


## A GIS ASSESSMENT OF THE GREEN SPACE PERCENTAGE IN A BIG INDUSTRIAL CITY (DNIPRO, UKRAINE)

YURIY BUCHAVYI<sup>1</sup>, VIKTORIIA LOVYNSKA<sup>2</sup>, ALLA SAMARSKA <sup>3</sup>

<sup>1</sup>Department of Ecology and Environmental Technologies, Dnipro University of Technology, Dmytro Yavornytskyi Av., 19, Dnipro, 49005, Ukraine; e-mail: buchavyi@gmail.com

<sup>2</sup>Department of Forest and Garden, Dnipro State Agrarian and Economic University, S. Yephremova St., 25, Dnipro, 49600, Ukraine; e-mail: glub@ukr.net

<sup>3</sup>Department of Ecological and Civil Safety, Ukrainian State University of Science and Technologies, Lazarian St., 2, Dnipro, 49010, Ukraine; e-mail: samarskaya.av@gmail.com

 Corresponding author

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### Abstract

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Green spaces in an industrially polluted city are extremely important for the physical activity and mental health of its inhabitants. The study aim was to analyze the urban green space dynamics and the greening degree of different functional zones typical for a big Ukrainian industrial city (Dnipro, Ukraine). This article used the remote sensing methods and geographic information systems (GIS) to assess the percentage of green spaces in the city of Dnipro, its eight districts, parks, ravines, and sanitary protection zones. The Normalized Difference Vegetation Index (NDVI) was used for mapping the urban green spaces within the ravines, parks, and sanitary protection zones. According to our results, 67% of Dnipro city is greened (NDVI >0.3). On average, there are 219 m<sup>2</sup> of green spaces per person, which is 24 and 4 times more than the minimum and optimal values recommended by the World Health Organization (WHO), respectively. It was found that the NDVI values were significantly lower in the territories of sanitary protection zones, compared to the other functional zones. The results of NDVI analysis indicate a significant variation of the studied parameter during the vegetative season, with two typical peaks of the green space vegetative activity. The peak of plant vegetative activity occurs in the first decade of June, followed by slight decline for 2–3 weeks, then there is another increase in the activity, reaching the maximum in mid-July. Even in autumn, the photosynthetic activity remains relatively high for most of the urban areas, declining only from mid-October. In addition, a method and algorithm for estimating and standardizing the level of the urban area greening based on the remote sensing methods and zonal statistics tools are proposed.

*Key words:* green spaces, NDVI, city, parks, ravines, sanitary protection zones, districts.

### Introduction

Urbanization is known to have resulted in many ecological problems (industrial and transport emissions, smog, haze, sewage discharges, enhanced eutrophication, growing dumps, unpleasant odor, noise, vibration, extreme heat events, green space and biodiversity losses, etc.) that influence both physical and mental health of urban residents (Bihuňová et al., 2021; Dimitrov-Discher et al., 2022; Liang, Gong, 2020; Lin et al., 2020; Oliver et al., 2019; Russo, Cirella, 2018; Vardoulakis et al., 2016; Yang et al., 2014). A rapid growth of cities and urban population share accompanied by significant energy and resource consumption is directly related to climate change and global warming. Especially heat and consequently heat-related stress (heat stroke, dehydration, exhaustion, cramps, and rashes) are felt in urban paved and built-up areas. This results from the well-known and adverse effect of urban heat islands. One of the reasons for this phenomenon is the lack or absence of urban green spaces and street tree cover. Thus, green spaces have been proven to miti-

gate climate change impacts, reduce temperature and heat island effect, providing shade and cooling. There are negative correlations between urban green spaces and temperatures (Aram et al., 2019; Chakraborty et al., 2020; Hsu et al., 2021; Lemonsu et al., 2015; Stone et al., 2010; Zhou et al., 2017).

Green spaces certainly provide many environmental and health benefits (Kingsley, EcoHealth Ontario, 2019). In addition to urban green space cooling effect, they have globally been considered to be the “green lungs” or “living buffers” of modern densely built-up cities and megalopolises (Jones, 2018; Xing, Brimblecombe, 2020). Urban greenery is usually able to mitigate and neutralize the harmful impacts of chemical compounds, biological agents, heat, and noise pollution. Thus, well-designed urban green spaces predominantly have a positive effect on urban ecosystem stability, biodiversity, public physical and mental health (Diener, Mudu, 2021; Dzhambov, Dimitrova, 2015; EEA, 2022; Fischer et al., 2018; Fuertes et al., 2020; Jerrett, van den Bosch, 2018; Liu et al., 2019; Margaritis, Kang, 2017; Twohig-Bennett, Jones, 2018; Xiao et al., 2022; WHO, 2017).

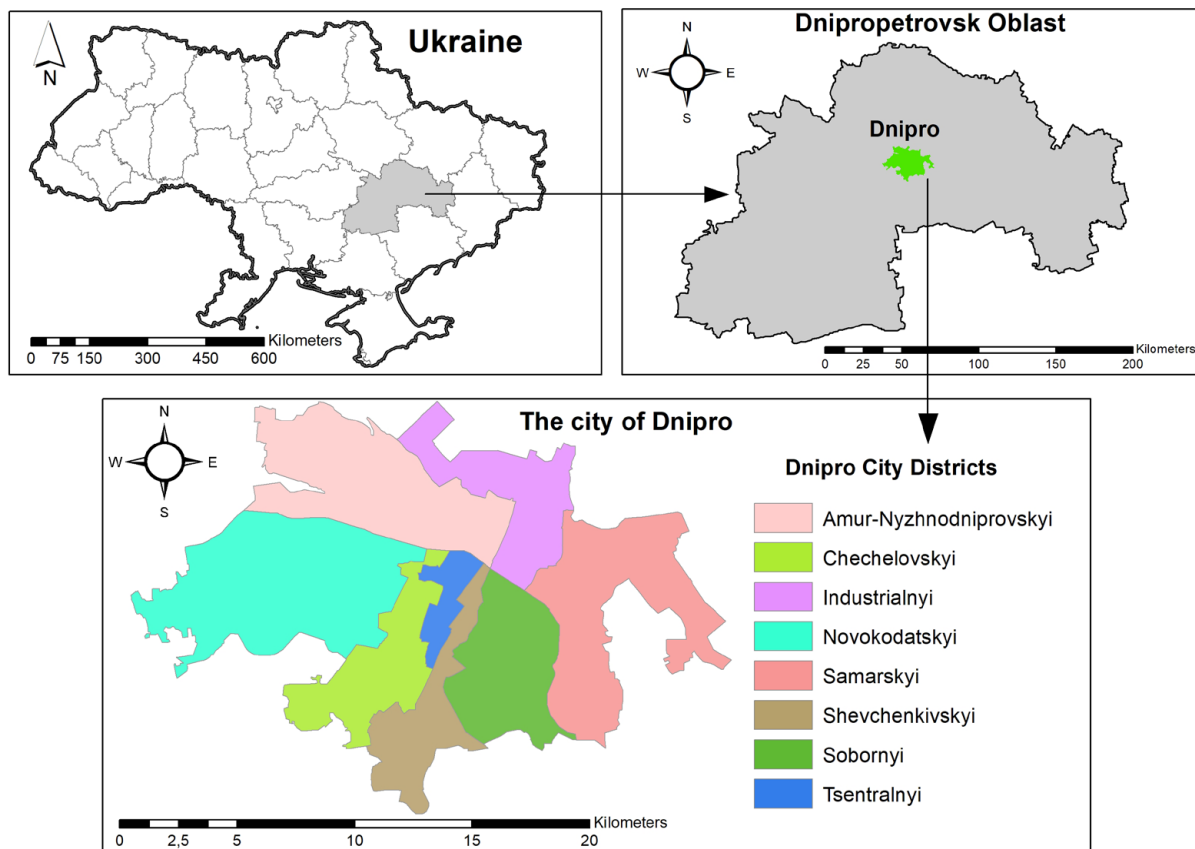


Fig. 1. Location of the study area.

Moreover, in the context of achieving and implementing United Nations’ Global Goal 11 (sustainable cities and communities), urban green spaces play an essential role in city sustainability and resilience. Therefore, solving many environmental, social, physical and mental health, recreational, cultural, and educational issues can be achieved through sensible and effective urban green space design and planning (EEA, 2022; Haaland, van den Bosch, 2015; Nikolaidou et al., 2016; Russo et al., 2017; Russo, Cirella, 2018; Saaty, De Paola, 2017; WHO, 2017; Zverkovskyy et al., 2018). The effectiveness of urban green spaces providing ecosystem and social services depends on their overall percentage and the area per capita, as well as the anthropogenic character and load in a city (Artmann et al., 2019; Russo, Cirella, 2018). Thus, according to the World Health Organization (WHO), the recommended minimal green space area per capita should be at least 9 m<sup>2</sup>, while the ideal value is 50 m<sup>2</sup> (WHO, 2012). Although the recommended minimal and ideal green space areas are highly important indicators, the accessibility, equitable distribution, environmental, social, and decorative quality of urban greenery also impact city sustainability and resilience (EEA, 2022; Jennings et al., 2016; Kabisch et al., 2016; Haas et al, 2021; Tian et al., 2014; Zhang et al., 2017). As for urban green space quality, including ecological, health, and ornamental aspects, plants used for greening must be diverse, healthy, vigorous, local, tolerant to severe city conditions, providing ecosystem services and cooler microclimates

(Bigirimana et al., 2012; Hunter, Luck, 2015; Quijas et al., 2010; Russo et al., 2017; Russo, Cirella, 2018; Song et al., 2020; Yorikina et al., 2022). Also, the possible negative impacts of urban green spaces and lack of planning in their design should be taken into account. For example, pollen allergy is believed to be one of the most common urban diseases. Therefore, species that produce pollen causing and triggering allergies should be avoided (Cariñanos, Casares-Porcel, 2011). Moreover, urban plants must be noninvasive, low or zero emitters of biogenic volatile organic compounds, and nonattractive to infection vectors such as malarial mosquitoes or disease-transmitting ticks (Calfapietra et al., 2013; Ren et al. 2017; Hansford et al., 2017). Consequently, the selection of suitable, safe, and high-quality urban plant species (trees, shrubs, forbs, and grasses) as well as the thoughtful design of green spaces is a difficult, important, and responsible task. Despite possible adverse effects of some plant species, green spaces should be an integral part of modern urban infrastructure and design, as well as city sustainability and livability. Taking into account the predominant ecological and social benefits of urban green spaces, concepts such as “garden city,” “city in a garden,” “forest city,” “vertical forest,” “healing garden,” “biophilic urbanism,” and so on have become paramount, common, relevant, and popular among urban planners, architects, engineers, and public ecological organizations (Bachrach, 2012; Newman, 2014; Pérez-Urrestarazu, 2015; Yuen, 1996). Thus, the sustainable and resilient devel-

opment of modern cities is impossible without the cultivation and maintenance of certain green space areas and their uniform and reasonable distribution in city districts. Because of huge city and megalopolis sizes, it is extremely hard to assess the percentage, distribution, and health state of urban green spaces by direct observation, which is time, money, and human resource consuming. In this context, remote sensing and geographic information systems (GIS) are irreplaceable and powerful tools, which help not only to map different changes in land cover and land use, but also to explore the health state and other indicators of green spaces (Drake et al., 2015; Hoerbinger et al., 2018). For these purposes, scientists have frequently been using one of the most widespread and reliable vegetation indexes – the Normalized Difference Vegetation Index (NDVI) (Gascon et al., 2016; Rouse et al., 1974; Su et al., 2019; Zbiri et al., 2022).

The study aim was to analyze the urban green space dynamics and the greening degree of different functional zones typical for a big Ukrainian industrial city (the case of Dnipro city). The study tasks were (1) developing a rapid, effective, and practical method of a city greening degree assessment, taking into account the functional zones and district separation; (2) assessing the percentage of green spaces in the city and its eight districts; (3) estimating the accessibility and distribution equability of green spaces; (4) identifying vacant lots for greenery; (5) evaluating the urban green space area per individual inhabitant of Dnipro city and its separate districts; (6) comparing these values to the WHO standards and the same values for other cities in Europe; and (7) providing reasonable recommendations on further green space development in Dnipro city, considering 12 environmental indicators of European green capital award.

## Material and methods

### Study area

The study area was the city of Dnipro. Its location is presented in Figure 1. Dnipro is a city in the central part of Ukraine, the administrative center of Dnipropetrovsk oblast region. The city area is 409.718 km<sup>2</sup>. Dnipro is the fourth most populous city in Ukraine (968,502 as of January 2022). It is one of the most prominent political, financial, scientific, and cultural centers in Ukraine. This city is also considered the "space capital" of Ukraine since Dnipro is one of the centers of rocket and space construction in the world. In addition, Dnipro is one of the largest industrial centers of Ukraine: ferrous metallurgy, metalworking, mechanical engineering, and other branches of heavy industry are especially developed here. Thus, the basis of the city's industry is the metallurgical complex. Dnipro produces 6.9% of the total volume of ferrous metallurgy in Ukraine. As a result, this has led to many ecological problems, especially air pollution. According to the comprehensive index of the air pollution by priority pollutants, the air pollution level in Dnipro is above average. As a rule, the concentrations of dust, nitrogen dioxide, ammonia, phenol, and formaldehyde in the air constantly exceed the maximum permissible concentrations (Ecological Passport, 2020). The climate of Dnipro is classified as a humid continental climate with no dry season and hot summers. The average annual air temperature is +9 °C, the lowest in January (−3.6 °C) and the highest in July (+22.1 °C). There are an average of 260 sunny days

per year. On average, 539 mm of precipitation falls in Dnipro annually, the least of which is in July, August, and September and the most in December and January. There are large natural blue spaces in Dnipro, which should be taken into account during the overall greening assessment. For example, the biggest river of Ukraine, Dnieper, runs through the city. Thus, Dnipro has the longest embankment in Europe, and along the right bank of the Dnieper, its length is about 32 km. This river and other water objects should be masked during the GIS analysis.

### Functional zones

Basing on the city layout draws, we consider it expedient to monitor green spaces and determine the indices of different area greening, in particular, parks (squares), ravine network, and sanitary protection zones (SPZs) of industrial enterprises and the city administrative districts.

### Districts

Dnipro includes eight administrative districts, which are presented in Figure 1. The biggest district is Novokodatskyi and the smallest is Tsentralnyi. The city districts are characterized by different land use, accessibility of green and blue spaces, anthropogenic load (industrial and transport), and, consequently, prestige. They are not equal. Splitting the city into districts allows us to compare their greening degree, determine vacant lots for greening, and mitigate the "green difference" between them through developing recommendations. Moreover, conclusions drawn for separate districts will be more correct than those for the whole city, which is large enough.

Monitoring the green space state and determining the area of greening in city administrative districts is necessary to meet the requirements for the greening of urban areas (Bilokon, 2004), according to which each resident must have at least 20 m<sup>2</sup>. The analysis of the administrative district greening levels will identify the most favorable ones or, conversely, the worst among them, which will be the basis for adjusting the city layout draw.

### Parks

Parks are an integral part of Dnipro city. The city has 19 parks. They serve many important functions: cultural, esthetic, recreational, educational, and provide ecosystem services. The city's parks are also habitats for different animals: squirrels, hedgehogs, swans, ducks, pheasants, hoopoes, and others. They are the places of recreation and entertainment for many city residents of all social groups. Depending on their nature and purpose, they are divided into culture and recreation parks, district, sports, children's, botanical, dendrological, zoological, historical, national, memorial ones, and others. Usually, most park areas are covered with green plants, which creates favorable conditions for visitors, but the species composition and sanitary condition of the trees need constant monitoring. The most famous and oldest parks in Dnipro were created at the end of the 18th century. Taras Shevchenko Central Park of Culture and Recreation that consists of the mainland and Monastyr Island has about 8000 trees and more than 2000 shrubs, 68 species in total. Lazar Globa Park has a large lake in the center.

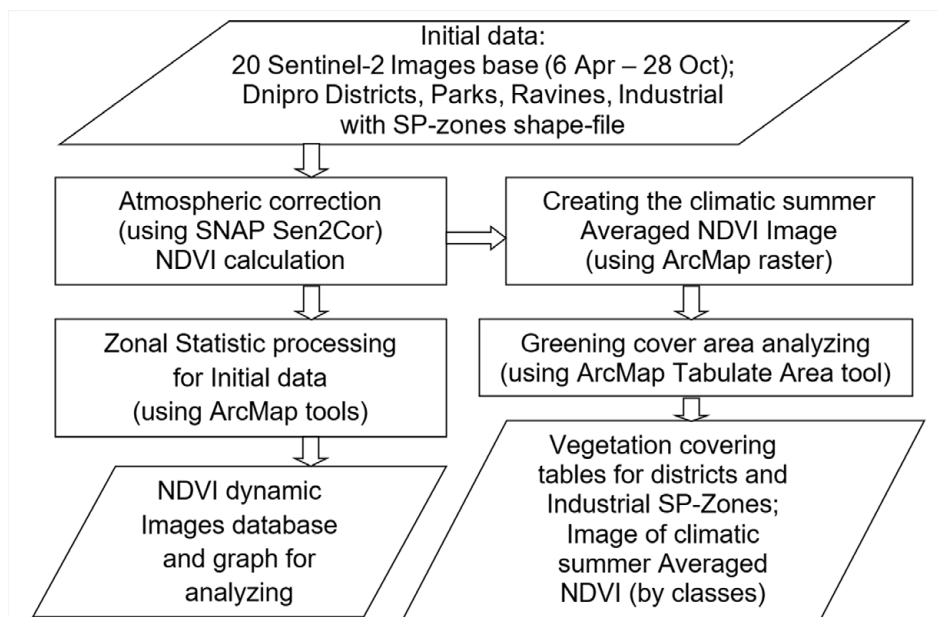


Fig. 2. Data processing algorithm for the monitoring of urban greening degree.

### Ravine

It is one of relief forms that are characteristic of Dnipro city. The city ravines can be defined as valleys with a temporary watercourse and slopes covered with mixed vegetation: grasses, shrubs, and trees. Predominantly, they are semi-natural green spaces, for example, Tunnel Ravine. It is a well-known resting place for Dnipro's citizens. Tunnel Ravine has incredibly complex topography and is completely cut by streams and gullies. There are various types of trees and shrubs in Tunnel Ravine, and the most widespread are oak, rough elm, mulberry, apricot, Tatar and American maple, black elder, common ash, white locust (robinia), ailanthus, white maple, and European smoke tree. The main part of woody vegetation belongs to artificial forest plantation (oak, apricot, robinia, maple). In Soviet times, trees were actively planted in the ravine to maintain the resistance of its slopes to erosion. Ravines are an integral part of the landscape of almost any settlement, usually occupying from 5 to 45% of its territory. In the steppe zone of Ukraine, especially in densely populated areas, urban ravines remain natural refuges for many species of flora and fauna. Ravines are also the areas of settlements' pristine nature, as well as residential areas promising for recreation during the relevant improvement work.

### Sanitary protection zones

According to the Ukrainian legislation, around each industrial enterprise, there should be an appropriate SPZ. In Ukraine, there is a standard determining the size of SPZs and their minimum area of greening in accordance with the industrial enterprise hazard class. Thus, their sizes depend on the hazard category of an enterprise which, in turn, depends on the volume of emissions and vary from 50 to 1000 m. SPZs play a role of green

buffer mitigating the influence of enterprise on citizens and reducing the levels of pollutants from industrial emissions to the maximum permissible levels. Trees, shrubs, and lawns improve air quality by minimizing the concentrations of dust and toxicants in the air, reducing the strength of sound waves, regulating dust and gas flows, and creating a comfortable microclimate. The effectiveness of reducing the adverse effect of pollution sources in the SPZs is determined by the area of greening and the quality of green spaces (Buchavyy, Horova, 2016). Therefore, SPZ must be greened and maintained by enterprises. Such a type of green spaces is typical for most Ukrainian cities. That is why it is important to evaluate their greening degrees separately. Thus, these functional zones are most important for assessing the level of the urban area greening and introducing a system of green space rapid monitoring using the remote sensing technologies and GIS.

### Remote sensing data processing

A data set of 20 multispectral aerial photographs obtained from Sentinel-2A and Sentinel-2B satellites was formed from the publicly available resource Copernicus Open Access Hub for the territory of Dnipro for the vegetation period (April–October) of 2020. Using Sentinel Application Platform (SNAP) Desktop and Sen2Cor module, we made the atmospheric correction of aerial photographs to eliminate the effects of atmospheric influence on the vegetation indices' calculations and obtained the Earth's surface albedo values in different spectral ranges.

The geo-information base, which contains in separate layers contours and attributive information about the districts, parks, SPZs, and ravines of Dnipro, is formed using the Environmental Systems Research Institute (ESRI) ArcGIS Desktop 10.5 program (Fig. 2). Then, for each image, the maps of photosynthetic

**Table 1.** Assessment of the greening degree and distribution of the Dnipro administrative districts areas according to classes of the vegetation indices (NDVI).

№.	Name	<0	0–0.3	0.3–0.5	0.5–0.7	>0.7	Area, m <sup>2</sup>	Vegetation covering, % (NDVI >0.3)
		%	%	%	%	%		
1	Tsentrалnyi	17.6	32.7	22.9	20.5	6.3	10,420,700	49.7
2	Chechelivskiyi	2.0	17.2	29.9	38.2	12.8	37,695,000	80.9
3	Industrialnyi	3.0	32.3	33.3	26.6	4.8	38,142,800	64.7
4	Shevchenkivskiyi	3.0	24.2	27.5	33.1	12.2	30,557,200	72.8
5	Sobornyi	31.7	20.2	17.6	21.6	8.9	44,147,900	48.1
6	Amur-Nyzhnodniprovskiyi	9.8	15.2	27.6	39.6	7.8	69,996,700	75.0
7	Novokodatskiy	8.9	12.2	18.5	30.2	30.2	89,406,400	78.9
8	Samarskiy	12.6	20.9	29.1	30.4	7.1	68,268,300	66.5
<b>Total</b>	<b>Dnipro city</b>	<b>11.1</b>	<b>21.9</b>	<b>28.5</b>	<b>30</b>	<b>11.3</b>	<b>48,579,375</b>	<b>67</b>

**Table 2.** The green space area per individual in Dnipro’s districts and the WHO standards.

№.	Name	Population	Vegetation covering, m <sup>2</sup>	Green area/person, m <sup>2</sup>	WHO values, m <sup>2</sup>		The 2016 European Green Capital Ljubljana, Slovenia
					Min.	Ideal	
1	Tsentrалnyi	48,780	2,792,747.6	57.3	9	50	560
2	Chechelivskiyi	85,587	19,224,450	224.6			
3	Industrialnyi	98,182	11,976,839.2	122			
4	Shevchenkivskiyi	107,151	13,842,411.6	129.2			
5	Sobornyi	112,888	13,465,109.5	119.3			
6	Amur-Nyzhnodniprovskiyi	123,165	33,178,435.8	269.4			
7	Novokodatskiy	134,803	54,001,465.6	400.6			
8	Samarskiy	59,627	25,600,612.5	429.3			
<b>Total</b>	<b>Dnipro city</b>	<b>770,183</b>	<b>21,760,259</b>	<b>219</b>			

activity of Dnipro city were constructed according to the NDVI values, followed by the analysis of its dynamics and the calculation of the average seasonal values for 2020. Using the tools of zonal statistics in the ESRI ArcGIS Desktop 10.5 program, we carried out classification of the studied objects of the city according to the green space condition and greening indicators and obtained the numerical values on the distribution of certain vegetation indices. The areas of different surface types according to NDVI were determined separately for each GIS object using the Tabulates Area tool. This methodological approach enabled to conduct a zonal statistical analysis of vegetation indicators in the Dnipro territory and determine the dynamics of the city greening indicators.

**Results**

Using zonal statistics tools, we carried out the analysis of the greening degree and the distribution of the areas of the administrative districts (Tables 1 and 2) and the industrial enterprise SPZs (Table 3) according to classes of the vegetation indices. According to the NDVI classification, the area is considered to be planted at values higher than 0.5 (Aquino, Oliveira, 2012). Table 1 presents the green space percentage in the city and its districts.

The obtained results show that 67% of Dnipro city is greened (NDVI >0.3). For comparison, the capital of Slovenia (the 2016 European Green Capital Award Winner) has the same percentage of total green infrastructure. According to the degree of landscaping, Dnipro only lags behind European capitals like Zagreb of the Republic of Croatia and Oslo of Norway (EEA, 2022). Although the percentage of green spaces is relatively high, the urban plants cannot cope with such a level of pollution. Moreover, there are many vacant lots for greenery, for example, abandoned enterprises on the left bank of the city. Thus, parks can be created on the site of abandoned enterprises. In this context, the role and importance of the city’s layout draws are growing as they have to reflect the integrity and unity of the greening system and allot reserve spaces to prevent the constantly increasing industrial and residential buildings from occupying the areas aimed at greening and recreational zones.

The layout draws of Dnipro city have to promote the preservation and protection of the existing green spaces, but it is almost impossible to develop them competently without preliminary estimation of the dynamics, reasons, and consequences of green space state. This justifies the topicality of control over the dynamics of the city greening state and the green space state itself, namely, the introduction of a permanent greenery monitoring

**Table 3.** Assessment of the greening degree and distribution of the areas of the industrial enterprise sanitary protection zones according to classes of the vegetation indices (NDVI).

Name	<0	0–0.3	0.3–0.5	0.5–0.7	>0.7	Area, m <sup>2</sup>	Vegetation covering (NDVI >0.3), %
	%	%	%	%	%		
„Interpaip NTZ“	1.6	53.2	30.0	13.9	1.3	5,421,700	45.2
„Dniprovskiy metalurhiinyi zavod“	0.5	44.3	24.6	23.2	7.4	2,922,800	55.2
„Dniprokoks“	0.3	23.7	29.9	32.0	14.0	817,700	75.9
„Zavod metalokonstruktsii Ukrstal Dnipro“	0.0	51.4	44.2	4.1	0.2	45,900	48.6
„Dnipropetrovskiy metalurhiinyi zavod“	0.0	29.1	50.0	15.6	5.3	153,600	70.9
„Dnipropetrovskiy tsementnyi zavod“	0.0	47.1	35.0	17.9	0.0	27,400	52.9
„InterMikro Delta, Ink“	0.2	15.7	18.6	35.2	30.2	1,612,300	84.1
„Dnipropetrovskiy trubnyi zavod“	0.0	34.3	28.5	28.0	9.2	1,016,000	65.7
„Dniprovazhmash“	0.7	20.0	22.9	37.7	18.7	276,300	79.3
„Dnipropetrovskiy kombainovy zavod“	1.4	62.8	24.4	10.8	0.5	205,600	35.7
„VO „Pivdennyi mashynobudivnyi zavod im. O. M. Makarova“	0.2	22.5	23.4	35.3	18.5	941,600	77.3
„Dnipropetrovskiy metalurhiinyi zavod im. Kominternu“	0.0	21.5	50.5	25.8	2.2	808,100	78.5
„Dnipropetrovskiy zavod prokatnykh valkiv“	1.4	45.4	40.0	12.6	0.7	95,600	53.2
„Dnipropetrovskiy zavod po remontu ta budivnytstvu pasazhyrskykh vahoniv“	0.1	43.1	37.6	17.2	1.9	338,800	56.7
Dniprovskiy zavod „Aliumash“	5.9	59.2	22.6	10.6	1.7	617,100	34.9
„Dniprovahonrembud“	0.0	19.9	42.8	33.7	3.5	192,100	80.1
„NVO Dnipropres“	3.7	40.1	23.2	24.4	8.6	1,196,300	56.2
„Dniprotiazhbummash“	0.0	70.7	19.5	9.4	0.4	140,800	29.3
„Dnipropetrovskiy strilochnyi zavod“	0.0	35.9	37.1	25.5	1.4	186,700	64.1
„Interpaip Dniprovormet“	0.0	39.7	44.7	15.4	0.2	268,700	60.3
„Dnipropetrovskiy kombinat kharchovykh kontsentrativ“	0.0	55.7	25.4	16.4	2.5	171,200	44.3
„Interkorn Korn Prosessinh Industri“	1.2	48.7	32.7	15.4	2.1	196,000	50.2
„Bars“	0.0	0.0	44.4	55.6	0.0	900	100.0
„Zavod mostovykh zalizobetonnykh konstruktsii“	0.3	35.6	40.6	22.3	1.2	185,600	64.1
„Dnipropetrovskiy ahrehatnyi zavod“	0.0	18.6	39.7	35.1	6.5	180,500	81.4
„Kondyterska fabryka A.V.K.“	3.2	63.7	19.2	13.9	0.0	38,000	33.2
„Dnipropetrovske lokomotyvne depo“ DP „Prydniprovska zaliznytsia“	0.4	77.9	15.9	5.5	0.3	173,100	21.7
„Dnipropetrovskiy miasokombinat“ Korporatsiia „Ahro-Oven“	1.5	41.6	30.2	21.8	4.9	799,700	56.9
„UZPVHSh“	0.0	16.6	20.4	37.6	25.4	45,700	83.4
„Prydniprovskiy remontno-mekhanichnyi zavod“	0.0	48.8	25.4	21.0	4.7	99,500	51.2
„Dnipromain“	0.5	25.0	26.7	43.4	4.4	137,400	74.5
Prydniprovska TES PAT „DTEK DNIPROENERHO“	44.8	11.8	13.7	24.9	4.8	6,474,700	43.4
Dnipropetrovskiy doslidnytskyi zavod „Enerhoavtomatyka“	2.3	79.7	17.3	0.7	0.0	56,200	18.0
„Dnipropetrovskiy silikatnyi zavod“	0.0	56.9	28.7	12.8	1.7	148,100	43.1
„MZ Dniprostal“	0.0	44.8	40.8	14.4	0.0	34,800	55.2
„Ukrsplav“	5.2	92.6	2.2	0.0	0.0	40,700	2.2
„Vinil“	27.4	59.3	9.1	4.2	0.0	43,000	13.3
„VESTA-Dnipro“	0.0	26.3	23.2	37.2	13.3	176,500	73.7
„Ista-Tsentr“	0.0	77.2	22.5	0.3	0.0	28,900	22.8

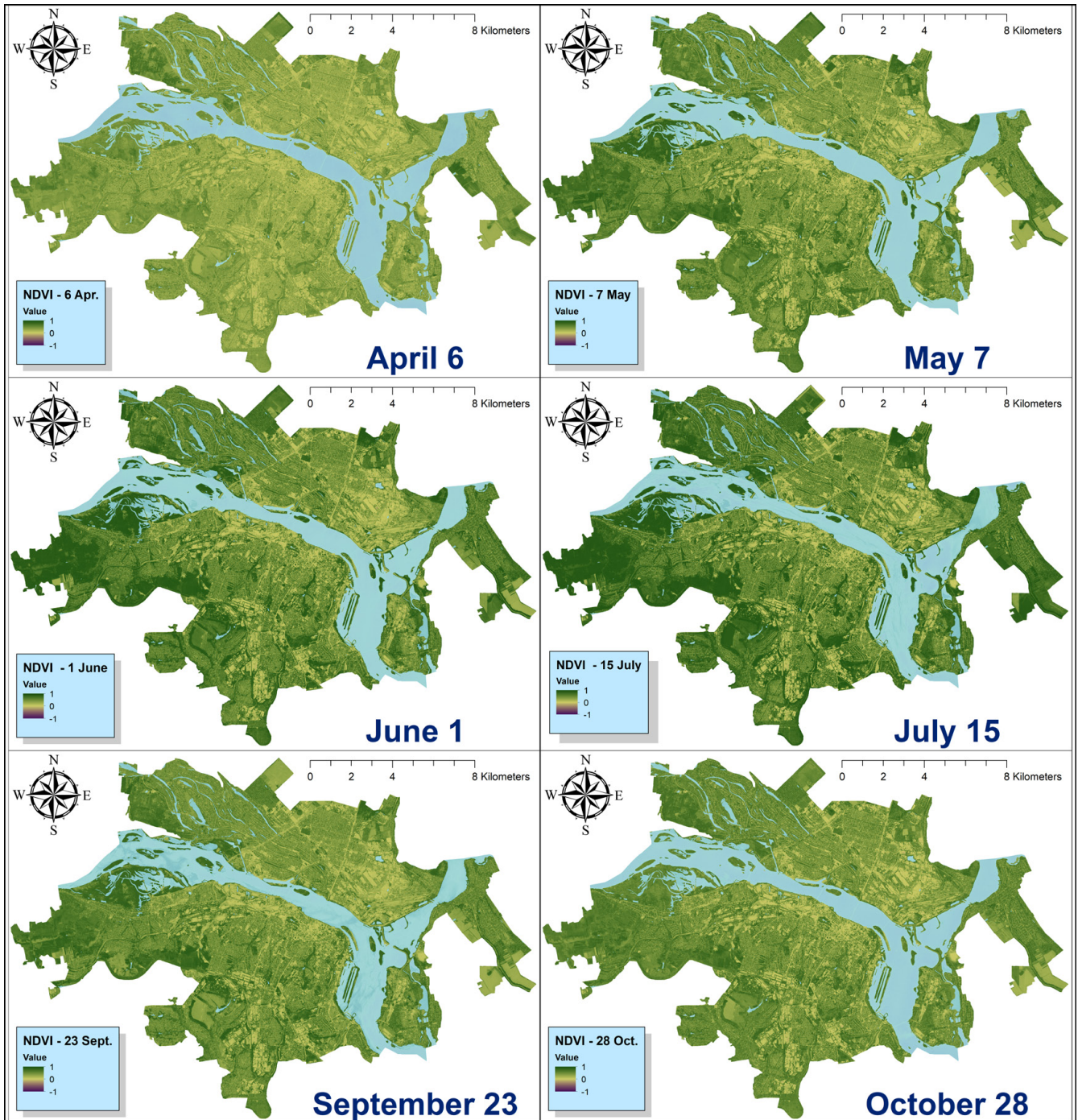


Fig. 3. The mapping of Dnipro city according to the green space photosynthetic activity.

system. On average, there are 219 m<sup>2</sup> of green spaces per person, which is 24 and 4 times more than the minimum and optimal values recommended by the WHO, respectively. But there are also data that in the cities of Ukraine, the actual extent of green space area per urban resident is 16.3 m<sup>2</sup> (Zhukov et al., 2015). It is obvious that the results always depend on the methods used for assessing the area of greening per capita. Table 2 shows the green space area per person. The obtained data demonstrate that the green spaces are unevenly distributed throughout the city be-

cause of different land use and cover. Among the city administrative districts, the least green are Tsentralnyi and Sobornyi, where the area of green spaces is less than 50%. Chechelivskiy, Nyzhnodniprovs'kiy, and Novokadats'kiy are the best according to NDVI. The outskirts of the city, as a rule, have more green spaces, which is related to the presence of private gardens and agricultural fields. This is typical of many cities in Ukraine. According to Table 1, the area of green spaces per inhabitant of the administrative district was determined in accordance with the standards (Table 2). These

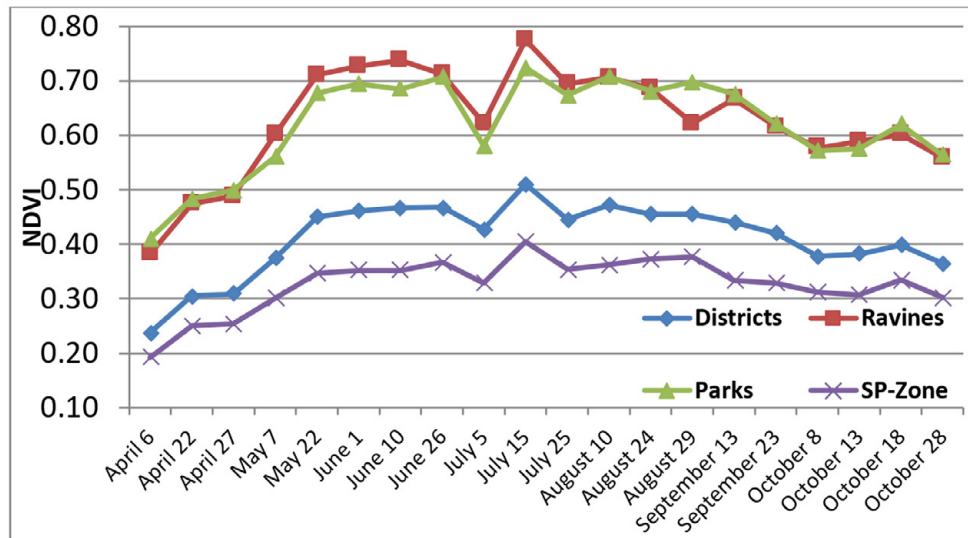


Fig. 4. Dynamics of the green space photosynthetic activity according to the modal indices of NDVI in different functional zones of Dnipro city.

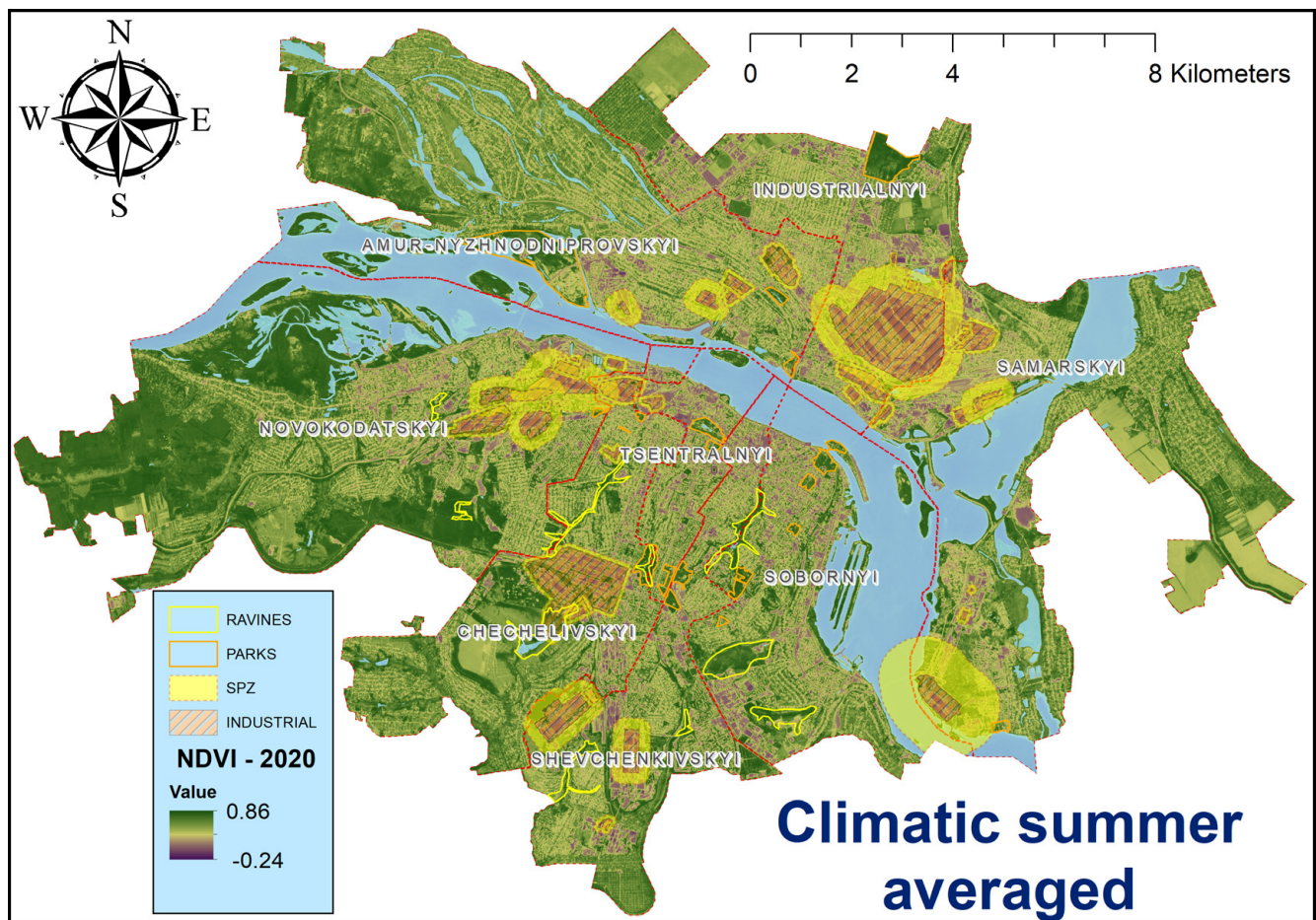


Fig. 5. Mapping of Dnipro city according to the average seasonal NDVI values.

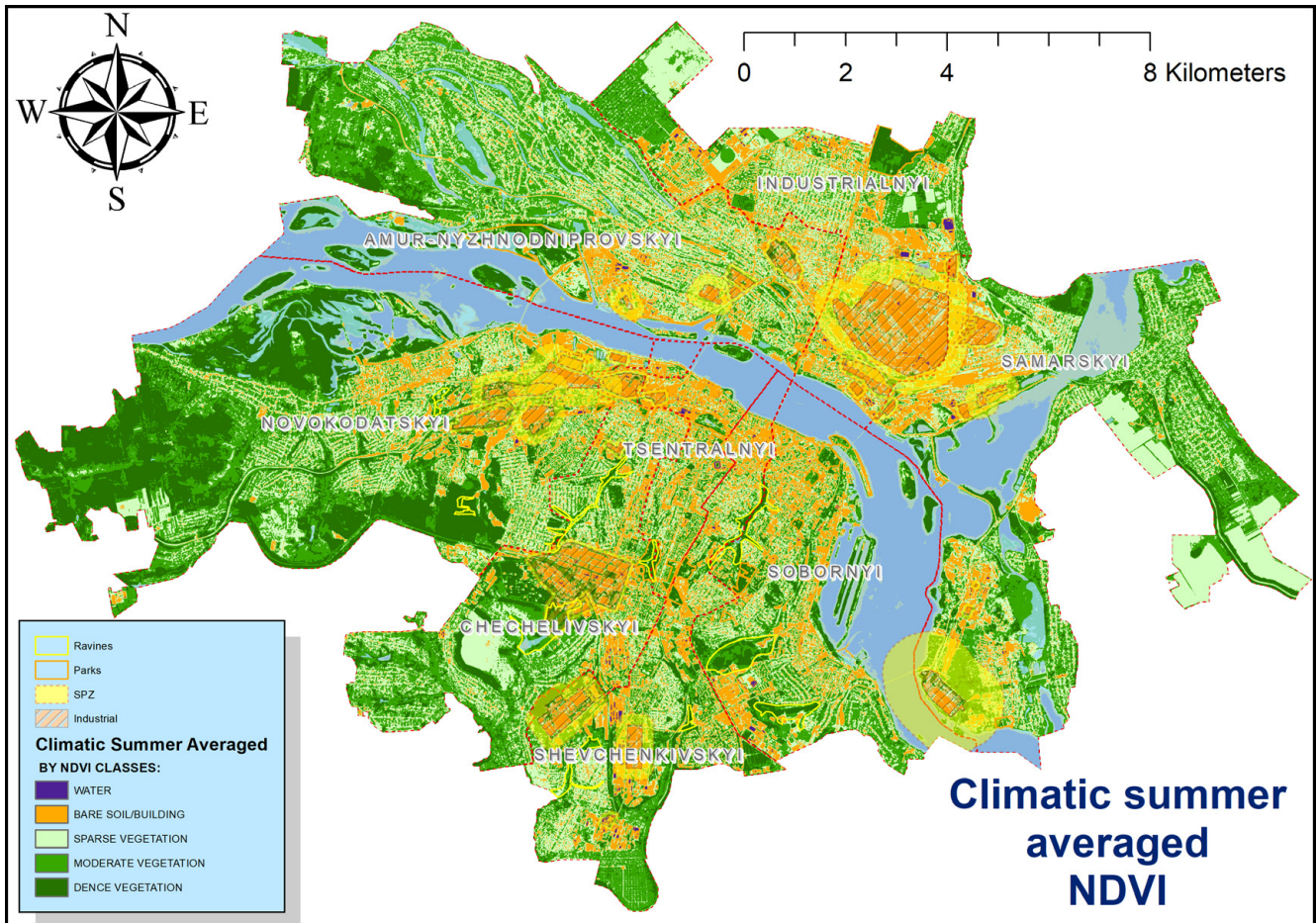


Fig. 6. Zoning of the urban areas according to the classes of average seasonal NDVI values.

indicators of greening the Dnipro city districts exceed both the state standards and WHO recommendations.

It should be noted that this ratio is generalized and was determined for the entire territory of any administrative district. However, for multistoried and densely populated residential construction, these figures will be much lower; so, there is a need to study this issue in more detail and collect the necessary data on the number of inhabitants of the individual residential communities and their areas. In any case, during urban land improvement of such residential communities, green spaces should be as close as possible to the place of people residence. Figure 3 clearly demonstrates the NDVI values in Dnipro city at a given moment. The figures highlight the areas of some ravines and parks that have significantly higher NDVI rates than other urban areas over a long period. The analysis of the NDVI modal indices dynamics in the functionally different areas (Fig. 4) illustrates that the highest indicators are characteristic of the city ravine network and the lowest are characteristic of the SPZs of industrial enterprises. Figure 4 also shows the modes of changes in the studied indicators during the growing season. In spring, there is a rapid NDVI increase for all of the areas. The peak of plant vegetative activity occurs in the first decade of June, followed by slight decline for 2–3 weeks, then there is another increase in the activity, which reaches the maximum in mid-July. Even in autumn, the

photosynthetic activity remains relatively high for most of the urban areas, declining only from mid-October. Due to the variability of indices over time, the average seasonal NDVI distribution maps (Fig. 5) were calculated to analyze the degree of the urban area greening, in particular, according to the classes that characterize the type of land surface and the degree of its greening (Fig. 6).

The analysis of the territory greening according to the average seasonal NDVI values gives a more objective assessment of the general characteristics of green spaces compared to the analysis of these data for a certain period of time. This results from the fact that throughout the growing season, the mode of changes in the NDVI values may differ significantly for different areas. For example, it is clear from Figure 3 that for meadows and lawns, the NDVI values in spring exceed those for the areas covered with trees and shrubs, while in mid-summer, the opposite trend is observed due to the suppression of meadow vegetation. In addition, this approach allows mitigating the impact of cloudy or shaded areas in the individual images, which is usually a significant obstacle in the analysis of the data from optical images. As a result of the SPZ greening degree analysis, it was determined that in eight of the 40 studied enterprises, the percentage of the SPZ area greening does not meet the standards (Order, Rules of the Ministry of Health of Ukraine, 1996).

## Discussion

The presented research results illustrate the current level of greening in different functional areas of Dnipro city and give an idea of the mode of greening in a typical industrial city located within the steppe zone of Ukraine. In the context of current research, it is found that at present, the data that characterize the state of green spaces in urban, industrialized areas are extremely insufficient (Bilokon, 2004; Buchavyi, Horova, 2016). The relatively weak information base of the distribution structure of the green part of the urban area reveals the problem of lack of the good urban management strategy. This primarily results from the inconsistency and lack of information about the dynamic changes in the indices of the assimilation system, which is a clear indicator of the green space state. The Sentinel-2 satellite image processing system with a fairly high level of resolution allows green space monitoring in urban areas and is quite informative (Yukhnovskyi, Zibtseva, 2020). After all, by evaluating the images obtained in different periods of time, it is possible to track the dynamics of green space as well as determine the ecological balance of the individual functional areas of industrial cities. NDVI is widely and successfully used to determine temporary changes in urban green spaces by a number of authors within Ukraine and abroad (Abutaleb et al., 2020). Some authors point out that temporary changes in a city green zone, which are based on the obtained NDVI values, can be used as an indicator of changes in the land use of a given area (Asmala et al., 2014; Garouani et al., 2017). It should be noted that it is confirmed in our study, because we found differences in the NDVI values in the areas of different functionality. This is especially true for SPZs, for which the calculated NDVI value was much lower than for parks and the ravine system. The data from the satellite images are also actively used in the quantification of the green zone as a result of urban expansion (Garouani et al., 2017; Lotfata, 2021).

The obtained results of NDVI showed insufficiently effective planning of the Dnipro green zone, especially for the SPZ areas. As can be seen from the presented map of the distribution of the average seasonal NDVI value (Fig. 6), much higher intensity of green space is observed only in the ravine system and parks and is characteristic only of some urban districts (Novokadatskyi, Nyzhnodniprovskyi, Chechelivskyi). The density of green spaces in these areas is primarily due to the proximity to the territory, which is a suburban forest belt (Lovinska, Sytnyk, 2014). It is natural that urban green spaces with low coverage of green spaces are concentrated in the city central areas, which, in general, can cause negative environmental and social impact on the population. After all, the uneven distribution of urban green spaces, in general, leads to a decrease in the biological productivity of their species components, the external expansion of the city, and ultimately can lead to the loss of biodiversity (Garouani et al., 2017).

Thus, considering the obtained patterns, this method of obtaining NDVI allows assessing the photosynthetic process dynamics clearly and quickly as well as regulating the share of green areas of different functionality in the urban system of populated cities.

## Conclusion

Using remote sensing, we separated out and classified three types of areas with green vegetation in the studied city according to

NDVI: ravines, parks, and green SPZs. The assessment of the photosynthetic vegetative activity according to NDVI indicates two peaks during the growing season: in the first decade of June and in the middle of July. A comparative analysis of the NDVI values of different functional zones of Dnipro city revealed that the lowest level of this parameter was in SPZs. In the future, the approach to estimating the average annual NDVI in different functional areas of the city can be used while planning the distribution of urban development and green planting at the regional level.

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