SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(3), 175-191

UDC 528.88:332.1:338.43
DOI: 10.48077/scihor3.2025.175

Impact of decentralisation and war on land cover in the Zhytomyr Region of Ukraine

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Article's History:
Received: 12.08.2024
Revised: 27.01.2025
Accepted: 26.02.2025

Abstract. This study aimed to examine land cover transformations in the Zhytomyr Region of Ukraine in response to decentralisation and war. It focused on assessing how shifts in local governance and the full-scale invasion have influenced land use dynamics, particularly changes in agricultural expansion, reductions in natural land cover types, and fluctuations in forested areas and water bodies. The study analysed land use patterns from 2016 to 2023 using Google Earth Engine's Dynamic World V1 data, combining geospatial data with qualitative semi-structured interviews. The

Suggested Citation:
Pyvovar, P., Levkovych, I., Skydan, O., Topolnytskyi, P., & Rozhkov, O. (2025). Impact of decentralisation and war on land cover in the Zhytomyr Region of Ukraine. *Scientific Horizons*, 28(3), 175-191. doi: 10.48077/scihor3.2025.175.

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results showed that the decentralisation process launched in 2014 has strengthened local self government and empowered communities to manage land resources. This period was characterised by the expansion of agricultural land and the reduction of natural land cover types, such as grasslands and scrublands. By contrast, the full-scale invasion that began in 2022 resulted in a shift in land use priorities due to labour shortages, rising resource costs, and limited access to markets, which led to shrinking agricultural land and partial restoration of natural ecosystems. Particularly significant fluctuations are noted in forested areas and water bodies because of energy demands and restrictions on activities in conflict zones. The findings underscored the need for adaptive land resource management in the context of socio-economic and political challenges, as well as the importance of land cover monitoring for regional planning and the sustainable use of natural resources. By analysing geospatial data from Google Earth Engine's Dynamic World V1 and qualitative semi-structured interviews, the study identified key trends from 2016 to 2023, evaluates the socio-economic and political drivers behind these changes, and highlights the challenges of adaptive land resource management in the face of instability. The findings contribute to a better understanding of the implications of land cover changes for regional planning and sustainable land use strategies

Keywords: land use change; GIS land monitoring; socio-economic impact; territorial reform; war effects

INTRODUCTION

Land cover analysis is a crucial tool for studying structural socio-economic transformations across different territories, ranging from local communities and districts to regional and national levels. In the context of decentralisation and armed conflict, the effective management of land resources has become particularly important. Decentralisation empowers communities to autonomously manage their territories, influencing land use patterns, infrastructure development, and agricultural expansion. At the same time, war introduces additional challenges, such as the disruption of economic networks, loss of human capital, and shifting land use priorities. Therefore, studying land cover changes in this context is essential for understanding the dynamics of socio-economic processes, their impact on regional development, and the formulation of policies for the sustainable use of land resources.

In Ukraine, the decentralisation process was officially launched in 2014 with the approval of the Concept of Reforming Local Self-Government and Territorial Organisation of Power in Ukraine, as outlined in Order No. 333-p of the Cabinet of Ministers of Ukraine (2014). The main goal of the reform was to strengthen local self-government and devolve powers and resources from the central government to the regions (OECD, 2018). This reform has contributed to improving the quality of public service delivery, increasing the financial autonomy of communities, and strengthening local democracy (Romanova & Umland, 2021). Notably, the amalgamation of territorial communities (ATCs) has influenced approaches to the management of socio-economic territories at the community, district, and regional levels, allowing for more efficient resource management and regional development. This has been particularly significant in enhancing Ukraine's resilience in times of war (Harus & Nivyevskyi, 2020).

On 24 February 2022, Russia launched a full-scale military invasion of Ukraine, resulting in widespread destruction, thousands of deaths, and the displacement of millions of people. This invasion had a profound impact on the territorial structure and governance of Ukraine, disrupting the functioning of local authorities, leading to the occupation of territories, altering land use, and forcing Ukraine to adapt its governance structures to wartime conditions (OCHA, 2023; UNHCR, 2024). Research on land use change traditionally relies on spatial data analysis and the identification of key socio-economic drivers. Many studies focus on urbanisation, demographic shifts, and economic development as primary factors shaping land cover transformations. For example, Zh. Yang *et al.* (2020) examined land use change in rural China between 1995 and 2015, concluding that industrialisation and urban expansion were the dominant forces driving these transformations. Similarly, Q. Xie *et al.* (2023) analysed land cover changes in Wuhan, China, and demonstrated that economic growth and infrastructure expansion contributed to the loss of arable land and an increase in built-up areas.

In the European context, A. Allan *et al.* (2022) conducted a systematic review, emphasising that land use change results from a combination of economic, political, and environmental factors. P. Pyvovar *et al.* (2023) highlighted that land cover transformations have a direct impact on local tax revenues, which is particularly relevant to territorial communities in Ukraine. Their study confirmed that decentralisation has led to improved land resource management, contributing to agricultural land expansion. Meanwhile, J. Wang *et al.* (2021) demonstrated that in China, agricultural land-use changes were closely linked to economic policies and social transformations. M. Kutia *et al.* (2023) investigated land cover changes in Changsha City, China, between 2005 and 2020, employing Landsat time-series satellite images and the Random Forest classification algorithm. Their study demonstrated a substantial increase in urban areas, which expanded from 3.23% to 15.95%, while forest cover declined until

2015, followed by a slight recovery. Cropland remained a dominant land type, peaking at nearly 50% in 2010, whereas water bodies showed little variation. The study confirmed the effectiveness of the applied classification method, highlighting its potential for sustainable urban planning. Similarly, S. Bulygin *et al.* (2021) examined strategies for improving saline and erosion-prone lands in Donetsk Region through prairie restoration. Their findings indicated that introducing salt-tolerant forage grasses significantly enhanced biomass productivity and nutritional value, with an increase in crude protein and essential nutrients. The research underscored the importance of adaptive agricultural practices for restoring degraded lands and ensuring sustainable fodder production.

This study aimed to determine the impact of decentralisation and military conflict on land cover dynamics in the Zhytomyr Region. The analysis focused on changes in the use of agricultural and natural lands, identifying key socio-economic drivers of these transformations between 2016 and 2023, and assessing the challenges associated with land resource management under crisis conditions.

MATERIALS AND METHODS

Study area. Zhytomyr Region is located in the north of the Right Bank of Ukraine, primarily within the Zhytomyr Polissia area (Fig. 1). The administrative centre is the city of Zhytomyr. The region is the fifth largest in Ukraine, covering 29,832 km^2. It extends 170 kilometres from west to east and 230 kilometres from north to south. Zhytomyr Region borders the Rivne, Vinnytsia, and Kyiv regions of Ukraine, as well as the Gomel Region of the Republic of Belarus. The region is situated at the junction of two natural zones: the southern part lies within the forest-steppe zone, while the northern part belongs to the mixed forest zone. The population of the region was 1,179,801 as of 1 January 2022 (SSSU, 2023).

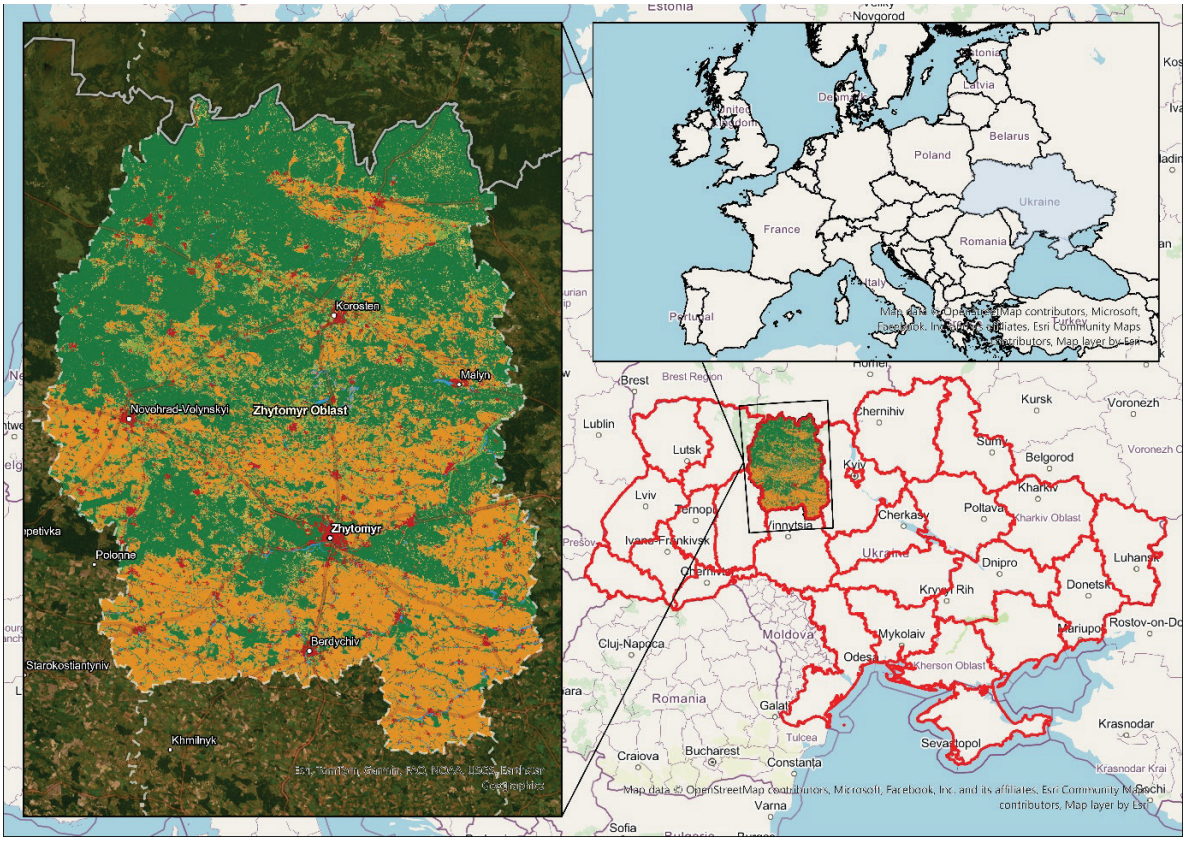

Figure 1. *Geographical location of Zhytomyr Region and its land cover, 2022*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

The selection of Zhytomyr Region for this study is based on several important factors. The region encompasses two natural zones – Polissia and Forest-Steppe – offering unique conditions for examining land use change, as the diversity of natural environments influences the structure and dynamics of land cover. Over the past decade, the composition of crops grown in the Zhytomyr Region has shifted towards southern crops, which are not typically cultivated in this region. This trend has sparked interest in investigating the impact of such changes on land use and the local economy. The study was conducted at Polissia National University, enabling the testing of hypotheses and discussions with local experts. This

approach ensured a comprehensive understanding of regional conditions and specific land use characteristics. In 2022, Russian troops invaded the Zhytomyr Region, temporarily occupying five villages. This created a unique opportunity to analyse the impact of military operations on land use and land cover dynamics.

Research design. This study adopts a mixed-methods approach that integrates geospatial analysis of land cover changes with qualitative research methods to assess the socio-economic and political drivers of land use transformation in the Zhytomyr Region. The research is structured into three main components:

1. Geospatial analysis of land cover change (2016-2023) using satellite data from Google Earth Engine's Dynamic World V1

2. Quantitative assessment of land use dynamics through geostatistical processing in ArcGIS Pro.

3. Qualitative validation and interpretation of changes via semi-structured interviews with local stakeholders, including community members, local authorities, and land use experts.

The geospatial analysis was conducted across three distinct periods:

- pre-decentralisation (2016-2019) – baseline trends prior to administrative ;
- decentralisation period (2020-2021) – assessment of land use transformation under new governance policies;
- wartime period (2022-2023) – analysis of the impact of military conflict on land cover dynamics.

The analysis focused on land cover trends and growth/decline rates, calculated as the ratio of each land cover category's area in a given year relative to the previous year. The study examined the following land cover categories:

- general land cover trends (overall transformations in land use);
- trees (forested areas and woody vegetation) – assessed for deforestation, afforestation, and stability in coverage;
- crops (agricultural land and cultivated fields) – analysed for expansion, contraction, and shifts in cultivated areas;
- grass (meadows, pastures, and other non-woody vegetation) – studied for natural ecosystem restoration or degradation;
- water, flooded vegetation, bush and scrub (water bodies, wetlands, and transitional vegetation types) – examined for seasonal and long-term variations;
- land cover transitions(detection of changes between different land cover types over time).

By integrating geospatial and qualitative approaches, the study provides a comprehensive understanding of land cover transformations and their socio-economic implications.

Collecting data. In cooperation with the World Resources Institute (WRI), Google provides the so-called "Dynamic World" tool. Dynamic World is an open and freely available dataset that can be used by scientists, governments, and companies (Brown *et al.,* 2022). Datasets for the Zhytomyr Region were generated on Google Earth Engine using GOOGLE/DYNAMICWORLD/V1 for the period 2016-2023. Based on satellite images, Dynamic World provides detailed data on the condition and use of land in real time at a resolution of ten metres. This means that Dynamic World can be used to quantify and analyse land cover conditions and changes in a region over a short period. Dynamic World V1 offers information on the following types of land cover in the so-called "Land Use/Land Cover Classification" (LULCC): water, trees (forested area), grass (meadows), flooded vegetation, crops (arable land), scrubs and bushes, built-up surfaces, bare soil, snow, and ice. Satellite image data for 2016-2023 were downloaded from the Google Earth Engine platform for further analysis of land use changes.

The algorithm for processing data and obtaining results was implemented in ArcGIS (Fig. 2) and consisted of the following steps:

1. Downloading data – Satellite images for 2016-2023 were obtained through the Google Earth Engine platform.

2. Importing tools – Tools from the Data Management Tools and Conversion Tools modules were imported to manage and process geospatial data.

3. Loading data – Raster images for 2016-2023 were imported for further analysis of land use changes.

4. Cropping raster images – The raster images were cropped according to the boundaries of the Zhytomyr Region, ensuring a focus on the study area.

5. Converting of raster data into polygons – The cropped raster images were converted into vector format (polygons) for a detailed analysis of land cover changes.

6. Polygon merging – Polygons were grouped by GRIDCODE values to simplify the data structure and optimise further processing.

7. Adding attribute fields – New fields were added to the attribute table to store information about the territory areas, allowing for quantitative analysis.

8. Intersecting polygons – The spatial intersection of land parcels between 2016-2021 and 2021-2023 was performed to identify and analyse changes in land use.

9. Calculating areas – For each polygon obtained from the intersection, the area in hectares was calculated, enabling a quantitative assessment of the scale of changes.

10. Exporting data – The results were exported to Excel for further statistical analysis and visualisation.

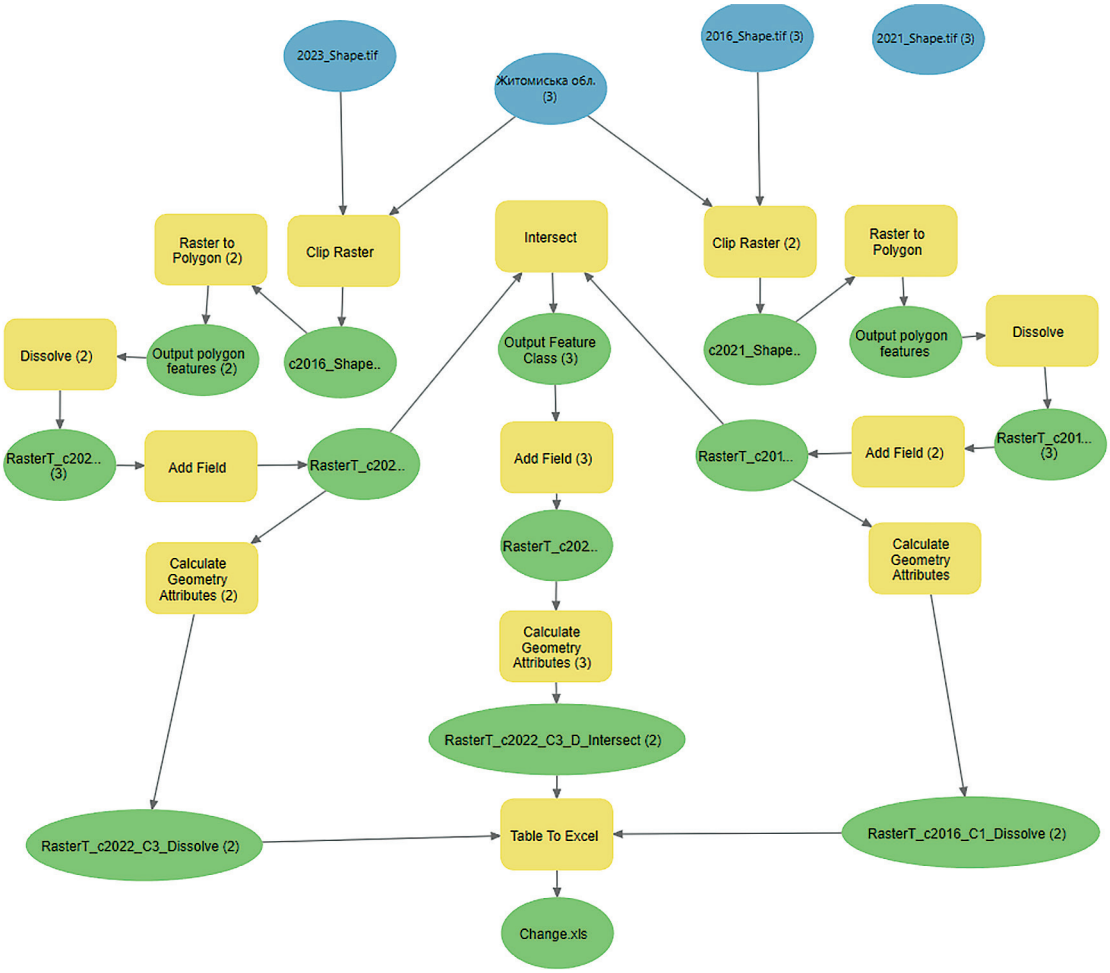

Figure 2. *Algorithmic scheme for determining land cover change in ArcGIS Pro ModelBuilder*
Source: *compiled by the authors*

The GOOGLE/DYNAMICWORLD/V1 dataset was chosen for the analysis because it provides images with a resolution of 10 metres and frequent updates, allowing for a detailed analysis of land cover changes at the level of individual sites. Continuous updates provide access to the most up-to-date data, which is critical for analysing rapid changes caused by decentralisation and military operations. The use of modern machine learning algorithms improves the accuracy of identifying different types of land cover. Integration with Google Earth Engine simplifies the process of data collection and processing, allowing for scalable analysis without loss of quality. In addition, the standardised land cover classification facilitates comparison with other studies and integration with additional data sources.

As part of the study, a series of semi-structured oral interviews were conducted in 36 settlements across the Zhytomyr Region with local residents, representatives of local authorities, and land use experts. The interviews were conducted in person where possible and remotely (via telephone or online platforms) in cases where physical access was restricted due to security concerns. Participation in the study was entirely voluntary, and respondents provided verbal, informed consent before the interview. During the interviews, participants were shown maps and visualised geospatial data, including satellite imagery and land cover change maps, to facilitate discussion and validate the observed transformations. Interviewers provided explanations of the detected changes, and respondents shared their insights into the underlying socio-economic and political factors driving these shifts. This approach ensured data triangulation, enhancing the reliability of the findings by integrating geospatial analysis with local knowledge and expert assessments. The study adhered to ethical research standards, ensuring confidentiality and anonymity for respondents (ASA's Committee on Professional Ethics (COPE), 1997). No personally identifiable information was recorded, and participants had the right to withdraw from the interview at any stage without providing a reason. The collected qualitative data were used solely for research purposes, contributing to a more comprehensive understanding of land cover changes in the region.

Research limitations. This study analyses land cover changes in Zhytomyr Region from 2016 to 2023 using

high-resolution geospatial data. While incorporating 2024 data could enhance the findings, maintaining methodological consistency was prioritised. Qualitative data collection was limited to the central and southern parts of the region due to restricted access in the north caused by military operations, potentially introducing geographical bias. Additionally, while the Dynamic World dataset provides high-resolution classification, certain land cover types, such as seasonally flooded vegetation, may require further field validation. Expanding ground-truthing and qualitative surveys in inaccessible areas could improve future assessments.

RESULTS AND DISCUSSION

Land cover, as an indicator of landscape transformation, plays a critical role in biogeochemical and hydrological cycles, influencing biodiversity and ecosystem productivity. In 2023, the land cover structure of the Zhytomyr Region comprised a diverse range of natural and artificial surfaces, which, according to geoinformation analysis, covered29,500 km^2 (official data indicate 29,800 km^2 (ZHOVA, 2023)). Among these, the largest proportion consisted of forested areas, which covered 55% of the region's territory, or approximately 16,340 km^2 (Fig. 3). Agricultural land, including cultivated areas, accounted for a significant share – 31%, or 9,275 km^2. Built-up areas, which included urban and industrial zones, covered 4% of the total area (1,098 km^2). The land cover also featured bush and scrub thickets, which covered 4% of the territory (1,148 km^2). Water resources, represented by rivers, lakes, and other water bodies, covered 1% of the region's area (177 km^2). Areas with flooded vegetation were minimal, comprising 0.04% of the total area (12.8 km^2). Grassy areas accounted for 5% (1,402 km^2). Less significant land cover categories included bare land with minimal vegetation, covering only 46 km^2. Given the above, the land cover structure in 2023 reflects a dynamic balance between natural and anthropogenic landscapes, which is essential for land use planning and environmental monitoring in the region.

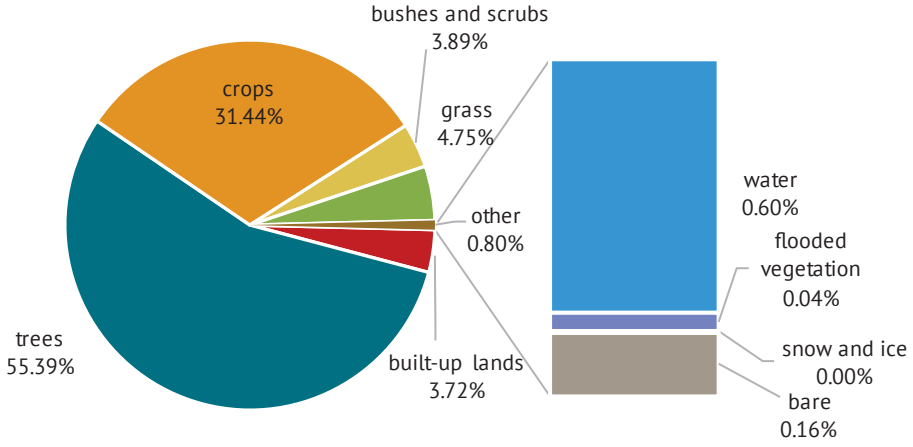

Figure 3. *Structure of land cover in 2023*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

It should be noted that the land cover structure, according to data obtained using the GOOGLE/DYNAMICWORLD/V1 classifier and official statistical data (ZHOVA, 2023), differs slightly (Table 1). This discrepancy arises because satellite image analysis classifies the Earth's surface based solely on the spectral characteristics of pixel imagery, whereas official statistics are based on the legal designation of land plots. At the same time, official statistical data (ZHOVA, 2023) do not capture dynamic land cover changes, as they rely on the legal status of land rather than actual spectral characteristics, which have remained unchanged over the past seven years. This results in inconsistencies, particularly in the context of rapid land use changes that are not promptly reflected in legal documents, rendering official statistics unsuitable for in-depth scientific analysis. Satellite imagery analysis for land cover research offers several advantages, including high spatial resolution and frequent data updates, enabling real-time monitoring of landscape changes. Additionally, advanced machine learning algorithms enhance the accuracy of land cover classification, and the ability to detect small-scale and short-term changes provides greater flexibility for natural resource research and management.

Table 1*. Dynamics of land use in Zhytomyr Region based on official statistics (km2), 2016-2022*

Main types of land cover \ Year	2016	2017	2018	2019	2020	2021	2022
Total	29,827	29,827	29,827	29,827	29,827	29,827	29,827

Table 1. Continued

Main types of land cover \ Year	2016	2017	2018	2019	2020	2021	2022
Agricultural lands, of which:	15,101	15,101	15,101	15,101	15,101	15,101	15,101
Forests and other wooded areas	11,234	11,234	11,234	11,234	11,234	11,234	11,234
Built-up lands	890	890	890	890	890	890	890
Open wetlands	1,012	1,012	1,012	1,012	1,012	1,012	1,012
Open lands without vegetation cover or with insignificant vegetation cover	383	383	383	383	383	383	383
Water	486	486	486	486	486	486	486
Bushes and scrubs	552	552	552	552	552	552	552
Other lands	169	169	169	169	169	169	169

Source: *ZHOVA (2023)*

The land cover map (Fig. 4) provides insights into the distribution of land cover classes in the Zhytomyr Region. The land cover map of the Zhytomyr Region is dominated by vast forests primarily in the central and northern parts, indicating the presence of protected areas. Agricultural land, concentrated in the south-western part of the region, reflects a high level of agricultural activity, supported by proximity to transport routes and settlements. Built-up areas are situated along major transport corridors and intersections, reflecting the region's administrative and industrial hubs. Water bodies are unevenly distributed, with a higher concentration in the northern part, influencing the microclimate and land use. The largest rivers in the region – Teteriv, Sluch, and Uzh – form a significant part of these water bodies. Meanwhile, scrubland zones act as transitional ecosystems between forests and agricultural areas, playing a key role in biodiversity restoration and conservation.

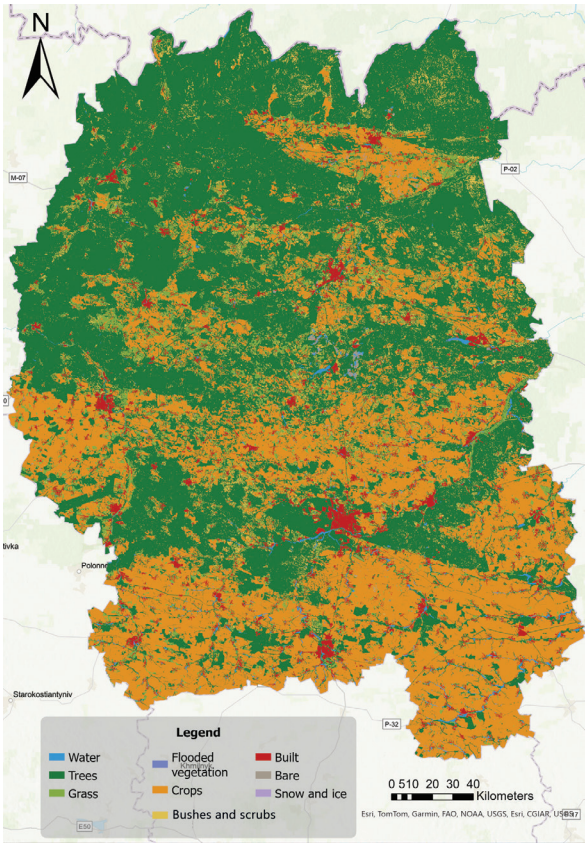

Figure 4. *Land cover of the Zhytomyr Region for 2023*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

Further quantitative analysis of different land cover classes reveals the dynamics and changes from 2016 to 2023 for each of the nine classes defined by the Google Dynamic World V1 classifier. During the study period, a clear upward trend is observed in the expansion of forested areas, agricultural land,

and bare land compared to 2016. Conversely, the proportion of other key land cover classes – such as wetlands, scrubs and bushes, and herbaceous coenoses, which contribute to ecological balance – has significantly declined (Table 2). The land cover structure during the analysed period, highlighting two key phases –decentralisation and full-scale war – is presented in Figure 5.

***Table 2**. Dynamics of land use in Zhytomyr Region based on the analysis of satellite images (km²), 2016-2023*

Indicator	2016	2017	2018	2019	2020	2021	2022	2023
Water	↓0.6	→0.6	↑0.7	↑0.7	→0.6	↑0.7	↑0.7	↓0.6
Flooded vegetation	↓0.0	↓0.0	→0.0	↓0.0	↓0.0	↓0.0	↑0.1	↓0.0
Built-up lands	↑3.9	↑3.9	↑3.8	→3.8	↓3.7	→3.8	↓3.6	↓3.7
Trees	↓52.7	→54.2	→54.4	↓53.3	↓53.2	→53.7	↓52.4	↑55.5
Crops	↓26.2	→28.9	→30.6	→31.1	↑32.0	↑32.7	↑33.8	↑31.5
Bushes and scrubs	↑7.3	↓4.3	↓3.5	↓4.7	→5.1	↓4.1	↓4.5	↓3.9
Snow and ice	↑0.1	↓0.0	↑0.1	↓0.0	↓0.0	↓0.0	↓0.0	↓0.0
Bare	→0.1	↓0.1	↓0.1	↑0.2	↑0.2	↓0.1	→0.1	↑0.2
Grass	↑9.0	↑8.2	→6.9	→6.4	↓5.4	↓5.2	↓4.9	↓4.8

Note: *↑ – increase, ↓ – decrease, → – stabilisation*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

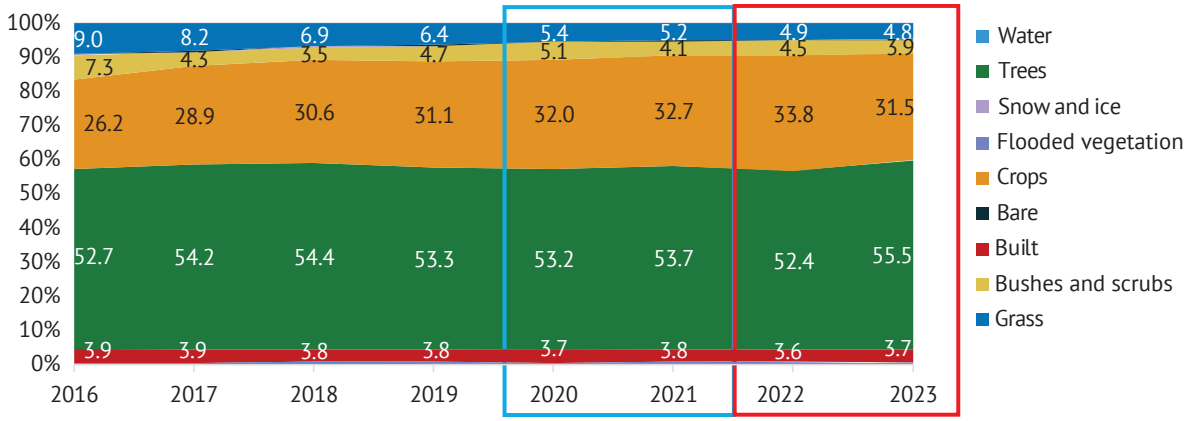

***Figure 5**. Dynamics of land cover changes in Zhytomyr Region*
Note: *Blue rectangle – decentralisation; Red rectangle – war*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

It is evident that the region has experienced land cover changes in both analysed subperiods. A detailed examination of changes in individual land cover classes and underlying the reasons is necessary. Recognising that reforms not only influence these changes but also drive their development, expert interviews were conducted to understand the preconditions for these transformations.

Forested areas remained the dominant land cover class in the Zhytomyr Region during the study period. Between 2016 and 2019, notable changes were observed in the forested areas of the Zhytomyr Region. The initial year (2016) was characterised by 1,549,515 hectares of forests, accounting for 52.7% of the total area. During 2017-2018, the forested area gradually increased, reaching 1,601,088 hectares in 2018, with its share rising to 54.4%. This growth was driven by active afforestation, the natural expansion of forests, and the successful implementation of digitalisation programmes for forest protection. However, in 2019, the forested area declined by 2%, or 33,000 hectares. This sharp decrease resulted from the abnormally dry autumn of 2019, which led to frequent and severe fires (Skydan *et al.*, 2021).

Based on qualitative semi-structured interviews, it was found that at the beginning of the decentralisation process in 2020, a decline in both the total forested area and its proportion was observed. With communities assuming power, control over forest resources significantly improved, leading to more effective measures against illegal logging. Additionally, communal forests were established to preserve community-owned woodlands. During this period, the local population gained greater influence over decisions regarding the allocation of local finances. Notably, one of the primary concerns raised by communities was the clearance of wild forest areas, particularly around cemeteries, roadsides, and solid waste dumps. The implementation of these measures, funded by local budgets, resulted in a

reduction in forested areas, as wild vegetation was cleared to enhance public spaces and improve safety.

The full-scale invasion of Ukraine by the Russian Federation has had a significant impact on land cover composition, particularly in forested areas. In 2022, the forested area decreased sharply, reaching its lowest level during the study period – 1,541,392 hectares (Table 2), while the proportion of forested areas fell to 52.4%. This decline was linked to the energy crisis in Ukraine, triggered by Russian missile attacks on energy facilities, which led the rural population to collect firewood for heating private homes. However, in 2023, the situation changed: the forested area expanded to 1,634,015 hectares, and the proportion of forested areas rose sharply to 55.5%. This growth can be attributed to several factors: 1) a significant portion of the territories bordering Belarus in Zhytomyr Region (a buffer zone of 357,000 hectares (Prospects of return to economic use..., 2024)) was closed not only to the public but also to any production activity, meaning no forest management operations were carried out in these areas; 2) limited export opportunities from Ukraine during the period of martial law; 3) the rural population had already harvested sufficient firewood in 2022 for three to five years, meaning this factor no longer influenced the forested area in 2023 (Fig. 6).

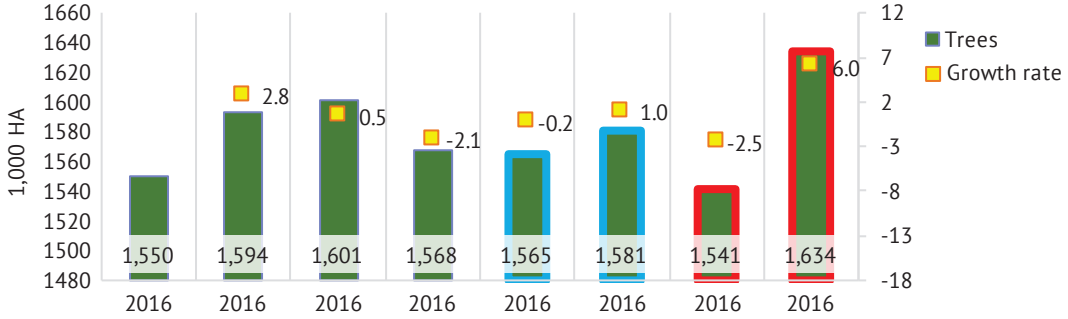

Figure 6. *Dynamics and rate of change of forest-covered areas in Zhytomyr Region*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

The analysis indicates that decentralisation, as a process of transforming local governance, has significantly affected the extent and composition of forested areas by strengthening control over the use of local natural resources and clearing wild vegetation. Meanwhile, during the full-scale invasion by the Russian Federation, the forested area reached its lowest level of the study period, due to the energy crisis and increased firewood collection, as well as the clearance of wild forests around villages and towns. However, in 2023, a sharp recovery in forest cover was observed, driven by restricted access to territories bordering Belarus, reduced exports, and a diminished demand for additional firewood.

Cultivated land is the second-largest class of land cover by area, which exhibited a stable upward trend from 2016 and 2022, followed by a sharp decline in 2023. Between 2016 to 2019, there was a significant increase in the extent and proportion of cultivated land, averaging 43,000 hectares or 3.3% annually. This period was characterised by the active expansion of agricultural areas due to the growing demand for energy crops (rapeseed, soybean, and sunflower) in export markets, the introduction of new technologies, and the intensification of agricultural activity in the region. From 2020 to 2021, when territorial communities became operational, the cultivated land area continued to expand, although the growth rate slightly declined: the average increase over this period was approximately 20,000 hectares (2.8%) annually. The decentralisation reform contributed to more favourable economic conditions for agribusiness and increased investment in the region's agricultural sector. This is evidenced by data on capital investments in agriculture in Zhytomyr Region: in 2019, they amounted to 1.797 billion UAH; in 2020, 1.990 billion UAH (an 11% increase); in 2021, 2.294 billion UAH (a 15%increase); and in 2022, 1.655 billion UAH (a 28% decrease) (SSSU, 2024).

During the wartime period of 2022-2023, fluctuations were observed in the cultivated land area (Fig. 7). In 2022, the area expanded significantly to 996,000 hectares, marking the highest level recorded during the entire analysis period – an increase of 35,000 hectares (2.9%). This growth was influenced by strong internal and regional migration trends. Internally, many urban residents moved to rural areas to live with their parents and relatives during the war in 2022. Regionally, some migration flows from conflict zones and frontline areas also sought refuge in rural settlements, including abandoned houses. These demographic shifts encouraged the rural population to increase cultivated areas. Additionally, agricultural enterprises continued operating out of inertia – winter sowing was completed, and fertilisers, plant protection products, and fuel had already been purchased, sustaining agricultural activity. However, in the second year of the full-scale war (2023), the situation changed dramatically: the cultivated land area decreased by

68,000 hectares (nearly 7% compared to the previous year). This sharp decline was driven by several war-related factors (Fig. 7):

1) In 2022, a significant proportion of the rural population was mobilised into the army, resulting in a shortage of labour for the operation of rural households. This severely reduced the possibility of cultivating fields and keeping livestock, as there were not enough workers to perform the full cycle of agricultural work for the following year. Consequently, large areas remained uncultivated, leading to an overall decrease in cultivated land.

2) The salaries paid to soldiers during mobilisation partially reduced the economic pressure on rural families, allowing them to survive without the need to maintain subsistence farms with an agricultural focus.

3) Russian missile attacks on ports disrupted agricultural supply and export chains, which significantly reduced the profitability of certain crops as access to international markets was limited. As a result, agricultural enterprises and farmers reduced the area under cultivation, further contributing to the overall reduction in cultivated land.

4) Due to the depreciation of the national currency, higher transport costs, and other economic pressures, prices for seeds, crop protection products, and fuel and lubricants rose significantly. The high cost of agricultural inputs limited their accessibility to farmers, resulting in a decrease in cultivated land area, as many were unable to afford to continue farming under these conditions.

5) The six-month export blockade in 2022 led to the accumulation of agricultural products within the country. This caused a decline in domestic prices, making production less profitable for farmers. Consequently, many farmers chose to lower production volumes or cease cultivating certain crops entirely, leading to a reduction in the overall area of cultivated land.

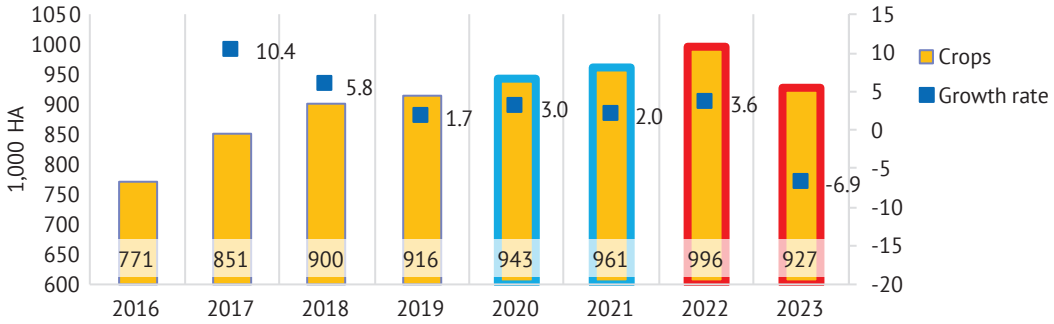

Figure 7. *Dynamics and rate of change of cultivated land in Zhytomyr Region*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

These factors demonstrate that the war has had a significant impact on the agricultural sector, particularly the extent of cultivated land. The combined effects of mobilisation, high input costs, infrastructure destruction, and export restrictions have resulted in a sharp decline in cultivated land area in 2023, with serious economic and social consequences.

From 2016 to 2023, the area of grassy communities in the Zhytomyr Region showed a steady decline, with a decrease in absolute area and a reduction in its share of the total land cover from 9% in 2016 to 4.8% in 2023. The average rate of decline over this period was approximately 8.6% per year, with an average annual reduction of around 17.8 thousand hectares. Notably, between 2016 and 2019, the share of grassy communities in the total land cover decreased significantly, from 9.0% in 2016 to 6.4% in 2019. Such a pronounced downward trend reflects a notable increase in the extensification of agricultural development and a substantial decline in cattle numbers, both in agricultural enterprises and rural households (Prospects of return to economic use..., 2024). In the period 2020-2021, the decline in grassy communities continued, although the rate of decrease slowed. The area fell from 157.800 hectares in 2020 to 151.600 hectares in 2021, while its share of the total land structure decreased from 5.4% to 5.2%. During this period, a slowdown in the reduction of the cattle population was recorded, which was reflected in the extent of grassy communities, as they serve which serves as a fodder base for cattle. At the same time, local authorities began implementing programmes to support livestock production as a strategic development priority, which contributed to a moderation in the decline of the cattle population and, consequently, to the stabilisation of grassland areas. The war period of 2022-2023 was also characterised by the continuation of negative trends in grassy communities: the area decreased by 4.1% in 2022 and by 3.5% in 2023 compared to the previous year. The slight apparent stabilisation in the rate of decline can be attributed to several factors: disruptions in regional food supplies and the migration of people from cities to rural areas prompted rural residents to maintain their cattle herds instead of reducing them, which in turn impacted the extent of grassland (Fig. 8).

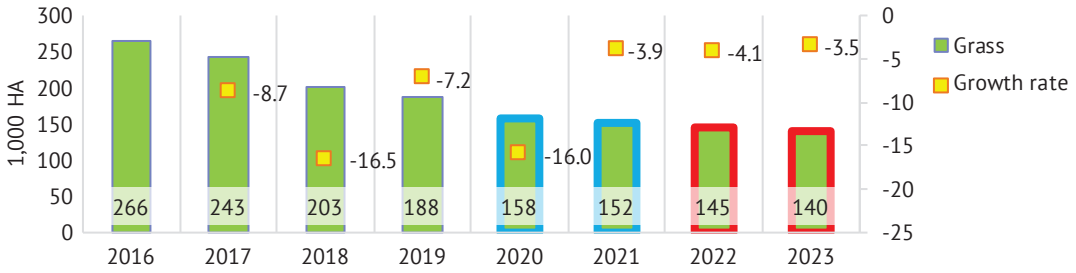

Figure 8. *Dynamics and rate of change of grassland communities in Zhytomyr Region*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

The land cover of the Zhytomyr Region includes ecologically important classes such as water bodies (water), wetlands (flooded vegetation), and scrublands (bush and scrub), which provide the ecological basis for biodiversity and ecosystem resilience. These categories play a key role in maintaining water balance, regulating the climate, and preventing erosion processes. During the period 2020-2021, the area of water bodies, wetlands, and scrublands in the Zhytomyr Region experienced significant fluctuations (Fig. 9). The area of water bodies initially decreased by 5.2% in 2020, but in 2021, it expanded by 4.1%, which may have resulted from changes in climatic conditions and water resource regulation. Wetlands also showed a decline: in 2020, the area decreased by 3.2%, and in 2021, it reached its lowest level during the period, with a further 15.1% decrease, which may suggest increased human impact, including land reclamation and agricultural development. The area of scrublands increased by 19.4% in 2020, likely due to natural regeneration, but in 2021, it decreased again by 19.5%.

The period 2022-2023 was critical for the balancing of land cover classes in the Zhytomyr Region, as evidenced by significant changes in their areas. In 2022, there was a sharp increase in the area of water bodies to 19,648 hectares, marking the highest figure over the last three years. However, by 2023, the area of water bodies had decreased to 17,744 hectares. This significant reduction can likely be attributed to military operations, including the release of water from dams to slow the advance of Russian troops. In 2022, the area of wetlands increased sharply to 1,723 hectares, a rise of 60%, as a result of the expansion of water bodies. However, in 2023, the area of flooded vegetation decreased again to 1,275 hectares, indicating the instability of this class and its sensitivity to external influences. In 2022, the area of scrublands increased to 132,188 hectares, indicating a temporary recovery of this class. However, in 2023, the area decreased again to 114,827 hectares, which may be linked to the intensified use of land for agricultural or forestry purposes (Fig. 9).

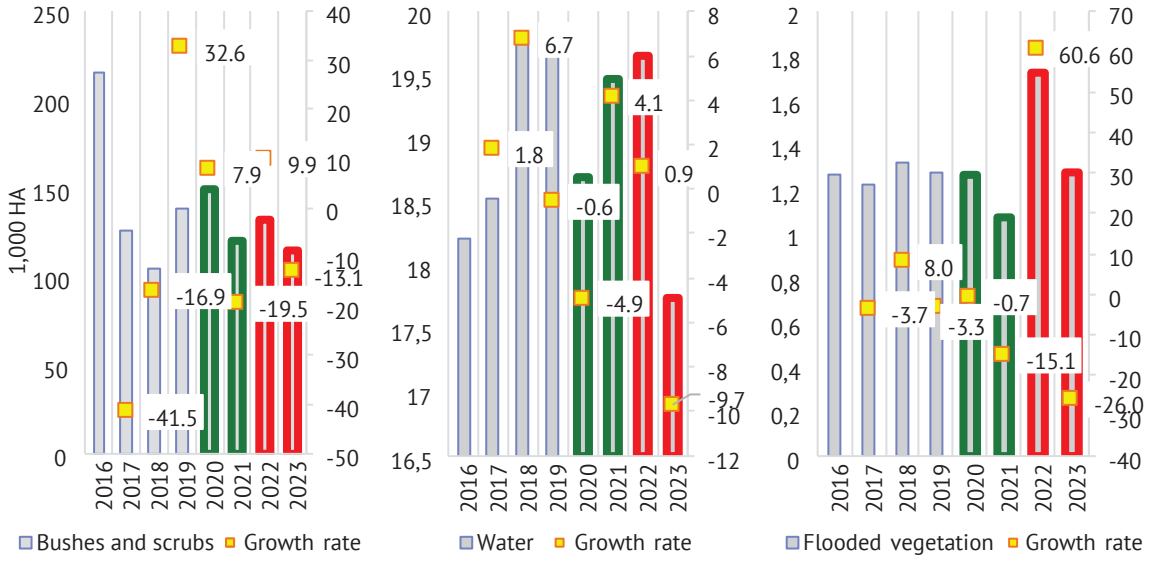

Figure 9. *Changes in balancing land cover classes*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

A general analysis of the balancing land cover classes in the Zhytomyr Region from 2016 to 2023 reveals significant fluctuations in the areas of water bodies, wetlands, and scrublands. These land cover

types have proven to be particularly vulnerable to anthropogenic impacts, including defence-related measures and industrial-scale land use for agricultural and forestry purposes. A decrease in the area of these classes, especially in critical periods, may have serious environmental consequences for the region, such as deterioration in water quality, soil degradation, and reduced ecosystem resilience to climate change. Therefore, it is essential to consider these factors when planning land use and developing strategies for the conservation of natural resources in the Zhytomyr Region (Fig. 10).

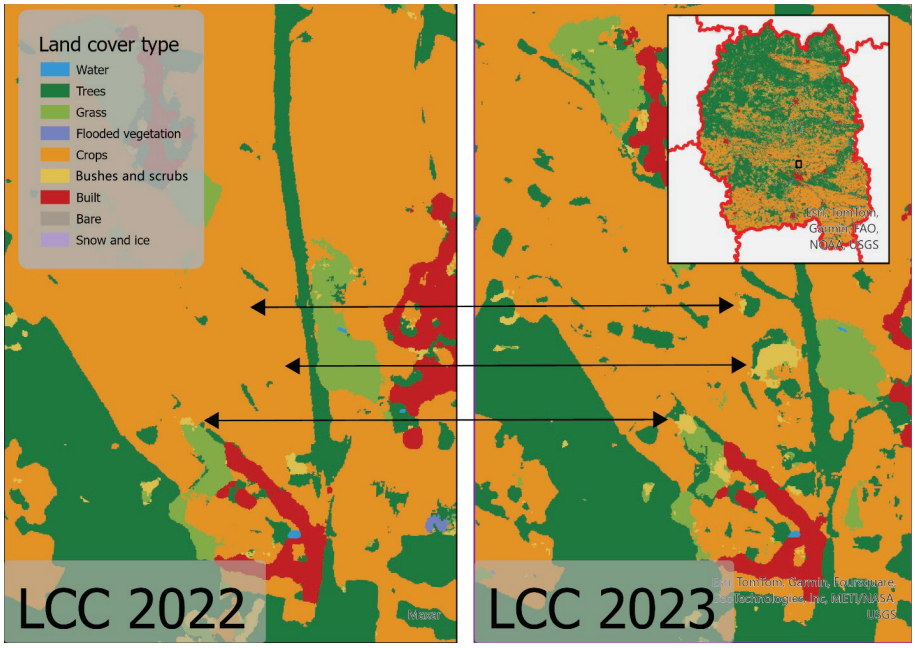

Figure 10. *Transition of cultivated lands into scrublands and forested areas (2022-2023)*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

Changes. An important element in the study of land cover structure and its transformation is analysing the transition of land from one class to another. Taking into account the previous results of this study, an examination was conducted on the transition of land from the 2016 classifications to those of 2021 (decentralisation) and from 2021 to 2023 (war). The study of such changes reveals significant transformations in land cover under the influence of both administrative and military factors. The period of decentralisation was marked by significant changes in wetlands, flooded vegetation, and scrublands due to land reclassification (Fig. 11). Wetlands expanded due to the conversion of part of the forested areas (1,762 hectares (9.7%)), including an additional 390 hectares (2.1%) from bare land and herbaceous coenosis. Further expansion occurred through the conversion of some forested areas (394 hectares (28.4%)) and cultivated land (31 hectares (2.2%)). In contrast, scrublands contracted significantly, as large areas were converted into forested areas (41,057 hectares (18.6%)) and cultivated land (54,140 hectares (24.5%)).

Cultivated land increased primarily at the expense of scrublands (54,140 hectares (24.5%)), herbaceous coenosis (134,541 hectares (17.2%)), and to a lesser extent at the expense of forested areas (42,107 hectares (2.7%)). This increase reflects the intensified development of land for agricultural purposes, resulting in the reduction of natural ecosystems and alterations in land cover across the region. Forested areas also experienced significant changes during the decentralisation period. Although a substantial proportion of forested land remained within its original classification (1,454,291 hectares (93.5%)), some areas were reclassified into other land cover categories. For example, a portion of forested areas was converted into cultivated land (42,107 hectares (2.7%)), scrublands (41,057 hectares (2.8%)), and herbaceous coenosis (27,874 hectares (1.9%)). At the same time, the forested area expanded due to the reclassification of land from other categories, including scrublands (76,887 hectares (34.8%)) and cultivated land (16,800 hectares (2.3%)). These changes indicate active reforestation processes and the utilisation of land previously occupied by other land cover types to expand forest plantations.

Thus, changes in land cover structure during the decentralisation period highlight significant transformations in ecologically important land categories, including forested areas, water bodies, scrublands, and cultivated lands. These processes reflect both natural trends and the influence of anthropogenic factors, including agricultural and forestry activities, which have

contributed to the transformation of Zhytomyr Region's natural landscapes. The war period (2022-2023) was characterised by substantial changes in the land cover structure of the Zhytomyr Region, particularly in key categories, such as wetlands, scrublands and forested areas, which were affected by both military operations and human activities. These ecosystems remained relatively stable during this period, with 16,306 hectares (85.5%) remaining within this classification. However, it is important to note that some land transitioned from other categories, particularly forested areas (415 hectares (2.3%)) and scrublands (80 hectares (0.4%)). Despite these transfers, the total area of water bodies declined slightly, primarily due to lower water levels resulting from military operations and the release of water from dams to impede military forces. Wetlands also underwent changes during the war period, with only 533 hectares (42.5%) remaining within this classification. Some areas, including 503 hectares (40%) of forested land and 69 hectares (5.5%) of cultivated land, were converted into wetlands. This suggests instability in the region's hydrological regime, which may be attributed to both military operations and climate change. The rise in waterlogging levels could also result from the destruction of infrastructure and a decline in land reclamation activities.

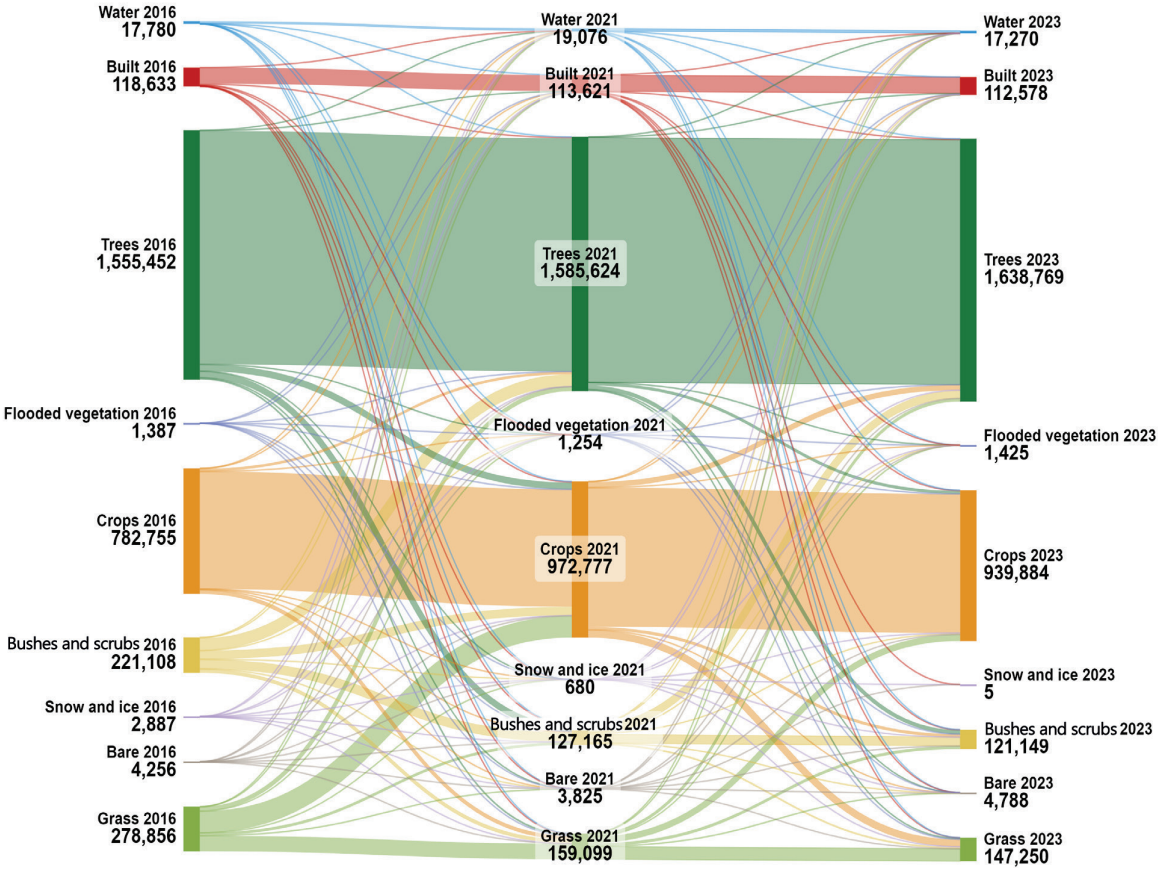

Figure 11. *Sankey diagram of the period of decentralisation and war, ha*
Source: *compiled by the authors based on the method of C. Brown et al. (2022)*

Scrublands continued to decline in area, with 55,187 hectares (43%) remaining within this classification. A significant portion was reclassified as forested land (25,457 hectares (19%)) and cultivated land (18,834 hectares (14.2%)). This reduction in scrublands reflects the intensified use of land for agriculture and other industrial purposes, which escalated during the war. Forested areas also experienced significant changes during the war. While 1,526,170 hectares (94.1%) of forested land remained within this classification, some areas were reclassified into other land cover categories. In particular, 34,317 hectares (2.2%) of forested land were converted into cultivated land, 50,555 hectares (3.3%) into scrublands, and 19,464 hectares (1.3%) into herbaceous coenosis. At the same time, forested land expanded due to the reclassification of land previously classified as scrublands (50,555 hectares (3.3%)) and cultivated land (34,317 hectares (2.2%)). These changes indicate that, despite the challenges of wartime, forests underwent regeneration, possibly due to reduced human activity in certain areas.

During the war period, cultivated land in the Zhytomyr Region also underwent significant transformations, reflecting the impact of military operations on

agricultural land. Over this period, cultivated land retained a substantial portion of its area, with 867,244 hectares (89.5%) remaining within this classification. However, some land was reclassified into other categories. For instance, 18,949 hectares (2.2%) became forested land, and 18,834 hectares (2.2%) were converted into scrublands. Additionally, 46,044 hectares (5.3%) of cultivated land were reclassified as herbaceous coenosis. These transformations reflect substantial changes in the use of agricultural land, which may be attributed to both the destruction of infrastructure and the temporary inaccessibility of certain areas, as well as shifts in agricultural priorities during the war. Simultaneously, cultivated land expanded through the incorporation of land from other classifications. For example, 41,541 hectares (4.3%) were reclassified from scrublands, which may indicate increased agricultural activity in certain areas. Land reclassification from other categories also included 18,949 hectares (2.2%) of forested land and 4,141 hectares (0.5%) of built-up land.

Comparing the two periods and focusing on differences among donor categories reveals that the role of donor categories changed between the decentralisation and wartime periods. During decentralisation, natural ecosystems such as scrublands and herbaceous coenoses served as the primary donor categories, whereas during the war, anthropogenic categories, particularly cultivated land and forested areas, assumed this role. The driving forces behind these transformations differ: decentralisation stimulated intensive land development and the expansion of agricultural and forest plantations at the expense of natural areas, whereas the war resulted in a reduction in economic activity, land abandonment, and the regeneration of natural ecosystems in formerly cultivated areas. The environmental consequences of these processes vary: during decentralisation, the decline of natural ecosystems may have negatively impacted biodiversity and ecosystem services, whereas, during the war, the restoration of natural categories may have had positive environmental effects. However, such regeneration also signals economic decline and social challenges.

Previous studies on land use change have primarily focused on natural factors, urbanisation, and climate change, but have rarely addressed the combined impact of administrative reforms (such as decentralisation) and external shocks (such as war) on land cover dynamics. While many researchers analyse the effects of decentralisation on governance, local budgets, and economic development, few investigate its influence on land cover transformation, particularly in conflictaffected regions. This study seeks to bridge this gap by examining land use changes in the Zhytomyr Region under the influence of both decentralisation and military conflict, using an integrated geospatial and qualitative approach. The following findings reveal significant land use changes in Zhytomyr Region, with distinct trends observed during the decentralisation (2020-2021) and wartime (2022-2023) periods. During decentralisation, local communities gained greater control over land management, leading to an increase in agricultural land and a decline in natural land cover categories. These results align with P. Pyvovar *et al.* (2023), who demonstrated that decentralisation in Ukraine facilitated the expansion of arable land as local governments took a more active role in land administration. Similar findings were reported by X. Li *et al.* (2016) in their study of Wuhan, China, where local governance policies significantly influenced land use priorities.

However, during the wartime period (2022-2023), these trends reversed. The total area of cultivated land decreased due to labour shortages, economic uncertainty, and supply chain disruptions, aligning with the conclusions of M. Forleo *et al.* (2017), who found that economic crises and social instability contribute to the contraction of agricultural areas. Simultaneously, the reduction of human activity led to a partial recovery of forested areas and water bodies, a trend also observed by Q. Xie *et al.* (2023), who noted that land use restrictions and decreased industrial activity facilitated the regeneration of natural landscapes in restricted zones. The authors' findings also suggest that war-induced instability in land use differs from land cover changes driven by natural disasters or internal conflicts. For instance, F. Krausmann *et al.* (2003) analysed land use trends in Austria, demonstrating that socio-economic transformations, particularly industrialisation, had longterm effects on land use. In contrast, in Zhytomyr Region, war-related disruptions resulted in temporary fluctuations in land cover rather than permanent conversions.

J. Bekere *et al.* (2023) explored the socio-economic drivers of land use and land cover (LULC) change in western Ethiopia, identifying both natural and anthropogenic factors. Their study found a sharp decline in forest cover, from 12.1% in 1990 to 2.6% in 2020, driven by demographic and economic variables. Through Pearson correlation and binary logistic regression, they demonstrated that education and land-holding size were negatively correlated with LULC drivers, while age and gender had a positive correlation. The findings highlight the necessity of integrated policy measures to mitigate human-induced landscape changes. Similarly, K. Cegielska *et al.* (2023) developed an LULC conflict risk assessment model, integrating spatial and social perspectives to examine the impact of suburbanisation in the peri-urban zones of Kraków. Their research revealed that agricultural land is particularly vulnerable to conflict due to unplanned urban expansion, demonstrating a methodological approach that combines GIS-based spatial analysis with public perception surveys. Meanwhile, P. Di Marzio *et al.* (2023) analysed land cover and socioeconomic changes over five decades in Molise, Italy, using CORINE Land Cover data alongside historical aerial imagery. They found that agricultural

expansion and human disturbances had fragmented the landscape, with natural vegetation confined to riparian formations. The study underscores the tension between agricultural intensification and biodiversity conservation in regions with a long history of land use transformation.

Another notable finding is that a significant portion of Zhytomyr Region's forested land was incorporated into buffer zones during the war, where economic activity was heavily restricted, leading to a measurable increase in forest cover. This phenomenon has been observed in other regions as well; for example, Q. Xie *et al.* (2023) found that the establishment of restricted zones in China led to similar increases in natural vegetation. Despite these insights, this study faces certain limitations. First, the classification of land cover is based on spectral characteristics rather than legal land use status, which may lead to discrepancies in the interpretation of agricultural and natural land categories. Second, restricted access to some areas due to military operations may have affected the accuracy of local observations, particularly regarding forested areas and water bodies. Lastly, while semi-structured interviews provided valuable qualitative insights, the geographical scope of interviews was limited to the central and southern parts of the Zhytomyr Region, potentially introducing regional bias in the interpretation of land use changes.

CONCLUSIONS

The analysis has shown that decentralisation and military conflict have significantly influenced land use changes in the Zhytomyr Region. During the local governance reforms (2020-2021), communities gained more control over land resources, enabling them to clear scrublands and naturally regenerated forests, reducing their area by over 5%, as these landscapes hindered infrastructure development, land management, and agricultural expansion. At the same time, natural landscapes – including meadows and scrublands – declined by an average of 5% per year. However, the full-scale war in 2022 drastically altered this trend: the area of cultivated land decreased by 7% in 2023, primarily due to mobilisation, rising agricultural costs, and restricted market access. In contrast, forest cover expanded by 3% in 2023, mainly due to the creation of buffer zones where economic activity was restricted, while water bodies increased by 19% in 2022, partly as a consequence of militaryrelated hydrological changes.

A detailed analysis of specific land cover categories highlights significant trends and processes over the study period. Forested areas experienced major fluctuations, with firewood collection driving deforestation in 2022, while restrictions on logging in border regions resulted in 92,600 hectares (5.7%) increase in forested land in 2023. Cropland expanded during the period of decentralisation but declined by 68,000 hectares (7%) in 2023 due to labour shortages, decreasing agribusiness profitability, and economic instability. Meadows and pastures underwent a significant reduction, shrinking from 9% of total land cover in 2016 to 4.8% in 2023, primarily due to a decline in livestock farming. Water bodies and wetlands expanded by 19% in 2022 but contracted again in 2023. Scrublands were mostly converted into croplands and forests over the study period; however, in 2023, a decline in agricultural activity led to a 14% increase in scrubland areas.

The findings indicate that economic and political instability necessitate adaptive land-use strategies at the local level. The war has resulted in the reversion of significant areas of cultivated land to their natural state due to the decline in agricultural activities. These dynamics underscore the critical need to incorporate external factors into land use planning and to develop sustainable land management strategies. Geospatial technologies have demonstrated their high effectiveness in monitoring land cover transformations. The applied methodologies not only facilitate the assessment of current land use conditions but also enhance long-term decision-making processes, contributing to more informed and data-driven land management practices. Further research should focus on the long-term impacts of administrative reforms and military action on land use and its broader socioeconomic and ecological implications, including potential changes in land use legislation. Research could also examine the environmental and economic impacts of land cover transformations in post-conflict recovery, as well as the development of adaptive land management models that take into account socio-economic and political factors.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Вплив децентралізації та війни на рослинний покрив у Житомирській області України

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Анотація. Це дослідження мало на меті вивчити трансформації ґрунтового покриву в Житомирській області України у відповідь на децентралізацію та війну. Основна увага приділялася оцінці того, як зміни в місцевому управлінні та повномасштабне вторгнення вплинули на динаміку землекористування, зокрема, на зміни в сільськогосподарській експансії, скорочення природних типів земного покриву та коливання лісових масивів і водних об'єктів. У дослідженні проаналізовано моделі землекористування з 2016 по 2023 рік з використанням даних Dynamic World V1 сервісу Google Earth Engine, поєднуючи геопросторові дані з якісними напівструктурованими інтерв'ю. Результати показали, що процес децентралізації, розпочатий у 2014 році, зміцнив місцеве самоврядування та розширив можливості громад в управлінні земельними ресурсами. Цей період характеризувався розширенням площ сільськогосподарських угідь і скороченням природних типів земельного покриву, таких як луки та чагарники. Натомість повномасштабне вторгнення, яке розпочалося у 2022 році, призвело до зміни пріоритетів у землекористуванні через дефіцит робочої сили, зростання вартості ресурсів та обмежений доступ до ринків, що спричинило скорочення сільськогосподарських угідь та часткове відновлення природних екосистем. Особливо значні коливання спостерігаються щодо лісових масивів та водних об'єктів, що пов'язано з енергетичними потребами та обмеженнями на діяльність у зонах конфлікту. Отримані результати підкреслюють необхідність адаптивного управління земельними ресурсами в умовах соціально-економічних та політичних викликів, а також важливість моніторингу рослинного покриву для регіонального планування та сталого використання природних ресурсів. Аналізуючи геопросторові дані з Google Earth Engine's Dynamic World V1 та якісні напівструктуровані інтерв'ю, дослідження виявило ключові тенденції з 2016 по 2023 рік, оцінило соціально-економічні та політичні чинники, що стоять за цими змінами, а також висвітлило виклики адаптивного управління земельними ресурсами в умовах нестабільності. Отримані результати сприяють кращому розумінню наслідків змін земного покриву для регіонального планування та стратегій сталого землекористування

Ключові слова: зміни у землекористуванні; ГІС-моніторинг земель; соціально-економічний вплив; територіальна реформа; наслідки війни