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Yelistratova, L. O., ORCID: <https://orcid.org/0000-0002-7823-5841>,
Apostolov, O. A., ORCID: <https://orcid.org/0000-0003-3470-7613>,
Khodorovskiy, A. Ya., ORCID: <https://orcid.org/0000-0003-2286-1517>,

Khyzhniak, A. V., ORCID: <https://orcid.org/0000-0002-8637-3822>,
Tomchenko, O. V., ORCID: <https://orcid.org/0000-0001-6975-9099>,
Lialko, V. I., ORCID: <https://orcid.org/0000-0002-7552-5915>.

Scientific Centre for Aerospace Research of the Earth Institute of Geological Science National Academy of Sciences of Ukraine, Kyiv, Ukraine

Use of Satellite Information for Evaluation of Socio-Economic Consequences of the War in Ukraine

The article is devoted to the assessment of the economic losses of Ukraine in 2022 as a result of armed conflict based on the analysis of remote sensing data. Today, under conditions of war in Ukraine, there are growing crises in the economic, social, natural, and other spheres of society. Under these conditions, there is a growing need for objective operational monitoring and assessment of the direction of changes in the economy and social sphere of life of the population. That is why the purpose of the study was chosen to evaluate the possibilities of using the VIIRS thermal imager data installed on the Suomi NPP satellite about the night illumination of the territory to monitor the socio-economic development of Ukrainian regions during military operations. The data from the Suomi NPP satellite for March 2021 (pre-war period) and 2022 (during the period of military aggression) were used for the study. Methodologically, the quantitative indicator chosen is the total light intensity (TLI), namely, the sum of the illuminance values of all pixels on the territory of each of the regions of Ukraine. It was found that the value of the total night illumination of the administrative regions of Ukraine depends on the number of settlements in the region, the development of industry and transport network, as well as the area of the administrative area. In addition, the intensity of illumination of the methodology of J. Vernon Henderson is closely related to an important indicator of economic activity—electricity consumption. The article presents statistical and illustrative results of the analysis of night illumination from the Suomi NPP/VIIRS satellite of the administrative regions of Ukraine for March 2021, and 2022. Analysis of the results showed that the value of the ratio of night light for March 2021, and 2022 vary in a wide range from 0.84 to 21.2. On average, the value of the change in the night light index for March 2021 and 2022 for all regions of Ukraine is 6.04. Such changes in nighttime illumination can be explained both directly by combat operations and by the observance of light camouflage, the introduction of curfew during martial law in Ukraine, as well as the small industrial and economic development of the economy in some regions of Ukraine and the low level of spatial concentration of the population. The novelty of this study is the improvement, based on the use of materials from the SNPP/VIIRS satellite with greater spatial resolution, of the previously developed nighttime illumination methodology and its practical application during active warfare.

Keywords: *satellite monitoring, nighttime light remote sensing, total light intensity, VIIRS, military action, socio-economic consequences.*

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Єлістратова Л. О., ORCID: <https://orcid.org/0000-0002-7823-5841>,
Апостолов О. А., ORCID: <https://orcid.org/0000-0003-3470-7613>,
Ходоровський А. Я., ORCID: <https://orcid.org/0000-0003-2286-1517>,

Хижняк А. В., ORCID: <https://orcid.org/0000-0002-8637-3822>,
Томченко О. В., ORCID: <https://orcid.org/0000-0001-6975-9099>,
Лялько В. І., ORCID: <https://orcid.org/0000-0002-7552-5915>.

ДУ «Науковий центр аерокосмічних досліджень Землі» ІГН НАН України, Київ, Україна

Використання супутникової інформації для оцінки соціоекономічних наслідків від війни в Україні

Стаття присвячена оцінці економічних втрат України у 2022 році внаслідок збройного конфлікту на основі аналізу даних дистанційного зондування землі. Сьогодні в умовах війни в Україні наростають кризові явища в економічній, соціальній, природній та інших сферах життєдіяльності суспільства. В цих умовах зростає необхідність в об'єктивному оперативному моніторингу й оцінці напрямленості подібних змін економіки й соціальної сфери життєдіяльності населення. Саме тому метою дослідження обрана оцінка можливостей використання даних тепловізора VIIRS, встановлених на супутнику Suomi NPP про нічне освітлення території для моніторингу соціального-економічного розвитку областей України під час військових дій. Для дослідження були використані дані супут-

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ника Suomi NPP за березень 2021 р. (довоєнний період) та 2022 р. (в період військової агресії). Методологічно кількісним показником обрано сумарну інтенсивність освітлення (CIO), а саме сума значень освітленості всіх пікселів по території кожної з областей України. У статті наведено статистичні й ілюстративні результати аналізу нічної освітленості з супутника Suomi NPP/VIIRS адміністративних областей України за березень 2021 та 2022 р. Аналіз отриманих результатів показав, що значення відношення показників нічної освітленості за березень 2021 р. та 2022 р. змінюється в досить широкому інтервалі від 0,84 до 21,2. Новизною проведеного дослідження є вдосконалення на основі використання матеріалів із супутника SNPP/VIIRS із більшою просторовою розрізненістю, розробленої раніше методики нічної освітленості та її практичне застосування під час активних військових дій.

Ключові слова: супутниковий моніторинг, дистанційне зондування нічного освітлення, сумарна інтенсивність освітлення, територій, VIRSS, військові дії, соціо-економічні наслідки.

Introduction

The world in which human civilization exists is one. In it live and develop according to the same laws and principles of its constituent states, different aspects of the whole [1]. The modern world is currently in a state of protracted economic crisis. The political confrontation between global players on the world stage, the destruction of the unipolar world, and specifically the Russian Federation's attempt to maintain its unconditional dominance in international politics and the entire economic space are further exacerbated. This uses unfair competition, solving the initially local military conflict of 2014 in Ukraine in Donbas and the annexation of Crimea, and a further full-scale military invasion took place on February 24, 2022. Instead of finding a consensus and a way out of the crisis, all this further leads to the geopolitical aggravation of interstate relations, ultimately intensifying the overall crisis of civilization. In addition, all this is unpredictable in its duration.

As of June 1, 2022, a full-scale war has continued in the country for more than three months. In Ukraine, there are already significant economic losses

in addition to human casualties, causing great damage to infrastructure. The situation remains volatile, the outlook is uncertain, and the economic consequences are already very tangible. If the conflict escalates, the economic losses will be even more significant and devastating [2].

Today, in the conditions of war, crisis events are growing in the economic, social, natural, and other spheres of life of Ukrainian society. There is a growing need for objective operational monitoring and assessment of the direction of such changes in the economy and social sphere of life in these conditions. Such monitoring is traditionally conducted on the basis of official statistics coming from the regions. In the case of hostilities, the collection of statistics is of secondary importance, and even a rough analysis of economic activity becomes a challenging task. The quality of such statistical information greatly influences the nature of predictive models of regional development. One of the methods of independent control of the received information can be the data from satellite observations [3].

Current state of the researched issue

Assessment of the impact of hostilities is, unfortunately, a matter familiar to Ukraine. The United Nations Office for the Coordination of Humanitarian Affairs released one of the first reports on the consequences of Russian aggression eight years ago. The document stated that in Donetsk and Luhansk oblasts in the first six months of the clashes in 2014, the losses were estimated at \$440 million [4]. In 2020, the Vienna Institute for International Economic Research (WIIW) performed a "systematic assessment of the costs of the armed conflict in the Donbas." Several methods were used to assess the overall effect of armed aggression in ORDLO. For example, for the factor of direct damage from

hostilities, researchers calculated the share of the cost of housing lost due to hostilities for areas controlled by Ukraine. They then studied the linear relationship between the intensity of hostilities and the damage to housing at the individual district level. Researchers have concluded that the minimum cost of reconstruction in the region at that time reached \$21.7 billion [4].

However, the war that began in February 2022 has much larger geography. All regions of Ukraine suffer from the actions of Russian troops. In such a situation, there are several approaches to estimating war losses and one can estimate both damages and economic losses from the overall impact of

hostilities. This is the approach that, for example, World Bank experts advise to use. Category damages, an assessment that involves the calculation of losses of physical infrastructure (destruction of residential buildings; utilities, roads, railways; educational and medical institutions), as well as an assessment of the financial value of these losses. The World Bank advises a recovery approach. That is, if a house is destroyed, it is necessary to estimate not its value at the time of destruction, but how much it will cost to build a house from scratch on the site of the destruction. In the conditions of the ongoing war, it is really almost impossible to give an accurate assessment of the destruction. Estimation of losses actually involves the calculation of "side" losses. Thus, full-scale military aggression against Ukraine has led to the closure of enterprises, the loss of hundreds of thousands of homes and jobs, the cessation of investment, and a reduction in consumer demand. All this has already led to a drop in GDP. To this, new budget expenditures on the defense and social protection of victims must be added. As a result, the consequences for the economy on a scale are not inferior to the direct destruction of physical infrastructure [5].

One of the first scientific estimates of Ukraine's economic losses due to the armed conflict in Donbas is given in the works [6–8].

In the first half of the twentieth century, the qualitative growth of space technology is a factor that reduces the importance of traditional factors that previously determined the success of the economic and social development of the country. Today, satellite data are becoming increasingly popular in various sectors of the economy.

Previous studies have found that night light correlate well with the population, with the values of regional gross domestic product, or with the development of individual industries [9–14].

Studies on the monitoring of the assessment of the state and changes in the general socio-economic development of Ukraine on the basis of indicator satellite information are covered in the works [3, 15, 16]. It should be noted that the study substantiates aspects of the use of remote sensing data during the military conflict in Donbas [17, 18].

The purpose of our study is to assess the possibilities of using VIRSS satellite data on night lighting of the territory to monitor the socio-economic development of the regions of Ukraine during hostilities.

Research Methods

The Suomi NPP is a next-generation polar orbital satellite that collects data worldwide daily, both day and night. The main thermal imager on the SNPP is the Visible Infrared Imaging Radiometer Suite (VIIRS), which allows obtaining night images of the earth's surface in the visible range of the spectrum every day with a spatial resolution of 450 meters. Data for March 2021 (pre-war period) and 2022 (during the period of military aggression)¹ were used for the study.

All work with night light data from the Suomi NPP satellite was carried out in the Erdas Imagine space data processing program and consisted of the following steps:

1) From the month composite for March for 2021 and 2022, with the help of Erdas Imagine using the SubSet function, the territory of Ukraine was sep-

arated using the contour of Ukraine in the format *.aoi.

2) A 2-channel image of the territory of Ukraine in the geographical coordinate system was formed using the LayerStack function of the Erdas Imagine program, where the first channel corresponds to the monthly data for March night lighting for 2021 and the second channel for March 2022.

3) With the help of the Reproject function of the Erdas Imagine program, the conversion of a 2-channel image of the territory of Ukraine into the WGS 84 / zone 36 coordinate system was performed.

4) To highlight the territory of each region, the contours of the regions of Ukraine in *.aoi format were used using the SubSet function of the Erdas Imagine program for a 2-channel image of the territory of Ukraine obtained in the third stage.

Presentation of the main material

After the war in Ukraine, there will be a question about the reconstruction of houses and infrastructure of the Ukrainian cities and villages.

There is such a large scale of destruction that it is already necessary to develop options and monitor the socio-economic development of Ukraine, both

¹ https://ngdc.noaa.gov/eog/viirs/download_ut_mos.html

at the level of each city and administrative region of Ukraine. Therefore, the selection of indicators and the selection of quantitative criteria that will assess a phenomenon are paramount in conducting such monitoring.

First of all, Ukrainian cities need to be rebuilt. Because it is not necessary to build in the same place, especially since people do not want to return to many places. The settlement of the population, population, agglomeration in administrative areas, and postwar migration of Ukrainians not only to industrialized regions such as Kyiv agglomeration but in the current realities of internal migration from the east (evacuation) to the west characterizes the economic activity of these regions.

As an indicator, the quantitative indicator proposed by the authors [15] was used: total light in-

tensity (TLI) is the sum of the values of the illuminance of all pixels in the territory of each of the regions of Ukraine. The value of the total nighttime lights of the administrative regions of Ukraine depends on the number of settlements in the region, the development of industry and transport network, as well as the area of the administrative region. Light intensity is closely related to an important indicator of economic activity—electricity consumption. Henderson, the author of the methodology, and colleagues found that in low- and middle-income countries, changes in nighttime lights by 1% are approximately equal to changes in income by 1% [15]. The results of the analysis of nighttime lights from the satellite Suomi NPP / VIIRS administrative regions of Ukraine for March 2021, 2022 are shown in **Table 1**.

Table 1. Values of night lighting (TLI), (nanoWatts / cm² / sr) and their change for March 2021 and 2022 for the administrative regions of Ukraine

Group	Oblasts of Ukraine	TLI			Group	Oblasts of Ukraine	TLI		
		March 2021	March 2022	2021/2022			March 2021	March 2022	2021/2022
1	Autonomous Republic of Crimea	81,725	97,869	0.84	14	Vinnitsia Oblast	44,721	13,815	3.24
2	Zakarpattia Oblast	19,811	19,872	1.00	15	Zaporizhzhia Oblast	38,662	11,415	3.39
3	Luhansk Oblast	22,174	21,920	1.01	16	Zhytomyr Oblast	24,064	6,363	3.78
4	Lviv Oblast	64,242	35,982	1.79	17	Poltava Oblast	45,698	9,048	5.05
5	Donetsk Oblast	71,686	35,999	1.99	18	Cherkasy Oblast	28,883	3,984	7.25
6	Kherson Oblast	16,949	8,306	2.04	19	Sumy Oblast	27,162	3,152	8.62
7	Chernihiv Oblast	16,847	7,615	2.21	20	Kirovohrad Oblast	27,847	2,912	9.56
8	Rivne Oblast	32,688	13,286	2.46	21	Dnipropetrovsk Oblast	99,858	9,855	10.13
9	Odessa Oblast	63,733	25,603	2.49	22	Chernivtsi Oblast	14,754	962	15.34
10	Kharkiv Oblast	51,594	20,325	2.54	23	Mykolaiv Oblast	23,144	1,278	18.11
11	Volyn Oblast	15,356	5,821	2.64	24	Ternopil Oblast	22,539	1,239	18.19
12	Kyiv Oblast	141,705	46,947	3.02	25	Ivano-Frankivsk Oblast	27831	1,313	21.20
13	Khmelnitsky Oblast	33,937	10,606	3.20					

The analysis of the obtained results (**Table 1**) reveals that the value of the ratio of nighttime lights indicators for March 2021 and 2022 varies in a fairly wide range from 0.84 to 21.2. Based on the analysis of the distribution of this ratio, the ranking of administrative regions of Ukraine was carried out. As a result, five groups of areas were identified, from an increase in nighttime lights to a catastrophic decrease: Group I: from 0.84 to 1.01; Group II: from 1.79 to 2.64; Group III: from 3.02 to 5.05; Group IV: from 7.25 to 10.13; Group V: from 15.34 to 21.20. The average value of changes in the indicator of

nighttime lights TLI for March 2021 and 2022 in all regions of Ukraine is 6.04.

Such changes in nighttime lights can be explained by hostilities (for example Chernihiv Oblast: was in 2021 — 16,847, became — 7,615; Sumy Oblast: was in 2021 — 27,162, became — 3,152), and by the light masking, during martial law in Ukraine (example: Lviv region: was in 2021 — 64,242, became — 35,982; Khmelnytsky Oblast: was in 2021 — 33,937, became — 10,606), as well as low industrial and economic development of the economy some regions of Ukraine (example: Chernivtsi Oblast: there were



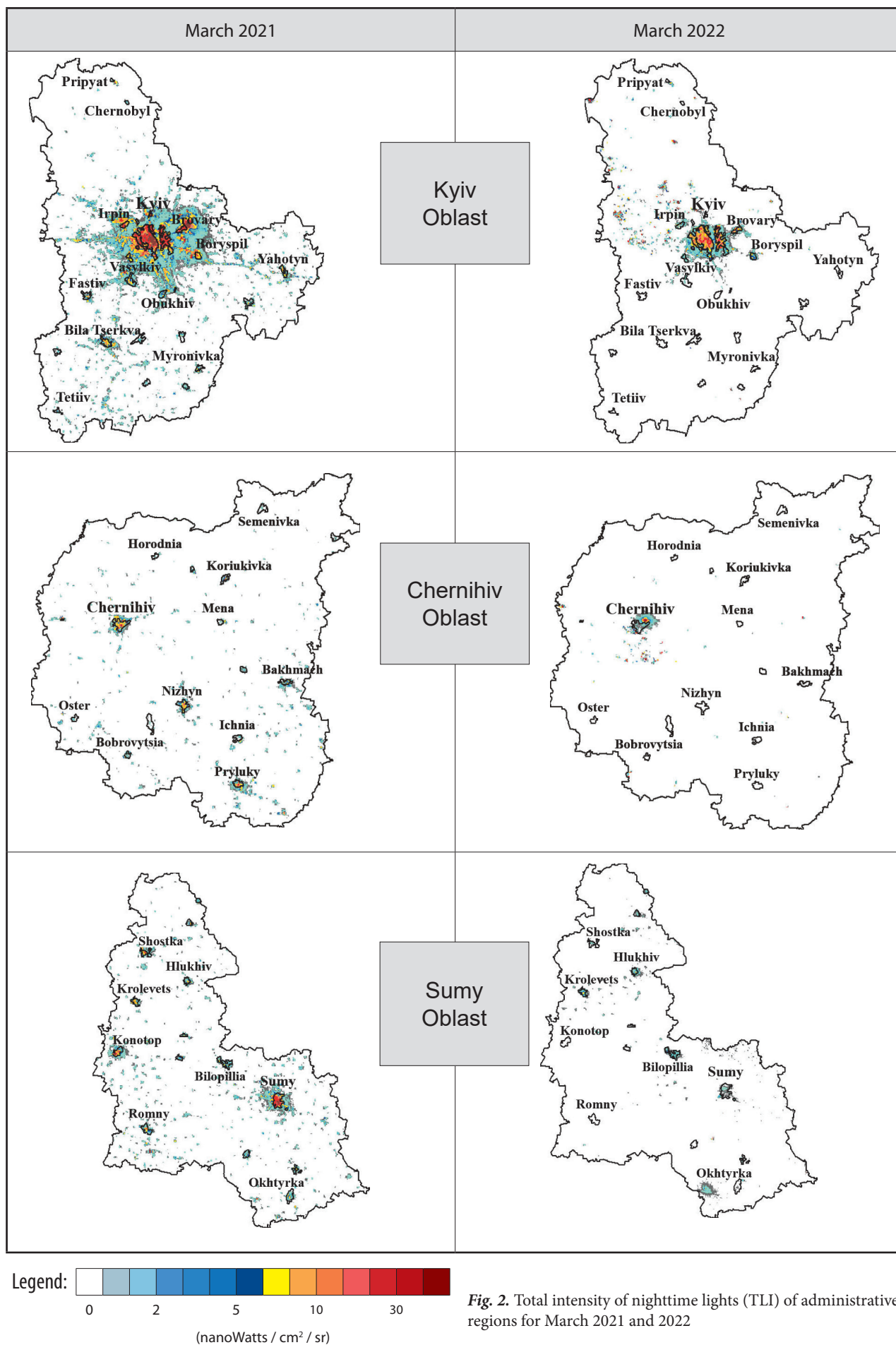


Fig. 2. Total intensity of nighttime lights (TLI) of administrative regions for March 2021 and 2022

14,754 in 2021, became — 962; Ivano-Frankivsk Oblast: there were 27,831 in 2021, became — 1,313), and low level of spatial concentration of the population (for example Ternopil Oblast: was in 2021 — 22,539, became — 1,239) before February 24, 2022.

Figure 1 shows information about the concentration of population, location of objects of economic activity, and accordingly, the reduction of night lighting throughout Ukraine in March 2021 and 2022.

During the military aggression of the Russian Federation on the territory of Ukraine, the decrease in the intensity of night lighting and the area is visu-

ally visible. There is a decrease in both the territory and the intensity of nighttime lights in large urban agglomerations (Kyiv, Lviv, Dnipropetrovsk, Kharkiv, Mykolaiv).

Small, low-energy facilities (villages, small towns, closures or suspensions of small-scale production, highways, and railways) were lost (**Figure 2**). In all three territories of administrative Oblasts, nighttime lights are increased in the administrative centers of Oblasts, while in other settlements, the intensity of lighting has catastrophically decreased and they are not reflected in the materials of space photography.

Conclusion

Information on nighttime lights can be used as operational independent monitoring of changes in the socio-economic situation of administrative regions of Ukraine during warfare, as well as serve as an additional source of data on population concentration. Further research should be conducted to detail the level of individual districts and cities. The analysis of the received materials gives an opportunity to quickly develop recommendations for the

elimination of the identified demographic and economic processes in certain areas of our state, which allows for preventing and eliminating humanitarian catastrophes during warfare. The novelty of the study is the improvement based on the use of materials from the satellite SNPP / VIIRS with greater spatial diversity, previously developed methods of nighttime lights and its practical application during active battles.

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