Green infrastructure development as a factor of Moscow metropolis sustainable development

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Abstract. The research is aimed at improving the sustainable development of cities, which focuses on the systemic goal setting of environmental development tasks, social policy and economic responsibility. The development of green infrastructure has been among the sustainable development goals of many cities around the world since the early 2000s. The study showed that the modern understanding of green infrastructure in Russia is still not widespread, which creates problems for the sustainable development of Russian cities in the future, since the implemented greening programs generally reflect a more simplified and fragmented meaning of the city's green infrastructure. It has been established that the situation in Russia has begun to change over the past few years: new scientific, methodological and practical approaches to the development of green infrastructure in Russian cities have been developed, leading state and public institutions presented ratings reflecting the ideology of the development of green infrastructure in cities within the framework of the principles of sustainable development. Based on the method of comparative and statistical analysis, the article identifies the features of the development of green infrastructure in Moscow, shows its advantages and problems, and suggests directions for its sustainable development based on innovative approaches to vertical gardening.

1 Introduction

The latest State of the Global Climate of the World Meteorological Organization (WMO) report makes the important finding that all major indicators of climate change in 2023 broke historical records: heat waves, floods, droughts, wildfires and rapidly intensifying tropical cyclones disrupted daily lives of millions of people and caused economic damage amounting to billions of dollars. Data from different regions showed that concentrations of major greenhouse gases continued to rise in 2023 after reaching record levels in 2022. In 2023, the global average surface temperature was 1.45 °C (with an error of ±0.12 °C) above pre-industrial baseline. Last year was the hottest in 174 years of observation. The record for previous warmest years was broken: 2016, with temperatures 1.29 ± 0.12 °C above the 1850-1900 average, and 2020, with temperatures exceeding 1.27 ± 0.13 °C [1]. Climate warming

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causes not only drought and famine, not only carries the risk of extinction of flora and fauna, but also significantly affects human health, "exacerbating existing diseases and leading to premature death and disability," as evidenced by longitudinal international studies by the WMO [2].

The most serious consequences of warming are manifested in cities, especially megalopolises, where inevitably form "heat islands"– zones of elevated temperatures over cities and industrial areas. The zones form from an increased release of thermal energy, resulting in the formation of thermal waste inevitably form with high risks both physical [3; 4], and people's mental health [5; 6]. In this regard, the creation and development of urban ecosystems and, above all, the greening of urban spaces with parks, alleys, and arboretums is a reliable way to preserve people's health [7;8]. Let us note that the problem of incorporating the natural landscape into urban space is not new, it has been solved from the very beginning of the construction of both ancient and modern cities [9; 10]. However, with the observed increase in the negative impact of the effects of the urban environment on humans in the growing cities of the world, especially megacities, the problems of developing green urban infrastructure in recent studies are considered in the paradigm of sustainable development [11]. And Russia is no exception. At the end of 2023, a decree of the President of the Russian Federation was signed on the approval of a new climate doctrine, which approved the goals of climate policy, the main of which is to ensure the safe and sustainable development of the country in the face of climate change and the emergence of associated threats. Federal and national projects, state programs Russia provides for the continuous development of cities, their transformation into integrated urban ecosystems, bringing the level of quality and comfort of life in line with the current needs of society with maximum rationalization of the resources used.

Modern Russia, as the largest country in the world by area, characterized by high rates of urbanization, includes 1122 cities (2024), each of which has its own historical, cultural, ethnographic and socio-economic features of formation and development. More than 75% of the Russian population lives in cities, where the overwhelming share of the country's GDP is created. That's why Russia is going through its own path of ESG transformation, taking into account national specifics: it is the regions and cities that have become the points of concentration of interests and efforts for the sustainable development of all parties involved. So the regions and cities make a significant contribution to the development of the ESG agenda in Russia. In 2023 VEB.RF – the Russian state development corporation that provides financing for socio-economic projects, adopted the Charter of Sustainable Cities of Russia (ESG Charter) – a document describing the fundamental principles and key tasks of sustainable urban development as an element of a comprehensive ESG transformation in the Russian Federation. By voluntarily joining the Charter, participating cities declare their intention to make targeted and consistent efforts to implement and promote ESG principles, apply best practices for implementing ESG projects in all areas of the city economy. ESG Charter will allow the exchange of best practices in project implementation, thereby forming a library of urban solutions with their success stories. In the spring of 2024, VEB.RF, together with the main state bank of Russia, Sberbank, developed an interactive ESG index of cities and regions to help territories solve their strategic objectives, as well as create a new convenient platform for exchanging experience in the successful implementation of sustainable development projects. The ESG index of Sberbank is a system of coordinates and tools that will allow territories to assess their progress towards sustainable development and determine directions for further environmental and socio-economic transformation.

The capital of Russia, Moscow, with a population of 13.1 million people (2024). Moscow is among the top 12 largest cities in the world in terms of area; the Russian capital ranks 7th. In a PwC study of the dynamics of urban development of cities around the world over 5 years, Moscow became one of the world leaders in landscaping: about 90% of the

Moscow population has access to green natural and recreational facilities within walking distance, which ensures its place in the top 3 out of 12 cities for this indicator. This indicates the high quality of landscaping in the Russian capital, which allows Moscow to develop its green infrastructure at a more systemic level.

The purpose of the article is to study the level of development of Moscow's green infrastructure in national ratings, determine the main advantages and problems of development, and put forward proposals innovative for Moscow greening.

2 Materials and methods

The most important tasks of sustainable cities in Russia are the rational use of natural resources, reducing the negative impact of cities on the climate, protecting natural landscapes and unique monuments of Russian nature. For example, in 2019, the Russian Government approved a Methodology for the formation of an urban environment quality index, which, as part of the assessment of six types of urban spaces, includes indicators for calculating the Urban Landscaping Index, which contains criteria requirements for the level of landscaping, the state of green spaces, the attractiveness of green areas; their safety and a variety of services in green areas. These criteria are contained in the Guidelines for Determining the priority directions of urban environment development using the Urban Environment Quality Index, the Ministry of Construction of Russia has developed a Greening Index. It should be noted that in the foreign practice of urban planning since the early 2000s, the concept of "green infrastructure" has been widely used [12]. In Russia, the tasks of developing a "green infrastructure" are actively being developed by scientists, public and expert communities [8;10;13]. So, at the St. Petersburg International Economic Forum 2023, the Smart Landscaping project, implemented in the Belgorod Region, was presented. The aim of this project is to maximize environmental, economic and aesthetic benefits through the creation of a management system for the city's green infrastructure. The project is implemented by the non-profit organization "Green Infrastructure of Cities" [14]. To summarize, in foreign and Russian literature one can distinguish three basic approaches to the goals of developing green urban infrastructure (Table 1).

Table 1. Basic approaches to understanding "green urban infrastructure"

Approach	Focus Source	Author, source
Sanitary-regulatory approach	Focuses on the development and further evolution of urban greening standards that regulate and compensate for harm to human health from all types of emissions into the environment.	B.A. Revich [8], [11].
Ecological-urban planning approach	Focuses on the environmental significance of the territory in the formation and development of the city's Master Plan, green urban infrastructure is considered as an innovatively managed network of natural areas to create a comfortable urban environment.	L. Maksimenko, O. Dudinova & O. Korobova [14], M. Muktiali, P. S. Hadi, H.Purnaweni & M. Mussadun[22].
Ecologically inclusive approach	Green infrastructure is considered as a strategically planned network of natural resources integrated into urban areas, one of the key goals of which is the conservation of biodiversity and ecology.	J. Briz, M. Köhler, I. de Felipe [16].

Source: compiled by the authors

This study uses materials from all the studies mentioned above. The second approach was used as a methodological basis, since our research has shown that the Ecological-urban planning approach is more suitable for the purposes of the study. In the study, green infrastructure is understood as a specially planned system of natural areas of natural and anthropogenic origin, located within the boundaries of a populated area, capable of providing a wide range of ecosystem services. Elements of green infrastructure include territories of natural complexes that can serve as ecological corridors (for example, green embankments and ravines), elements of urban landscaping (parks, green walls and roofs, permeable sidewalks and road surfaces, etc.), as well as water spaces.

3 Results and discussion

It should be noted that within each approach there is an evolution of ideas, although of course all three approaches have an internal hierarchical connection. The multiplicity of approaches explains the discrepancy between not only international, but even national methods for measuring the level of development of green infrastructure in cities. In this study, we will compare the level of development of green infrastructure in Moscow in national ratings, identify the main advantages and problems of greening development in Moscow, and propose ways to solve them. To assess the level of development of green infrastructure in Moscow, we compared the level of development of green infrastructure in five national ratings of Russian megacities (Table 2).

Table 2. Top 15 large cities in Russia in "green" ratings.

Cities with a population of over a million	Ranking Compiler				
	MSU*	Roscosmos **	Marketing Logic ***	Ministry of Construction ****	VEB.RF and SBER*****
Volgograd	13	10	12	14	34,7
Voronezh	8	5	5	8	45,4
Yekaterinburg	9	2	8	13	42,2
Kazan'	12	12	10	6	77,4
Krasnoyarsk	10	13	9	12	34,3
Moscow	2	7	2	3	72,8
Nizhniy Novgorod	5	9	4	4	53,1
Novosibirsk	**3**	**8**	**3**	**7**	**52,3**
Omsk	6	15	7	15	44,3
Perm'	1	1	1	5	77,6
Rostov-na-Donu	7	6	6	11	44,6
Samara	14	4	13	10	39,1
Sankt-Peterburg	15	14	15	2	40,6
Ufa	4	3	14	1	48,9
Chelyabinsk	11	11	11	9	49,3

* Rating of green cities of Moscow State University (2020) https://perm.mk.ru/social/2020/05/29/uchenye-mgu-perm-ustanovila-rekordnye-pokazateli-doli-ozelenennykh-territoriy.html

** Rating of green cities by Roscosmos (2022) https://geonovosti.terratech.ru/ecology/shestnadtsat-zelenykh-megapolisov/

*** Marketing Logic (2022) https://www.marketing-logic.ru/news/57

**** Green space index Ministry of Construction of Russia (2022) https://minstroyrf.gov.ru/press/indeks-kachestva-gorodskoy-sredy-za-2021-god

***** Environmental assessment, ESG index of cities and regions VEB.RF and SBER (2023) https://xn----ctbjbleaab3chwacdqgef8f3d.xn--80afd3bal.xn--p1ai/region16/Kazan

As can be seen from Table 2, according to four out of five ratings, Perm is the greenest city in Russia. Moscow ranks second in three of the five indices and third in two of the five analyzed ratings. Third place, according to Table 2, is occupied by Novosibirsk. To compile the entire rating of the development of green infrastructure in Russian megacities, it is necessary to create a weighted integrated rating, which will be done in our next studies. In relation to the topic of this study, we note that the development of green infrastructure in Perm is largely associated with the quality of management factor, the continuity of which is clearly visible in the history of the city. The foundation of the "green" frame of the city was laid by the first governor 300 years ago in the urban planning plan (https://ru.wikipedia.org/wiki). The actions of subsequent generations of city and regional authorities were aimed at maintaining and developing green areas, which makes it possible to keep the central part of the city with high density buildings well-greened, comfortable for living and environmentally friendly.

Solving the problems of developing greenery and preserving the city's ecology in the context of urbanization and urban population growth is impossible without the use of ESG principles of sustainable development: environmental (E), social (S) and managerial (G) responsibility. These three principles - environmental protection, social responsibility and good governance - not only emphasize the relevance of sustainability and responsibility of the state and business, but also help to balance economic growth and conserve natural resources in all areas of the urban economy. And vice versa: for example, for Moscow we can conclude that the city has the potential for sustainable development due to a large area of vegetation and favorable natural and geographical conditions [17]. Within ten years, the southwestern territories, consisting of 50% green areas, were annexed to the city and the capital has an additional opportunity to improve green infrastructure. That's why is planned to create up to 90 recreation areas and parks in New Moscow [18].

According to Mosstat (https://77.rosstat.gov.ru/folder/70759/document/203591), the area of green space within the capital in 2022 amounted to an impressive 91.6 thousand hectares, which is equal to 35.8% of the total area of urban land. This figure is almost 1.5 times higher than the Russian average (24.7%). Moreover, these figures do not include green spaces in specially protected natural areas, taking into account which the total green area of Moscow increases by another quarter. The structure of the capital's green fund includes 16.9 thousand hectares of public green spaces, such as parks, gardens, squares and boulevards, as well as 67.2 thousand hectares of urban forests. For comparison, in the Moscow region the area of green spaces is 60.2 thousand hectares or 15.7% of urban land, of which 19.7 thousand hectares are public green spaces, 11.6 thousand hectares are forest parks, 16.8 thousand. hectares - urban forests and 4.8 thousand hectares - landscaping along local roads. Moscow's green infrastructure is complemented by a developed network of streets, driveways and embankments with a total length of 6.4 thousand km. (https://77.rosstat.gov.ru/folder/70759/document/203591).

Thus, Moscow has a powerful green infrastructure, the level of development of which significantly exceeds all-Russian indicators. The combination of extensive green areas and a modern road network creates a comfortable urban environment.

In connection with climate change, an increase in average annual temperature and a large volume of emissions of harmful substances into the atmosphere in the city, further development of green infrastructure is necessary, which, in our opinion, is associated with the still little practiced vertical gardening of Moscow.

In the regulations of Russian cities, vertical gardening is indicated as one of the elements of comprehensive improvement and landscape organization of the territory. In particular, the current version of the norms and rules for the design of comprehensive landscaping in the city of Moscow, adopted more than 20 years ago, provides for the use of vertical landscaping

on the facades of buildings and structures with a recommendation to limit the height of landscaping to three floors.

In practice, vertical gardening in Moscow is widely used in the form of small architectural forms (treillages, trellises, pergolas, flowerpots, flower beds) mainly in recreational areas - in gardens, parks, boulevards, squares, etc. Directly on city streets - primarily in highways connecting the city center with external highways use elements of container gardening, the devices of which allow for the implementation of multiple options for the placement of green spaces in space (both in horizontal and vertical planes) [19]. A good example of vertical gardening is the revival of the famous residential complex in the center of Moscow "Bolshaya Dmitrovka", which includes several buildings: a mansion built in 1903 and new houses. The windows of one of the new buildings, according to the project being implemented, will overlook a vertical forest: the wall located opposite will be "camouflaged" up to the roof with trees and shrubs (mainly coniferous species recommended by Russian experts).

In the study A.I. Litvinova, N.A. Yevstigneyeva and Yu.V. Yevstigneyeva, based on a generalization of international experience, proposes the following classification of vertical gardening of urban spaces:

- «stationary landscaping of vertical surfaces with climbing plants planted in the ground in close proximity to the base of buildings;
- landscaping using special mobile (mobile) or stationary containers (containers, flowerpots, flowerpots, tubs, etc.) for growing plants in nutritious soils;
- stationary landscaping of vertical surfaces using the hydroponics method - growing plants on artificial substrates (without soil)» [19].

Taking into account the fundamentally limited scale of further greening of the largest metropolis of Russia by laying out large tracts of parks and arboretums, the presence of extensive foreign experience in vertical gardening of the world's megacities, as well as the presence of an appropriate regulatory framework, mass vertical gardening is an innovative direction for the development of green infrastructure in Moscow. We consider it necessary to adopt a comprehensive program for the development of green infrastructure in Moscow based on modern technologies for vertical gardening of urban spaces, since the solution to this strategically significant task will require significant material costs and additional training for a large number of specialists in various fields - architects, designers, technologists, landscape designers, biologists, managers.

4 Conclusion

The world's largest cities are vying to become the greenest city while demonstrating success in achieving sustainable development goals. We agree with the opinion, that «this is especially true for million-plus cities with high population density and urban development, huge traffic and intense rhythm of life, a variety of harmful emissions and other negative impact factors. The green infrastructure of cities has a direct impact on the state of the city's ecology, but the state of green infrastructure in cities cannot be considered solely as an environmental factor. Green infrastructure affects the quality of life in cities. Landscaped parks and squares in dense urban areas, beautiful flower beds and well-groomed grass for relaxation and play have long been recognized as an effective means of relieving psychological tension and stress, relaxing and restoring a person's strength in conditions of increased urban noise and aggressive environment» [19].

In order for green infrastructure to develop and have a positive impact on people, high-quality management is necessary, in particular, control over compliance with SNiPs during new construction and reconstruction, as well as over the further state of the city's green framework. The task of creating comfortable living conditions in cities through the development of green infrastructure is one of the key goals of Federal and national projects,

as well as state programs of Russia. The indicator of the share of green infrastructure in the total territory of the city is mandatory according to Russian urban planning legislation and WHO standards. Greening indicators are used in a number of ratings of Russian cities as the basis for calculating the per capita indicator of green space provision in cities.

The good state of greening of urban spaces is a clear indicator of the safety and quality of life of people; it is an important factor in the leadership of cities and a reliable basis for their sustainable development in the future. This thesis is confirmed by the city of Moscow, which simultaneously occupies a leading position in world greening ratings, green development ratings of Russian cities, as well as a comprehensive ESG rating of Russian cities and regions as the basis for calculating the per capita indicator of green space provision in cities.

Moscow has a powerful green infrastructure, the level of development of which is 1.5 times higher than all-Russian indicators. The combination of extensive green areas and a modern road network creates a comfortable urban environment. Due to climate change, an increase in average annual temperature and a large volume of emissions of harmful substances into the atmosphere in the city, the further placement of new green spaces is necessary. As a further "green" development of the Russian capital, we consider it necessary to widely develop the practice of vertical gardening, which is still not widespread in Russia and Moscow.

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