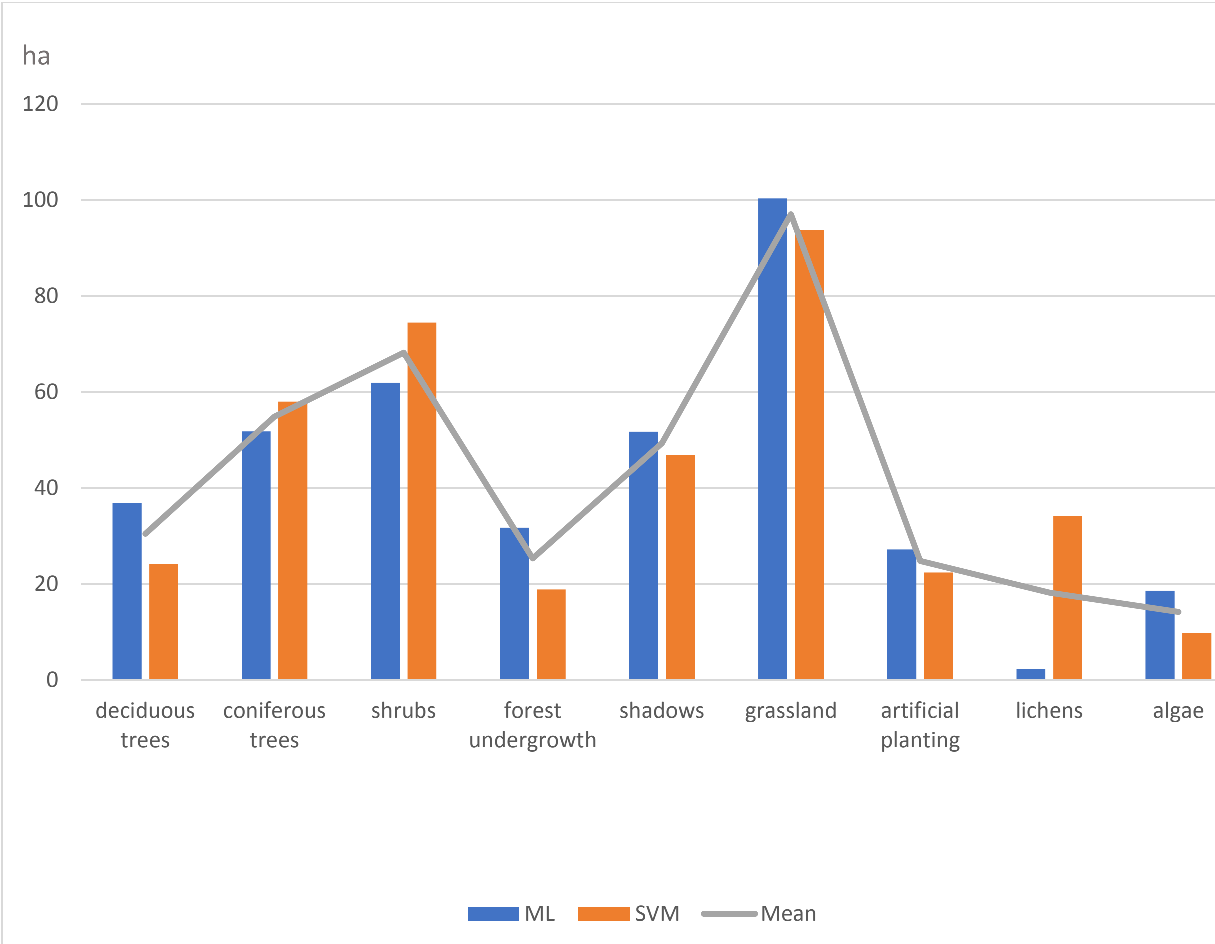

Figure 2. Comparison of ML and SVM results

Figure 3

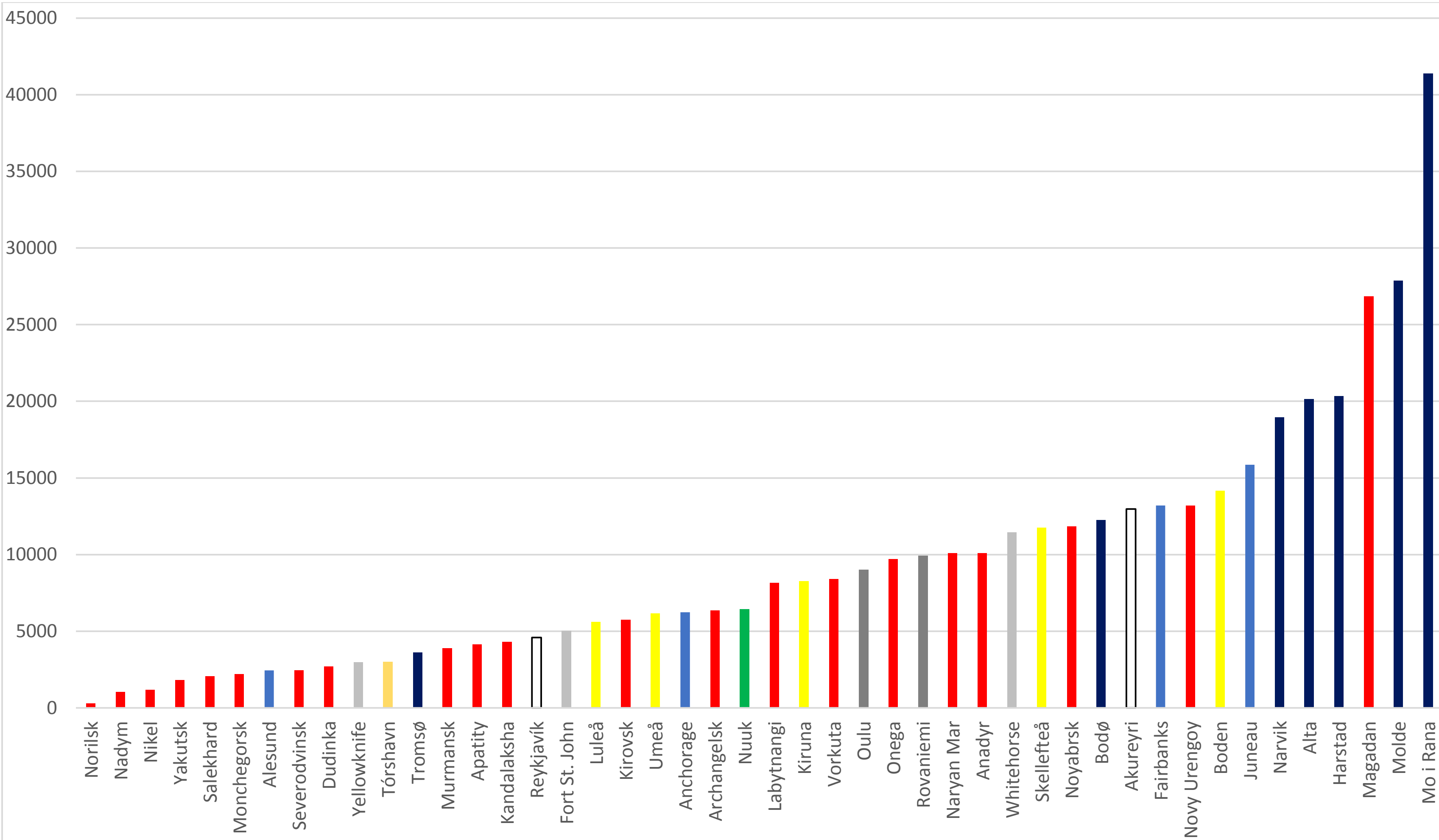

Figure 3. Green area (hectares) per 100 000 population in Arctic cities (grey - Canada; dark grey - Finland; green - Greenland; white - Iceland; black - Norway; red - Russia; yellow - Sweden; blue - USA)

Figure 4

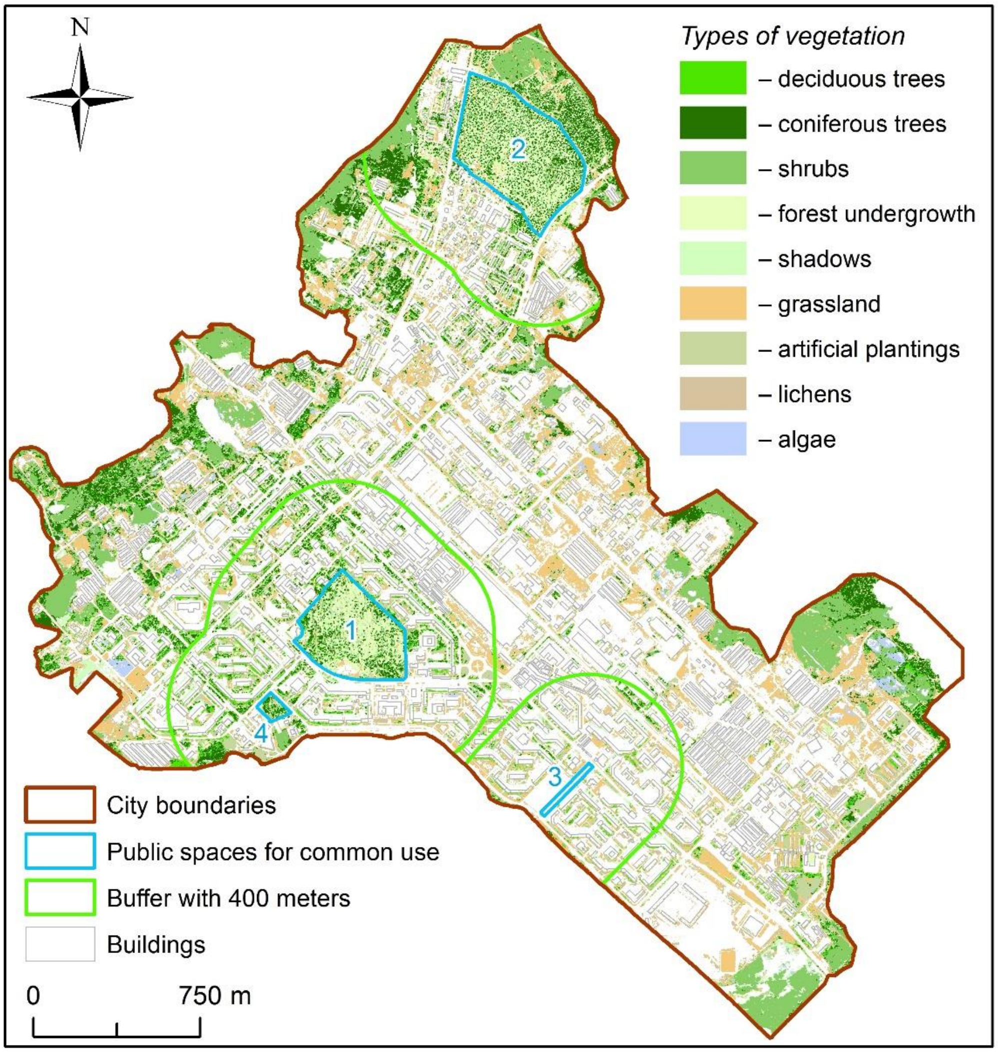

Figure 4. Accessibility of public spaces of common use and distribution and composition of vegetation cover in the city of Nadym. Public spaces for common use: 1 - park Kozlova; 2 - Cedar Grove; 3 - Strizhov boulevard; 4 - Remizov square. Data sources: WorldView-3 image (provided by DigitalGlobe via Polar Geospatial Center); City of Nadym master plan (NII PG, 2017).

Figure 5

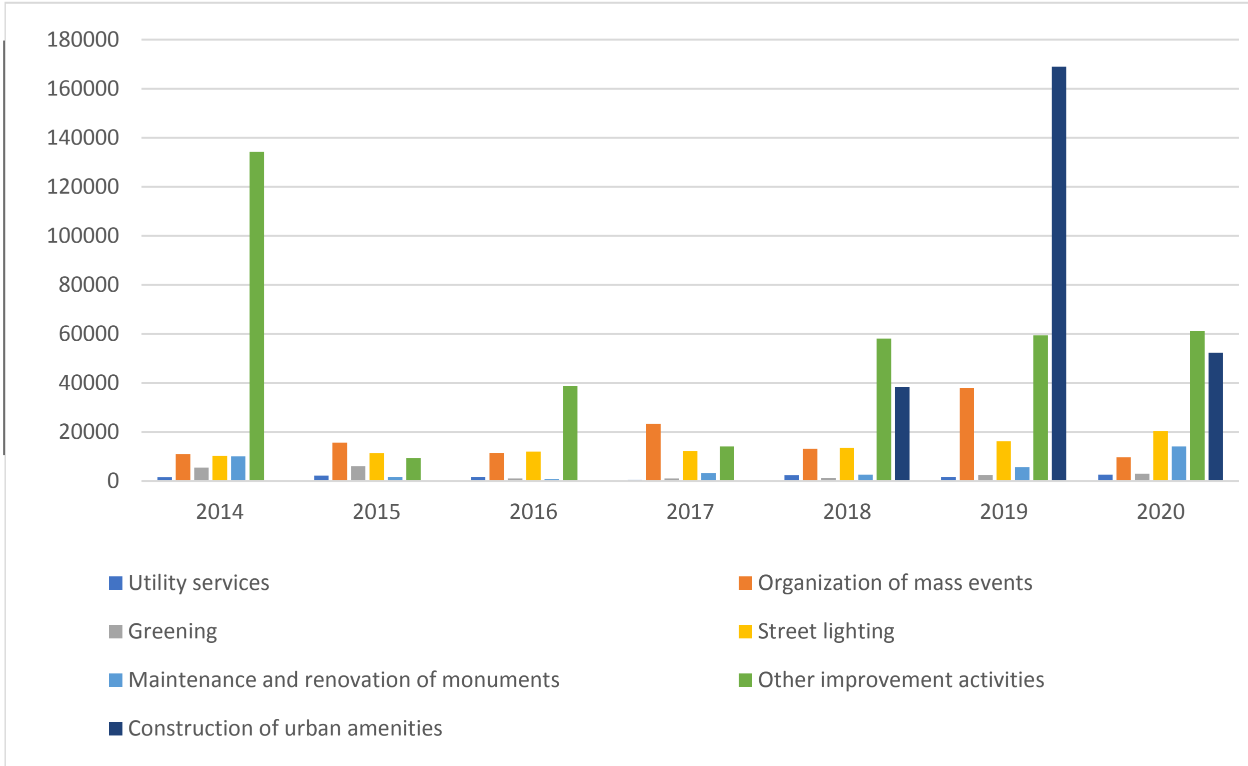

Figure 5. Dynamics of expenses within the objective "Raising the level and increasing the quality of the amenities of the municipality of the city of Nadym to create a comfortable and safe living environment for the population" of the Program "Provision of high-quality housing and communal services", thousand Rubles (from Postanovleniie, 2020).

Figure 6

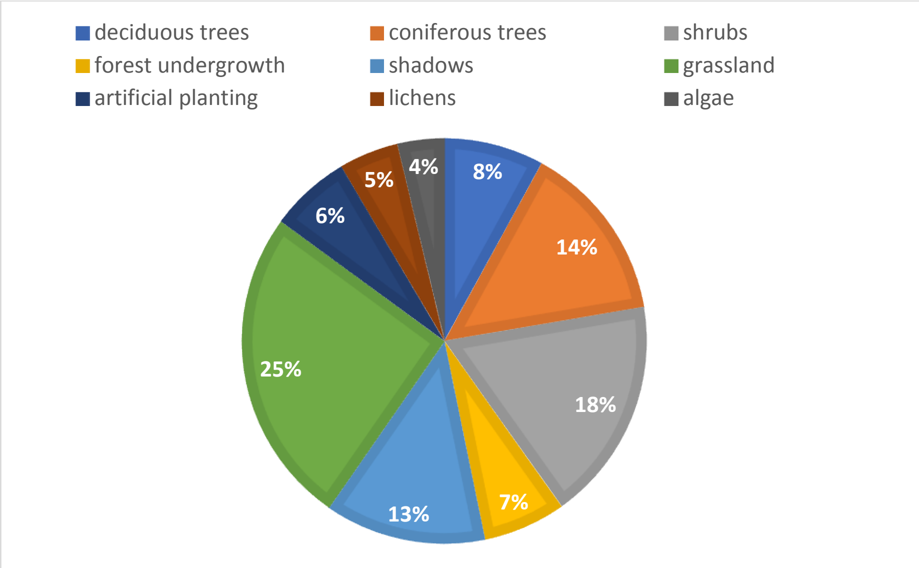

Figure 6. Green spaces vegetation composition