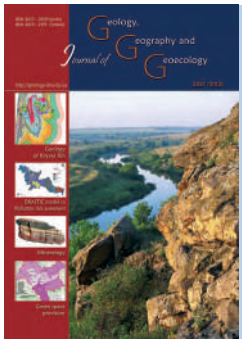

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The green infrastructure within the framework of a compact city concept (by example of Kyiv)

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Abstract. The goal of the study is to determine the actual areas and the geographical distribution of Urban Green Spaces (UGS) in Kyiv; compile and analyse the ratings of the city administrative districts by key UGS indicators and substantiate the level of comfortable living in each district according to the concept of a green compact city. The goal stems from the announcement of an official strategy of transforming Kyiv into a comfortable compact city with an attractive green infrastructure. To achieve this goal, we have calculated a number of major indicators of the modern green infrastructure of Kyiv in all ten city districts. According to the method we developed, we analysed the drawings of the urban development master plan and regulatory documents, and conducted a field survey of significant UGS sites in Kyiv. The data obtained were used to make a UGS map of Kyiv and other thematic maps. For the most accurate calculation of key UGS indicators, we processed several thousand contours in Kyiv's cartographic base. The sizes of Urban Protected Areas (UPA) were found separately, and their share in the total city territory and of each district (Conservation Coefficients) was determined. In so doing, UPA distribution was found to be very irregular, with a total area of 174.9 km^2, or about 21.2% of that of Ukraine's capital. We analysed the ratio of the city population and the areas of green spaces in each Kyiv district. To identify districts with a different UGS coverage, we calculated the Greenness Coefficients (GC) and compiled a rating of Kyiv districts by their level of greenness, using the Greenness Coefficients Index. Significant GC variations in different city districts were substantiated. In contrast to previous studies, we calculated the provision of Kyiv residents with green zones of not merely common usage, but also with those of all other kinds, including UPA. We also calculated the Green space provision per person and compiled ratings of Kyiv districts by the Green Space Provision Index. The results were presented on a relevant map. Based on calculating the share of protected areas in the total UGS area, we found the ratings of Kyiv districts by the Green space legally protected Index. Wherein, we found significant variations among the districts by the ratio of protected areas and green spaces deprived of any legal protection. This increases their vulnerability to projected development attempts. We calculated the Integral Green Space Index (GSI) based on processing all significant UGS indicators of Kyiv. GSI allows for an integral assessment of the condition of the Urban Green Infrastructure (UGI) in Kyiv, and it is the key criterion of its compliance with modern requirements to an ideal compact city. Holosiivskyi District received the highest GSI rating. It is uniformly replete with UGS, which are provided for quality recreation and, at the same time, are protected by environmental legislation. Solomianskyi District received the lowest rating, and almost all the elements of its existing UGI require a cardinal optimisation. As a whole, the indicators we calculated can create an illusion of adequate provision of Kyiv with UGS. Actually, they are distributed very irregularly in the majority of districts. The results of our study are indicative of the presence of many challenging locations that require an extension of existing UGS and the development of new ones pursuant to the principles of compact city planning. Since UGI planning depends on the implementation of the Urban Development Master Plan, it makes sense to include the Green Space Index to the key indicators of the Kyiv Development Strategy. The draft new City General Plan should also be refined with account of the above-mentioned problems.

Keywords: Urban Green Spaces, Urban Green Infrastructure, compact city conception, green space provision per person, Green Space Index, rating of Kyiv districts

Зелена інфраструктура в рамках концепції компактного міста (на прикладі Києва)

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Анотація. Мета дослідження – з'ясувати реальні площі та географічний розподіл міських зелених зон (МЗЗ) Києва, скласти і проаналізувати рейтинги адміністративних районів за основними індикаторами МЗЗ та обґрунтувати рівень комфортності проживання у кожному з них відповідно до концепції компактного зеленого міста. Актуальність дослідження пов'язана з офіційним проголошенням переходу Києва до нової стратегії розвитку в рамках концепції компактного міста з привабливою зеленою інфраструктурою. В процесі виконання поставленої мети розраховано низку важливих показників сучасної зеленої інфраструктури Києва, які в різних районах міста істотно відрізняється. Проаналізовано креслення діючого і проектованого

Генеральних планів міста, нормативні документи, проведено натурне обстеження визначних МЗЗ Києва. На основі отриманих даних створено низку тематичних карт. Окремо визначено площі міських природоохоронних територій (ПОТ) та розраховано їх частку в загальній площі міста і районів (коефіцієнти заповідності). ПОТ загальнодержавного і місцевого значення розподілені містом дуже нерівномірно, а їх загальна площа становить 174,9 км^2, або майже 21,2% столиці України. Також встановлено частку ПОТ у складі зелених зон різного призначення та обґрунтовано значні відмінності районів Києва за рівнем захищеності їх зелених насаджень. З'ясовано співвідношення чисельності населення і площі зелених зон всіх видів у кожному районі Києва. Для ідентифікації районів з різним охопленням МЗЗ використано коефіцієнти озеленення, за якими в кожному районі визначено відповідні індекси. На основі отриманих результатів складено рейтинг районів Києва за рівнем озеленення. Також оцінено забезпеченість кожного мешканця Києва зеленими зонами не лише загального користування, але й усіх інших видів, включаючи ПОТ. Після опрацювання всіх значущих індикаторів визначено інтегральний індекс зелених зон (ІЗЗ) як головний критерій відповідності Києва та його окремих районів сучасним вимогам до компактного зеленого міста. На основі цього складено рейтинг районів, за яким перше місце посів Голосіївський район, найбільш рівномірно насичений зеленими зонами, більшість з яких охороняються законом. Найнижчий рейтинг має Солом'янський район, який значно відстає від решти районів за усіма розрахованими показниками і тому потребує кардинального оновлення майже всієї існуючої зеленої інфраструктури. Результати дослідження певною мірою спростовують уявлення про достатню забезпеченість Києва зеленими зонами та їх захищеність. Наведені розрахунки свідчать про необхідність розширення існуючих і створення нових МЗЗ в багатьох проблемних локаціях відповідно до принципів планування компактного міста.

Ключові слова: міські зелені зони, міська зелена інфраструктура, концепція компактного міста, забезпеченість зеленими зонами на людину, індекс зелених зон, рейтинг районів Києва

Introduction

In the end of the past century, the concept of city sprawl lost its standing and even became an obstacle to sustainable urban development, with discussions still being held. The concepts that are being gradually transformed into a policy of developing green compact cities have got a growing support worldwide. In 2018, roughly 55.3% of the world population (4.22 billion people) lived in urban localities. Of these, 1.7 billion people (23% of the world population) lived in million-plus cities. By 2030, the expected urban population will grow to 60%, with every third person living in a city with a population of at least a half of a million (The World's Cities in 2018). Cities account for roughly 70% of global carbon dioxide gas emission and for the highest concentration of atmospheric pollution and waste. Twenty-seven world metropolitan cities, with a population of over 10 million, produce 12% of the world waste (Gonçalves, 2018). Urbanisation results in depletion and degradation of ecosystems, a declining resistance to climate changes, and a loss of substantial ecosystem services in cities and around them. The adverse consequences of prolonged urbanisation are more pronounced in countries with a low level of economic development and with no strategic planning of urban land usage.

The result of intense search for a model of sustainable urban planning was the green compact city – the ideal one preferred worldwide. It is characterised by closeness, mixed land usage and an attractive green infrastructure. In this case, the significance of urban greening increases considerably, and it becomes a resource for urban development. This means that the natural components of a city become its integral part, capable of overcoming the contradictions and conflicts among all other components, rather than simply being a compensation for the technogenic consequences of urbanisation. Green space is a fundamental part of sustainable city development. It facilitates air cleaning, climate control, and improvement of landscape quality (Tappert et al., 2018).

Until recent times, cities worldwide were urbanised without account for such indicators as air pollution, CO_2 emission, acoustic pollution, and green zones. Currently, they are the priority factors and an essential part of integrated strategies of urban planning. Green urban zones (Pardo, 2019) are valuable assets that are instrumental in reducing healthcare costs, mitigating climate changes, and increasing land productivity and energy effectiveness. Protected areas in big cities, irrespective of the adverse impact of urbanisation on their biodiversity, enjoy certain advantages of their management, in particular, access to political power centres and state financing (McNeely, 2001). In this case, parks, woodlands and other natural territories within city boundaries can be the drivers of urbanisation by attracting population and stimulating housing development around them (Brambilla & Ronchi, 2016).

Urban Green Space (UGS) usually includes all the green space within city boundaries (forests, parks, private orchards, trees and bushes along railway tracks, and so on) irrespective of the form of ownership. The provision of city residents with UGS is usually assessed by several indicators, the key ones are UGS availability, accessibility and attractiveness. Various variants of UGS usage are most often linked to their management features, economic constraints, spatial planning, legal and social norms, and preferences of the residents (Biernacka & Kronenberg, 2019). One of the major practical aspects of UGS development is not the achievement of a particular indicator per capita, but rather the development of dif-

ferent models of green city planning. Limited areas for greenery call for the development of alternative concepts of modern city planning, in particular, the Urban Green Infrastructure (UGI), nature-based solutions, biophilic urbanism (e.g., Singapore), sponge cities (Shanghai in China), forest cities, edible green infrastructure, eco-urbanism and landscape urbanism (Russo & Cirella, 2018).

The main goal of the policy of sustainable development of a compact city is the protection of the urban environment from inevitable degradation in case of urban sprawl. A high quality of living in compact cities can be ensured by development densification with simultaneous preservation of greenery within residential districts and the city as a whole. Accounting for the contradictions between the need of compact development, on the one hand, and preservation of green zones, on the other hand, the landscape planning of such cities uses the concepts of ecosystem services and a green infrastructure. An important principle of planning the UGI of a compact city is its overall integration into the "grey" infrastructure, i.e. housing or other development, roads, utility services, and so on (Artmann et al., 2017). In the event of insufficient greenery, city residents will experience a substantial curtailment of important ecosystem services. Hence, the underpinning of planning green compact cities should be the integration of the concepts of reasonable growth and the urban green infrastructure (Artmann et al., 2019).

Successful implementation of the compact city concept involves an integrated approach to sustainable development, i.e. achieving a trade-off between development densification and the quantitative and qualitative greening of city districts. The goal of development densification is to counteract the adverse consequences of urban sprawl under conditions of ineffective land management. In particular, loss of green spaces due to urban development concentration can be compensated by improving the quality of plantation (Haaland & Bosch, 2015). Urban sprawl will inevitably lead to a growing demand in such ecosystem services as clean air and the opportunity of outdoor recreation because presently these services are provided largely by suburban green zones (Baró et al., 2016).

Nowadays, cities worldwide are investing more and more funds in the UGI. An example of an ideal compact city is Ljubljana, Slovenia. It was the winner of the European Green Capital nomination of 2016. The city has 542 m^2 UGS per resident. Over 46% of the city's territory is covered with natural forests, and all the UGS covers 75% of the city total area (Ljubljana – winner 2016 European Green Capital, 2016). The Portuguese capital Lisbon has become the Green Capital of Europe of 2020, focusing on creating an UGI and associated greenery chains. In Lisbon, 76% of the residents live within 300-metre access to UGS (European Commission: Lisbon is the 2020 European Green Capital Award winner). Urban forests are the basis of the UGI, and they improve the environmental footprint of a city. Apart from woodlands, urban forests include city and district parks, private greenery, groups of trees and separately standing trees in squares, sports grounds, parking spaces, streets, and so on. With proper management, forests facilitate an increasing resilience of city landscapes. The ecosystem approach to their management is focused to maximising carbon capture from the atmosphere (Salbitano et al., 2016). For instance, London's UGI includes over 1.5 million trees and bushes in parks, gardens, forests and open spaces, which provide the residents with important ecosystem services. The cost of these services within city boundaries is estimated at about 60 million pounds sterling annually (Rogers et al., 2015).

The majority studies' results demonstrate that the distribution of greenery is closely linked to the geographic location and the city's historical development. With no single method for determining population provision with UGS, a variety of indicators is used, and their number is increasing (Le Texier et al., 2018). UGS is an important part of the public space of a city and often it is the only opportunity for urban residents to have accessible daily contact with the nature. Planning the UGI is still a relatively new instrument of the European Union's policy, whereas it has just started to originate in Ukraine. Studies dedicated to modern approaches to urban environment greening are also scarce. In practice, neither the UGS concept, nor the UGI are used. The current classification of greenery also fails to contribute to implementing advanced urbanistic concepts (Yukhnovskyi & Zibtseva, 2018). Positive changes have occurred over the past two years: The First All-Ukrainian Forum "The Green Infrastructure of Ukraine's Cities" was held and the first interactive map for planting trees was presented in Kyiv.

The ***purpose of the study*** is to determine the actual areas and the geographical distribution of UGS, analyse the ratings of Kyiv's administrative districts by key UGS indicators and substantiate the level of comfortable living in each of them according to the results obtained within the framework of the concept of a compact and green city.

Material and methods

Kyiv was chosen as the subject of the study not only because it is the capital and the biggest city

in Ukraine. Kyiv's territory is confined to the strip of contact of two landscape zones and the Dnipro River valley. Landscapes of the mixed forest type are common in the northern, north-western and western parts of the city. They are predominantly elevated terrace plains and slopes with turf-podzolic and turf soils that was formed under pine and oak-pine forests. The remaining city territory is covered with landscapes of the broadleaved woodland type. They are elevated accumulation-denudation loess plains and slopes with grey and dark-grey soils formed under fresh oak groves. Kyiv's left bank is abundant in old terrace alluvial plains with turf-podzolic soils formed under dry and fresh coniferous forests. In the north and south, the city's territory is traversed by inundated and insular landscapes with sod and meadow soils under grass-mixed cereal meadows.

In 2017, Kyiv was acknowledged the greenest European capital among metropolitan cities with a population of over 2 million. By the Normalized Difference Vegetation Index (0.389), Kyiv was far ahead of Berlin (0.246) that was placed second by the Capital Greenness rating (Gärtner, 2017). However, since that time, Kyiv has lost its positions because many green zones were alienated for development. Due to this, the environmental conditions in the city have deteriorated considerably. The official policy of transforming Kyiv to a compact and green city in practice facilitates the legalisation of chaotic development.

Kyiv has a special status in the system of the administrative-territorial structure of Ukraine as the main political, administrative, scientific, and cultural and tourist centre. It is the site of central state government bodies, municipal and regional administrative bodies, and diplomatic missions of foreign states. The city has valuable natural landscapes and an historical-and-cultural legacy of worldwide significance. An important advantage of the city is its geostrategic location on the crossroads of major economic and transport links. At the same time, uncontrollable development of the city territory leads to degradation of valuable natural landscapes and contraction of recreation zones, with the ecological situation being deteriorating dramatically. Exceeding the ultimate amounts of available development resources is creating risks for the preservation of a comfortable urban environment.

The city is divided into ten administrative districts, significantly differing in size (Table 1). The biggest district among them is Holosiyivskyi, and the smallest one is the Pecherskyi district (Fig. 1). Kyiv's permanently settled population as of 01.03.2020 was 2.925.700 and the actual population is 2.966.900 (Ofitsiinyi sait Holovnoho upravlinnia statystyky u m. Kyievi, 2020). Solomianskyi district has the biggest permanent population and Pecherskyi district has the smallest one. The average population density in Solomianskyi district is roughly six times higher than that in the least populated Holosiyivskyi district (Fig. 2). These indicators are extremely important for determining the provision of residents with UGS, which significantly varies in different districts of the city.

The algorithm of our study consists of a chain of consecutive actions focused to achieving the goal (Fig. 3). We analysed the drawings of the effective Kyiv Development Master Plan and the one being elaborated, the regulatory documents of the Kyiv City Council, the registries of public recreation zones, OpenStreetMap (OSM) and Google Map geospatial data, and conducted a field survey of significant UGS sites in Kyiv. This helped create a UGS map of Kyiv, other supplemental maps and fill them with

Table 1. Territorial and demographic indicators of Kyiv and administrative districts (as of 1.03.2020)

Districts of Kyiv	Area, km^2	Population, persons	Average population density, persons per km^2	
Holosiivskyi	155.59	252.553	1.623	Low
Desnianskyi	141.396	366.624	2.592	
Darnytskyi	127.846	340.928	2.667	
Obolonskyi	108.484	316.299	2.915	
Sviatoshynskyi	102.455	336.787	3.287	Medium
Dniprovskyi	68.678	356.982	5.198	High
Podilskyi	34.555	204.871	5.929	
Pecherskyi	19.77	158.468	8.016	Very high
Shevchenkivskyi	26.11	210.959	8.079	
Solomianskyi	40.579	381.218	9.394	
Kyiv (total)	825.463	2.925.689	3.544	

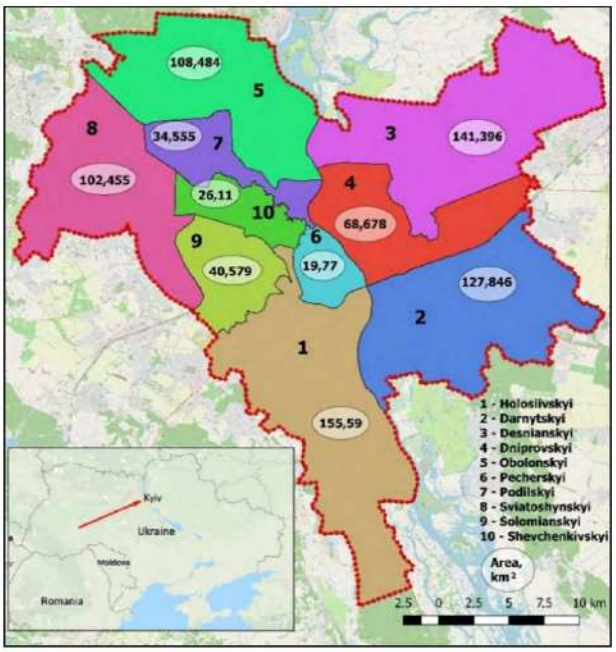

Fig. 1. Administrative districts of the Kyiv city

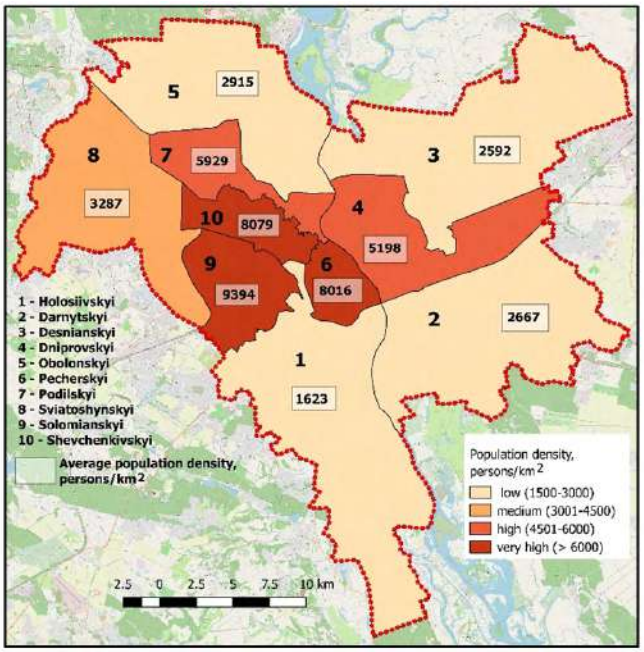

Fig. 2. Population density in the Kyiv city

relevant content. When creating the maps, all the thematic layers of spatial data were uploaded into the QGIS environment reduced to a unique cartographic projection. This is required for correct representation of topological data and accurate calculation of attributive characteristics. The result of overlay analysis was the creation of a polygonal shapefile containing the contours of all UGS within city boundaries, including the territories and sites of the nature reserve fund of statewide and local significance.

Having obtained the cartographic base of Kyiv UGS, we calculated the actual geometric characteristics of the UGS using a Field calculator. Using the collation maps method, this enabled compiling a series of thematic maps with representation of key UGI indicators. The information content of these maps was taken from our own calculations of Kyiv UGS and those of its individual administrative districts.

For the most accurate calculation of key UGS indicators, Greenness Coefficients, Green Space Coefficients, the Green space legally protected and the City Nature Index, we processed 3.548 contours within Kyiv boundaries. The land area of Urban Protected Areas (UPA), a part of the city UGS, was

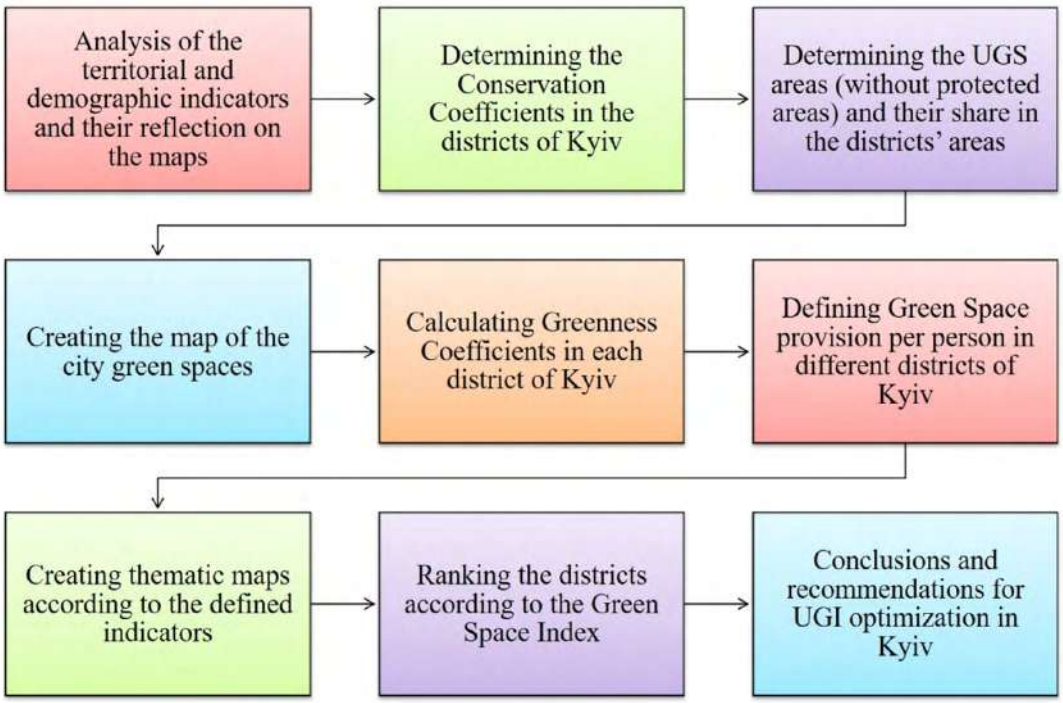

Fig. 3. Research algorithm of the Kyiv Urban Green Infrastructure

determined separately. For this, we calculated 146 contours of varying size (Table 2). UPA of statewide and local significance are distributed across the city very unevenly, with the total area of 174.9 km^2, or about 21.2% of Ukraine's capital area. The main indicators that represent UPA's share in the total area of each district are the Conservation Coefficients.

Table 2. Urban Protected Areas within the Kyiv city

Districts of Kyiv	Area, km^2	UPA, k^{m}2	Number of contours	The average area of the contour, km^2	Conservation Coefficients, %
Solomianskyi	40.579	0.398	6	0.066	0.98
Darnytskyi	127.846	4.007	4	1.002	3.13
Desnianskyi	141.396	4.573	7	0.653	3.23
Dniprovskyi	68.678	5.940	22	0.270	8.65
Shevchenkivskyi	26.110	2.858	23	0.124	10.95
Pecherskyi	19.770	2.317	11	0.211	11.72
Podilskyi	34.555	4.149	18	0.231	12.01
Obolonskyi	108.484	31.53	9	3.503	29.06
Holosiivskyi	155.590	64.108	32	2.003	41.20
Sviatoshynskyi	102.455	55.034	14	3.931	53.72
Kyiv (total)	825.463	174.914	146	1.198	21.19

We also processed 3.402 contours for determining the areas of all kinds of UGS with the exception of protected areas (Table 3). The number of contours and their average areas vary depending on districts' areas. The total area of UGS within Kyiv boundaries is about 277.9 km^2. In different city districts, the UGS size varies drastically. In this case, Greenness Coefficients characterise the UGS share in the entire territory of the districts. It is calculated by dividing the total area of each district by the UGS area in this district, without accounting for the UPA area.

Since UGS are spread across the city very unevenly, their geographic location is of important practical significance. Even under the condition of presence of big areas, UGS can be concentrated only in one part of a district. Districts with different UGS covering are identified using Greenness Coefficients (GC), which characterise the percentage quotient of dividing the UGS area on the total area of Kyiv districts. Then, the Greenness Coefficients Index (GCI) is found for each district. The reference GCI value for the city as a whole is taken to be a unit, and the GCI of each district is found from the formula:

$$GCI_d = \frac{GC_d}{GC_c}, \quad (1)$$

where GCI_d – district GCI, GC_d – district GC, GC_c – total city GC.

Then, district ratings by the greenery level are found. Based on the results obtained, the priority districts for planning an expansion or optimisation of the Kyiv UGI can determined.

Table 3. Urban Green Spaces of the Kyiv city (without UPA)

Districts of Kyiv	Area, km^2	UGS (without UPA), km^2	Number of contours	The average area of the contour, km^2	Greenness Coefficients (without UPA), %
Desnianskyi	141.396	91.400	291	0.314	64.64
Darnytskyi	127.846	76.379	396	0.193	59.74
Dniprovskyi	68.678	26.374	331	0.080	38.40
Obolonskyi	108.484	37.654	413	0.091	34.71
Podilskyi	34.555	6.124	165	0.037	17.72
Solomianskyi	40.579	5.605	432	0.013	13.81
Holosiivskyi	155.590	19.146	461	0.042	12.31
Sviatoshynskyi	102.455	11.069	376	0.029	10.80
Shevchenkivskyi	26.110	2.380	349	0.007	9.12
Pecherskyi	19.770	1.751	188	0.009	8.86
Kyiv (total)	825.463	277.882	3,402	0.082	33.66

The green space provision per a person (GSPP) characterises the ratio of the number of population and the areas of UGS of all kinds in each Kyiv district. This indicator is the quotient of dividing the district UGS area on the permanent number of residents in the same district. Likewise, having accepted the GSPP value as a basic one for the city as a whole, the formula (2) is used to calculate the Green Space Provision Index (GSPI) for each district:

$$GSPI_d = \frac{GSPP_d}{GSPP_c}, \quad (2)$$

where $GSPI_d$ – district GSPI; $GSPP_d$ – district GSPP; $GSPP_c$ – total city GSPP.

Green space legally protected (GSLP) characterises the ratio of available UPA and the total UGS area in different Kyiv districts. GSLP is the percentage quotient of dividing UPA on the total UGS area of a district. Next, the Green space legally protected Index (GSLPI) is found for each district. The reference GSLPI value in the districts is accepted to be this index for the city as a whole. Then GSLPI for each district is found from the formula:

$$GSLPI_d = \frac{GSLP_d}{GSLP_c}, \quad (3)$$

where $GSLPI_d$ – district GSLPI; $GSLP_d$ – district GSLP; $GSLP_c$ – total city GSLP.

Having processed all significant indicators, the integral Green Space Index (GSI) is determined as the key criterion of compliance of Kyiv and of all of its districts with current requirements to a compact and green city. It directly affects the level of comfortable living in the city and in its separate districts. The GSI for each district is found from the formula:

$$GSI_d = GCI_d + GSPI_d + GSLPI_d, \quad (4)$$

where GSI_d – district GSI; GCI_d – district GCI; $GSPI_d$ – district GSPI; $GSLPI_d$ – district GSLPI.

Results and their analysis

According to the Goals of sustainable development in Ukraine, one of the tasks of the goal 11 is providing overall access to urban green zones open to all residents (Sustainable Development Goals in Ukraine, 2016). One of the five key priorities of the Kyiv Development Strategy up to 2025 is an environmentally clean and green city. The latest version of the Strategy has an updated life comfort index with the following indicators: emission of pollutants to the atmosphere, share of disposed waste in their total volume, area of nature reserve lands and provision of residents with green zones of common usage. However, the weight coefficient of the "Eco policy and environmental control" sector in the calculation of the life comfort index is merely 7% (The Kyiv Development Strategy Until 2025 new version, 2018). The condition of Kyiv's green zones and their spatial distribution depends directly on the implementation of the Urban Development Master Plan. Starting from 1958, when Kyiv became a million-plus city, its annual residential growth exceeded 50.000. This made the city a powerful industrial and scientific centre. The most balanced planning document in Kyiv's history was the Master Plan of 1967, according to which urban development was about equally allocated to both Dnipro banks. The last draft Master Plan of Soviet times was not implemented because of the Chernobyl NPP nuclear accident in 1986. It provided for abandoning the concept of the radial-ring urban structure and expanding the city boundaries extensively to the north and south (Palekha, 2017).

After Ukraine had gained independence, the drafting of a new quality Kyiv Development Master Plan continued for ten years. At the time of its approval in 2002, the city area was 835.5 km^2, including a development area of 339.3 km^2 (40.6%). The Master Plan provided for increasing the greenery area of common use by 232.000 ha – from 529.000 to 761.000. Accordingly, its provision for residents had to grow from 20.3 to 28.7 m^2/person in 2020 (Heneralnyi plan mista Kyieva na period do 2020 r. Osnovni polozhennia, 2001). However, during less than ten years, this indicator dropped to 18.5 m^2/person (at a norm of 20 m^2/person). Big greenery zone areas were destroyed for housing development, thereby having curbed the opportunity of developing a compact urban planning structure. Failing to meet many planning indicators and the many violations of Master Plan 2020 stimulated the initiation of a qualitatively other strategy of the capital's spatial development. The chief goal of elaborating a new version of the Master Plan, among other things, was to create a comfortable and safe urban environment. If earlier Kyiv was actively incorporating suburban territories, then now the city's area had to remain unchanging. This meant that "compactness" was to be the underpinning of the principles of sustainable development of the capital. In the new version of the Master Plan, increasing the population's provision with greenery was planned more prudently – from 18.5 to 23.5 m^2/person in 15-20 years (Heneralnyi plan mista Kyieva. Osnovni polozhennia, 2015).

Presently, a new draft of the Kyiv Development Master Plan up to 2040 has been worked out. It has been officially disclosed to the public for discussion.

The draft plan envisages to finally abandon a substantial expansion of the city by incorporating surrounding inhabited localities, and to focus efforts on developing a comfortable compact city based on its resources and potential. By 2040, the plan is to increase UGS areas of common use by 23.000 ha and create 36 new parks and 17 buffer parks, predominantly in new residential districts. The planning also provides for adding eleven new sites to the existing nature reserve fund (NRF) and expand the territory of the Holosiyivskyi National Natural Park (NNP) to 126.000 ha (Ofitsiinyi sait komunalnoi orhanizatsii «Kyivhenplan». Proiekt Heneralnoho planu mista Kyieva, 2020). However, some experts perceive the new project as an attempt to legalise the many new developments and the detailed plans of territories approved in disregard for the Master Plan in effect (Titamyr, 2020). Therefore, before submitting the draft plan for appraisal, prior to its final approval by the Kyiv City Council, it must be reviewed thoroughly.

Since 2005, the Kyiv City Council has been trying to come to a suitable decision on determining the city planning parameters for the formation, functioning and development of an UGS chain. First, a five-year Program of development of the Kyiv green zone was approved and then it was prolonged three times, without ever being executed in full scope. The key tasks of this Program included an inventory of all UGS within city boundaries and a prolongation of the moratorium on alienation of land plots from the territory of the city's green structure. The Program has not been executed to date and the inventory has yet again been prolonged. Common use of UGS in Kyiv include five categories: recreation and entertainment parks, recreation parks, specialty parks, public gardens, and boulevards. In 2018, most parks were located in the Holosiyivskyi (23%) and Dniprovskyi (20%) districts of Kyiv. The smallest number of parks was in the Sviatoshynskyi (3%) and the Podilskyi (1%) districts (Vakulyk, 2018).

The effective Program of ecological well-being of Kyiv for 2019-2021 provides the increasing of the provision of common use of UGS from 22.0 to 23.5 m^2/person (Ofitsiinyi veb-sait Kyivskoi miskoi rady. Pro zatverdzhennia Kompleksnoi miskoi tsilovoi prohramy ekolohichnoho blahopoluchchia mista Kyieva na 2019-2021 roky, 2018). This document states that the area of all kinds of UGS is 565.000 ha, or 67.4% of the city's territory (Table 4). 216.000 ha of it are located within urban development limits. The UGS structure includes 111 parks, 466 public gardens, 59 boulevards and 326.000 ha of urban forest, the territory of which has thirty-seven recreation zones. However, these data turned out to be significantly overstated as compared to the draft Kyiv Development Master Plan data and the indicators that we have calculated in this study.

New state building standards (SBS) were put into effect in Ukraine in 2019. They envisage imposing restrictions on development in green, landscape and recreation zones. "Green lines" should help in determining the areas of all common use of UGS, recreation woods and urban forests, and of NRF sites. In other words, local self-administration bodies should approve the green lines in the master plans of inhabited localities and detailed plans of territories. The structure of common use UGS area, including big parks with an area of over 100 ha and urban forests with an area of over 500 ha, should involve no less than 10% of the total UGS area. The time of transport access to city parks should be within 20 minutes, and to those of district ones, no more than 15 minutes

Table 4. Distribution of green spaces by districts of Kyiv (as of 2018)

Districts of Kyiv	Green spaces area, ha						
	Parks	Small parks	Boulevards	Prospectuses	Squares	Streets	Others
Holosiivskyi	495.4	46.1	61.7	79.1	27.9	71.4	225.8
Darnytskyi	154.5	39.6	1.5	25.8	5.0	68.8	1,044.0
Desnianskyi	504.7	11.4	3.2	27.3	–	73.6	517.4
Dniprovskyi	483.2	30.3	27.0	14.9	1.5	45.9	52.6
Obolonskyi	177.5	117.7	12.8	20.9	–	125.7	100.7
Pecherskyi	211.2	7.2	14.2	–	1.5	59.0	53.7
Podilskyi	173.5	25.6	2.3	18.6	–	50.3	566.1
Sviatoshynskyi	60.3	51.7	13.1	37.3	–	131.6	441.4
Solomianskyi	180.6	53.3	11.3	18.2	-	86.7	205.9
Shevchenkivskyi	379.2	41.7	7.2	2.6	–	93.0	32.8
Kyiv (total)	2,820,1	424.6	154.3	244.7	35.9	806.0	3,240.4

Source: Ofitsiinyi veb-sait Kyivskoi miskoi rady. Pro zatverdzhennia Kompleksnoi miskoi tsilovoi prohramy ekolohichnoho blahopoluchchia mista Kyieva na 2019-2021 roky, 2018

(Derzhavni budivelni normy Ukrainy. Planuvannia ta zabudova terytorii, 2019).

For a detailed analysis of the current condition of UGS in Kyiv and its separate districts, we plotted on the map all the UGS within city boundaries, irrespective of the form of their ownership (Fig. 4). This helped calculate the total UGS area, which is 452.8 km^2, or 54.8% of the entire city territory. We also determined UGS areas and calculated the Greenness Coefficients for each of the ten capital districts (Table 5). As a result, the Greenery level leaders are Park, with an area of 219.4 ha, located on the Dnipro islands among bedroom communities. Sviatoshynskyi district was the runner up by this rating owing to the Sviatoshynsko-Bilychanskyi urban forest. It is the northern branch of the single in Ukraine urban Holosiyivskyi NNP. Obolonskyi district, third by the GCI rating, is the site of the Pushcha-Vodytsia oak-pine forest, part of which has the status of a reserve of statewide significance. Darnytskyi district was the fourth in the ratings of districts by the greenery level, and it is one of the oldest and biggest districts in Kyiv.

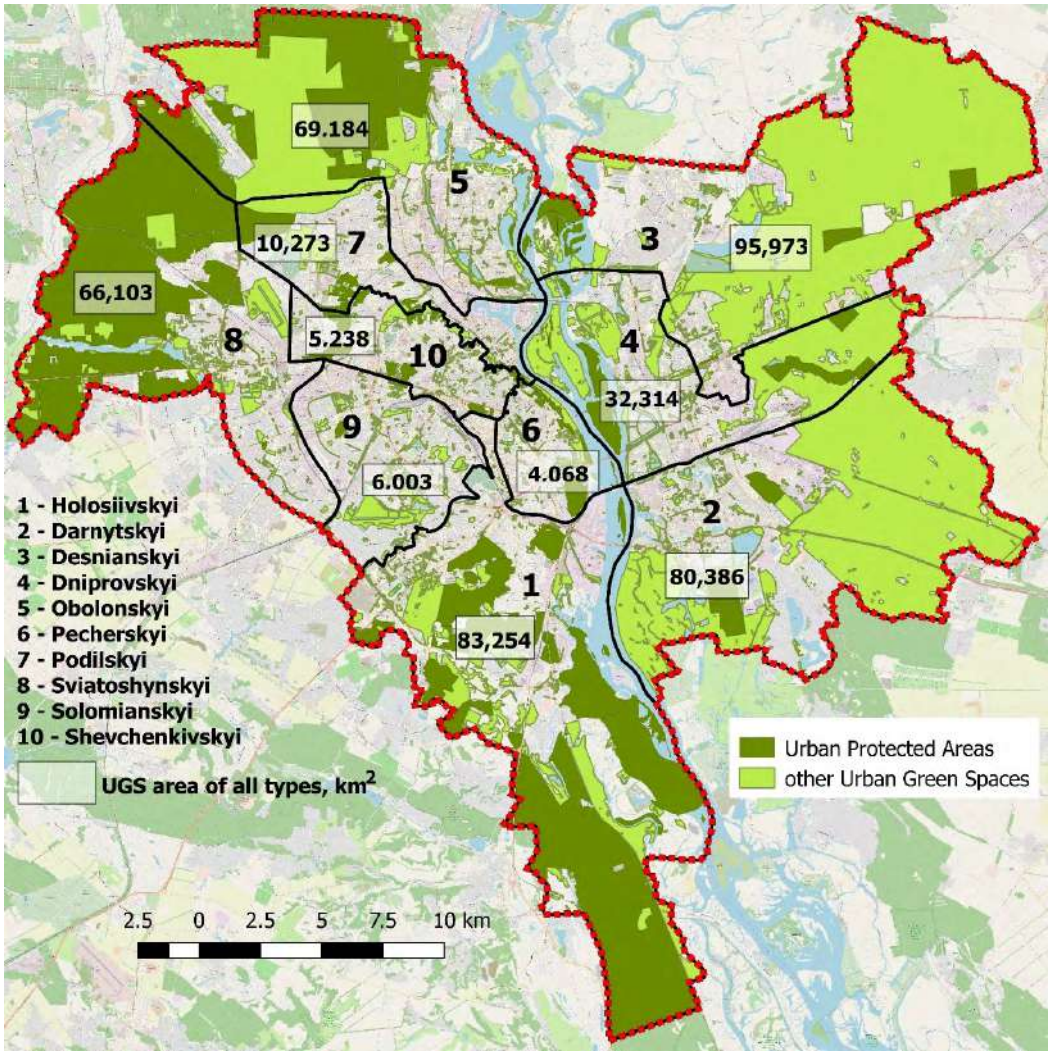

Fig. 4. Urban Green Spaces of the Kyiv city

the Desnianskyi (67.9%), Sviatoshynskyi (64.5%), Obolonskyi (63.8%) and Darnytskyi (62.9%) districts of Kyiv. The smallest greenery level is found in the densely populated Solomianskyi district where the UGS covers only 14.8% of its territory (Fig. 5).

The primacy of Desnianskyi district by the Greenness Coefficients Index is due to the presence on its territory of eleven recreation and entertainment parks, over thirty public gardens and a big urban forest. The biggest and the best known one is Muromets On one side, it is surrounded by a forest, and on the other one, it flanks the Dnipro River. The district has five big parks and the Osokorkivski Luky landscape reserve with an area of 148 ha and unique wetlands. At the same time, Darnytskyi district is distinct from other ones by the presence of densely developed residential blocks and industrial enterprises, in particular, chemical and pharmaceutical ones, which results in its substantial environmental degradation as a whole.

As expected, Solomianskyi district had the lowest GCI, with the main UGS being concentrated in its southern part. The biggest UGS is the Pronivshchyna stow located in the upper reach of the Sovka River. This historical locality has been preserved in a natural ravine, the greater part of which has been developed. In addition, Solomianskyi district is the most densely populated one in Kyiv.

A somewhat different rating of Kyiv districts was found by the Green Space Provision Index. It was calculated with account of UGS of all kinds, including urban forests and UPA in each district (Table 5). Population figures were taken from the official website of the Chief Statistics Department in Kyiv. Holosiyivskyi district has the biggest GSPP (329.65 sqm per a person) because it has the biggest area and the smallest population (Fig. 6). Desnianskyi district was the runner up where each resident is provided, on the average, with 261.78 sqm of green spaces. Darnytskyi district was the third with an index of 235.79 sqm per a person. Obolonskyi district, with the fourth rating, also has a high index. Solomianskyi district has the lowest rating (15.75 sqm per a person), with the densest population and an area about four times smaller than that of the Holosiyivskyi district. Hence, the GSPP in the Solomianskyi district is smaller by more than twenty times.

Table 5. Main indicators and ratings (R) of Urban Green Spaces in the Kyiv city

Districts of Kyiv	UGS, km^2	GC, %	GCI	R	GSPP, sqm/pp	GSPI	R	GSLP, %	GSLPI	R	CGSI	R
Holosiivskyi	83.254	53.51	0.98	5	329.65	2.13	1	77.0	1.99	2	5.10	1
Darnytskyi	80.386	62.88	1.15	4	235.79	1.52	3	4.98	0.13	9	2.80	5
Desnianskyi	95.973	67.88	1.24	1	261.78	1.69	2	4.76	0.12	10	3.05	4
Dniprovskyi	32.314	47.05	0.86	6	90.52	0.58	6	18.38	0.48	7	1.92	8
Obolonskyi	69.184	63.77	1.16	3	218.73	1.41	4	45.57	1.18	5	3.76	3
Pecherskyi	4.068	20.58	0.38	8	25.67	0.17	8	56.96	1.47	3	2.02	6
Podilskyi	10.273	29.73	0.54	7	50.14	0.32	7	40.39	1.05	6	1.91	9
Sviatoshynskyi	66.103	64.52	1.18	2	196.28	1.27	5	83.25	2.16	1	4.60	2
Solomianskyi	6.003	14.79	0.27	10	15.75	0.10	10	6.63	0.17	8	0.54	10
Shevchenkivskyi	5.238	20.06	0.37	9	24.83	0.16	9	54.56	1.41	4	1.94	7
Kyiv (total)	452.796	54.85	1.00		154.77	1.00		38.63	1.00		3.00	

Sviatoshynskyi district is the undisputable leader among Kyiv districts by the Green Space Legally Protected Index. Its protected areas occupy 83.25% of all UGS. It locates the Sviatoshynskyi-Bilychanskyi woodland with an area of 6.463 ha. Since 2014, it has the status of a national natural park of statewide significance. The predominant greenery comprises lucent oak groves, oak-pine and pine forests including many valuable plant species listed in The Red Book of Ukraine (TRBU). The most common TRBU species are *Lilium martagon* L., *Carex umbrosa* Host, *Epipactis helleborine* (L.) Crantz, *Neottia nidus-avis* (L.) Rich) (Pryadko et al, 2014). Besides, the Sviatoshynskyi urban forest, with an area of 240 ha, is located in the Sviatoshynskyi district.

As expected, Holosiyivskyi district was the runner up by the GSLPI rating because the share of protected areas in its UGS structure is 77%. Four of the five branches of the Holosiyivskyi NNP are located in this district: the Lisnyky stow, the Bychok stow, the Teremky stow and the Holosiyivskyi Forest with the total area of 4.525.52 ha. There are rare species included in TRBU and the IUCN Red List, such as the common snowdrop (*Galanthus nivalis* L., 1753), the two-leaf squill (*Scilla bifolia* L., 1753), the violet helleborine (*Epipactis purpurata* Sm., 1828), the broad-leaved helleborine (*Epipactis helleborine* (L.) Crantz, 1769), the martagon lily (*Lilium martagon* L., 1753), etc. (Onyshchenko et al., 2016). The smallest GSLP share belongs to the Darnytskyi (4.98%) and Desnianskyi (4.76%) districts located on Kyiv's left bank. Among right-bank districts, the last place in the rating belongs to Solomianskyi district with a GSLP of 6.63%. In other words, in three Kyiv districts, the UPA share is less than 7% of the total UGS area. This dramatically downplays the perspectives of preserving the natural component of urban landscapes in these districts and worsens their attractiveness in terms of living comfort.

By summarising the processed ratings, we can calculate the integral Green Space Index, allowing for an integrated evaluation of the UGI in all ten Kyiv districts. As evident from Table 5, Holosiyivskyi district received the highest GSI (5.1) and the runner up was Sviatoshynskyi district. Both these districts are

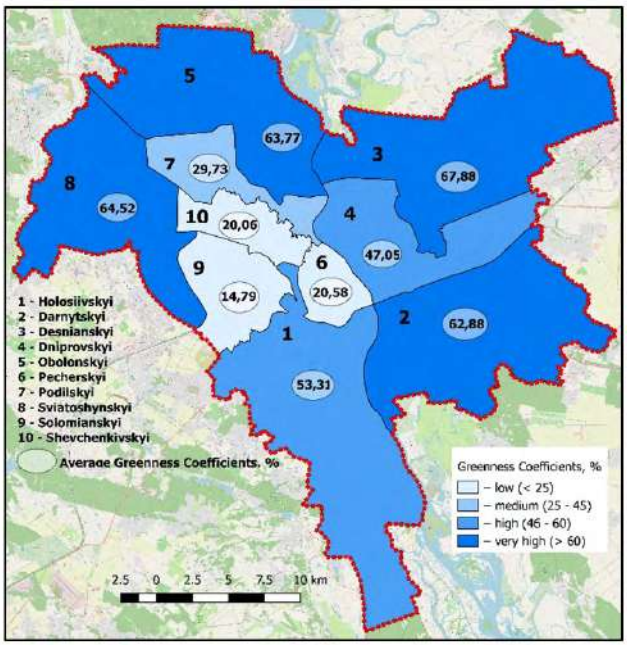

Fig. 5. Greenery levels of Kyiv districts

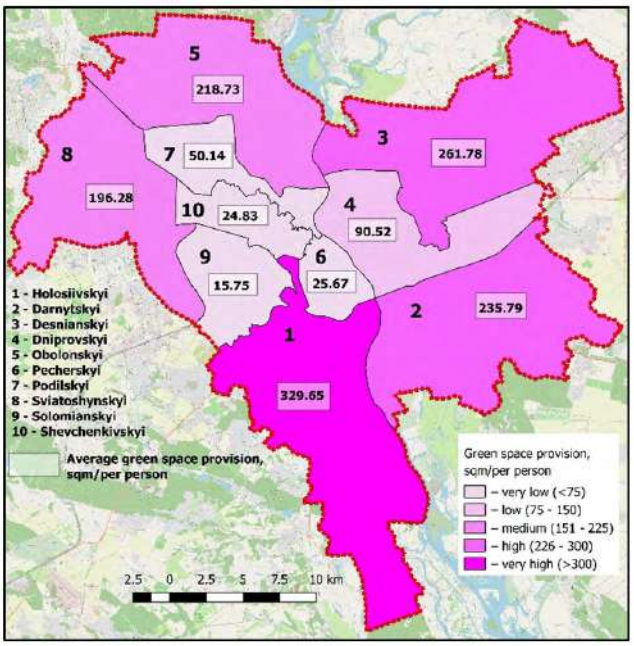

Fig. 6. Green space provision in Kyiv districts

more or less uniformly covered with UGS, which have been developed for quality recreation and, at the same time, are protected by nature conservation laws. A significant share of UGS is located at a 15-minute walking distance from residential communities. Of course, there are certain discrepancies in the provision of UGS for local residents in separate residential districts. Over the previous decade, Holosiyivskyi district is the place where many new housing complexes with dense development and insufficiently developed street greenery are located. Sviatoshynskyi district has a shortage of UGS in some locations in the Mykil'ska and Pivdenna Borshchahivka residential districts, which are burdened with old housing.

The GSI rating of the Obolonskyi, Desnianskyi and Darnytskyi districts was the lowest (from 3.8 to 2.8). Their UGI is fairly developed, though the UGS territorial distribution is uneven by being concentrated primarily in one part of the districts. Therefore, roughly one-half of the residents are deprived of easy access to recreation zones. The UGS in only the Obolonskyi district is arranged quite evenly in all residential neighbourhoods, which are replete with parks, public gardens and boulevards within pedestrian access. Almost all of them are developed for recreation**.** Desnianskyi district, the second largest district by area after Holosiyivskyi district, is distinguished by uneven UGS distribution. Substantial UGS lands are concentrated in its eastern part on Dnipro islands. There are many "grey" zones here, with dense high-rise building development. There is a scarcity of UGS mostly in the Troyeshchyna residential district where, in the first place, it would be expedient to plan new UGS. Darnytskyi district is abundant in urban forests and water bodies; however, many of them are unsuitable for quality recreation. In other words, the UGI is in decay and needs an expansion, especially in the Pozniaky residential district where UGS is most underprovided. Most UGS in the Desnianskyi and Darnytskyi districts have no legislative protection, and can be developed in some time.

Outright, four districts (Pecherskyi, Shevchenkivskyi, Dniprovskyi and Podilskyi) have roughly the same GSI rating (from 2.02 to 1.91). On top of that, the first two districts differ by a very high population density. This means that their UGI is in a poor condition, and only in some locations it is satisfactory. Most residents in these districts have no convenient access to recreation sites, and are made to spend much time to overcome the big distances to UGS. This is like in the Dniprovskyi district where the main UGS is confined to island, riverside and central parts of the district. UGS expansion is especially needed in densely populated residential neighbourhoods that border on industrial zones. The Podilskyi district UGS is concentrated most in its western part, closer to the Dnipro River, whereas the Vynohradar residential district is almost without them. Shevchenkivskyi district is experiencing a critical shortage of UGS, with its bulk being concentrated along its perimeter. The most densely populated central residential districts are particularly short in greenery. Accounting for one of the biggest population densities in Kyiv, expanding the chain of UGS in Shevchenkivskyi district is more challenging than in other districts of the city. In Pecherskyi district, about one-half of all UGS are located

in the M.M. Hryshko National Botanical Garden. The bulk of UGS is concentrated along the Dnipro River and street greenery is inadequate. Expanding existing and developing new UGS is most needed in the Klov stow and in new housing developments, the number of which is growing from year to year.

Solomianskyi district is far behind other Kyiv districts in the GSI (merely 0.54). This is the expected result of its lowest positions in all the ratings we had compiled. Here, a cardinal renovation of almost all existing UGI elements is needed. Expanding and creating new UGS in Solomianskyi district is most critical for the densely developed Vidradnyi residential area with an industrial zone, and for the Chokolivka and Zhuliany residential districts. This district has a critical shortage of UPA, making it impossible to specify conventional "green lines" for developers. In fact, the new Kyiv Development Master Plan draft provides for creating a landscape protected area of local significance in Solomianskyi district called Sovska Balka with an area of 9.7 ha; however, for a long term of 20 years this is insufficient.

Therefore, as is evident, UGS in most Kyiv districts is confined to distant territories close to water bodies and separate woodlands. Their fairly substantial share in the city's overall territory and the calculated Greenness Coefficients are creating an illusion of sufficient provision of the city with UGS. However, our study is indicative of the need to expand existing UGS and create new ones in many locations according to the principles of compact city planning. The new draft Master Plan should be modified with regard for UGI elements requiring priority optimisation.

Conclusions

The ideal of sustainable urban planning today is a compact city with an attractive green infrastructure. UGS in compact cities perform many functions, provide valuable ecosystem services and are accessible for city residents. Following modern trends, the Kyiv administration has declared an environmentally clean and green city as the key priority of the Kyiv development strategy. Instead, UGS are falling victim to competition with other elements of the Kyiv infrastructure, and are used often as reserved space for housing development or other urban development projects. In other words, urban densification leads to UGS loss and contraction of green space provision per capita. The studies conducted point to the practicality of including the Green Space Index in the mix of key indicators used for assessing the comfort of living in Kyiv and in its separate districts.

The realities of creating a compact city call for imposing a moratorium on destroying UGS in areas popular for development, and UGS should be expanded in districts with a low Green Space Index rating. The results of this study should serve for clearly identifying priority "green lines" in different Kyiv districts, which should be approved in the new Master Plan. With account of the shortcomings in the development of the Kyiv UGI (uneven territorial distribution, insufficient provision for the population, misuse, etc.), the regulatory and legal framework should be revised in terms of conducting a geoecological assessment of all UGS and the functions they perform. Special emphasis should be placed on optimisation and connectivity of the UPA chain in conditions of inevitable densification of urban territories. Since excess population density in separate Kyiv districts is one of the factors that considerably increase the environmental load on urban landscapes, it is necessary to make an inventory of UGS ecosystem services and perform their integral environmental and economic assessment.

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