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Green space trends in small towns of Kyiv region according to EOS Land Viewer – a case study

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Abstract: The state of ecological balance of cities is determined by the analysis of the qualitative composition of green space. The lack of green space inventory in small towns in the Kyiv region has prompted the use of express analysis provided by the EOS Land Viewer platform, which allows obtaining an instantaneous distribution of the urban and suburban territories by a number of vegetative indices and in recent years – by scene classification. The purpose of the study is to determine the current state and dynamics of the ratio of vegetation and built-up cover of the territories of small towns in Kyiv region with establishing the rating of towns by eco-balance of territories. The distribution of the territory of small towns by the most common vegetation index *NDVI*, as well as by *SAVI*, which is more suitable for areas with vegetation coverage of less than 30%, has been monitored. We found that the share of dense vegetation in the territory of towns increased on average from 2.4 to 49.3% during 1990–2018. The share of the vegetation cover of moderate density decreased from 40.8 to 27.1%, and of sparse one from 37.5 to 14.9%. High variability of these indicators is noted. The share of open area for small towns decreased on average from 15.4 to 3.8%. The vegetation-free areas in 1990, 2005 and 2018 accounted for 3.8, 2.6 and 4.4%, respectively, which may indicate the intensive expansion of built-up areas over the last fifteen years. The development of urban greening systems was completely individual and depended not only on natural conditions but also on the manifestations of anthropogenic activity. The reduction of the ecological balance of the territories of small towns as of 2018 took place in the following sequence – Irpin, Tarashcha, Boiarka, Rzhyshchiv, Kaharlyk, Skvyra, Myronivka, Yahotyn, Uzyn.

Keywords: ecological balance; express analysis; rating; vegetation indices

The urbanized territory is a dynamic complex that is constantly expanding and in need of ecological balance, making urban landscapes the most important area of environmental research. Long-distance comparisons of landscaping systems require detailed information on their relative abundance, vegetation composition and spatial structure (Kopecká et al. 2017). Understanding the patterns of urban landscaping and its spatial and temporal dynamics provides valuable information for general urban planning. First of all, the assessment of the ecological balance of urban areas requires objective information on the types of land use and eco-stable (green) areas. Unfortunately, researchers and planners pay less attention to the study of small towns. Currently, not more than half of the small towns of the Kyiv region have relevant master plans. Greening schemes are not developed for them, and the inventory of green areas has never been conducted here due to the limited funds of local budgets. At

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the same time, Ovcharenko and Zalyubovskaya (2018) believed that traditional methods of landscape research are too cumbersome and costly, and the means of conducting them are outdated. Instead, an up-to-date and promising area of green space exploration is the use of open-source space imagery (Landsat 8, Sentinel-2) with a spatial resolution of 10–60 m, providing spatially consistent coverage of large territories with high spatial detail and periodicity. Based on such data, Rudenko et al. (2019) identified trends in land use in Ukraine's forest-steppe zone during the years 1992–2018, in particular, the increase in the share of land under construction, and revealed that the period of major changes occurred in 1994–2004.

The availability of satellite remote sensing data has increased significantly in recent decades, and is now a powerful source for analysing the temporal dynamics of urban conditions and quantifying urban environmental friendliness in a cost-effective way (Deng et al. 2009; Liu, Yang 2013). At the same time, the increasing spatial resolution of commercial satellite imagery has influenced the emergence of new research and applications for urban applications (Deng et al. 2009; Patino, Duque 2013). The most common satellite applications include an index of quality of life assessment, urban growth analysis, assessment of the level of development, urban social vulnerability and more.

Patino and Duque (2013) established a correspondence between vegetation indices for satellite data and urban green space inventory materials. The possibilities of combining remote sensing data and spatial metrics to analyse and model urban growth and land use dynamics were investigated by Herold et al. (2005). The systematic combined use of these tools allows for a new level of information that improves understanding of urban dynamics and helps develop alternative concepts of urban spatial structure development. According to Powell et al. (2007) to monitor the evolution of the urban environment also requires the use of medium resolution multispectral imaging. Such images are considered the best source of research because they provide the only unique long-term consistent set of digital data (He et al. 2013). However, calculating classification and vegetation indices using medium spatial resolution images may not be effective in quantifying physical information on urban landscaping. The fundamental problem of obtaining accurate satellite data is the variability of the urban environment (Small, 2001; Powell et al. 2007), as well as a rigid classifier of urban vegetation by which it is identified only as present or absent (Myint 2006). Usually, comparisons are used in studies (Foody, Boyd 1999). In doing so, Small (2001) did not prefer the normalized difference vegetation index (*NDVI*), which is commonly used for global monitoring, but the estimation of vegetation shares. The integration of several methods on a medium-resolution scanner satellite image database allows accurate modelling of the vegetation fraction, despite the complex mosaic of different types of urban cover (Gan et al. 2014). Data on the temporal dynamics of vegetation are useful for in-depth studies of long-term changes in urban greening, regional comparison of cities with different economic and natural conditions, studying the relationship between urban greening and urbanization, obtaining information on sustainable urban development.

The methodological framework used to study temporal and spatial changes in land use and land cover to meet the need for scientific information on sustainable development is evolving rapidly (Liu, Deng 2010). Specific features of the urban landscape require further consideration of the possibilities and limitations of using satellite data and appropriate methods of analysis (Herold et al. 2005; Patino, Duque 2013).

Li and Wenliang (2016) identified probable errors in determining the impervious surfaces of urban areas, in particular due to obstacles with large tree crowns. The use of satellite data in urban governance and, in particular, urban development, is a promising and effective method that is widely used and opens new opportunities (Panarin, Panarin 2009). Remote sensing ground cover indices are the most important urban indicators that contribute to sustainable urban planning and management.

Considering that small towns are the most widespread and the least researched category of Ukrainian cities, where the inventory of green spaces has not been conducted at all, we consider the determination of their territories as an example of a metropolitan region extremely relevant.

The purpose of the work is to determine the current state and dynamics of the ratio of vegetation and built-up area of small towns of the Kyiv region and on their basis to establish the rating of towns by eco-balance of territories, which should extend the researches we conducted earlier (Yukhnovskyi, Zibtseva 2018; 2019).

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MATERIAL AND METHODS

The study was based on the EOS Land Viewer, real-time image processing and analysis software that allows obtaining the instant territory distribution across a range of vegetation indices and scene classification. We have considered the *NDVI* Territory Allocation to be the most commonly used, including for estimating urban areas. Also a modification of the soil-adjusted *NDVI–SAVI* index is used, which is recommended for less than 30% vegetation area. The software used provides an instant division of the requested urban area into a rectangle to which part of the suburban area also falls.

The Land View service was used to obtain satellite images (average resolution) of the studied small towns and surrounding areas at specified time periods (year and decade of the month), capture scenes and processed values of *NDVI* and *SAVI* indices. Processing of *NDVI* and *SAVI* indices was carried out by an automated software tool the types of coverage with the transfer of the indicators in Excel and the subsequent analysis and interpretation of the received data. Overall step-by-step description of this process supplemented by relevant screenshots (Figures 1–4) is outlined below:

Step one of interaction with the software starts by searching for a specific town. The software automatically outlines the territory of the desired town.

In the second step (Figure 1), we search for a satellite image taken within the time of interest (year, month, and day).

At the next step (Figure 2) we select a combination of channels which are used to obtain various surface characteristics (vegetation indices, types of coverage, etc.)

Next, we obtain data on distribution of the territory of the studied town by types of vegetation, presence of open ground and absence of vegetation in percentage or absolute units of area (m^2 or ha). Examples of obtained data for the types of coverage of Vyshneve town with percentage distribution tables by *NDVI* and *SAVI* indices are shown in Figures 3 and 4, respectively.

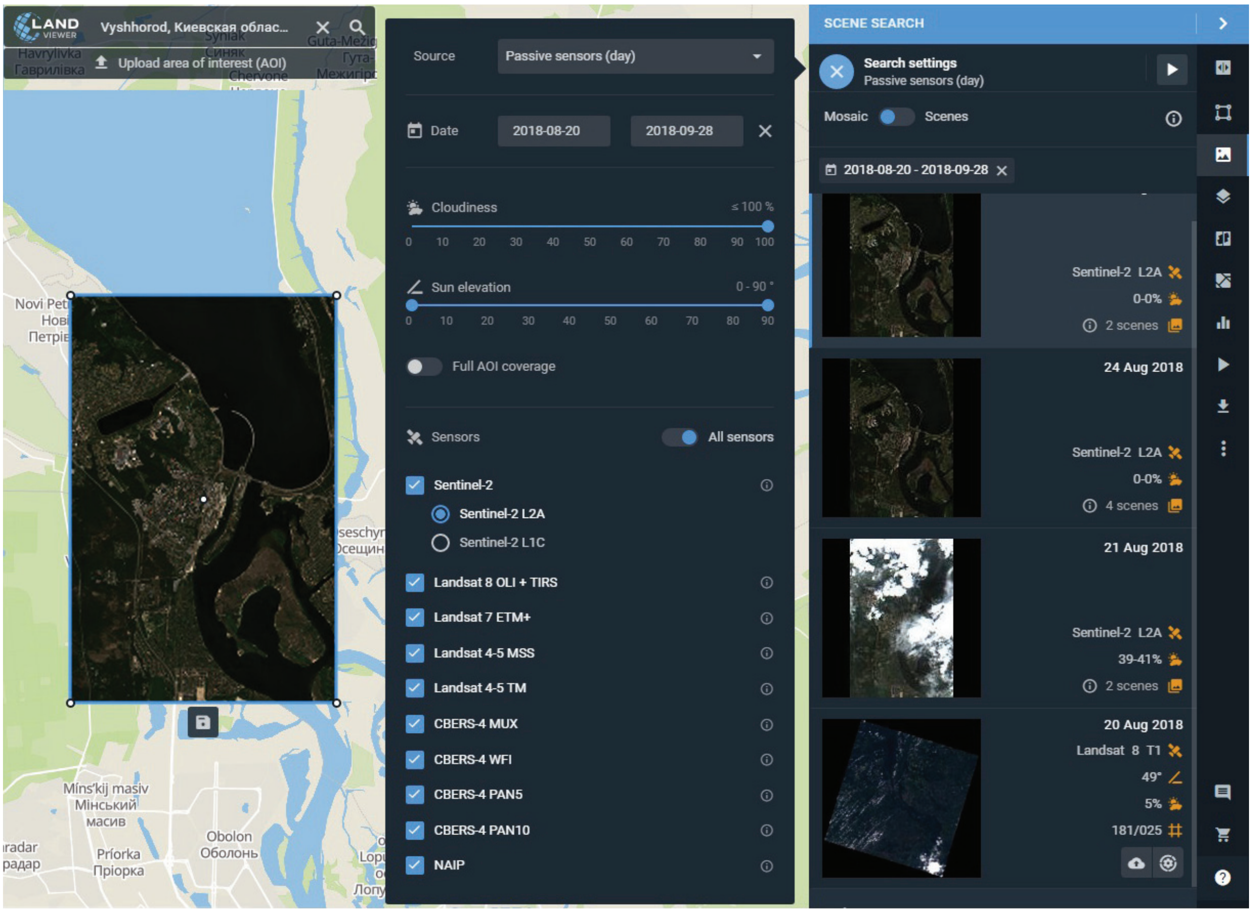

Figure 1. Search for a satellite image

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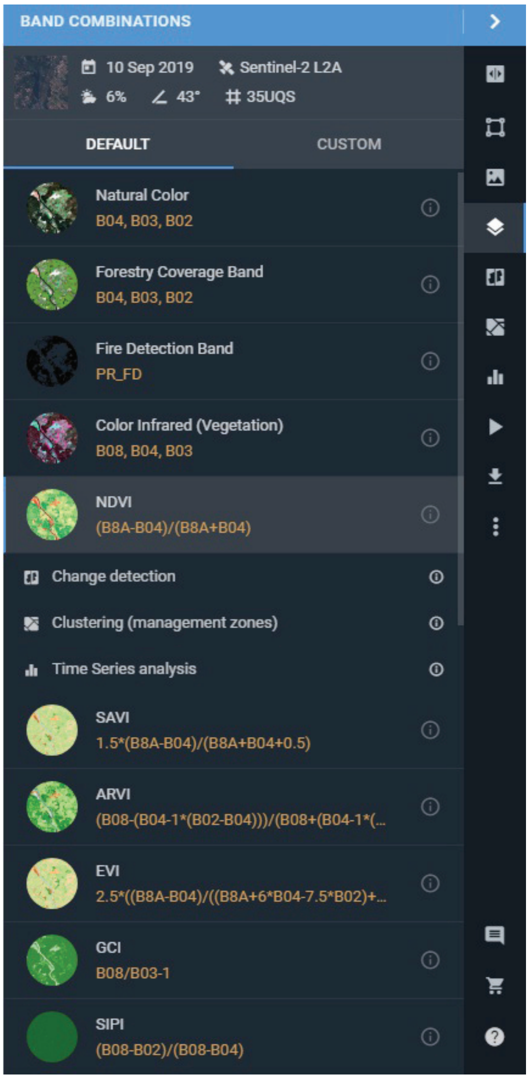

Figure 2. Selection of a combination of channels

The above-described data collection process has been carried out for the rest 19 small towns within the same time frame or respective retrospectives.

The main task was the simultaneous coverage and relative assessment of the territories of all small towns of Kyiv region. The available Landsat 8 or Sentinel 2 satellite data is usually evaluated from 26 to 28 August, given that early autumn is the best time for green space inventory. In addition, the dynamics of the territories of twenty small towns was analysed according to satellite images in the summer of 1995, 2005 and 2018.

The EOS Land Viewer Web Interface for *NDVI* provides the following automatic distribution of the territory: 0.6–1 dense vegetation (trees), 0.4–0.5 moderate, 0.2–0.3 sparse (variable usually shrubs and meadows), 0.1 – open ground, < 0.1 – vegetation is absent.

RESULTS AND DISCUSSION

Publicly available Google Earth satellite imagery (Figure 5) shows that suburban green zones (ideally in the form of a green ring) are not present around any small town. Usually, they are surrounded by arable land.

Forests are only near Boguslav (mainly from the north), Tarashcha (from the northwest and southeast), Berezan (in the southwest), south of Pereyaslav, in the east of Tetiiv, northwest of Ukrainka, southwest of Fastiv and Boiarka, in the east west of Irpin, southwest of Vyshhorod, that is near half of the small towns in the region. The largest forests are near the town of Irpin.

We tracked the dynamics of the percentage distribution of the territory of small towns of Kyiv region, obtained by *NDVI* and interpreted by different types of coatings, including different vegetation density as of 1990, 2005 and 2018. Figure 6 shows data for 1990 and 2018, which means that in 1990 there was sparse and moderate vegetation in the territory of towns.

Quantitative values for towns varied greatly and did not allow high accuracy, but the average area of moderate vegetation was 40.8 ± 3.36%, sparse – 37.5 ± 2.15%, and dense (analogous to woodland) only 2.4 ± 0.74%. At the same time, the surface of the open ground averaged 15.4 ± 2.00%, and the area without vegetation (usually the surface of reservoirs) – 3.8 ± 1.86%. Such a wide range of fluctuations is caused by the presence or absence of reservoirs in urban areas, as rivers flow in the territories of more than half of the small towns of Kyiv region.

The average area of moderate vegetation in 2005 increased by 8% and averaged 48.9 ± 2.31%, the area of sparse vegetation decreased by 12% and amounted to 25.3 ± 1.83%, and the area of dense vegetation increased by 14% – up to 16.7 ± 2.00%. The average area of open ground decreased to 5.9 ± 1.32%, and without vegetation to 2.6 ± 1.43%.

The dense vegetation in 2018 was prevalent in urban areas, the area of which increased by more than 32% and averaged 49.3 ± 3.10% (V = 28.11; P = 6.12). The area of moderate vegetation decreased by more than 21% compared to 2005 and amounted to 27.1 ± 1.66%, while the area of sparse vegetation decreased by more than 10% to

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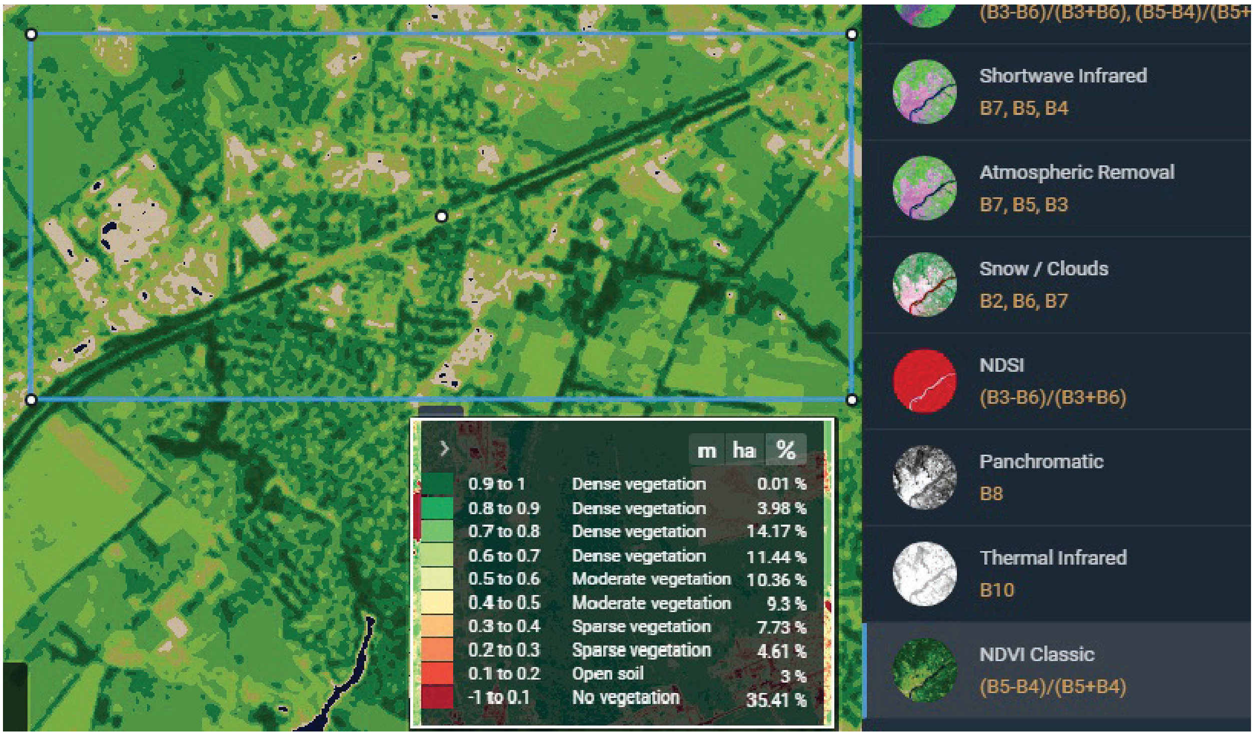

Figure 3. Distribution of the territory of Vyshneve by *NDVI* index

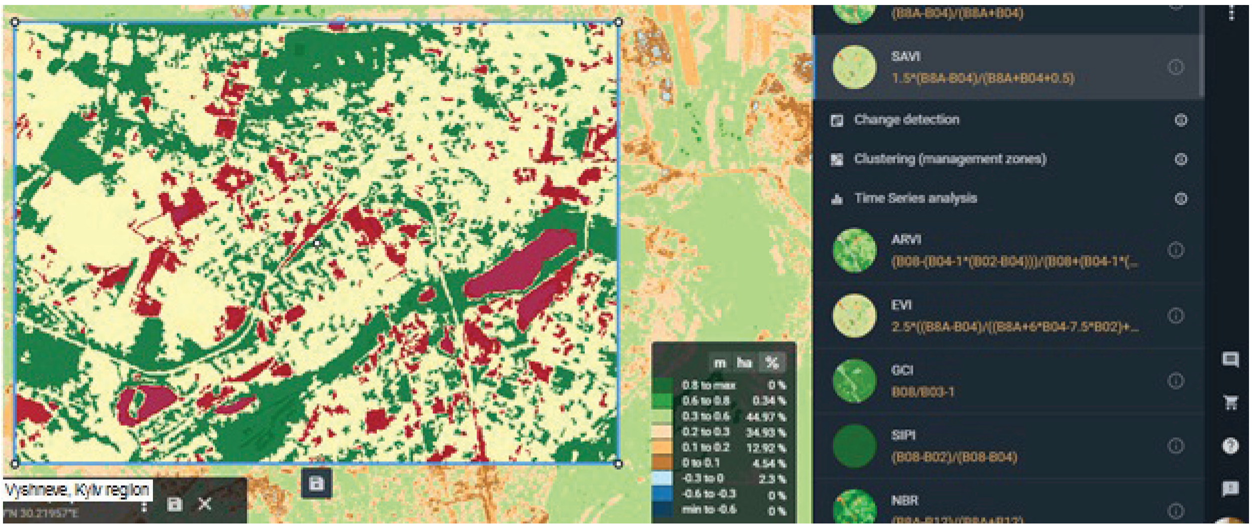

Figure 4. Distribution of the territory of Vyshneve by *SAVI* index

14.9 ± 1.71%. In this case, the area of ground cover was 3.8 ± 0.77%, and without vegetation it varied most strongly, but less than in 2005 and increased 1.7 times on average to 4.4 ± 1.90%.

We assume that the dynamics of ground areas and areas without vegetation has also been affected by the disadvantages of using the *NDVI* vegetation indicator itself in urban environments, where the presence of areas with sparse vegetation with coverage below 30% is likely. That is why we have applied the distribution of urban areas and *SAVI*. Figure 7 shows the breakdown of the so-called "scene classification" that the EOS Land Viewer has been providing since 2018, where towns are located in the order of the decreasing percentage of vegetation area.

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Figure 5. Nearly treeless areas of the towns of Yahotyn (A), Kaharlyk (B), Skvyra (C), Uzyn (D), Myronivka (E), Vyshneve (F) according to Google Earth Pro (Google, Mountain View, USA)

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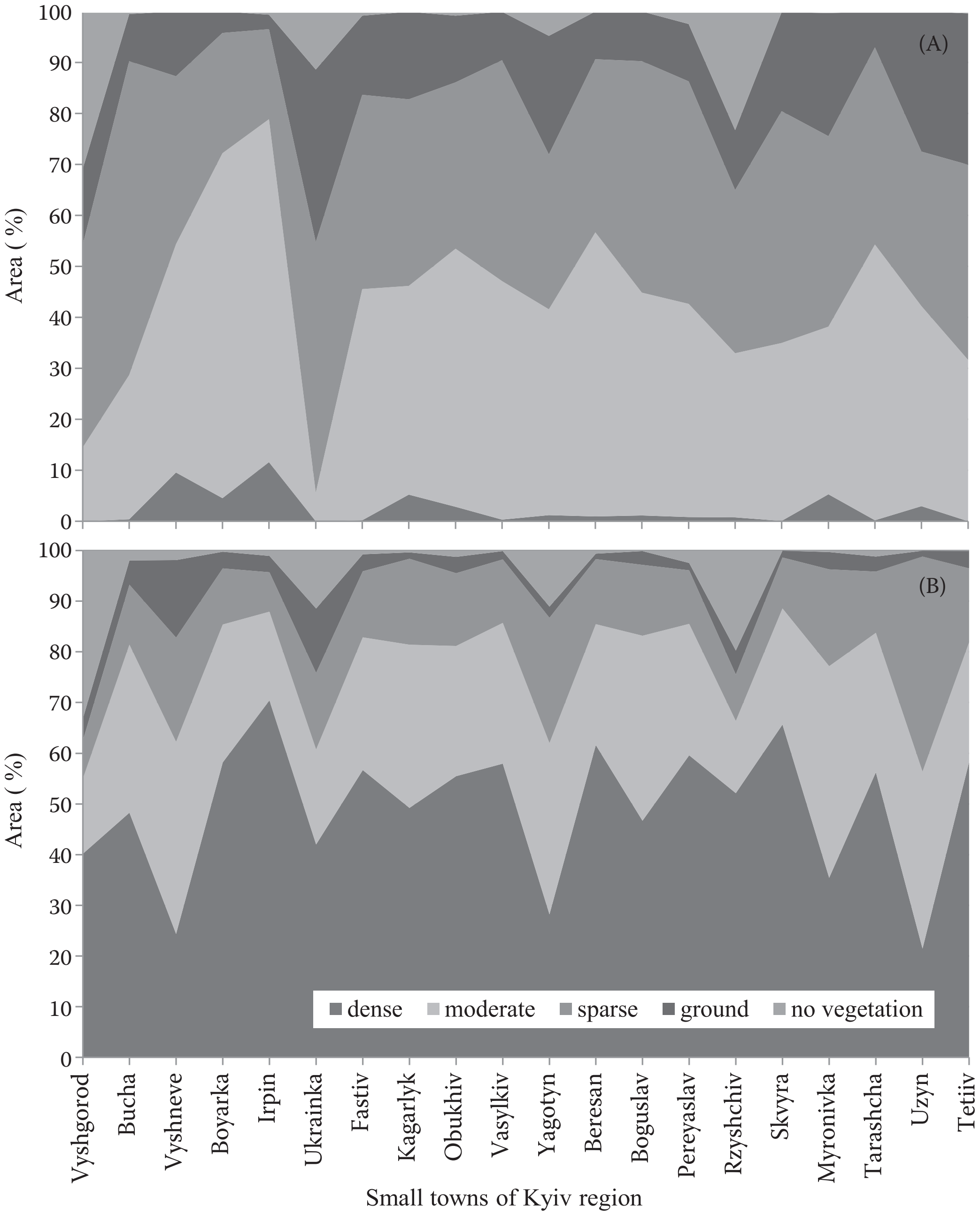

Figure 6. Dynamics of distribution of the territory of small towns of Kyiv region by types of coverage as of 1990 (A) and 2018 (B)

At the beginning of the rating there are towns such as Irpin, Tarashcha, Boiarka, Obukhiv, Vasyl'kiv, which are surrounded by suburban forests, and at the end of the rating – Uzyn, Myronivka, Kaharlyk, Skvyra – towns among the ploughed areas. The towns of Yahotyn, Ukrainka, Vyshhorod, Rzhyshchiv should be promoted in the eco-balance rating significantly ahead, given the large areas of eco-stabilizing water surfaces, which also belong to green infrastructure. Such an adjusted rating is shown in Figure 8.

Taking into account the water surfaces of Rzhyshchiv, it moved from the eleventh position to the third, Vyshgorod – from the thirteenth to the seventh, Ukrainka – from the fifteenth to the thirteenth, Yahotyn – from the twentieth to the eighteenth. Uzyn and Myronivka are the last in the rating, also at the end of the rating are Kaharlyk, Skvyra, and Vyshneve.

Figure 9 shows the dynamics of the vegetation cover of the territories of the explored towns for 1985, 1990, 2005 and 2018 and the ratings of the towns by the percentage of vegetation cover as of 1985 and 2018.

Vyshneve now identified among the towns with the worst eco-balance, ranked top in 1985, indicat-

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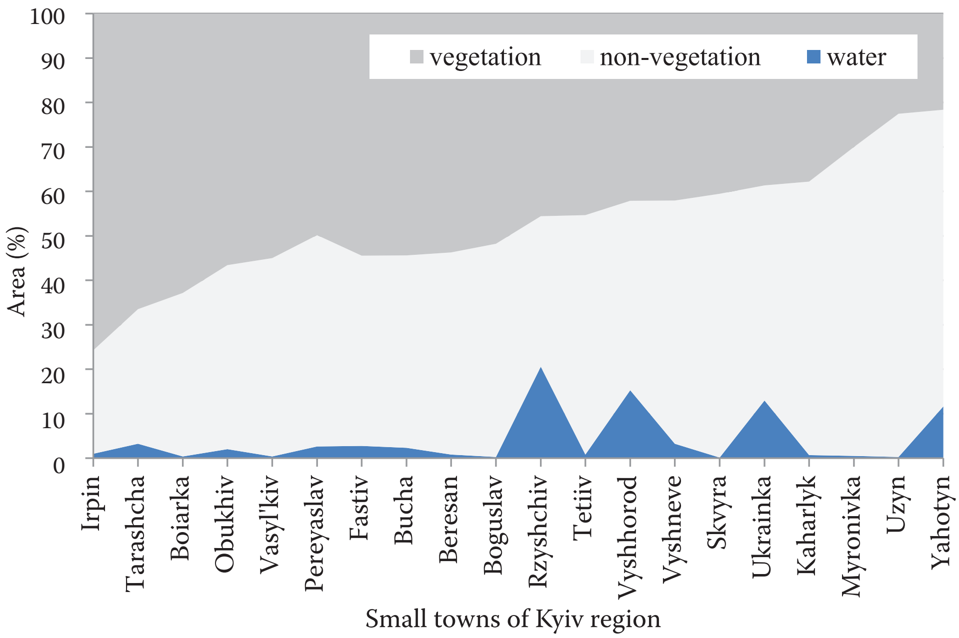

Figure 7. Scenario of coverage distribution of the territory of small towns of Kyiv region according to the 2018 *SAVI* vegetation index

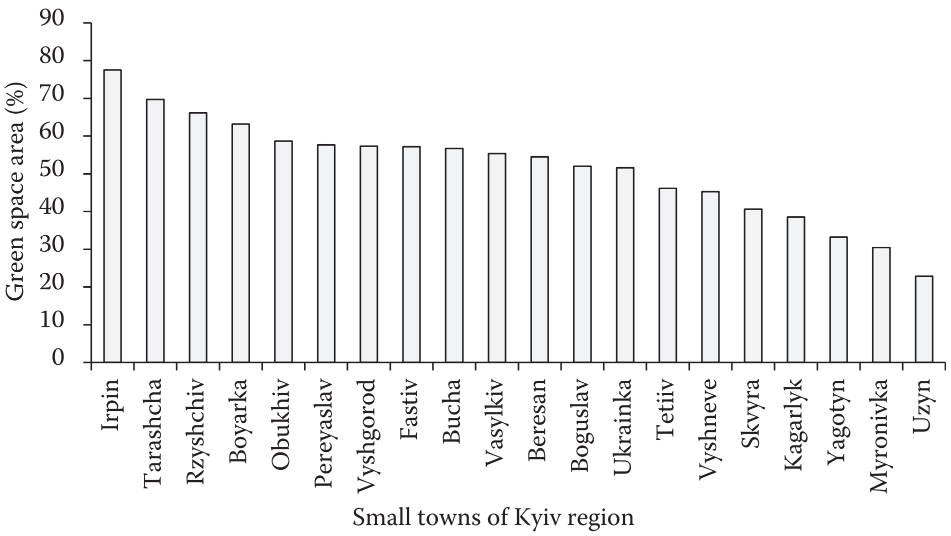

Figure 8. Eco-balancing rating of small towns by the percentage of green infrastructure for 2018

ing that the area's ill-considered destructiveness over the course of the thirty years was indicative. The same applies to the territories of the towns of Skvyra and Uzyn. Instead, in 1985–2018, according to the satellite distribution, the eco-balance of the territories of the towns of Ukrainka, Rzhyshchiv, Vyshhorod, Bucha, Tarashcha, Boiarka, and Irpin was improved. This was due to the increase in the density of plantations (growth of tree plants) over time in the towns and their surrounding areas and the smaller onset of development on the woodlands.

Similar results are provided by the *NDVI* 1985 territory analysis of towns, which sums up the percentage of areas covered by dense and temperate vegetation for the eco-balance of urban areas. We did not take any sparse vegetation into account due to the significant errors of this indicator, explained above. Vyshneve also leads the ranking in this division. Tarashcha, Skvyra, Fastiv, Tetiiv are among the leaders. Uzyn, Boguslav, Obukhiv, Vasyl'kiv, Berezan are also among the best half of the list. Ukrainka, Rzhyshchiv, Vyshhorod, Bucha, Yahotyn are closing the rating of the towns.

According to all the comparisons made by us of the percentage distribution of the territories of small towns, the towns of Irpin, Tarashcha, Boiarka, Rzhyshchiv top the list for 2018, and Kaharlyk,

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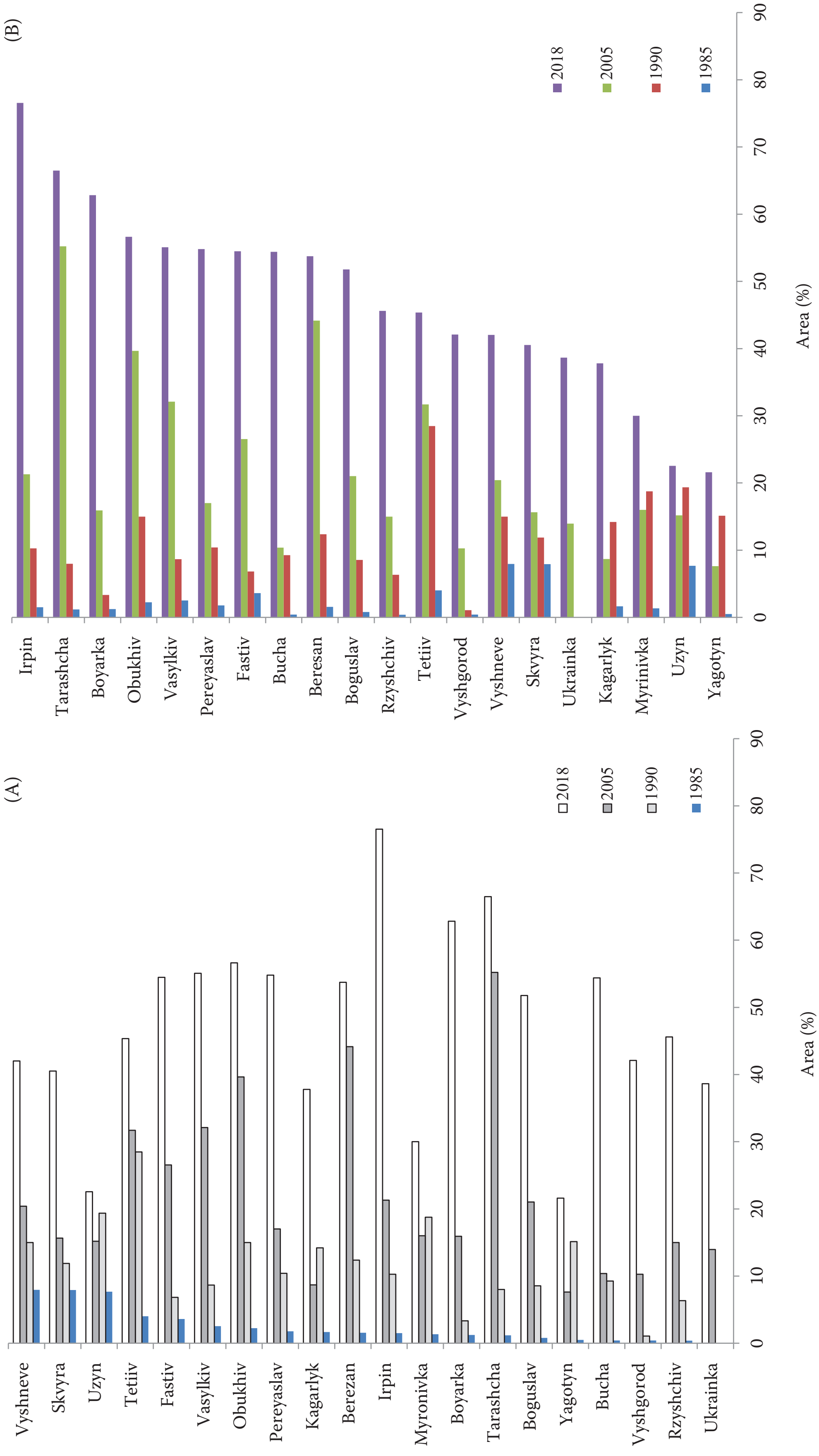

Figure 9. Rating of towns by percentage of land cover for 1985 (A) and 2018 (B)

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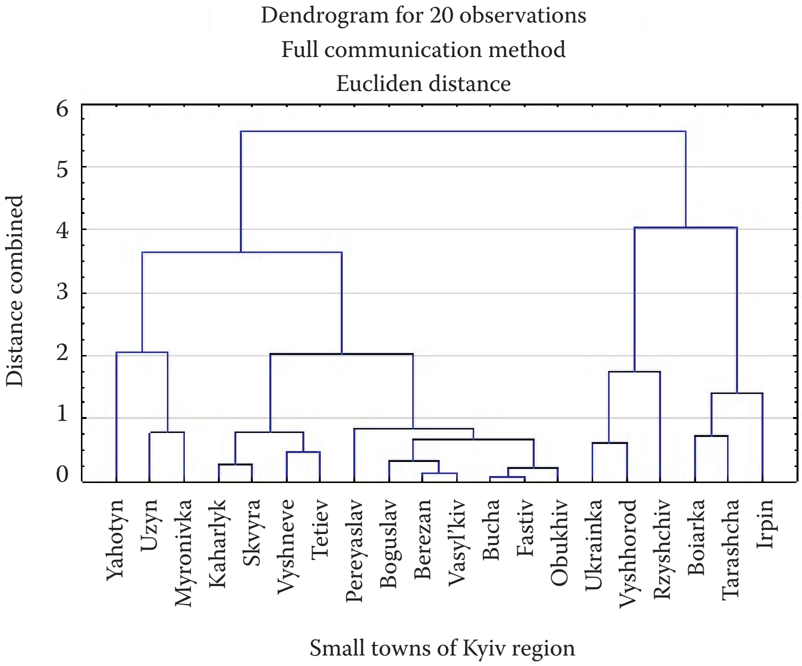

Figure 10. Dendrogram of similarity of small towns of Kyiv region according to the classification of scenes for 2018

Skvyra, Myronivka, Yahotyn, Uzyn are closing the list. It is in these small towns that the actual photos of the territories as treeless are shown in Figure 5. The situation with green infrastructure, and therefore with eco-balance, is the worst.

Vyshneve and Uzyn were among the best in ecological balance (percentage of vegetation coverage) for 1985. They have now significantly lost their positions and are now at the end of the ranking. Bucha and Ukrainka, Rzhyshchiv, Vyshhorod, the towns along the Dnieper River with significant inclusion of the surface of reservoirs in the territorial boundaries, are among the worst cities in terms of ecological balance.

According to the distribution by soil-adjusted *SAVI*, the town of Vyshneve moved in the time dynamics from the first position in 1985 to the fifth in 1990, ninth in 2005, fourteenth in 2018 and taking into account all green infrastructures – to the fifteenth position. The town of Skvyra moved from second to fourteenth position.

The town of Uzyn moved from third to second position, then thirteenth and nineteenth (and taking into account all green infrastructures – to the last twentieth position). Instead, Ukrainka gradually rose from the last position to the fifteenth (and for all green infrastructures – to the twelfth). Rzhyshchiv moved from the penultimate to the sixteenth, fourteenth, and tenth position (for all green infrastructures – the third level) and Vyshhorod moved from the sixteenth to the twelfth position (and for all green infrastructures – to the seventh).

Cluster analysis of urban areas dividing the classification of scenes into water surfaces, vegetation and "non-vegetation" (other types of cover) as of 2018 allowed to obtain a dendrogram (Figure 10). According to the obtained data the studied small towns may be subdivided into two groups. The first group consists of six towns which are characterized by relatively better indicators: a larger area of vegetation and water surfaces (i.e. more developed green infrastructure); these are the towns of Ukrainka, Vyshhorod, Rzhyshchiv, Boiarka, Tarashcha and Irpin. The remaining fourteen towns belong to the second group. Figure 11 shows the clusters of studied towns according to the classification of scenes.

Cluster analysis also identified four smaller subgroups (clusters). The first cluster included three towns: Rzhyshchiv, Vyshhorod and Ukrainka. They are located directly on the right bank of the Dnieper River and have large areas of water surfaces and vegetation cover. The second cluster includes eight towns with the smallest share of water surfaces, but with the largest share of vegetation cover. These are the towns of Irpin, Tarashcha, Boiarka, Obukhiv, Vasyl'kiv, Fastiv, Bucha, Berezan. These towns are surrounded by large forests. The third cluster includes six towns: Pereyaslav, Boguslav, Tetiiv, Vyshneve, Skvyra, Kaharlyk, with average values of vegetation cover. The fourth cluster consists of

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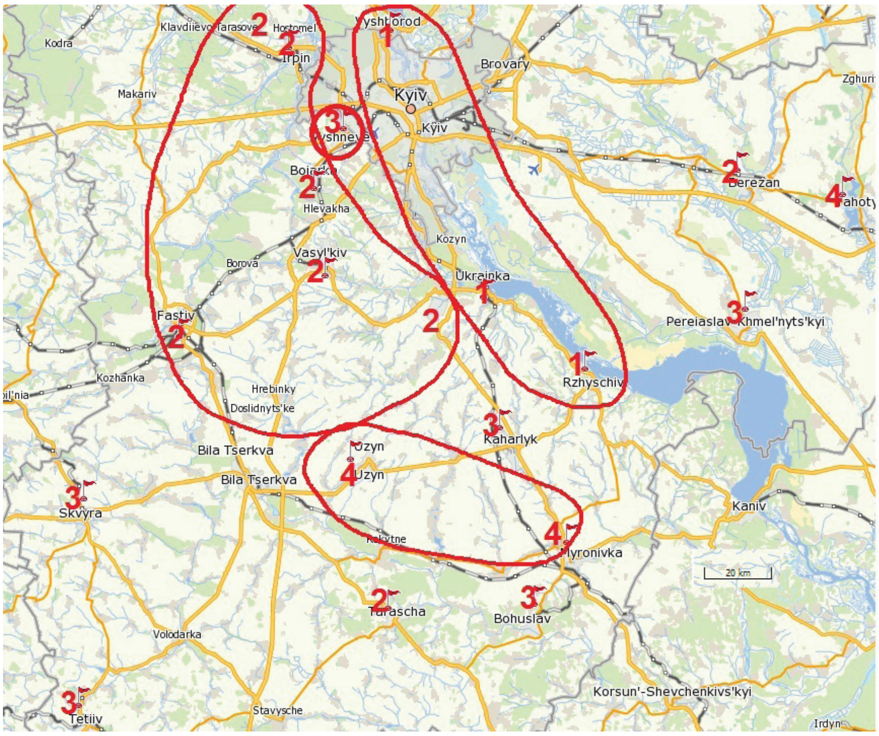

Figure 11. Clusters of studied towns according to the classification of scenes (1 – Rzhyshchiv, Vyshhorod, Ukrainka; 2 – Irpin, Tarashcha, Boiarka, Obukhiv, Vasyl'kiv, Fastiv, Bucha, Berezan; 3 – Pereyaslav, Boguslav, Tetiiv, Vyshneve, Skvyra, Kaharlyk; 4 – Myronivka, Uzyn, Yahotyn)

three small towns: Myronivka, Uzyn, and Yahotyn with a minimum share of vegetation.

It is advisable to create forests in their suburban areas to increase the eco-balance of small towns.

CONCLUSION

It is justified that in the context of current data constraints on small-scale green space systems the medium resolution images obtained from the Landsat 8 and Sentinel 2 satellites are informative enough. Snapshots of different time periods allow you to track the simultaneous dynamics of green coverage, and hence the eco-balance of small cities and to perform their comparative analysis.

Extremely convenient for landmark large-scale comparative studies is the EOS Land Viewer software with the ability to instantly split the study areas by vegetative and scene classification. It was found that the most correct for the overall assessment of the ecological balance of urban areas were *SAVI* indicators with a percentage of green infrastructure, as well as *NDVI* with a percentage of dense and temperate vegetation.

Studies have shown that in the territory of small towns of Kyiv region for the period from 1985 to 2018, the percentage of areas under sparse stands was from 37.5 to 14.9% and it increased under dense plantations from 2.4 to 49.3%. At the same time, the share of ground cover in the experimental urban territories decreased from 15.4 to 3.8%, and the areas without vegetation increased on average from 3.8 to 4.4%.

The development of green plantations in small towns was completely individual and depended not only on natural conditions but also on the directions of anthropogenic activity. As of 2018, the rating of the eco-balance of urban areas of Irpin, Tarashcha, Boiarka, Rzhyshchiv is at the top, and Kaharlyk, Skvyra, Myronivka, Yahotyn, Uzyn are closing the list.

In order to increase the level of ecological balance of urban areas, one of the most urgent measures is to create broad protective and recreational strips in the form of suburban forests, which is not problematic in the studied Polissya and forest-steppe conditions.

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