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P. V. PYVOVAR[1], Candidate of Economic Sciences, Associate Professor, Head of the Educational-Scientific Center of Space and Geo-Information Technologies of Polissia National University

ORCID ID https://orcid.org/0000-0001-7668-2552,

E-mail: symon-pyvovar@ukr.net

P. P. TOPOLNYTSKYI[1], Candidate of Technical Sciences, Associate Professor, Associate Professor of the Department of Computer Technologies and System Modeling

ORCID ID https://orcid.org/ 0000-0001-7460-1130

E-mail: topolua@ukr.net

O. V. SKYDAN[1], Doctor of Economics, Professor, Rector

ORCID ID https://orcid.org/0000-0003-4673-9620

E-mail: skydanolegv@ukr.net

S. L. YANCHEVSKII[2], Candidate of Technical Sciences, Head of the Information and Analytical Center

ORCID ID https://orcid.org/0009-0007-0546-396X

E-mail: yan.serg.77@gmail.com

[1] Polissia National University

7, Staryi Blvd., Zhytomyr, 10008 Ukraine

[2] National Center of control and tests of space vehicles

8, Kniaziv Ostrozkykh Str., Kyiv, 01010 Ukraine

GIS-BASED LAND-USE/LAND COVER CHANGE ANALYSIS: A CASE STUDY OF ZHYTOMYR REGION, UKRAINE

Today, the deep and wide implementation of geoinformation technologies in the many fields of human activity is due to the powerful development of three scientific and technical components: statistical, software, technical, and space technologies. In this article, based on GIS technologies, an analysis of the state of land use and its changes in the territory of the Zhytomyr Region, as well as the impact of Russian aggression against Ukraine on these processes, was carried out. The structure and the dynamics of the main classes of the land cover of the region for the past 7 years were analyzed, the main causes and consequences of such trends were determined, and the analysis of changes in the land cover was carried out. According to the results of this study, in 2022, 52 % of the territory of the Zhytomyr Region was under forested areas, which consist of two categories: forests and other forested areas. The first category remained unchanged during the studied period since the government system of protection and reproduction of forest resources functions effectively. While the second category significantly decreased due to the fact that firewood is the most available fuel resource for heating buildings, so the population began to harvest wood in the form of felling and clearing old gardens, forested bushes and rivers (irrigation canals), and forest strips. Agriculture of the Zhytomyr Region develops due to extensification. According to Google Dynamic World data, in 2022, 34 % of the territory of the Zhytomyr Region is systematically used for growing agricultural crops. Over the past seven years, there has been a significant increase in cultivated land by 27 %. In the structure of the land cover of the Zhytomyr Region, the grass cover is 4.9 %, but it is gradually decreasing. A decrease was observed for all types of territorial communities until 2021 (10 %

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annually on average), while, in 2022, the decline slowed down significantly in rural and village territorial communities and stopped in urban ones. This dynamic is connected with two factors: 1) part of the gardens of rural households were sown with grass due to the fact that men were mobilized to the Armed Forces of Ukraine as a result of Russian aggression, and growing grass requires less human costs; 2) Russian aggression caused a shortage of certain food products, and their significant increase in price while keeping cattle provides food for the rural household, so, in 2022, most of the offspring from cattle were not sold and left for further maintenance. In turn, the increase in cattle requires more feed, an important component of which is grass.

Keywords: *land-use, land cover change, rural area, urban area, GIS technologies.*

INTRODUCTION

Land cover use (LCU) is a change in the way a certain area of land is used or the frequency of openness (cultivation) of the soil, and land cover change (LCC) characterizes a change in certain functional characteristics of the land, such as a change in the type of cenosis in the form of the transformation of natural biocenoses into agrocenoses and vice versa. The study of global environmental change and sustainable development land cover use and land cover change (LCU/LCC) research has attracted increasing attention worldwide. In many countries of the world, numerous groups of scientists deal with the issues of the state of land use and its change in the context of the development of rural and urban areas. The analysis of the state and trends of land cover changes is currently used in the following areas of human social and economic activity: agriculture (classification and monitoring of the state of development of agricultural crops, soil cover, the state of weediness, etc.); environmental monitoring; analysis and monitoring of the consequences of natural and anthropogenic disasters, urban or rural development, etc.

However, the study of LCU/LCC trends through the identification of land use changes using remote sensing images is one of the important methods for understanding and adapting the land resources of both a small community and the country. Also, the results of the LCU/LCC analysis are a prerequisite for a deeper understanding of the LCU/LCC and for helping regional and national policymakers to set improvement goals in areas close to the country's national and food security while respecting the areas of sustainable development.

The question is: what are the distribution and dynamics of land cover changes in the studied area during 2016—2022 and how did Russian aggression affect them?

The goal of this research is a GIS-based land-use/land cover change analysis in the Zhytomyr Region during 2016—2022 and the impact of Russian aggression on these processes. To achieve the goal, the following steps must be performed: 1) GIS-based analysis of the distribution dynamics of land cover types (forest, cultivated land, pastures and hayfields, surface water bodies, built-up land) in the cross-section of rural and urban areas; 2) GIS-based analysis of the dynamics of land cover changes in the cross-section of rural, settlement, and urban areas; 3) analysis of the impact of Russian aggression on land use processes in the Zhytomyr Region.

Since the first image of the Earth from space, which was obtained (1946), the understanding of land cover use and land cover change has evolved from simplicity and abstraction to realism and complexity. If, at the first stages of LCU/LCC research, it concerned the study of the physical fact of change, today it is about identifying the factors of global environmental changes and the development of models for forecasting its further progress. The first important result of the study of the state of the land cover (1970th) was the understanding that the processes occurring on the surface of the earth in the form of LCU/LCC affect the formation of the regional climate [32]. In the future, there was a much wider set of results (state of the ecosystem, the structure of soils and forests, etc.) of the impact of the LCU/LCC process. But the greatest concern among scientists is the impact on biotic diversity both at the regional and global levels [17], the dynamics of soil degradation processes [51], and the state and forecasting of the ability of biological systems to meet human needs [37, 55].

Within the framework of this study, the works of Prakasam C., Javed A. and Khan I., Mark M., and Kudakwashe M. are of greatest interest. Prakasam C. studied the dynamics of LCU/LCC in Kodaikanal Taluk, Tamil Nadu, over 40 years, as a result of which he found a significant increase in built-up and cultivated land while the area under forest and water bodies decreased [36]. Javed A. and Khan I. examined the change in land use processes from 2001 to 2010 as part of a study of the mining industry in India. The researchers established the fact of a significant decrease in forested areas, cultivated land, and open water. At the same time, the area of built-up land, wasteland, and uncultivated land increased, while the main factor of such changes was due to anthropogenic activity [23]. Mark M. and Kudakwashe M. studied changes in land use processes in the Shurugwi district of the Midlands Province of Zimbabwe between 1992 and 2002 and found a significant increase in cultivated area at the expense of a decrease in forested areas. They explained such changes with the "Land Reform and Resettlement Program". Significant areas of forests have been cut down for various activities related to agriculture, the use of wood for heating houses, material for building houses and cattle pens, etc. [29]. Cegielska K. and others conducted a similar study for Hungary and Poland for the years 2000 and 2012. As a result, trends towards a decrease in agricultural land and an increase in built-up areas were revealed in Poland and were more intensive than in Hungary [7]. Interesting results were obtained by a group of Italian and Austrian scientists who studied the dynamics of land cover changes in the European Union from 2000 to 2018. In general, there was a reduction in agricultural land due to the intensification of agriculture, which resulted in an increase in pastures, hayfields, and meadows and a slight increase in the area of built-up land during this period [42]. An in-depth analysis of the dynamics of land cover change and its impact on the economic and ecological system was carried out by a team of scientists from Bangladesh. For the analysis, they used images from a group of Landsat satellite devices for the period from 1999 to 2019. As a result of the conducted scientific research, the dynamics of the decrease in the area of agricultural land due to the increase in built-up areas, forests, reservoirs, and salt marshes was revealed [43].

An important step in the development of the LCU/LCC was made by a team of scientists from the USA, who prepared a reference set of land cover data. As a result, such studies have allowed many scientific teams from different countries around the world to develop reliable classification models and, in general, to gain more confidence in satellite images [48]. A decisive scientific study for the development of GIS technologies in the field of development of forecasts and scenarios of future changes in the land cover was made by a team of scientists from Brazil, who developed scenarios of changes in the land use and land cover under the influence of agricultural development in areas of local vegetation for the territories of the Cerrado / Atlantic Forest in the Prata River basin for 2033, 2050, 2080, and 2100. Developed scenarios of changes in the structure of the land cover indicate the development of agricultural production and the reduction of wetlands, savannas, coastal forests, seasonal forests, and wet meadows [48]. Portuguese scientists conducted a long-term analysis of land cover in rural areas based on Landsat satellite images from 1995 to 2015. Based on the selected training data, the team applied the statistical method of clustering K-means spectral signatures for each class of land cover and achieved an accuracy of 76 %, while even such low accuracy in the long term provided an understanding of the dynamics of the main changes in the land cover [11].

It should be noted that similar studies were conducted for the territory of Ukraine. Thus, the work [24] under the leadership of Kussul N. M. (Institute of Space Research of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine, Kyiv) proposed a methodology for constructing retrospective maps of the land cover of large areas based on satellite data with a spatial resolution of 30 m using intelligent methods of processing time series of Landsat data for 1990, 2000, and 2010. Also, in the work of Yailymov B.Ya. [58], an automated information technology was developed for land cover mapping based on satellite data fusion methods and models. The new approach was presented by a team of domestic scientists led by Skakun S., the essence of which was to evaluate the effectiveness of using multi-time satellite synthetic aperture radar (SAR) to obtain images in the C-band and optical for the classification of agricultural crops in Ukraine [46].

The improvement of LCU/LCC products (increasing the resolution of maps) directly depends on the resolution of satellite technologies, including spectral radar sensors. The most requested land-use/

land cover products are the National Aeronautics and Space Administration (NASA) MCD12Q1 dataset with a resolution of 500 m (2001—2018) [49], the European Space Agency (ESA) Global Land Dataset Service (CGLS) Land Cover 100 m (2015—2019) [6], and GlobLand30 (2010) [8]. Despite the wide demand for these products at the national and global levels, they have one significant drawback – their spatial resolution does not allow monitoring of small areas that are important for monitoring and analysis of local land use (gardens of rural households, forest strips, meadows, swamps, etc.). One of the first to address this shortcoming is the European Space Agency (ESA) and the Copernicus program, which makes it possible to obtain optical and radar data from Sentinel satellites (with a resolution of 10—20 m), operated since 2014 with open access. Thanks to advances in machine learning algorithms and cloud computing platforms for Earth observation, such as Google Earth Engine (GEE) [18] and open EO [44, 47], the Sentinel satellites have enabled large-scale LCU maps with 10 m resolution [34]. And as a result, three global 10-meter LCU maps based on Sentinel were published in 2021: Google Dynamic World (DW) [34], ESA World Cover 2020 (WC) [59], and Esri 2020 Land Cover (Esri) [23]. A common characteristic of all three products is multi-temporal vision, while the significant difference is that WC and Esri are updated once a year with a significant time lag (up to 1 year), and DW provides land-use/land cover maps promptly in almost real-time (with a time lag of 7 days). Using the global ground truth dataset with a minimum mapping unit of 250 m^2, the team of scientists from different countries found that Esri had the highest overall accuracy (75 %) compared to DW (72 %) and WC (65 %) [17].

It should be noted that the deep and wide implementation of geoinformation technologies in the sphere of human activity is due to the powerful development of three scientific and technical components: statistical component, software, and technical and space technologies.

Statistical component. The deepening of the development of GIS technologies is directly related to the implementation of statistical methods for the analysis of large data sets (big data analysis) in the process of analyzing geoinformation (geodata). The following methods play a particularly important role: machine learning controlled (with a teacher), machine learning uncontrolled (without a teacher), machine learning based on reference vectors (SVM), random forest (RF), spectral angle mapping (SAM), fuzzy adaptive mapping with resonance theory (Fuzzy ARTMAP), Mahalanobis distance (MD), radial basis function RBF), decision tree (DT), multilayer perception (MLP), naive Bayesian classifier (MLC), and fuzzy logic, while unsupervised classification methods include cluster affinity propagation algorithm (AP), fuzzy C-means algorithms, K-means algorithm, ISODATA (iterative self-organizing data), etc.

The software and technical component are the fundamental basis for the processing and interpretation of geoinformation, which is created because of the collection, processing, and publication of geographic or spatial data using a computerized system. Systems can include computers and networks, standards and protocols for the use and exchange of data between users within a number of different applications. Typical applications are land registration, hydrology, cadastral surveys, land valuation, planning, or environmental monitoring. Geodata comes in many different forms, such as maps or images taken from the air or space, i.e., remote sensing data. Geodata can be stored in a database, which can have special extensions for storing, processing, and manipulating spatial data. Geoinformation is the result of data analysis using a computer program called a “geographic information system” or GIS. The environment in which GIS works (machines, people, networks) is called a “spatial information system” and is designed and created to respond to the strategic needs of people or organizations in spatial information [9].

Space technologies. Today, most countries are developing their own space programs to support management decision-making in the field of communications, industry, national security, and climate change studies [14]. As a result of such activity, as of 2021, there were 7.5 thousand active satellites in the Earth’s orbit, which is 28 % more than in 2020 [29]. Such active development and application of space technologies in all spheres of economic activity is one of the important tools for achieving the goals of global development due to the provision of operational and high-quality information [35].

MATERIALS AND METHODS

Study area. Zhytomyr Region is a region in the north of Ukraine, within the Polissia Lowland, in the south, within the Dnieper Highlands. Its administrative center is the city of Zhytomyr. It consists of 4 districts: Zhytomyr District, Berdychiv District, Korosten District, and Novograd-Volynskyi District. It has 5 regional cities (Berdychiv, Zhytomyr, Korosten, Malyn, Novograd-Volynskyi), 7 district cities (Andrushyvka, Baranivka, Korostyshiv, Ovruch, Olevsk, Radomyshl, Chudniv), 43 urban-type settlements; 1619 rural settlements. The population is 1,231,239 people. The area is 29,832 km². As a result of the decentralization reform, 66 territorial communities were created on the territory of the region, of which 12 are urban, 22 are settlements, and 32 are rural (Fig. 1). According to the Law of Ukraine "On Local Self-Government", a territorial community joins residents united by permanent residence within a village, town, or city, which are independent administrative-territorial units, or voluntary associations of residents of several villages, towns, and cities, which have a single administrative center [2]. According to Article 140 of the Constitution of Ukraine, a territorial community is the residents of a village, settlement, city, or a voluntary association of residents of several villages into a rural community [10]. As of 2021, there are 1,469 communities in Ukraine formed by uniting villages, settlements, and cities. A territorial community, the administrative center of which is the city, is an urban territorial community, with the center in the settlement — a settlement territorial community, and with the center in the village — a rural territorial community.

Considering that Ukraine consists of 24 regions and 1 autonomous republic (AR Crimea), we chose the Zhytomyr Region for the following reasons: 1) The Zhytomyr Region is unique as its land cover is evenly distributed between forested and agricultural territories, which makes it is possible to identify

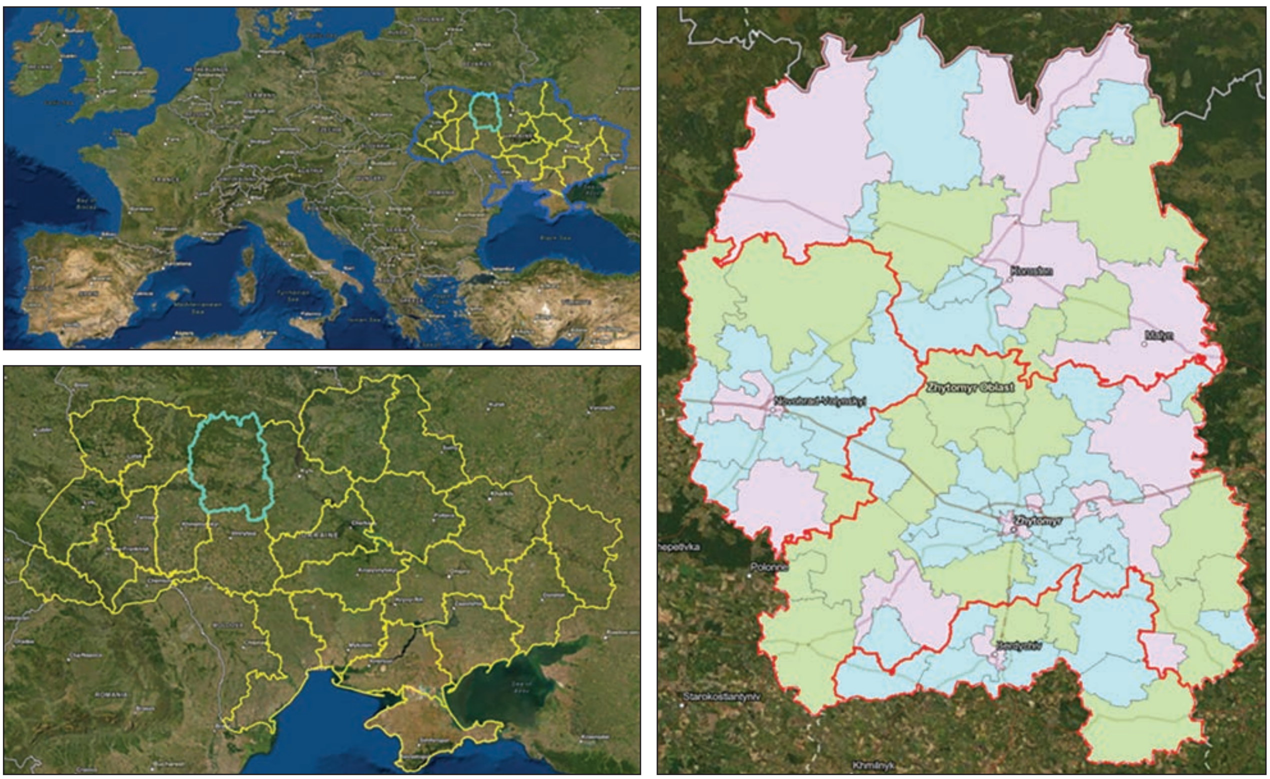
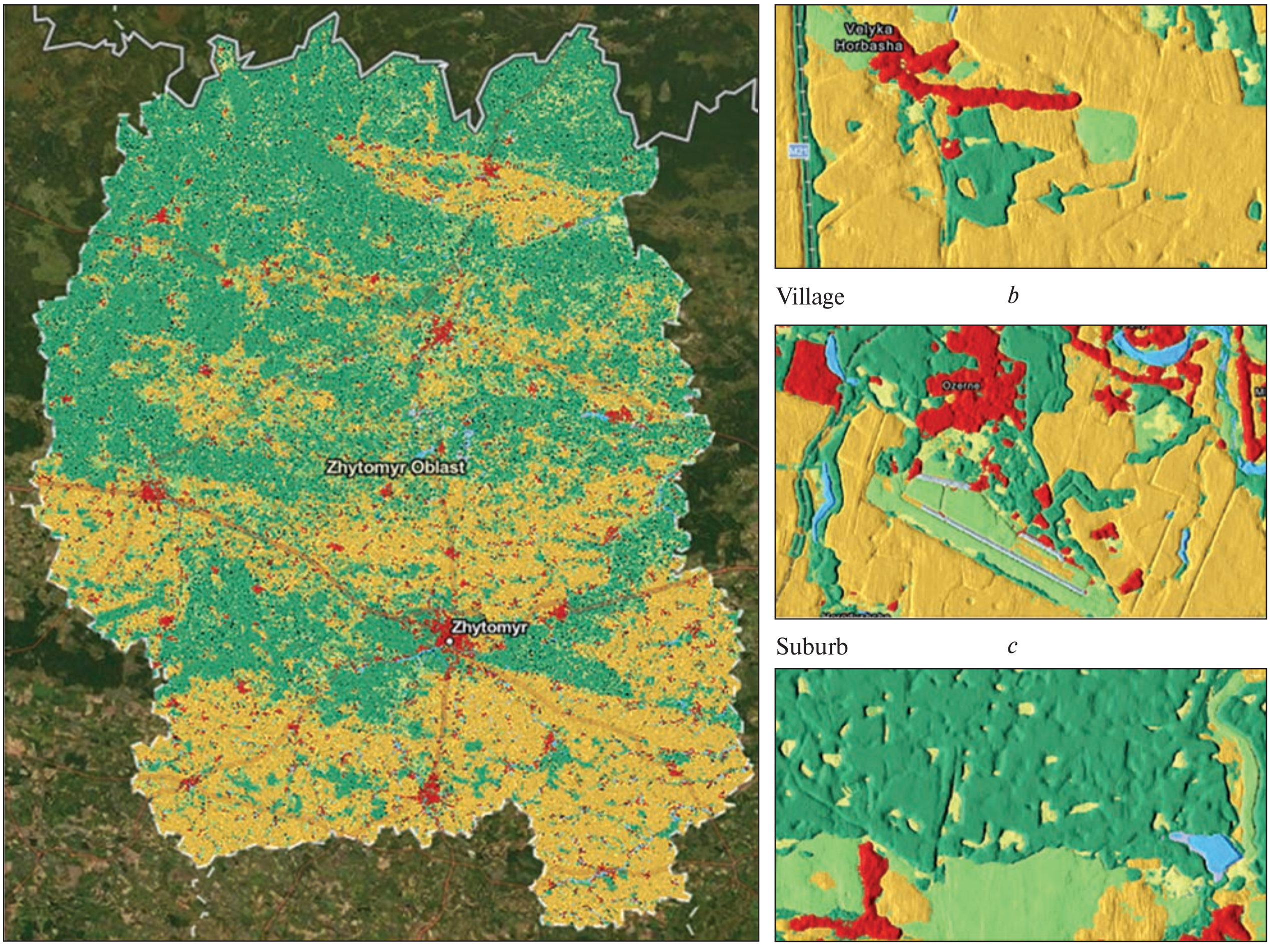


***Figure* 1.** Geographical position of Ukraine and its administrative-territorial division. Yellow line — state and regional (region) borders of Ukraine (green line — the Zhytomyr Region); red line — district borders; grey line — territorial community (TC) borders; blue color — rural TC; pink — urban TC; green — settlement TC



Region oblast *a*; Village *b*; Suburb *c*; Forest *d*

***Figure* 2.** Land cover classification of the Zhytomyr Region according to the methodology of the Google Dynamic World. More detail color characteristics presented in Table 1

Table 1. **Characteristics of land cover classes according to the methodology of the Google Dynamic World**

LULC class	Color	Examples
Water		Permanent and seasonal water bodies
Trees		Includes primary and secondary forests, as well as large-scale plantations
Grass		Natural grasslands, livestock pastures, and parks
Flooded vegetation		Mangroves and other inundated ecosystems
Crops		Include row crops and paddy crops
Shrub & Scrub		Sparse to dense open vegetation consisting of shrubs
Built Area		Low- and high-density buildings, roads, and urban open space
Bare ground		Deserts and exposed rock
Snow & Ice		Permanent and seasonal snow cover

trends in changes in agricultural and forest land use; 2) over the past 10 years, the structure of cultivated areas has changed in the territory of Zhytomyr Region in the direction of southern crops, atypical for these territories, therefore, the question of the influence of these cultures on the land cover of the region becomes important; 3) this research was carried out at the Polissia National University, which is located in Zhytomyr, which gives an opportunity to contact with experts in the business and scientific spheres.

Data sources. In this study, we used an automated approach for high-resolution, near-real-time (NRT) globally consistent land cover classification (LULC) using deep learning on 10-m Sentinel-2 images developed by a team of data scientists from Google and scientists from the National Geographic Society, Boston University, World Resources Institute [5]. The datasets are generated on the GEE platform using the GOOGLE/DYNAMICWORLD/V1 product with a resolution of 10 m and directly exported for further processing in ArcGIS PRO and R for the period 2016 to 2022 (Fig. 2). The Dynamic World V1 product provides an opportunity to obtain label information for nine classes (Table 1), which are water, trees, grass, flooded vegetation, crops, shrub & scrub, built area, bare ground, snow & ice.

Methodology. In this study, we used the Google Earth Engine platform to download raster classified images, then, in the ArcGIS PRO environment, the raster images were transformed into vector objects, based on which zonal statistics were calculated for each land cover class at the level of three types of territorial communities. The resulting array of data was systematized and grouped in the software environment R.

RESULTS

The structure of the LULC in 2022 (Fig. 3) shows that 52 % of the area of the Zhytomyr Region is covered by forests, which are concentrated mainly in the northern part of the region and in the central part along the Teteriv River. At the same time, agricultural land is mainly concentrated in three locations: 1) the southern part of the region (Berdychiv District); 2) a central belt with a width of 40—60 km; 3) in the north, the Ovrutsky ridge. A tenth of the region's area is occupied by shrub, scrub, and grass, which were mainly concentrated along roads and water bodies, the share of which is 0.63 %. The share of built-up land is 3.7 %, which is evenly distributed over the entire area of the region, with a significant concentration in the cities of the region.

It should be noted that the structure of the land cover based on the data obtained as a result of the processing of satellite images and the data of official statistics differ slightly (Table 2), i.e., with the help of GIS technologies, it is impossible to distinguish all lands of a certain class within the framework of official statistics since satellites classify land plots exclusively in a color spectrum, and official statistics are based on the legal status of land parcels. Below, there is a list of the main differences in the most important land cover classes.

1) **Agricultural lands.** According to the Dynamic World methodology, agricultural land is represented by such types of land cover (cultivated land) and a part of grass (not including natural herbaceous coenoses). In turn, according to the official method of collecting statistical information in Ukraine, data on agricultural land includes three categories: 1) arable land, 2) fallow, and 3) perennial plantings, hayfields, and pastures. As a result of comparing crops (land cultivated during the year) from Dynamic World and arable land from official statistics, we see a difference of 3.8 %, which is explained by the fact that the statistical office collects such information from only a part of agricultural producers (agricultural enterprises and rural households) and further extrapolates these data to the entire region. The difference between grass from Dynamic World and Fallow from official statistics is explained by the fact that grass includes all land on which grass grew, including pastures, hayfields, meadows, and land under grass near rivers, forests, etc., while fallow in official statistics includes only land plots under grass intended for agricultural production (sale of hay, silage, use for fodder for farm animals). Also, according to official statistics, perennial plantings, hayfields, and pastures are included in agricultural areas, while according to Dynamic World, perennial plantings are classified as trees, and hayfields and pastures are classified as grass.

2) **Forested areas.** According to the Dynamic World methodology, any territory that includes primary and secondary forests, as well as large-scale plantations,

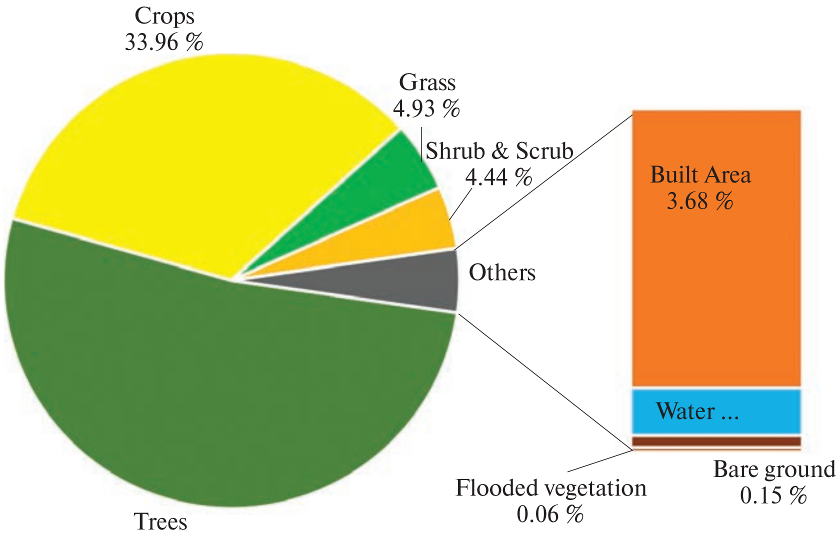


***Figure* 3.** Structure of LCLU Google Dynamic World of the Zhytomyr Region in 2022

Table 2. **Comparison of the structure of land cover classes of the Zhytomyr Region in 2021 based on Google Dynamic World vs Official Ukraine statistics**

Type	Google Dynamic World — 2021	Official statistics — 2021 [13]	
Crops (cultivated land)	33.9	Arable	37.7
Grass	4.93	Fallow	2.1
		Perennial plantings, hayfields, and pastures	10.8
Trees	52.14	Forest	37.7
Built Area	3.68	Built-up lands	3
Shrub & Scrub	4.44		
Bare ground	0.15	Open lands	1.3
Flooded vegetation	0.06	Wetlands	3.4
Water	0.63	Open bodies of water	1.6
		Others	2.4
Total	100	Total	100

is defined as forested, while official statistics provide territories registered in the State Agency of Forest Resources of Ukraine. In other words, industrial gardens, parks, temporarily forested territories as a result of the termination of agricultural activities, etc., are not taken into account, which, as a result, gives the error of 14.4 %.

3) **Built-up lands.** The register of built-up lands is maintained by the State Land Cadastre of Ukraine, which includes lands: under one- and two-story buildings; under three or more floors; industry; under open pits, quarries, mines, and similar; used for commercial purposes; public purpose; mixed-use; used for transport and communication (under roads, railways, airports and related structures, others); used for technical infrastructure (for waste removal, water supply and wastewater treatment, for the production and distribution of electricity); used for recreation and other open lands (green spaces for public use, campsites and rest houses, occupied by current construction and set aside for construction, under hydrotechnical structures, streets, squares, embank-

ments, cemeteries). At the same time, according to the Dynamic World methodology, low- and high-density buildings, roads, and urban open spaces are classified as built-up land. Despite the fact that all types of built-up land in the Dynamic World methodology correspond to the types of official statistics (of which there are many more), the share of built-up land in the Dynamic World methodology is 0.68 percentage points more than reported by official statistics. Such a difference may indicate that these percentage points are unregistered built-up land.

4) **Water bodies.** An important feature of the Dynamic World methodology is the use of satellite images with a resolution of 10 m, that is, the area of the smallest pixel is equal to 100 m^2, which is often insufficient for the identification of small rivers, streams, and channels. At the same time, in our opinion, the state (area) of large rivers and reservoirs adequately describes the dynamics of general water bodies.

One of the important elements of the analysis of the land cover of any territory is the study of the dynamics of changes. In our case, we will study changes over the past 7 years (Table 3) by classes of land cover of the Zhytomyr Region. The greatest changes during the studied period, 227 thousand ha or almost a third, occurred in such a type as cultivated land. Such an increase was mainly due to such classes as Grass (–124 thousand ha or –50 %), Trees (–8.4 thousand ha or –0.5 %), and Shrub & Scrub ((–81 thousand hectares or –65 %). The gradual increase of Water by 1.5 thousand hectares or 8.5 % is noteworthy, which serves as the basis for increasing cultivated land since very often agricultural producers use irrigated agriculture. The fact of improvement of the water regime of the Zhytomyr Region is the increase of such type of land cover classes Flooded vegetation by 0.4 thousand hectares or by 37 %.

Forested areas — the areas of the land cover of any territory on which the share of tree cover is at least 10 %. Such territories include forests, field protection forest strips, agricultural gardens, and forest parks. According to Google Dynamic World data, in 2022, 52 % of the territory of the Zhytomyr Region is forested. Of these territories, 34 % belonged to urban

Table 3. **Dynamic of land cover changes of the Zhytomyr Region based on Google Dynamic World**

LCC class	*S*, kha							Change 2016/2022	
	2016	2017	2018	2019	2020	2021	2022	kha	%
Trees	1551.5	1594.8	1601.5	1569.4	1566.0	1582.2	1543.1	–8.4	–0.5
Change, %		2.8	0.4	–2.0	–0.2	1.0	–2.5	—	—
Crops (cultivated land)	777.7	857.5	907.6	922.0	950.1	969.6	1005.0	227.3	26.5
Change, %		10.3	5.8	1.6	3.0	2.1	3.6	—	—
Grass	270.6	247.7	206.8	191.3	160.8	153.7	146.0	–124.5	–50.3
Change, %		–8.4	–16.5	–7.5	–16.0	–4.4	–5.0	—	—
Shrub & Scrub	212.3	123.7	102.8	137.8	148.7	119.1	131.4	–80.9	–38.7
Change, %		–41.7	–16.9	34.0	7.9	–20.0	10.4	—	—
Built Area	117.8	115.7	115.3	114.3	110.3	112.9	109.0	–8.8	–7.6
Change, %		–1.8	–0.3	–0.8	–3.5	2.3	–3.4	—	—
Water	17.2	17.6	18.9	18.7	17.7	18.5	18.7	1.5	8.5
Change, %		2.1	7.3	–0.7	–5.2	4.3	1.1	—	—
Bare ground	4.1	3.1	6.4	5.2	5.1	4.0	4.4	0.3	11.3
Change, %		–25.5	108.6	–17.8	–2.9	–21.7	11.5	—	—
Flooded vegetation	1.3	1.2	1.3	1.3	1.3	1.1	1.7	0.4	36.5
Change, %		–4.0	8.7	–3.9	–0.4	–15.1	59.2	—	—
Total	2953	2961	2961	2960	2960	2961	2959	6.9	0.2
Change, %		0.3	0.0	0.0	0.0	0.0	–0.1	—	—

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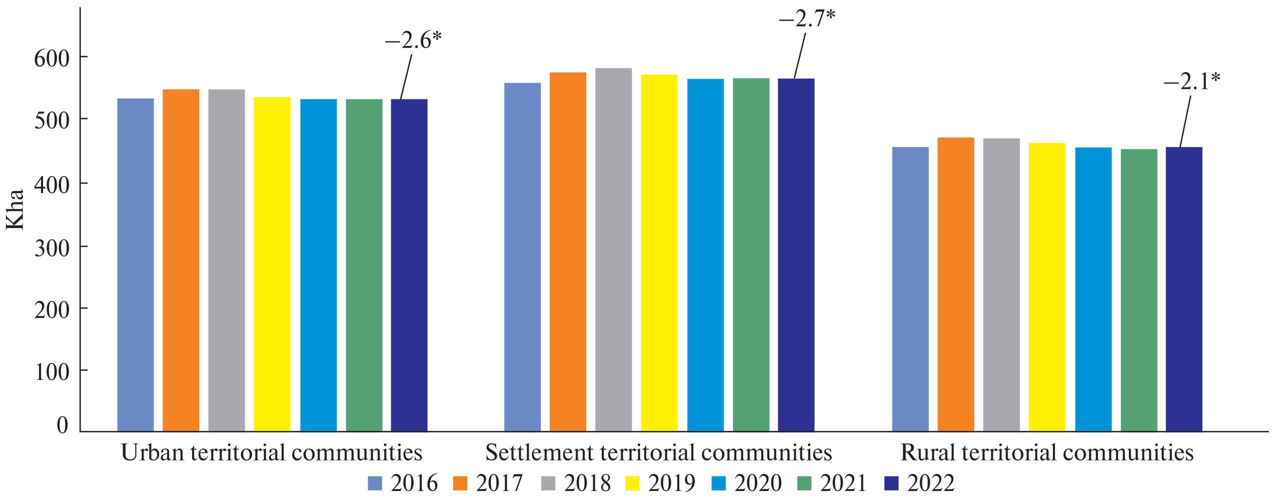

***Figure* 4.** Forested area of the Zhytomyr Region in 2022, according to Google Dynamic World

territorial communities, 36 % to settlement communities, and 30 % to rural communities (Fig. 4).

As of 2022, there is a significant decrease in forested areas of the region in all types of territorial communities by approximately 2...3 %. This decrease is related to Russian aggression against Ukraine, which negatively affected the price and stability of supplies of basic resources for home heating (firewood, gas, electricity). Given that firewood is the most available of these three resources for home heating, the population began harvesting wood in the form of felling and clearing old orchards, wooded bushes and rivers (irrigation canals), and forest strips (Fig. 5).

Crops (cultivated land) are the land systematically cultivated and used for growing various agricultural plants to obtain agricultural products for profit or subsistence. These lands are the basic means of production in the agricultural production of both agricultural enterprises and rural households. According to Google Dynamic World data, in 2022, 34 % of the territory of the Zhytomyr Region is systematically used for growing agricultural crops. Of these territories, 23 % belonged to urban territorial communities, 43 % to settlement communities, and 33 % to rural communities. According to Fig. 6, over the past seven years, there has been a significant increase in the area of cultivated land by 29 %. This growth was mainly due to the decrease in the number of cattle both in Zhytomyr and in Ukraine as a whole, which affected the transformation of grassy agrocenoses into cultivated ones (Fig. 7). At the same time, the largest increase in cultivated land was in urban territorial communities — by 35.9 %, which in turn is related to the logistics costs of enterprises for the transportation of goods and equipment: large agricultural companies choose to invest in those territories with the good roads in the region and the presence of a railway station, which is an indispensable attribute of all urban areas.

Such significant changes in the direction of agricultural expansion are also related to climate change.

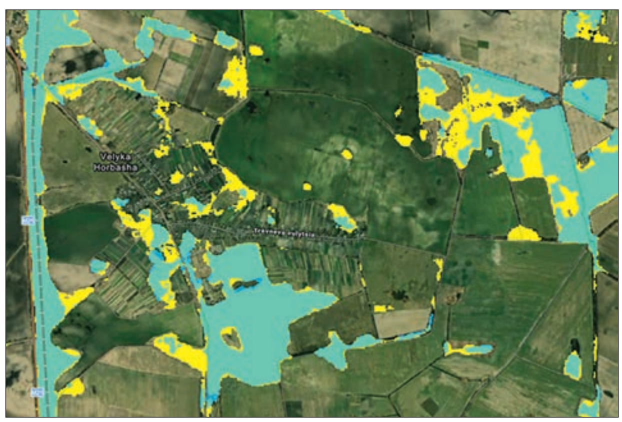

***Figure* 5.** Example of change in Forested area in 2022 compared to 2016. (Village of Velyka Gorbasha, Chernyakhiv settlement territorial community, the Zhytomyr Region. Yellow polygons are forested areas in 2021, and blue polygons are forested areas in 2022)

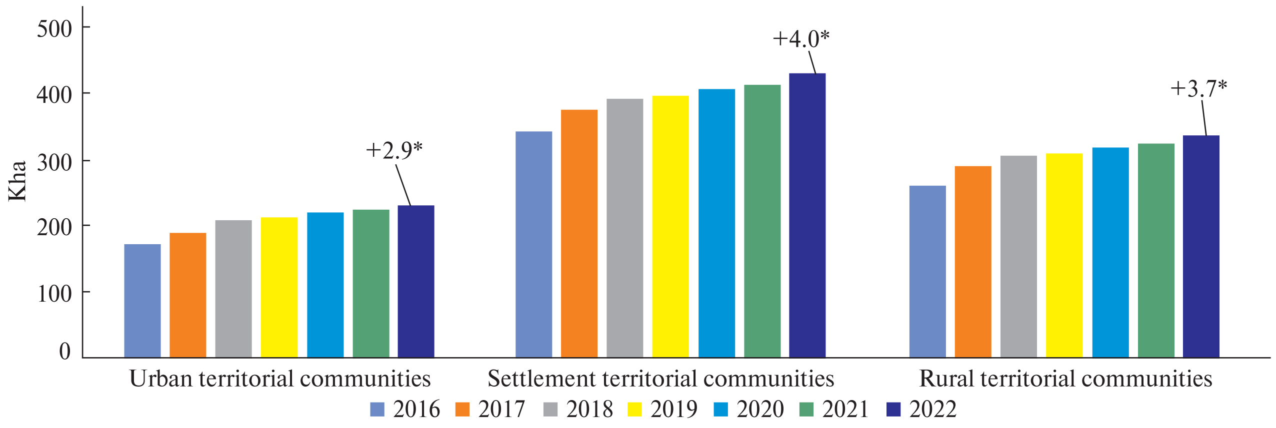

Figure **6.** The area under crops of the Zhytomyr Region in 2022, according to Google Dynamic World

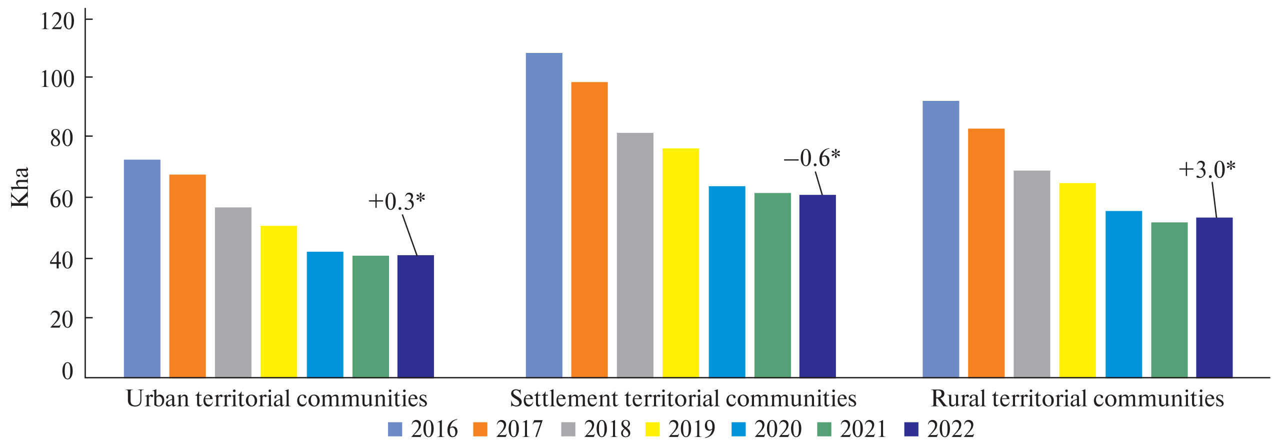

Figure **7.** The area under the grass of the Zhytomyr Region in 2022, according to Google Dynamic World

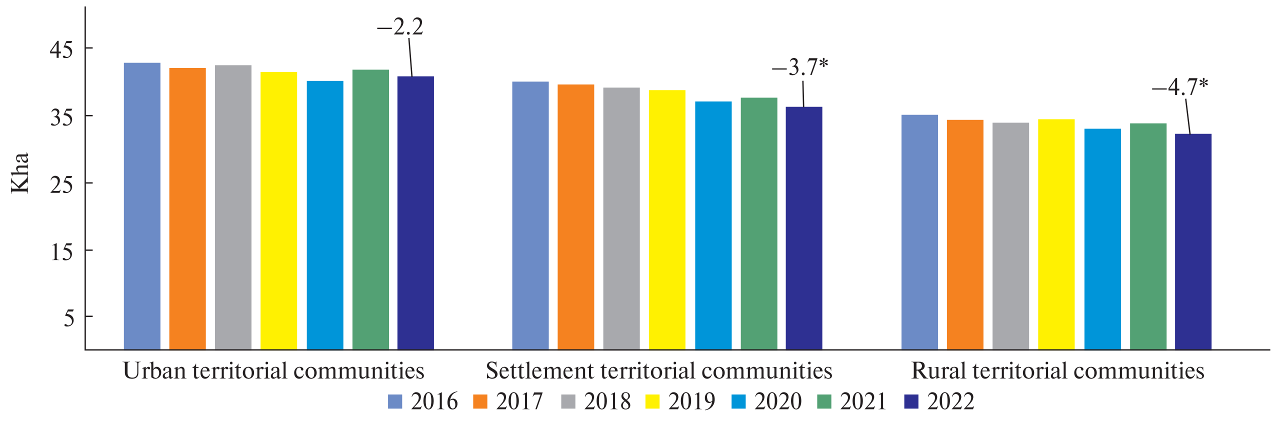

Figure **8.** Built area of the Zhytomyr Region in 2022, according to Google Dynamic World

Thus, studies [19, 21] carried out for the period from 2000 to 2015 demonstrate that in the territory of the Zhytomyr Region in all seasons of the year, there is an excess of temperature indicators compared to the norm: in winter — by 1.3...2.5 °C, in spring — by 1.0...1.9 °C, in summer — by 0.8...2.4 °C, in autumn — by 0.5...1.7 °C. Therefore, there is a trend towards an increase in average monthly temperatures, which indicates a change in the climate toward warming. Moreover, the warming is more noticeable in the winter months. On average, during 2000—2015, the annual temperature in the region increased by 1.8 °C. In turn, warming affects the activation of humus decomposition processes in grants and increases the efficiency of fertilizer application, the productivity of photosynthesis due to the increase in the content of carbon dioxide in the atmosphere, and the extension of the growing season in the entire territory of the region. In the Polissya zone over the past 10 years, warmer winter and early spring periods have formed, which will promote the growth and development of southern crops, atypical for these territories: soybean (increase by 6 times in 2020 compared to 2010), sunflower (15-fold increase), rapeseed (2.5-fold increase), corn (15-fold increase) [40].

Grass cover is an important component of both agricultural and ecological agrocenoses and, as noted, is one of the indicators of livestock development in the region. In the structure of the land cover of the Zhytomyr Region, the grass cover occupies 4.9 %, but it is gradually decreasing. A decrease was observed for all types of territorial communities until 2021 (10 % annually on average), while, in 2022, the decline slowed down significantly in rural and settlement territorial communities and stopped in urban ones (Fig. 7). This dynamic is connected with two factors: 1) part of the gardens of rural households were sown with grass due to the fact that men were mobilized to the Armed Forces as a result of Russian aggression, and growing grass requires less human costs; 2) Russian aggression caused a shortage of certain food products and their significant increase in price while keeping cattle provides food for the rural household. So, in 2022, most of the offspring from cattle were not sold and left for further maintenance, in turn, the increase in cattle requires more feed, an important component of which is grass.

Built-up land in the Zhytomyr Region accounted for 3.7 % in 2022, with a significant decrease of 3.5 % compared to 2021 (Table 3). If we consider the decrease in urban and rural communities during the past two years, it can be noted that in urban communities the drop is –2.2 % while in rural communities — –4.7 % (Fig. 8). It should be noted that the important stimulator of such a decrease in rural areas is the gradual destruction of many agricultural buildings of Soviet heritage (farms, warehouses, storage facilities for equipment), which have not found their demand in the modern conditions of agrarian business. Whereas in urban areas, the main stimulator is the lack of demand for certain industrial areas, which over time become overgrown with bushes and trees (Fig. 9).

In the general structure of the land cover, open water bodies occupied 0.63 % in 2022, and during the studied period, a gradual increase in the area of open water bodies by 8.3 % was observed. 24 % of open water bodies are located in urban communities, 40 % in settlement communities, and 34 % in rural communities. It should be noted that the largest increase in the area of open water bodies was observed in urban communities by 2.8 %. At the same time, the growth in settlements and rural communities was 0.4 % and 0.8 %, respectively (Fig. 10). Such a gradual increase in the water potential of the region contributes to both the change in the structure of the cultivated areas and the change (improvement) of crop cultivation technologies by agricultural commodity producers: the abandonment of deep plowing, the implementation of Notill and Striptill technologies.

The class shrub & scrub includes small woody plants, usually with several stems, that do not grow high from the ground (25...50 cm). There is no clear difference between a small tree and a large shrub. Some species may have a bushy form when growing outdoors, but develop into small trees in moist, sheltered locations. Shrub & scrub in the territory of the Zhytomyr Region can include abandoned agricultural plots, young forests from 3 to 7 years old, and swampy areas 3...7 years after clearing. Shrubs, turning into dead trees in autumn and spring, very often become the cause of fires in the territory of the Zhytomyr Region. Shrubs and scrubs in 2022 accounted for 4.4 % of all areas, while a significant decrease was observed

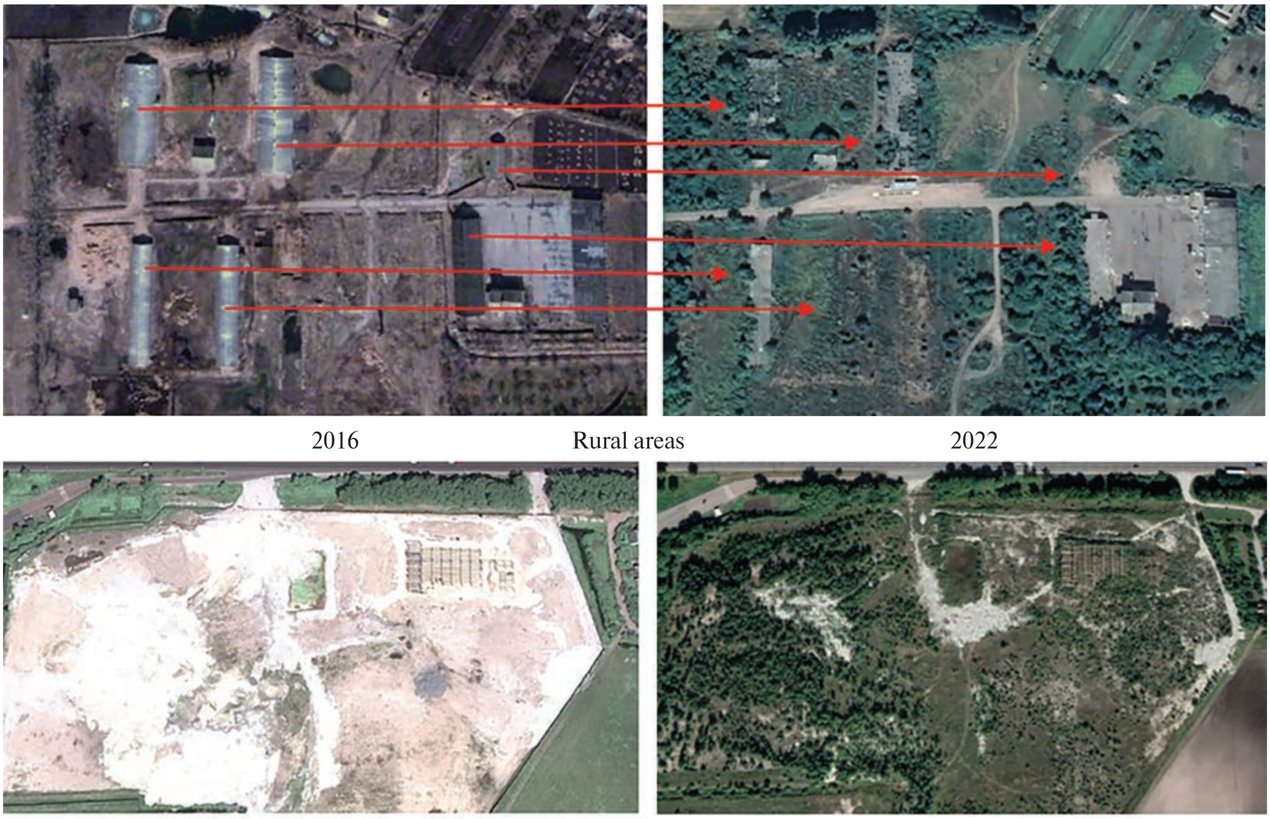

***Figure* 9.** Transformation of Built area of the Zhytomyr Region from 2016 to 2022, according to Google Dynamic World

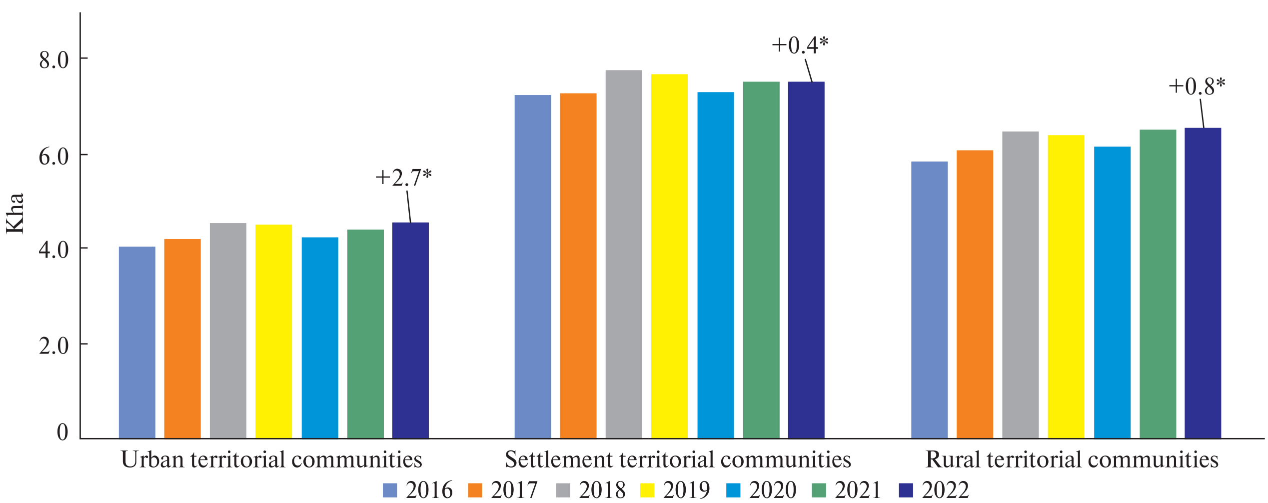

***Figure* 10**. The area under the water of the Zhytomyr Region in 2022, according to Google Dynamic World over the studied period by 39 %, or by 27 kha. This significant decrease is primarily due to the expansion of agriculture. Agricultural commodity producers are gradually clearing and seizing previously abandoned or waterlogged agricultural plots (Fig. 11).

In the process of analyzing land cover changes, it is important not only to identify the fact and volume of changes but also the directions of changes, that is, what types of land cover classes have been transformed over a certain period. In our case, we investigated how the land cover classes of 2016 were transformed into the classes of 2022 (Table 4).

According to the analysis of land cover changes, 92 % of forested areas remained unchanged, and the other 8 were transformed into: 3.3 % — crops; 3.1 % — shrub and scrub; and other — 0.6 %. Such results indicate that the state system of protection and reproduction of forest resources works effectively. At the same time, the main transformation processes take place with forested territories that are not subject to state protection: forested bushes, forested areas near open water bodies, forested swamps, and abandoned orchards.

94 % of croplands remained unchanged, while the largest share of land 2.7 % and 1.6 % was transformed into grasslands and trees, the remaining 1.2 % to bare, built, shrub and scrub. Such trends with the transformation of croplands into grass indicate the presence of grass in crop rotations of agricultural producers. Also, the transformation into flooded vegetation is the result of the reclamation of natural agrocenoses by agricultural expansion, so part of the natural swamps

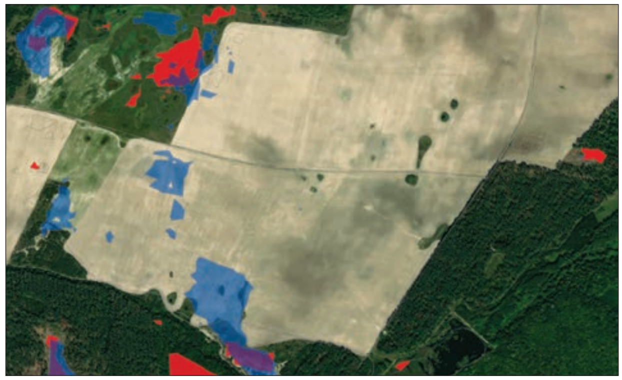

***Figure* 11.** Case of transformation of area under shrub & scrub of the Zhytomyr Region from 2016 to 2022, according to Google Dynamic World. Blue polygons — shrub & scrub of 2016, red — shrub & scrub of 2022

drained by agricultural enterprises eventually become unsuitable for further agricultural use.

53 % of grass in 2016 remained unchanged to 2022, i.e., 83 thousand hectares of the Zhytomyr Region can be attributed to natural grassy biocenoses (meadows, meadows, natural hayfields). In turn, the other 32 % were transformed into croplands, 5.5 % — into shrub and scrub, 8.5 % — into trees, and the last two indicate the presence of a forest resource reproduction system since after felling a forested area, the grass is recognized there in the first two years (according to Google Dynamic World), and bushes and trees are recognized there in the next 3-4 years.

Significant differences regarding land cover changes at the level of different types of territorial communities were not recorded as a result of this study since

Table 4. **Transition area matrix of land cover of the Zhytomyr Region from 2016 to 2022, %**

To 2022	From 2016							
	Water	Trees	Grass	Flooded vegetation	Crops	Shrub & Scrub	Built area	Bare ground
Water	89.9	0.1	0.1	**29.0**	0.0	0.1	0.1	4.6
Trees	**4.9**	92.2	8.5	19.2	1.6	**30.0**	**6.4**	8.0
Grass	0.5	0.8	32.1	3.0	**2.7**	11.7	1.2	4.4
Flooded vegetation	1.2	0.0	0.1	36.5	0.1	0.1	0.0	0.7
Crops	1.3	**3.3**	**53.3**	4.9	94.4	26.6	**6.3**	**48.2**
Shrub & Scrub	0.7	3.1	5.5	6.9	0.8	29.4	3.1	7.7
Built area	0.3	0.2	0.2	0.1	0.2	1.9	82.8	3.3
Bare ground	1.2	0.1	0.1	0.3	0.1	0.3	0.1	23.1

territorial communities began to be created in 2015, and the final completion of formation (including the unification of already existing ones) took place in 2020.

DISCUSSION

The study of modern achievements in the field of scientific and software remote sensing of the Earth made it possible to perform GIS-based LCU/LCC analysis in the Zhytomyr Region during 2016—2022 and how Russian aggression affected these processes. The structure of the land cover of the Zhytomyr Region for the past 7 years was analyzed, the dynamics of the main land cover classes of the region was shown, the main causes and consequences of such trends were determined, and the land cover changes analysis was carried out. The analysis showed that significant changes in land cover occurred in 2022 as a result of Russian aggression against Ukraine.

The results obtained in this article, in most cases, coincide with the results of scientific research in the field of land use analysis based on GIS technologies. Thus, a team of Hungarian researchers [25] concluded that the expansion of agricultural land, both for commercial production and crop production, is the main driving force of land cover change. The results regarding the expansion of cultivated areas in the world while reducing or staying the same forests, grasslands, shrubs, and other lands, are consistent with the results of previous studies [17, 28, 54]. A promising direction is to determine the influence of the main driving forces and factors (demographic, economic, technological, institutional, political, and biophysical factors) on the state of land use.

Unlike many Ukrainian scientists, who conducted similar studies [24], we did not build our own land cover classification model but used the already completed, verified GOOGLE/DYNAMICWORLD/V1 product. Also, in the work, it was not possible to determine significant land cover changes analysis at the level of three types of territorial communities (rural, settlement, urban) since the part of the territorial communities began to be created in 2015, and the final completion of the formation (including the unification of already existing ones) took place in 2020 year. Although in the future, these will be very important and interesting studies.

CONCLUSIONS

In this article, a GIS-based LCU/LCC analysis was carried out in the Zhytomyr Region in 2016—2022. To achieve this goal, data sets generated on the GEE platform using the GOOGLE/DYNAMICWORLD/V1 product and processed in the ArcGIS PRO environment were used (summary statistics within polygons (classes)), the resulting array of geodata was grouped in R programming language on the level of territorial communities of the Zhytomyr Region. As a result of the analysis, the following conclusions were obtained:

1. In 2022, 52 % of the territory of the Zhytomyr Region was covered by forests. Of these territories, 34 % belonged to urban territorial communities, 36 % to settlement communities, and 30 % to rural communities. The forested territories of the region consist of two categories: forests and other forested territories such as (gardens, forest strips, and wooded areas of land (swamps, abandoned lands, etc.). The first category does not change due to the functioning of the state system of protection and reproduction of forests, while the second category has been significantly reduced, especially over the last year. This decrease occurred in connection with the Russian aggression against Ukraine, which negatively affected the price and stability of supplies of the main energy resources for heating the population’s homes (firewood, gas, electricity). Given that firewood is the most accessible of these three resources for home heating, the population began to harvest wood in the form of felling and clearing old orchards, wooded bushes, rivers (irrigation channels), forest strips, etc.

2. Agriculture of the Zhytomyr Region is developing due to extensification since, over the past 7 years, the increase in agricultural cultivated areas was 27 %. According to Google Dynamic World data, in 2022, 34 % of the territory of the Zhytomyr Region has been systematically used for growing agricultural crops. Of these territories, 23 % belonged to urban territorial communities, 43 % to settlements, and 33 % to rural ones. The growth of the area of cultivated land caused the increase in the level of plowing, which in the Zhytomyr Region is 37 % of the entire territory and 74 % of agricultural land. Human expansion into the natural environment in the form of

plowing natural biocenoses is more present in urban areas due to the presence of logistical infrastructure (roads, railways, railway stations) as a factor of investment attractiveness.

3. In the structure of the land cover of the Zhytomyr Region in 2022, the grass covers 4.9 % of the territory, but it is gradually decreasing. A decrease was observed for all types of territorial communities until 2021 (10 % annually on average), while, in 2022, the decline slowed down significantly in rural and settlements territorial communities, and it stopped in urban ones. This dynamic is conditioned by two factors: 1) part of the households plots of rural households were sown with grass due to the fact that men were mobilized to the Armed Forces of Ukraine because of Russian aggression, and growing grass requires less human costs; 2) Russian aggression caused a shortage of certain food products and their significant increase in price while keeping cattle provides food for the rural households. So, in 2022, most of the offspring from cattle were not sold and left for further maintenance. In turn, the increase in cattle requires more feed, an important component of which is grass.

4. Built-up land is one of the indicators of the development of industry in urban areas and the livestock industry in rural areas. Built-up land in the Zhytomyr Region is 3.7 % in 2022, while a significant decrease of 3.2 % compared to 2021 is observed. Such an essential decrease is explained by the closure of a significant number of enterprises in urban areas, which led to the overgrowth of their territories with shrub and scrub and trees. At the same time, in rural areas, there is a sharp destruction of old collective farm buildings, such as abandoned complexes for keeping farm animals, storage facilities for agricultural products, etc.

5. Shrub and scrub in 2022 accounted for 4.4 % of all areas, while a significant decrease was observed over the studied period by 65 %, or by 81 kha. This significant decrease is primarily due to the expansion of agriculture. Agricultural commodity producers are gradually clearing and taking over previously abandoned or waterlogged agricultural plots.

Land cover classification based on satellite imagery is vital for decision-making in business, regional, and national governance. Enterprises receive up-to-date information about the state of a natural object — a production object and state and regional authorities can use this information to plan the strategic development of territories, develop programs for the preservation of natural biocenoses, etc.

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П. В. Пивовар[1], керівник навчально-наукового центру космічних та геоінформаційних технологій,
доцент, канд. економ. наук
ORCID ID https://orcid.org/0000-0001-7668-2552,
E-mail: symon-pyvovar@ukr.net
П. П. Топольницький[1], доцент кафедри комп'ютерних технологій і моделювання систем, канд. техн. наук, доцент
ORCID ID https://orcid.org/ 0000-0001-7460-1130,
E-mail: topolua@ukr.net
О. В. Скидан[1], ректор, проф., д-р економ. наук
ORCID ID https://orcid.org/0000-0003-4673-9620
E-mail: skydanolegv@ukr.net
С. Л. Янчевський[2], нач. інформаційно-аналітичного центру, канд. техн. наук
ORCID ID https://orcid.org/0009-0007-0546-396X,
E-mail: yan.serg.77@gmail.com

[1]Поліський національний університет
Старий Бульвар 7, Житомир, Україна, 10008
[2]Національний центр управління та випробувань космічних засобів
вул. Князів Острозьких 8, Київ, Україна, 01010

АНАЛІЗ ЗМІН ЗЕМНОГО ПОКРИВУ НА ОСНОВІ ГІС: ПРИКЛАД ЖИТОМИРСЬКОЇ ОБЛАСТІ, УКРАЇНА

На сьогодні глибоке та широке впровадження геоінформаційних технологій у сферу діяльності людини зумовлене потужним розвитком трьох науково-технічних складових: статистичної, програмно-технічної та космічних технологій. У роботі на основі ГІС-технологій аналізується стан землекористування та його зміни на території Житомирської області та вплив на ці процеси російської агресії проти України. Було проаналізовано структуру та динаміку основних класів земного покриву Житомирської області за сім років, визначено основні причини і наслідки таких трендів, проаналізовано зміни земного покриву. Для досягнення цієї мети було використано набори даних, згенеровані на платформі GEE за допомогою продукту GOOGLE/DYNAMICWORLD/V1 і безпосередньо експортовані для подальшої обробки в середовище ArcGIS PRO. Остаточні результати були згенеровані на програмній мові R. Відповідно до результатів цього дослідження у 2022 році 52 % території Житомирської області знаходились під лісовкритими територіями, які складаються з двох категорій: лісів та інших лісовкритих територій. Перша категорія за досліджуваний період залишалася без змін, тоді як друга категорія суттєво зменшувалась у зв'язку із тим, що дрова є найбільш доступними із паливних ресурсів для обігріву житла, тому населення почало здійснювати заготівлю деревини у формі вирубування та зачищення старих садків, заліснених чагарників та річок (іригаційних каналів), лісосмуг. Сільське господарство Житомирської області розвивається за рахунок екстенсифікації. Відповідно даних Google Dynamic World у 2022 році 34 % території Житомирської області систематично використовуються для вирощування сільськогосподарських культур. За останні сім років відбулось суттєве зростання площ культивованих угідь на 27 %. У структурі земного покриву Житомирської області трав'янистий покрив займає 4.9 %, але поступово зменшується. По всіх типах територіальних громад спостерігалося зменшення до 2021 року (в середньому щорічно 10 %), тоді як у 2022 році падіння суттєво сповільнилося в сільських та селищних територіальних громадах, а у міських — зупинилося. Така динаміка пов'язана із двома факторами: 1) частина городів сільських домогосподарств була засіяна травою у зв'язку з тим, що чоловіки були мобілізовані до ЗСУ в результаті російської агресії, а вирощування трави вимагає найменше людських затрат; 2) російська агресія спричинила нестачу певних продуктів харчування та їхнє значне подорожчання, при цьому утримання великої рогатої худоби забезпечує харчами сільське домогосподарство, тому у 2022 році більшість приплоду від ВРХ була не реалізована і залишена для подальшого утримання, в свою чергу збільшення ВРХ вимагає більше кормів, важливим компонентом яких є трава.

Ключові слова: землекористування, зміна земного покриву, сільські території, міські території, ГІС-технології.