River zones as a tool for increasing the urban sustainability in large cities of Russia

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Abstract. This work studies the main parameters of the major river zones in ten large cities in Russia in terms of their potential to form a blue-green corridor and its efficiency and integrity, which are essential for creating a more sustainable urban environment. We used several indicators to evaluate these aspects, like the green infrastructure availability of river zones, vegetation fragmentation, intactness of the unsealed 200-m riverside line and a functional structure of river zones. The integrated assessment revealed that river zones actually form a blue-green corridors only in two cities, Omsk and Krasnoyarsk. These two blue-green corridors, as well as the potential corridors of Nizhny Novgorod, Ufa and Irkutsk, can be considered the most effective ones. On the contrary, in Kazan, Rostov-on-Don and Khabarovsk, river zones least of all resemble corridors. In the remaining cities, river zones have an insignificantly fragmented vegetation, so they can be probably turned into blue-green corridors if numerous former industrial zones along the river will be transformed into new green elements, and if the existing infrastructure will get more vegetation.

1 Introduction

In natural landscapes, river valleys perform the role of ecological corridors, which are crucial to ensure the ecosystems' sustainability. This function is also partially preserved in urban areas, where rivers can become the axis to connect separate elements of green infrastructure to form continuous blue-green corridors. Unlike other urban green elements, blue-green corridors formed by rivers and riverine zones are mainly responsible for the natural exchange of matter and energy between green elements, thus supporting most natural processes, ensuring biodiversity, and making urban ecosystems more intact, healthy and resilient [1]. Moreover, the blue-green corridors not only connect green elements inside the city, but also link them with suburban and rural ecosystems, thus making green infrastructure more resilient to the urban impact [2].

Healthy and intact green infrastructure is usually a much more self-sufficient system than unorganized green areas in a poor condition. Firstly, it requires fewer financial costs and investments for its maintenance. Secondly, it copes more efficiently with a number of regulating services (like flood and erosion control or air purification), thus benefiting the urban population and environment even more. In this context, the formation of a blue-green corridor inside the city can make urban green infrastructure more efficient and economically profitable [3].

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However, despite this importance of blue-green corridors, river zones are usually the oldest parts of urban development, densely built-up and significantly transformed. For that reason, in many countries the national government has launched a number of projects, aimed at naturalization of valleys and general river zones improvement, to enhance the urban ecosystems' sustainability and resilience [4].

The assessment of the contribution of blue-green corridors to urban sustainability and their efficiency has been performed in numerous studies that focus on the corridors' functions for biodiversity conservation [5]; green transport efficiency, pedestrian accessibility and city connectivity [6]; cooling effect [7, 8]; and improving urban green space accessibility and recreation [9]. There are also studies that perform an integrated assessment that consider several corridors' functions and their overall efficiency [10]. The issue of urban blue-green corridors and river zones is also addressed in several studies for Russian cities [11, 12, 13]. However, most studies focus on relevantly small regional cities or Moscow and individual ecological functions. Besides, few works give a direct answer whether the river form an efficient blue-green corridor.

To ensure the efficient spatial planning and green infrastructure management in large cities, it is crucial to form an accurate idea of the river zones' current state and its ability to perform the stabilizing function of the blue-green corridor. Its assessment can be carried out by calculating its provision with green infrastructure, vegetation fragmentation and continuity of the unsealed riverside line [14].

Therefore, to most accurately assess the ability of the river zone to function like an urban blue-green corridor, it is necessary to consider different indicators. For this purpose, we conducted the integrated assessment research for the major river zones of 10 large cities in Russia. Our study included several steps: mapping green infrastructure from remote sensing data; calculating the fragmentation, availability and continuality indicators; and comparing the results for all case studies. There are three main questions we pursue in this work:

1) Do the river zones in the case studies form a blue-green corridor?
2) How efficient are the formed blue-green corridors?
3) Is it possible to create blue-green corridors in the cities which do not have them yet?

2 Materials and Methods

2.1 Study area

We chose the river zones of 10 cities in Russia with population over 500,000 inhabitants as the case studies: Samara, Omsk, Ufa, Krasnoyarsk, Irkutsk, Nizhny Novgorod, Rostov-on-Don, Volgograd, Kazan and Khabarovsk. The major rivers in all the case studies have a total length of more than 10,000 km and a drainage basin area of at least 50,000 km2.

In this research, we describe the term river zone as an urban area that is adjacent to the largest river in the city and is transformed due to the urban development (built-up to a different degree, or remaining semi-natural) and occupies the lowest parts of the valley (terraces' slopes and floodplains). The river zones' boundaries are determined by their functional, geomorphological and social role in the city and may differ in size, but do not exceed the 1500-m buffer of the river. In this work we study only zones of major rivers, which are usually more functionally diverse and heterogeneous. Moreover, large rivers can both pose a threat to the urban sustainability and provide a great volume of urban ecosystem services, which is not always the case for smaller rivers, especially in large cities [15].

2.2 Methodology

To answer the main questions about the ability of the river zones to provide regulating and habitat supporting ecosystem services like an urban blue-green corridor, we conducted the integrated assessment, using six indicators that describe the amount, efficiency and intactness of green infrastructure inside the river zones: 1) the green infrastructure availability of all river zones, and 2) of a densely built-up part of river zones; 3) vegetation fragmentation; 4) intactness of the unsealed 200-m riverside line of all river zones, and 5) of a densely built-up part of river zones; 6) a functional structure of river zones.

We used semi-automated iso-cluster ArcMap tool with Sentinel-2 satellite images to obtain data on the landcover and green infrastructure. We also used materials of the City Master Plans to assess the river zones' functional structures.

The last step of our research is the integrated assessment of the river zones potential to form blue-green corridors. In order to conduct it, all the indicators' values were standardized. Thus, each indicator can score a maximum of 100 points, and the city can receive a maximum of 600 points. Given that it is not possible for an urban area to be completely unsealed or without fragmented green infrastructure, we have taken a threshold of 350 points as the best possible result for considering the river zone as a blue-green corridor. This threshold value is supported by other studies[16, 17] that suggest that at least half of the urban area should remain unsealed with relatively intact and accessible vegetation to form a sustainable green corridor.

3 Results and Discussion

3.1 Green infrastructure availability

The green infrastructure availability, demonstrates the general ability of the river zone to perform regulating and supporting services. Since urban ecosystem are mainly represented by green infrastructure, it can be considered the only source of ecosystem services in the city. Therefore, its size directly effects the volume and quality of the performed services. However, this indicator does not take into account the continuity of vegetation (individual isolated small green elements do not form an intact corridor), therefore it characterizes the potential for the general maintenance of biodiversity, rather than ensuring it through the formation of a blue-green corridor.

Therefore, to assess the ability of the river zone to provide regulating services of a blue-green corridor, we assumed that if the river zone is a blue-green corridor, then 100% of its area is completely unsealed. Accordingly, the real percentage of green infrastructure within the river zone is the proportion of lands that potentially support and provide biodiversity. Our assessments revealed that there are two cities where river zones are less than half covered by green infrastructure (Irkutsk, Kazan), which means that river zones perform their function as a blue-green corridor to less than half of its capacity. Three other cities have green infrastructure occupying the major part of river zones (Khabarovsk, Rostov-on-Don, Omsk). Inside the urban core, river zones are more than 60% green in Krasnoyarsk and Omsk, and less than 45% in Rostov-on-Don, Kazan and Samara.

3.2 Vegetation fragmentation

According to different authors [18, 19], a patch size of 10 ha can be considered the minimum for the most sustainable ecosystem functioning. Our results show that the average patch size in all studied cities is 5 ha, with a maximum value of 8 ha in Volgograd and 7 ha

in Samara and Nizhny Novgorod. Considering, that we are talking about densely built-up urban areas, the average patch size of 7 ha can be considered as a positive value.

On the whole, the most fragmented green infrastructure of river zones is typical for semi-arid steppe cities like Samara and Volgograd. Cities with a large share of industrial and special functional zones, situated along the main river (Khabarovsk and Kazan). The least fragmented green infrastructure can be found in cities with a lot of recreational areas along the river (Krasnoyarsk, Nizhniy Novgorod, Irkutsk).

Green infrastructure fragmentation is generally one of the most common indicators to assess ecosystems' resilience and includes a number of metrics. However, interpretation of fragmentation metrics is complex. First, there are no reference values that would allow fragmentation to be assessed as high or low. Secondly, the fragmentation of one urban area can be characterized both positively and negatively by different metrics, thus making the interpretation of fragmentation results a controversial subject.

3.3 Intactness of the 200-m riverside line

The closest zone to the water (the riverside line) is an especially important indicator in terms of biodiversity support, since it is the habitat for waterfowl and different species of riverine vegetation [20]. Therefore, the less sealed it is, the more supporting services it can provide. The size of the water protection zone (200-m buffer of the river) is regulated by the Water Code of Russia.

The share of green infrastructure in these buffers is the lowest in Kazan and Rostov-on-Don. The most intact riverside lines of the main rivers are found in Omsk, Krasnoyarsk, Ufa and Nizhny Novgorod, which have more than 60% of unsealed area. Moreover, the riverside line inside the urban core also remains quite intact in the first two cities. Therefore, river zones of Omsk and Krasnoyarsk have the most intact riverside line, with more than 65% of their area being green even inside the urban. The opposite situation, where the riverside line is mostly sealed (up to 90% inside the urban core) do not provide regulating and habitat supporting services, can be found in Khabarovsk and Kazan. In other cities, the share of the green infrastructure inside the 200-m buffer is close to 50%, which is still not enough to form a full-fledged blue-green corridor. However, based on such a network, it is possible to create a single corridor by connecting larger green elements with smaller ones.

3.4 Functional structure

The predominance of one out of three functional zones inside the river zone define its functional structure. As a result, we found out that river zones of Nizhniy Novgorod, Omsk and Krasnoyarsk mostly consist of natural and recreational zones (> 50% of total area); river zones of Kazan and Volgograd have a relatively high share of industrial areas (>30%); and the river zones of the rest of the cities mostly consist of business and residential areas (>50%). The first type of functional structure seems to be the most capable in the aspect of blue-green corridor formation. However, most natural and recreational zones are situated aside from the urban core (on the islands or undeveloped banks), thus not really contributing into the formation of blue-green corridors which are supposed to go throughout the city. In this aspect, it is the third type where the more efficient blue-green corridors can be formed, since residential and business areas can have green elements, which are actually close and beneficial to the population in terms of regulating services [21].

3.5 Integrated assessment and discussion

In most cities, it is the river zones that have the most intact and least transformed green infrastructure. However, only in two cities, Omsk and Krasnoyarsk, river zones can be considered blue-green corridors due to the high share of green infrastructure, intact riverside lines and low fragmentation. On the contrary, in Kazan, Rostov-on-Don and Khabarovsk, river zones least of all resemble corridors. In the remaining cities, river zones have an insignificantly fragmented vegetation, so they can be probably turned into blue-green corridors if numerous former industrial zones along the river will be transformed into new green elements, and if the existing infrastructure will get more vegetation (particularly embankments). The results of the integrated assessment are presented in Figure 1.

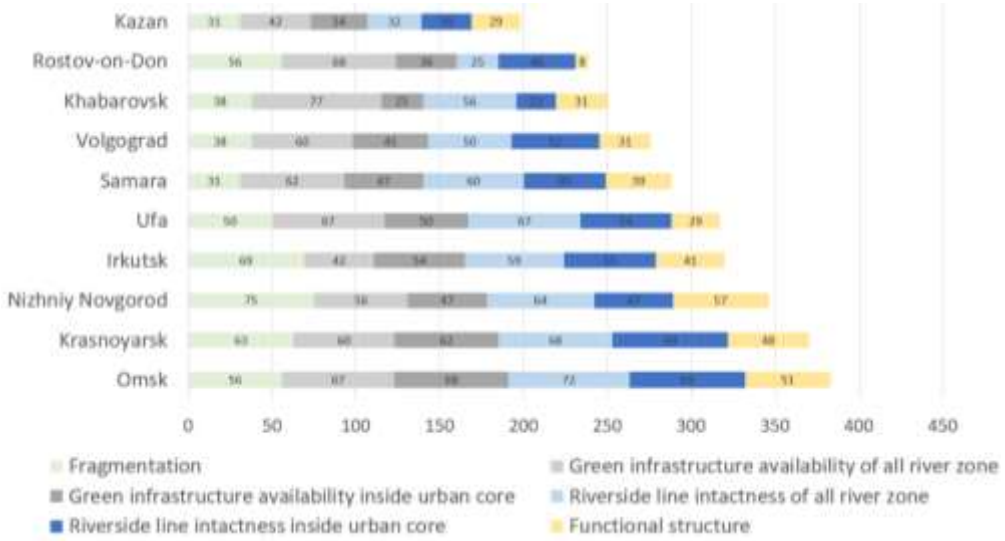

Fig. 1. The integrated assessment of river zones potential to form blue-green corridors.

The blue-green corridor can be considered effective in the aspect of urban sustainability improvement when it does not only perform regulating and supporting services, but also has a direct beneficial effect on the population [22]. In other words, the efficient blue-green corridor should directly pass through the most built-up part of the city, and river zones should occupy a significant area from the populated part of the city. In this context, the blue-green corridors of Omsk (fig. 2) and Krasnoyarsk, as well as the potential corridors of Nizhny Novgorod, Ufa and Irkutsk, seem to be the most effective ones.

In each city one of two situations is observed: either inaccessible and poorly maintained green elements predominate, which can, though, form a blue-green corridor; or the blue-green corridor is not formed, but the river areas have a lot of relatively small green elements with vegetation of unnatural origin. On the one hand, the fragmented green infrastructure creates less sustainable habitats. However, dispersed green infrastructure is distributed more evenly throughout the urban territory, which is important for creating a sustainable urban environment. Therefore, it is still an open dispute whether the efficient urban green infrastructure should remain dispersed or intact [23].

Being part of a large valley, urban river zones often include vast areas of land that is inconvenient for development, even inside the urban zone. It makes them practically the only zone inside the densely built-up city center, protected from intense further development [24]. Thus, urban river zones may be considered the main reserve for the implementation of green infrastructure in large cities. Unlike small river valleys, the large

ones usually occupy more area and can form a big corridor at the whole urban (or even agglomeration) spatial level. It is this feature that makes it possible to create a blue-green corridor on the basis of the major river zone and its green infrastructure [25].

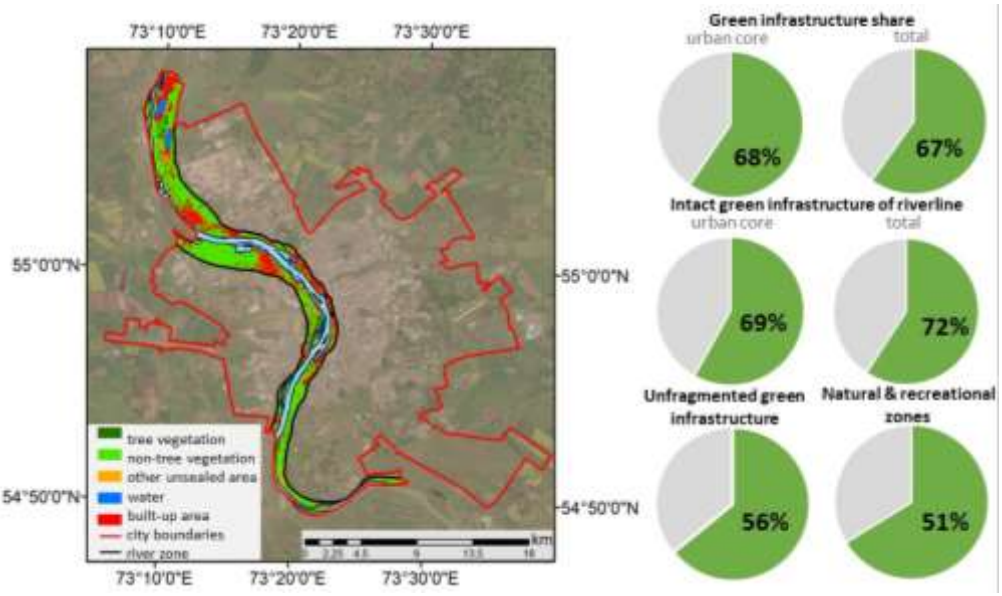

Fig. 2. A blue-green corridor and its parameters of the major river zone in Omsk.

However, at the same time large river zones are often more difficult to renaturalize in comparison to small river valleys [26]. Moreover, considering the urban configuration of many cities (i.e. those, located only on one bank), in some cases it may be more efficient to create a blue-green corridor on the basis of small river valleys and their zones [27]. For example, the formation of the blue-green corridor along the Volga River reservoir in Kazan may be considered impractical, due to the large number of operating transport and industrial facilities located in the river zone, as well as due to the complex morphology of the coastline. In this case, it is more efficient to form a corridor along the Kazanka River and the elongated oxbow Lakes Nizhniy Kaban and Verkhniy Kaban, which pass directly through residential and business districts of the city.

The potential blue-green corridor in Khabarovsk may not be as effective in contributing to urban sustainability, as the city is situated only on one bank of the Amur River, and the largest riverine green areas are far from the urban core. In this city, the creation of a blue-green corridor is seen as the most challenging one due to the lack of undeveloped territories and a number of transport and industrial areas in the river zone. Moreover, the most populated part of the city is somewhat far from the Amur, thus the major river zone is not the most efficient basis for the blue-green corridor.

The opposite situation can be observed in Rostov-on-Don, where the Don River with the adjacent green infrastructure is the most important climate-regulating mechanism of a city with a hot steppe climate. Strong fragmentation and a weak degree of a river zone greening currently complicate the formation of the blue-green corridor, which is, though, of utter importance for this semi-arid city.

4 Conclusion

Despite the fact that rivers and valleys are considered key ecological corridors in the landscape, our results demonstrate that this function is not always preserved inside urban areas. Rivers and river zones are indeed corridors between different parts of the city. However, it is precisely the regulating and habitat supporting functions that the river zones do not always perform due to the degree of spatial development and vegetation fragmentation. Even those parts of river zones, which are relatively inconvenient for construction, become isolated, thus preventing the river zones from forming an intact and fully functioning urban blue-green corridor.

To achieve sustainable urban development and to create a comfortable urban environment, it can be recommended to make undeveloped green areas more accessible to the population by taking into account compliance with sanitary and landscaping measures. It is also crucial to develop riverine green infrastructure not according to the residual principle (by creating or leaving green areas in places that are not convenient for any other urban use, like islands and slopes), but by considering existing standards for urban development (e.g., the WHO standard of at least 9 m^2 of green area per person) and by creating green elements in a way that allows to form an intact and efficient blue-green corridor.

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