# Geoecological Functions of Green Infrastructure in the Largest Cities of Russia

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**Abstract**. Intensive and diverse human activity in large cities and their environs leads to a significant change in the environment: the relief, hydrographic network changes, natural vegetation is destroyed or replaced by urbophytocenoses, the soil cover is greatly transformed, climatic characteristics change, i.e. a specific type of urban microclimate is formed. In large cities, the anthropogenic impact becomes predominant over the natural factors of soil formation, which leads to the formation of specific soils and soil-like bodies (formations). In this case, the type of land use is the determining factor of the soil cover. Adverse environmental impacts lead to soil degradation, resulting in the destruction of vegetation. All this together leads to a deterioration in the chemical composition of the air and the general environmental situation that affects people's health. Unfavorable ecological processes significantly impede (prevent) the fulfillment by soils of the ecological functions assigned to them. A significant part of the territories of large cities is located in the zone of action of negative processes that affect the ecological state of the soil cover and soil functions. Ecologists predict that these impacts will intensify.

## 1 Introduction

The terms "urban soils" and "city soils" appeared at the early stages of studying soil formation in the urban environment and were defined in different ways [1]. The "soils of a city" include any soils on its territory: natural or almost natural (with a natural profile and analytical diagnostics of pollution or biogeochemical features that are clearly different from natural soils), "semi-urban" urban soils and actually "urban soils" - urbanozems and their variants [4 ]; the separation of urban soils from non-soil formations is carried out conditionally. It is generally accepted that they perform the ecological functions of soils and, therefore, can be considered as soils [9]. According to UN estimates, in 2050, 68% of the world's population will live in cities. Now this figure is 55% and there are about 4.2 billion urban residents in the world (in 1950 there were only 751 million). In the Russian Federation, the level of urbanization is almost 75% (Rosstat, 2020). Among more than 1,100 cities in Russia, 134 have a population of over 100 thousand people, and 16 largest cities have more than 1 million people. More than 34 million people, or 23% of the country's population, live in the largest cities of Russia, while their total area is only 0.06%

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of the country’s territory. Occupying a minimal area, cities, all the less, due to the large population and the development of the economy, have a disproportionately significant impact on the biosphere. Most of the ecosystem services consumed by city dwellers are produced by ecosystems located not only outside the city limits, but also at a much greater distance - on the other side of the country or even the world [5]. Calculations of the volume of use of, for example, ecosystem services such as food production and the assimilation of nitrogen and carbon, made for 29 largest cities of the countries of the Baltic basin, showed that this requires an area equivalent in area to the entire watershed, which is several hundred times larger than the area of the cities themselves . Ecological footprint calculations performed by WWF-Russia in 2014 for the Russian regions showed that the ecological footprint of the largest Russian cities - Moscow and St. Petersburg - was 7.1 and 7.33 global hectares, respectively [6]. The same subjects have the lowest biocapacity: Moscow has 0.03, St. Petersburg has 0.1 gha. For the purposes of this report, cities are viewed as holistic socio-ecological systems, fully dependent on the landscape that surrounds them and the links between urban and rural areas. Due to their size, natural ecosystems preserved in cities cannot fully meet the needs of citizens in ecosystem services [7]. However, the preservation of these ecosystems is critically important not only in a utilitarian sense - to clean the air, reduce noise, etc., but above all from the point of view of providing intangible services - aesthetic, cultural, recreational, which are important not only for today’s cities, but also for their further development. The calculation of the proposed, required and used volumes of urban ecosystem services is a special task in its content, for which it is not always possible to use the same approaches that were used earlier in the Prototype of the National Report on Ecosystem Services of Russia for assessments within vast territories at the level of subjects and regions RF. At the same time, the phasing of the formation and identification of ecosystem services and the assessment of their value to humans, proposed in the first volume of the prototype of the national report, is also applicable to urban ecosystems. The main stages of such studies include: - identification and mapping of the main ecological structures in cities, their characteristics and processes; – identification of the main ecosystem functions - the results of the functioning of urban ecosystems - and services - the ecological functions of urban ecosystems that can be useful to humans; – assessment of the benefits and value of ecosystem services in non-monetary (biophysical) and monetary indicators [6].

Urban ecosystems are areas of vegetation, sometimes including bodies of water, in areas where buildings or sealed surfaces occupy a large part of the territory, and the population density is very high. In urban planning, cities are a combination of “gray” - sealed, built-up - and green (often green and blue) infrastructure [8]. Elements of green infrastructure in the city act as providers of ecosystem services. In terms of its content, the concept of “green infrastructure” is close to that used in the practice of domestic urban planning since the 1980s. the concept of “ecological frame of the city”, but wider than it in terms of included elements [7]. The classification of elements of green infrastructure, which in cities are often created by man, can be carried out for various reasons. One of the first works on the assessment of urban ecosystem services in Stockholm proposed to distinguish 7 main types of urban ecosystems providing services: street gardens, lawns/parks, urban forests, cultivated land, wetlands, lakes/seas, rivers [6]. Such a classification includes elements of a very different scale - for example, urban forests play an important role for the city as a whole and are of citywide importance, while trees along streets and roads, on the contrary, are important at the local level for air purification and noise pollution reduction. Later, for the purposes of urban planning, a more detailed classification of elements was carried out and their division into four levels - regional (urbanized region), district (neighborhood), street (streetscape) and house (building). For Russian cities with predominantly micro-district development, the following levels can be called equivalent: 1) agglomeration - the city and its surroundings; 2) urban - districts within the city; 3) microdistrict - quarters within the microdistrict and street gardening; 4) intra-quarter - house gardening [9]. Depending on the size of the city, individual levels of green infrastructure may be omitted, but for the largest cities, all four levels of planning are present.

## 2 Research Methodology

The objects of the study were 16 largest cities of the Russian Federation with a population of more than 1 million people: Moscow, St. Petersburg, Novosibirsk, Yekaterinburg, Nizhny Novgorod, Kazan, Chelyabinsk, Omsk, Samara, Rostov-on-Don, Ufa, Krasnoyarsk, Perm, Voronezh, Volgograd, Krasnodar [6]. The territories of cities (with the exception of Moscow) were taken within their 2000 administrative boundaries (taken from the Open Street Map database). Moscow is considered within the boundaries after 2012, that is, it includes the territory of New Moscow. Being the most populated city, Moscow is also distinguished by the highest population density (even taking into account the territory of New Moscow, which almost doubled the area of the capital in 2012). At the same time, the bulk of the population is still concentrated within the old boundaries of the city, i.e., the actual population density is much higher (about 12,000 people/km2). The next largest city is St. Petersburg, but its population density is much lower, even compared to other cities with a smaller population. From the point of view of “compactness”, i.e. with the main building within the urban core and limited expansion into adjacent territories, such cities as Rostov-on-Don, Krasnoyarsk, Nizhny Novgorod seem to be the most favorable [8]. The latter is one of the most populated millionaires, but rather small in area. All studied largest cities of Russia lie within the temperate zone, most of which - located in the European territory of Russia (ETR) - belong to the area of influence of the Atlantic air masses. Cities in the south of ETR are already within the Atlantic-continental region. Cities to the east of the Ural Mountains belong to the continental West Siberian region, and the easternmost of the studied cities, Krasnoyarsk, already lies in the continental East Siberian region [9].

Inside the urban core of the main building, the vegetation cover has been largely transformed, however, large forest areas are often included within the administrative boundaries, retaining the features of zonal vegetation, which determines the amount of environmental stabilizing functions provided and the degree of sustainability. So, according to the type of zonal vegetation, cities are conditionally divided into three groups: forest (Moscow, St. Petersburg, Nizhny Novgorod, Kazan, Ufa, Krasnoyarsk, Perm, Yekaterinburg, Krasnodar), steppe (Rostov-on-Don, Volgograd, Omsk) and forest-steppe or “transitional” (Samara, Voronezh, Chelyabinsk, Novosibirsk). The former, in turn, include subtaiga, southern taiga, middle taiga, and broad-leaved forests. Among the steppe cities, cities of the southern and typical steppes of the European part and Siberia stand out [9].

From 16 to 61% are occupied by woody vegetation of different densities in cities. According to the Master Plans of cities, per capita coverage in them ranges from 4 to 135 m2 (depending on the city and region). The lowest rates are in Chelyabinsk (2.1–5.8 m2), Perm (4.0–10.0 m2), Rostov-on-Don (6.7–10.0 m2) and Volgograd (10.0 m2). The maximum values are in Yekaterinburg and Novosibirsk. Taking into account the area of all woody vegetation, the figures are significantly higher. In 3 out of 15 cities per capita provision with tree plantations is less than 100 m2, in 6 - 100-200 m2, in 6 - more than 200 m2 [10].

Urban areas are technogenic modifications of landscapes, where ecosystems conditionally indigenous or close to them in their successional state and their typical biodiversity have been preserved only in specially protected areas (SPNTs). The number of PAs by city also differs quite strongly - in 9 out of 15 cities there are less than 10 objects, most of all in Voronezh (47) and Moscow (120). In part, such large differences in numbers can be explained by the different status of protected areas. For example, in Moscow, natural monuments are often located on the territory of much larger natural and historical parks and landscape reserves, in fact, giving an artificial increase in indicators [7]. A similar situation is developing in Voronezh. However, absolute indicators of the area and number of protected areas are not very informative for assessing the provision of residents with the opportunity to communicate with wildlife. More informative is the indicator of the share of the area of protected areas from the area of the city. When calculating this indicator, it is necessary to take into account the fact that protected areas can be located not only in the city, but also in adjacent suburban municipal areas [6]. Thus, the largest protected area in Rostov-on-Don, the Levoberezhny nature reserve, also extends to the territory of the city of Bataysk and the Azov region, the Voronezh upland oak forest nature reserve is located on the territory of the city of Voronezh and the Ramonsky municipal district. The ratio of the area of protected areas to the area of the city is highest in Chelyabinsk, Voronezh and Rostov-on-Don, but in the last two cities, parts of protected areas located in nearby areas are partially included in the calculations. It should be noted that in Rostov-on-Don, by a special decree of the regional government in 2017, the previously existing two protected areas were abolished - within the Botanical Garden of the Southern Federal University and the Rostov Zoo, but a vast Levoberezhny nature reserve was created, one of the goals of which was the conservation biodiversity during the construction of the stadium for the World Cup. Omsk, Yekaterinburg and Krasnoyarsk have the worst indicators (less than 1% of the city area is occupied by protected areas). In Krasnoyarsk, there is only one very small PA, and in Yekaterinburg, none of the 19 PAs exceeds an area of 25 ha, which calls into question their effectiveness in terms of biodiversity conservation [7].

## 3 Results and Discussions

Firstly, lands of third-party users can be located within the boundaries of protected areas, which often include owners or tenants of infrastructure facilities that are poorly compatible with the status of protected areas [8]. As shown below in the case of Moscow, the development of protected areas with sports and entertainment facilities, as well as illiterate park improvement, can lead to the loss of natural ecosystems and biodiversity. Secondly, the degree of their fragmentation is of paramount importance for the ability of protected areas to conserve biodiversity. As a preliminary assessment of the impact of fragmentation on protected areas, an assessment of the "edge effect" was carried out, which occurs in the "border" zones of green areas, where chemical and physical (noise and light) pollution, vehicles knocking animals down, microclimate disturbances are quite large, which negatively affects structure and functioning of ecosystems [9]. The Fragstat program was used to determine the area of green infrastructure free from the influence of the edge effect. Hansen tree cover rasters with a resolution of 30 x 30 m were used for the calculation, to which the Total core area (TCA) calculation operation was applied. The "background value" was the non-woody vegetation class of the classified image, for which a matrix was loaded into Fragstats, where the "tree cover" class was set to true, and empty pixels were set to false. To verify the values, fragmentation was also calculated for a classified NDVI raster with four classes: water surface; a surface devoid of vegetation; permitted vegetation cover; dense vegetation cover [10]. For the first class, NDVI values less than 0 were accepted, for the second - up to 0.2; for the third - 0.2–0.35. The values above defined the fourth class. In our study, the edge zone buffer is 120 m, since it is usually at a distance of 100–200 m from the edge of the forest that the most noticeable changes in the functioning of ecosystems occur [11]. Knowing the area of the territory devoid of the influence of the edge effect, we calculated the share of this area from the total area of green infrastructure, thus obtaining the value of the proposed volume of services. For all cities, it turned out to be less than the share of the area of protected areas from the entire GI. In absolute terms, the area of the territory not subject to the edge effect is the largest in Moscow, which is most likely determined by a large forest area in the northwest of New Moscow with rare development islands [16]. Yekaterinburg, Voronezh and Chelyabinsk are distinguished by a high proportion of integral arrays. In the first of them, this is due to large areas of protected areas on the urban periphery; in Chelyabinsk, high values of the indicator are achieved due to the slightly transformed Shershnevsky urban forest [17]. The smallest values of the proposed volume were noted in Volgograd, Omsk, St. Petersburg and Perm. In the first two cities, due to natural conditions and insufficient artificial landscaping, there are no large parks with closed landscapes. St. Petersburg also does not have weakly fragmented large areas due to the high building density and the predominance of mostly open nature parks and squares in the green infrastructure system. In Perm, at high values of the total forest coverage, the largest forest area in the east is significantly disturbed by development patches (new residential areas, sanatoriums, military training grounds)[12]. There is no correlation between indicators of the share of the territory without the "edge effect" and the total area of protected areas [13]. This indicates that even with a large area of protected areas, they can be significantly fragmented and not properly perform the function of biodiversity conservation in the city. For example, in St. Petersburg, with a significant share of protected areas in the area of green infrastructure, due to significant fragmentation, the opportunities for biodiversity conservation are significantly reduced than they could be with such an area of protected areas. Such examples indicate the need to reduce the fragmentation of the protected area network [15]. Gaseous substances contained in the emissions of mobile sources spread in the atmosphere under the influence of diffusion, the concentration of gaseous pollutants in the air decreases as they move away from the highway and rise to a height [14]. The pollutants involved in atmospheric transport can be transferred to other areas of the city and contribute to the deterioration of atmospheric air quality in general. Green spaces located in the buffer zone of highways experience the maximum impact of toxic emissions and play the role of a barrier to the further spread of pollution. At the same time, taking into account the ability of tree plantations to purify the air, including from gaseous pollutants, it is possible to calculate the volume of such an ecosystem service provided by all green spaces within the city, regardless of their proximity to highways.

## 4 Conclusions

According to the classification of urban green infrastructure in the Urban Atlas project, its elements include agricultural land. Obviously, unlike many cities in developing countries and China, where agricultural land makes a significant contribution to ensuring food security, in Russian cities they play a much smaller role. From the point of view of providing food, the personal subsidiary farms of citizens, which in most urban districts account for all the sown areas of agricultural crops, are of primary importance. Only in Volgograd, Voronezh, Yekaterinburg and Omsk does a part of the sown area belong to agricultural organizations. The areas of perennial plantings (berry bushes, fruit orchards) almost entirely belong to personal subsidiary plots. In accordance with the classification of ecosystem services adopted in the Prototype of the National Report on Ecosystem Services of Russia, we do not consider food production as an ecosystem service. For food production, the complex of regulating services on agricultural lands is most important, which includes water regulation services, services for the formation of fertile soils and the prevention of their erosion. The complex of these services can be indirectly estimated by their contribution to food production.

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