Chapter 19
Accessibility to and Fragmentation of Urban Green Infrastructure: Importance for Adaptation to Climate Change

Ieva Misiune and Justas Kazys

Significance Statement Urban green infrastructure (GI) is one of the key strategies to respond to environmental problems. It helps to support biodiversity, adaptation to climate change and ensure the provision of ecosystem services (ES). Scientific literature suggests that there are thresholds for minimum viable green area patch sizes. Besides the size, accessibility is another important factor for the supply of ES. This work assesses how demand and accessibility can be improved addressing fragmentation of GI in Vilnius, Lithuania. The analysis shows that climate adaptation policy should guide the development of GI addressing simultaneously the demand of ES and fragmentation of the GI, for instance, by reconnecting existing natural areas in this way increasing accessibility and reducing the risk of further habitat fragmentation.

Keywords Urban green infrastructure · Ecosystem services · Fragmentation · Accessibility · Climate change adaptation

1 Introduction

Healthy ecosystems can support biodiversity and provide a range of ecosystem services (ES) important for human well-being, enhance resilience and adaptation to climate change. It is especially important in urban environments as over half of the world population lives in the cities raising an enormous pressure on the natural environment (United Nations, 2019). Since urban population continues to grow, the pressures and the demand for healthy ecosystems and their services increase as well.

Urbanization causes environmental problems, such as urban heat island (UHI) effect, increased runoff due to impervious surfaces, change in biodiversity when non-native species change native species and the level of their diversity, and increased production of carbon dioxide (Bryant, 2006). Additionally, urbanization

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I. Misiune (✉) · J. Kazys
Institute of Geosciences, Faculty of Chemistry and Geosciences, Vilnius University, Vilnius, Lithuania
e-mail: ieva.misiune@chgf.vu.lt

I. Misiune et al. (eds.), *Human-Nature Interactions*,
https://doi.org/10.1007/978-3-031-01980-7_19

causes fragmentation and homogenization of the landscape's diversity and, thus, contributes to the decrease in habitat diversity (Antrop, 2004). Ultimately these problems contribute to more severe consequences of climate change and deteriorating quality of life.

Urban green infrastructure (GI) is one of the key strategies to respond to the pressures, including climate change, and to support biodiversity as well as ES provision in urbanized territories. GI is a network of (semi-) natural areas which can help in mitigating the impacts of urbanization and deliver different environmental, socio-cultural and economic benefits (EC, 2013). A number of documents at European level address the ecological problems in cities and the need to improve the quality of life of its citizens (EP, 2013/2663 (RSP)). GI is acknowledged as being an important strategy for the effective solutions and for the implementation of EU Biodiversity Strategy 2020.

Strategies for optimal design of GI could provide climate-related benefits such as microclimate regulation, air purification, reduction of carbon emissions, precipitation and runoff regulation. For UHI reduction trees are seen as the best microclimate regulation option (Venhari et al., 2017; Balany et al., 2020). Studies dealing with urban forest impacts on microclimate regulations found that older and larger trees have greater benefits for cooling and air pollution reduction. Venter et al. (2020) identified negative correlation between land surface temperatures to tree canopy cover and vegetation greenness in Oslo (Norway). Nastran et al. (2019) defined that higher proportion of forest, higher largest patch index and higher proportional landscape core are associated with a lower UHI in the cities of new EU members. Even very small parks that are heavily forested can produce greater cooling effects than parks or lawns with grass only (Jaganmohan et al., 2016). Although even small green spaces can decrease the temperature, most of the studies indicated that the larger the park (>3 ha), the stronger the effect (Venhari et al., 2017). Thus, the extent and type of GI areas are more important than the typology of urban development in which urban greening strategies are located (Jaganmohan et al., 2016).

For sustainable city planning it is important to know the demand of urban ES and if public urban green spaces (UGS) can meet it. At the same time, it is essential to ensure an effective planning of GI with healthy and resilient ecosystems that provide the key urban ES and can help adapting to and mitigating climate change effects. Thus, this analysis provides insights on how the demand can be addressed reducing the fragmentation of the major GI elements – urban forests and UGS – in Eastern European capital Vilnius, Lithuania. The work focuses on the social demand using population data and accessibility to GI using a spatial analysis approach. Further, fragmentation examination allows to identify the areas of GI that can address better the demand and at the same time has a high improvement potential. Some planning recommendations are provided at the end.

2 Materials and Methods

2.1 Study Area

Vilnius is the capital of Lithuania situated in the southeast of the country with over 561,000 inhabitants. It is the only growing city in the country with an intensive internal rural to urban migration. Regardless of an ongoing urban sprawl, a large share of the city is covered with green infrastructure. Public UGS, which are intensively used (having recreational infrastructure) and extensively used UGS (without infrastructure) cover over 3300 ha (8.25%) of the city. Urban forests cover over 13,450 ha (33.55%) and are open to people for recreational use. Altogether these elements of GI make up 16,758.66 ha (42%) of the city municipal area. Additionally, 2385 ha is covered by allotment gardens, agricultural areas and water bodies, which are the elements of GI. These territories, however, not always are accessible publicly, thus, were not included in the analysis. Nearly 39% of the territory is urbanized with 12% (4709 ha) having impervious surfaces (Fig. 19.1).

Neris, the second longest river in the country, flows over the whole town from its North to South. The richness of green spaces like urban parks, forests and protected areas as well as the water bodies provide a multitude of ES to the residents of Vilnius city. Based on GreenMatch's findings, however, the surface temperature in Lithuania has increased the most compared to other 31 European countries, with an increase of 0.325 °C per decade. Years 2019 and 2020 were the hottest throughout the instrumental measurements (since 1770). During the first two decades of the twenty-first century compared to the twentieth century, the average air temperature in winter and spring became warmer by 1.6 °C, in summer by 1.4 °C, and in autumn by 1.3 °C. No significant trends have been observed in the sequence of annual precipitation (since 1887), but in recent decades' precipitation has increased in the cold and decreased in the warm period. This is due to the prevailing marine air masses in warm winters and a more frequent recurrence of anticyclonic processes in summers (Bukantis & Kažys, 2020).

2.2 Dataset and Methods

The dataset of urban GI for the study area was prepared according to the latest Vilnius city master plan (V-Planas, 2020). Official municipal data on land use with 15 land use types, location and number of inhabitants was acquired from the city municipality.

The main components of urban GI in Vilnius are: intensively used UGS (having more recreational infrastructure, like benches, playgrounds and other), extensively used UGS (usually without recreational infrastructure), urban forests and water bodies, which only partly included in the analysis. Allotment gardens and agricultural areas are important for GI connectivity in the city, however, these territories are

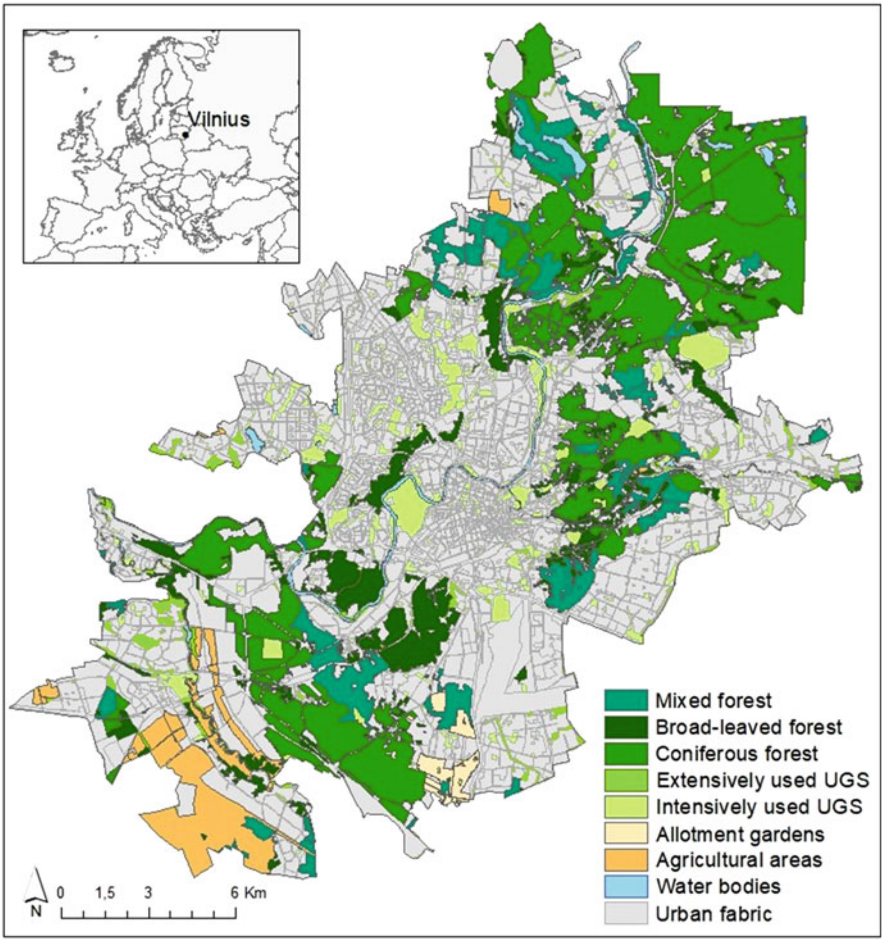

Fig. 19.1 Green Infrastructure of Vilnius city. Source: own elaboration based on the land use data from Vilnius municipal plan. (V-Planas, 2020)

not public and thus will not be included in further analysis. All mentioned green spaces compose a network of (semi-) natural areas which provide different ES and ultimately helps mitigating the impacts of urbanization, like air pollution, urban heat-island effect and others. Different urban GI areas can provide different ES, however, the size and the type of the green space is a decisive factor for the capacity of the ecosystem and its potential to adaptive climate change effects.

Scientific literature has a choice of indicators dealing with ES demand. Many approaches use comparative methods and define several indicators, based on provision or accessibility to GI. Social demand for urban ES was assessed using population data – inhabitant number living in each apartment building or private house within the city limits – and it was calculated using a kernel function.

In this study, we defined access a maximum 300 m linear distance to the boundary of urban green space of a minimum size of 1 hectare (10,000 m^2) as recommended default options for the indicator (Annerstedt van den Bosch et al., 2016). Distance of 300 m and the size of the green space are suggested to serve as a proxy measure for assessing public accessibility to urban green spaces.

Fragmentation of urban GI was assessed using The Landscape Fragmentation Tool (LFT), which provides a method to quantify landscape fragmentation (Parent & Hurd, 2008). The tool classifies a land cover type of interest (in this case urban GI) into four main categories:

- Perforated – GI pixels along the edge of an interior gap that are degraded by "edge effects".
- Edge – GI pixels along the exterior perimeter of a GI area that are degraded by the "edge effect".
- Patch – small isolated fragments of GI that are completely degraded by "edge effect".
- Core: GI pixels that are not degraded by "edge effects". They are further subdivided into: small core (smaller than 101 ha); medium core (between 101 and 202 ha); and large core (larger than 202 ha).

The classification of pixels is based on studies of forest ecology, which have found that the size of forest patch impacts its viability in terms of supporting wildlife. Larger areas are more likely to support greater numbers of interior species and as it was discussed in the Introduction it also helps to adapt to climate change more effectively. All geospatial and geostatistical analysis was performed using ArcMap 10.7.1.

3 Results and Discussion

3.1 Addressing the Demand by Fixing Fragmentation in the Study Area

The results of the assessment in Vilnius are presented in Figs. 19.2, 19.3, 19.4 and Tables 19.1 and 19.2. As one may see the highest demand of ES are in the center and the west of the city (Fig. 19.2). These territories have the highest number of people usually living in multistorey houses with no gardens or private backyards. It is important for them to have a good access to UGS so to avoid severe climate change effects or for recreational purposes.

The analysis shows a spatial disproportion of GI (Fig. 19.1) and demand of the UGS (Fig. 19.2) which is a serious issue for supplying ES in Vilnius. The demand for the UGS greatly correlates with the values of territorial index of matter artificiality found by Jukna (2014). Maximum values of this index are dominant in greatest matter artificiality core territories of cities with very high building density level.

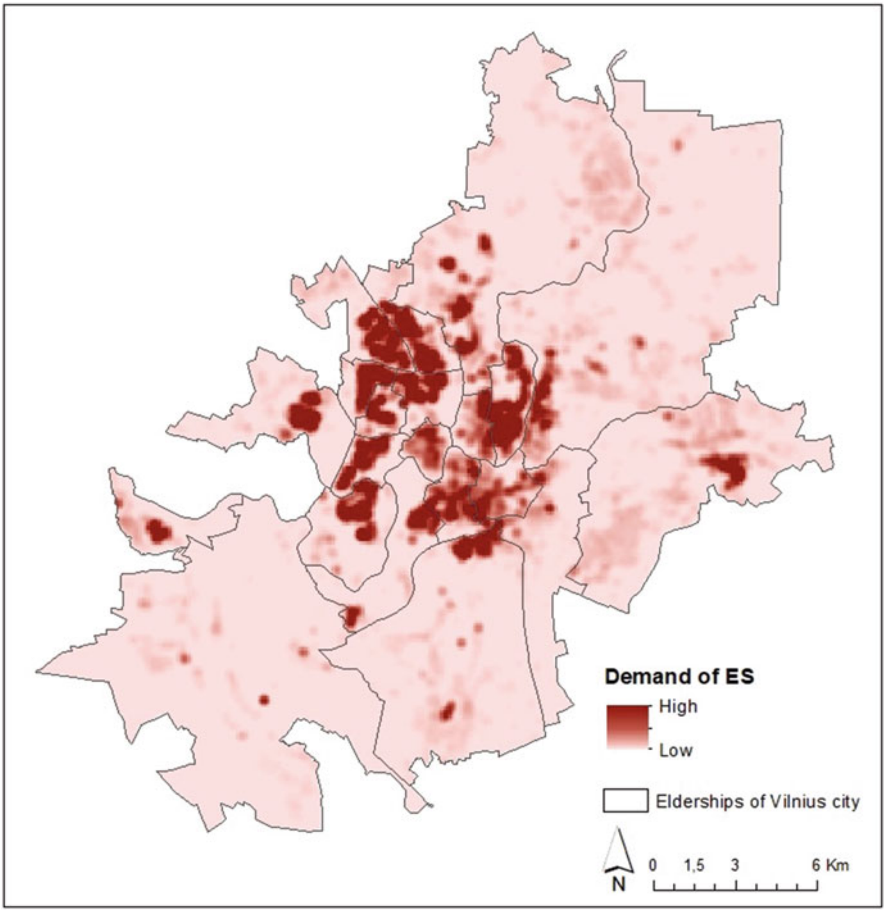

Fig. 19.2 Demand of the UGS in the study area based on inhabitants' location

Vilnius characterized by a greatest diversity of technogenisation area types, which can be seen through the whole city's structure, also in the center of it (Jukna, 2013). The areas of the highest demand of UGS are related to processes of massive industrialization and urbanization during the communist period, massive urban transitions in the post-1990 period and the changing occupational structure and an increase in social inequalities since 2001 (Valatka et al., 2015).

Geospatial analysis of urban GI shows gradient change in its fragmentation. This obviously depends on the dispersion of GI within the city limits. In the city center urban GI is most fragmented and has the smallest patches, which are scattered in the territory. Patch is considered a small isolated fragment of forest or other type of GI that are completely degraded by "edge effect". The core elements of GI increases with the distance from the city center as urban forests are mostly at the far north and south of the city. However, these core areas are affected by forest pixels along the edge of an interior gap in a forest ('Perforated' in Fig. 19.3) that are degraded by "edge effects".

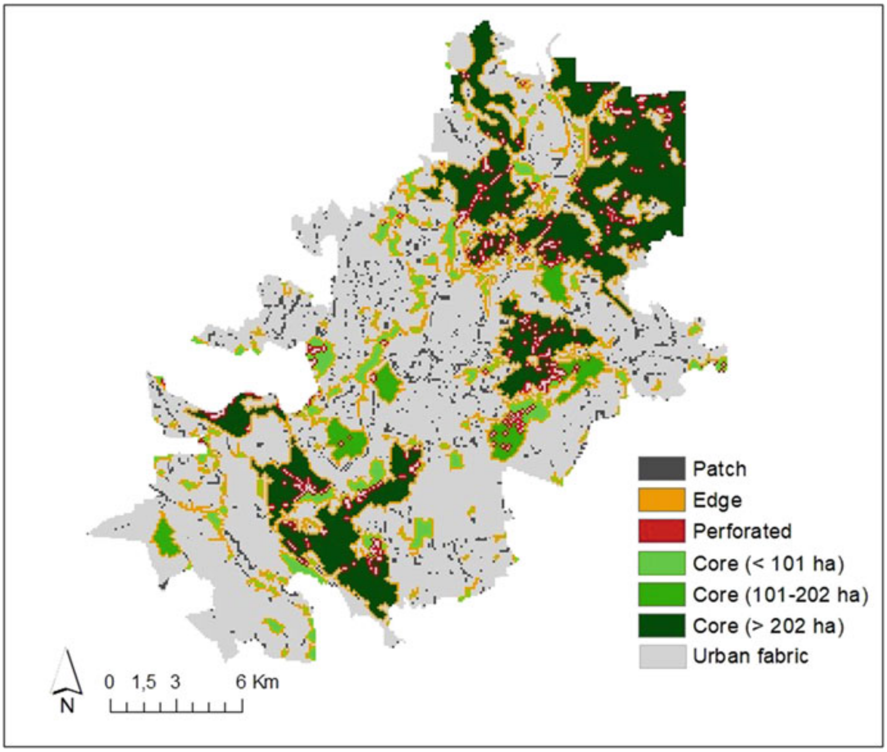

Fig. 19.3 Fragmentation of urban GI in the study area

Looking at the share of different fragmentation units of the GI one can see that core forest areas over 202 ha make up almost half of the GI in Vilnius (Table 19.1). These territories, however, are at the outskirts of the city and do not address the demand, which is concentrated in the city center. Another important insight is that one quarter of the GI territory is considered as degraded by the "edge effect" (Edge in Fig. 19.3).

Even though Vilnius has a lot of green spaces, fragmentation shows that ES related to the microclimatic and air quality are hardly accessible in most central parts and could become even less accessible in the future due to climate change higher average temperature and the higher magnitude and recurrence of extreme events such as heat waves. The probability of temperature extremes generally increases non-linearly with increasing global warming levels. The most recent research showed that, compared to the historical climate, warming will result in strong increases in heat wave area, duration, and magnitude. These changes are mostly due to the increase in mean seasonal temperature (Vogel et al., 2020). In Lithuania, the annual average temperature could increase from 1.5 to 5.1 °C (depending on different emission scenarios) until 2100 (Keršytė et al., 2015). The temperature changes could be slightly higher according to the newest CMIP6 project modelling results (Tebaldi et al., 2021). Moreover, future climate change could intensify UHI

Fig. 19.4 Accessibility to: (**a**) urban forest; (**b**) intensively used UGS having recreational infrastructure; (**c**) extensively used UGS without infrastructure

Table 19.1 Share of different fragmentation units of the green infrastructure in Vilnius

GI fragmentation units	Share of the units, %
Patch	8.03
Edge	25.28
Perforated	8.47
Core (<101 ha)	8.66
Core (101–202 ha)	2.27
Core (>202 ha)	47.29

Table 19.2 Number of people living 100 m and 300 m from the closest GI, including water bodies

	Forest	Intensively used UGS	Extensively use UGS	Water bodies
100 m	67,670 (11,98%)	242,516 (42,93%)	15,996 (2,83%)	10,173 (1,8%)
300 m	256,954 (45,49%)	418,309 (74,053%)	64,444 (11,4%)	74,007 (13,1%)

effect and warming will probably be equivalent to about half the warming caused by climate change by the year 2050 (Huang et al., 2019).

There is not a lot of evidence about UHI magnitude in Vilnius. However, some studies revealed the existence of this phenomena. Mažeikis (2013) used Enviro-HIRLAM numerical weather prediction model and found the differences in meteorological parameters (air temperature, wind speed, precipitation field) in the urbanized areas in Lithuania (Vilnius case study). Higher anthropogenic heat flux sums up to higher sensible heat flux and it means that the energy available for UHI formation near surface air is higher. Urbanavičiūtė and Bukaintis (2020) found that the average monthly air temperature (2012–2017) measured at Vilnius University meteorological station (located in the city center) at all times of the year were 0.8–1.54 °C higher than temperatures recorded in suburbs (Trakai Vokė and Civil Aviation meteorological stations). The highest UHI magnitude values are reached in warm season (May-September). In most cases, UHI effect persisted not only during the day, but also at night time.

The higher magnitude of recurrence of heat waves, UHI effect with a combination of air pollution (mostly of traffic) could cause serious health, social and other problems in central parts of Vilnius, which lacks GI. Venter et al. (2020) identify the increase of health risk threshold in Oslo (Norway) during the summer (>30 °C) while each city tree was replaced by the most common non-tree cover. In Vilnius, heat related mortality could increase from 7 deaths per year in 2015 up to 46 deaths in 2100 if there would no adaptation and reduction measures implemented (Martinez et al., 2018). Pfeifer et al. (2020) indicated that heat and heat waves lead to an increase in mortality in Nordic climatic region, despite these countries having low average temperatures, suggesting that relatively high temperatures as compared to more normal temperatures may be of importance.

Accessibility visualizations in Fig. 19.4 show the access to different types of GI. It is no surprising, that intensively used UGS having recreational infrastructure, like benches, lights or playgrounds (Fig. 19.4b) are concentrated in the areas with the highest demand (Fig. 19.2). However, these are usually small fragmented patches having low capacity to provide regulating ES related to climate adaptation. There are much less people that has access to the core areas of GI or other type of GI (Table 19.2).

The Fragmentation map of urban GI (Fig. 19.3) illustrates that the most core elements could not support ES functions, such as microclimatic regulation and air purification in the place with highest demand (Fig. 19.2); in Vilnius, the accessibility to forests (Fig. 19.4a), which could fully support these functions, are lower than 50% (Table 19.2). Moreover, the accessibility to water bodies, which could additionally improve microclimate regulations, is even more limited (Table 19.2).

The expansion of perforation zones (Perforated in Fig. 19.3) could be related to extensively used UGS without infrastructure (Fig. 19.4c). Even though now the accessibility to extensively use UGS is limited (Table 19.2), it could trigger the collapse of core components as a result of the growing demand of its usage in the future. Therefore, the situation in perforation zones should be monitored and maintained to prevent the loss of core elements in Vilnius.

3.2 GI Planning for Effective Adaptation to Climate Change

Urban green cover in Vilnius can be improved in different ways. First of all, improving connectivity between existing elements of urban GI by preservation of green corridors and connection of patches identified in the fragmentation analysis. This helps to counter fragmentation and increases ecological coherence. Identifying multifunctional zones is another effective technique for GI development. Territories that support healthy biodiverse ecosystems and at the same time encompass compatible land uses such as recreation, forestry or farming. Such territories should become a backbone of the urban GI from the city center to the outskirts. Nevertheless, there are two noticeable problems in the city: lack of core elements and over exploitation of them. Even though the percentage of accessibility to intensively used UGS is high (Table 19.2), most of these UGS are recognized as patches in Fragmentation map (Patch in Fig. 19.3). In the future, planners should include more core elements in the most demanding districts in Vilnius. Foremost larger GI elements would serve for climate adaptation. Second, it would benefit the city dwellers as they tend to look for larger green spaces to have longer and more diverse physical activities that the small parks and gardens even with recreational infrastructure cannot support. It means that the demand for larger spaces in central parts of the city (like Vingis park, Karoliniškės landscape reserve, Neris river embankments, etc.) will grow. It is even more important if the pandemic lockdown situation recurs in the future as now a lot of citizens spend their time in the biggest intensively used UGS in the city center. The overexploitation of these core elements could lead to a loss of the core functions in the future.

Urban GI is currently receiving growing attention from urban planners and policy makers as an important strategy to reduce heat related effects in the cities (Balany et al., 2020; Venter et al. 2020). From a policy standpoint, tree protection standards can greatly reduce UHI (Sung, 2013). Urban GI inclusion into urban spatial panning and policies are seen as a key to success. A proper identification of climate change risks and threats would allow effectively plan land use or operational regimes. Thus, the interest of city dwellers and the principles of climate change adaptation must be addressed in municipal spatial planning documents. However, there are limited policies for urban GI of climate mitigation and adaptation in Lithuania. Kilpys et al. (2017) provided the recommendations for climate change mitigation and adaptation for municipalities. Recent Vilnius city master plan (2021) briefly indicates several measures, including nature based solutions for climate change adaptation. The development of GI, therefore, especially in high demand areas, should be better addressed by policy makers and urban planners for effective adaptation policies.

4 Conclusions

The large part of Vilnius territory covered by GI and makes the City to be seen as “a green city”. However, the largest part of the ‘core’ (>202 ha) vegetation areas, which are essential in securing ES supply (microclimatic regulation and air purification), are located in the outskirts of the city. The quarter of city area, instead of creating ‘core’ and ‘patch’ fragments, is indicated as ‘edge’ territories. This fragmentation and unequal distribution of urban GI affect the demand and accessibility of ES. Now there is a great dislocation of GI accessibility and areas with higher demand of UGS and so of ES in Vilnius City. The disproportion of demand and accessibility will raise due to climate change processes (e.g. UHI) and continuing fragmentation of GI. Moreover, the absence of proper climate change adaptation regulations could bring more severe challenges for the city in the future.

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