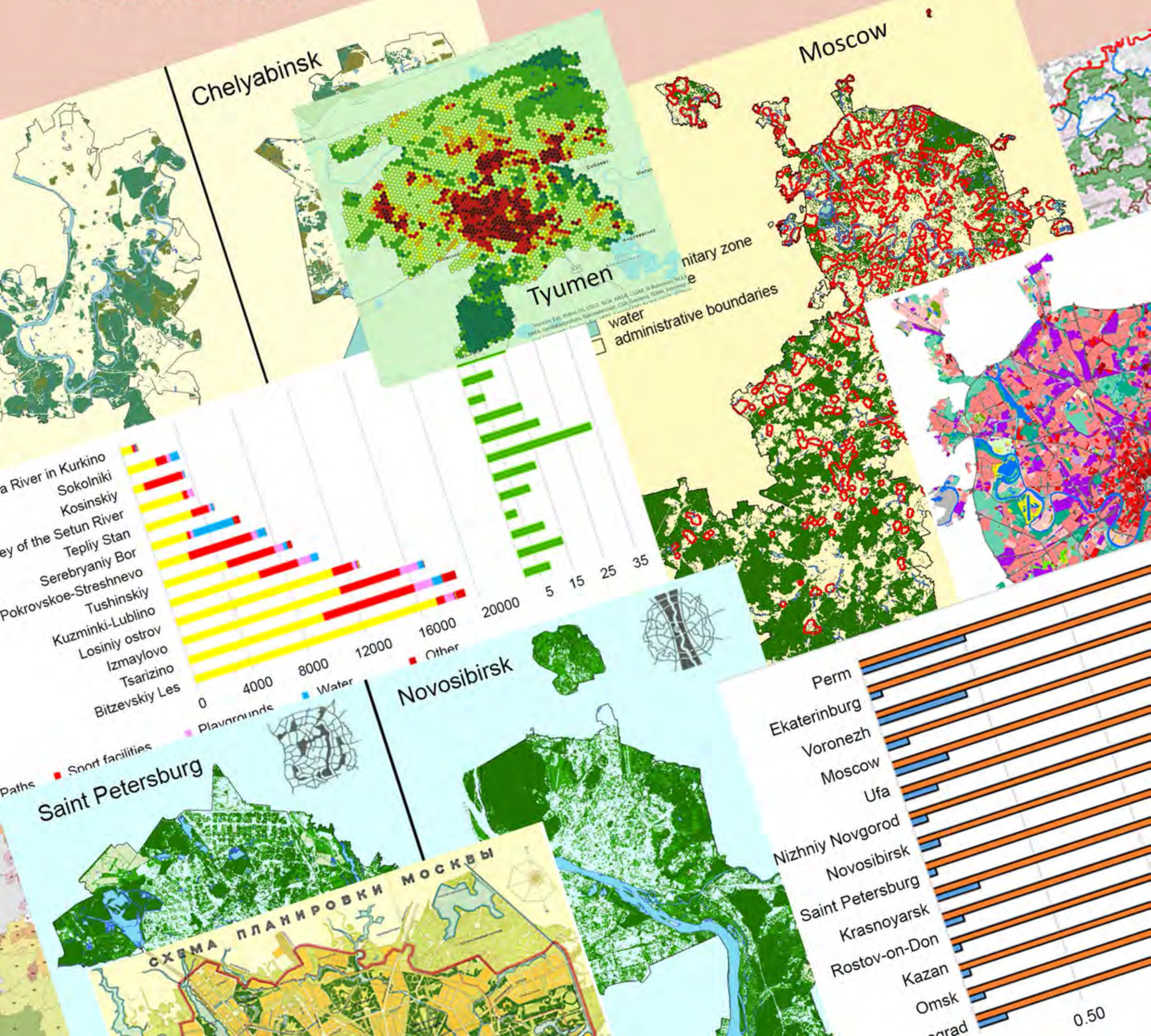
Ecosystem Services of Russia

Prototype of the National Report

Green infrastructure and ecosystem services of Russia's largest cities

TEEB-RUSSIA



TEEB-Russia

Biodiversity
Conservation
Center

Leibniz Institute of
Ecological Urban and
Regional Development

ECOSYSTEM SERVICES OF RUSSIA

PROTOTYPE OF THE NATIONAL REPORT

Volume 3
Green Infrastructure and Ecosystem Services of Russia's Largest Cities

Edited by O. A. Klimanova

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Content

Introduction

The Russian-German project "TEEB-Russia" (https://teeb.biodiversity.ru/ru/) is being conducted by the Biodiversity Conservation Center (Moscow) in cooperation with the Leibniz Institute of Ecological Urban and Regional Development (Dresden) in accordance with the decision of 23 May 2012 of the permanent Russian-German working group "Conservation of Nature and Biological Diversity". The project is supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), and by the Ministry of Natural Resources and Environment of the Russian Federation.

The TEEB-Russia project aims to develop approaches to ecosystems and ecosystem services assessment in Russia. The project is the country's first national pilot assessment of ecosystem services. The first stage of the project (TEEB-Russia 1, 2013–2015) resulted in methodological approaches to ecosystem services assessment at the national level and their pilot assessment in the form of scientific indicators for the federal subjects of Russia. The project also suggested ways to compare Russia's regions and the development of international relationships in the use and fostering of ecosystem services. The second stage of the project, TEEB-Russia 2 (2018–2019), supplemented the derived methodology by analyzing interconnected indicators of ecosystem services and biodiversity. It also established principals for the integration of ecosystem services and biodiversity indicators in the development of ecosystem accounting in Russia.

The results of the first and second stages of TEEB-Russia are presented in Volumes I and II of the Prototype National Report of Ecosystem Services of Russia, which are published in Russian[1] and English[2].

In recent years, the concept of urban ecosystem services has become an important instrument in the decision-making processes of urban spatial development or when assessing socio-economic sustainability. In Russia, the study of urban ecosystem services and biodiversity is still at a relatively early stage. There are very few publications on the topic, and these usually focus on individual aspects.

Volume 3 of the Prototype National Report on Ecosystem Services of Russia contains initial results on the assessment of ecosystem services performed by urban green infrastructure in the country's most populated cities as well as an overview of the main problems of urban biodiversity conservation in the case study of Moscow. The assessment was conducted at two spatial levels: at the city level for Russia's 16 biggest cities and at the intracity level for Moscow districts.

In this report, we define urban ecosystem services as those benefits that city-dwellers receive from urban green infrastructure. The introduction of "green infrastructure" into the system of urban spatial planning can be linked to the development of ecosystem services assessment (MEA, 2005). Following the European Commission (2013), we define urban green infrastructure as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services in urban settings. It incorporates green spaces (including forests, meadows, links, wetlands, agricultural lands, etc.) but also water bodies within the city, a complex of multifunctional vegetated areas (including forests, meadows, links, wetlands, agricultural lands, etc.) within the city. This definition does not exclude the important issue of connectivity between urban and suburban green elements when assessing the ecosystem services of urban green infrastructure (Seppelt et al., 2011). However, this interpretation allows us to distinguish between the roles of intracity green infrastructure and green belt ecosystems around the city.

To assess the state of urban green infrastructure and its ecosystem services, we made use of remote sensing data, materials from open geoportals, field/statistical data as well as relevant literature.

The report consists of seven sections. First, the aim, objectives and research methods are presented in Chapter 2, followed by the results of the analysis for Russia's 16 biggest cities in Chapter 3 as well as Moscow and Tyumen in Chapters 4 and 5. Finally, in Chapter 6, we analyze the principles of urban green infrastructure management which can safeguard the most important ecosystem services for the city and as well as preserve biodiversity.

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[1] https://teeb.biodiversity.ru/publications/Ecosystem-Services-Russia_V1_web.pdf
https://teeb.biodiversity.ru/publications/Ecosystem-Services-Russia_V2_web.pdf

[2] https://teeb.biodiversity.ru/publications/Ecosystem-Services-Russia_V1_eng_web.pdf
https://teeb.biodiversity.ru/publications/Ecosystem-Services-Russia_V2_eng_web.pdf

1. Key Messages

1. Our analysis of the current state of urban green infrastructure and its most important ecosystem services in Russia's 16 most populated cities showed that green infrastructure and ecosystem services are vital factors that determine the quality of life of city-dwellers. However, there is great variation between cities in the availability of green infrastructure and ecosystem services, with some having a very low provision. This suggests that indicators for green infrastructure and ecosystem services should be included in the decision-making processes of large cities.

We investigated Russia's largest cities, i.e. with populations over one million. These are Moscow (detailed in Section 4), Saint Petersburg, Novosibirsk, Ekaterinburg, Nizhniy Novgorod, Kazan, Chelyabinsk, Omsk, Samara, Rostov-on-Don, Ufa, Krasnoyarsk, Perm, Voronezh, Volgograd and Krasnodar (all discussed in Section 3) as well as Tyumen (Section 5). Urban green infrastructure consists of woodland and other forms of vegetation, water bodies and agricultural lands (see Sections 3.2, 5.3). The range of values for the per capita stock of green infrastructure varies widely in the studied cities, namely from 2 to 135 m^2 (according to data from the country's so-called "General Plans" for urban development). The lowest figures are found in Chelyabinsk, Perm, Rostov-on-Don and Volgograd; the highest in Ekaterinburg and Novosibirsk. The per capita extent of woodland within the city boundaries generally exceeds 100 m^2 for the considered cities; here the only exceptions are Saint Petersburg and Rostov-on-Don.

Targets on biodiversity conservation are only achieved in limited areas of urban green infrastructure via special protection measures (see Section 3.3). The share of protected area in the urban precincts ranges from 0% in Krasnoyarsk to 14% in Chelyabinsk. The share of woodland in the protected areas ranges from 1.8% in Omsk to 80% in Moscow. Protected areas in half of the analyzed cities preserve more than 10% of the tree vegetation in the city. There is no tree cover in Krasnoyarsk's protected areas.

Urban green infrastructure performs ecosystem services that directly influence the quality of life of local residents. We analyzed the key regulating services (i.e. the removal of air pollutants from point sources and automobiles, regulation of the urban microclimate, a complex of regulating services for food production) and recreational ecosystem services (i.e. the formation of natural conditions for recreation). By comparing the provided and demanded volumes of ecosystem services, we found that Russia's biggest cities are deficient in the ecosystem service of air purification (see Section 3.4). Reflecting minimum standards for the supply of green space for recreation, it can be stated that the availability of recreational services can be considered sufficient in most cases. These results, however, need careful elaboration based on the maximum recreational carrying capacity of ecosystems, which varies for different types of ecosystem, climatic conditions and recreational activities.

2. Urbanization processes, mass construction, increasing population densities and the environmentally inadequate development of transport infrastructure in Russia's most populated cities are reducing the stock of green infrastructure and consequently the supply of ecosystem services, especially in districts undergoing breakneck development. As a result, environmental indicators for the quality of life of the urban population are decreasing.

The case study of Moscow showed that, in the period between 1991 and 2014, densely built-up areas continued to expand at the expense of the city's open spaces (see Section 4.2.1). For example, the per capita stock of woodland decreased within the boundaries of what is termed "Old Moscow" (i.e. the pre-2012 urban precincts) and the city's forest-park protective belt (see Sections 4.2.3.2 and 4.2.3.4). The city's renovation program will further reduce the stock of green space, in particular destroying mature woodland aged 40–60 years, which is especially efficient in the provision of ecosystem services (see Section 4.2.3.4).

The development of transport infrastructure in Moscow and the Moscow Region without any consideration of ecosystem preservation is fragmenting suburban ecosystems and destroying links between suburban and urban ecosystems. The resulting isolated ecosystems have low sustainability, thus further endangering biodiversity (see Sections 4.2.3.2 and 4.2.3.3).

3. In addition to the decreasing area of green infrastructure per person, the ecological quality of green infrastructure elements is also deteriorating. This can generally be attributed to the weakening of natural conservation regulations for green infrastructure, the increasing recreational use of green infrastructure and inappropriate "upgrading" of green infrastructure which does not pursue the aim of preserving natural ecosystems and biodiversity. If current spatial policies on urban natural areas and suburban forest-park zones are maintained, these will further degrade ecosystems, undermining their sustainability and impairing the most important regulating, aesthetic and cognitive ecosystem services.

The case study of Moscow showed that, over the last 20 years, the consistent replacement of environmental priorities in green infrastructure management with policies favoring recreational use and the removal of limitations on economic development has negatively affected the ecological quality of green infrastructure. We can identify the most destructive processes for the sustainability and biodiversity of urban and suburban ecosystems as follows.

– A gradual weakening of natural conservation regulations of both urban green infrastructure and the suburban forest-park belt (see Sections 4.3.3.2–4.2.3.4).

– The rejection of a complex, nuanced approach to the use and protection of ecosystems in New Moscow, where currently there are no protected areas and all forests are classified as "specially protected green areas" of the city of Moscow, a status that does not foresee any special measures to conserve biodiversity (see Section 4.2.3.3).

– The widespread notion amongst local officials that green infrastructure (including protected areas) is not useful due to the provided ecosystem services which safeguard a healthy urban environment but rather that green space should be developed for sport, leisure and commercial activities. Our assessments showed that the real visitor density in protected areas with a recently established recreational infrastructure is many times larger than the recommended maximum recreational carrying capacity for forest ecosystems. This excessive load degrades natural ecosystems and lowers biodiversity in the protected areas, thus undermining the provision of all manner of environmental, aesthetic and educational ecosystem services. Further, city-dwellers are deprived of the opportunity to experience wildlife at first hand (see Section 4.2.3.4).

– The "upgrading" of green infrastructure by the municipal authorities serves to harm or destroy natural diversity. Typical upgrading measures are: the sealing of natural vegetation and soils with paving and other impermeable ground coverings, the excessive and frequent mowing of lawns, the widespread removal of fallen leaves, unprofessional pruning of trees, the harming of arboreal root systems during landscaping work, the (vertical) straightening and strengthening of riverbanks, the fencing-in of water bodies as well as the use of heavy machinery during periods of bird-nesting and animal breeding (see Section 4.2.3.4).

4. The decreasing extent of green infrastructure and deterioration of its ecological quality (see bullet points 2 & 3) actually violate the constitutional right of a significant share of the urban population to a healthy environment. This is driving public protests and awareness of the high cost of environmentally destructive methods of mass "upgrading" of the green infrastructure.

The case study of Moscow shows how urban planning policy that ignores the aim of preserving green infrastructure foments new areas of conflicts between local citizens and developers, thereby triggering fresh public protests (see Section 4.2.3.4). On the one hand, this confirms citizens' recognition of the importance of green space and ecosystem services conservation; on the other hand, it shows how governmental disregard for such concerns not only degrades green infrastructure but also undermines various socio-economic factors and the psychological well-being of local citizens.

The costs of "upgrading" urban green space – a process that actually destroys natural ecosystems – should be classified as "environmentally harmful subsidies". The rejection of such upgrading measures could save billions of rubles and help maintain the high ecological quality of the urban environment.

5. Major revisions to urban planning policy are required to safeguard the constitutional rights of citizens to a healthy environment. These should fully reflect scientifically backed standards for green infrastructure and its quality, including indicators of biodiversity and urban ecosystem services.

Through our analysis of the major problems of green infrastructure and ecosystem services in Russia's biggest cities, we can identify the following essential components of successful urban spatial planning.

– Accounting and monitoring of indicators of different green infrastructure elements (per capita and total). In view of the gaps in statistical information and the lack of structured data on the condition and dynamics of green infrastructure at the urban level, it is important to make use of remote-sensing data and public geoportals as freely available sources of information. They offer up-to-date information on the location and extent of green infrastructure elements.

– Assessment and monitoring of indicators on the condition and quality of green infrastructure. Data on the extent of green infrastructure is insufficient to safeguard a healthy urban environment: it is also necessary to consider key indicators of the quality of green infrastructure such as the level of fragmentation and biodiversity as well as the capacity of ecosystems to perform ecosystem services. By analyzing the largest protected natural areas in Moscow, we found that an increase in the planned carrying capacity of recreational infrastructure is closely connected to a rise in the fragmentation of local ecosystems (see Section 4.2.2.3), thereby weakening sustainability and the ability to preserve biodiversity or perform ecosystem services. To improve the sustainability of urban protected areas, it is vital to preserve the connections between these and with suburban natural areas. Here the concept of "green rays" (or "wedges") as laid out in the General Plans of Moscow must be maintained.

– Assessment and monitoring of ecosystem services provided by green infrastructure. Today, urban ecosystem services are assessed using a number of different methods. In this report, we tested two different approaches. The first was to assess the provided and demanded volumes of ecosystem services in case studies of Russia's 16 biggest cities (see Section 3.4) and Tyumen (see Section 5.4). The second approach was to assess the relative availability of ecosystem services provided by green infrastructure elements in Moscow's various districts and okrugs (Section 4.3). Both methods are applicable for the assessment of ecosystem services in large cities, depending on the aims and available data.

– Accounting of green infrastructure and ecosystem services indicators in urban administrative units at different levels. In some cases, satisfactory indicators for the availability of green infrastructure to the local population are ensured by large green areas on the urban outskirts. At the same time, there may be a lack of green elements in densely populated built-up districts. Examples of an uneven distribution of green infrastructure and ecosystem services within the city can be found in the administrative districts of New and Old Moscow (see Sections 4.2.1 & 4.3) and in Tyumen (see Sections 5.3 & 5.4).

– Maintaining the entire complex of ecosystem services, based on a balance of recreational opportunities and nature conservation tasks within green infrastructure management. The case study of Moscow reveals the lack of such a balance today, since the aim of increasing the recreational use of green infrastructure and protected areas comes at the expense of biodiversity conservation (see Section 4.2.3.4). This renders it difficult to achieve the established aims of this spatial policy, namely, to improve the ecological culture and quality of life of local citizens. When natural areas are replaced by recreational facilities, this makes the urban environment more monotonous and city-dwellers are deprived of close contact to wildlife. Further, the most important aesthetic and educational ecosystems are lost and there is a reduction in the ecological quality of life of citizens. The ecological culture of the population is certainly not fostered when plant and animal species are decimated by upgrading work and natural green elements are replaced by artificial objects.

– A differentiated approach to green infrastructure elements and the zoning of protected areas that takes into account the balance between recreational opportunities and nature conservation tasks. This approach enables an optimal balancing of tasks and helps to preserve the entire complex of ecosystem services. The main objective of designating protected areas is to conserve natural ecosystems with their typical diversity rather than to deliberately increase the number of visitors by building sport and leisure infrastructure.

2. Aim of the report and analytical methods

2.1. Aim and objectives

Continuing the focus of the project TEEB-Russia 2, Volume 3 aims to assess the volume of ecosystem services provided by urban green infrastructure on different spatial levels and to form adequate principles for ensuring the integration of knowledge on ecosystem services and biodiversity into Russia's official spatial planning and assessment documents on the urban environment. This work can be considered a preliminary stage for the further analysis of data on urban biodiversity and its integration into the ecosystem services assessment. Another prerequisite for the assessment is up-to-date knowledge of the state of green infrastructure management in cities, in particular regarding several specific features: changes in the prioritization of ecosystem services, whereby recreational services are regarded as more valuable than regulating ones; increased pressures on green zones due to expanding built-up areas, both in the center and on the city outskirts; and an acute need to improve the processes of urban green infrastructure planning on different spatial levels.

To achieve our aims, we pursued five major objectives:

– to create an inventory of different elements of green infrastructure on the urban level for Russian cities with populations over one million;
– to define the main trends in the transformation of green infrastructure in the period 2000–2016;
– to analyze the main problems of nature conservation and biodiversity in the city;
– to assess the provided, demanded and consumed volumes of ecosystem services as well as their ratio for two of the most important urban types, namely regulating and recreational services;
– to define the intracity differences in the volumes of ecosystem services as well as the factors underlying their formation (the case study of Moscow);
– to determine the role of green infrastructure and its ecosystem services in Russia's official spatial planning documents.

2.2. The main terms and assessment approaches

2.2.1. Cities as objects of ecosystem services assessment

In 1950 there were only 751 million people living in the world's urbanized areas. Today the figure is approximately 4.2 billion or around 55% of the global population. According to the United Nations, by 2050 around 68% of humankind is expected to be urbanized. In Russia, the figure is currently around 75% (Rosstat, 2019). There are more than 1,100 cities and towns in the country, of which 134 have populations of over 100,000 and 16 over a million. About 34 million people or 23% of the country's population reside in these largest cities, which only occupy about 0.06% of Russia's landmass.

Even though cities occupy such a small area, they still have an enormous impact on the biosphere due to their large populations and high level of industrial activity. A significant share of ecosystem services consumed by city-dwellers is produced not only by ecosystems outside the urban boundaries but also by those situated on the other side of the country or even the world (Rees, 1992; Folke et al., 1996; Rees and Wackernagel, 1996). An assessment of the consumed volume of ecosystem services such as food production or carbon and nitrogen accumulation for 29 of the largest Baltic cities demonstrated that an entire drainage basin at least 565 times bigger than the total urban area is required to produce these services (Folke et al., 1997). Calculations of the ecological footprint for Russian regions carried out by WWF–Russia in 2014 showed that the ecological footprints of the two most populated Russian cities, namely Moscow and Saint Petersburg, were 7.1 and 7.33 global hectares per capita correspondingly. These cities also have the smallest biological capacity: the estimated figure for Moscow is 0.03 hectares and Saint Petersburg 0.1 hectares.[3]

In this report we regard a city as an integrated socio-ecological system that fully depends on the surrounding landscapes and connections between urban and rural districts (Grimm et al., 2008). While the elements of natural ecosystems within a city are clearly unable to satisfy residents' demand for ecosys-

[3] https://wwf.ru/resources/news/zelenaya-ekonomika/wwf-podschital-ekologicheskiy-sled-regionov-rossii/

tem services, conservation of these ecosystems is not just a utilitarian question for today: the benefits of air purification, noise reduction and, most importantly, the provision of non-material cultural, recreational and aesthetic functions are also an aid to future urban development (Gómez-Baggethun et al., 2013).

Special methods are required to assess the provided, demanded and consumed volume of urban ecosystem services. These may differ from those methods applied to vast territories at the regional and municipal levels described in the National Prototype Report on Ecosystem Services in Russia (Bukvareva, Zamolodchikov, 2018; Bukvareva, Sviridova, 2020). However, the steps of formation and creating an inventory of ecosystem services as well as assessing their value for humans as presented in Volume 1 (Bukvareva, Zamolodchikov, 2018) are applicable to urban ecosystems. These main steps can be defined as follows:

– to define and map the major ecological structures in the cities as well as their characteristics and processes;
– to determine the main ecological functions and services of urban ecosystems that can benefit city dwellers;
– to assess the value and usefulness of ecosystem services by means of non-monetary (biophysical) and monetary indicators.

In this report, unless otherwise noted, urban ecosystem services refer to services provided by ecosystems which are situated within the administrative boundaries of the city. To calculate the demanded volume, open data is available from Rosstat on the urban “okrugs”, a particular type of municipality that includes two to three settlements with a contiguous territory. However, the boundaries of urban okrugs do not always match city boundaries; indeed, in some regions of Russia with a high level of urbanization and industrial development (for example in the Urals), these differences can be drastic.

According to many authors (e.g. Pickett et al., 2003, Grunewald et al. 2018), urban ecosystems are the vegetated areas (sometimes including water bodies) in areas where a significant proportion of land is built-up or sealed and where population density is high. In urban planning, cities are described as a combination of “grey” infrastructure (meaning built-up or sealed) and “green” infrastructure (or more usually “blue and green”, meaning vegetated and with water bodies). In the city, ecosystem services are provided by elements of green infrastructure.

The concept of “green infrastructure” is closely related to that of the “urban ecological network” (Vladimirov, 1986) popular in national urban planning schools of the 1980s. Green infrastructure, however, encompasses a wider range and thus volume of elements. It should be stressed that despite its wide usage by scholars and journalists, the term “ecological network” is not a category of legislation within the Russian Federation. Rather, it is a notion accepted by the public as well as the scientific community. To characterize urban vegetated areas, national schools of urban planning traditionally use the term “green plantings”, which are defined by GOST 28329-89 as “a complex of tree, shrub and herbaceous vegetation in a specific area”. This definition does not consider the main emergent features of the ecological network, in particular its integrity, connectivity and hierarchy of green elements, which ensure its function of stabilizing the local environment.

Elements of green infrastructure, which in cities are usually artificially designed, can be classified by various factors. One of the first studies to assess urban ecosystem services of a city, namely Stockholm, was by Bolund and Hunhammer (1999). They defined seven main types of urban ecosystems that provide services: street vegetation, links/parks, urban forests, agricultural lands, wetlands, lakes/sea, rivers. This classification includes elements at different scales. Thus, while urban forests perform a significant role for the city in general, roadside trees can help to purify air and reduce noise at the local level.

A more detailed classification of green elements by Gómez-Baggethun and Barton (2013) for the purposes of urban planning grouped these into four levels: elements at the regional (urbanized district), neighborhood, streetscape and building level. Analogously, we can identify the following levels for Russian cities with their prevailing micro-district structure: 1) agglomeration (the city and its surroundings); 2) urban (districts within the city); 3) micro-district (neighborhoods within one micro-district plus street vegetation); and 4) intradistrict (the green areas of individual dwellings). Depending on the size of the city, some levels of green infrastructure can be absent. All four planning levels will, however, be found in the most populated cities.

In Volumes 1 and 2 of the National Prototype Report, natural ecosystems with a specific degree of biodiversity are regarded as the providers of ecosystem services at the regional level. Such a method is applicable for assessments at regional level, such as for the federal subjects of Russia. Yet when assessing ecosystem services in the cities, the main providers are unsealed lands within the urban boundaries, which can include the remaining natural ecosystems and artificial green elements created and maintained by human intervention. The stocktaking, classification and assessment of these elements is the starting point for any assessment of urban ecosystem services.

2.2.2. Classification and assessment of urban ecosystem services

Many classifications of urban ecosystem services found in the literature (for example: Bolund and Hunhammar 1999; Gómez-Baggethun and Barton 2013) are based on existing systems offered by the Millennium Ecosystem Assessment (MEA, 2005) and The Economics of Ecosystem Services and Biodiversity (TEEB, 2010) while highlighting those services which are more significant in cities (Table 2.2.2).

At the same time, given the high population density and city dwellers' dependence on urban nature, previous studies have considered not just positive ecosystem services but also their negative functions – the so-called "ecosystem disservices" – such as the dispersal of allergy-causing pollen and volatile compounds (Chaparro and Terradas, 2009; Geron et al., 1995), the unwelcome shading of buildings by nearby trees, tree fall (Lyytimäki and Sipilä, 2009), the danger to life in poorly lit parks and the impairment of monuments and public space by the activities of birds (Bixler and Floyd, 1997). In this report, however, we do not consider such negative functions of urban green infrastructure.

Table 2.2.2. A classification of urban ecosystem services/functions and indicators according to Gómez-Baggethun and Barton, 2013

Ecological functions	*Ecosystem services*	*Parameters for biophysical assessment*
The transformation of energy by photosynthesis	Food provisioning	Food provision, t/yr
Infiltration and regulation of groundwater and surface runoff	Runoff regulation	Soil capacity for infiltration, the ratio between sealed and unsealed lands, %
Photosynthesis, shading, evapotranspiration	Temperature regulation in the city	Leaf Area Index; temperature reduction by tree cover* area of tree cover (°C)
Absorption of noise waves by vegetation and water surfaces	Noise reduction	Leaf area (m^2) and distance from roads (m); noise reduction (dB / unit of vegetation cover)
Filtration and fixation of gases and suspended particles	Removal of air pollutants	Amount of O_3, SO_2, NO_2, CO and $PM_{10\,\mu m}$ (t/yr), absorbed by tree vegetation* tree cover area (m^2)
Physical barrier to kinetic energy	Mitigation of the negative effects of extreme weather conditions	Vegetation density inside natural barriers that protect constructions from the sea
Decomposition of organic matter	Waste utilization	Concentrations of P, K, Mg and Ca compared to relevant standards for soil and water quality
Carbon sequestration	Climate regulation	CO_2 sequestration by trees (carbon storage multiplied by 3.67 for the transformation of CO_2)
Pollen dispersal	Pollination and seed dispersal	Biodiversity; diversity of birds and bee species
Ecosystems with recreational or scientific and educational value	Recreation and educational development	Area of public green space per capita (or 1000 persons)
Providing habitats for animals	Animal watching	Abundance of birds, butterflies and other animals, assessed in terms of their aesthetic value

* ecosystem services assessed in this report

2.3. Spatial scales of analysis and data sources

To achieve the aforementioned objectives, the research was conducted on two spatial levels, namely:

– the city level, whereby, for the purposes of integrated assessment, the urban area within the administrative city borders is viewed as an undifferentiated unit, i.e. intracity differences are ignored. In this work we analyzed 16 Russian cities with population of over one million;

– the intracity level, whereby the city's districts are individually assessed. In this work, we analyzed 146 districts of Moscow, which itself is a separate federal subject of Russia.

The data sources used in the research are shown in Table 2.3.

Table 2.3. Scales of assessment and data sources

Objective	*Urban level for 16 cities*	*Intracity level for Moscow districts*
To create an inventory of green infrastructure	Landsat 5,7,8 images (2016); High-Resolution Global Maps of 21st-Century Forest Cover Change (Hansen et al., 2013); OpenStreetMap data	OpenStreetMap data; High-Resolution Global Maps of 21st-Century Forest Cover Change (Hansen et al., 2013)
To assess changes in the area of green infrastructure between 2000 and 2016	High-Resolution Global Maps of 21st-Century Forest Cover Change (Hansen et al., 2013)	Atlas of Urban Expansion, 2012, High Resolution Global Maps of 21st-Century Forest Cover Change (Hansen et al., 2013)
To assess the demanded and provided volumes of ecosystem services	Authors' calculations; Database of municipal districts, Rosstat, 2016; Roshydromet, 2017	Klimanova et al., 2018; Database of municipal districts, Rosstat, 2016

2.4. Data processing and analytical methods

2.4.1. The level of cities

For our analysis, we used the administrative boundaries of cities as indicated by the OSM portal. The general inventory of green infrastructure was realized in two steps. Firstly, we utilized images taken on a cloudless, summer day of the Landsat 5, 7 and 8 series for the years 2000–2016 with a spatial resolution of 30 m. The selected images were from the period May 30 to September 3. These were also used to create a Normalized Difference Vegetation Index (NDVI) raster. Subsequently, a supervised classification was conducted to distinguish two classes of land cover: 1) non-vegetated surface (NDVI = 0.18–0.30), and 2) vegetated surface. NDVI values for dense/healthy/tree vegetation, which is the most valuable for ecosystem services, are usually quite high. In our case the diapason for this type of vegetation was 0.35–0.50.

Since the studied cities are in different climate zones and multi-temporal images were used, we had to verify our tree vegetation raster using spatial data on tree cover from the Maryland University website *Global Forest Change*. In some cases (particularly for cities in the steppe zone), NDVI data was insufficient to create an inventory of all green infrastructure due to the diverse condition of agricultural lands, which are the main source of provisioning ecosystem services. Thus, we extracted spatial data from OpenStreetMap (OSM) by selecting "farmland" categories from the OSM "landuse" key. According to the definitions of OSM key elements, "farmland" is an area used for tillage, including croplands, pastures, orchards, etc. We extracted this selected data and added it as agricultural lands to the maps, defined it as a unique value in the legend and subtracted the area from the total non-tree vegetation area. The verification of these OSM shapes using a high-resolution "Base map" in ArcGIS 10.3 showed that the OSM "farmland" category does not capture all agricultural lands in Rostov-on-Don and Samara. For this reason, all the missing polygons were defined manually through visual inspection, supplemented by land use data from the open geoportal Wikimapia. The maps and materials created on this basis were used to establish our inventory of ecosystems that perform services.

The resulting maps specified all elements of urban green infrastructure and their different ecosystem services. The area of tree cover could be used to evaluate the provided volume of regulating services. In general, the area of agricultural land can be used to assess the degree of provisioning services (a share of agricultural lands from the total urban area). However, we were forced to use another method based on statistical data to assess provisioning services because, during the OSM data verification by a high-resolution satellite image, we determined that OSM vectors did not include all agricultural lands. As visual interpretation of satellite images is relatively inaccurate, some agricultural lands are always neglected in this kind of calculation.

It is also difficult to map habitat conservation services due to the lack of open data and materials. While OSM vectors have the categories "nature reserve" and "protected areas", which are specially protected natural areas (hereinafter PAs), including biosphere reserves, *zapovedniks*, nature parks, dendrological parks, etc., our research revealed that not all protected areas are captured by OSM data in the studied cities. Moreover, some green elements such as urban parks and squares may be included in this OSM category even if, in reality, they do not enjoy any special status as protected areas.

OSM data was also used to assess cultural, recreational and air purifying services. For the first two, we selected not only OSM recreational categories such as "recreational ground", "park", "village green" but additionally the categories "wood, "forest", "meadow", "grass" and "cemetery", which are all areas that can also be used for recreation. A further problem were those green elements simultaneously assigned to several OSM categories. For instance, an element defined as "wood" under the "vegetation" category can be called a "park" under the "landuse" category, since woods are often situated inside parks, yet in OSM, elements usually cannot belong to several categories. Thus, we consider all OSM woods and meadows suitable for recreation. Regarding the service of air pollution removal, we used OSM to extract industrial zones which were considered to be point sources of pollution. As not all OSM materials are fully updated, they sometimes include industrial zones that no longer operate or have relocated outside the city. Nonetheless, we used this data as no other more accurate open geospatial information on industrial zones was available. It would be possible, however, to manually define industrial zones for each city using maps given by General Plans or functional zoning schemes.

2.4.2. The level of Moscow's municipalities

To assess the current state and volume of urban ecosystem services, we used a method adopted by EU researchers based on a typology of urban land usage (according to the Urban Atlas classification) and related ecosystem services. Using OSM data, the area of each type was calculated in the ArcMap program during the map modelling. This work is a pilot assessment of current and predicted potential of ecosystem services in Moscow, based on OSM data that was matched with Urban Atlas codes of land use types according to the EEA technical report "Green infrastructure and territorial cohesion" (2012).

Generally, a number of input data sources are needed to convert the typology of urban land usage into the code classification of Urban Atlas such as Earth Observation Data at spatial resolution 2.5 m, topographic maps at 1:50,000 scale and other information materials.

As most of these sources are hard to obtain, we made use of processed OSM materials as input data.

It should be stressed that, due to the voluntary nature of its contributions, the details and accuracy of OSM data may vary between cities. However, large cities such as Moscow usually have relatively adequate and accurate data.

The OSM data had to be processed for our research purposes. An initial preparatory step was to extract the desired data by selecting attributes and creating new layers with Urban Atlas codes for OSM categories. For instance, a polygon layer "water" was transformed into two layers according to Urban Atlas categories: one for water bodies such as lakes, ponds and water reservoirs; and the other for wetlands (Table 2.4.2).

Table 2.4.2. Matching OSM categories to Urban Atlas codes

Code in Urban Atlas	*Land-use types in Urban Atlas*	*Objects selected and extracted from OSM*	*OSM layers*
11100–11240	5 urban fabric types (of different density)	residential, allotments	landuse-polygon
12100	Industrial, commercial, public, military and private units	industrial, commercial, military, brownfield; school, hospital	landuse-polygon; poi-polygon
12210	Fast transit roads and associated land	primary, secondary, tertiary, motorway, trunk	highway-line
12230	Railways and associated land	railway	railway-line
14100	Green urban areas	garden, park, theme-park, zoo, water-park; nature-reserve, cemetery	poi-polygon; landuse-polygon
1420	Sports and leisure facilities	recreation-ground; playground, pitch-sport, horse-riding, golf-course, dog-park, stadium	landuse-polygon; poi-polygon
32000	Herbaceous vegetation associations	meadow; grassland, heath; fell; reedbed	vegetation-polygon; surface-polygon; poi-polygon; water-polygon
33000	Open spaces with little or no vegetation	beaches, dunes, sand	poi-polygon
4000	Wetlands	wetland, bog, marsh, swamp	water-polygon

The data processing also included the creation of buffers around line objects such as roads and rivers as well as overlaying, field calculations and zonal statistics gathering.

The first step in our modelling process was to distinguish urban patterns by means of five Urban Atlas density classes for built-up area (from Continuous high density to Discontinuous very low density).

Residential, industrial and commercial areas were extracted from the “landuse” OSM layer by selecting via attribute to the new “districts” layer. Then we calculated the area of all buildings in the “building” layer, converted this layer to a raster and overlaid it with the “districts” layer using a *Tabulate Area* instrument. The resulting overlay was joined with the original “districts” layer to be rated by Urban Atlas density intervals.

The second modelling step was to create “fast transit roads and associated land” land-use classes by selecting main roads from a polyline layer “highway”. Here it was necessary to create buffers around these lines according to the road width and the adjacent safety zone.

A further land-use class, “other roads and associated land”, was created using a similar algorithm.

The third modelling step was to create the remaining land-use classes by selecting the necessary objects and joining them in new layers.

The most complicated selection process concerned land-use categories such as “green urban areas”, “sports and leisure facilities” or “herbaceous vegetation associations”, since these objects can feature in three or four standard OSM layers. Also, these layers usually contain many errors and thus require further processing and verification. For example, urban lawns can be assigned to the “grassland” category of the “surface” layer; flower beds can be identified as “garden” in the “poi-polygon” layer, etc.

Finally, the fourth modelling step was to overlay all new category layers classified by Urban Atlas to create a unified land-use layer, whose geometry was then corrected. The area occupied by each land-use class was also calculated both absolutely and in relative terms.

Based on this data, we evaluated the total provided volume of ecosystem services, expressed as the share of the municipal district area that performs a specific type of ecosystem service.

3. Russia's most highly populated cities

3.1. General characteristics of the case studies

Russia has 16 cities with a population of over one million, namely Moscow, Saint Petersburg, Novosibirsk, Ekaterinburg, Nizhniy Novgorod, Kazan, Chelyabinsk, Omsk, Samara, Rostov-on-Don, Ufa, Krasnoyarsk, Perm, Voronezh, Volgograd and Krasnodar (see Table 3.1.1). These cities form the case studies for the research described here. The urban area under study is limited to the administrative borders as defined in the year 2000 (apart from Moscow, whose borders were drastically revised in 2012). The data with city borders was exported from OSM.

Table 3.1.1. The area and population of Russia's largest cities according to the Federal State Statistic Service, 2016

City	*Urban area in km²*	*Population (thousands)*	*Population growth 2000–2016 (%)*	*Population density per km²*
Chelyabinsk[4]	504	1,178	8.8	2,337
Ekaterinburg	401	1,456	15.0	3,631
Kazan	635	1,232	11.9	1,940
Krasnodar	295	900	29.0	3,050
Krasnoyarsk	378	1,083	23.8	2,865
Moscow	2,432 (1,029 under old borders)	12,381	24.7	5,091
Nizhniy Novgorod	317	1,262	–7.0	3,981
Novosibirsk	481	1,603	14.6	3,333
Omsk	580	1,016	–11.6	1,752
Perm	806	1,456	44.2	1,806
Rostov-on-Don	355	1,125	11.1	3,169
Saint Petersburg	1,439 (594 under old borders)	5,282	11.4	3,670
Samara	543	1,170	1.2	2,155
Ufa	667	1,116	2.3	1,673
Volgograd	861	1,015	2.2	1,179
Voronezh	601	1,040	14.5	1,730

Moscow is not just Russia's biggest city, but also the most densely populated. This is also true of the so-called "New Moscow", the result of changes to the urban boundary in 2012 that doubled the area of the capital. Nonetheless, the majority of the population is still concentrated in "Old Moscow", where the population density is in fact much higher (about 12,000 per/km²) than official figures show. The population density of St. Petersburg, Russia's second largest city, is much lower than in some less populated cities.

Regarding the degree of compactness, three cities – Rostov-on-Don, Krasnoyarsk and Nizhniy Novgorod – show a low level of urban sprawl, i.e. their built-up area is mostly concentrated in the center. For instance, Nizhniy Novgorod has only a moderate area despite it being one of the most highly populated cities in Russia.

All studied cities are situated in the temperate climate zone. Most are located in the European part of Russia and thus influenced by air masses from the Atlantic Ocean. Cities in the south of European Russia lie in the semi-arid continental climate zone. Some cities lying east of the Urals belong to the continental Western Siberian region, while those located even further east are located in continental Eastern Siberia.

Vegetation cover inside the urban cores is generally different to the surrounding landscapes. However, large swathes of urban forests are often found within the administrative city borders. These green elements, which usually conserve some features of zonal vegetation, determine the provided volume of

[4] The order of cities is done by English alphabet.

supporting ecosystem services and their stability. Thus, all of the studied cities can be divided into three groups according to the type of zonal vegetation. The first group comprises cities in the forest zone: Moscow, Saint Petersburg, Nizhniy Novgorod, Kazan, Ufa, Krasnoyarsk, Perm, Ekaterinburg and Krasnodar. The second group comprises cities in the steppe zone: Rostov-on-Don, Volgograd and Omsk. And the last is a transitional forest-steppe group: Samara, Voronezh, Chelyabinsk, Novosibirsk (see Table 3.1.2). The forest group comprises middle and southern taiga, sub-taiga and broadleaf forests. Regarding the steppe group, these are the southern and typical steppes of the European and Siberian regions.

Table 3.1.2. General geographical features of Russia's largest cities according to Rosgydromet; Google Earth; Bozhilina, 2017

City	*Ecological zone*	*Average elevation, m*	*Average air temperature in January, °C*	*Average air temperature in July, °C*	*Average annual precipitation, mm/yr*	*Zonal vegetation*	*Rivers*	*Thermal comfort*
Chelyabinsk	forest-steppe	225	–14	19.3	430	Herbaceous and poaceae forest-steppes	The Miass, Lake Smolino and Lake Pervoe	unfavorable
Ekaterinburg	forest	270	–12.6	19	541	Mixed subtaiga forests	The Iset	unfavorable
Kazan	forest	60	–10.4	20.2	562	Broadleaf and dark coniferous subtaiga forests	The confluence of the Kazanka and Volga	favorable
Krasnodar	forest-steppe	30	0.6	24	735	Herbaceous and poaceae forest-steppes	The Kuban	favorable
Krasnoyarsk	forest	287	–15.5	18.7	487	Light coniferous forests of the southern taiga	The confluence of the Kacha and Enisey	unfavorable
Moscow	forest	186	–6.5	19.2	707	Broadleaf and dark coniferous subtaiga forests	The river Moscow	favorable
Nizhniy Novgorod	forest	200	–8.9	19.4	648	Dark coniferous forests of the southern taiga	The confluence of the Oka and Volga	favorable
Novosibirsk	forest-steppe	150	–16.5	19.4	460	Herbaceous and poaceae forest-steppes	The confluence of the Inya and Ob	favorable
Omsk	forest-steppe	90	–16.3	19.6	415	Herbaceous and poaceae forest-steppes	The confluence of the Om and Irtysh	favorable
Perm	forest	149	–12.8	18.6	657	Dark coniferous forests of the southern taiga	The confluence of the Chusovaya and Kama	favorable
Rostov-on-Don	steppe	50	–3	23.4	615	Stipa and herbaceous steppes	The confluence of the Mertvy Donets and Don	seasonal comfort
Saint Petersburg	forest	3	–5.5	19.1	661	Dark coniferous forests of the middle taiga	The Neva delta	favorable
Samara	forest-steppe	100	–9.9	21.5	563	Herbaceous and poaceae forest-steppes	The confluence of the Samara and Volga	favorable
Ufa	forest	150	–12.4	19.7	589	Broadleaf forests	The confluence of the Ufa and Belaya	favorable
Volgograd	steppe	35	–6.3	23.6	406	Stipa and festuca steppes	The Volga	seasonal comfort
Voronezh	forest-steppe	154	–6.1	20.5	584	Herbaceous and poaceae forest-steppes	The Voronezh	favorable

3.2. Green infrastructure

The main features of green infrastructure in Russia's most populated cities are shown in Table 3.2.1. Tree vegetation of varying density makes up 16% to 61% of the total expanse of green infrastructure. The cities of the steppe zones, Omsk and Volgograd, have the smallest share of tree cover at 18% and 16% respectively, while cities of the forest zone such as Ekaterinburg and Perm have the most tree cover at 58.8% and 61.3% resp. Although Voronezh is situated in an ecological zone with climate conditions similar to that of Omsk and Volgograd, its tree cover is about two times greater. The same disparity can be seen when comparing the lower extent of tree vegetation of Kazan with that of Perm and Ekaterinburg, which have similarly favorable climate conditions. Although Krasnoyarsk and Rostov-on-Don lie in different ecological zones, their extent of tree cover is similar. The analysis of the current situation in the case studies showed that in cities in the steppe zones, large forests both natural and artificial located outside the main urban core are often incorporated within the administrative borders. In the steppe zones, these are usually used for recreation. In contrast, forested areas in the forest zone are usually not incorporated within the city.

Of course, woodland is not the only element of urban green infrastructure, which encompasses other unsealed areas and of course farmland. According to Rosstat, 13 of 16 cities are in this category. The only cities that do not contain any agricultural land are Moscow, Saint Petersburg and Kazan. Omsk, Volgograd, Krasnodar and Rostov-on-Don have the largest area of farmland and perennial plantings, which partly compensate for the lack of tree vegetation (see Figs. 3.2.1–3.2.4).

For planning purposes, the total green infrastructure in the city is calculated as the sum of all public or private green areas and street vegetation in a specific district. According to the General Plans for urban development, green infrastructure per capita varies from 4 to 135 m^2, depending on the city and district. The lowest figures are found in Chelyabinsk (2.1–5.8 m^2 per capita), Perm (4.0–10.0), Rostov-on-Don (6.7–10.0) and Volgograd (10.0), with the highest figures in Ekaterinburg (38.60) and Novosibirsk (88.0 – 135.0). Our research showed that three of the 16 cities have less than 100 m^2 of green infrastructure per capita; seven cities have about 100–200 m^2 per capita and six cities have more than 200 m^2 of green infrastructure per capita. If we consider that not all tree vegetation is captured in standard assessments, the actual per capita values will be much greater.

Table 3.2.1. The key features of green infrastructure in Russia's largest cities – total area and percentage share of the urban area

City	*All green infrastructure*		*Woodland*		*Agricultural land*		*Protected areas*		*Green infrastructure, m^2 per capita*	
									According to the General Plans (not including all tree cover)	*Including all tree cover*
	km^2	%	km^2	%	km^2	%	km^2	%		
Chelyabinsk	235.19	46.7	60.93	26.80	7.9	3.08	68.0	13.5	2.1–5.8	195.4
Ekaterinburg	213.85	53.3	152.3	58.80	6.3	4.07	120.2	30.0	38.60	240.7
Kazan	311.08	49.0	178.32	28.08	35.1	5.52	34.7	5.5	…	554.4
Krasnodar	128.4	37.8	54	16.00	40	11.8	6.4	2.0	120	140
Krasnoyarsk	197.59	52.3	125.93	31.60	0.3	3.26	1.0	0.3	10.0–16.0	206.6
Moscow	1719.93	70.7	1323.5	54.42	109.5	4.50	176.0	7.2	27.8–29.8	17.8
Nizhniy Novgorod	303.79	95.8	215.72	45.40	3.1	1.38	76.0	24.0	16.0–63.5	194.6
Novosibirsk	300.72	62.5	194.97	37.70	2.3	4.96	11.0	2.3	88.0–135.0	118.1
Omsk	346.32	59.7	104.71	18.00	10.1	8.34	5.0	0.9	…	254.9
Perm	595.65	73.9	502.13	61.30	10.2	1.67	86.0	10.7	4.0–10.0	146.5
Rostov-on-Don	215.63	60.7	114.99	29.00	10.1	7.52	33.0	9.3	6.7–10.0	90.3
Saint Petersburg	334.32	23.2	236.2	16.41	70.3	4.89	78.9	5.4	12.8–16.0	32.6
Samara	306.10	56.4	130.5	41.00	3.1	1.39	12.8	2.4	< 9.0	180.8
Ufa	433.62	65.0	342.97	47.50	9.7	7.14	13.0	1.9	…	243.7
Volgograd	473.46	55.0	147.43	16.00	121.5	8.06	35.7	4.2	10.00	126.6
Voronezh	348.00	57.9	279.24	50.00	7.8	7.63	76.0	12.6	12.8–16.0	225.0

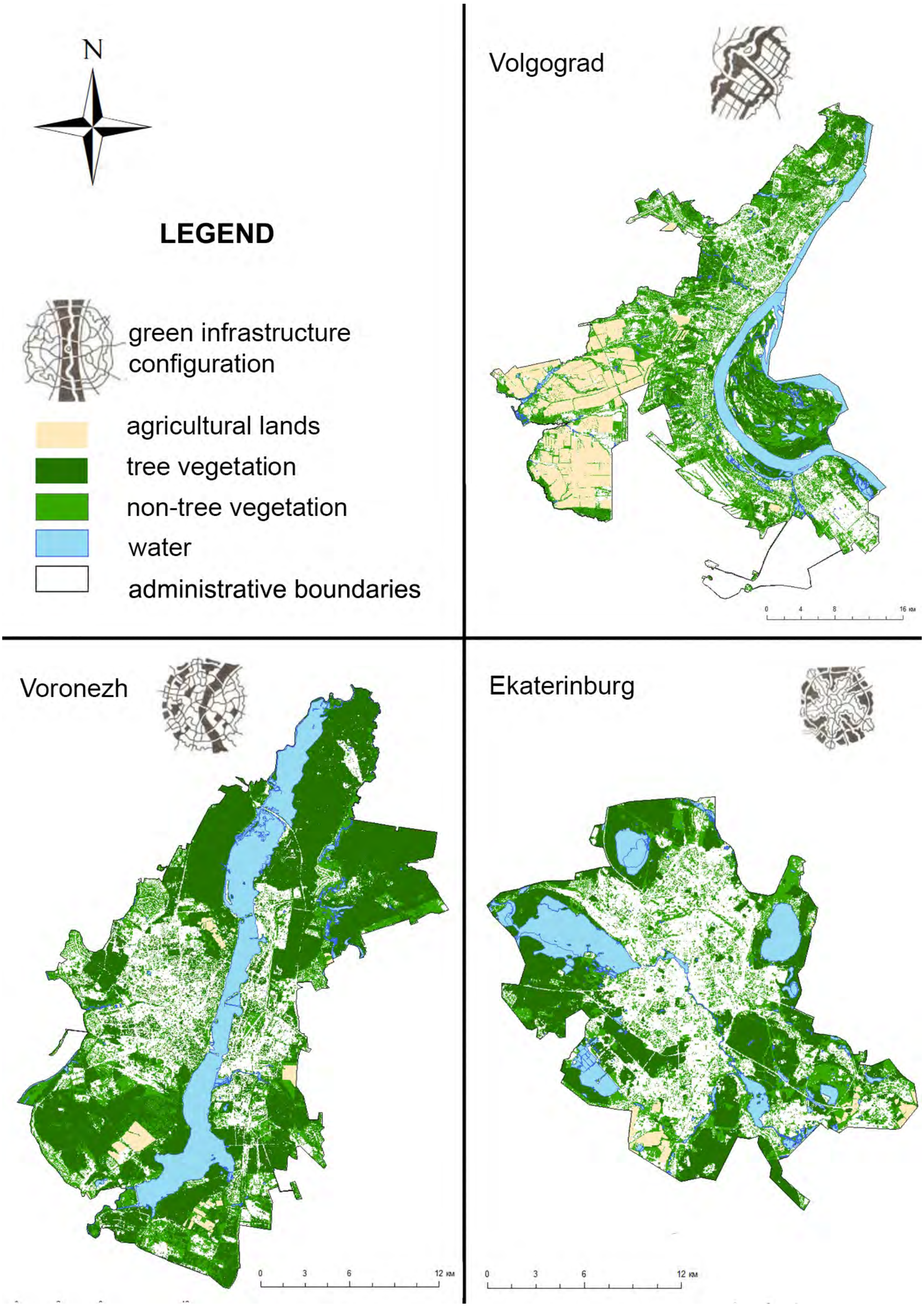


Figure 3.2.1. Green infrastructure of Volgograd, Voronezh and Ekaterinburg

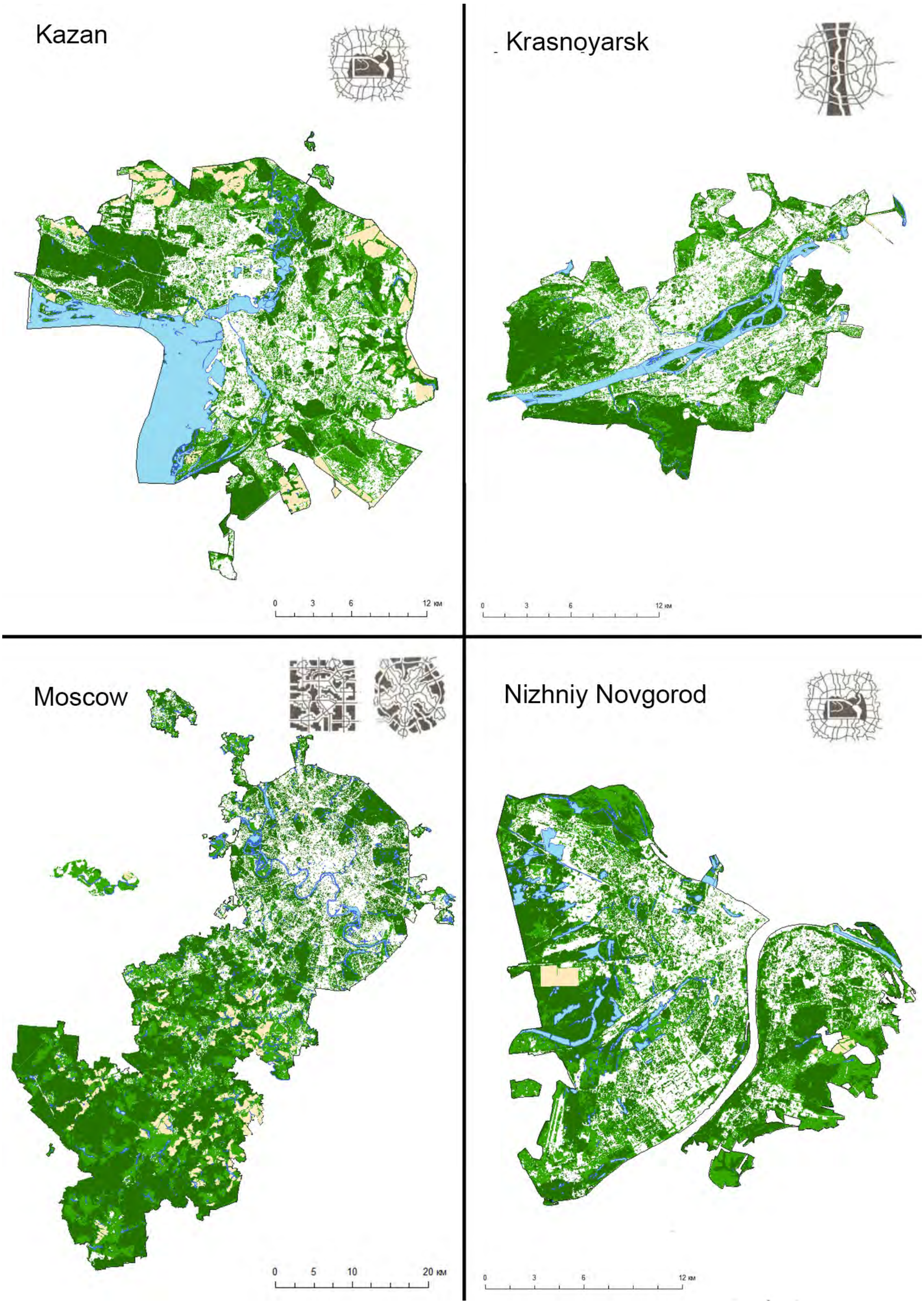


Figure 3.2.2. Green infrastructure of Kazan, Krasnoyarsk, Moscow and Nizhniy Novgorod

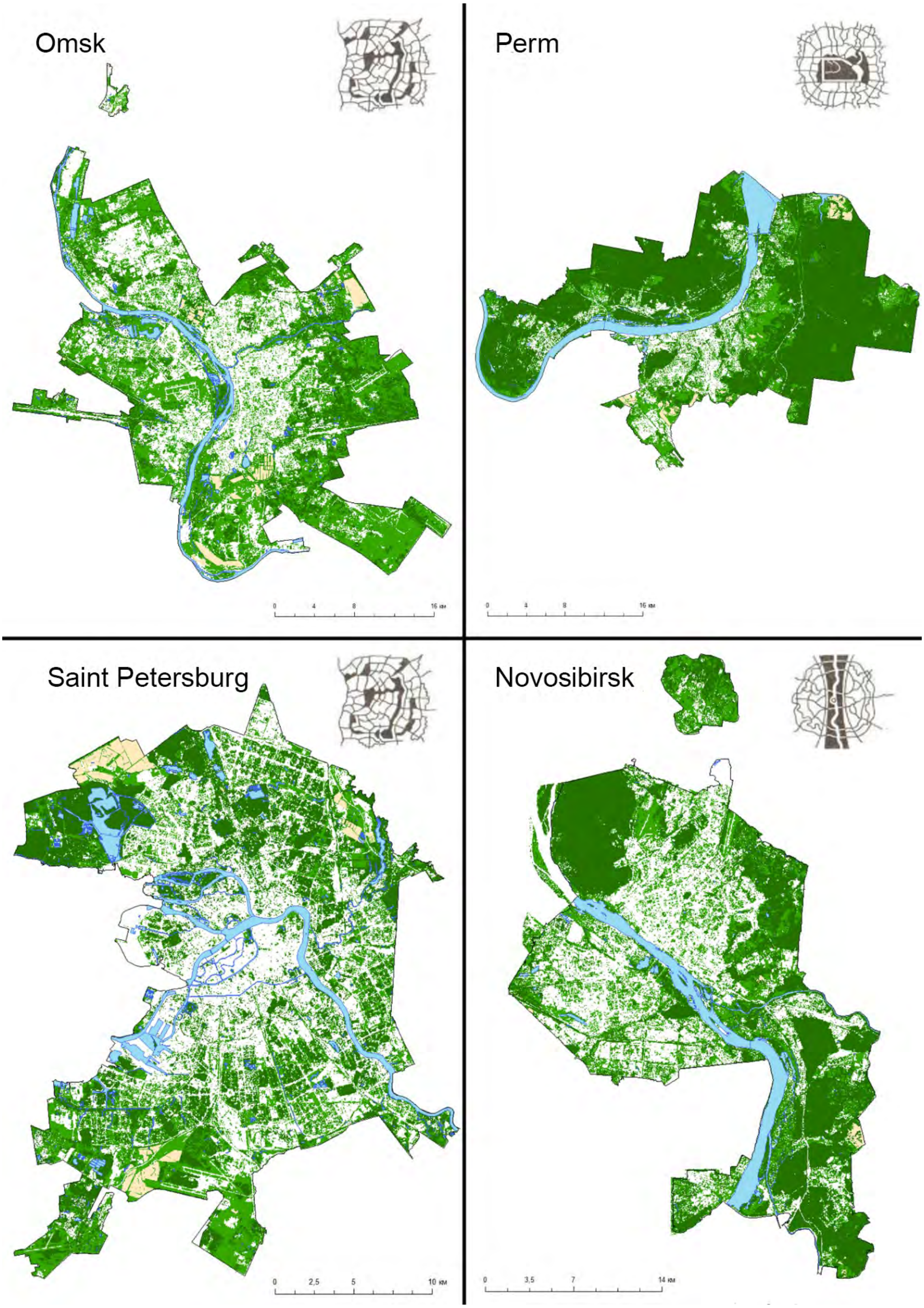


Figure 3.2.3. Green infrastructure of Omsk, Perm, Saint Petersburg and Novosibirsk

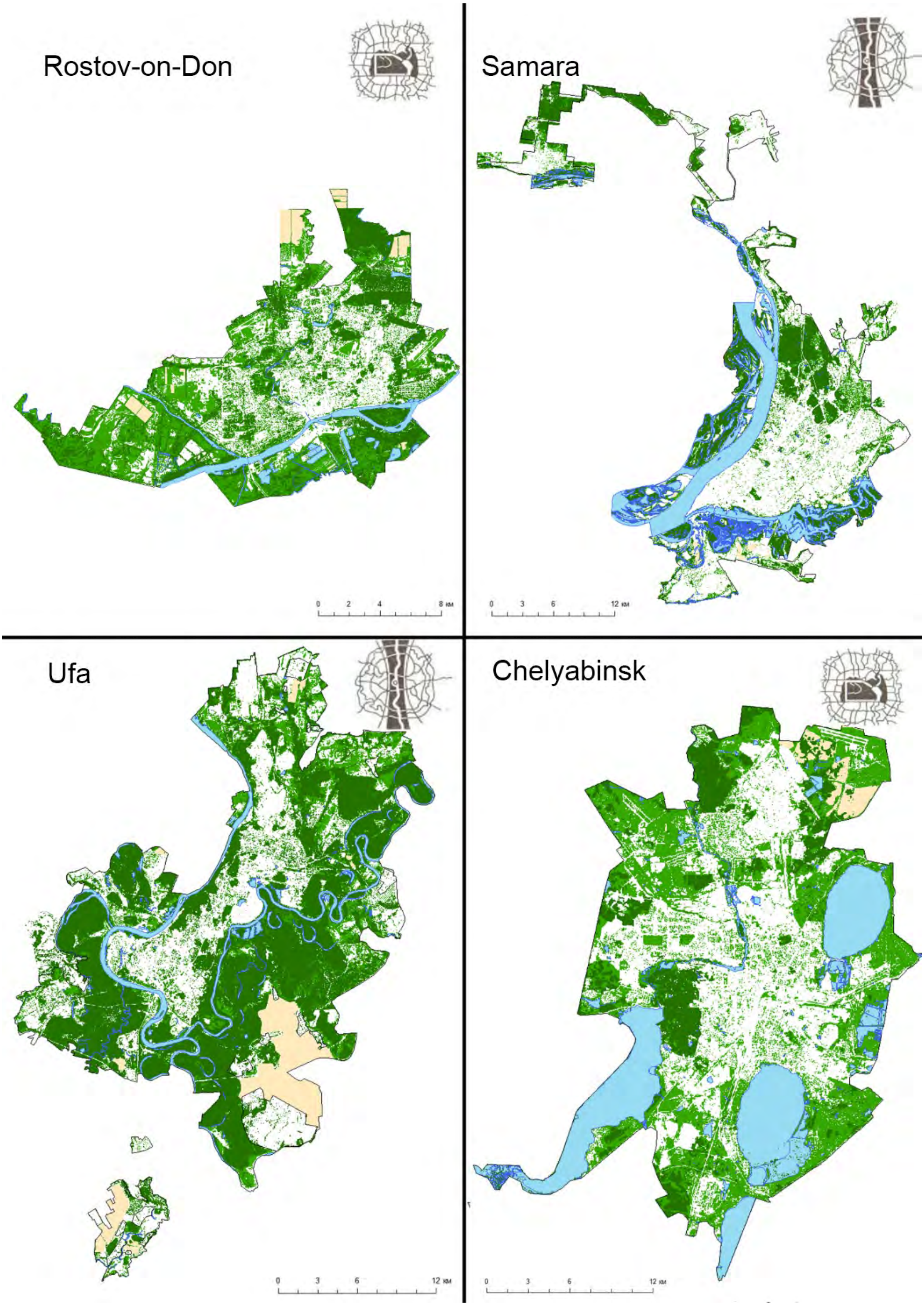


Figure 3.2.4. Green infrastructure of Rostov-on-Don, Samara, Ufa and Chelyabinsk

3.3. Biodiversity conservation

Urban areas are technogenic modifications of landscapes in which natural or semi-natural landscapes with successional ecosystems and typical biodiversity are preserved only in protected areas (PAs). Table 3.3.1 shows the main indicators of the extent and number of protected areas in Russia's biggest cities (excluding Krasnodar).

Table 3.3.1. Protected areas in the system of green infrastructure in Russia's largest cities

City	Protected areas		Share of protected areas (%)		The largest protected areas and their status
	Total area, ha	Number	from the total urban area	from the area of tree cover	
Chelyabinsk	7,153	3	14.28	34.3	Natural monuments "Kashtaksky bor" (3,288 ha), "Lake Smolino" (2,720 ha)
Ekaterinburg	137	16[5]	0.12	1.4	Park-stadium of the Himmash plant (25 ha), Park "Sem Kluchey" (15 ha), the 50th anniversary of the Komsomol Park (13.8 ha)
Kazan	3,576	7[6]	5.82	5.2	Urban forest park "Lebyazhye" (3,396 ha)
Krasnoyarsk	0.0001	1[7]	0.00	…	Spring in the Akademgorodok area
Moscow	17,600	120	6.87	79.7	Natural-historical Park "Moskvoretsky", National Park "Losiny Ostrov"
Nizhniy Novgorod	3,413	34	8.31	16.0	Natural monuments "Zheleznodoroznie dachas" (1,034 ha) and "Gnilitsky dachas" (456 ha)
Novosibirsk	1,024	3[8]	2.04	5.4	...
Omsk	457	7[9]	0.81	1.8	Natural and recreational complex "Pribrezhny" (286.2 ha), Natural Park "Bird Harbor" (113.05 ha)
Perm	4,349	12[10]	5.43	20.2	Zakamsky pine forest (1,033 ha), Verkhnekurinsky (857 ha) and Levshinsky (952 ha) protected natural landscapes
Rostov-on-Don	3,300	1[11]	9.47	32.1	Natural reserve "Levoberezhny"
Saint Petersburg	6,143[12]	15	4.38	31.0	Nature reserve "Sestroretskoye swamp" (1,877 ha), nature reserve "Lake Shchuchye" (1,157 ha)
Samara	1,267	6[13]	2.34	4.1	Natural monuments "Sokoli Gory and the Volga bank between Studeny and Koptev ravine" (394 ha) and "Samarskoe Ustye" (350 ha)
Ufa	1,250	3	1.77	4.6	Medical and recreational area "Green Grove" (1,202 ha)
Volgograd	2,300	1[14]	2.68	18.0	Mineral water deposit in Kirovsky district of Volgograd
Voronezh	7,575*	47	12.70	27.2	Natural reserve "Voronezh Nagornaya Dubrava" (7,020 ha, including part of the territory in the Ramonsky district)

The cities with the largest total areas of PAs are Moscow, Chelyabinsk, Saint Petersburg and Voronezh. Each has more than 6,000 ha of protected natural ecosystems. In Moscow the figure is almost

[5] Zaitsev O.B., Polyakov V.E. Protected natural areas of Ekaterinburg. Ekaterinburg, 2015. 51 p.

[6] Decree of the Cabinet of Ministers of the Republic of Tatarstan № 520 of July 29, 2009, "On approval of the state register of specially protected natural areas in the republic of Tatarstan and introduction of changes in individual decisions of the Office of the Specialty Cabinets of the Ministry.

[7] List of protected areas of regional importance – http://www.doopt.ru/?id=5

[8] http://oopt.aari.ru/category/Административно-территориальное-деление/Сибирский-федеральный-округ/Новосибирская-область

[9] http://www.omsktfi.ru/nature/uniqobjects/oopt/618--01102011-.html

[10] http://permgenplan.ru/upload/cheme/tom1_final.pdf

[11] Decree of the government of the Rostov region of 12 May 2017, No. 354 "On protected landscapes and protected natural areas".

[12] Atlas of protected natural areas of Saint Petersburg.

[13] http://www.priroda.samregion.ru/external/ecology/files/c_68/Reestr_osobo_ohranyaemyh_prirodnyh_territorij_federal'nogo_znacheniya.pdf

[14] Decree of the Government of the Russian Federation of 15 July 1992 № 488 "On the establishment of the boundaries and regime of the sanitary protection districts of the Talgi resort in the Republic of Dagestan, the mineral water deposit in Volgograd and the Krasnoufimsky mineral water deposit in the Sverdlovsk region".

three times higher, namely 17,600 ha. The lowest figures (under 500 ha) are found in Omsk, Ekaterinburg and Krasnoyarsk. In Krasnoyarsk, the total extent of the PA is just 0.0001 ha, representing a spring in the Akademgorodok area.

There is also a significant disparity in the number of protected areas in the studied cities: 9 out of 15 cities have fewer than 10 protected areas, with Voronezh (47) and Moscow (120) having the largest number. Such a large difference in the number of PAs can be partially explained by the varying status of protected areas. For example, in Moscow, natural monuments are often located on the territory of much larger natural-historical parks and landscape reserves, thus artificially increasing this indicator. A similar situation is developing in Voronezh.

However, the extent and number of protected areas are not very useful indicators to assess how well citizens are provided with the ecosystem service *communicating with nature*. Here the percentage share of protected areas from the total urban area is more informative. When calculating this indicator, it is necessary to consider that protected areas are not just located in the city but also in the adjacent suburban municipal areas. Thus, the largest protected area of Rostov-on-Don, the Levoberezhny nature reserve, also extends over the territory of Bataysk and the Azov region, while the Voronezh Nagornaya Dubrava nature reserve is located within the city of Voronezh and the Ramonsky municipal district. The proportion of protected area to total urban area is highest in Chelyabinsk, Voronezh and Rostov-on-Don (although in the last two cities, the figure partially includes some protected areas located outside the municipal boundary). It should be noted that in Rostov-on-Don, two previously existing protected areas (within the Botanical Garden of the Southern Federal University and the Rostov Zoo) were abolished by a special decree of the regional government in 2017, while at the same time a vast natural reserve, Levoberezhny, was created. Here the aim is to preserve biodiversity during the construction of a stadium for the FIFA World Cup. Omsk, Ekaterinburg and Krasnoyarsk have the lowest proportions of PAs to total urban area at less than 1%. In Krasnoyarsk there is only one very small protected area, while in Ekaterinburg none of the 19 protected areas exceeds an area of 25 hectares, thus undermining their ability to contribute to biodiversity conservation.

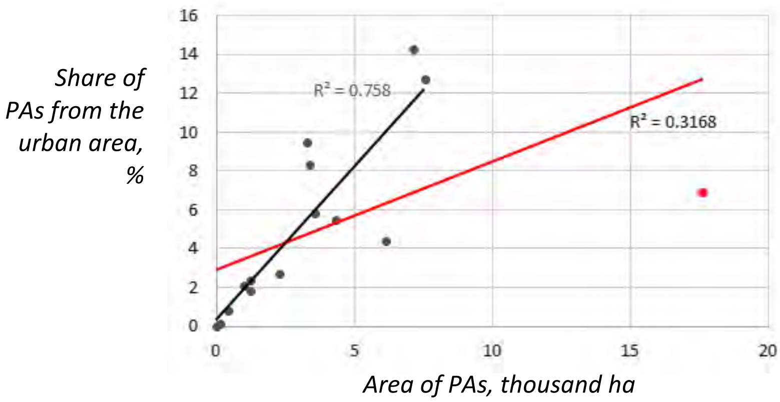


Figure 3.3.1. The correlation between the total extent of PAs and the proportion of PA to the urban area. The cities are shown as black dots apart from Moscow which is marked in red. The black line shows the correlation for all cities excluding Moscow; the red line the correlation for all cities including Moscow

Looking at Figure 3.3.1, we note a positive correlation between the total extent of protected areas and the percentage share of protected areas from the total urban area for the studied cities (black dots on the graph) excluding Moscow. This indicates an increasing provision of the population with the opportunity to communicate with nature in the city as the total area of protected areas grows. However, Moscow (red dot on the graph) does not show this trend. Despite having the largest area of protected areas, the percentage share of PA to Moscow's total area is rather small. This anomaly can be attributed to the fact that all forests on the territory of New Moscow are classified as "specially protected green areas" rather than PAs (see Section 4.2.3). This lower share of protected areas in Moscow compared to the general trend for most of Russia's largest cities indicates an insufficient development of the network of protected areas, jeopardizing the possibility of preserving biodiversity within Moscow's green infrastructure.

Regarding the proportion of PAs within the area of tree cover, the studied cities can be divided into three groups: those with a high (> 30%), medium (10–19%) and low (< 10%) proportion of protected areas in urban tree plantations. The first group includes the already mentioned cities with large protected areas along with Rostov-on-Don. The second group comprises Perm, Nizhny Novgorod and Volgograd. The remaining cities form the third group, namely those with few protected areas and a small total area.

Urban protected areas are rather diverse in regard to their official status. All cities have natural monuments, usually with regional status. The largest protected areas can also have their own individual status, which is not governed by federal legislation on protected areas. In Moscow, for example, these are natural-historical parks while in Omsk we can point to a natural recreation complex.

However, the extent and number of protected areas are not suitable indicators to assess their ability to preserve biodiversity in the city. Firstly, the protected areas may contain sites belonging to third-party users, which often include the owners or tenants of infrastructure facilities that are poorly compatible with the status of protected areas. Moscow is one example (see Section 4) of a city where the upgrading of protected areas with sports and entertainment facilities combined with inadequate improvements to parks can lead to the loss of natural ecosystems and biodiversity. Secondly, the level of fragmentation strongly determines the ability of protected areas to conserve biodiversity.

As a preliminary assessment of the impact of fragmentation on protected areas, we investigated edge effects, which occur in the border zones of green areas. These are chemical and physical forms of pollution (e.g. noise and light), the killing of wildlife by vehicles as well as microclimate disturbances which are large enough to negatively affect the structure and functioning of ecosystems (Petrişor, 2016).

The Fragstat program was used to determine the area of green infrastructure free of edge effects. For the calculation, we used rasters of Hansen's tree cover with a resolution of 30 x 30 m, for which we calculated the "total core area" (TCA – the total area of the territory outside the edge effect). To give a background value, we took the class of non-tree vegetation of the classified image. The matrix was loaded into Fragstats, where the class "tree cover" was assigned the value *true*, and empty pixels were assigned the value *false*. To verify the values, fragmentation was also calculated for the classified NDVI raster using four classes: water surface; non-vegetative surface; sparse vegetation; dense vegetative cover. For the first class, we took NDVI values below 0; for the second, up to 0.2; and for the third, 0.2–0.35. The values above were defined as class 4. In our study, the buffer of the border zone was 120 m wide, since the most noticeable changes in the functioning of ecosystems usually take place at a distance of 100–200 m from the edge of the forest (Meffe, 2012).

Knowing the area of the territory uninfluenced by the edge effect, we calculated the share of this area from the total area of green infrastructure. In all cities, it turned out to be less than the share of the area of protected areas from the total green infrastructure (Table 3.3.2).

Table 3.3.2. The assessment of natural habitat conservation inside protected areas for the Russia's largest populated cities

City	*Share of protected areas from the total area of green infrastructure, %*	*The area uninfluenced by the "edge effect", ha*	*Share of the area without the edge effect influence from the total area of green infrastructure, %*
Chelyabinsk	30.41	2,300	9.78
Ekaterinburg	0.64	2,050	9.59
Kazan	11.50	750	2.41
Krasnoyarsk	0.00	560	2.83
Moscow	10.23	5,610	3.26
Nizhniy Novgorod	11.23	490	1.61
Novosibirsk	3.41	1,250	4.16
Omsk	1.32	90	0.26
Perm	7.30	300	0.50
Rostov-on-Don	15.30	710	3.29
Saint Petersburg	18.37	180	0.54
Samara	4.14	1,480	4.84
Ufa	2.88	720	1.66
Volgograd	4.86	160	0.34
Voronezh	21.77	2,260	6.49

In absolute values, the largest area without an edge effect is found in Moscow, most likely determined by a large forest area in the northwest of New Moscow with only a few built-up “islands”. Ekaterinburg, Voronezh and Chelyabinsk have a particularly high proportion of integrated green areas. In the case of Ekaterinburg, this is due to extensive protected areas on the urban periphery, while the high values in Chelyabinsk can be attributed to the barely transformed Shershnevsky urban pine forest. The smallest areas free from the influence of the edge effect are noted in Volgograd, Omsk, Saint Petersburg and Perm. In the first two cities – due to natural conditions and insufficient artificial vegetation – there are no large parks with dense tree canopy. Saint Petersburg also has no unfragmented large areas due to the high building density and large number of open-air parks and squares in the system of green infrastructure. In Perm, the largest forested area to the east is significantly disturbed by urban developments (new residential areas, sanatoriums, military training grounds). There is no correlation between the proportion of territory without the “edge effect” to the total area of protected areas (Fig. 3.3.2). This indicates that even in cities with a large extent of protected areas, these green spaces can be significantly fragmented. Hence, they cannot properly perform the function of preserving urban biodiversity. For example, in Saint Petersburg, which has a significant proportion of protected areas within the city’s green infrastructure, the function of preserving biodiversity is significantly reduced due to fragmentation. Such examples indicate the importance of reducing fragmentation in the network of protected areas.

On the other hand, in a number of cities (the most striking example being Ekaterinburg), the proportion of protected areas without the edge effect is quite high considering the relatively small total extent of PAs. This suggests that these preserved forest areas should be granted conservation status as soon as possible.

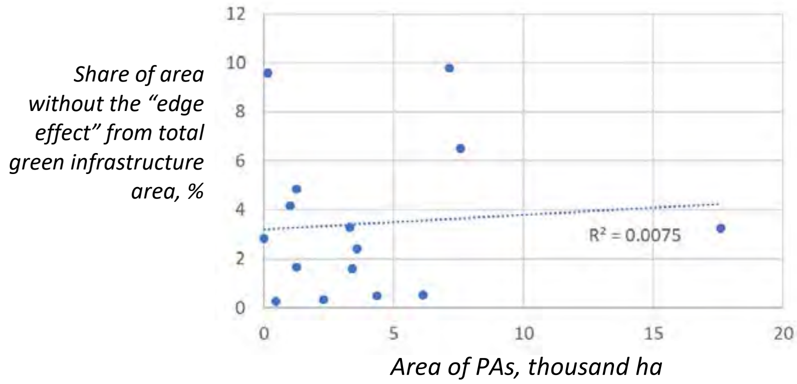


Figure 3.3.2. No correlation between the total extent of PAs and the proportionate area showing no edge effect

3.4. Ecosystem services

3.4.1. Regulating services

3.4.1.1. Removal of air pollution from vehicles

Motor vehicles are the main source of air pollution in most of the studied cities. Their share of vehicle emissions from total air emissions varies from 34% in Krasnoyarsk to 94% in Moscow (Fig. 3.4.1.1.1). Gaseous pollutants contained in the exhaust fumes circulate in the air under the influence of atmospheric diffusion. Their concentration gradually decreases at greater heights and distances from roads. Such gases can circulate to other city districts where they undermine the air quality. Trees and shrubs in buffers around the roads are most affected by the pollutants; at the same time, they act as barriers to the further diffusion of pollutants. Nowak (2016, 2018) has assessed the volume of gaseous pollutants removed by urban woodland, regardless of the proximity to the roads (see Table 3.4.1.1.1).

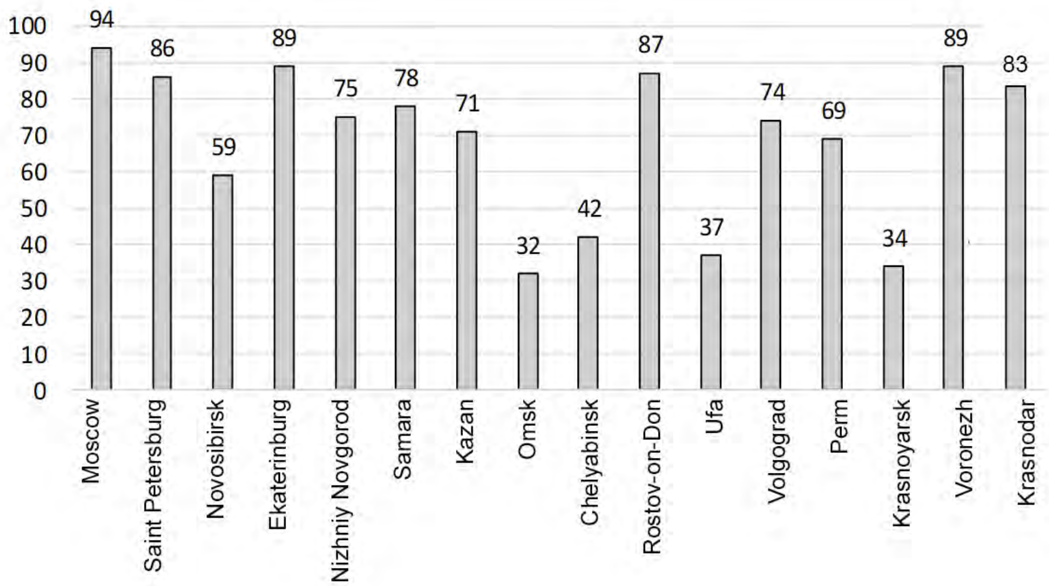


Figure 3.4.1.1.1. Share of automobile emissions from total air emissions in the most populated cities, according to Rosgydromet, 2018

Table 3.4.1.1.1. Average values for the removal of air pollutants by various forest types (Nowak, 2016, 2018)

Forest type	*CO, t/ha/yr*	*SO_2, t/ha/yr*	*NO_x, t/ha/yr*	*CO + SO_2 + NO_x, t/ha/yr*	*Total, t/ha/yr*
Dark coniferous	0.0002	0.0022	0.0072	0.0096	0.0124
Light coniferous	0.0002	0.0025	0.0078	0.0105	0.019
Broadleaf	0.0006	0.0033	0.0081	0.012	0.0171
Mixed	0.0004	0.001	0.0055	0.0069	0.0136
Small-leaf	0.0002	0.0007	0.0047	0.0056	0.0144

For the current study, we assessed the **ES volume of pollutant removal provided** by woodland using similar approaches to those employed for assessing air pollution removal by suburban forests in TEEB-Russia Volume 2 (see Section 1.1.1 in Bukvareva, Sviridova, 2020). We defined the forest type and the related average value of air pollutant removal for each city (Table 3.4.1.1.2). Further, we assumed that all woodland inside one city belongs to one corresponding forest type. Therefore, the provided volume was calculated by multiplying the area of tree cover by the average value of air pollutant removal indicated in Table 3.4.1.1.2.

The provided volume depends on the area of woodland inside the city. This figure varies greatly between the studied cities: the highest values are found in Moscow (913 km^2), Perm (502 km^2) and Voronezh (335 km^2), the smallest values in Chelyabinsk (31 km^2), Omsk (58 km^2), Krasnodar (54 km^2) and Rostov-on-Don (64 km^2).

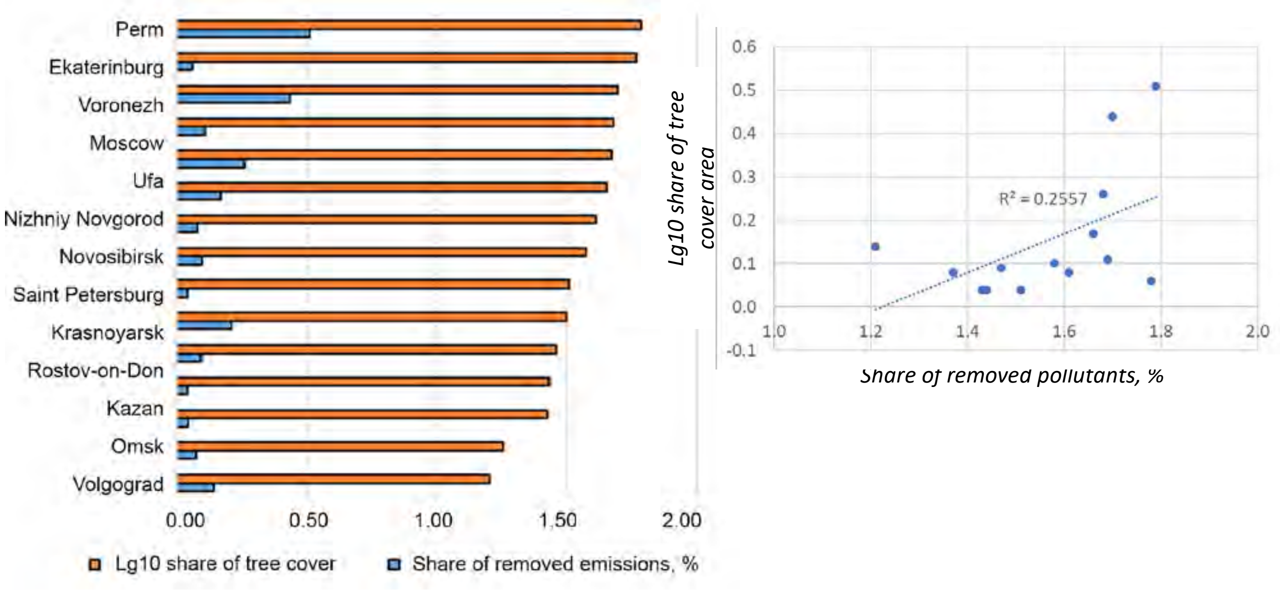
Table 3.4.1.1.2. Provided and demanded volumes of the ES of removal of air pollution from vehicles

City	SO_2			NOx			CO			Total (SO2 + NOx + CO)		
	Pollution emissions, tonnes/yr	Absorbed pollution, tonnes/yr	Share of absorbed pollutants from total emissions, %	Pollution emis-sions, tonnes/yr	Absorbed pollution, tonnes/yr	Share of absorbed pollutants from total emissions, %	Pollution emissions, tonnes/yr	Absorbed pollution, tonnes/yr	Share of absorbed pollutants from total emissions, %	Pollution emissions, tonnes/yr	Absorbed pollution, tonnes/yr	Share of absorbed pollutants from total emissions, %
Chelyabinsk	400	4.27	1.07	7,300	28.64	0.39	71,400	1.22	0.00	79,100	34.12	0.04
Ekaterinburg	900	15.23	1.69	16,500	83.77	0.51	156,700	6.09	0.00	174,100	105.09	0.06
Kazan	1800	17.83	0.99	35,700	98.08	0.27	248,900	7.13	0.00	286,400	123.04	0.04
Krasnodar	334	42.30	0.13	3,021	104.00	0.03	55,825	7.70	0.0001	59,180	154.00	0.0026
Krasnoyarsk	300	31.48	10.49	5,500	98.23	1.79	56,300	2.52	0.00	62,100	132.23	0.21
Moscow	4,400	132.35	3.01	79,100	727.93	0.92	742,300	52.94	0.01	825,800	913.22	0.11
Nizhniy Novgorod	500	21.57	4.31	8,400	118.65	1.41	77,900	8.63	0.01	86,800	148.85	0.17
Novosibirsk	600	13.65	2.27	10,000	91.64	0.92	99,100	3.90	0.00	109,700	109.18	0.10
Omsk	200	7.33	3.66	7,300	49.21	0.67	70,400	2.09	0.00	77,900	58.64	0.08
Perm	500	118.00	23.60	9,300	376.60	4.05	88,300	10.04	0.01	98,100	502.13	0.51
Rostov-on-Don	300	8.05	2.68	6,200	54.05	0.87	63,100	2.30	0.00	69,600	64.39	0.09
Saint Petersburg	2,100	23.62	1.12	37,600	129.91	0.35	361,100	9.45	0.00	400,800	162.98	0.04
Samara	500	9.14	1.83	8,900	61.34	0.69	85,100	2.61	0.00	94,500	73.08	0.08
Ufa	400	24.01	6.00	6,800	161.20	2.37	66,000	6.86	0.01	73,200	192.06	0.26
Volgograd	300	10.32	3.44	4,900	69.29	1.41	52,200	2.95	0.01	57,400	82.56	0.14
Voronezh	400	92.15	23.04	7,000	226.18	3.23	69,100	16.75	0.02	76,500	335.09	0.44

At this stage, the **demanded ES volume** is simply the total emissions from automobiles in the city (Table 3.4.1.1.2). This value can be found in the "Annual report of air pollution in Russian cities, 2017", issued by Rosgydromet. Here we note a significant difference between the cities: those with the greatest loads are Moscow, Saint-Petersburg and Kazan, while Volgograd, Krasnoyarsk and Rostov-on-Don produce less than 70,000 tonnes of emissions per year.

Comparison of the provided and demanded ES volumes. The ratio between the required and provided ES volume indicates the proportion of air pollutants removed by tree vegetation. This value does not exceed 1% in the studied cities (Table 3.4.1.1.2). Slightly more sulphur dioxide (SO_2) is absorbed than the other two pollutants (CO, NOx). In this case the demanded volume for removal is smaller than the consumed volume, meaning that more SO_2 emissions can be absorbed by the existing woodland. In contrast, carbon monoxide (CO) is removed in smaller volumes than other pollutants due to its intense emissions and the low absorption capacity of CO by trees.

The results of the preliminary ES assessment of Russia's most populated cities showed that today's urban green infrastructure is unable to remove all emissions. The best results were found in Voronezh and Perm (Table 3.4.1.1.2, Fig. 3.4.1.1.2), which are rather green and have comparatively low emissions. It should be also stressed that Moscow, despite having the largest green area, shows the worst results for all studied gases due to the enormous volume of vehicle emissions. The correlation between the proportion of removed pollutants and the relative extent of green area is extremely low, also indicating the inadequate capacity of this ecosystem service (Fig. 3.4.1.1.2).



a b

Figure 3.4.1.1.2. Correlation between the proportion of removed pollutants and the proportion of tree cover in the cities: a) diagram of cities ordered by the proportion of tree cover; b) correlation diagram

On the whole, these results agree with our previous assessment in Volume 2 (see Section 1.1.1 in Bukvareva, Sviridova, 2020: The removal of air pollutants from point sources by suburban forests for the federal subjects of Russia). However, the methods used to conduct the current assessment can also be improved. For instance, the approach should include the modelling of pollutants transported through the surface air, as this is where most of the pollutants are concentrated. Also, the configuration of each city's transport system should be considered.

3.4.1.2. Removal of air pollution from stationary point sources

Compared to automobiles, emissions from point sources present a smaller share of total emissions in Russia's most populated cities. To mitigate the effect of industrial zones on the environment and human health, special sanitary buffers are created around industrial areas. These must be of sufficient size to ensure that chemical, biological and physical air pollution does not exceed established safety guidelines.

Regarding industries classified in *danger categories* I and II, buffers must decrease concentration values to an acceptable level of health risk[15].

The size of a sanitary buffer depends on the *danger class* of the industry. For danger classes I, II and III the buffers are 1,000 m, 500 m and 300 m, respectively; for IV and V, the size is determined by field data and instrumental measurements. In this study we adopted the 300 m buffer (danger class III), under the assumption that the most populated cities do not have many dangerous industries within their borders. While Sanitary Norms and Regulations of Russia (SanPin) do not elaborate on the type of vegetation inside the buffers, it is stated that these must decrease the negative effect on the environment (including chemical and physical pollution), present a barrier between the residential and industrial areas, absorb pollutants and regulate the microclimate.

ES volume provided by tree vegetation. In this research we only considered the extent of woodland inside the buffer as the most effective type of vegetation to mitigate negative chemical and physical impacts and to purify the air. Specifically, we selected all areas in the OSM land-use layer with the tag "industrial" and created merged buffers of width 300 m around these. Then we calculated the area of tree vegetation inside these buffers using raster data on tree cover determined by M.C. Hansen for 2016. The provided volume of this ES was found to vary between 6.16 and 104.1 tonnes/yr, depending on the area of green infrastructure inside the buffers.

At this stage, **the demanded volume** was defined like many other ES in this report as total emissions from point sources inside the city. This assumption can be justified by the fact that in Russia there is no freely available geospatial data with identified point sources and emissions volume. This lack of information makes it impossible to calculate the demanded ES volume for each industrial area individually. In fact, green infrastructure inside the sanitary buffers is not required to remove all air pollutants, but simply decrease their level to the maximum permissible concentration (MPC). Moreover, green infrastructure inside the buffers is especially effective against flaring and other low-lying sources of air pollution. Pollutants from tall chimneys are transported over large distances and thus removed from the air by urban forests.

Comparison of the provided and demanded ES volumes. The ratio between the demanded and provided ES volumes is less than 1% in all case studies (Table 3.4.1.2.1). Considering that a large proportion of pollutants is transported away from the point source, we can assume that the major role of green infrastructure inside the sanitary buffers is to partly decrease the demanded volume of air purification provided by other urban and suburban forests, which also perform this ecosystem service.

Table 3.4.1.2.1. The assessment of the ES air pollution removal (gaseous pollutants) by green infrastructure inside the sanitary buffers of Russia's most populated cities

City	*Pollution emissions, tonnes/yr*	*Absorbed pollution, tonnes/yr*	*Share of absorbed pollutants from total emissions, %*
Chelyabinsk	140000	6.72	0.00
Ekaterinburg	24000	15.87	0.07
Kazan	32000	24.30	0.08
Krasnodar	12000	17.20	0.0014
Krasnoyarsk	129000	26.25	0.02
Moscow	63000	104.19	0.17
Nizhniy Novgorod	32000	19.60	0.06
Novosibirsk	85000	23.46	0.03
Omsk	171000	6.16	0.00
Perm	39000	31.05	0.08
Rostov-on-Don	12000	21.60	0.18
Saint Petersburg	73000	49.68	0.07
Samara	29000	26.40	0.09
Ufa	141000	10.35	0.01
Volgograd	23000	7.84	0.03
Voronezh	11000	37.20	0.34

[15] Sanitary and Epidemiological Rules and Norms SanPiN 2.2.1 / 2.1.1.1200-03. Sanitary protection zones and sanitary classification of enterprises, structures and other objects. New edition (2014).

Similar to the case of air pollution removal by suburban forests, the provided ES volume depends on the deforestation level in the sanitary buffers. In our study, we could not identify a single city where tree vegetation covered more than 30% of a buffer (Fig. 3.4.1.2.1). The maximum proportion was found in Perm (30%), with the lowest values in Chelyabinsk (7%) and Volgograd (9%). Figs. 3.4.1.2.2–3.4.1.2.4 illustrate the woodland within the sanitary buffers in these three cities.

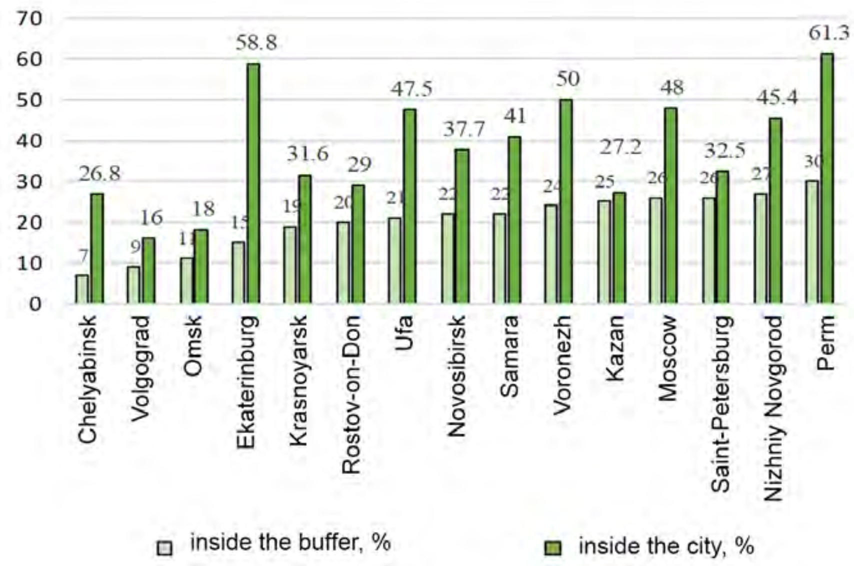


Figure 3.4.1.2.1. Share of tree vegetation from the total urban area and the total area of 300 m-buffers around industrial areas in Russia's most populated cities, %

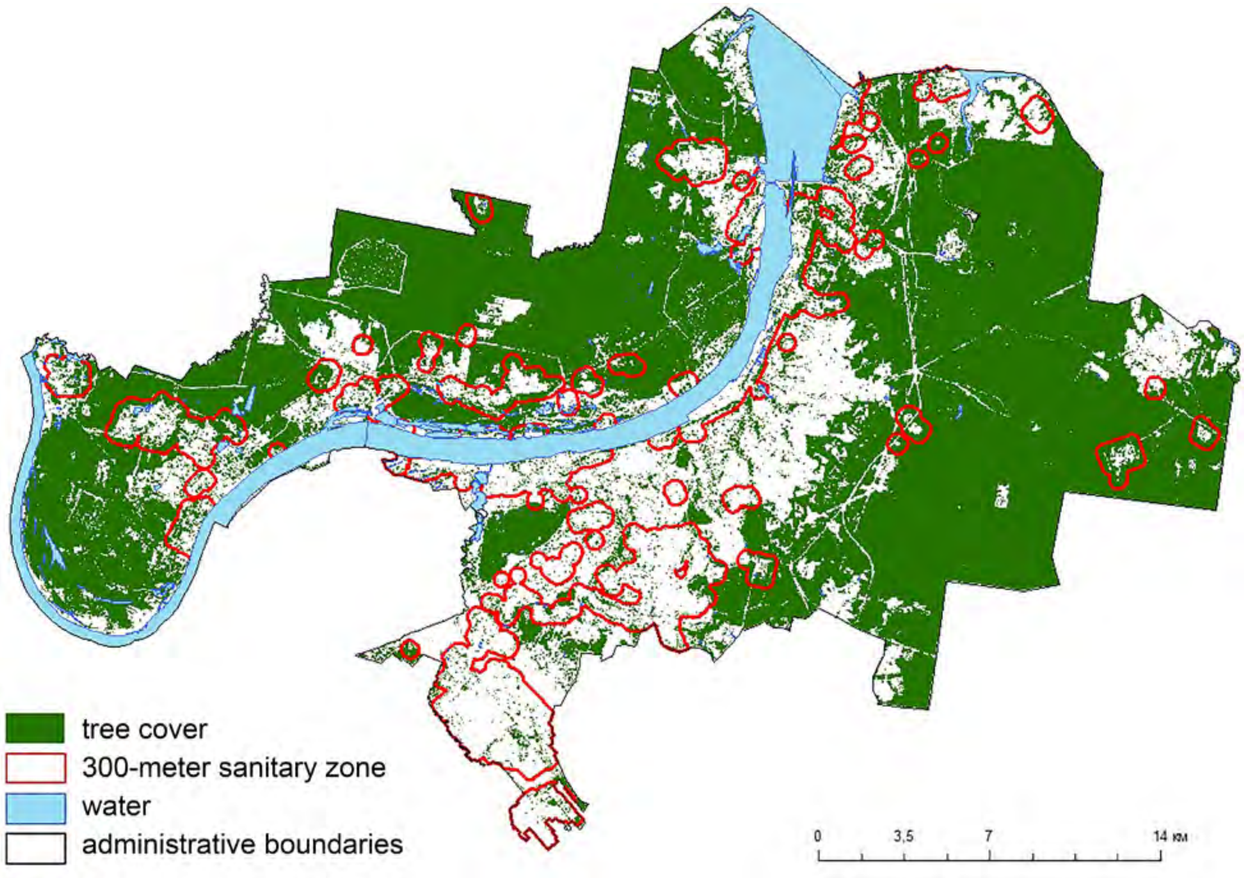


Figure 3.4.1.2.2. Tree vegetation in the sanitary buffers around industrial zones in Perm

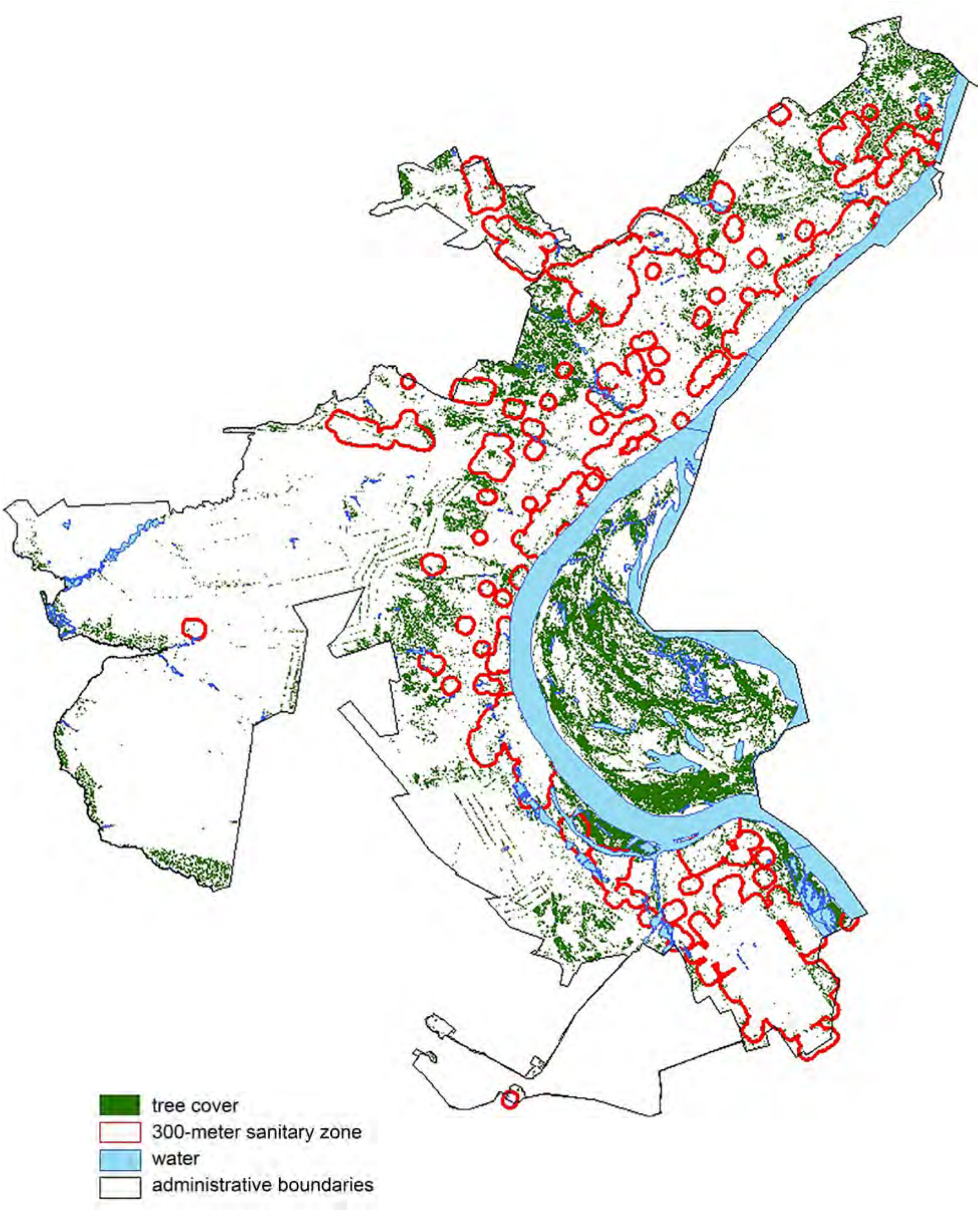


Figure 3.4.1.2.3. Tree vegetation in the sanitary buffers around industrial zones in Volgograd

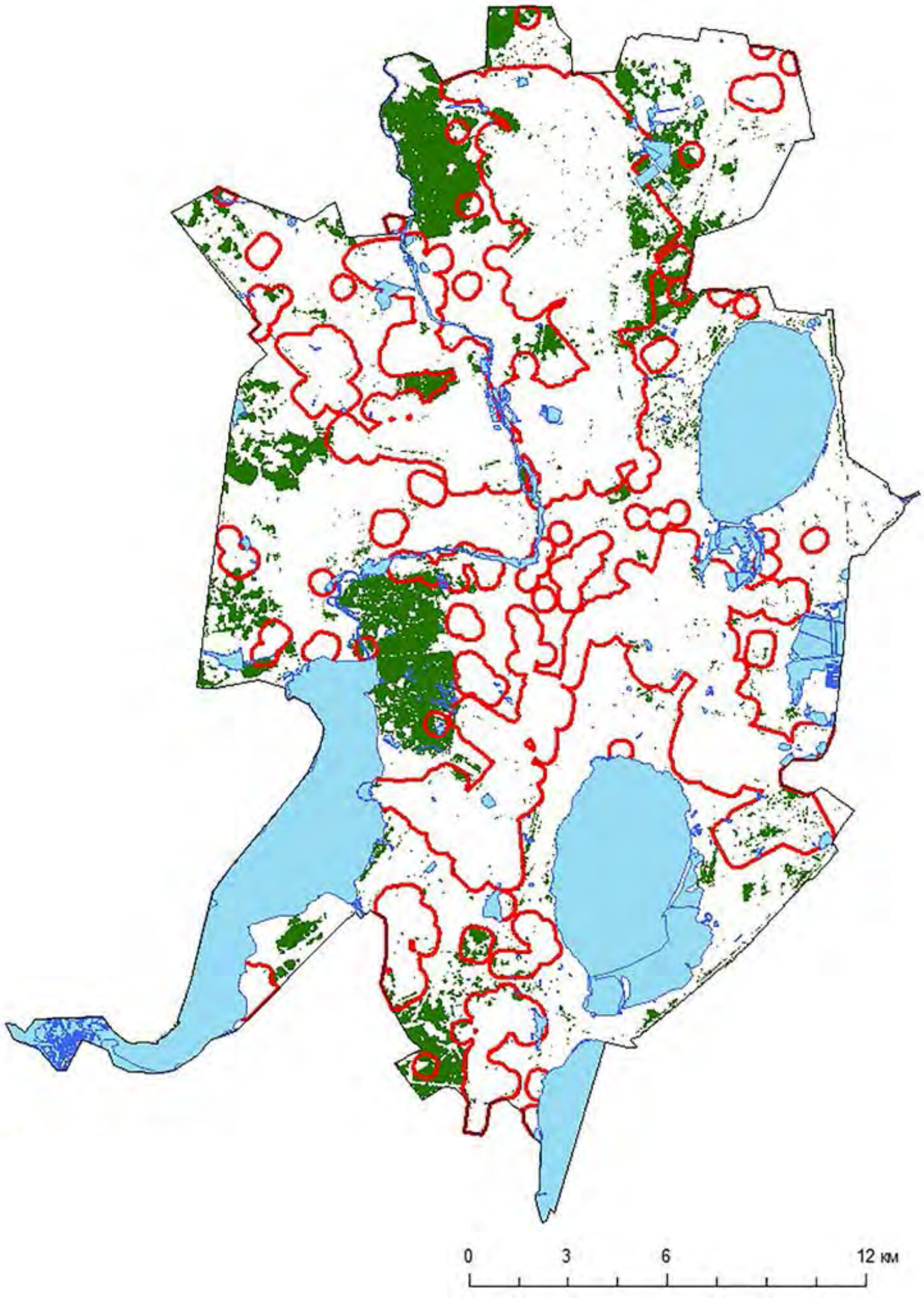


Figure 3.4.1.2.4. Tree vegetation in the sanitary buffers around industrial zones in Chelyabinsk

The extent of woodland in the sanitary buffers reflects the zone in which a city lies: for instance, values for this indicator are higher in cities in the forest zone than in the steppe zone. At the same time, the sanitary buffers are much more deforested than the cities themselves. Among other findings, we would like to highlight the following facts: the largest industrial zones were found in the biggest cities, namely Moscow and Saint Petersburg; in contrast, Ufa and all cities of the steppe group with an agricultural specialization such as Rostov-on-Don and Omsk showed the smallest area of industrial zone. Despite the large number of industrial zones in Moscow and Saint Petersburg, these cities also have the most highly vegetated sanitary buffers (Figs. 3.4.1.2.5–3.4.1.2.6).

Sanitary buffers are also relatively well vegetated in Kazan, Nizhniy Novgorod and Perm. An unsatisfactory level of green infrastructure in sanitary buffers was found in most steppe and forest-steppe cities with a small share of tree vegetation from the total urban area (Krasnodar, Chelyabinsk, Volgograd and Omsk). Among the cities from the steppe and forest-steppe group, the best results were found for Voronezh, whose buffers show almost 30% vegetative cover. Despite a large share of total tree vegetation in Ekaterinburg, the city's sanitary buffers are poorly vegetated, because most woodland is located in protected areas. Moreover, the majority of Ekaterinburg's industrial zones is concentrated in the densely built-up center, where there is little green infrastructure. We also noted that sanitary buffers are better vegetated in those cities where the industrial zones are on the outskirts rather than in center.

On the whole, sanitary buffers in all studied cities are vegetated less than recommended by SanPin for industrial danger classes V, IV and III (60–50% of green area inside the buffer). In this research we did not calculate the share of tree cover for each industry zone individually, meaning that in reality some industries – especially those on the outskirts – may be vegetated according to the standards. However, our results show that most industries do not have sufficiently vegetated sanitary buffers.

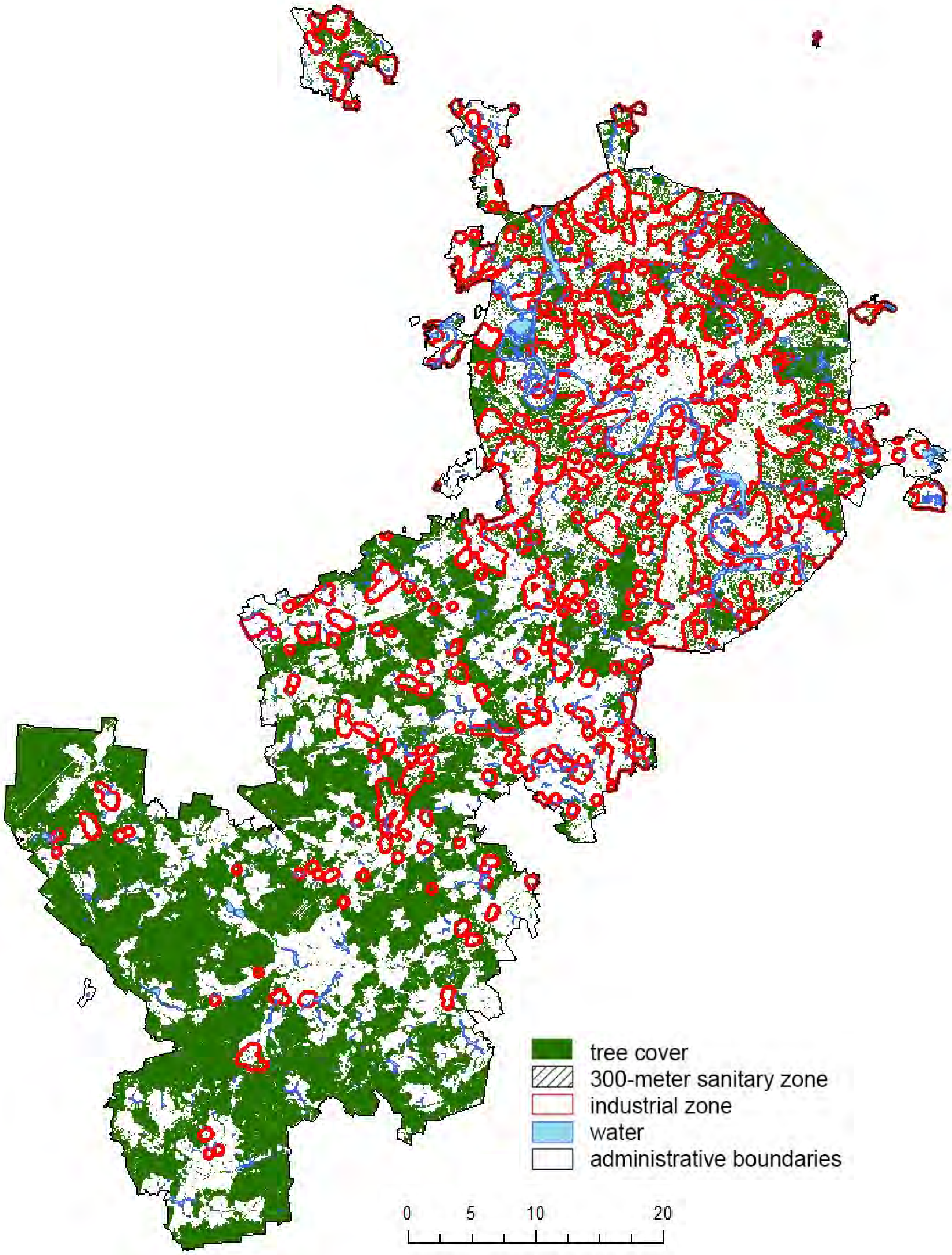


Figure 3.4.1.2.5. Tree cover in the sanitary buffers around Moscow's industrial zones

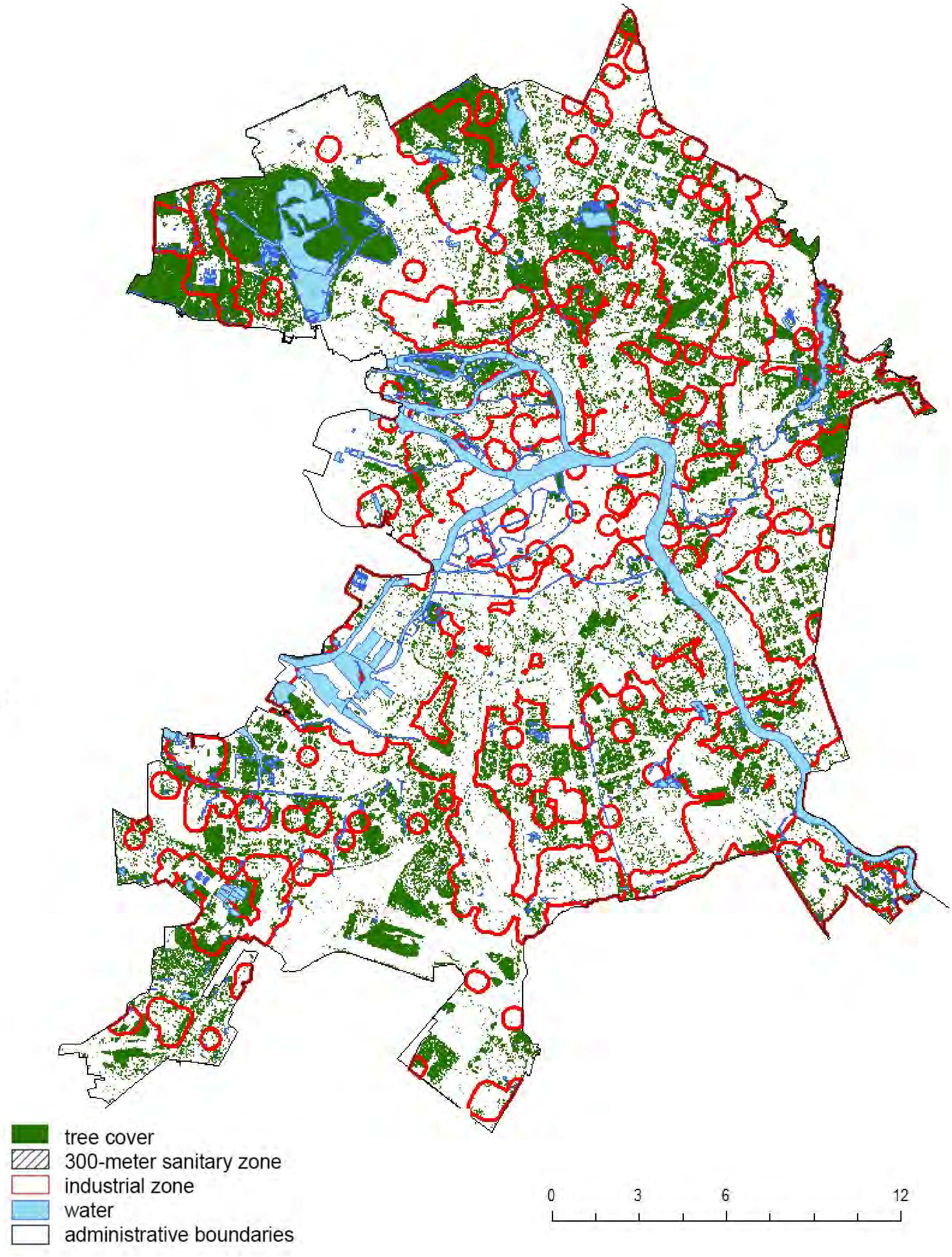


Figure 3.4.1.2.6. Tree cover in the sanitary buffers around Saint Petersburg's industrial zones

3.4.1.3. Urban microclimate regulation: cooling effect

Urban green infrastructure plays a crucial role in regulating the urban microclimate, particularly in reducing the *heat island effect* (Gill et al., 2007, London Climate Action Plan, 2018). An urban heat island is a built-up area in the city with higher temperatures than in nearby open space. This difference in temperatures is caused by a specific heat exchange between the atmosphere and the built-up area (Forman, 2015). The intensity of an urban heat island depends on local meteorological factors and the ratio between built-up and unsealed green areas in the urban land-use system (Grimmond et al., 2010). A case study of Berlin showed that large elements of green infrastructure have a more efficient cooling effect on the surrounding area than small elements (von Stulpnagel et al., 1990). Specifically, the temperature in the center of a large green element (> 500 ha) is 5 °C lower than in adjacent territories (ibid.). The cooling effect in Moscow ranges from –4.3 to +0.3 °C (with an average of –1.3 °C) (Sorokina, Lokoshenko, 2015). Depending on the size of the green element, the area benefiting from the cooling effect may vary between 500 and 1,500 m (von Stulpnagel et al., 1990, Marsh, 2010, Tyrvainen et al., 2005).

ES volume provided by green infrastructure. Assuming that in cities with similar geographical features, large green elements (> 500 ha) perform the most efficient cooling effect at a distance up to 1,500 m, we determined the average area cooled by parks. Assuming a near circular form for the cooled area, we calculated the area using the following equation: $S_3 = S_1 + S_2$, where S_1 is 500 ha, S_2 is the cooled area and S_3 is the total area of park and the area which it cools. The resulting sum of a park's area and its cooled area is 1,893 ha. This is 3.8 times bigger than the park itself. We took this value as a coefficient to calculate the nominal area influenced by similar parks and their tree vegetation in each city (see Table 3.4.1.3).

Here the **demanded ES volume** is simply the urban area including the area of tree cover. Table 3.4.1.3 shows that some of the studied cities do not have sufficient green infrastructure to perform an optimal climate regulation (i.e. less than 100% of the urban precincts enjoys a cooling effect). These include cities in the steppe zone such as Volgograd, Omsk, Krasnodar, Chelyabinsk and Samara. While Saint Petersburg was also found to be suboptimal in this ecosystem service, our adopted method is probably less suitable here as it does not take account of the numerous channels and water bodies in the city which also have a significant cooling effect. The cooled area in Perm, Moscow and Nizhniy Novgorod was found to be two times bigger than the urban precincts. This can be attributed to the high shares of developed green infrastructure and tree vegetation in these cities.

Table 3.4.1.3. Urban microclimate regulation by tree vegetation in Russia's most populated cities

City	*Area cooled by green infrastructure, ha*	*Total urban area, ha*	*Share of urban area receiving cool air, %*
Chelyabinsk	23,068.10	50,400	45.77
Ekaterinburg	57,660.78	40,100	143.79
Kazan	67,511.95	63,500	106.32
Krasnodar	147,521.7	33,930	23.00
Krasnoyarsk	47,677.10	37,800	126.13
Moscow	501,077.10	243,200	206.03
Nizhniy Novgorod	81,671.59	31,700	257.64
Novosibirsk	73,815.64	48,100	153.46
Omsk	39,643.21	58,000	68.35
Perm	190,106.42	80,600	235.86
Rostov-on-Don	43,535.21	35,500	122.63
Saint Petersburg	89,425.32	145,100	61.63
Samara	49,407.30	54,300	90.99
Ufa	129,848.44	66,700	194.68
Volgograd	55,817.00	86,100	64.83
Voronezh	105,720.26	60,100	175.91

Do these results prove that cities where the cooled area is twice the urban area have sufficient green infrastructure to mitigate the heat island effect? In fact, we can assume that this is only partly true. The efficient performance of this service depends first and foremost on the location of green elements, which ideally should be situated within the densely populated urban center and not only at the outskirts. This center is the built-up core of the heat island, which exposes the majority of city dwellers to excessive heat. However, our data only allows us to assess the configuration of green infrastructure qualitatively (Fig. 3.2.1–3.2.4). These results demonstrate that the main challenge to climate change adaptation in all of Russia's biggest cities is a lack of green infrastructure in the urban center.

Thus, to improve our assessment methodology, it is necessary to consider not just the scale of heat islands in Russian cities but also the size of existing green elements. Better knowledge of the form, size and location of parks can help to calculate the affected area more accurately.

When assessing the microclimate regulation of urban green infrastructure, it is also possible to investigate how the cooling effect specifically affects residential areas. In this case, the demanded cooling will simply be the area of a residential zone when average daytime surface temperatures are higher than normal. The provided cooling will be the area of a residential zone that receives an influx of cool air.

3.4.2. Provisioning services: food production

According to the *Urban Atlas Project's* classification of urban green infrastructure, this also includes agricultural areas. It seems that their role in Russian cities is not as important as in most cities in developing countries and China, where urban agricultural lands are crucial for food security. In our case studies, croplands maintained by private households are the most important form of such food provisioning in cities. They usually make up the majority of all croplands within the urban precincts. Volgograd, Voronezh, Ekaterinburg, Omsk and Krasnodar are the only case studies where we found a considerable area of croplands belonging to agricultural businesses. Most permanent croplands such as fruit orchards belong to private households.

Agricultural lands make up 2.95% of the total urban area in Rostov-on-Don and 11% in Krasnodar (see Table 3.4.2.1). The share depends not only on the ecological zone and climate conditions but also on the historical formation of the city.

According to the ecosystem services classification of TEEB-Russia (Bukvareva, Zamolodchikov, 2016), food provisioning is not considered to be an ecosystem service. However, complex regulating services such as runoff regulation, soil formation and erosion control are essential to secure food production on agricultural lands. These regulating services can be indirectly assessed regarding their input to food provisioning.

ES volume provided by green infrastructure is expressed as an indirect indicator, namely gross yield of household croplands during the year. Typical cultivated crops are potatoes and other vegetables as well as fruits. Drawing on official statistical data for the municipalities, we additionally calculated the share of croplands and permanent croplands from the total urban area.

Table 3.4.2.1. Valuation of ecosystem services that help secure food production in Russia's most populated cities

City	*Share of cropland from total urban area (%)*	*Index of the provided ES volume – gross yield from the household croplands (cwt/yr)*	*Demanded volume (cwt/yr)*	*Ratio between demanded and provided volumes (%)*
Chelyabinsk	7.30	298,574.0	1,920,140	15.55
Ekaterinburg	3.50	337,464.4	2,373,280	14.22
Kazan	4.02	534,759.4	2,008,160	26.63
Krasnodar	11.8	358,963.0	1,467,000	2.45
Krasnoyarsk	4.44	238,530.1	1,765,290	13.51
Moscow	5.96	No data	20,181,030	No data
Nizhniy Novgorod	No data	No data	2,057,060	No data
Novosibirsk	4.10	219,386.9	2,612,890	8.40
Omsk	7.85	518,004.4	1,656,080	31.28
Perm	No data	220,188.1	2,373,280	9.28
Rostov-on-Don	2.95	139,162.4	1,833,750	7.59
Saint Petersburg	4.48	No data	8,609,660	No data
Samara	No data	105,664.0	1,907,100	5.54
Ufa	6.01	390,701.5	1,819,080	21.48
Volgograd	7.76	464,020.4	1,654,450	28.05
Voronezh	3.57	No data	1,695,200	No data

The demanded ES volume. Households mostly grow potatoes and other vegetables as well as fruits for trade or private use. According to the recommendations of the World Health Organization, a healthy diet should include 400 grams of fruits and vegetables every day (in addition to potatoes and other root vegetables). Considering that this recommendation also includes crops that cannot be cultivated in the temperate zone such as bananas, oranges, grapefruits, etc. we halved this norm to 200 g per capita per day (or 73 kg/year) to calculate the demanded volume. According to recommendations of the Ministry of Health of the Russian Federation, an annual rational norm of potato consumption is 90 kg per capita. Thus, a total standard value for vegetable, fruits and potato consumption can be set at 163 kg per capita per year. The demanded volume was calculated by multiplying this value by the total population of a city.

Ratio between the demanded and provided ES volumes. While modern large cities are generally not self-sufficient in food, our analysis showed considerable variation in the ratio from 5.54% in Samara to 31.28% in Omsk (see Table 3.4.2.1). It should be noted that this potential input into food provisioning is bigger than the percentage of agricultural lands in the city. This implies that household croplands are highly productive and important for food security in several of Russia's most populated cities.

To assess more accurately the input of urban agricultural lands to food provisioning, it would be necessary to take account of the particular features of the local fruit & vegetable markets as well as the consumption of crops (statistical data on different types of crops) and people's preferences for local products.

3.4.3. Cultural services: forming natural conditions for recreation

The most important ecosystem service provided by urban green infrastructure is to establish conditions for recreational walking and sports. Unfortunately, it is technically difficult to assess this kind of ecosystem services in Russian cities: firstly, due to the variety of green elements with diverse conditions for recreation; and secondly, because of the wide range of recreational activities and a lack of standards to regulate the permissible recreational carrying capacity. As previously mentioned, urban green infrastructure encompasses protected areas (PAs). PAs are a part of an urban improvement system even though recreation is not their main aim.

ES volume provided by green infrastructure is here calculated as the maximum permissible number of people who – considering the status of a specific green element – can simultaneously and comfortably visit an element of urban green infrastructure for recreational walking. The assessment was done in the following stages.

1. First it was necessary to define the types of green infrastructure suitable for recreation. Here we used the attributes "*vegetation", "landuse vegetation", "landuse"* as provided in OpenStreetMap layers. Based on the descriptions of the keys, we selected elements from the following categories: "*wood"*, *"forest"*, *"orchard"*, *"grass"*, *"meadow"*, *"village_green"*, *"recreation_ground"*, *"garden"*, *"park"*, *"allotments"* and *"cemetery".* Generally, the borders of these elements correspond with the outlines of green infrastructure we received from a classified NDVI image and Hansen's tree-cover raster, thus proving their relevance.

From the values of areas suitable for recreation, we subtracted the areas of PAs. Other green elements were unified into one group (Fig. 3.4.3.1–3.4.3.4).

2. In Russia there is a standard method used to calculate the maximum permissible recreational carrying capacity of natural ecosystems (Temporal methods…, 1987). This considers two aspects: 1) types of tourism (i.e. excursions, planned and unplanned tourism, everyday recreation); and 2) types of forest or grassland ecosystems (in particular, the type of ground vegetation in natural ecosystems). Minimum values for mass daily recreation were used to calculate the recreational carrying capacity of PAs. We selected an average norm for the simultaneous recreational carrying capacity of protected areas (without considering the vegetation type) of 2 per/ha; this was a recommendation given by the authors of the temporal methods for the birch forests of the broadleaf and coniferous zone. We also ignored factors such as the type of vegetation cover in the protected areas, the age of trees, the length of paths and roads, the level of air pollution, etc. Regarding the other elements of green infrastructure, we selected the norms of recommended recreational carrying capacity to get an average value of 50 per/ha. We also calculated the provided volume, based on minimum norms of recreational carrying capacity for protected areas.

3. The provided volume, expressed as a permissible number of simultaneous visitors (depending on the status of the visited green element but ignoring the level of recreational development), was assessed by multiplying standard values by the areas of PAs and other green elements (Table 3.4.3.1).

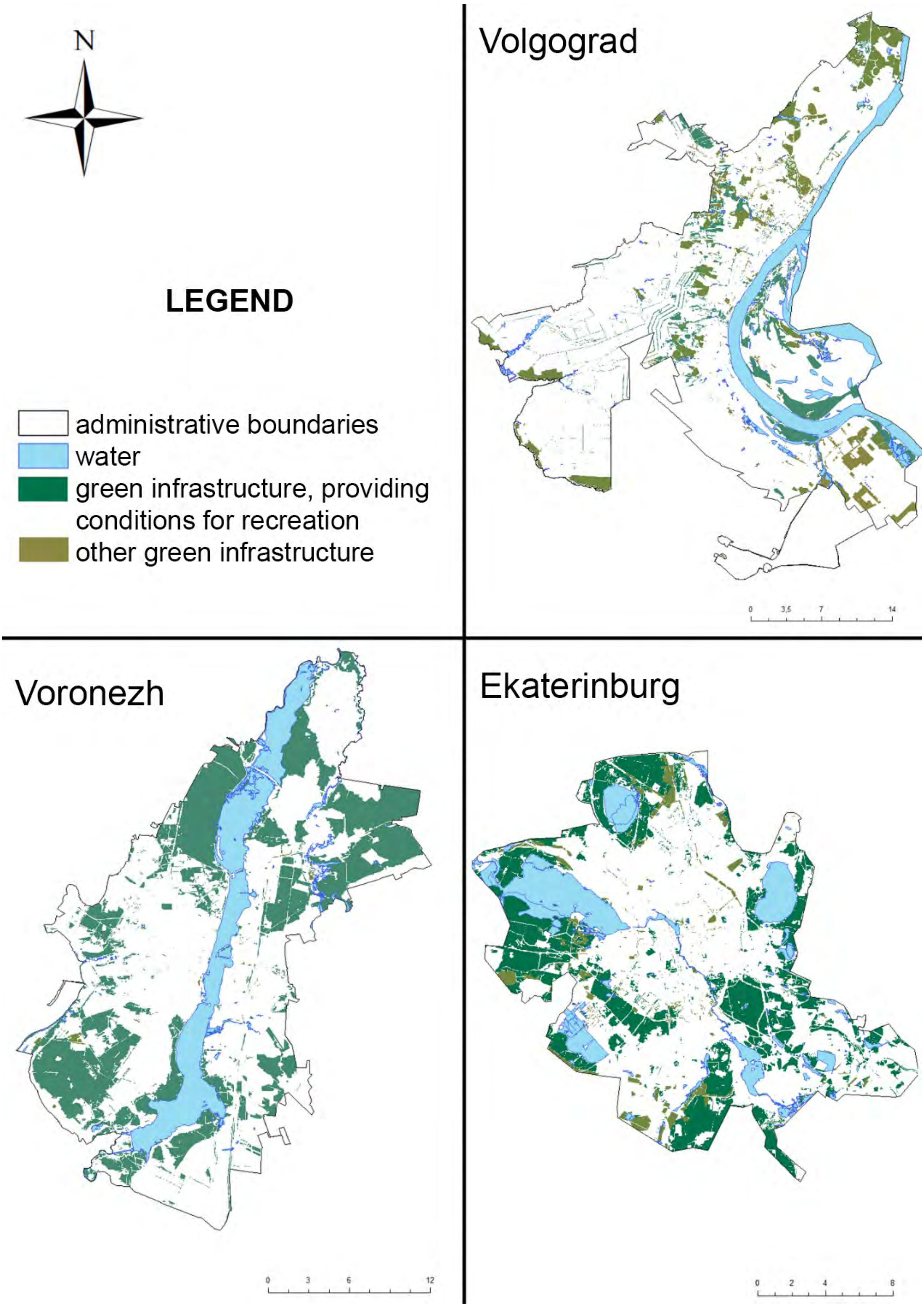


Figure 3.4.3.1. Green infrastructure capable of performing recreational services in Volgograd, Voronezh and Ekaterinburg

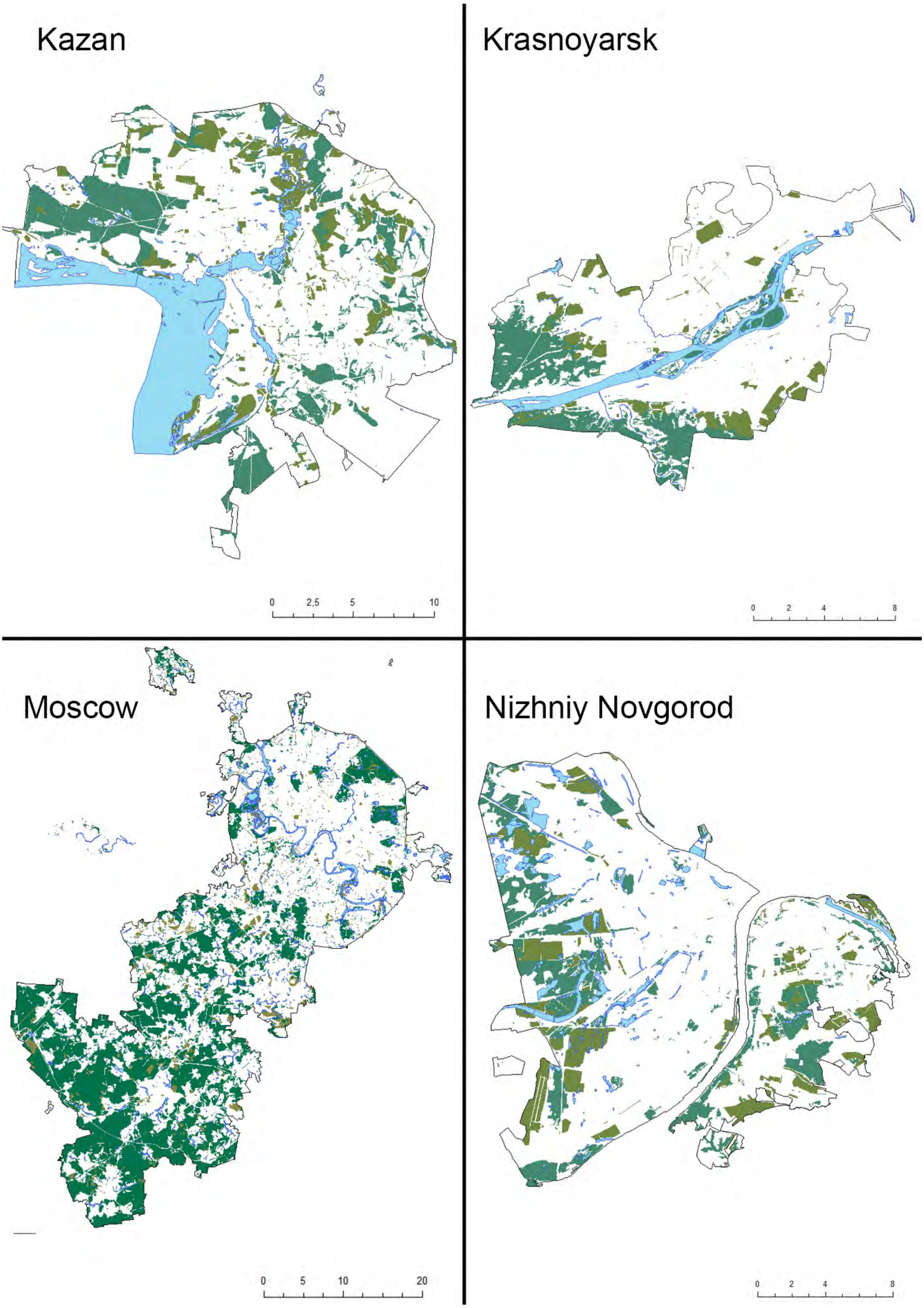


Figure 3.4.3.2. Green infrastructure capable of performing recreational services in Kazan, Krasnoyarsk, Moscow and Nizhniy Novgorod

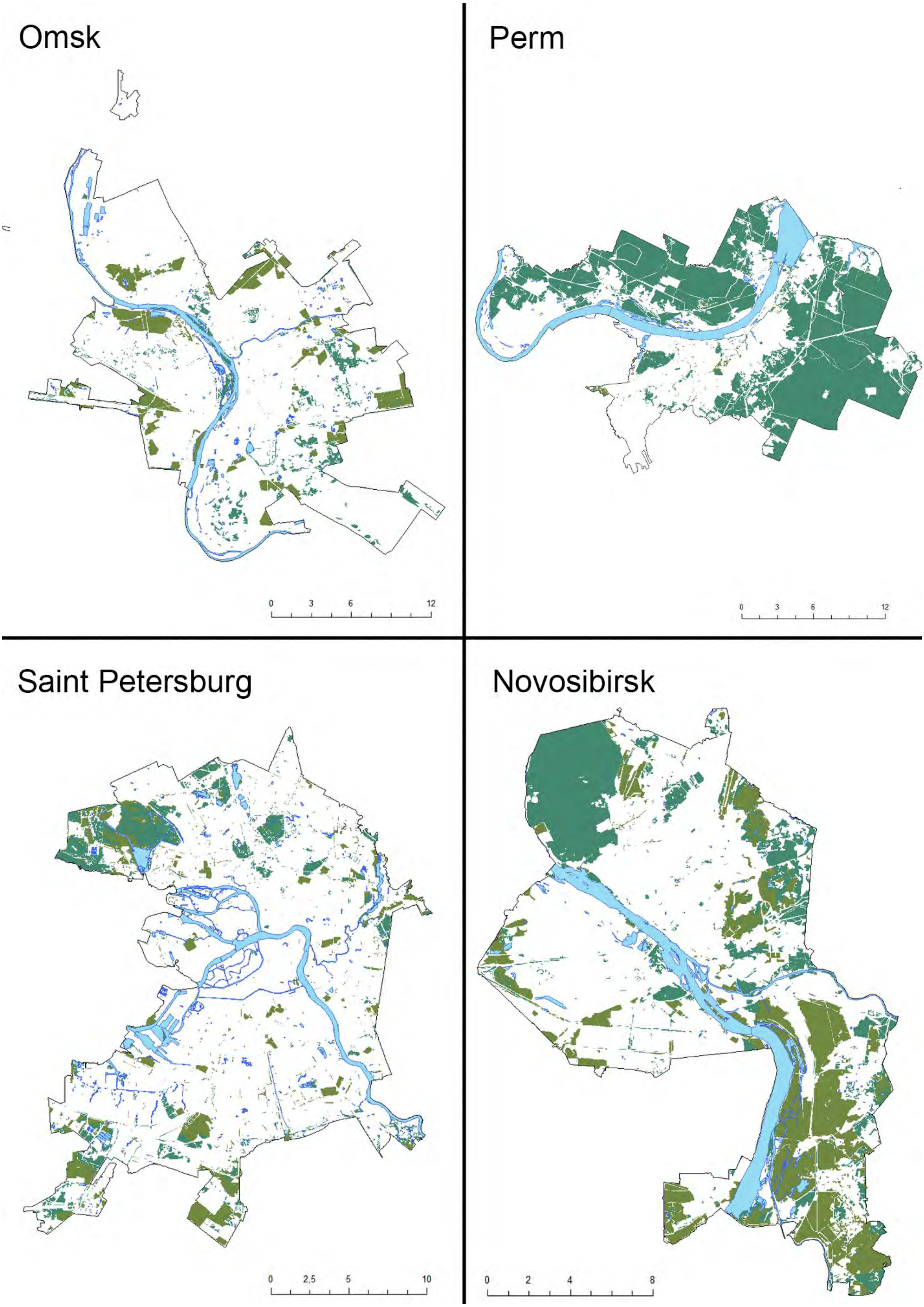


Figure 3.4.3.3. Green infrastructure capable of performing recreational services in Omsk, Perm, Saint Petersburg and Novosibirsk

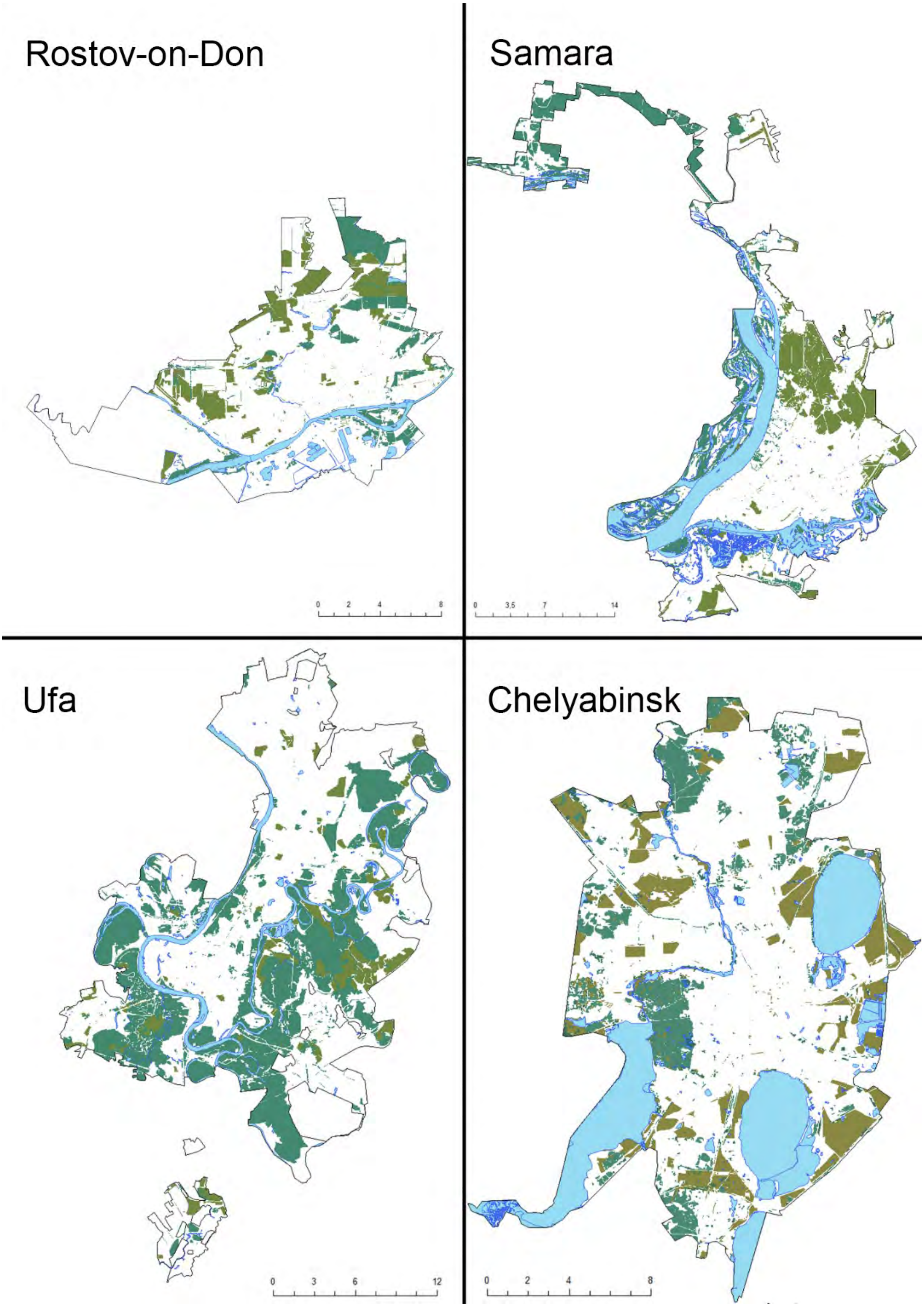


Figure 3.4.3.4. Green infrastructure capable of performing recreational services in Rostov-on-Don, Samara, Ufa and Chelyabinsk

The demanded ES volume assessment was based on the recommended number of simultaneous park visitors according to the standard figure (for example[16] of 5% of the urban population.

Comparison of the provided and demanded ES volumes. When taking account of different recreational carrying capacities, the results show that all cities (except Rostov-on-Don) can supply a considerably larger volume of recreational service than the city demands (the ratio is above 100%). Rostov-on-Don shows low provided volumes because we made use of OSM data that shows few recreational areas and probably defines small private green elements as built-up areas of low density, which are thus not selected as a land-use category for recreation. The ratio between the demanded and provided volumes changes when applying a standard value for recreational carrying capacity of protected areas and other elements of green infrastructure (2 per/ha). In this case, the ES supply exceeds the demand in only two cities, Voronezh and Perm. In other cases, the demand is greater than the supply.

Thus, we see that the results can be made more accurate by:

1) using the most reliable information on green infrastructure capable of performing recreational services and its current state;

2) defining the types of recreational activities to specify the norms of carrying capacity for each one individually;

3) detailing the norms for permissible recreational carrying capacity that does not deteriorate natural ecosystems in consideration of the specific environmental and geographical features of the area: slopes, soil and vegetation cover, factors of fauna disturbance, etc.

Table 3.4.3.1. An assessment of the recreational services provided by urban green infrastructure in Russia's most populated cities

City	*No. of simultaneous visitors to PAs*	*No. of simultaneous visitors to other elements of green infrastructure*	*Total no. of visitors with different coefficients of maximum carrying capacity*	*Total no. of visitors with a carrying capacity coefficient of 2 per/ha*	*Recommended no. of visitors*	*Ratio of the provided and demanded volumes under different coefficients of maximum carrying capacity (%)*	*Ratio of the provided and demanded volumes with a carrying capacity coefficient of 2 per/ha (%)*
Chelyabinsk	14,306	227,350	241,656	23,400	58,900	410.28	39.73
Ekaterinburg	275	583,135	583,410	23,600	72,800	801.39	32.42
Kazan	7,152	606,200	613,352	31,400	61,600	995.70	50.97
Krasnoyarsk	0	435,000	435,000	17,400	54,150	803.32	32.13
Moscow	35,200	4,010,000	4,045,200	195,600	619,050	653.45	31.60
Nizhniy Novgorod	6,826	204,350	211,176	15,000	63,100	334.67	23.77
Novosibirsk	2,048	778,800	780,848	33,200	80,150	974.23	41.42
Omsk	914	332,150	333,064	14,200	50,800	655.64	27.95
Perm	8,699	1,907,535	1,916,234	85,000	72,800	2632.19	116.76
Rostov-on-Don	6,600	20,000	26,600	7,400	56,250	47.29	13.16
Saint Petersburg	12,286	1,817,850	1,830,136	85,000	264,100	692.97	32.18
Samara	2,534	651,650	654,184	28,600	58,500	1118.26	48.89
Ufa	2,500	1,102,500	1,105,000	46,600	55,800	1980.29	83.51
Volgograd	4,600	500,000	504,600	24,600	50,750	994.29	48.47
Voronezh	15,150	981,250	996,400	54,400	52,000	1916.15	104.62

[16] Decree of the Moscow Government, 23 December 2013 № 1098/55 "Instructions. Regional park standard of the Moscow region".

4. Moscow

Moscow is Russia's largest city and one of the 30 most highly populated urban areas in the world. Administratively, it is treated as a "federal subject" of the Russian Federation. Moscow has 146 municipalities, combined into 12 administrative districts. The urban population is continually growing: from 1991 to 2015 it jumped from around 9 to 12 million. At national level, the Moscow agglomeration is unique not only in terms of its size but also the primary role it plays in the country's economy (Mahrova et al., 2012). Since the collapse of the Soviet bloc, the economic system has undergone significant change over the intervening years. This has boosted the central importance of Moscow while also transforming the various sectors of the urban economy. In particular, the capital has seen a rise in non-manufacturing while industrial production has decreased.

4.1. General characteristics of nature and landscape

Forest ecosystems in Moscow mostly inherited their species composition from natural biotopes. They were formed at the intersection of regions with contrasting soil and geomorphological conditions: the Smolenskaya Highlands dominated by pine woods, Mesherskaya Lowlands with broadleaf oak and linden forests, and the Moskvorezko-Okskaya Plains with their spruce and broadleaf forests. Willow and alder woodland, peatlands and meadows are also quite common due to the extensive river drainage system and high runoff. Wetlands can be found on the interfluves.

Vegetation cover in present-day Moscow comprises fragments of natural forests or grasslands as well as green infrastructure elements such as parks, boulevards and other public green areas. Pine woodland makes up 21% of Old Moscow's tree vegetation (Pokrovskoe-Streshnevo, Kuzminskiy, Aleshkinskiy forests). Pine is usually found in mixed pine-oak and pine-linden woods. Spruce forests are not so widespread, making up only 1.9% of Moscow's green area (Losiniy Ostrov, Bitzevskiy and Kunzevskiy forests). Oak woods, which form 10% of urban forest, are more common in the southern part of the city (Birulevskiy, Izmaylovskiy, Kuskovo forests). Linden woods, which are widely dispersed, make up 18% of all tree cover in Old Moscow. The majority of Moscow's woodland consists of small-leaf secondary forests, particularly birch (39% of the total area of Old Moscow) and aspen (3.8%). Due to the significant transformation of river valleys, today there exists only small fragments of floodplain forests (willow and alder woods). Limited areas of meadow and wetlands can be found in the Krylatskie Hills, the Teplostanskaya Highlands and the Shodnya Valley as well as along the banks of the Chertanka, Gorodnya and Ramenka rivers. Large extents of the traditional floodplains disappeared following the regulation of Moskva River. Some of these, however, can still be found in Moskvorezkiy and Brateevo parks. A few isolated areas of floodplain peatland can be found in the lower course of the Gorodnya River, along the riverbanks of the Setun and Serebryanka, on the Shuchinskiy peninsula and in Serebryaniy Bor forest.

The territory of New Moscow has a significantly different structure of ecosystems. More than half of all woodland is made up of small-leaf forests (65%), dominated by birch and aspen. Coniferous forests, particularly pine and spruce forests, comprise 18.1% and 7.9% of New Moscow's woodland, respectively. In most cases, coniferous forests were planted in the 20th century. Broadleaf forests occupy less territory (6%) and are mostly oak. Woodland dominated by linden makes up 2.2% of urban forests. Other tree species such as alder, larch, willow, ash, fir, maple, poplar, elm, etc. can be found in the forests of New Moscow. The most valuable of these are fir, larch, elm, maple and ash, which can all be found only as silvicultures of different age. As introduced species, larch and fir are foreign to the local flora. Grey alder belongs to the small-leaf species that actively occupy abandoned agricultural land and clearings. Black alder is frequently found in peatlands and on wetlands of small rivers. Willows commonly grow on the floodplains. Almost one third of all forest area consists of mature and over-mature woodland stock. These generally feature aspen, birch and alder. Coniferous forests are mostly middle-aged.

Unlike forests, urban green space of different functions is not self-regulating but needs constant management and restoration. Green areas often have a specific monotonous and planned vertical structure, and a scant variety of species. Urban tree stocks are dominated by linden, poplar, maple, ash, elm, oak, birch and coniferous species such as larch, Siberian spruce and thuja. Shrubland is also artificially formed; the ground vegetation consists of many species and often includes weeds.

Thus, we see that Moscow's vegetation is a complex pattern of forests (fragments of zonal vegetation) with historical cultural landscapes and artificial green elements of diverse condition and species composition. The legislative basis and organizational forms of green infrastructure management have shifted in line with the urbanization of the Moscow region, passing through many phases and programs, from the "Green Outfit of the City" to the "Natural Complex of Moscow" and "Green Network" (a so-called "urban-ecological" network for Old Moscow and "natural-ecological" network for New Moscow). This can be viewed as a response to the various trends in urban green infrastructure development.

4.2. Moscow's green infrastructure: its current condition, the history of management and main problems

4.2.1. Land-use structure

Information systems on land-use and land-cover based on the remote sensing data are widely used by European researchers for ecosystem assessment both at the urban and regional levels. The Urban Atlas can be considered a best practice model. Implemented by the Copernicus Land Monitoring Service, the Urban Atlas gives details of the transformation in land-use and land-cover for the years 2006, 2012 and 2018. This data is available for 319 cities with populations over 100 000, for the EU countries and for 785 urban areas of the EU, the EFTA countries, the Western Balkans and Turkey (2012). Data on street vegetation and buildings heights can be downloaded together with the main layers on land use.

Urban Atlas data forms a picture of a city as a complex of diversified and integrated land-cover areas. This complex considers not only the availability of green infrastructure elements but also defines their functions and their role in forming a well-balanced and comfortable urban environment for all citizens. Such a complete picture is required to correctly assess ecosystem services.

Following the implementation of Urban Atlas, the European Commission for the Environment developed methods to calculate ecosystem services for the purposes of urban spatial planning. For instance, the technical report *Green infrastructure and territorial cohesion* (2012) matched various types of ecosystem services to categories of urban land-use in the Urban Atlas (Table 4.2.1.1).

Table 4.2.1.1. Urban Atlas codes and matching ecosystem services

Ecosystem services	*Code*	*Green infrastructure elements*
Adaptation to climate change	20100 20200 30000	Agricultural lands Wetlands Forests
Climate change mitigation	14100 20100 20200 30000	Urban green space Agricultural lands Wetlands Forests
Runoff regulation	20200 50000	Wetlands Water bodies
Biodiversity conservation	20200 30000	Wetlands Forests
Formation of conditions for recreation	14100 14200	Urban green space Sport and recreational centers
Fostering cultural identity	14100 50000	Urban green space Forests
Provision of food security	20100	Agricultural lands

Table 4.2.1.1 shows that this approach reveals the multi-functionality of green infrastructure. In particular, urban forest turns out to be the most valuable and multi-functional type of green infrastructure. Sport and recreational areas, on the contrary, perform few functions; although not always a part of natural green infrastructure, they are still important locally by helping to create a comfortable environment at the level of urban blocks.

The Urban Atlas is maintained by a large research agency on the basis of diverse cartographic materials at high spatial resolution. While the project does not encompass Russian cities, the described methods can be applied to these using OpenStreetMap data (which, however, is less accurate). Through reclassification (see Section 2.3.2), we were able to obtain typical Urban Atlas land-cover categories for Moscow.

The current structure of land-use was derived from data for 2016 (Table 4.2.1.2, Fig. 4.2.1.1). Land-use maps for Old Moscow and New Moscow are shown in Figs. 4.2.1.2 and 4.2.1.3.

One half of the area of "Greater Moscow" is built-up (44%). A somewhat higher proportion is dedicated to green infrastructure (55%) (Table 4.2.1.2). It is clear, though, that this favorable ratio can be attributed to Moscow's huge expansion in 2012, when vast undeveloped territories of "New Moscow" became incorporated into the city.

Forests make up the majority share of urban green infrastructure (33% of the total area of Greater Moscow) (Table 4.2.1.2, Fig. 4.2.1.1). A considerable proportion is taken up by arable land (12%), which brings many valuable services for climate adaptation such as permeability, moisture saturation, an ability to regulate runoff and a high biodiversity of invertebrates in soils. Cultivated land is also capable of accumulating and binding greenhouse gases, what is important for climate regulation.

A considerable proportion of built-up area is made up of a discontinuous (13% of the total urban area) and isolated (13%) urban fabric of low-density, where the level of soil sealing is 30–50%. Together, these categories comprise more than half of built-up land (Fig. 4.2.1.1). These widespread low-density areas help reduce the impact of climate change, in particular urban heat islands, which can have a severe impact on the health of local residents. Clearly, areas with a continuous/discontinuous high-density urban fabric with more than 80% soil sealing are most vulnerable to excess heat. In total, this form of development covers about 1,385 ha or 0.53% of the urban area.

Table 4.2.1.2. Proportions of various types of urban fabric and green infrastructure in Greater Moscow, 2016

Land-use types	*Codes**	*Area, ha*	*Share of total area, %*
Built-up areas			
Continuous urban fabric (soil sealing > 80%)	11100	85	0.03
Discontinuous dense urban fabric (soil sealing 50–80%)	11210	1,300	0.51
Discontinuous medium density urban fabric (soil sealing 30–50%)	11220	5,452	2.12
Discontinuous low density urban fabric (soil sealing 10–30%)	11230	34,343	13.38
Discontinuous very low density urban fabric (soil sealing < 10%)	11240	34,499	13.44
Industrial. commercial. Public, military and private unit	12100	16,090	6.27
Fast transit roads and associated land	12210	7,772	3.03
Other roads and associated land	12220	8,831	3.44
Railways and associated land	12230	3,412	1.33
Airports	12400	179	0.07
Mineral extraction and dump sites	13100	52	0.02
Construction sites	13300	3,450	1.34
Total for built-up areas		115,465	44.64
Main green infrastructure elements			
Land without current use	13400	234	0.43
Green urban areas	14100	7,414	2.89
Sports and leisure facilities	14200	1,020	0.40
Arable land	21000	31,918	12.43
Permanent crops	22000	1,422	0.55
Pastures	23000	321	0.13
Forests	31000	86,149	33.55
Herbaceous vegetation communities	32000	2,312	0.9
Open spaces	33000	5,112	1.99
Wetlands	40000	834	0.32
Water	50000	4543	1.77
Total for the main elements of green infrastructure		*141,279*	*55.36*

* codes correspond to the European Urban Atlas (https://land.copernicus.eu/user-corner/technical-library/urban-atlas-mapping-guide)

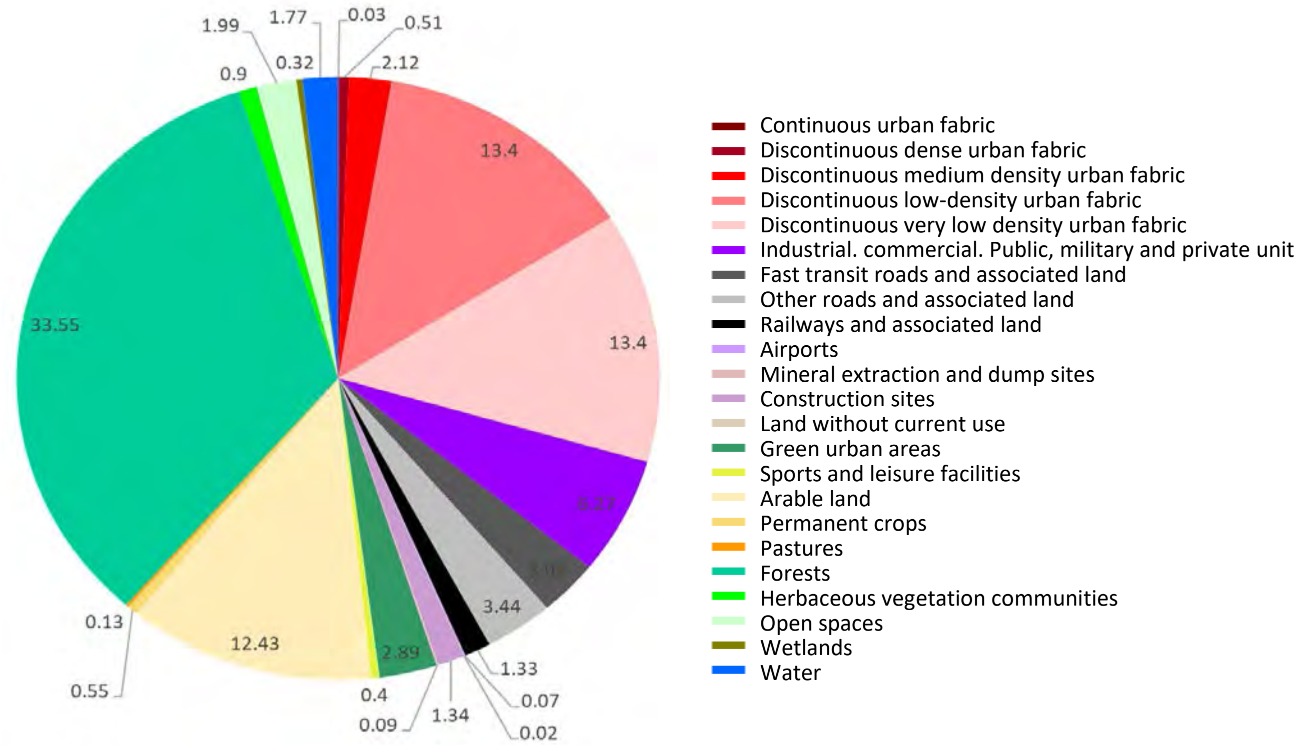
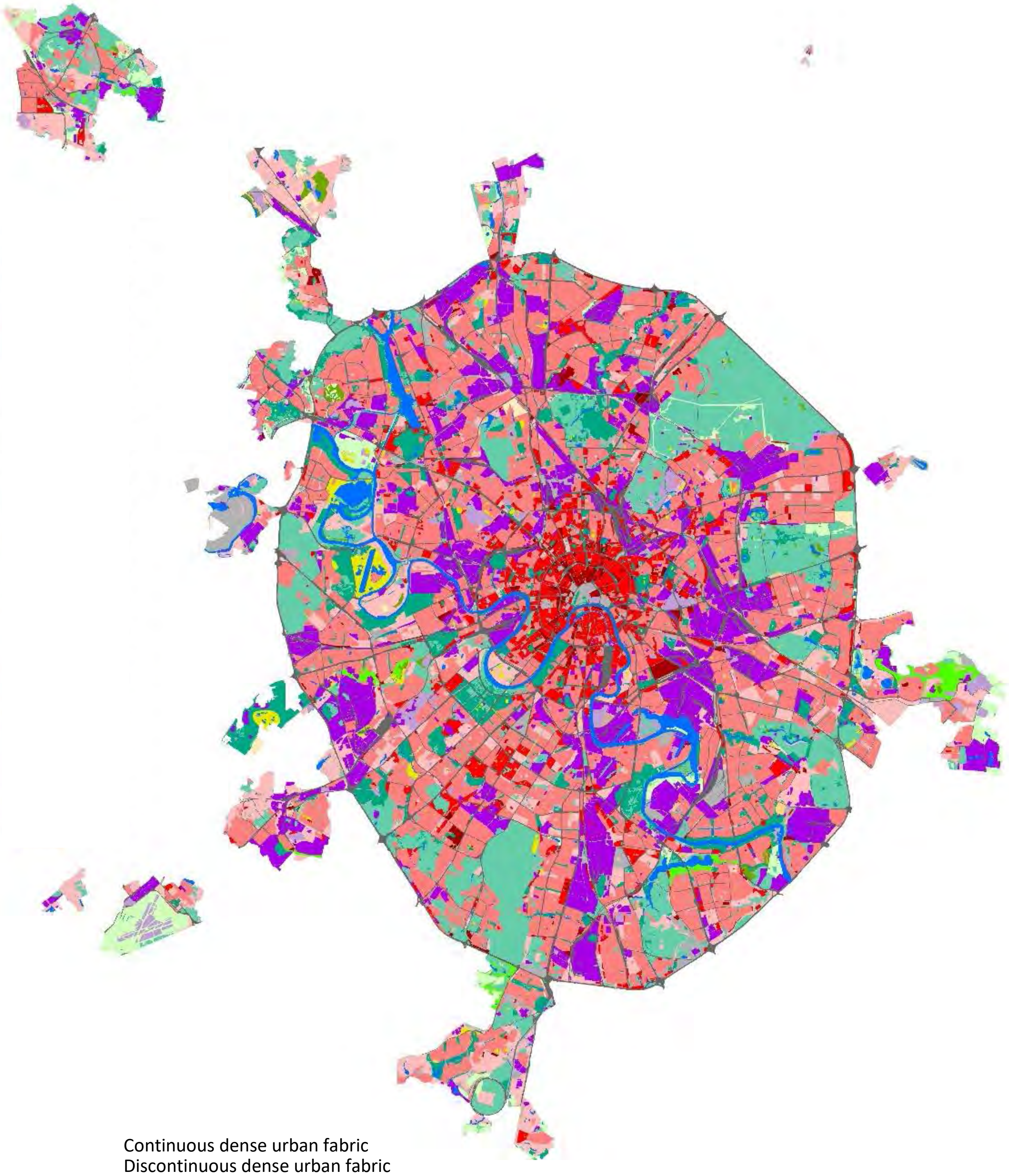


Figure 4.2.1.1. Proportions of various types of urban fabric and green infrastructure in Greater Moscow



Continuous dense urban fabric
Discontinuous dense urban fabric
Discontinuous medium density urban fabric
Discontinuous low density urban fabric
Discontinuous very low density urban fabric
Industrial zones, etc.
Fast transit roads and associated land
Other roads
Railways
Airports
Mineral extraction and dump sites
Construction sites
Land without current use
Green urban areas
Sports and leisure facilities
Arable land
Gardens and permanent crops
Pastures
Forests
Wetlands
Waterbodies

Figure 4.2.1.2.
Land-use structure in Old Moscow

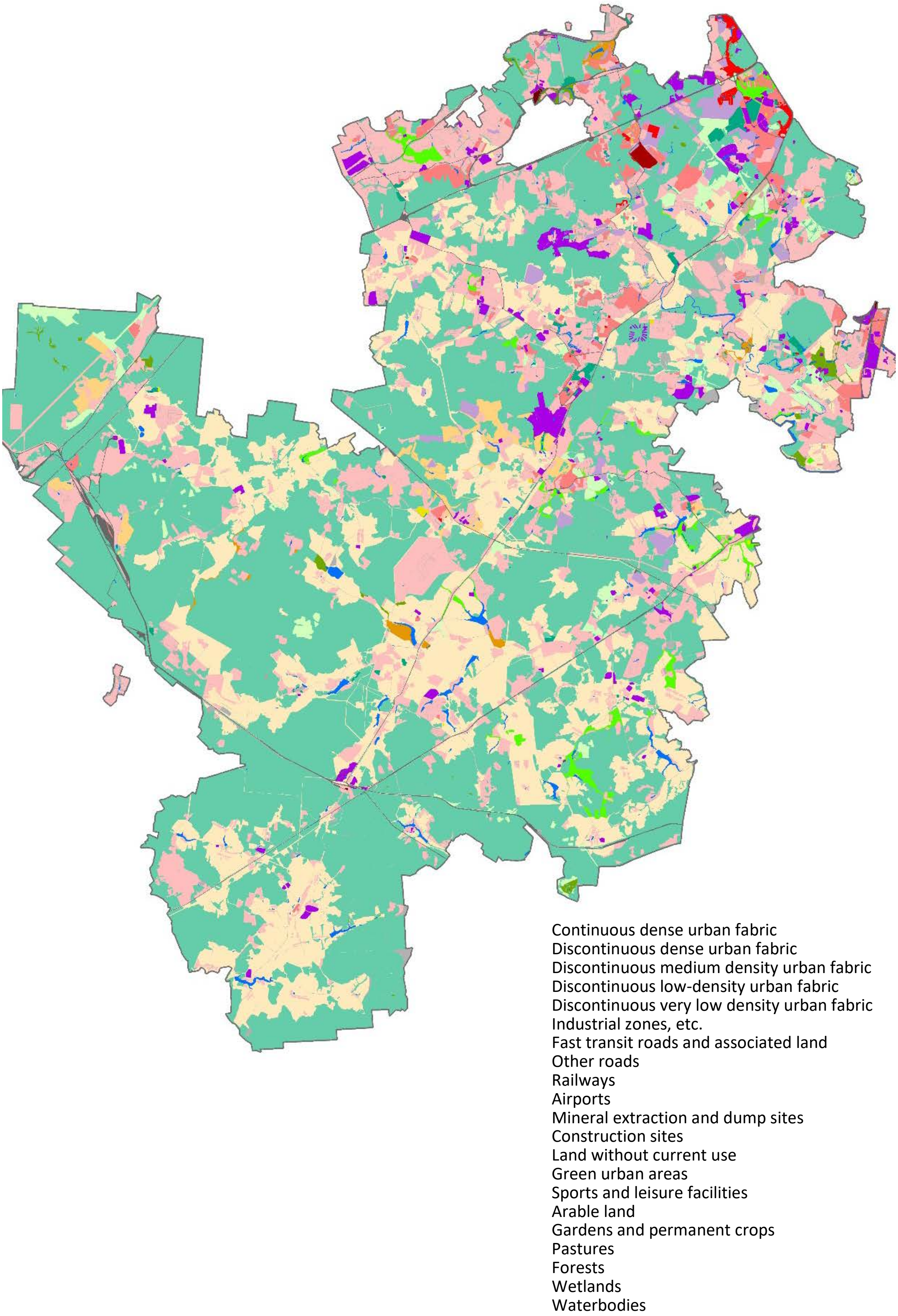


Figure 4.2.1.3. Land-use structure in New Moscow

Urban development trends in Moscow during the period 1991 to 2014 were calculated using data taken from the Atlas of Urban Expansion. The results of this analysis were as expected (Table 4.2.1.3) – the dense urban fabric that covered 44% of Old Moscow in the early 1990s continued to grow, reaching 62% in 2014. We also note a surprisingly high rate of increase in New Moscow – from 0.6 to 4.07%, i.e. an eight-fold expansion in dense urban fabric since the 1990s. The area of discontinuous urban fabric also increased significantly in New Moscow. The area of open urban space roughly tripled. Meanwhile, open space in Old Moscow steadily shrank from 23 to 17%. At the same time, the share of isolated elements of green infrastructure, i.e. surrounded on all sides by built-up areas and unconnected to other green elements, increased by a factor of two in both Old Moscow and Greater Moscow.

Open rural areas, which potentially offer the highest level of urban ecosystem services, also contracted, namely from 60.85 to 47.2%. This drop was most apparent in New Moscow, where the proportion fell from 90.68 to 73.51%. In Old Moscow, the proportion of open rural areas (which are still found in Mnevniki) practically halved, from 20.16 to 11.57%. The extent of water bodies fell dramatically in Greater, Old and New Moscow: most of these (including former peat-patches and ponds) were drained or filled-in.

Table 4.2.1.3. Transformation of the urban fabric, 1991–2014

Types of urban fabric with different levels of greenery	*Share of built-up areas with different levels of greenery from total urban area, %*								
	Greater Moscow			*Old Moscow*			*New Moscow*		
	1991	*2001*	*2014*	*1991*	*2001*	*2014*	*1991*	*2001*	*2014*
Dense urban built-up area	18.90	24.88	29.03	43.75	56.22	61.58	0.60	1.84	4.77
Sparse urban built-up area	4.29	4.37	5.29	7.60	5.17	4.38	1.88	3.84	6.07
Rural built-up area	2.49	2.77	2.47	1.42	0.94	0.64	3.32	4.17	3.86
Open urban spaces	11.54	11.54	13.74	23.17	18.71	17.70	3.03	6.37	10.93
Isolated open spaces	0.58	0.78	1.24	1.28	1.41	2.10	0.07	0.32	0.60
Open rural spaces	60.85	54.43	47.22	20.16	15.18	11.57	90.68	83.09	73.51
Water bodies	1.36	1.24	1.02	2.61	2.37	2.03	0.41	0.38	0.26

By analyzing the data, we identified two qualitatively different periods of urbanization in Moscow. During the first, from 1991–2001, more than 3% of open urban space was sealed and built over. During the second period from 2001–2015, most open spaces disappeared. The first stage was also accompanied by a mass transformation of rural fabric into the dense urban fabric (4.7% – in fact, old rural structure was destroyed there to be occupied by a new urban one). This pace of transformation was halved during the second period.

To define the impact on ecosystem services, we determined the main categories of change, allowing us to identify the most significant transformations of ecosystem services during the period 2001–2014 (Table 4.2.1.4).

Table 4.2.1.4. Transformation of the urban fabric, 2001–2014

	Transformation types	*Share of different transformation types from the total area, %*			*Effects on ecosystem services*
		Greater Moscow	*Old Moscow*	*New Moscow*	
1	Open rural space → urban open space	4.05	1.74	5.85	All ecosystems decrease
2	Open rural space → rural built-up space	0.77	0.08	1.29	All ecosystems decrease
3	Rural built-up space → sparse urban built-up space	1.03	0.51	1.45	Fragmentation of urban green infrastructure
4	Open rural space → isolated open space	0.64	0.90	0.46	All ecosystems decrease
5	Open rural space → dense urban built-up space	0.47	0.51	0.45	Increase in built-up density
6	Sparse urban built-up space → dense urban built-up space	1.66	1.93	1.49	Increase in built-up density
7	Open urban space → dense urban built-up space	1.62	2.69	0.83	No significant changes
8	Open urban space → sparse urban built-up space	0.51	0.29	0.69	No significant changes

The processes of transformation of built-up areas with diverse levels of greenery are as follows:

– an increase in built-up density in pre-existing urban areas (transformation type 6);
– the transformation of rural built-up space into urban space (transformation type 3);
– areas with isolated elements of built-up space see an increase in built-up area – 2.13% of total urban space (transformation types 7 and 8);
– the expansion of built-up areas in former open rural space – 5.93% of total urban area (transformation types 1,2,4 and 5).

Regarding the potential for ecosystem services, the last two processes (Greater Moscow's area) are the least favorable since they describe the inclusion of vast rural areas into the urban fabric and their isolation from rural green infrastructure, including forests.

Open rural spaces, which have the highest potential for regulating the environment, turned out to be the most demanded land at the current stage of urbanization. They are developed into all types of built-up space. Moreover, they are transformed into open urban space or isolated urban space. In the first case, the area completely loses its ecosystem services; in the second, ecosystem services are significantly limited.

Based on the mentioned-above trends in the period 2001–2014, we estimated the likely loss of green areas providing ecosystem services in the period 2025–2045 (Table 4.2.1.5). We also calculated the likely changes in the areas of river valleys, since these are especially valuable for runoff regulation and biodiversity conservation.

Table 4.2.1.5. Scenarios for the reduced area of green infrastructure under the current development model

Green infrastructure elements	*Area, ha*				
	2021–2025	*2026–2030*	*2031–2035*	*2036–2040*	*2041–2045*
Urban green area	7,256.1	7,101.53	6,950.26	6,802.22	6,657.34
Sport and leisure area	1,061.3	1,038.70	1,016.58	994.93	973.73
Forests and urban woods	82,108.6	80,359.70	78,648.04	76,972.83	75,333.31
Herbaceous vegetation communities	2,177.9	2,131.51	2,086.11	2,041.68	1,998.19
Unsealed areas	4,939.7	4,834.51	4,731.53	4,630.75	4,532.12
Wetlands	745.4	729.55	714.01	698.80	683.92
River valleys	5,397.3	5,282.30	5,169.78	5,059.67	4,951.90
Plantings along the roads and railways in the 100-m buffer	29.1	28.43	27.83	27.23	26.65

4.2.2. Moscow's protected areas

4.2.2.1. The main problems

According to data from the Department of Nature Management and Environmental Protection of Moscow, the city has 121 protected areas (PAs) with a total area of 17,900 ha (Fig. 4.2.2.1.1). The use, conservation and management of PAs are regulated by the Law of the City of Moscow № 48 of 26 September 2001 "On the PAs in Moscow".

The national park Losiniy Ostrov and 10 natural-historical parks have the status, aims and vast areas that correspond to a relatively high IUCN category II.

Moscow's PAs are categorized not only by the form of nature management but also by their functions. Among the 121 urban PAs, there are 10 natural-historical parks, 10 zakazniks, one national park and one botanical park while the rest are natural monuments. The most important general aims of urban PAs are to conserve ecosystems and their biodiversity as well as to support the environmental balance. Other aims include the conservation of historical and cultural monuments in the natural-historical parks and the promotion of the recreational potential of urban green space by means of the natural zakazniks. The Law permits the use of protected areas for the purposes of culture and educational, recreation, sport and health improvement. However, the current legislative basis securing PAs stresses that their main function is environmental. This is the main difference between PAs and other areas of urban green infrastructure.

Regarding the current protected areas of Moscow, we can define the following key problems.

1) Low availability of PAs in some districts, especially in the center. This deficit can be compensated by creating parks and other green elements at the sites of demolished buildings. In the future, new green elements of a significant size can perform environment regulating services. At the same time, however, those

districts with a high availability of PAs suffer from poor transport connections, making them difficult to access. This can be a particular problem for disabled people.

2) The overloading of the recreational carrying capacity threatens ecosystems and biodiversity. According to data from the Department of Nature Management and Environmental Protection of Moscow, about 70,000 people make specially guided environmental excursions every year. Further, the approximate number of visitors to Moscow's urban PAs is three times the total urban population. An analysis of the carrying capacity of recreational infrastructure in 10 of the largest PAs showed that the visitor density significantly exceeds permissible recreational loads for PAs (see Section 4.2.2.2).

3) Inappropriate use of PAs, the development of sports and entertainment facilities, an unsuitable maintenance that destroys natural ecosystems and harms biodiversity (see Section 4.2.3.4).

4) A high level of fragmentation of the majority of urban PAs (see Section 4.2.2.3) as well as the destruction of ecological corridors between urban PAs and Moscow's greenbelt (see Section 4.2.3.2).

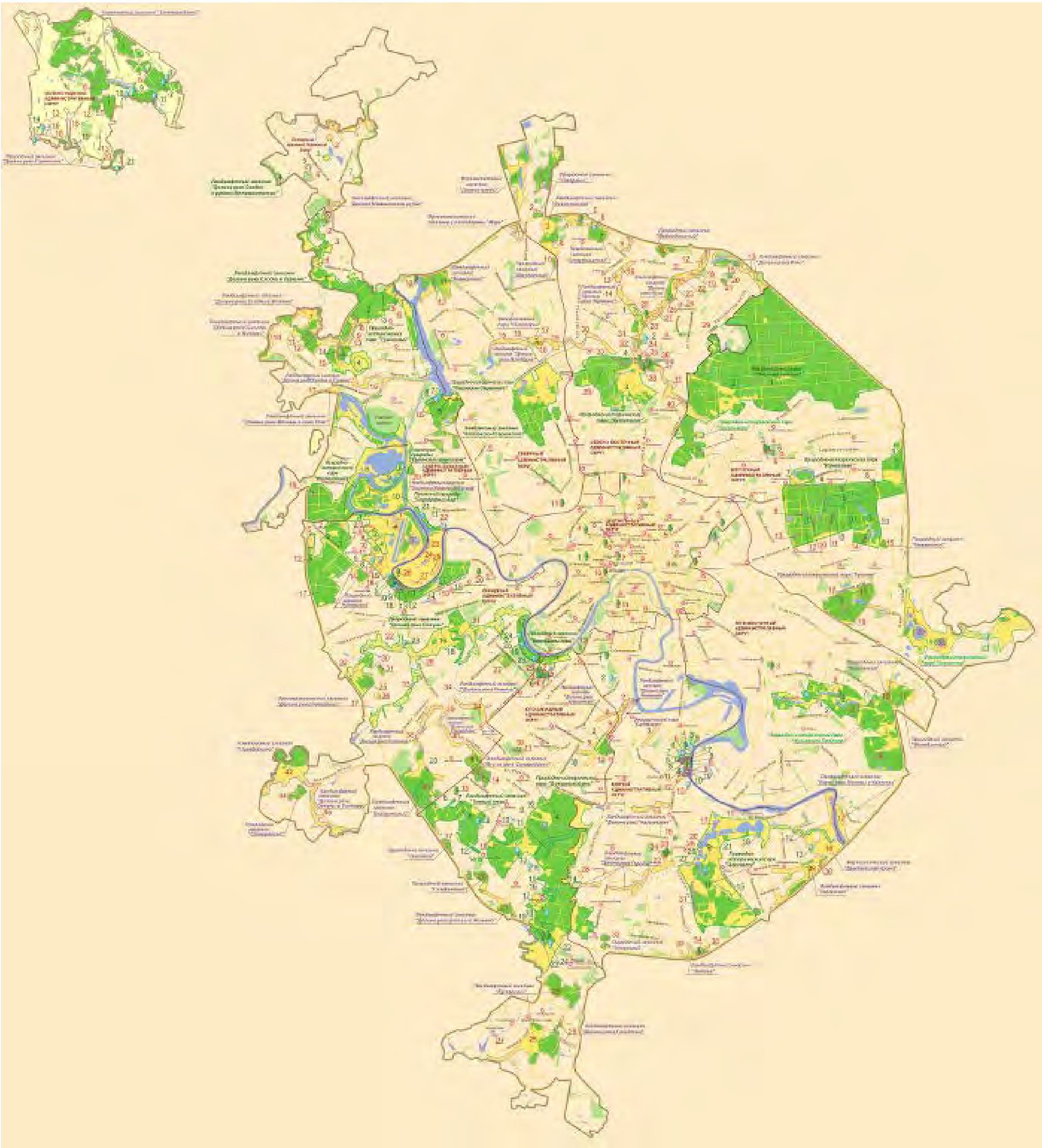


Figure 4.2.2.1.1. PAs of Moscow according to the local Department of Nature Management and Environmental Protection (http://www.dpioos.ru/eco/ru/oopt)

4.2.2.2. Impact of recreation on Moscow's protected areas

Today, a strategy to develop recreational infrastructure and attract tourists is being implemented in Moscow's PAs. A great deal of infrastructure is being constructed for different types of recreation such as educational programs, sports & games, play areas for children, walking, outdoor recreation and recreation beside or on water bodies. We analyzed the carrying capacity of the recreational facilities at Moscow's largest PAs. The results show how many people can be simultaneously accommodated by the recreational infrastructure of a protected natural area. The figures are purely estimates based on standard values presented in the corresponding thematic documents[17] [18] (Table 4.2.2.2.1).

Table 4.2.2.2.1. Norms for the simultaneous accommodation of different types of recreation

Recreational activity	*Number of people normally taking part*
Badminton, tennis, table tennis	2, 4
Volleyball	12
Gorodki	2–15
Mini-basketball	10
Streetball	6
Mini-football	12
Boules	2, 4, 8
Croquet	6, 10
Fitness training	11–20

We chose a standard value of 0.5 m^2 space per capita for playgrounds; 3–4 persons per one meter of beach for water bodies; 1 person per 20 m length of path for walking; etc. Based on the cartometric assessments of open data (OpenStreetMap, Yandex Maps), we defined the size and quantity of such facilities in PAs. We also used additional data sources such as the various websites of the investigated PAs as well as the Mospriroda Institute and Open Data Portal of Moscow Government, where it is possible to find information on the recreational potential of natural areas.

The total carrying capacity of the recreational infrastructure of PAs was determined by the following formula:

$$E=\sum P_i$$

where P_i = standard capacity of i-type recreational object.

The carrying capacity of sport facilities for team games was determined by the number of team players. For playgrounds and sport grounds, we adopted standard values (for example, 4 m^2 per capita). The carrying capacity of walking paths was defined by their length. For water bodies, we took the shoreline length, the standard carrying capacity of beaches and the number of boats at the quay. If water bodies were not developed for recreation, their carrying capacity was simply ignored. Picnic spots were also assessed with the help of existing standards or, if available, from the PA websites. Museum complexes and sport stadiums, which can be found in some PAs, were not considered in the research. Table 4.2.2.2.2 gives the carrying capacities of recreational infrastructure for 13 of Moscow's largest PAs.

Trails and paths have the largest carrying capacity and can simultaneously accommodate 1,000 people. Sport objects also have a considerable carrying capacity due to their workout parks and game courts. Water bodies have the smallest carrying capacity (Table 4.2.2.2.2, Fig. 4.2.2.2.2 a).

Our analysis showed that "Bitzevskiy Les", "Tsarizino" and "Izmaylovo" have the largest carrying capacities of the studied objects (Table 4.2.2.2.2, Fig. 4.2.2.2.2 a). These are PAs with vast territories and infrastructure for all types of recreation. There are some differences between the cases regarding visitor density (Table 4.2.2.2.2., Fig. 4.2.2.2.2 b). Thus, the maximum density of 34 persons/ha is found in the relatively compact protected area of "Pokrovskoe-Streshnevo"; in contrast, the minimum density of around 4 persons/ha was determined for the *zakaznik* "Valley of the Shodnya River in Kurkino", which has a very low infrastructural capacity. "Losiniy Ostrov" also has a small carrying capacity due to its large area. We should stress that educational programs are much less developed in the PAs than sport or general rec-

[17] Moscomsport order of 15 February 2016 № 25 – Moscow Sport Department Standard "Universal sport grounds; football pitches, volleyball, basketball, tennis and table tennis courts; gorodki courts; workout parks. General requirements…"

[18] GOST P 52169-2012 Equipment and covering for playgrounds. Construction safety and testing methods. General requirements.

reational facilities. For example, ecotrails are present in only nine of the 13 protected areas, while educational centers on the environment exist in only three protected areas. Other protected areas are only visited for general excursions.

Table 4.2.2.2.2. The carrying capacity of recreational infrastructure in the studied PAs in Moscow

PAs	*Carrying capacity, persons*						*Visitor density, persons/ha*
	Water bodies	*Sport objects*	*Play grounds*	*Trails and bike paths*	*Stables and picnic spots*	*Total*	
Landscape zakaznik "Valley of the Shodnya River in Kurkino"		140	29	797	200	1,166	4.1
Landscape zakaznik "Tepliy Stan"	98	1,196	212	3,257	60	4,823	15.4
Nature zakaznik "Valley of the Setun River"		302	350	3,080	40	3,772	5.4
National park "Losiniy Ostrov"		1417	268	11,099	185	12,969	3.9
Natural monument "Serebryaniy Bor"	2,768	222	234	2,507	520	6,251	19.0
Natural-historical park "Bitzevskiy Les" "		562	676	17,210	760	19,208	8.7
Natural-historical park "Izmaylovo"	300	4,244	1,293	11,223	110	17,170	10.7
Natural-historical park "Kosinskiy"	21	2,721	117	746	40	3,645	10.0
Natural-historical park "Kuzminki-Lublino"	444	2,742	960	6,333	31	10,509	10.1
Natural-historical park "Pokrovskoe-Streshnevo"	531	4,426	445	2,215	60	7,677	33.7
Natural-historical park "Sokolniki"	512	732	320	2,036	20	3,620	15.8
Natural-historical park "Tushinskiy"	251	3,388	623	4,466	340	9,068	13.9
Natural-historical park "Tsarizino"	654	6,445	1,280	9,613	1,020	19,012	14.6

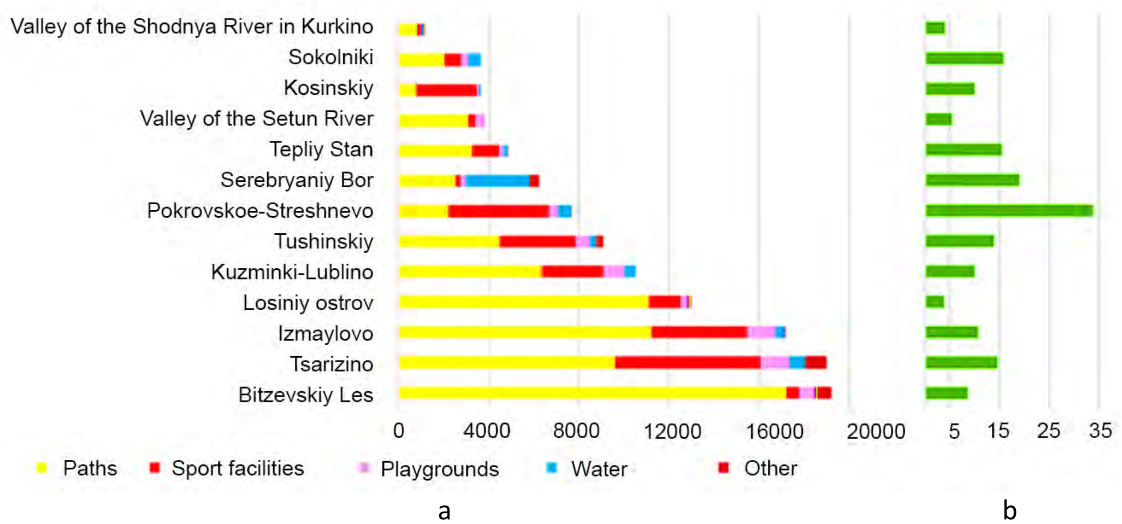


Figure 4.2.2.2.2. The capacity of recreational infrastructure in PAs of Moscow: a) the capacity of recreational objects of different types, persons; b) the density of planned visitors in PAs

The results for the studied protected areas show that visitor density for the recreational infrastructure varies from 4 to 34 persons/ha, in most cases exceeding 10 persons/ha. These values are considerably above the average permissible recreational loads for forests in the coniferous-broadleaf zone (2 persons/ha) (Temporal methods, 1987; see Section 3.4.2). Such overburdened carrying capacities will inevitably lead to the degradation of ecosystems and biodiversity in the PAs.

4.2.2.3. The degree of fragmentation of protected areas

The majority of Moscow's PAs are compact. Indeed, 85 of them (comprising 70% of all urban protected areas) are less than 10 ha in size. Moreover, a considerable number (52) are actually natural monuments with an area less than 1 ha (Table 4.2.2.3.1). Very few of the protected areas in Moscow are large. 13 protected areas (mostly natural-historical parks) have an area of between 100 ha and 1000 ha; only six are bigger than this (one of which, "Moskvorezkiy", consists of eight clusters). Despite their small number, these huge PAs make up the largest proportion of Moscow's protected green areas (Fig. 4.2.2.3.1).

Table 4.2.2.3.1. PAs grouped by size, according to the Department of Nature Management and Environmental Protection (http://www.dpioos.ru/eco/ru/oopt)

Area, ha	*Number of PAs*	*Prop. of the total number of PAs, %*	*Total area of PAs in the group*	*Prop. of the total protected area in Moscow, %*	*Categories of PAs*	*Protected objects*
<1	52	43.0	18	0.1	Natural monuments	Springs, trees, geological objects
1–10	33	27.3	166	0.9	Natural monuments	Groups of springs, alleys, gulches, ravines, meadows, forest territories
10–100	17	14.0	545	3.0	Natural monuments, landscape *zakazniks*	River valleys, forest territories, wetlands
100–1000	13	10.7	4,248	23.7	*Zakazniks*, natural-historical parks *	Natural and natural-historical complexes
> 1000	6	5.0	12,939	72.2	Natural-historical parks, national park	Natural-historical parks: "Moskvorezkiy", "Izmaylovo", "Bitzevskiy Les", "Tsarizino", "Kuzminki-Lublino"; National park "Losiniy Ostrov"

* consists of several clusters

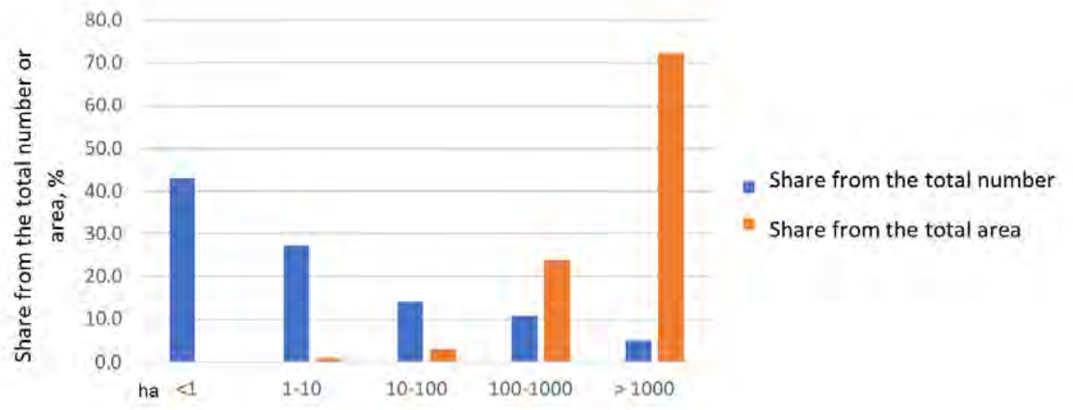


Figure 4.2.2.3.1. Shares of PAs of different size-groups from their total area and number in Moscow, according to the Department of Nature Management and Environmental Protection (http://www.dpioos.ru/eco/ru/oopt)

Hence, despite the relatively large number of PAs in Moscow (121), most are too small to fully conserve ecosystems and their biodiversity. Furthermore, fragmentation effects are also undermining large protected areas. These are being fragmented by various forms of misuse such as major building projects, inadequate planning and excessive recreational use (i.e. an increasing number of walking trails and the construction of recreational infrastructure).

The main factor causing the fragmentation of ecosystems is the enormous recreational load on Moscow's PAs. This is being deliberately intensified through additional recreational infrastructure. To assess this load, we calculated the ratio between the area and perimeter of territories occupied by natural ecosystems for 13 of the city's PAs. Here the ratio is defined as PAR = P/S, where P is the perimeter and S the area of the natural territory (Rutledge, 2003). Vegetated territories were defined by means of a supervised classification of a satellite image in ArcMap. We used a Sentinel-2 image from 28 August 2019 with a 10x10 m spatial resolution. We also merged water surfaces with vegetation to avoid the fragmentation of vegetation by watercourses. Next, we deleted pixels representing roads, trails and recreational objects. The PAR index was calculated on a 50x50 m grid. The results are shown in Table 4.2.2.3.2 and Fig. 4.2.2.3.2. We should stress that our assessments on fragmentation may be underestimates as we did not consider non-recreational infrastructure and constructions such as medical complexes, fire stations or communal facilities.

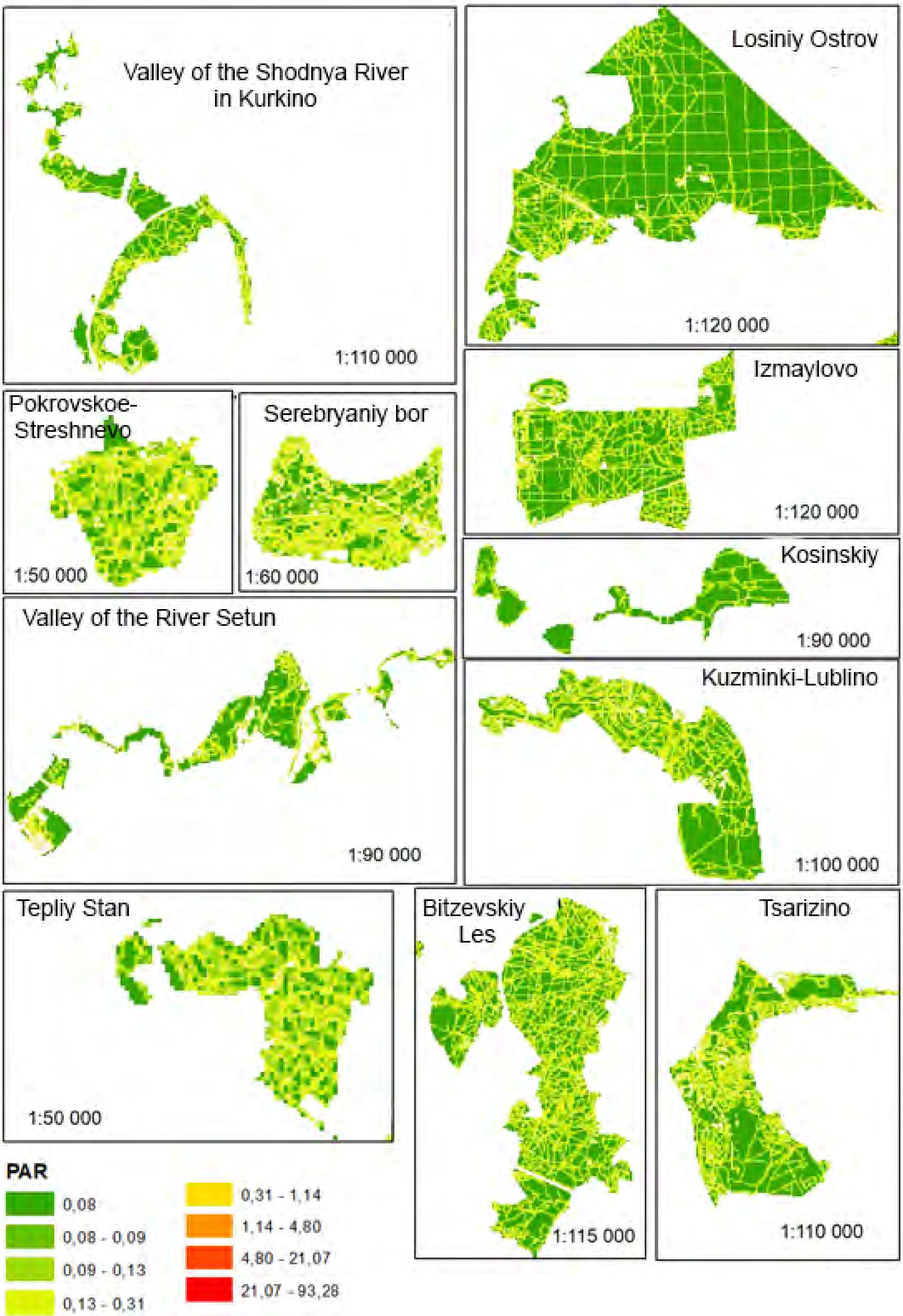


Figure 4.2.2.3.2. The fragmentation of several of Moscow's largest PAs

Table 4.2.2.3.2. Fragmentation parameters in Moscow's 13 largest PAs

Protected areas	*PAR index*		*Area of un-fragmented territories (PAR⩽0.08), ha*	*Share of un-fragmented cells (PAR⩽0.08), %*
	Average value in cells	*Standard deviation*		
National park "Losiniy Ostrov"	0.110	0.041	2,052	61
Natural-historical park "Bitzevskiy Les"	0.135	0.050	623	28
Natural-historical park "Izmaylovo"	0.120	0.038	584	36
Natural-historical park "Tsarizino"	0.127	0.045	453	35
Natural-historical park "Kuzminki-Lublino"	0.119	0.036	351	34
Nature *zakaznik* "Valley of the Setun River"	0.179	0.123	215	31
Natural-historical park "Tushinskiy"	0.146	0.074	215	33
Natural-historical park "Kosinskiy"	0.098	0.024	195	53
Landscape *zakaznik* "Valley of the Shodnya River in Kurkino"	0.104	0.028	105	37
Natural-historical park "Sokolniki"	0.122	0.033	60	26
Landscape *zakaznik* "Tepliy Stan	0.140	0.050	58	19
Natural monument "Serebryaniy Bor"	0.235	0.159	41	13
Natural-historical park "Pokrovskoe-Streshnevo"	0.138	0.042	38	16

If PAR index values are below 0.08, then the area is entirely covered by natural objects. The higher the index value, the more fragmented the area.

Indicators of fragmentation and recreational disruption are closely connected. This can be seen in the correlation between the share of land comprising trails or infrastructure and the PAR index in cells (Fig. 4.2.2.3.3).

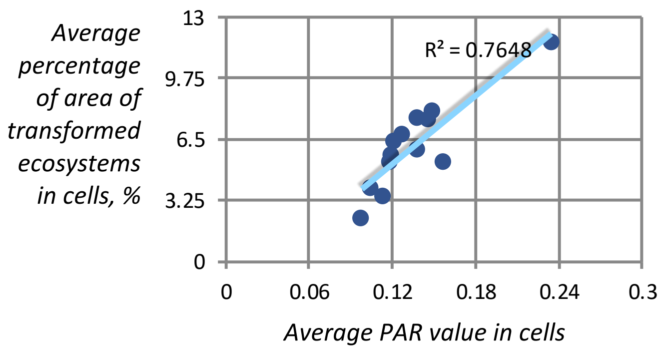


Figure 4.2.2.3.3. Correlation between indicators of recreation disruption and ecosystems fragmentation in protected areas

Table 4.2.2.3.2 shows that the largest area of unfragmented cells (PAR≤0.08) can be found in the national park "Losiniy Ostrov" and in the natural-historical parks "Izmaylovo", "Bitzevskiy Les" and "Tsarizino". The results are unexpected as these are the largest PAs in Moscow. However, other fragmentation indicators are not clearly linked to the size of PAs. Even though it is certainly not the largest protected area, the minimum value for fragmentation (average PAR value in cells) is found in the natural-historical park "Kosinskiy". This can be attributed to the lack of recreational infrastructure in the park (see Section 4.2.2.2). In contrast, "Serebryaniy Bor" is the most fragmented PA (Table 4.2.2.3.2, Fig. 4.2.2.3.2).

The creation of recreational infrastructure not only intensifies the recreational load on the PAs, but also significantly increases the fragmentation of ecosystems. Figure 4.2.2.3.4 demonstrates how the share of unfragmented ecosystems area decreases when the visitor density increases in line with new recreational infrastructure.

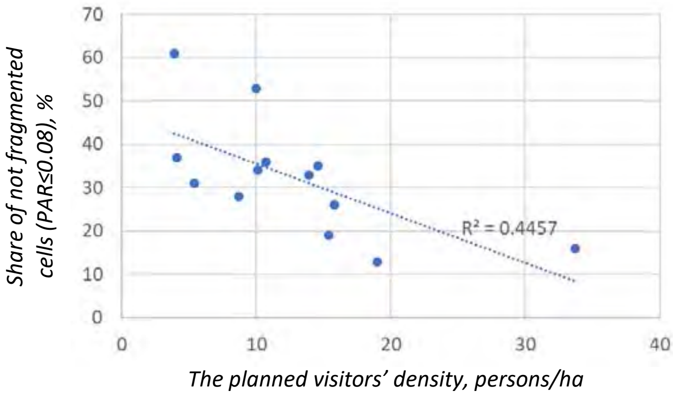


Figure 4.2.2.3.4. The share of unfragmented ecosystems decreases as the planned visitor density rises in the 13 largest PAs

4.2.3. The history of green infrastructure management in Moscow and modern problems of biodiversity conservation in the city

4.2.3.1. The main stages of nature conservation in Moscow

"Green infrastructure" or "green capital of the city" forms the basis for a positive ecological environment that benefits both citizens and urban ecosystem services. To understand current problems of green infrastructure, it is first necessary to consider its historical development. Transformations in green infrastructure reflect changes in various factors such as the socio-economic and urban planning environment, municipal environmental policy (and of the country as a whole), legislation, governance mechanisms, accessibility and transparency of information as well as public participation in solving environmental problems. All these interrelated factors affect the extent and condition of natural ecosystems, and consequently the volume and quality of ecosystem services.

Biological diversity ensures the normal functioning and resilience of ecosystems. Growing urbanization in Moscow, as elsewhere, has reduced this essential biodiversity and increased the need to protect nature as the basis for vital urban ecosystem services.

The history of the transformation and conservation of Moscow's green spaces can be divided into periods that roughly correspond to major stages in the city's development (Fig. 4.2.3.1).

Stage 1. Although pre-20th-century Moscow was vastly smaller in extent than the modern city, nature protection decrees have been issued since the 17th century. Various sources describe the protection of the hunting grounds and natural resources near Moscow in tsarist time (Blagosklonov et al., 1967, Rysin, 1997). In 1742, a plan for the imperial capital city of Moscow was drawn up. This was mainly concerned with the width of streets and the placement of houses. At the time, St. Petersburg was the capital (since 1712) rather than Moscow.

Stage 2. In 1775 Catherine II approved the "Projected Plan for the City of Moscow". Later, this plan became the basis for new designs in 1817 to rebuild Moscow after its destruction by fire during the Napoleonic War. The city's river network was significantly transformed by new canals and embankments. The Neglinnaya River was redirected underground.

Stage 3. In 1918, Moscow once again became the capital. In 1935, the first General Plan of Moscow set a population limit of five million and expanded the urban boundaries to 600 square kilometers. The General Plan did not just consider administrative city boundaries but also took into account the natural surroundings as integral to the city. This proved extremely important in fostering an awareness of the natural environment. The General Plan of 1935 became the starting point for all subsequent planning in Moscow.

Stage 4. By 1960, the territory of Moscow had dramatically expanded outside the boundaries indicated by the General Plan of 1935. However, there remained the basic requirements to retain "green wedges" and corridors within the city.

Stage 5. In the 1980s and especially from the 1990s onwards, urban and suburban green spaces have been significantly reduced and negatively affected by the encroachment of urban areas outside the Moscow Ring Road, accompanied by mass construction and the development of transport infrastructure.

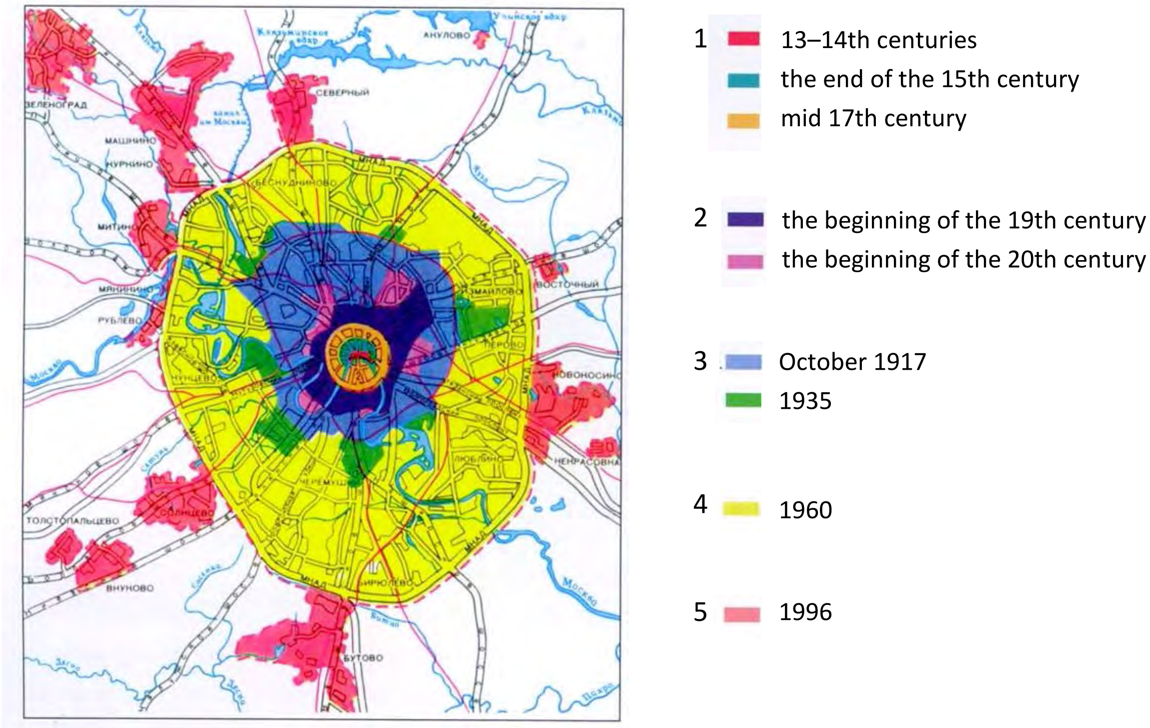


Figure 4.2.3.1. Moscow's expansion from the time of its foundation to the end of the 20th century (Moscow: Encyclopedia, 1997)

4.2.3.2. History of the forest-park protective belt of Moscow

The General Plan of 1935 encompassed the following task: "to create a Forest-Park Protective Belt (FPPB) within a radius of up to 10 km, consisting of large suburban forests evenly spaced and serving as a reservoir of clean air for the city and a place of recreation for the population, and to connect these forests with the city center". Despite lacking any modern concept of the "environment" or, indeed, "ecosystem services", one of the priorities of the General Plan of 1935 was to ensure a favorable environment for the population, conditions for healthy life and local recreational opportunities. Urban greenery was considered one of the most important elements of Moscow's territorial planning (Fig. 4.2.3.2.1). The "Scheme of greening Moscow" included in the General Plan of 1935 contained the following justification: "Due to the enormous importance of green spaces for the sanitary and hygienic living and recreational conditions of workers and the architectural design of the city, the long-term plan outlines a significant increase in green areas in Moscow." Further, the General Plan emphasized the inextricable link between the FPPB and city green areas, and the need to connect them by means of green strips from FPPB to the city center. Another aim was to create new city parks and boulevards.

In 1948, the forests of FPPB were assigned to the Moscow City Executive Committee under the control of the USSR Ministry of Forestry. The FPPB encompassed 28 forest parks. The goal was to maintain the sustainability of the forest while permitting recreational use.

Figure 4.2.3.2.1. Scheme for the greening of Moscow according to the General Plan of 1935[19]

The main decisions regarding the Moscow FPPB were made by the authorities of the USSR and RSFSR (Russian Soviet Federative Socialist Republic). By a decree of the Supreme Soviet of the USSR (1950), 7,700 hectares of forest were restored following wartime clearings. All FPPB forests were declared forests of the "first group", i.e. "protective forests" in modern terminology. The Law on Nature Conservation in the RSFSR[20] of 1960 defined forest-park belts of cities as protected natural objects where hunting, new construction and other types of economic use were prohibited.

In the 1950s, urban development expanded beyond the Moscow Ring Railway. In 1960, a new city boundary was established along the Moscow Ring Road; in addition, the area of the FPPB was expanded to 165,000 hectares, of which more than 70,000 hectares were forest. In the 1960s, more than 500 new industrial enterprises were established within the FPPB as an "exception".

[19] Russian State Library, https://dlib.rsl.ru/viewer/01003401886#?page=730
[20] The Russian Soviet Federative Socialist Republic.

Large areas of the former FPPB inside the Moscow Ring Road were turned into urban forests. However, these did not become detached from the suburban forests since the road at that time was not very wide, there were no fences and the volume of traffic was low.

The new General Plan of Moscow approved in 1971 retained the concept of “green wedges” or “green rays” from the periphery to the city center (Fig. 4.2.3.2.2). According to this General Plan, the FPPB should be expanded to 275,000 hectares; however, this was not realized. On the contrary, 11,000 hectares of forest were redesignated in 1984 to allow the construction of large new districts: Kurkino, Mitino, Severny, Novo-podrezkovo, Novo-Kosino-Zhulebino, Butovo and Solntsevo. Multi-storey residential housing also began to be built inside the Moscow Ring Road, including over filled-in small river channels, causing the river network to rapidly shrink. This led to the fragmentation of natural areas due to the extinction of natural connecting corridors.

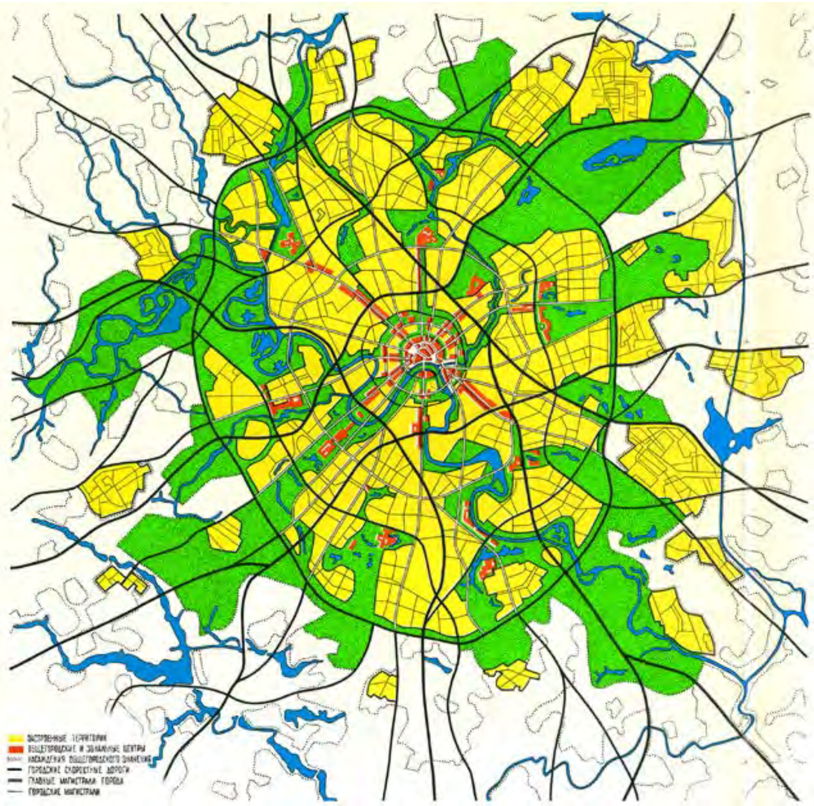


Figure 4.2.3.2.2. Green wedges indicated in the General Plan of 1971 (General Plan…, 1971).
Color code: green = green space, blue = water bodies, yellow = built-up areas, red = city centers

Many experts pointed out that other capital cities did not have such a rich natural environment and diversity as Moscow. The habitats of a number of species listed in the Red Data Book Moscow (2001) and Moscow Region (1998) are found in the FPPB. The Laboratory of Forest Science of the USSR Academy of Sciences established plots for the long-term monitoring of forest communities and identified reserved forest areas for the comparative analysis with areas suffering anthropogenic impact (Rysin, Savelyeva, 1985; Rysin, Rysin, 2011). The Institute of Geography of the USSR Academy of Sciences and the Moscow State University developed the foundations for recreational management in reservoirs near Moscow (Kazanskaya et al., 1977).

The situation changed after the collapse of the USSR. In the early 1990s, the construction of cottages was launched on the territory of FPPB, including in protected zones with historical and cultural monuments and protected sources of drinking water. Construction was often chaotic, in some cases without proper environmental engineering. As a result, by 1995 the extent of forest within the FPPB had decreased by 30,000 ha compared to the figure in 1961.

Nevertheless, even post-1991, the FPPB was still regulated by the Law of the RSFSR “On Environmental Protection”, and thus regarded as a special form of PA in which the use of natural resources was limited. In 2002, the new Federal Law “On Environmental Protection” was adopted. This law abolished the status of protected areas for the FPPB and relieved the Moscow authorities from the obligation to maintain the FPPB. Thus, Moscow’s financing of forestry activities in the FPPB stopped in 2002.

More severe negative changes began after 2006 with the adoption of the new Forest Code of the Russian Federation. This code permitted the leasing of forests, including under the guise of "recreational purposes", which, in practice, often led to their development as built-up areas. Subsequently, forestries became consolidated, traditional forest management was abolished and the number of forestry workers (primarily the forest wardens) drastically curtailed. Unsurprisingly, the net impact has been to reduce the size of forested areas and undermine their condition. In 2009, new amendments to the Forestry and Land Codes abolished the category "forest park" in the Russian Federation. In the Moscow region, 28 forest parks within the FPPB were subsequently abolished and replaced by eight conventional forestries.

In addition to these negative repercussions on forests and the redesignation of large areas for construction, the area of the FPPB has decreased due to the development of transport infrastructure, which does not take into account the effect of fragmentation of natural areas. In 1996, the Moscow Ring Road was reconstructed and widened, turning it into a solid barrier between urban and suburban natural areas. This effect intensified after the installation of lighting, fences and noise barriers along the road. The reconstruction was followed by a rapid growth along the Moscow Ring Road of cottage settlements, gas stations, shopping centers and, in recent years, multi-story housing. The construction of a highway through the Khimki forest park in the northern part of the FPPB also led to the reduction and fragmentation of natural areas.

All these factors have served to significantly reduce the extent of green space, which is now many times less than the area required to create a favorable environment for local people. In 2006, the area of forest parks was 6.5 times less than stipulated in 1975, according to which the area of forest parks outside the city should be 150–200 m^2 per person, and thus much less than the WHO standard of 300 m^2 of suburban forest park per person.

In 2017, amendments were adopted to the federal law on the transfer of land from one category to another (the so-called "forest amnesty"). According to Greenpeace Russia, this will lead to the automatic exclusion of about 69,000 hectares of forests from the forest fund and their transferal to territories that do not provide for forest protection[21] (Fig. 4.2.3.2.3).

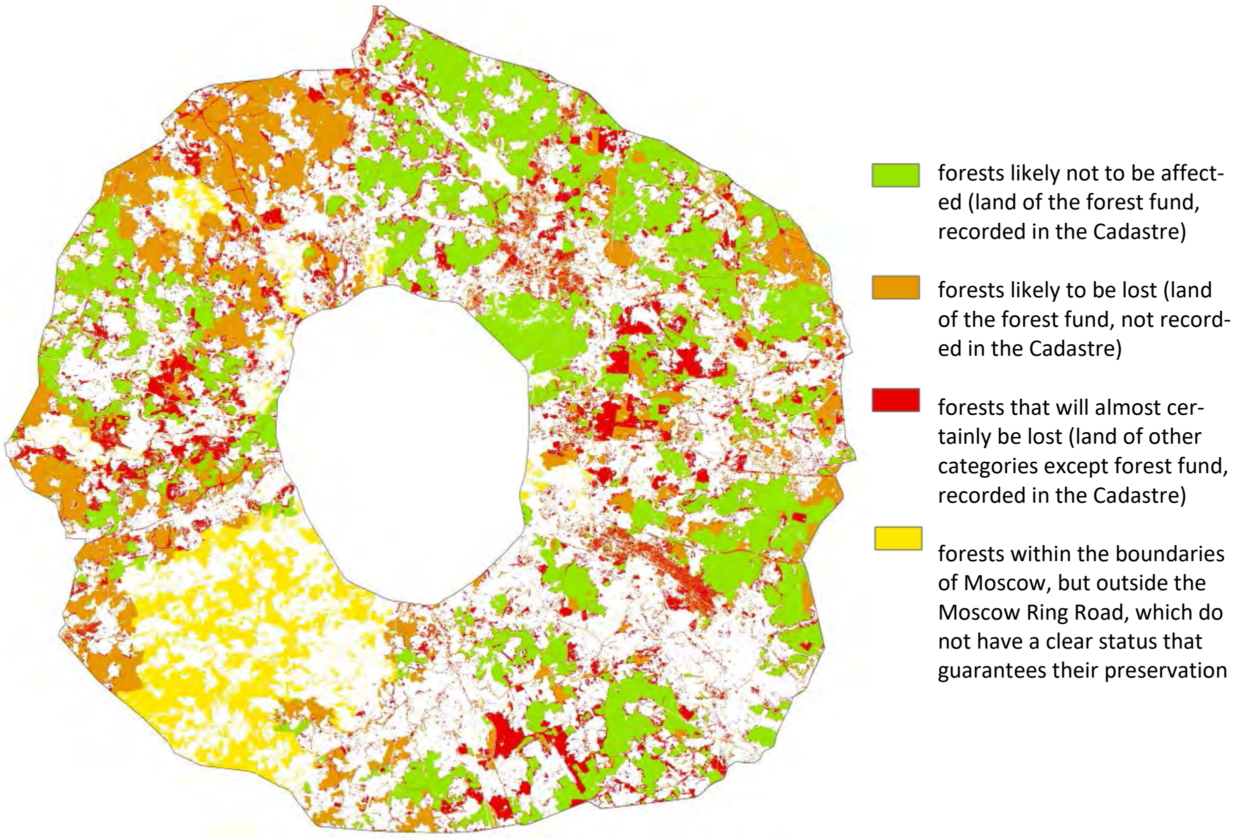


Figure 4.2.3.2.3. Potential loss of forests in the near-Moscow region between the Moscow Ring Road and the Small Moscow Ring (A107) after the adoption of the "forest amnesty" (according to Greenpeace Russia)

[21] http://www.forestforum.ru/viewtopic.php?f=9&t=21184

In 2020, the Governments of Moscow and the Moscow Region revoked the environmental requirements (established in 1948) for green areas of the FPPB as well as liability for their violation. Other important restrictions have been abolished such as the ban on: the use of cars, motorcycles, bicycles and horses off established roads; hanging hammocks, swings and ropes from trees for drying clothes or for any other purpose; attaching advertisements to trees, climbing trees, damaging tree trunks, breaking branches, walking on lawns; campfires, and much more.

Today, therefore, the FPPB has actually lost the mechanisms for its preservation. This has happened despite the vital role that the suburban forests play in creating a favorable environment for local residents and providing opportunities for them to relax outside the city.

4.2.3.3. New Moscow

In 2012, the area of Moscow increased by a factor of 2.5 when 149,000 hectares of land in the southwest towards the border with Kaluga region were incorporated into the capital (Fig. 4.2.3.3.1). A relatively small cluster of sites was also annexed in the Moskva River valley to the west (Fig. 4.2.3.3.5). This brought the total area of New Moscow to 1,480 km^2. The annexed territories include 71,564 hectares of federal forests (forest cover 34.6%), which are planned to be developed as "urban forests", as well as eight regional and seven locally protected areas with an area of 3,500 hectares. Forests that were part of the forest fund before 2012 and within the boundaries of Moscow were assigned to the new category "specially protected green area (SPGA) of the city of Moscow" (Fig. 4.2.3.3.1).

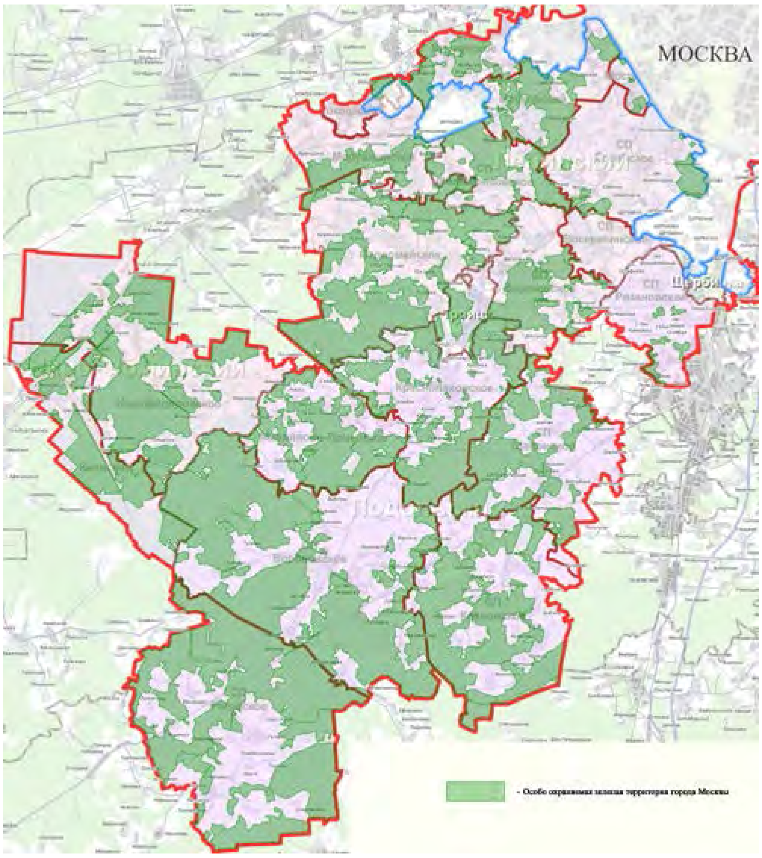


Figure 4.2.3.3.1. Specially protected green areas (SPGAs) of New Moscow[22]

There are plans to build 105 million square meters of real estate on the annexed territories and increase the population to two million. This will be accompanied by rapid economic development. To maintain ecosystem services and ensure a favorable environment for a growing population, it is necessary to strengthen nature protection measures to reflect the intensity of territory development. Unfortunately, however, protection mechanisms in the annexed territories have been weakened, thereby seriously undermining the stability of natural ecosystems and the provisioning of vital ecosystem services.

[22] Website of the Department of Nature Management and Environmental Protection of Moscow, http://www.dpioos.ru/eco/ru/oozt

At the time of its annexation to Moscow, there were six regional nature reserves (*zakazniks*) in the main (southwestern) territory of New Moscow. Together they constituted 1.5% of the territory of New Moscow. In addition, New Moscow had a further three forest parks from the FPPB with a total area of 6,385 ha. In addition to the protected areas which became part of New Moscow, it was planned to create a number of new regional reserves and natural monuments there. To date, however, these plans have not been implemented. Moreover, the status of the former regional PAs now incorporated into Moscow has not yet been confirmed, while the regional regulations of these PAs are no longer valid.

The category of "specially protected green area (SPGA)", which covers all forests of New Moscow, is absent in the federal environmental legislation. The purpose of the SPGA was determined in 2012 by decrees of the Moscow Government as the performance of environmental protection, climate control, sanitary and recreational functions. Initially, activities unrelated to the conservation and study of SPGA were prohibited; two years later, however, the construction of "roads, railways and other linear objects, as well as buildings and structures that are their integral technological part" was allowed. At the same time, the SPGA does not provide any special measures for the protection of Red Data Book species. The absence of the category of SPGA in the legislation makes it easy to change their boundaries and redesignate territories for development or other forms of use. As a result, various areas of SPGA were designated for the construction of garages, an ambulance station, a school, a kindergarten, a sports motorcycle track, the expansion of a landfill, etc.

Currently, therefore, there are no actively protected areas in New Moscow. Information about PAs on the territory of New Moscow is missing from the website of the city's Department of Nature Management and Environmental Protection. The transfer of all forests to the category of SPGA does not in any way solve this problem. The tasks of preserving natural ecosystems in New Moscow have everywhere been replaced by the creation of urban parks and recreation areas. By 2035, it is planned to create about 90 recreational areas of various types with a total area of about 12,000 hectares for walking, general recreation, historical and cultural activities, children's play areas and sports as well as archaeological, zoological and agricultural parks (Fig. 4.2.3.3.2).

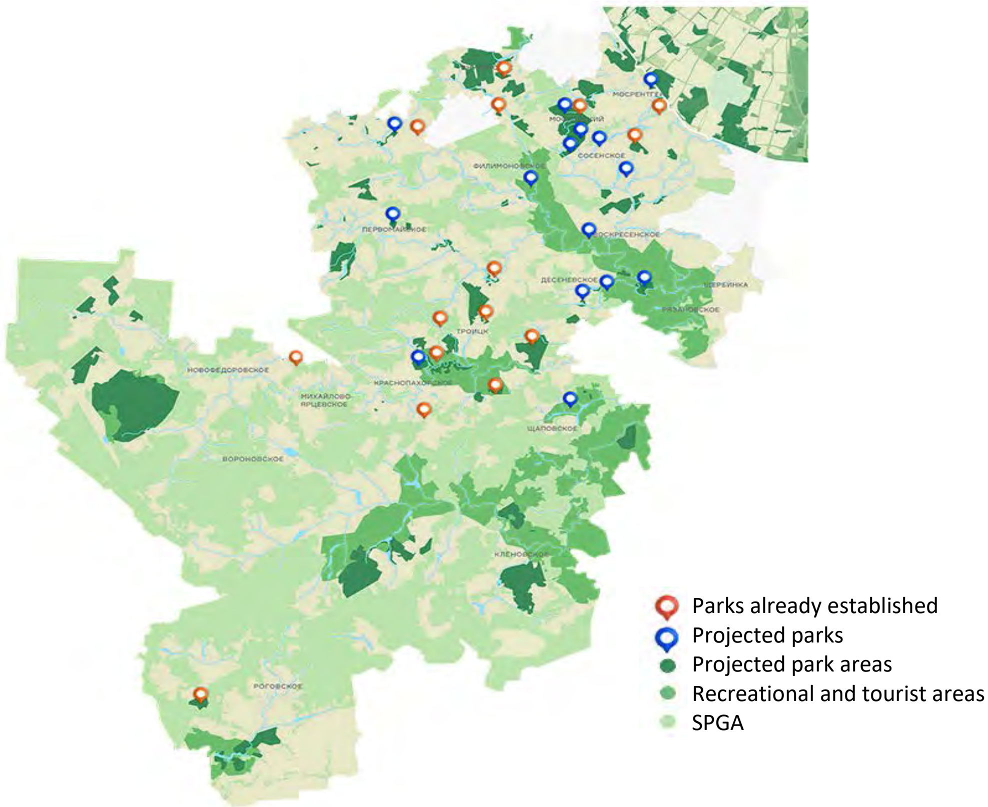


Figure 4.2.3.3.2. Parks, recreational and tourist zones of New Moscow in 2020[23]

[23] Site of the Complex of Urban Planning Policy and Construction of Moscow, https://stroi.mos.ru/new-moscow/obustroistvo-parkov

In the annexed territories and in the rest of Moscow, a common practice in recent years has been to turn natural areas into parks (see Section 4.2.3.4, below). Natural areas are drastically changed by this practice due to soil sealing and the replacement of natural communities by artificial flower beds and other landscaping measures. This disrupts natural ecosystems, reduces biodiversity and undermines the provision of ecosystem services (Fig. 4.2.3.3.3).

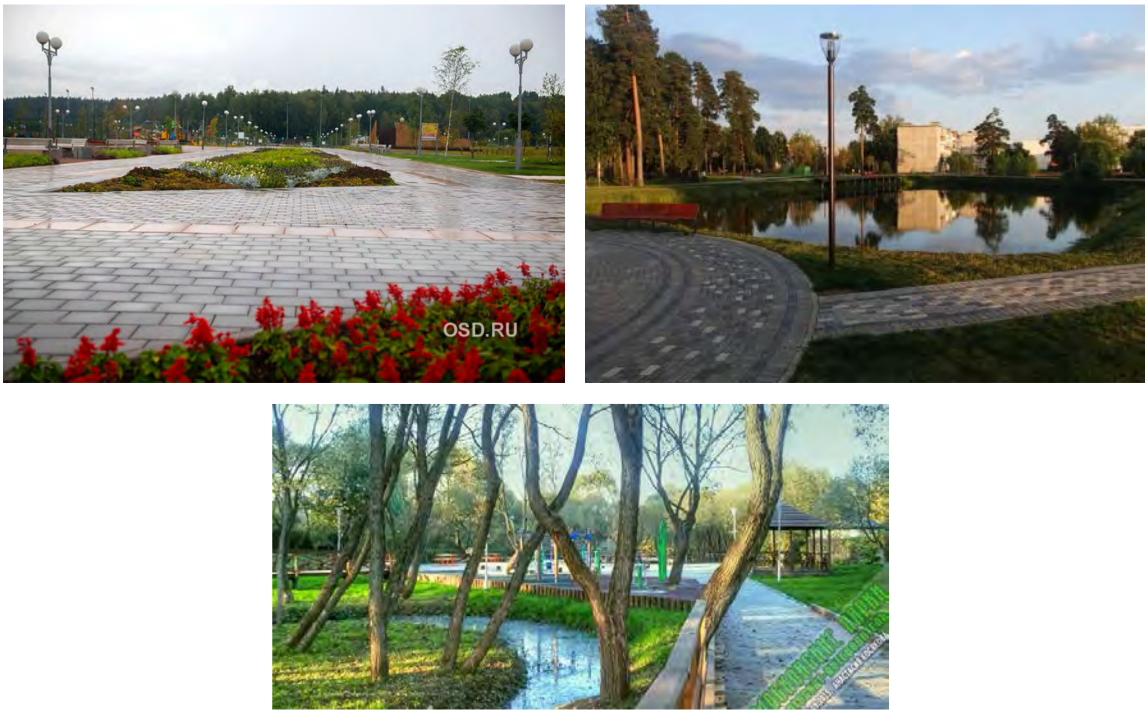


Figure 4.2.3.3.3. Various park designs in New Moscow

The expansion of Moscow was not taken into account in the construction of the Central Ring Road of the Moscow Region (the highway passing within a radius of 25–65 km to the center of Moscow), a project which was established before recent increase in the area of Moscow. In addition to the highway itself, the project provides for the construction of transport infrastructure and development hubs, industrial and warehouse facilities, logistics centers, technology parks, and multi-story residential complexes (Fig. 4.2.3.3.4).

Figure 4.2.3.3.4. A section of the Central Ring Road in New Moscow[24]

[24] https://pbs.twimg.com/media/EPX47b5XkAAOZYc.jpg

Clearly, the implementation of such a large infrastructure project without due regard to environmental factors will merely degrade the countryside, leading to a loss of biodiversity and essential ecosystem services. The possible environmental impact, in particular the loss of regulating ecosystem services, from the felling of protective forests during the construction of the Central Ring Road was not discussed at public hearings.

In addition to the main territory in the southwest, new areas to the west were also incorporated into the capital. These areas are in the immediate vicinity of Moskva River, largely within the second belt of the Sanitary Protection Zone (SPZ) of the river (Fig. 4.2.3.3.5). As the Moskva River is the main source of drinking water for Moscow, sanitary-epidemiological regulations restrict economic activities near its banks. While construction is permitted within the second belt of the SPZ, any such activities are closely regulated. There is a ban on any facilities that may be sources of chemical or microbial pollution of water, soil or groundwater. Until 2019, the boundaries of the second belt of the SPZ were set at a distance of at least 500 m from the water's edge or along the tops of the first slope near water bodies. However, in 2019, a joint decree of the Government of Moscow and the Moscow Region reduced the size of the SPZ by a factor of six, thereby significantly expanding the area of permitted development along the rivers. Although the Ministry of Justice of the Russian Federation subsequently ruled that this decree contradicts federal legislation, the threat of development in these areas remains.

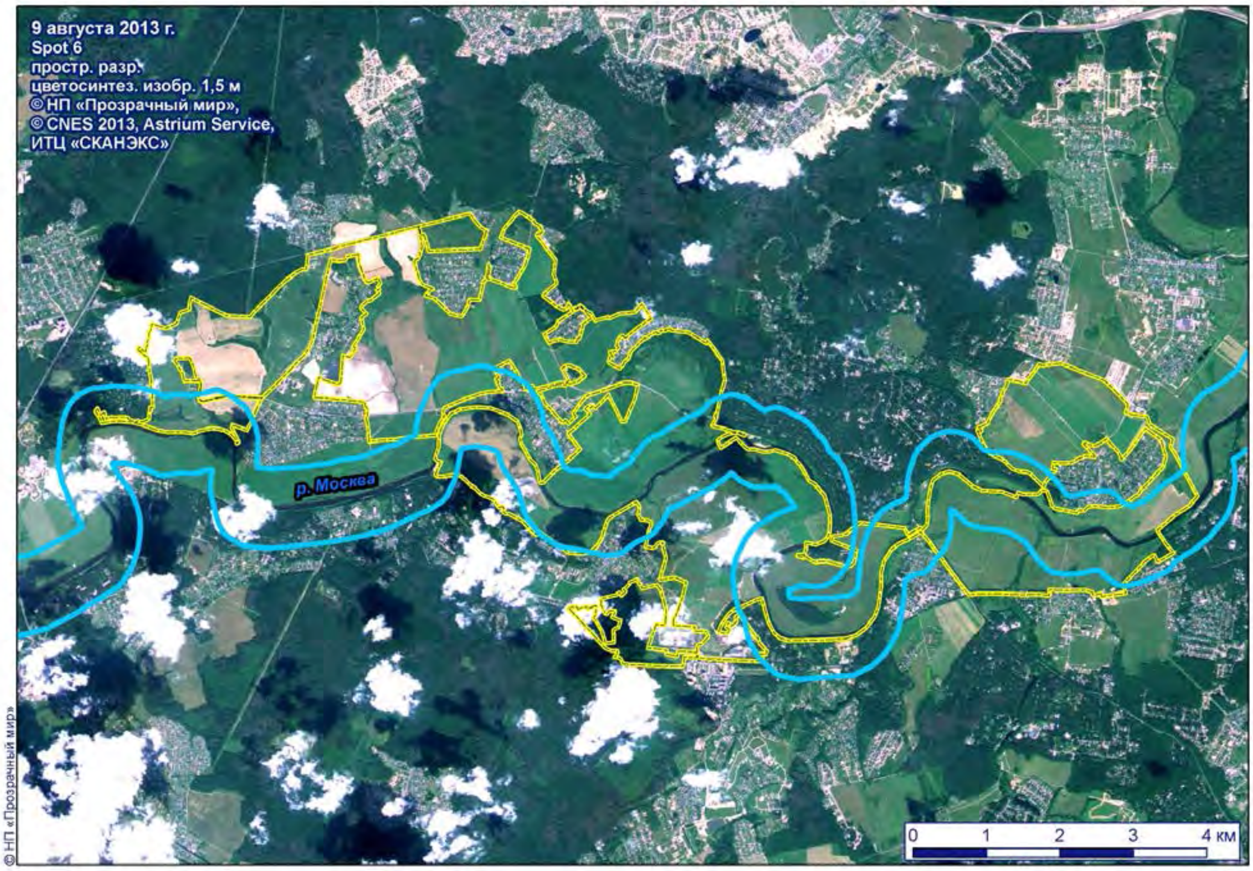


Figure 4.2.3.3.5. The boundaries of the western cluster of areas newly annexed by Moscow (shown in yellow) and the border of the second belt of the Moskva River Sanitary Protection Zone (shown in blue). According to NP "Transparent World"

Several existing and planned local protected areas are located in the western cluster of New Moscow (Fig. 4.2.3.3.6). There are also old manor parks created 150–200 years ago on this territory, which today constitute areas of mature forest. These valuable natural sites and centers of biodiversity may now be lost following their incorporation into Moscow.

Figure 4.2.3.3.6. Valuable green elements in the western cluster of New Moscow: a) Aksininskoe swamp; b) floodplain forest; c, d) Kozinskaya Gorka (photos: M. Sementsova, NP Transparent World)

An alternative proposal to the urban development of the western cluster of New Moscow was to create a national park called "Moscovia". The plans for this park encompassed the Moskva River valley with adjacent woodlands stretching over several administrative districts to give a total area of 150,000 hectares. The creation of the national park was intended to create conditions for ecological and educational tourism near the Moscow region and to prevent the transformation of these areas into built-up zones. While local residents supported the idea of "Moscovia" national park, the Ministry of Natural Resources of the Russian Federation was unable to agree on its borders with the Ministry of Ecology of the Moscow Region. Finally, plans to create the park were abandoned.

4.2.3.4. Natural areas of Moscow within the Moscow Ring Road

History of Moscow's natural areas in Soviet and post-Soviet times

As noted in Section 4.2.3.1, certain environmental measures were already introduced in Moscow before the Russian Revolution, although these were primarily concerned with the protection of hunting grounds or religious sites and had no scientific grounding. In Soviet times, the first act of territorial nature protection in Moscow was the decree of the Council of People's Commissars of the USSR in 1940, which declared the Lesnoy experimental site of the K. A Timiryazev Moscow Agricultural Academy a reserve, banned buildings and established protection of green spaces and plantings.

The general plans of Moscow drawn up in 1935 and 1971 aimed at the preservation and formation of "green wedges" to connect the forest-park belt of Moscow with inner-city green spaces (see Section 4.2.3.2).

In 1960, the adoption of the "Law of the RSFSR on Nature Protection" created the legal basis for the protection of air, water, soil, flora and fauna, the organization of various types of PAs as well as public participation in nature conservation. From the 1960s to the 1980s, a number of other important decisions or measures regarding environmental matters were implemented:

– rules for protection of wild animals of the Moscow region have been established; forty rare species were identified;
– Russia's first national park was created, "Losiny Ostrov", 3,000 ha of which is located within the Moscow Ring Road;
– decisions were made to preserve the diversity of wild flora and prevent the collection or trade of rare and endangered plant species in the region;
– 56 natural monuments were approved, including geological objects, springs and old manor parks.

In the 1970s, interdisciplinary studies of the ecology of highly urbanized territories emerged in the USSR (Kavtaradze et al., 1987). There arose the concept of the coupled development of nature and society (Brudny, Kavtaradze, 1987), which suggests that the preservation of biodiversity is an essential condition for the normal development of society. In 1989, the Moscow Territorial Subdivision of the USSR State Committee for Nature Protection became the state organization for nature protection in the capital, a role it held until 2000. One of its most important functions was the environmental assessment of economic activities in natural and green areas, which in fact prevented thousands of attempts to illegally intervene in the natural environment of the city. In the period from 1989 to the end of the 1990s, the following major decisions were made or measures implemented in regard to environmental matters:

– in 1970–1990, a "Comprehensive Scheme of Specially Protected Natural, Historical and Cultural Areas of Moscow and the suburban zone until 2000" was developed (Bakhtina, 2000);
– in 1989, at a session of the Moscow City Council, the task of preserving the diversity of Moscow's wildlife in the modern sense was first suggested;
– in 1991, an additional 69 natural monuments were established: small river valleys, plant and animal habitats, as well as Russia's first Natural Park, "Bitsevsky Forest";
– in 1995, the concept, composition and territory of the Natural Complex of Moscow was defined, which included not only natural but also artificially landscaped territories, areas of water, as well as reserve territories, where the aim was to restore natural diversity;
– in 1995, the Parliament of RF (State Duma) adopted a package of environmental laws, the most important of which were "On Environmental Assessment", "On Specially Protected Natural Areas" and "On the Animal World", which became the legal basis for the protection of nature and biodiversity;
– in 1998, the law of the city of Moscow "On the regulation of urban planning activities in the territories of the Natural Complex of the city of Moscow" was adopted;
– in 1998, 11 new regional PAs were established, including a number of large natural and historical parks that combined objects of natural and cultural heritage.

The formation of the Natural Complex of Moscow was scheduled to be completed by 2005, bringing its area to 24,800 hectares (Morozova, 2012).

Thus, until 2000, territorial and legislative methods of nature protection were consistently applied in order to help conserve Moscow's natural communities and biodiversity. Indeed, a fully-fledged basis for an ecological network was created and a scheme drawn up for its development.

In 2000, however, some negative changes began to undermine Russia's environmental protection system. In order to "remove administrative barriers and accelerate economic development", the RF State Committee for Environmental Protection and its regional divisions were liquidated. Environmental protection functions were transferred to the Ministry of Natural Resources. The number of employees fell. The weakening of protection legislation marked the beginning of a period of "de-ecologicalization" (Mikhaleva, Yablokov, 2011).

Nevertheless, work continued on the development of Moscow's PA system:

– in 2001 the law "On specially protected natural areas in the city of Moscow" was adopted and the list of rare species of animals, plants and fungi was approved, this becoming the basis for the Red Book of Moscow, of which two editions have meanwhile been published (2001, 2011);
– in 2005, the law "On the Scheme for the Development and Spatial Designation of Specially Protected Natural Areas in the City of Moscow" was adopted, resulting in the approval of several large PAs and a number of natural monuments.

Thanks to these efforts, by the end of 2010, there were 96 PAs in Moscow covering an area of 18,200 hectares, which is more than 18% of the city's area. The statutes governing PAs legally ensured the protection of key areas for the conservation of biological diversity. However, these successes were unable to reverse the general negative trend of weakening environmental policy in Moscow.

Since the mid-2000s, and especially after 2010, there has been a significant and consistent de-ecologization of urban development, reflected both in legislation and in practice. Various efforts by experts and the public to reintroduce environmental considerations to urban development plans have essentially been ignored. In 2015, Moscow deputies canceled public hearings as well as the state environmental assessment of the General Plan of Moscow. In 2018, responsibility for the Department of Nature Management and Environmental Protection was transferred from the Mayor of Moscow to the Department of Housing and Communal Services and Improvement. This not only greatly lowered the status of environmental concerns, but also transferred the solution of environmental protection problems to the department that causes the greatest harm to Moscow's natural areas. In 2020, the Parliament (State Duma) of the Russian Federation abolished the state environmental assessment of and public hearings for projects of construction of permanent buildings and structures of PAs.

The de-ecologization of urban planning policy in relation to the Natural Complex of Moscow has resulted in two main negative and interrelated processes:

– a reduction in the total area of tree plantations in the city (except for the territory of New Moscow);
– a decreased quality of natural ecosystems within protected areas and green areas.

Reduction of tree cover in Moscow after 2000

In the 2000s, the interests of developers triumphed over the goals of wildlife protection in Moscow. In 2006, the Moscow Government noted that "the territorial resources for mass housing construction provided by the General Plan are practically exhausted." This view that more land was needed for construction led to changes in federal legislation. In 2007, amendments were made to the RF Urban Development Code aimed at removing administrative barriers to the construction of housing. Environmental assessments and public control over urban planning documentation were abolished. Indeed, wildlife conservation was excluded from the list of priority tasks of urban planning policy in Moscow.

Decision-makers have quickly come to see PAs and other green areas primarily as sites for the development of the sports, entertainment and commercial sectors. In contrast, the task of protecting the most important ecosystem services in order to maintain a high-quality urban environment (including climate regulation, air purification, noise protection and the aesthetic value of wildlife) has receded into the background. The City Program of Environmental Protection for 2012–2016 aimed to build an infrastructure for mass recreation and thus increase the number of visitors to PAs, goals which are certainly incompatible with their intended purpose of nature protection. The objectives of intensifying the recreational use of PAs and other green areas were reiterated in 2014 in the Moscow program "Development of City Environment".

As a result, after 2010, a number of decisions were made that actually led to a reduction in the area of green areas in the city:

– in 2010, the updated General Plan of Moscow to 2025 combined PAs, natural and green areas into one category, thereby weakening the nature protection regime and endangering the most valuable areas for biodiversity conservation;
– areas occupied by garages became excluded from the PAs as a result of the so-called "garage amnesty", a step which will likely lead to the subsequent development of these sites;
– legislative approval of the previous illegal seizures of sections of the forest-park belt of Moscow for the development of cottages (the so-called "forest amnesty");
– a number of decisions on the construction of transport infrastructure in PAs;
– the adoption in 2010, 2012, 2013 and 2015 of a number of legislative acts permitting construction of permanent buildings and cultural, educational and sports facilities in PAs;
– preparation of proposals by the Institute for Urban Design in 2019 for planned zones to permit development of protected areas.

This policy led to a reduction in Moscow's green area despite its growing population. From 2000 to 2014, the area of Moscow's woodland decreased by more than 600 hectares[25]. This has reduced the availability of green infrastructure for urban residents and decreased the ecological quality of life.

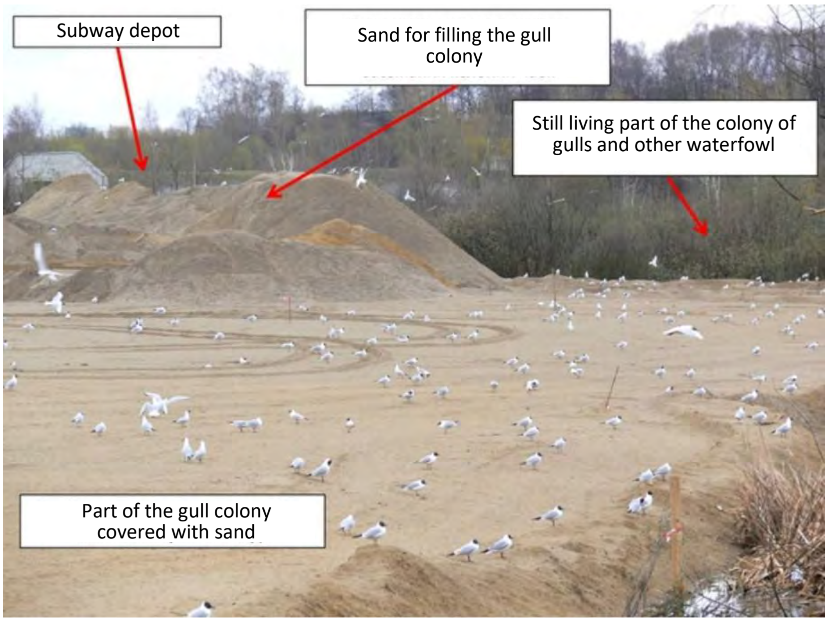
[25] http://president-sovet.ru/documents/read/467/
http://president-sovet.ru/presscenter/publications/read/3985/

The following can be cited as examples of a direct reduction in the area of natural areas:

The area of the Kuskovsky forest park has been curtailed several times. In 2015, the territory of the buffer zone of the forest park was reduced. In 2016, 12 hectares of forest were cut down for the construction of the North-East Expressway. In 2020, the Kuskovo Natural and Historical Park with an area of only 42 hectares was created, even though the total area of the forest park was 312 hectares; the remainder of the forest park received the status of a “green area of common use”. A planned upgrading to create a park will destroy natural ecosystems.

In 2019, the floodplain “Brateevskaya” became Moscow’s first fauna reserve. However, three important sites were not included in the reserve. Furthermore, the habitats of species listed in the Moscow Red Data Book were destroyed in one part of the reserve due to the construction of a subway depot (Fig. 4.2.3.4.1 a).

An example of inappropriate capital construction in the Teply Stan reserve is shown in Fig. 4.2.3.4.1 b.



a

b

Figure 4.2.3.4.1. Examples of the destruction of natural ecosystems due to development of PAs:
a) backfilling of a gull colony in April 2020 to construct a subway depot;
b) a kindergarten on the territory of the Teply Stan landscape reserve

One example of the implementation of the strategy to transform PAs into “places of culture, sports and entertainment” is the transfer in 2013 of the reserve “Vorobyovy Gory” to the management of the Gorky Central Park of Culture and Leisure. Here the aim was to transform the surviving areas of broadleaf forest in the Moscow River valley, unique for the city center, into a sports and entertainment complex[26]. At the same time, the fact that estimations of the number of visitors did not take into account the specifics of hillside ecosystems, which will surely lead to an increase in recreational activities in certain areas, thereby impairing the ability of the ecosystem to restore itself.

The strongest threat to the provision of green space is the approval in 2017 of a redevelopment program (so-called «renovation») which, by replacing old houses with new estates, will increase building density by a factor of 2.5 to 3. As a result of the renovation, around 2,700 hectares of green spaces are likely to be impaired and approximately 100,000 mature trees felled. Some areas may lose more than 25% of their green areas (Fig. 4.2.3.4.2). Currently, there are no plans to adequately compensate for the loss of these green spaces. The redevelopment program will destroy woodland planted 40–60 years ago, i.e. the most ecologically efficient sites that perform essential and irreplaceable ecosystem services for the capital.

[26] https://stroi.mos.ru/articles/vorob-ievy-ghory-novyi-tramplin-kanatnaia-dorogha-i-sportivnyie-obiekty

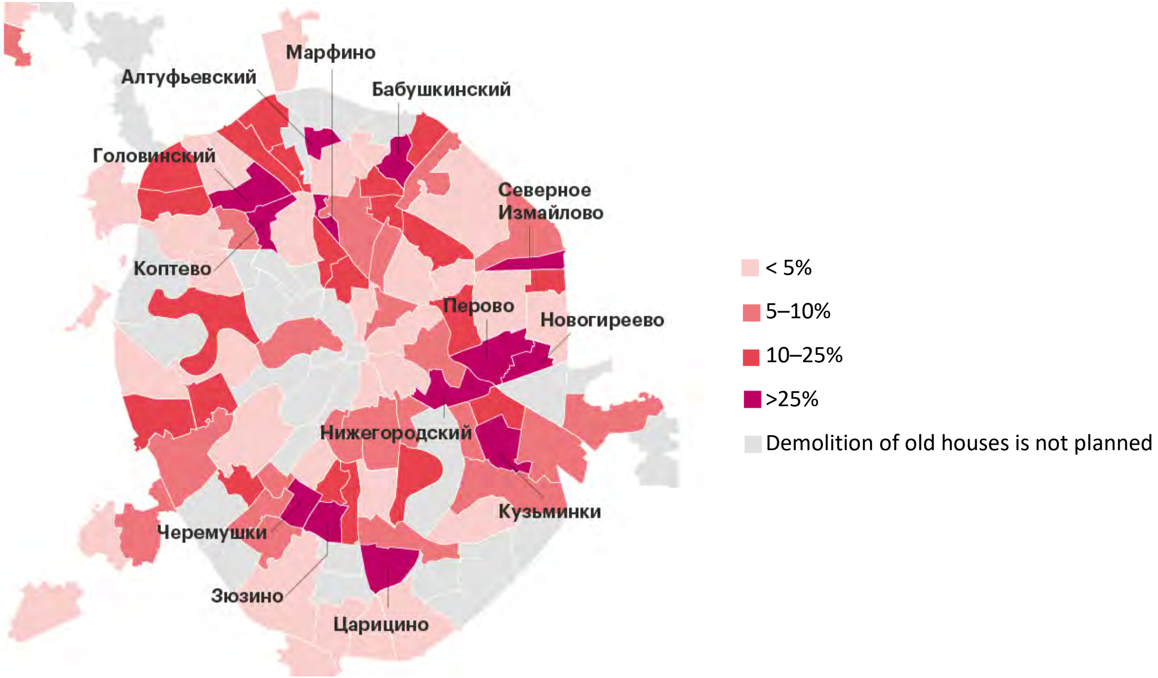


Figure 4.2.3.4.2. Probable loss of green spaces as a result of redevelopment plans, according to Greenpeace Russia[27]

<u>Deterioration in the quality of green areas due to their redesign as parks</u>

In recent years, the mass upgrading of green areas into parks has had an extremely negative impact on Moscow's wildlife. Here various landscaping methods have been employed to create artificial green elements that are incompatible with natural ecosystems. The updated General Plan of Moscow to 2025 brought together PAs, natural and other green areas into one category, designating these as "areas to be redesigned in order to restore, recreate and establish new green spaces". In practice, the "redesign" of these areas usually consists of transforming natural ecological communities into artificial and unstable urban green spaces. In 2013, in order to improve Moscow's urban wastelands, there began a massive program of upgrading aimed at transforming these sites into so-called "people's parks". In practice, however, this was primarily realized by redesigning the remnants of natural ecosystems into artificial landscapes with extremely poor biodiversity, for example paved areas and artificial lawns on imported soil with free standing trees and no undergrowth.

The main forms of upgrading and maintenance of Moscow's green infrastructure which damage or actually destroy natural diversity are as follows:

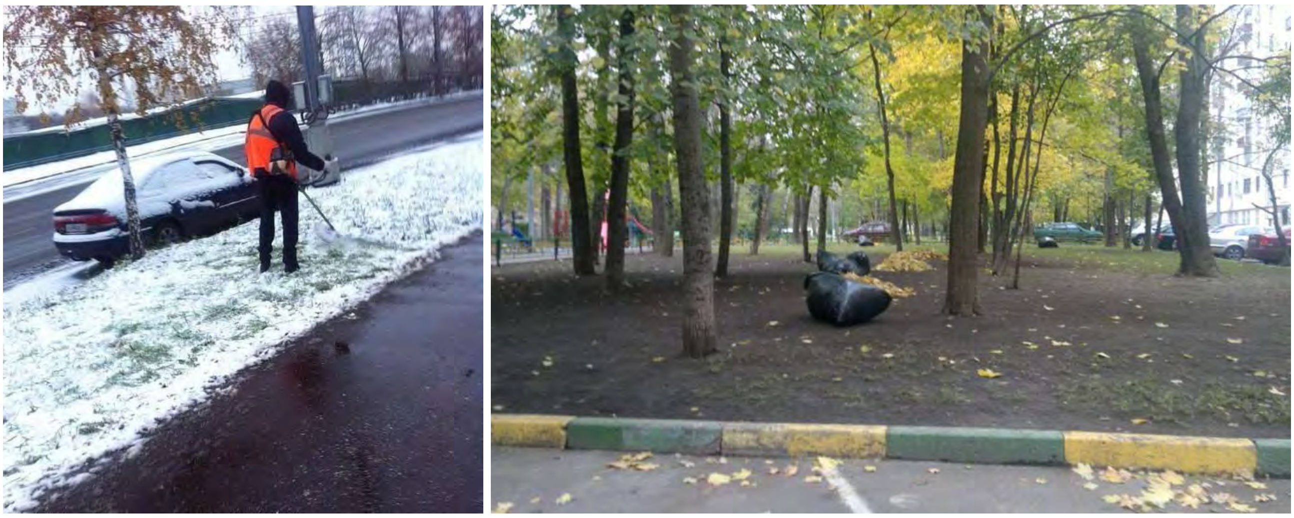
– the replacement of natural vegetation and soil cover with paved surfaces, imported soil, roll lawns and other foreign decorative components (Fig. 4.2.3.4.3, 4.2.3.4.4);
– excessive mowing of lawns (up to 16 times per season), thereby practically destroying the grass cover (Fig. 4.2.3.4.5 a);
– the widespread collection of fallen leaves, resulting in frozen soil in winter, an increased amount of dust in dry weather and degrading of the tree layer (Fig. 4.2.3.4.5 b);
– the destruction of tree roots when laying curbs and pylons or sealing the root system with hard coverings, leading to tree death (Fig. 4.2.3.4.6);
– non-professional, excessive tree pruning and destruction of the tree crown (Fig. 4.2.3.4.6);
– the installation of strong decorative lighting, causing environmental light pollution and negatively affecting flora and fauna (Fig. 4.2.3.4.7);
– carrying out upgrading work during wildlife breeding season including bird nesting.

[27] https://www.rbc.ru/society/23/05/2017/5923ec349a79470107efc6b9?from=newsfeed

a b

Figure 4.2.3.4.3. Upgrading of the natural and historical park Kuzminki-Lyublino: a) meadow with a fountain "Firebird" before the upgrading work; b) the same area today

Figure 4.2.3.4.4. Stages in replacing natural grass with artificial turf in the People's Park in Pechatniki (photo: People's Council of the Pechatniki District)



a b

Figure 4.2.3.4.5: a) grass mowing is carried out even during winter; b) collecting fallen leaves, leaving the soil unprotected

Figure 4.2.3.4.6. Unprofessional handling of trees

Figure 4.2.3.4.7. One of a thousand of pole-mounted floodlights installed in the PA “Vorobyovy Gory” ahead of the 2018 FIFA World Cup

In recent years, the maintenance and transformation of Moscow’s natural areas has increasingly been carried out by organizations that are not ideally suited to such activities. These may be construction organizations, such as the State Budgetary Institution “Automobile Roads”, that do not have specialist staff familiar with the regulations for maintaining green spaces, for example. Upgrading work is then carried out using heavy machinery and methods that almost completely destroy natural ecosystems (Fig. 4.2.3.4.8).

Figure 4.2.3.4.8. The use of heavy equipment in the upgrading of green areas. Work is carried out during the nesting period

The above forms of park upgrading ignore current regulations on the creation, maintenance and protection of green spaces in Moscow. Moreover, such activities may even extend into PAs, where the care of vegetation is strictly regulated.

The disturbance of aquatic and near-water ecosystems as a result of upgrading work on green areas deserves separate consideration. The river valleys and natural water bodies that have survived in the city are vital for the preservation of biodiversity, including rare species listed in the Red Data Book of Moscow. Several PAs have been established in small river valleys. In the 1980s, it was proposed to restore sections of rivers that had been redirected underground and reestablish ecological connections of the riverine network. However, recommendations of the Moscow Red Data Book (2011) on the conservation of habitats of rare and vulnerable species were ignored in the program “Protection of surface and underground waters of the city” (2011). This program included measures such as “rehabilitation”, “overhaul of the water channel” and other changes to water bodies that destroyed the habitats of water-loving and aquatic animals and plants. In 2013, it was decided to make recreational upgrades to small rivers. By strengthening the banks of waterbodies using gabions and logs (in some cases creating vertical banks), these then became impenetrable obstacles to small animals and chicks. The landscaping of riversides and their repeated mowing actually destroys local ecosystems and animal habitats (Fig. 4.2.3.4.9). In 2014, restricted access to the riverbank by various types of fences was recorded at 28% of the water protection zones of “Old Moscow” (Report..., 2015). As a result, species diversity is decreasing in upgraded river sections, also within PAs; a number of species of water-loving and aquatic animals have disappeared entirely, including some listed in the Red Data Book of Moscow. Landscaped water bodies no longer function as ecological corridors to connect the city’s green “islets”. Therefore, Moscow’s river network continues to lose its vital role in nature conservation and environmental protection, biodiversity is sharply reduced, and Muscovites can no longer experience various forms of wildlife in the city.

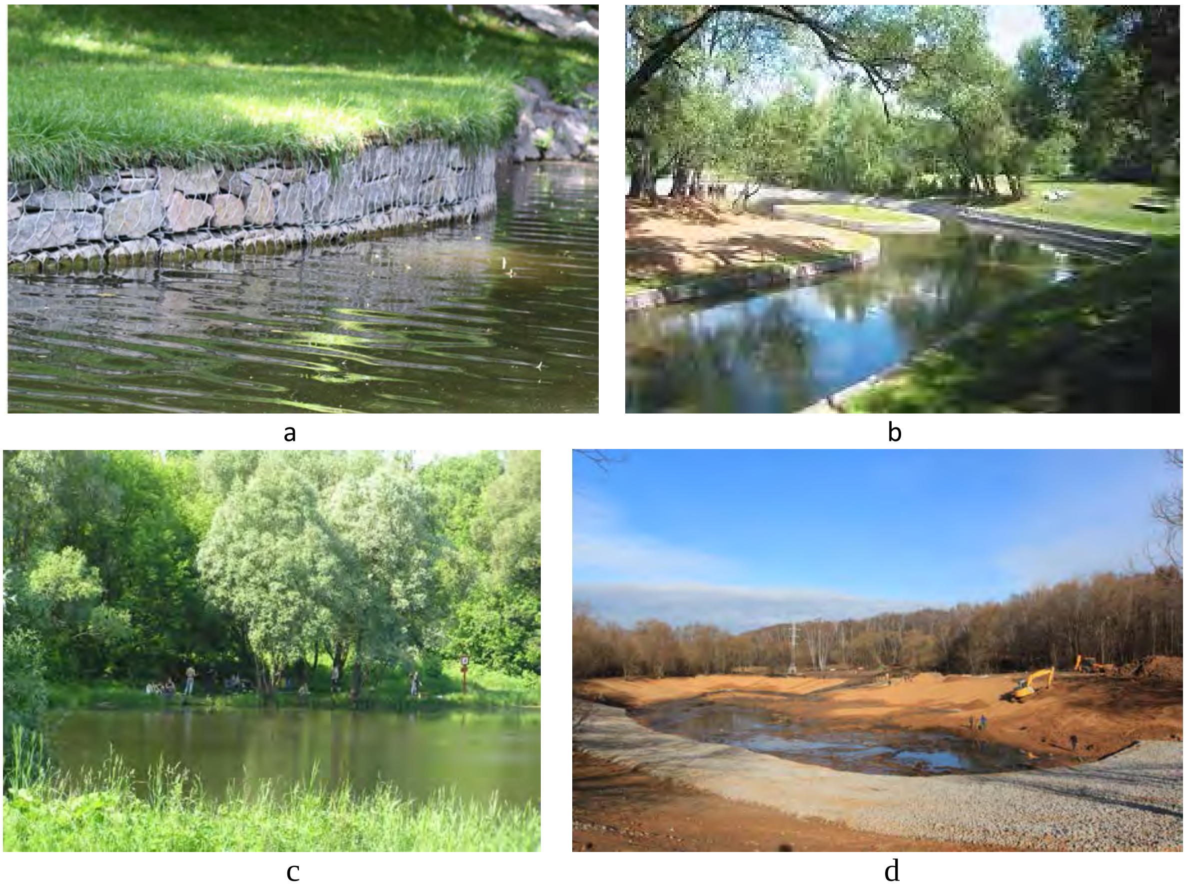


Figure 4.2.3.4.9. Examples of the destruction of riverside ecosystems through landscaping measures: a) close-up of a vertical, strengthened riverbank[28]; b) bank protection of Setun River in Moscow[29]; c–d) Bogatyrsky pond in Losiny Ostrov National Park before and during landscaping work

[28] https://iz.ru/news/545524
[29] http://ecoland21.ru/design/landscaping/

The forms of landscaping discussed above pose the greatest threat to Moscow's PAs. Such work contradicts the regime of special protection, the designated use of PAs, regulations indicated by the Red Data Book of Moscow and other provisions of the current environmental legislation. Nevertheless, in 2020, the Department of Capital Repair of the city of Moscow was allocated funds for the redesign of PAs, breaching existing rules and in conflict with previous development projects. The Department of Capital Repair does not in fact possess a permit to carry out work in PAs or other natural areas. Even though the nature protection rules in PAs do not foresee any radical reconstruction measures, pre-design studies have already begun for the landscaping of a number of PAs.

The prospect of disastrous upgrading also threatens newly created PAs. In 2020, after a long pause, two dozen new PAs were approved by Moscow's local government (Fig. 4.2.3.4.10). Unfortunately, many PAs have already lost some of their biodiversity due to the long wait for approval, while in the future the new PAs may lose further biodiversity following redesign work.

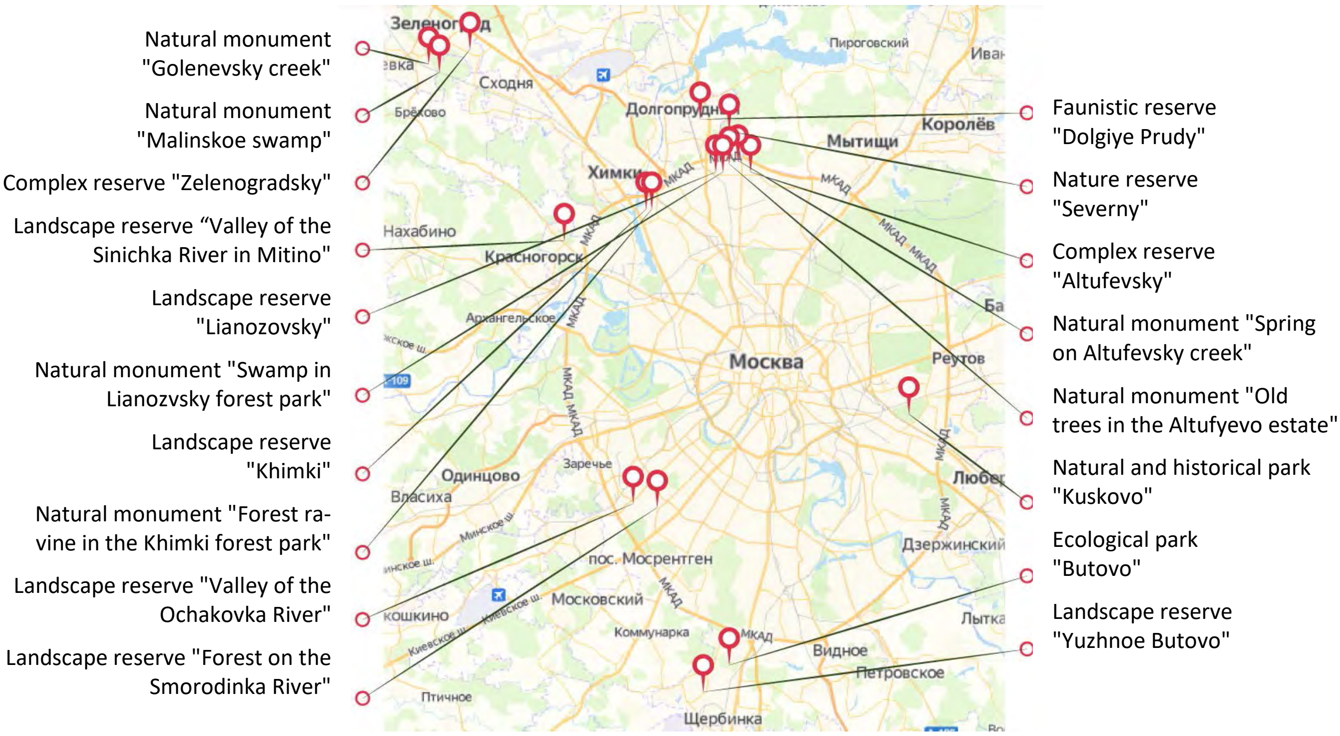


Figure 4.2.3.4.10. Protected Areas approved in 2020[30]

<u>Socio-economic aspects of the destruction of natural areas</u>

The rationale for the mass redesign of Moscow's green areas, including PAs, is the desire on the part of the city authorities to attract a larger number of citizens to these sites. In their opinion, this should have a positive effect on the level of ecological culture and the quality of life of citizens (Report..., 2012). And indeed, the number of visitors to the city's natural and green areas is constantly growing. In the five years from 2010 to 2015, the mass of summer visitors to parks rose from 7 to 25.6 million[31].

Yet from an ecological perspective, it is certainly a fundamental mistake to assess the effectiveness of policies on urban green areas solely by the number of visitors, without taking into account the changes in the quality of natural complexes. Obviously, the maximum number of visitors can be achieved at fully developed sites featuring sports and entertainment complexes. Therefore, this focus on the number of visitors as a priority goal for Moscow's green areas is having the effect of replacing natural ecosystems with various artificial elements and recreation infrastructure. At the same time, wildlife islets that provide irreplaceable

[30] https://msknovosti.ru/society/v-moskve-sozdadut-18-osobo-ohranyaemyh-prirodnyh-territoriy/
[31] http://www.m24.ru/articles/103735

environmental, aesthetic, and educational services are actually disappearing. In sum, the ecological quality of the urban environment is decreasing rather than increasing, and citizens are being deprived of a critical opportunity to communicate with wildlife.

Such redesigned green space as practiced in Moscow is likely to have a negative influence on the ecological culture of local people. The ubiquitous and visible examples of the destruction of meadows, trees and bird nests by heavy machines, the concreting over of the banks of rivers/lakes and vast areas of parks as well as the creation of artificial decorative structures in place of natural sites can only teach a certain disregard for nature. The notion that nature in the city is superfluous becomes widespread.

Another important negative aspect of the mass upgrading of green areas is the high cost. The multiple mowing of lawns costs tens of thousands of rubles per hectare, the construction of 1 meter of paved pathways with curbs costs thousands of rubles, the laying of 1 m^2 of rolled lawns costs hundreds of rubles. The annual costs of upgrading Moscow's green areas total billions of rubles[32]. At the same time, a significant part of these funds is in fact being spent on the destruction of ecosystems and biodiversity. Such outgoings could be classified as "environmentally harmful subsidies", the rejection of which would not only save billions of rubles but also help maintain the high ecological quality of the urban environment, preserve biodiversity and ecosystem services.

The massive felling of trees and upgrading of natural areas has provoked protests from local residents and environmental specialists. In 2016, a special meeting of the Council for the Development of Civil Society and Human Rights (which advises the President of the Russian Federation) was devoted to these problems[33]. Council members "expressed their serious concern about the growing attack on civil rights, including environmental rights, the practice of misusing natural complex objects and specially protected natural areas. This reduces the ecological efficiency of the territories and the opportunities for Moscow residents to take recreation and to restore their health. Thus, the constitutional right of Moscow residents to a favorable environment, guaranteed by Art. 42 of the Constitution of the Russian Federation, is violated."

The policy, which is helping destroy the city's Natural Complex, has fueled public protests by local residents. Council members have stressed that "an aggressive urban planning policy, coupled with ill-considered tree felling and development of green areas, generates a large number of conflict situations between residents and developers. Citizens' discontent, the number of protests and their mass character are growing." The main sites fought over in the year 2016 by initiative groups of residents aiming to protect natural areas are shown in Fig. 4.2.3.4.11.

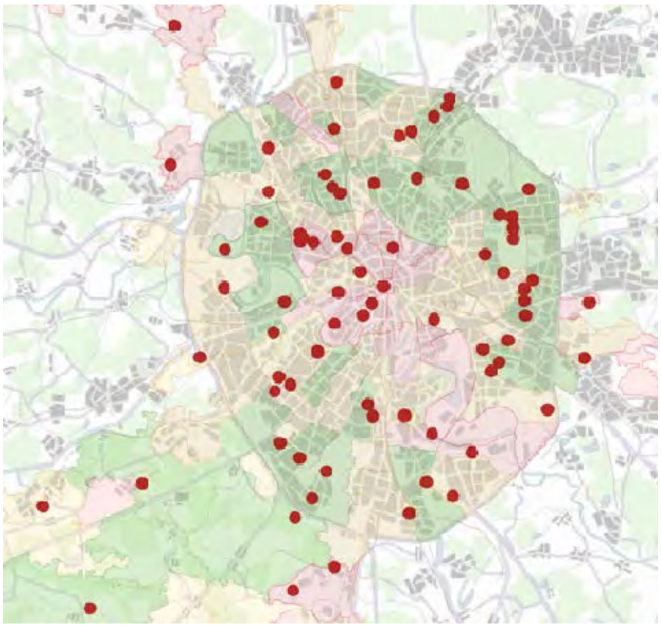


Figure 4.2.3.4.11. The main sites of environmental dispute in Moscow, 2016 (based on the materials of the Human Rights Council under the President of the Russian Federation)

[32] https://www.interfax.ru/moscow/583086
[33] http://president-sovet.ru/documents/read/467/

4.3. Ecosystem services of Moscow

To assess ecosystem services of the municipal districts of Moscow, we considered the area of green infrastructure elements (see Section 4.2.1). This method drastically differs from those we previously used to assess the ecosystem services of Russian regions (Ecosystem services…, 2016, 2020) and the most populated cities of Russia (see Section 3). Unlike these earlier approaches, the method applied here does not define quantitative parameters of the provided and demanded volumes but is based on the proportion of area of green infrastructure elements that perform ecosystem services. In this analysis, in this analysis, our classification of the ecosystem services performed by green infrastructure elements (Table 4.3.1) differs significantly from the ecosystem services classification accepted by the TEEB-Russia project (Ecosystem services…, 2016). However, in this case, we considered it expedient to follow our own ideas regarding this method of assessing ecosystem services.

Table 4.3.1. Types of ecosystem services and green infrastructure elements that perform them

Types of ecosystem services	*Codes according to Table 4.2.1.1*	*Share of urban area, %**
Climate regulation	14100, 14200, 21000, 22000, 23000, 25000, 31000, 32000, 33000	52.84
Runoff regulation	21000, 22000, 23000, 25000, 31000, 32000, 33000, 40000, 50000	51.63
Provisioning	21000, 22000, 23000, 25000	13.11
Natural conditions for recreation	14100, 14200, 31000, 32000, 33000, 50000	41.55

* The sum of the values in this column exceeds 100% because elements of green infrastructure can perform more than one ecosystem service

As ecosystem services were assessed for Greater Moscow, the results suggest a rather more favorable citywide situation than other cities of similar area and population. Yet at the level of individual urban areas and districts, the figures for the volume and variety of ecosystem services can vary drastically. Clearly, New Moscow has a much better provision of ecosystem services than the municipal districts within the Moscow Ring Road. The average values for administrative okrugs clearly demonstrate the situation (Table 4.3.2, Fig. 4.3.1).

Table 4.3.2. The provided volume of ecosystem services in Moscow's administrative okrugs

№	*Administrative Okrug*	*Share of area of green infrastructure elements that provide ecosystem services (% of the okrug's area)*			
		Climate regulation	*Runoff regulation*	*Provisioning*	*Conditions for recreation*
1	Central	8.3	4.9	0.0	12.5
2	Northern	13.3	12.2	1.3	14.7
3	North-Eastern	17.7	8.8	0.2	18.4
4	Eastern	39.4	37.9	0.4	40.4
5	South-Eastern	17.6	15.4	0.2	20.7
6	Southern	16.7	16.6	0.0	21.7
7	South-Western	33.6	29.2	0.0	34.4
8	Western	26.7	17.4	0.2	30.0
9	North-Western	30.0	28.2	0.2	38.4
10	Zelenogradsky	33.4	32.9	0.0	34.2
11	Novomoskovsky	50.5	51.0	12.0	39.4
12	Troitsky	81.7	82.3	25.1	57.2

Predictably, the Central Okrug has the lowest potential ecosystem services due to the high proportion of sealed areas and limited green space. On the other hand, Troitskiy and Novomoskovsky Okrugs of New Moscow have the greatest potential due to their high proportions of unsealed lands. Among the okrugs of Old Moscow, the Eastern Okrug has the highest potential of the analyzed ecosystem services due to the large Losiniy Ostrov national park. Zelenogradsky Okrug, which is situated outside the Moscow Ring Road, also shows good results.

At first glance, these results give the impression that New Moscow provides ecosystem services to Moscow's other okrugs. This, however, is only partially true, especially concerning air quality (due to the prevalence of westerly winds). Other functions of New Moscow's green infrastructure elements have either a transit function (runoff regulation) or a strictly local character (for example, heat reduction).

By analyzing the areas of green infrastructure elements, we can also define the relative inputs of specific ecosystem services to the total volume of services in the administrative okrugs. Thus, Fig. 4.3.2 demonstrates that provisioning services only play a significant role in two okrugs of New Moscow, which have the largest extent of agricultural lands. Central Okrug has the highest potential for recreational services yet the worst results for runoff regulation, since it lacks any runoff regulating elements of green infrastructure without recreational functions (such as agricultural lands or wetlands). The runoff regulation potential is also relatively low in North-Eastern Okrug. Regarding the other okrugs, green infrastructure elements that provide runoff regulating services make up one quarter or even one third of the green infrastructure area. All okrugs are more or less equally provided with climate regulating services (about one third of the green infrastructure area).

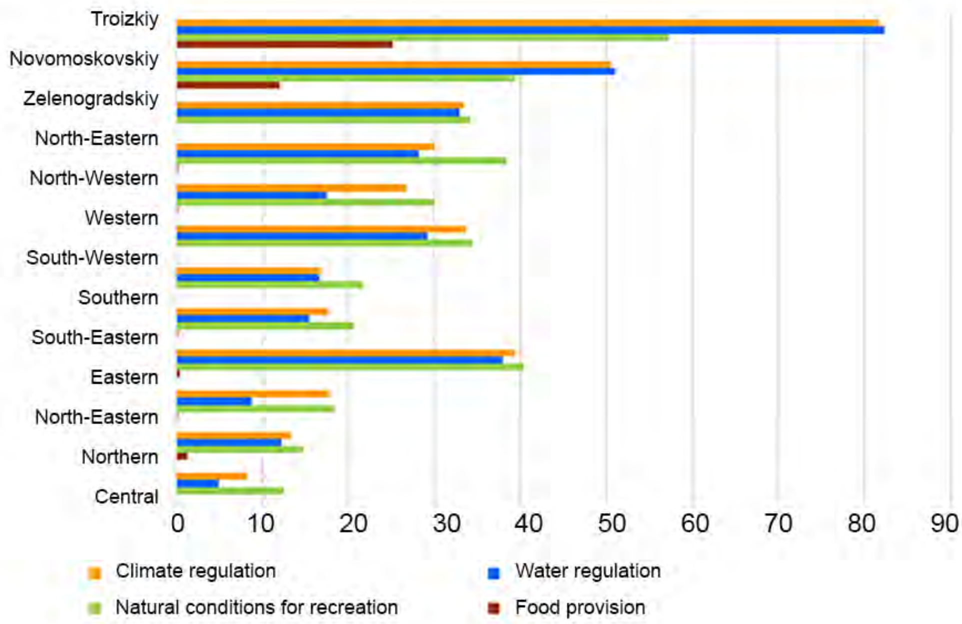


Figure 4.3.1. Share of green infrastructure area that provides the analyzed ecosystem services from the area of the administrative okrugs of Moscow, % of the area of okrug

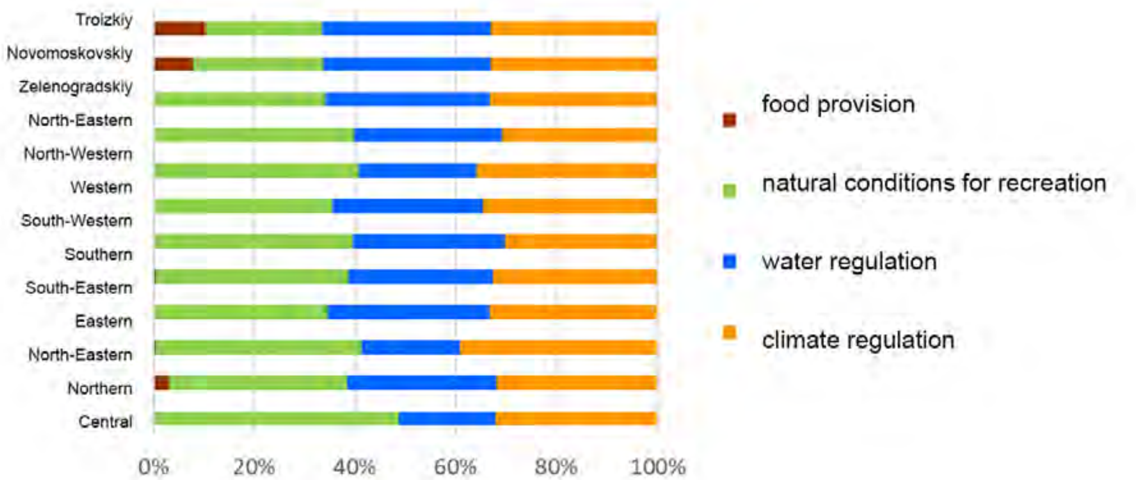


Figure 4.3.2. Relative shares of different ecosystem services provided by green infrastructure in the administrative okrugs of Moscow

We also calculated the green areas that provide ecosystem services in 146 municipal districts of Russia. The examples in Figs. 4.3.3–4.3.5 demonstrate the possibilities of analyzing ecosystem services distribution by municipal districts within the city.

The potential for climate regulation (Fig. 4.3.3 a) is highest in New Moscow's districts and in some districts of Old Moscow with large green areas. The potential is minimal in the central districts.

Provisioning services (Fig. 4.3.3 b) are practically absent inside the Moscow Ring Road and in the highly urbanized northern districts of New Moscow, adjacent to the Moscow Ring Road. The districts outside Old Moscow show a significant potential for the ecosystem service of food production since they have relatively large areas of agricultural lands.

The proportion of runoff regulation services potential (Fig. 4.3.4 a) is similar to that of climate regulation. The majority of Old Moscow's districts have less than 20% of unsealed areas that can perform runoff regulation. The situation is much better in New Moscow, where the area occupied by dense urban fabric is much smaller.

The maximum recreational potential is found in the southern districts of New Moscow and in a number of districts within Old Moscow that have a significant share of natural and other green areas. The northern districts of New Moscow and many other districts of Old Moscow have average values for recreational potential. An extremely low or even no potential is found in almost half of the districts of Old Moscow, especially in the central part of the city (Fig. 4.3.5 a).

Our testing of the method to assess ecosystem services indicators by considering the area of green infrastructure elements shows its applicability to the urban context. However, some vital clarifications are required for further use.

Firstly, it is necessary to clarify and justify the relation between ecosystem services and green infrastructure elements, possibly by scoring the contribution of green infrastructure elements to each ecosystem service.

Secondly, the results based on the areas of green infrastructure elements should be specified for a number of ecosystem services by analyzing additional geographic and ecosystem parameters. For example, the total area of green infrastructure is not the only indicator that can be used to assess the service of runoff regulation. The integrity of ecosystems within river valleys (the valley mouth) is also a significant parameter for this type of ecosystem services. Fig. 4.3.4 b shows that this indicator is extremely low in Old Moscow, making up just a few percent in the majority of the valley. The northern districts of New Moscow show average results. The southern districts of New Moscow have a satisfactory level of integrity regarding ecosystems.

Thirdly, to use this method as a basis for decision-making, it should be supplemented with an analysis of population density and other socio-economic indicators. Our results based on the areas of green infrastructure elements can be considered as indices of the provided ES volume, since the existing area occupied by green infrastructure performs ecosystem services (climate and runoff regulation, conditions for agriculture and recreation) regardless of the number of consumers. The population density in the municipal district (our data basis from municipal statistics of 2016) can serve as an indirect index of the demanded ES volume. The proportionate area of green infrastructure elements, normalized to the population density, can be considered as the ratio index between the provided and demanded ES volumes, i.e. the degree to which demand for the service is met. By comparing the indices of the provided ES volume and the level to which demand for the service is met in the example of recreational services (Fig. 4.3.5 a, b), we note the greatest disparity in the most populated districts. Due to the large areas of green infrastructure in many districts of Old Moscow, the index of the provided volume is quite high (Fig. 4.3.5 a). These areas are in the upper half of the provided ES volume index range; some even show the highest values. Regarding the satisfaction of demand for the service (Fig. 4.3.5 b), almost all districts (except a unique zone of Losiniy Ostrov) are in the lower half of the index range, with the majority of districts showing minimal values. In New Moscow, the most drastic disparity in the index values occur in the area closer to the Moscow Ring Road. Therefore, despite the significant area of green infrastructure and quite a high recreational potential in some districts of Old Moscow, the level of the population's satisfaction with these ecosystem services is quite low.

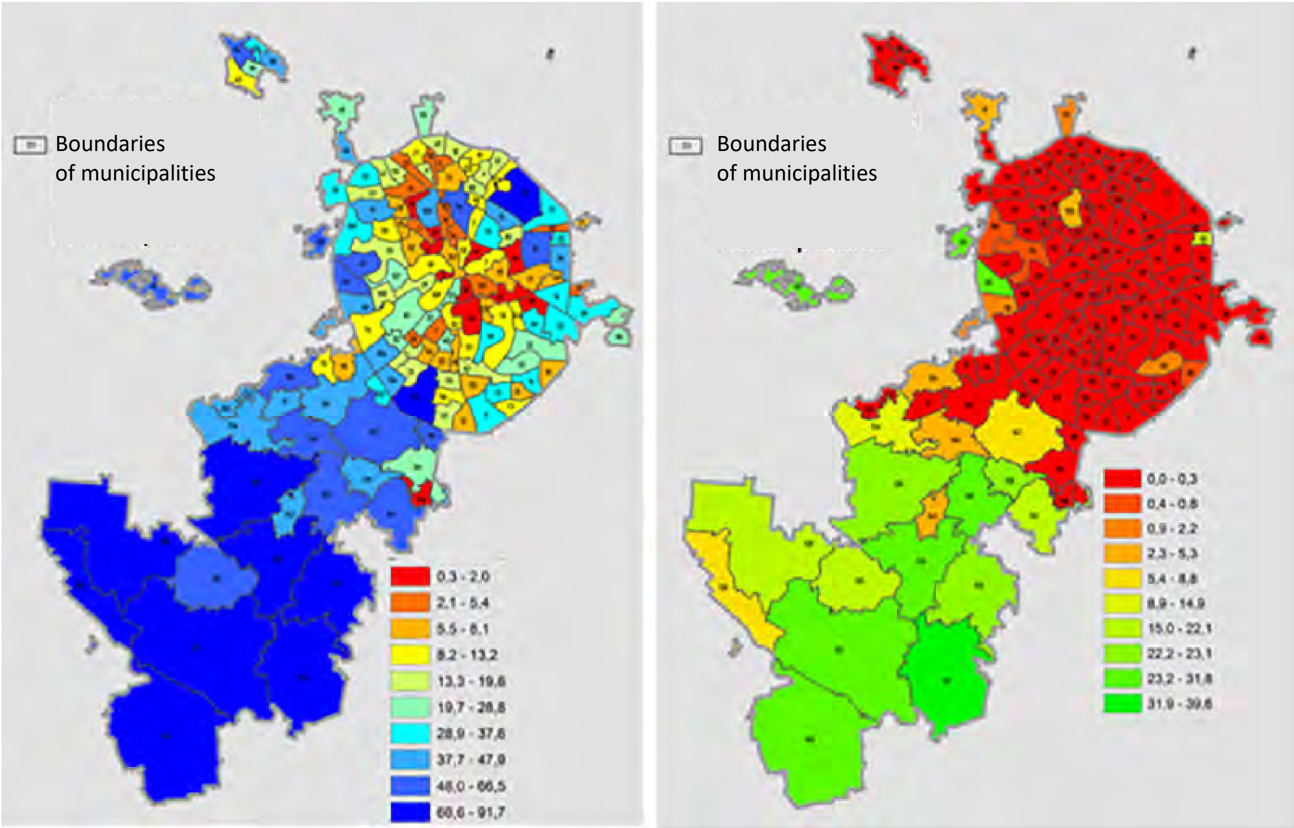


Figure 4.3.3. The share of green infrastructure elements (% of the area of municipal districts) that perform the ecosystem services of a) climate regulation; b) food provisioning

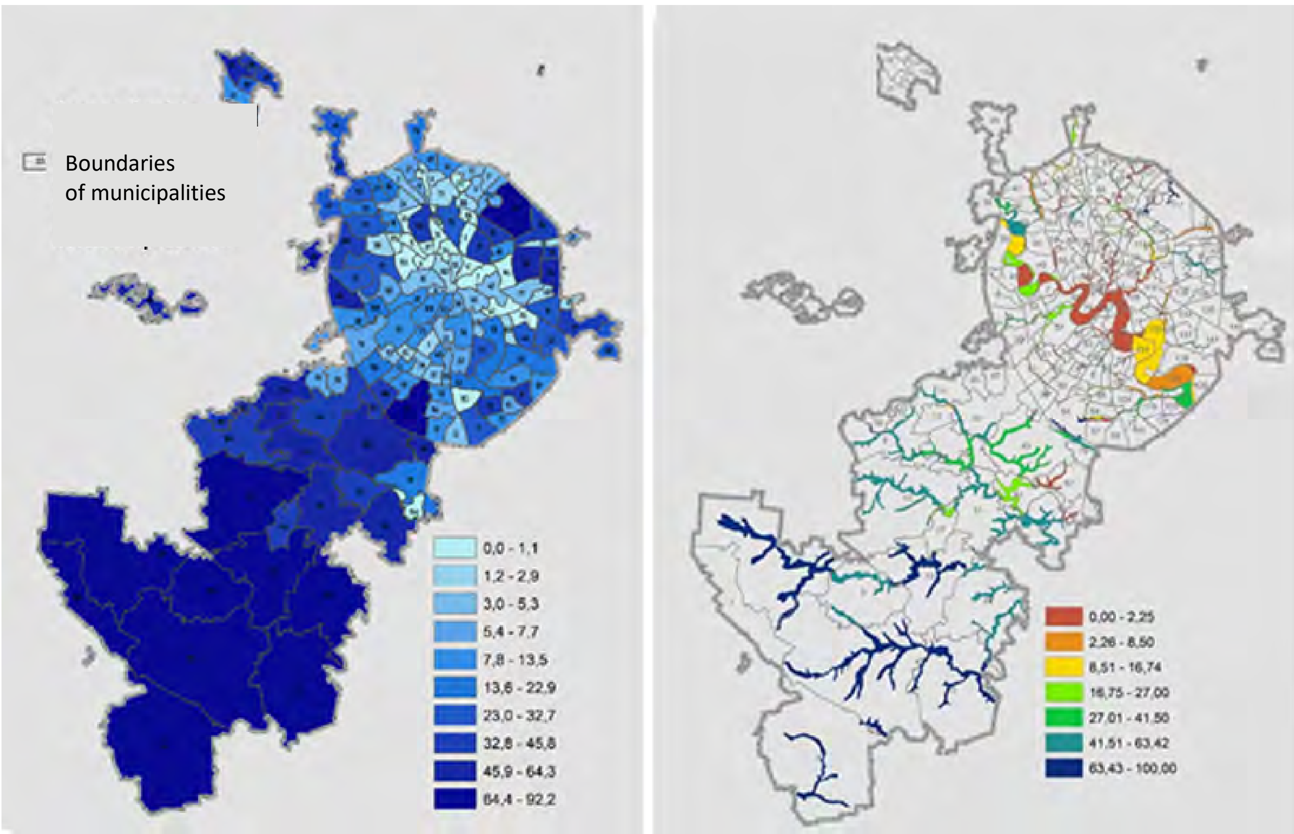


Figure 4.3.4. The share of green infrastructure elements (%) that perform the ecosystem service of runoff regulation: a) share of area inside the municipal districts; b) share of area inside parts of river valleys in the municipal districts

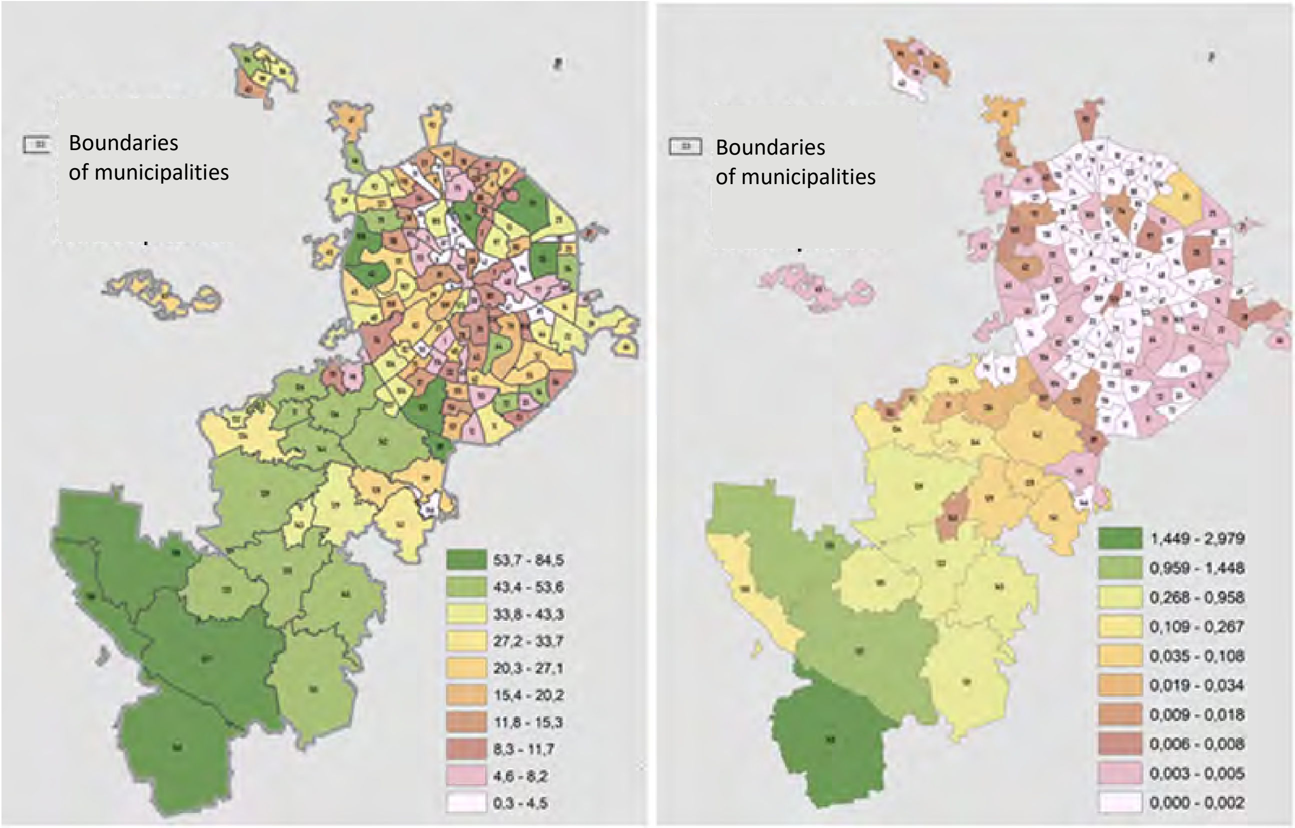


Figure 4.3.5. The share of green infrastructure elements (%) that perform recreational ecosystem services: a) share of area inside the municipal districts; b) same indicator, normalized to the population density

5. Tyumen

5.1. Formation and management of green infrastructure in the city of Tyumen

Tyumen was the first Russian settlement in Siberia. For more than four centuries, it has been an important administrative and industrial center as well as a transport hub connecting the European part of Russia with the northern regions. Currently, Tyumen is also a large cultural, scientific and educational center, and enjoys one of the highest levels of inward investment.

The urban district-city of Tyumen is the capital of Tyumen region, located in the southwest part of the West Siberian Plain in the basin of Tura River. The city's thriving economy is accompanied by a growing population, rising more than 40% to 807,271 in the decade from 2010 to 2020. This growth is the result of inward migration (mainly intraregional and interregional migration) and natural population expansion (the city of Tyumen has one of Russia's highest birth rates).

The city is made up of four administrative districts: Vostochny (pop. 200,324), Kalininsky (pop. 217,311), Leninsky (pop. 193,484) and Tcentralny (pop. 196,152) (all figures from 2020). The city's current spatial growth can largely be attributed to the expanding suburbs. The General Plan for the city of Tyumen foresees a concentric urban development.

Tyumen was founded in July 1586 on the site of an ancient Tatar settlement. Over the four centuries of its existence, the city has gone through various periods of expansion and improvement. Analysis of the general (spatial) plans of Tyumen in different historical periods allows us to trace the creation and management of the city's green infrastructure and to determine the changing provision of green infrastructure facilities to meet the needs of the local population.

Table 5.1.1. The provision of green space in the city of Tyumen over different historical periods (Kiseleva, 2016)

Year	Population	Urban area, km^2	Total area of green spaces, km^2	Area of green spaces within residential zone, km^2	m^2/person	
					Historical value	Standard value[34]
1861	20,000	11.88	1.77	0.43	21.55	8
1905	29,651	11.88	4.03	0.40	13.61	8
1917	54,349	13.60	3.60	0.83	15.30	13
1921	54,349	23.67	10.14	1.06	19.42	13
1937	79,200	24.83	5.40	0.94	11.87	13
1986	395,200	70.93	14.85	3.90	9.86	16
1999	559,600	231.58	69.49	7.90	14.12	16
2015	679,861	444.07	263.18	2.89 (except forest parks)	4.25	16

According to the General Plans of 1765, 1808, 1861, 1905, the city of Tyumen was built up mainly with low-rise private buildings. The expansion of the city borders during this period followed the active development of industry, however, some districts were excluded from the General plans: the Zaretch'e ("Other bank") district after a strong flooding in 1888, the Bol'shoe Goroditsche ("Big Settlement") district due to its proximity to the ravine. At the same time, the formation of railway network determined mainly the eastern direction of the city's expansion. These General plans reflect the elements of the city's green landscaping elements or recreational facilities.

After the revolution of 1917, industry continued to develop intensively in Tyumen, the population and territory of the city increased, in this regard, the General Plan of 1921 established the formation of new districts of low-rise buildings along the railway to the south and southeast. (Ivanenko, 2004). As a result of the suppression of religious belief by the Soviet authorities, the mass destruction of religious buildings began in the 1930s (Alekseeva, 2014). Their territories were turned into parks.

Tyumen's importance as an industrial center increased during the Great Patriotic War of 1941–1945, when essential economic sectors were moved from central Russia to the east. Since 1944, Tyumen has been a regional center (Alekseeva, 2014). the city had developed during the post-war period to the south and

[34] SP 42.13330.2011 Urban planning. Planning and development of urban and rural settlements. Updated edition of SNiP 2.07.01-89.

southeast with rapidly spreading suburbs, paved roads and entirely new neighborhoods featuring the so-called “Khrushchev houses”. At this time, a powerful industrial zone formed in the southeast of the city.

The General Plan of 1987 foresaw the city’s internal development without significantly expanding the urban boundaries. According to the plan, Tyumen was supposed to become a multi-story city. During this period, multi-story buildings were erected in the historical center; the traditional wooden buildings were either demolished or upgraded. The 1990s saw further construction activities, namely the erection of 9- and 12-story buildings. This was accompanied by a significant reduction in the urban greening of central streets. The outskirts of the city began to undergo development.

In the early 2000s, there began a program of mass upgrading and reconstruction of parks as well as the construction of brand-new green spaces. In 2006, a new General Plan was prepared and published. This contained forecasts for three time periods, namely the years up to 2015, to 2025 and to 2040. According to the General Plan, Tyumen would undergo massive expansion (Ivanenko, 2007). The ratio of multi-story to low-rise buildings indicated in the General Plan was 7:3. The highest share of private low-rise buildings was in the west, northeast and northwest of the city. Multi-story buildings should make up most of the central part on the river’s left bank. The eastern part was mainly dedicated to industrial zones and production areas. At the time of the approval of the first edition of the General Plan in 2008, the area of green infrastructure in the city was 559,7 hectares (including forest parks) which equated to 9,5 m2/person.

By studying Tyumen’s historical development in this way, we were able to trace the changes that have occurred in the urban environment. For the purposes of comparison, we calculated the provision of green space in the different historical epochs (Table 5.1.1). The overview of the formation and management of Tyumen’s green infrastructure shows that the current provision of green areas and plantings is the lowest it has ever been, highlighting the need for reconstruction and creation of new recreational zones in the city.

5.2. Modern blue-green infrastructure of the city of Tyumen

Tyumen’s total urban area is 698.5 km^2. Of this, the zones of residential, public and business development cover 80.17 km^2 (or 11.55% of the total area), industrial development 52.24 km^2 (7.48%), green zones 85.1 km^2 (12.2%) and water bodies 38.17 km^2 (5.46%). There is an unbalanced distribution of green zones and water bodies throughout the city.

The city’s modern blue-green infrastructure encompasses the internal ecological framework, namely recreational green areas (forest parks, parks, squares, boulevards, embankments), green areas performing sanitary and hygienic functions (sanitary protection zones, green space around hospitals, schools, kindergartens) as well as artificial and natural water bodies (Fig. 5.2.1) and the external framework, namely the forest greenbelt (Fig. 5.2.2). Currently, the total green space dedicated to recreational purposes within the urban boundaries is 478 hectares (i.e. 0.68% of the total urban area) or 5.9 m^2/person, a figure which is almost three times lower than the norm. In 2017 it was decided to establish a forested greenbelt around the city of Tyumen in order to compensate for the loss of green areas. The forest belt has become one of the largest in Russia; its area of 73,149 hectares is almost the same as the whole of Tyumen.

The city’s inner ecological framework also includes three forest parks: Gagarinsky, Zatyumensky, and Gilevskaya rosha.

Yuri Gagarin Forest Park is a natural monument of size 104.8 hectares located within the city. It features natural pine and birch woodland as well as shrubs and herbaceous vegetation. Rare and endangered species of plants, wildlife and fungi can be found here. The forest park also features an archaeological monument “Mysovskie kurgany”[35]. The Department of Subsoil Use and Ecology of Tyumen Region is responsible for managing and maintaining the park, which is very popular among local residents and visitors. In summer there are many cyclists and in winter the area is used for skiing. In general, this forest park performs recreational, sanitary and hygienic functions.

Zatyumensky Forest Park is also a natural monument. It is located in the city territory between two streets: Yamskaya and Barnaulskaya. Again, the Department of Subsoil Use and Ecology of the Tyumen Region is responsible for the upkeep and care[36]. The area of the forest park is 77.193 hectares. The tree stocks

[35] http://docs.cntd.ru/document/906605163

[36] https://admtyumen.ru/files/upload/OIV/D_nedro/%D0%94%D0%BE%D0%BA%D1%83%D0%BC%D0%B5%D0%BD%D1%82%D1%8B/%D0%97%D0%B0%D1%82%D1%8E%D0%BC%D0%B5%D0%BD%D1%81%D0%BA%D0%B8%D0%B9.pdf

are dominated by pine and birch, although oak can also be found. In fact, Zatyumensky is the only oak regeneration site in the Tyumen region (Tetior, 2006). The park features children's playgrounds and ski runs as well as hiking and bicycle paths. The main tasks of the park are to protect the landscape and the diversity of rare flora and fauna species. Moreover, it is a traditional venue for various citywide environmental and sports events all year round. The ski track is especially popular. Asphalt paths have been laid throughout the forest park and there are also some nature trails.

Gilevskaya rosha Forest Park is located between Lake Krivoye in the north and the Voinovka river in the south. The park's total area is 79.9 ha[37]. It does not belong to the list of specially protected natural areas and objects. There are both natural and artificial plantings in the park. The woodland stock stand is dominated by pine (60%) and birch (39%). In the 1990s, the park became a favorite location for Tyumen residents seeking peace and quiet. There are many visitors at all times of the year.

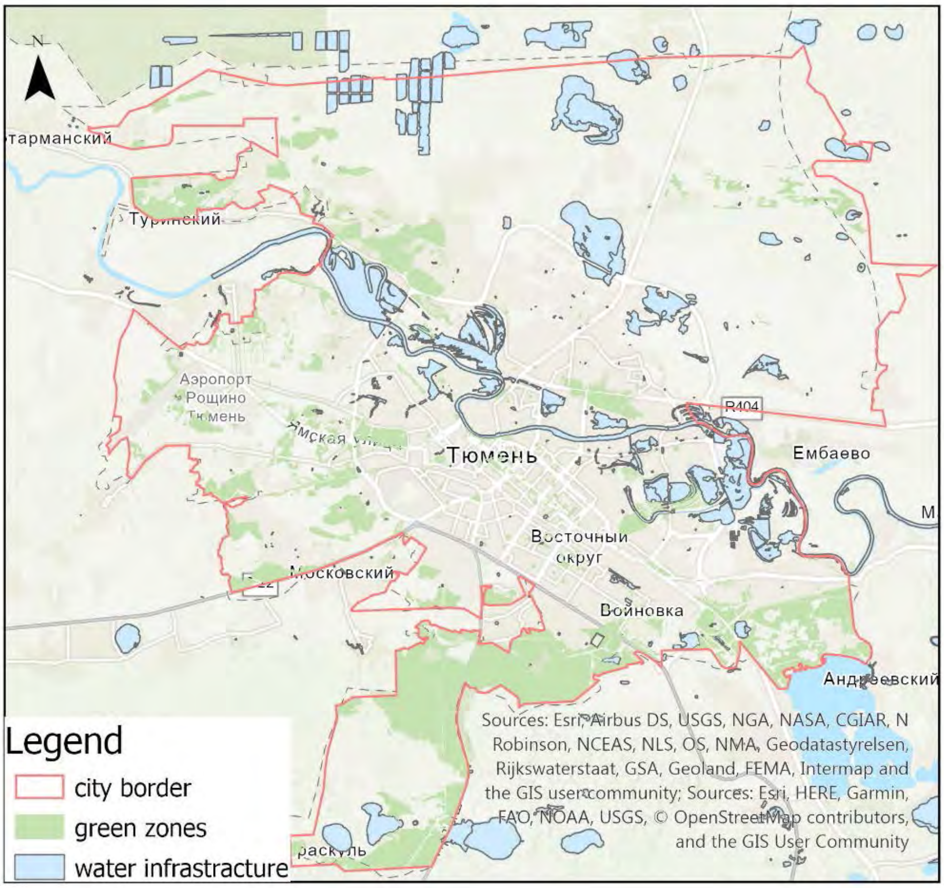


Figure 5.2.1. Green and blue infrastructure of the city of Tyumen

The forest greenbelt of the city of Tyumen was established by Resolution No. 937 of the Tyumen Regional Duma of 14 December 2017. This accorded the suburban forest stocks the status of a forest greenbelt, thereby legally anchoring restrictions in use. Before the adoption of Resolution No. 937, Tyumen's suburban forests belonged to the forests of the State Forest Fund and did not enjoy any such legal status.

In the Russian Federation, the area of forest belts is determined by the population of urban area[38]. For the city of Tyumen, the minimum size of the forest-park belt should have been 19,780 hectares; in fact, the area was initially set at 66,216 hectares prior to the resolution No. 2615 of the Tyumen Regional Duma of 25 June 2020 "On changing the area of the forest park green belt around the city of Tyumen", which increased the size to 73,149 hectares, more than 3.5 times higher than the required minimum.

The functions performed, the mode of use, and the procedure for creating the forest greenbelt in Tyumen, defined by Order No. 90 "On the establishment of the boundaries of the forest-park green belt around the city of Tyumen", were drawn up based on Article No. 62 of the Federal Law "On environmental protection".

[37] http://docs.cntd.ru/document/441525161
[38] http://base.garant.ru/12171631/

In the Tyumen region, the basic shape of the forest greenbelt is a ring with different vegetative patterns. To the north, north-east and east, there is mainly coniferous and deciduous woodland; this, however, does not form a continuous tract but rather alternates with swamps and sites generally used as farmland; the woodland to the west, south-west, south and south-east is more less fragmented, as here less land is used for agricultural. The most developed woodland stock is found in suburbs to the south-west and south.

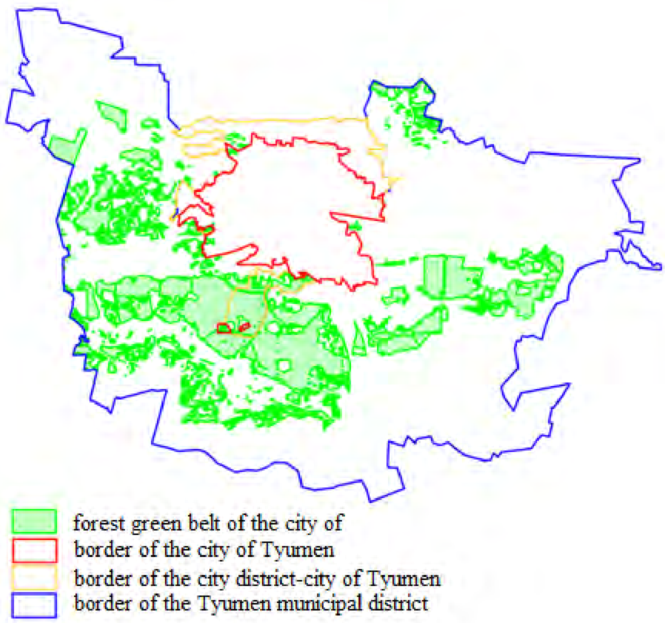


Figure 5.2.2. Forest greenbelt of the city of Tyumen[39]

The blue infrastructure is represented by a transit section of the Tura River along with three shallow tributaries (the Tyumenka River, the Babarynka River, the Klyuchi Stream), various lakes (Lake Alebashevo, Lake Tsimlyanskoe, Lake Krugloye, Lake Pesyanoe, Lake Tsyganskoe, Lake Lipovoe, Lake Krivoe) and ponds (the flooded quarries of Yuzhny, Unity, Shkolny, Student, Polevoy, Chisty, Dambovsky).

5.3. Modern urban geosystems of the city of Tyumen

The city of Tyumen is located in the Tura River valley, within the subtaiga landscapes of Western Siberia. To the south of the city, there is a large pine forest; to the north, the territories are mostly treeless, with intensive development of agriculture. Within the city there are also extensive birch and pine woodlands, the largest being the Gagarin forest park and Gilevskaya grove. The wide dissected floodplain of Tura is a mosaic of abandoned channels, lakes, deciduous forests, boggy meadows and isolated low-rise private and warehouse buildings. The high-lying right bank of the Tura is dissected by tributary streams and ravines. Steeper parts of the valley are covered by dense deciduous forests, while flatter areas are built-up with garages and low-rise buildings.

The interaction between the natural landscape and developed areas is underpinned by the spatial structure of Tyumen's urban geosystems. These are relatively homogeneous territories that have a certain urban function, specific land cover pattern and are located on the same landform.

In our analysis, we considered the following functions of urban areas: residential, cultural and business, industrial, transport, storage, recreational, nature conservation and agricultural. The function of an urban geosystem was recognized by visual interpretation of high-resolution images.

The classification of multi-temporal, multi-spectral images resulted in a land cover map featuring the following classes: water bodies; riparian meadows; coniferous trees; deciduous trees and shrubs; arable land; mixed tree-shrub-meadow vegetation; built-up areas and a class of shaded areas (indicating high-rise development).

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[39] https://admtyumen.ru/files/upload/OIV/D_Wood/%D0%9A%D0%B0%D1%80%D1%82%D0%B0%20%D1%81%D1%85%D0%B5%D0%BC%D0%B0.JPG

The classification was carried out using Sentinel-2 images (provided by the European Space Agency) acquired on 6/6/2018, 1/7/2018, 26/9/2018, 27/1/2019, 7/4/2019 and 2/5/2019. Classes of land cover were allocated separately, based on their features specific to a particular season. Thus, water bodies were identified by high Normalized Difference Wetness Index (NDWI) values on 1 July 2018, the riparian meadows were flooded on 2 May 2019, and became dry land on 1 July. Conifers retain high values of the Normalized Difference Vegetation Index (NDVI) in winter and were identified by images dated 27 January and 7 April 2019. Arable lands were derived from the difference between NDVI values on 6 June and 26 September 2018. Deciduous trees and shrubs were identified by NDVI values of more than 0.8 on 1 July 2018. Built-up and sealed areas were recognized by the highest values (above – 0.4) of the normalized building index VrNIR-BI, calculated for 1 July 2018.

As a result, we obtained a classified image of the city of Tyumen (Fig. 5.3.1). Land cover within the ring road is characterized by the following ratios: built-up areas together with the shadows of high-rise buildings at 31%; green areas at 62%, of which 54% is mixed vegetation, 4% deciduous forests, 3% coniferous forests and 1% riparian meadows; arable land at 4%; water bodies at 5%. It should be noted that the high proportion of mixed vegetation in the urban land cover is largely due to the vast undeveloped floodplain and low-rise housing with private gardens.

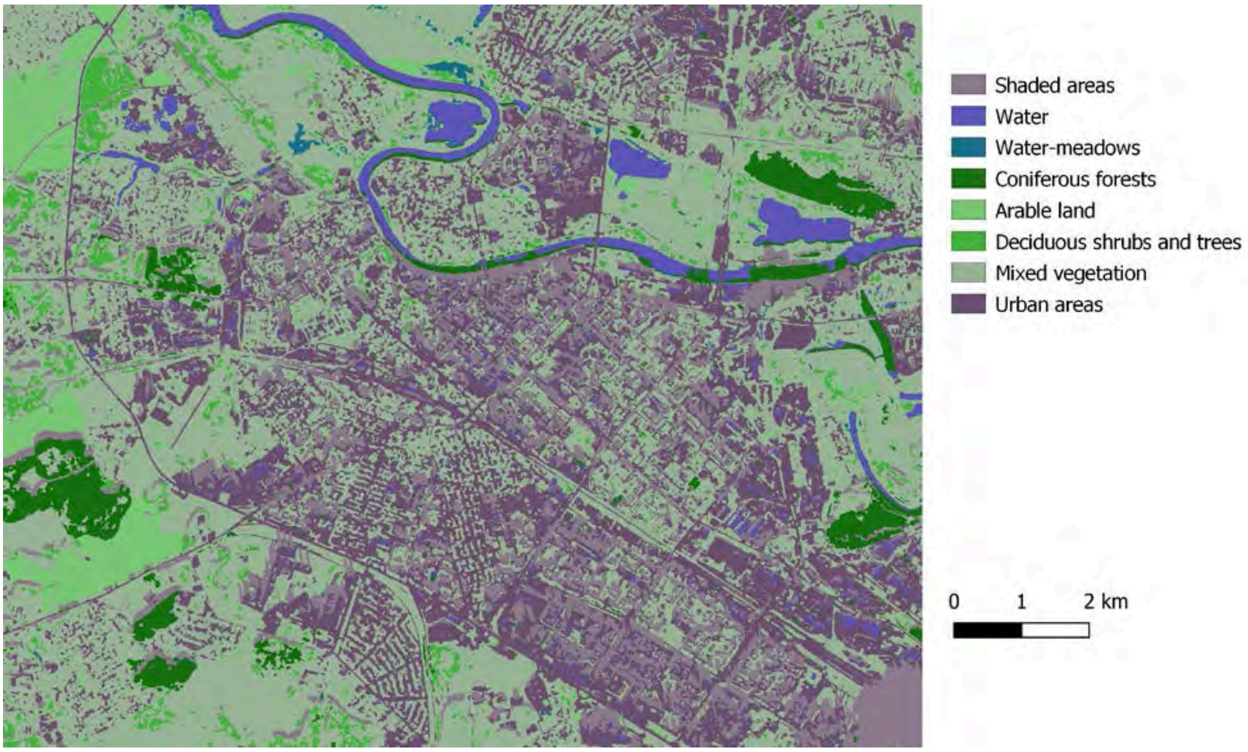

Figure 5.3.1. Classification image

The relief was divided into the following classes: low floodplain (up to 54 m), high floodplain (54–58 m), low terrace (58–72 m), middle terrace (72–86 m), high terrace (86–120 m), steep slopes of terraces (10–20°), ravines and valleys of small rivers.

As a result of the multi-level classification, we created a map of urban geosystems. The created map of urban geosystems covers the urban area bounded by the Ob'yezdnaya (bypass) road and contains 546 unique contours combined into 25 classes (Fig. 5.3.2).

Using the identified classes of landscape cover, it was possible to identify the most typical urban geosystems.

Buildings with a variable number of stories in the historic center. The historical center of Tyumen was constructed on the high-lying bank of the Tura River. The buildings here are generally from the late 19th to early 20th centuries. Later, single multi-story buildings began to take the place of low-rise buildings. This area has a high level of soil sealing and can be easily distinguished on almost all spectral indices. Asphalted areas and dense buildings take up 65% of the territory. The proportion of green space is much lower than the average for the whole of the city, reflected in the low NDVI value of 0.12.

Private low-rise buildings. Such urban geosystems cover up to a third of Tyumen's area and are widespread both on the urban outskirts and near the center. Close to the historical center, private buildings can be found on the left bank of the Tura, which is basically a swampy floodplain. Another large array of low-rise buildings is located between Chervishevsky Tract street and Melnikayte Street on a high-lying flat area above the floodplain. Low-rise buildings are also found on a high-lying terrace between large ravines. Two classes of landcover are dominant within the urban geosystem of private buildings, which are build-up areas and mixed vegetation (33 to 50 % of urban districts' area). The average NDVI for the private sector is 0.18, just below the average. This is because the private sector has sufficient green space. Many plots are used for urban agriculture, and therefore have been plowed up for this purpose.

Five-story residential buildings. This type of urban geosystem development, which emerged in Tyumen in the 1950s to 1970s, is found mainly to the east of the historical city center on a relatively flat terrace above the floodplain. Over the years, mature broad-leaved and small-leaved trees such as poplar, birch, linden, maple and wild apple have managed to grow on this territory. Conifers can be found: pine and – to a lesser extent – spruce and larch. The proportions of land cover classes in the five-story residential blocks are as follows: 32% of wasteland and undefined classes 28% of low-density construction, 19% of dense buildings, 7% of sealed territory, 4% of coniferous vegetation and 10% of deciduous vegetation. Such a natural environment is indicated by a relatively high NDVI value of 0.21.

Residential nine-story buildings. This type of development is in many ways analogous to the five-story blocks. The only significant difference is that this form has less of a mosaic pattern. The houses themselves occupy a large area and are distinguishable in the Landsat-8 image, while the spaces between are more extensive than those of five-story buildings. For 30–40 years, deciduous and coniferous vegetation has grown in areas around these large-panel buildings. The distribution of classes and the NDVI value almost wholly coincide with the values for the five-story blocks. The yards of the new residential nine-story buildings are paved and used as a parking lots, so the class of built-up areas together with the shadows of high-rise buildings occupies 90% of the area and the NDVI decreased and amounts to 0.11–0.15.

Residential twelve-story and sixteen-story buildings. Over the past 20 years, Tyumen's population has almost doubled. Today huge areas of the city are occupied by new housing blocks. These districts were constructed in the southeast of the city on a high terrace as well as on the swampy left bank of the Tura. Buildings generally have 9 to 16 floors. In the relatively short time since their construction, little vegetation has grown. There are large areas of lawn between the houses. The NDVI value is also low at – 0.11–0.12.

Industrial zones. There are vast industrial zones on the outskirts of the city as well as alongside the railway line. Industrial zones are characterized by a high level of soil sealing. The spaces between warehouses and factory floors are usually asphalted. Thus, the average proportion of sealed land and areas with dense buildings is 56%. Wasteland accounts for 20%. While the NDVI is only 0.13, this is higher than in areas of new development. This relatively better result can be attributed to the long history of Tyumen's industrial zones, giving sufficient time for the growth of mature trees.

Parking lots, shopping centers. These urban geosystems are characterized by the highest level of soil sealing and an almost complete absence of vegetation. The largest shopping centers in Tyumen are Kristall, Panama and Lenta. They cover an area of almost 35 hectares (including car parks). The average NDVI value in this urban geosystem is only 0.06; further, the proportion of asphalted areas and areas with dense buildings is more than 85%. The other 15% is partly made up of grassy areas in front of the shopping centers.

Ravines. A significant share of Tyumen's vegetation is concentrated in urban ravines. These ravines have slopes of up to 30 degrees, rendering development practically impossible. The bottoms of the ravines are flat and mostly waterlogged, encouraging the growth of alder, willow and aspen, which are all tree species typically found in floodplains. Such vegetation is characterized by a higher NDVI index of 0.40. The proportion of vegetative land cover is 60%. The remaining 40% includes the class of intermediate values and low-rise buildings.

Vacant lots. Most vacant lots are large undeveloped spaces in outlying areas of the city. Often the appearance of this class can be attributed to hydrogeological conditions that prevent construction. For this reason, the left bank of the Tura river with its floodplains and waterlogged areas is much less developed than the right bank.

Recreational areas of Tyumen can be divided into three classes – large forest parks with an area of 75–105 hectares, city parks with an area of 10–24 hectares and city parks with an area of 1–8 (up to 12) hectares. Forest parks are represented by dense birch and pine forests, the density of tree stands is 80–95%, summer NDVI values are higher than 0.8. Opinion polls have shown that these green spaces are the most popular recreational facilities in the city. City parks have paved paths and benches, the density of tree stands is reduced to 15–75%. The greening of small city parks is irregular, the density of trees ranges from 5 to 80%, while the popularity of parks among city dwellers is closely correlated precisely by the share of tree canopies, the most popular are the park Berezovaya Roshcha, Nemtsova, Tekutyevsky Boulevard, where the share of trees is 70–80% of the total area.

Figure 5.3.2. Map of the urban geosystems of Tyumen (Kharitonova, 2018)

The greatest potential for the production of ecosystem services is possessed by urban geosystems with high NDVI rates, and therefore with a high share of green infrastructure facilities. Such urban geosystems include, the classes of vacant lots and recreational areas, as well as nine-storey and five-storey residential buildings. Low-rise buildings with private gardens, despite the relatively low building density, are characterized by a reduced ecosystem potential. The ability of urban geosystems to provide the "cooling effect" service depends both on the density of tree plantations and on the elevation – in the summer season, low terraces and floodplains are relatively cooler compared to medium and high terraces.

The potential for the provision of recreational services, in addition to specially designated areas, is also high in quasi-natural undeveloped areas – steep slopes of terraces, where ski and toboggan runs spontaneously appear in winter; near floodplain lakes, where skating rinks and auto racing tracks appear in winter; near the urban geosystems of gullies and ravines, where a wide range of recreational services is possible.

5.4. Ecosystem services of the city of Tyumen

Our aim in this study was to evaluate the essential ecosystem services provided by urban ecosystems, to assess the demand-supply ratio of urban ecosystem services and to map the distribution of the demand and supply of such urban ecosystem services for the city of Tyumen.

Most studies on urban ecosystem services highlight the huge importance of direct and local ecosystem services. In urban areas, ecosystem services are provided by semi-natural ecosystems such as elements of green infrastructure (urban greenbelts, forests, parks, tree canopies, gardens, lawns), blue infrastructure (natural wetlands including lakes, marshlands, rivers, creeks, streams and artificial ponds, water-filled quarries and canals) and other natural ecosystems or ecosystem components (e.g. soils, rocks)[40]. A broad set of urban ecosystem categorizations is required to capture the great variety of urban ecosystems. For the city of Tyumen, we categorized urban ecosystem services according to the CICES classification. In the following we present two examples of ecosystem service evaluation for the city of Tyumen: an assessment of the demand-supply ratio of micro and regional climate regulation (cooling effect, regulation, and maintenance CICES Section) and physical and intellectual use of landscapes (seascapes) in different environmental settings (everyday recreation, cultural CICES Section)[41].

Despite the absence of a generic framework for urban ecosystem assessment in Russia, we could identify the following approaches from previous assessments of urban ecosystem services in the country: monetary and non-monetary assessments, demand-supply ratio assessment (or an assessment of demand only), assessment based on statistical or remote sensing data for the whole city without paying attention to inner complexity as well as analyses of the spatial distribution of demand and supply of urban ecosystem services[42]. For this study we conducted a (non-monetary) assessment of the spatial distribution of the demand for and supply of cooling effect and everyday recreation.

5.4.1. Recreational services: forming natural conditions for daily recreation

Daily recreation is one of the essential urban ecosystem services provided by a city's green infrastructure. In the case of Tyumen, we attempted, firstly, a general approach to assess the supply-demand ratio of daily recreation by comparing the total number of people engaged in recreation in elements of urban green infrastructure with the maximum permissible number who can simultaneously visit these elements; and secondly, a more detailed comparison of the number of those engaged in recreation with the maximum permissible number within a hexagonal fishnet. Under the second approach, it is possible to define niches for the reconstruction, creation and improvement of urban green infrastructure.

We created a population density map (Fig. 5.4.1.1) using ArcGIS PRO software to assess the demand for daily recreation. Vector layers from the free resource Open Street Maps[43] (administrative boundaries, buildings) were used to create the map. We verified these vector layers using Landsat-8 images and field observation. The Landsat-8 images were taken from the same year, i.e. 2016, to assure a reliable verification process. Clearly, data on the number of inhabitants in every residential building in the city was also required to calculate the population density. We estimated the number of inhabitants using the average area of living space per person (30 sq. m) and the average household size in the Russian Federation as well as the total area of living space in every residential house or the number of detached houses[44]. To calculate the area of living space, we used the "building" layer clipped inside the boundaries of Tyumen's urban precincts; the area of the polygons representing residential buildings was multiplied by the number of floors. To calculate the number of inhabitants, we divided the total living space of residential buildings by the average living space per person. For detached houses, the number of inhabitants was set at the average household size, i.e. 2.8 persons. Therefore, every building polygon contained information about the number of inhabitants. To facilitate the data aggregation, we created a point layer using the centroids of the building polygons (applying the same attributes).

A map of the city of Tyumen's green and blue infrastructure (Fig. 5.3.1) was created in the ArcGIS PRO software to assess the supply of daily recreation. As our data basis we used vector layers from the free resource Open Street Maps (water bodies, specially protected natural areas, lakes, large rivers, land use, surface types, vegetation, land area). We verified these vector layers using Landsat-8 images and field observation. Landsat-8 images were taken from the same year as the data for the population density map, i.e. 2016, again to ensure reliability in assessing the supply-demand ratio using OSM vector layers. The map of urban green and blue infrastructure included various types of green spaces and water bodies, i.e. urban forests, parks, lawns, gardens, dachas, shrubs, river valleys, rivers, lakes, ponds.

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[40] https://www.eea.europa.eu/publications/annual-report-2010/download
[41] https://cices.eu/
[42] https://www.elibrary.ru/
[43] https://www.openstreetmap.org/
[44] http://www.demoscope.ru/weekly/ssp/rus_hh_10.php

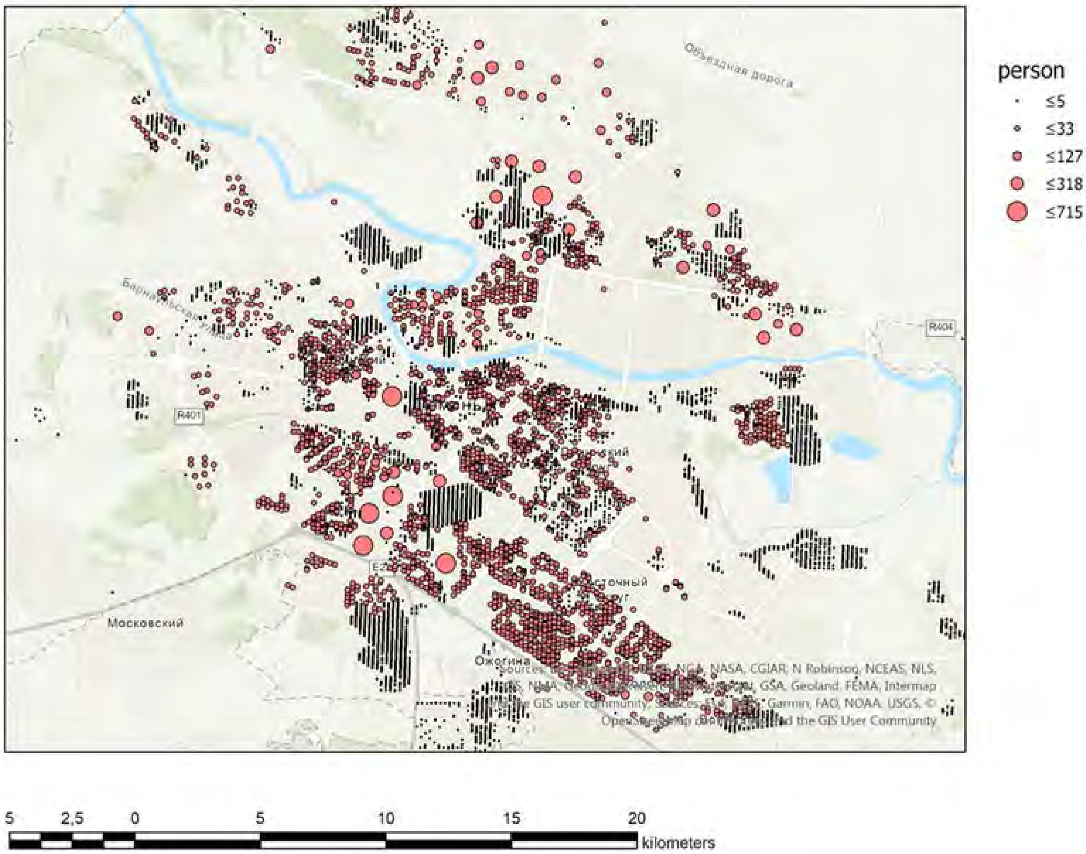

Figure 5.4.1.1. Map of the population density of the city of Tyumen

The volume of ES provided by green infrastructure was derived from the map of Tyumen's blue-green infrastructure. Here we set the maximum permissible number of people engaged in recreation in urban green zones at 50 per hectare[45], the figure stipulated by the design norms for integrated improvement in the city of Moscow[46]. The map of Tyumen's blue-green infrastructure enabled us to pinpoint the elements of urban blue-green infrastructure suitable for recreation (i.e. urban forest, parks, gardens). The area of these elements in hectares was multiplied by the maximum permissible number of people engaged in recreation. In this way we created a shapefile in which every polygon of the elements suitable for recreation had as an attribute the maximum permissible number of people within its borders. A hexagon fishnet aggregated these polygons with a radius of 500 m using the weighted sum method to enable a comparison of supply and demand for daily recreation. The same fishnet was used to map the distribution of demand. The end result of this spatial analysis was a shapefile – a map of the spatial distribution of the supply of daily recreation (Fig. 5.4.1.2) – with hexagon polygons indicating the maximum possible number of people simultaneously engaged in recreation within their borders. Next we created a thematic map to better illustrate the results of this assessment using the graded colors method. In such a map, quantitative differences between mapped objects can be identified by their changing colors. Data is classified into ranges, each of which is assigned a different color scheme. We categorized the maximum possible number of people engaged in recreation within each hexagon into five ranges using the natural breaks method and colored the hexagons in terms of their relevance to the range.

In this way we were able to determine that the green infrastructure of the city of Tyumen had a capacity for the simultaneous recreation of 34,034 people. The supply is higher at the periphery of the city, where the most extensive recreational zones are located, primarily along the river and on the left bank (Gagarin

[45] Decree of the Moscow Government dated August 6, 2002 N 623-PP "On the approval of the norms and rules for the design of integrated improvement in the city of Moscow" (MGSN 1.02-02 17) was used for the city of Tyumen due to fact that the Rules of improvement in the city of Tyumen do not contain any norms for the maximum permissible recreational pressure and due to the lack of regional standards.

[46] Decree of the Moscow Government dated August 6, 2002 N 623-PP "On the approval of the norms and rules for the design of integrated improvement in the city of Moscow" MGSN 1.02-02 17.

Park, Lake Alebashevskoye, Lake Pesyanoe) and partly to the west (Zatyumensky Park, Lake Tsimlyanskoye, Olovyannikov Park), where urban green infrastructure gradually merges into the forest greenbelt. The map of the distribution of daily recreation shows the maximum permissible number of people in every hexagon.

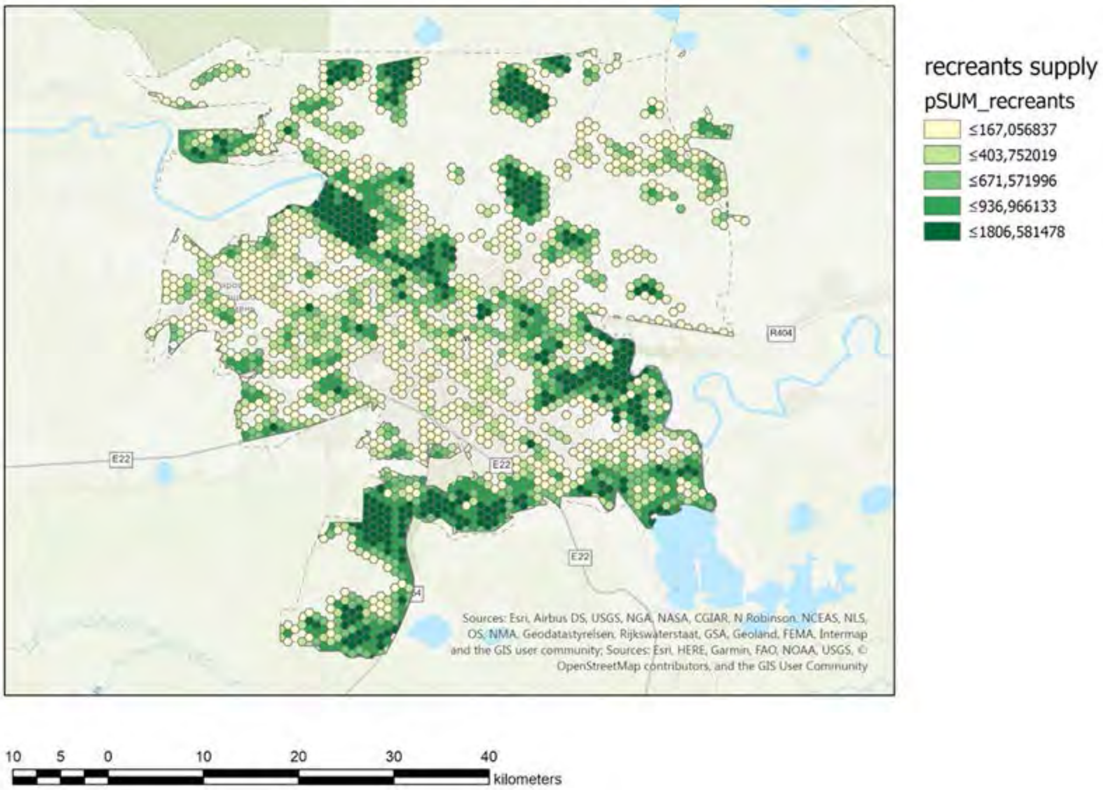

Figure 5.4.1.2. The spatial distribution of the ES daily recreation provided by green infrastructure

The demanded ES volume was derived from the map of Tyumen's population density. For this we simply assumed the standard park value for the Moscow region[47], namely that demand for daily recreation is 5% of the urban population[48]. The map of Tyumen's population density enabled us to specify the number of inhabitants in every residential building. To define the number of people simultaneously engaged in recreation in green space, we multiplied the number of inhabitants in each building by 0.05. This gave us a shapefile where every point – centroid of the building polygons – had an attribute, namely the number of people simultaneously engaged in recreation. A hexagon fishnet aggregated these points with a radius of 500 m to facilitate our comparison of the supply and demand for daily recreation. The same fishnet was used to map supply. As a result of this spatial analysis, we created a shapefile that mapped the spatial distribution of the demand for daily recreation (Fig. 5.4.1.3), in which hexagon polygons indicate the number of people simultaneously engaged in recreation within their borders. Next, we created a thematic map to illustrate the results of the assessment of the demand for daily recreation. Here we again used the graded colors method. We categorized the maximum possible number of people engaged in recreation within the hexagonal borders into five ranges using the natural breaks method and colored the hexagons to reflect the range of values.

From the map of population density and our estimation of the number of inhabitants in Tyumen's residential buildings, we calculated the urban population to be 711,660 in 2016. The correct figure according to official statistics was 720,525[49]. Therefore, we can assume that our map of the city of Tyumen's population density is reliable (only a 1% deviation from official statistics). We estimated the total number of people

[47] Resolution of the Moscow Government dated December 23, 2013 No. 1098/55 "Instructions. Regional park standard of the Moscow region".

[48] Resolution of the Moscow Government dated December 23, 2013 No. 1098/55 "Instructions. Regional park standard of the Moscow region" was used for the city of Tyumen due to fact that the current rules for upgrading measures do not contain any norms for the maximum permissible recreational pressure and the lack of regional standards.

[49] https://www.gks.ru/scripts/db_inet2/passport/pass.aspx?base=munst71&r=71701000

simultaneously engaged in recreation at 35,583 in 2016. Most visitors for recreation were concentrated in the center and south-east of the city, where there are residential districts with dense and mainly high-rise buildings, and thus a high population density. In the map of demand for daily recreation, every hexagon shows the number of individuals simultaneously engaged in recreation.

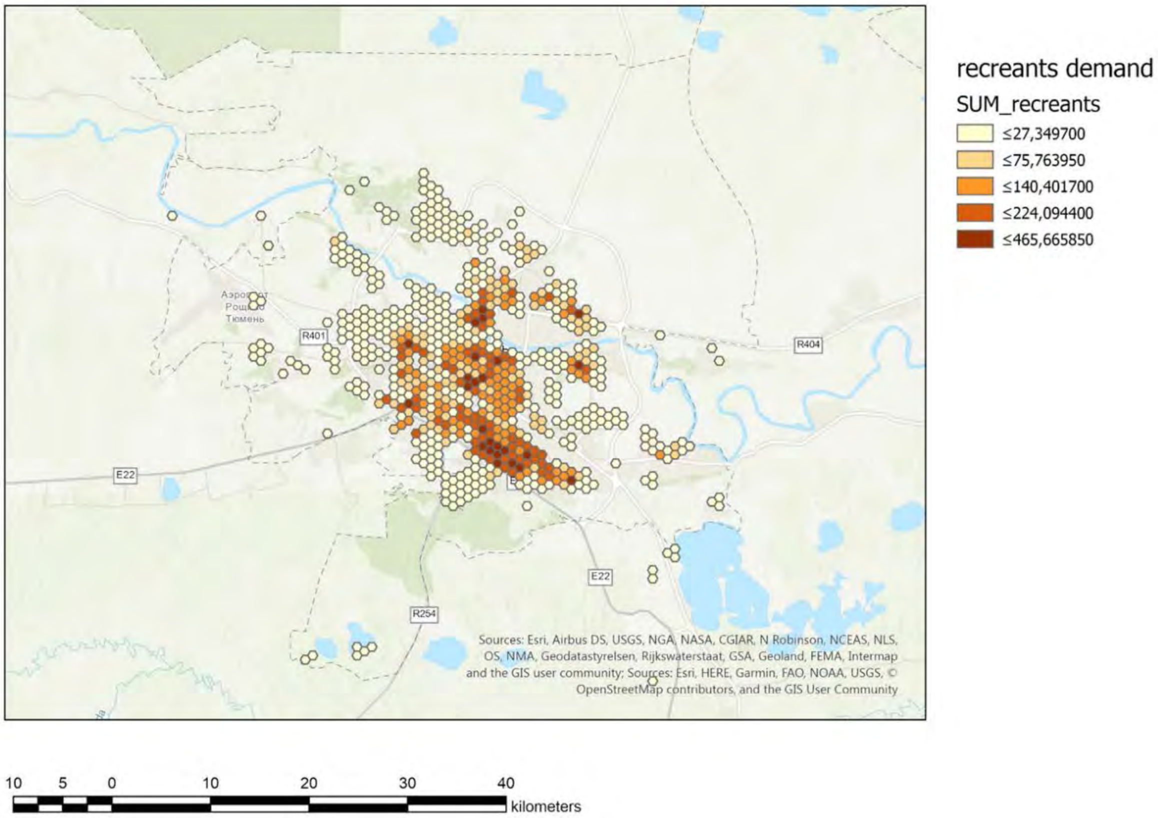

Figure 5.4.1.3. The spatial distribution of demand for daily recreation

To assess the supply-demand ratio of daily recreation, we merged the shapefiles of the maps of the spatial distribution of supply and demand for daily recreation. Then we subtracted the maximum permissible number of people simultaneously engaged in recreation from the number of those simultaneously engaged in recreation in each hexagon. The calculated ratios helped to distinguish those territories with sufficient and insufficient supply of daily recreation services. The hexagons with minus values have an insufficient ecosystem service, while those with positive values have a sufficient service. To illustrate our assessment of the supply-demand ratio of daily recreation, we created a thematic map using the graded colors method. We categorized the ratio values in each hexagon into seven ranges determined manually with a special color for zero ratios and variously colored hexagons to reflect the particular value range.

Comparing the provided and demanded ES volumes. From the perspective of the whole city, the supply of daily recreation almost meets the demand (only 4% of people wishing to engage in recreation lack space at any one time). However, Tyumen's central and southeastern districts are poorly provided with green infrastructure, with only a few insignificant squares and parks serving a high population density. The integrated map (Fig. 5.4.1.4.) shows that these areas are characterized by an apparent deficit of daily recreation. Moreover, if we consider the degree of accessibility of recreational areas for the urban population, then 22,460 local residents out of 35,583 do not have green zones within a radius of 500 m from their homes (that is, within easy walking distance). In other words, there is an acute shortage of green spaces to serve the local population. Unfortunately, the newly created forest greenbelt is poorly accessible to the majority of residents.

The supply of recreational opportunities in the city center is much lower than demand, in contrast to the suburbs, where supply is much higher. Those areas suffering a significant lack of ecosystem services should be considered for the development of new green infrastructure.

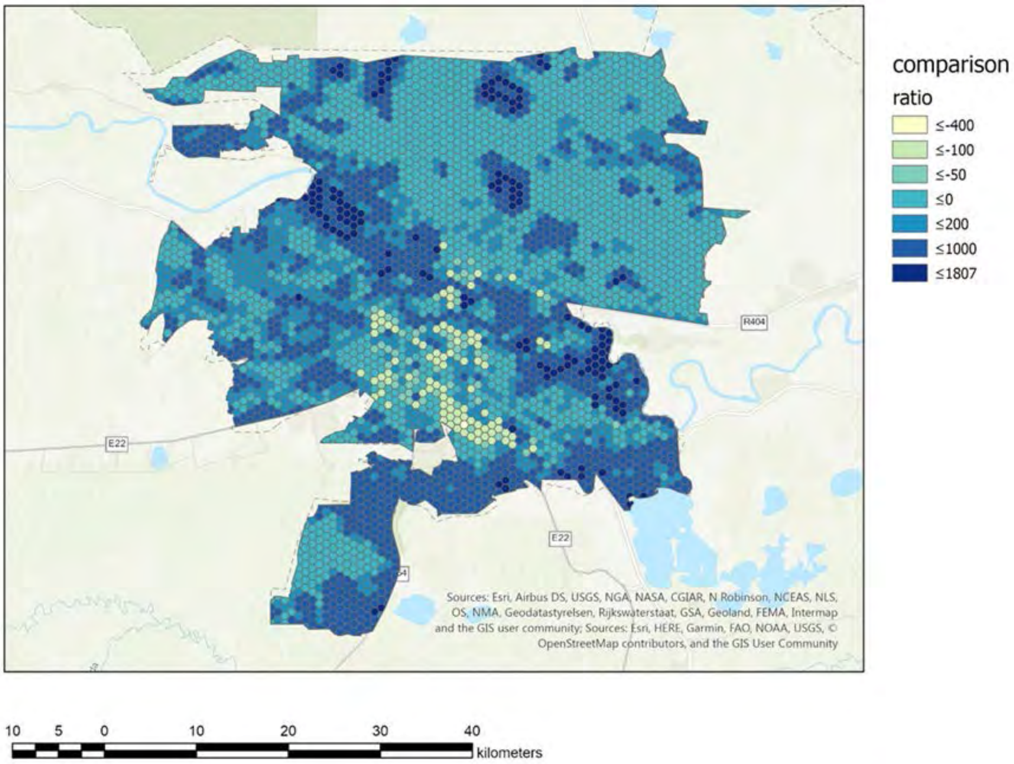

Figure 5.4.1.4. The comparison of provided and demanded ES volumes of daily recreation

5.4.2. Urban microclimate regulation: cooling effect

The cooling effects of urban blue-green infrastructure play an important role in reducing the occurrence of urban heat islands (UHIs). The phenomenon of the urban heat island was already detected in Tyumen in the years 1977 and 1978; at that time, the excess heat was in the range of 1.8 °C to 2.0 °C, mainly over the central part of the city (according to field observations at eight points in January, April, July and October). The hot summer of 2020 further highlighted the demand for the supply of cool air.

To compare the provided and demanded volumes of the ES cooling, we first developed a UHI map for the city of Tyumen. This was realized by aggregating data on surface temperatures from the LANDSAT 8 space images (specifically, we used Landsat 8 images taken on 22 June 2015, 10 July 2016, 14 August 2017, 16 July 2018 and 19 July 2019). Images with minimum cloud cover were selected. The ENVI software package was used to obtain geothermal scenes. The images were processed to determine the fire hazard in natural areas: the channel with the infrared spectrum was selected from the multispectral image using the "Radiometric Calibration" tool to reflect information on the temperature (in Kelvin) for each individual pixel. To convert temperature values from Kelvin to Celsius, we used the following equation and the Band Math tool for mathematical operations with layers:

$$tK - 273.15 = tC$$

After these processing steps, each pixel of the geothermal scene contained information on the temperature in degrees Celsius. These geothermal scenes were illustrated using a gray gradient: the higher the temperature, the lighter the pixel color. Annual geothermal scenes (data from 22 June 2015, 10 July 2016, 14 August 2017, 16 July 2018, 19 July 2019) were aggregated to identify persistent temperature anomalies and urban heat islands. The geothermal scenes were aggregated using the Raster Calculator tool to determine average pixel temperatures. For better performance, pixel coloring was carried out in ArcGIS PRO software.

The cooling effect is considered an ecosystem service during hot summer days when thermal heat stress occurs. According to the Physiological Equivalent Temperature (PET) index (Höppe, 1999), the temperature range of 18 to 23 °C does not create heat stress for the population during summer months. If the average temperature is lower than 23 °C, therefore, we will not consider the cooling effect to be an ecosystem service. To evaluate the beneficial cooling effect as well as define and evaluate territories suffering heat stress, we used the geothermal scene containing information on the surface temperature in degrees Celsius. Applying the raster calculator in ArcGIS PRO software, we subtracted 23°C (the maximum temperature of comfortable thermal conditions) from the geothermal scene's pixel temperature attribute. Pixels with minus values provided cool air, while those with plus values required cool air (Fig. 5.4.2.1).

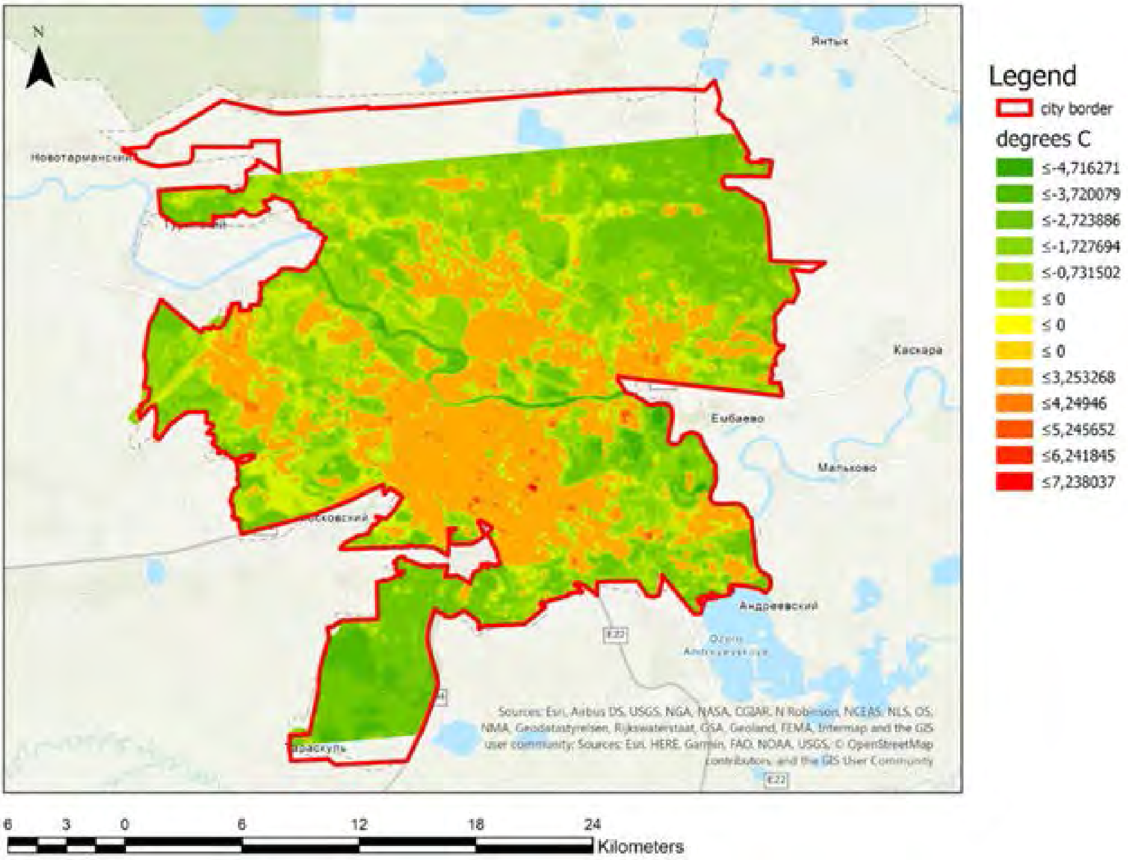

Figure 5.4.2.1. Distribution of the calculated temperature difference from the maximum comfortable temperature

A hexagon fishnet was used to aggregate each pixel's values with a radius of 500 m using the average value calculation method (Fig. 5.4.2.2). In this case, the average value indicates the extent of the cooling effect for people within a radius of 500 m. Hexagon fishnet was chosen because it is the most suitable for aggregating data concerning accessibility at the urban scale. The hexagons with negative values have sufficient cooling effect while hexagons with positive values have insufficient cooling.

The surface temperature analysis using satellite images LANDSAT 8 pinpointed areas with higher temperatures (areas undergoing heat stress) and those below the maximum comfortable temperature (area providing a cooling effect) (Fig. 5.4.2.1). Urban heat islands are created by particular designs and characteristics of urban surfaces, which lead to a change in the energy balance. Specifically, changes in the energy balance are caused by various thermal volumetric properties (heat capacity and thermal conductivity) and radiation properties (albedo, emissivity) of surfaces: for example, dark surfaces absorb significantly more solar radiation (city roads, paved parking lots near offices, shopping centers, residential buildings) and higher temperatures are detected over multi-story residential buildings, industrial and energy facilities as well as flat-roofed shopping centers. In our analysis the temperature above these surfaces was over 23°C, and therefore cooling is required. In comparison, the surface temperatures of green areas (parks, squares, green areas of low-rise private residential buildings) and water surfaces were lower. The temperature above these surfaces was below 23°C, and therefore these sites provide a cooling effect (Table 5.4.1).

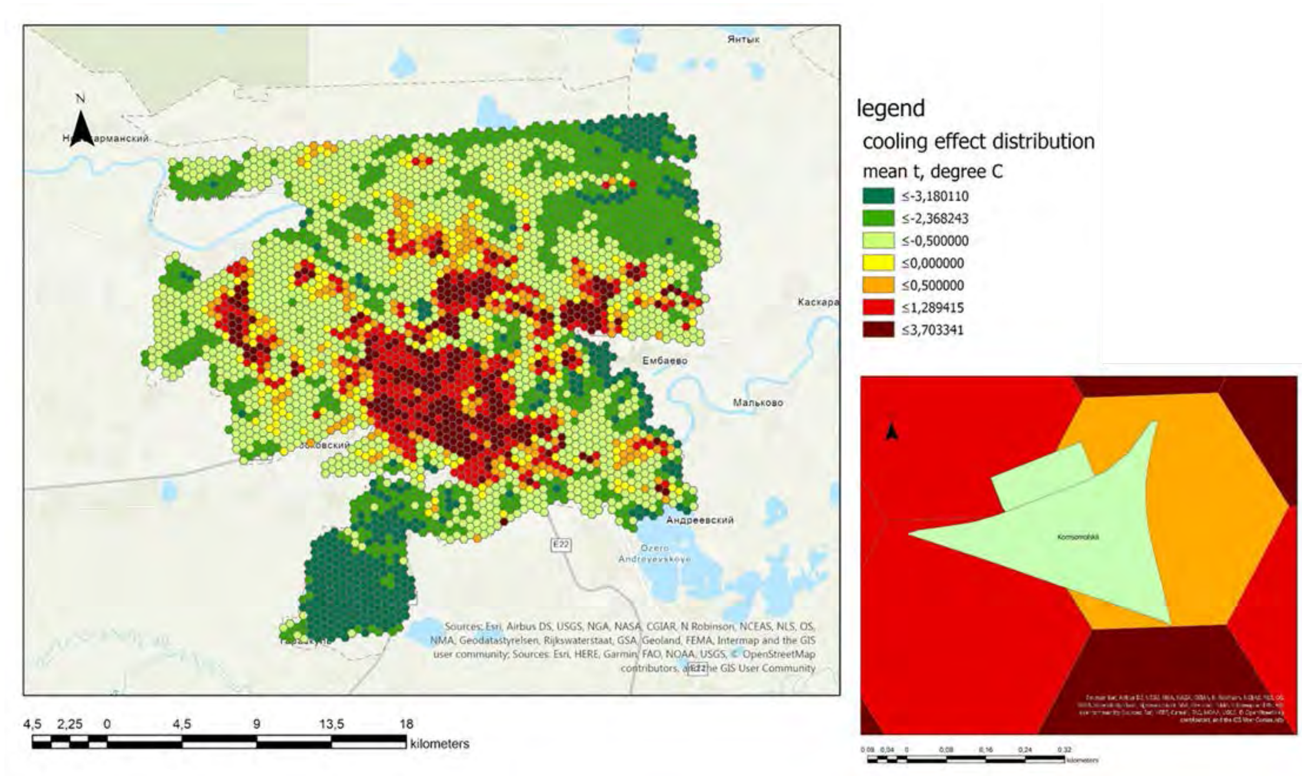

Figure 5.4.2.2. Distribution of the demand (red) and supply (green) of cool air

Table 5.4.1. Parameters to determine the cooling effect

Parameter	*Temperature, ℃*
Physiological Equivalent Temperature	+23
Maximum temperature Deviations from the average temperature (positive temperature anomalies) Minimum temperature Deviations from the average temperature (negative temperature anomalies)	+30.23 (industrial site) +6.43 +17.23 (water bodies) –6.57

Despite the cooling effect of green areas (parks, squares and green areas of low-rise private residential buildings) and water bodies within highly sealed and densely built-up territories, the temperatures at such sites are still higher than 23 °C (Fig. 5.4.2.2). For example, the average temperature of a bin, on the territory where the Komsomolsky park is located, is 0.7–3.2°C lower than the average temperature of the neighboring bins (Fig. 5.4.6). This means that the provided supply of "cooling effect" is insufficient to meet demand.

While only 23% of the urban area of Tyumen requires "cooling effect", this particular area is home to 87% of residents.

Calculations made by a more generalized method show that the green and blue infrastructure and the forest greenbelt of Tyumen provide ecosystem services more than the population requires. At the same time, spatial analysis showed that the supply of ecosystem services with a high local value (provision of conditions for daily recreation and a cooling effect) in the central part of Tyumen (buildings with variable number of stories in the historical center) and in areas with high-density buildings (new residential buildings) in the southeastern part of the city does not cover the demand.

If we ignore the city's complex and heterogeneous urban design, it is possible to say that the inner-city blue-green infrastructure and forest greenbelt of Tyumen provide much more cool air than demanded by the population.

Yet our spatial analysis shows that in central areas of Tyumen, the supply of the ES cooling effect (and indeed daily recreational opportunities) does not meet demand.

6. The principles of managing urban green infrastructure

6.1. The problems of urban green infrastructure in General Plans of cities

One of the principles to ensure a full and efficient functioning of urban green infrastructure (including the provision of ecosystem services) is the careful planning of green areas. Through intelligent spatial planning it is possible to create an integrated network of green elements. This is one of the most important factors determining the stability of green infrastructure in the city (Lafortezza, 2013; Meerow, 2017). In US or European cities, urban planners draw up special "plans on the spatial planning of urban green areas" or include details on green infrastructure in other strategic planning documents (von Haaren et al., 2019; Grunewald et al., 2021). For example, the Greater London Plan contains a section on "Green infrastructure and open spaces: the green network of London". It is essential that these documents contain a full inventory of all existing green objects along with their quantitative and qualitative characteristics, justifications and recommendations for the creation of new objects as well as the description of all measures for the maintenance and improvement of the green network, etc. (Slätmo, 2019).

The main instrument of urban spatial planning in Russia is the General Plan. In addition to maps of the planning zones and objects, the General Plan includes general information on the areas under consideration (including the main risk factors for natural and human-induced emergencies involving nature) and data on the types, names and functions of the planned objects (including green infrastructure elements), and programs. The contents of the General Plan are regulated by Russia's Urban Planning Code (Article № 23). According to this Urban Code, General Plans are not obliged to have a special section dedicated to environmental protection or green infrastructure. However, the commentary to Art. 23 of the Urban Planning Code refers to the general urban planning requirements for the functional zones of the city, including the condition and quantity of green areas. Moreover, the General Plan must include cartographic materials on the PAs and functional zones. However, this is the full extent of the requirements under the current Code in regard to green infrastructure accounting.

One current focus in the field of spatial planning is to improve the assessment of the volume and quality of ecological measures foreseen by the General Plans. When evaluating the inclusion of new, popular environmental trends in the plans such as "climate adaptation", "ecosystem services", "green infrastructure", "smart city concept", etc., an efficient approach is to use content-analysis plans in which the contents are coded by key topics or words (Mayring, 2016).

Here we assessed the level of elaboration of green infrastructure and ecosystem services topics in spatial planning documents by considering the General Plans of Russia's most highly populated cities (see Section 3). The assessment methodology is described in detail in Klimanova et al. (2020). It is important to point out that the term "green infrastructure" does not feature in the General Plans. Instead, we find terms such as "natural network", "natural-ecological network" or "ecological network", which correspond to the country's schools and traditions of urban greening. All plans also feature the terms "green area", "plantings" and "green zone", which have official definitions in GOST 28329-89: "The urban greening. Terms and definitions".

Our assessment encompassed the following aspects:
– the level of correctness and adequacy of graphical materials;
– the consistency of the goals and objectives of the ecological network;
– a description of the current and previous conditions;
– the inclusion of ecosystem services into the assessment of green infrastructure;
– the inventory of blue-green diameter elements as a part of the ecological network;
– the development of conservation and maintenance measures for green infrastructure elements.

In our assessment, we also considered the connectivity of green elements, gross and per capita indicators of green area, the availability of green elements and minimum standards of green space.

When analyzing the General Plans of 16 cities with populations over one million, we divided the documents into three groups. The first included those General Plans that feature all the mentioned parameters and aim to develop green infrastructure. Five cities are in this group: Moscow, Novosibirsk, Perm, Volgograd and Rostov-on-Don. However, our research also showed that the current state of green infrastructure in the last two listed cities is far from satisfactory. Moreover, mass construction in Moscow over recent years has also undermined the urban green infrastructure (see Section 3.2.3.4). Nevertheless, the General Plans of these cities include various proposals to restore ecological corridors disrupted by mass construction as well as to improve and maintain green infrastructure elements located on wetlands, which are unsuitable for construction. The second group includes the General Plans of Saint Petersburg, Nizhniy Novgorod, Kazan, Omsk, Voronezh and Krasnodar. These do not feature the full spectrum of green infrastructure parameters, instead analyzing single ecosystem services and regarding the creation of a green network as lying outside the main aims of spatial planning. Finally, the third group consists of the General Plans of Chelyabinsk, Krasnoyarsk, Samara, Ufa and Ekaterinburg, where the strategy of green infrastructure planning does not consider the formation of an interconnected multifunctional ecological network. Instead, it focuses on achieving acceptable values of per capita availability.

On the whole, it should be admitted that a full set of ecosystem services and biodiversity indicators is not assessed in the existing General Plans of Russia's largest agglomerations. Recreational functions are usually the main drivers for the development of urban green infrastructure. However, the case study of Moscow's PAs (see Section 4.2.3.4) demonstrates that a strategy directed at increasing the number of visitors without any consideration of the recreational carrying capacity will merely degrade local ecosystems and ultimately lower the quality of recreational services. Another frequently mentioned ecosystem service, considered in almost half of the studied cities, is to improve air flow and purification, while only Volgograd and Saint Petersburg mention the "assimilative capacity of plantings". The noise reduction and buffer functions of green areas around residential zones are often ignored. Erosion control services are mentioned only in Ufa and Kazan, even though this function is significant for all cities situated on large rivers and in the steppe zone with intense wind erosion and a high rate of ravine formation.

6.2. The priorities of green infrastructure planning in Russia's most populated cities

To optimize the state of the environment and living standards in today's growing agglomerations, it is necessary to implement green infrastructure planning simultaneously at three spatial levels, namely regional, urban and local, with the following key targets:

– at the regional level (outside the city boundaries): to form a natural-ecological network and a green belt which together can stabilize and safeguard the environment;
– at the urban level: to form a continuous network of parks and small green elements providing recreational functions between residential blocks; to improve the urban-ecological network by taking account of local residents' demand for recreation and standards of recreational infrastructure;
– at the local level: to ensure the necessary quality of life within the framework of urban morphotypes and to protect against negative impacts, also by creating artificial elements of green infrastructure within the urban-ecological network.

Depending on the size, configuration and geographical position of an agglomeration, it is possible to apply different scenarios of green infrastructure planning. For example, Ekaterinburg is a rapidly growing agglomeration in the forest zone with preserved forest (at a distance of 50–80 km from the city) and a greenbelt adjacent to the city. To create an ecological network in this city, the main planning mechanisms should be the preservation of small forest massifs inside the suburban greenbelt, which performs recreational functions for local residents; the creation of ecological corridors to connect the suburban belt with more distant forests; assigning the status of a protected natural area to forests outside the city in order to ensure runoff regulating services and biodiversity conservation.

Chelyabinsk agglomeration is another case. Situated in the forest-steppe zone and having a large industrial sector and a poor environmental condition, the local authorities must establish ecological corridors and zones of ecological rehabilitation between the forests and elements of urban green infrastructure as well as create new artificial green elements inside the city and increase connectivity between small forests. At the same time, it is extremely important to safeguard existing green infrastructure and to improve the urban environment by reducing emissions and raising the quality of air and water.

We recommend the following universal mechanisms of green infrastructure development at the agglomeration level:

– ensuring that strategies of socio-economic development in the largest agglomerations take account of integrated planning and environmental maintenance;
– developing and establishing regulatory documents that define the term and contents of "ecological network" as an important instrument to ensure a good quality of life;

– ensuring that a section on landscape planning (aimed at developing an ecological network) becomes mandatory in General Plans and spatial planning programs;
– analyzing the best practices of other large agglomerations and, on this basis, developing standardized legal regimes for a well-functioning ecological network;
– developing and adopting a standard methodology in Russia for the quantitative assessment of ecosystem services and developing budgetary and extra-budgetary mechanisms to ensure the functioning of ecological networks;
– developing and adopting standards on recreation that provide local people with a minimum level of services.

Today considerable experience has been accumulated in assessing critical parameters of the design and functional efficiency of separate elements of green infrastructure as well as the ecological network as a whole.

Special models are used to characterize the spatial configuration, enabling us to assess the most important features of both the ecological network and its structural elements using so-called landscape composition and configuration metrics as well as other various measures of "disturbance" such as dissection, perforation, fragmentation, contraction, shrinkage and attrition.

Landscape metrics can help us assess landscape and habitats diversity, the relative proportions of valuable ecosystems (for example, wetlands or floodplains), neighborhood parameters, the environmental state of borders, etc. In turn, by assessing diverse ecosystems within a part of the ecological network, we can calculate the potential of specific ecosystem services.

Metrics describing the disturbance of parts of the ecological network allow us to discern basic long-term trends and identify the main risks, for example the vulnerability of protected forests to windfall or the danger of forest fires. When investigating river basins, disturbance metrics enable us to quantitatively assess their general functional state and ultimately their ability to provide a normal balance of solid and water runoff. Together the metrics can serve as an objective tool to assess and monitor the spatial configuration, connectivity, integrity and functional sufficiency of an ecological network at three spatial levels, i.e. federal subjects, macro-regions and the country as a whole.

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