Mon2026-073

Index-based assessment of agro-landscape degradation using remote sensing data under explosive impacts

P. I. Trofymenko *(T.H. Shevchenko National University "Chernihiv Colehium"),* ***V. Yu. Belenok*** *(State University "Kyiv Aviation Institute"),* ****R. S. Poralo*** *(Taras Shevchenko National University of Kyiv),* ***I. R. Stakhiv*** *(Taras Shevchenko National University of Kyiv),* ***O. S. Melnyk*** *(Sumy National Agrarian University),* ***V. B. Levchenko*** *(T.H. Shevchenko National University "Chernihiv Colehium")*

SUMMARY

The study develops and tests an integrated methodology for the remote assessment of agricultural landscape degradation caused by explosive impacts using multispectral PlanetScope data for 2022 and 2024. The relevance of the approach is determined by the temporary inaccessibility of damaged areas due to mine hazards and military risks, which increases the importance of remote monitoring.
The methodology is based on the application of nine spectral indices: NDVI, EVI, SAVI, GNDVI, and ARVI (vegetation indices); NDWI (water index); and BSI, BI, and IBI (soil indices). In addition, specialized indices - CDI, EII, and SRI - were developed to improve the detection of surface exposure, structural disturbances, and soil moisture deficit associated with explosive impacts.
The approach includes threshold-based delineation of index anomalies and spatial validation of explosive crater boundaries, followed by a year-to-year comparison to assess recovery dynamics. The results show that the highest assessment accuracy is achieved through the combined use of indices: soil indices are most effective for detecting bare surfaces, while vegetation and water indices perform better in vegetated areas. Monitoring revealed heterogeneous recovery patterns and persistent zones of degradation, highlighting the need for long-term remote monitoring and reclamation planning of damaged agricultural landscapes.

Introduction

Land resources are deteriorating under the pressure of anthropogenic drivers (Datsko et al., 2025). In Ukraine, since 2022, military operations have emerged as an additional stressor, generating blast craters within agricultural land, mechanically disrupting the soil profile, altering moisture regimes, and causing the loss of vegetation cover (Trofymenko et al., 2024). This, in turn, necessitates rapid monitoring of the affected areas (Solokha et al., 2023).

Remote sensing (RS) methods and spectral indices are widely used to assess land degradation (Dindaroglu et al., 2022). Although NDVI is the most commonly applied index, it does not allow the underlying causes of disturbance to be disentangled (Shelestov et al., 2023), which substantiates the use of a multi-index approach that accounts for vegetation, water, and soil-related metrics, as well as integrated indicators (Bonchkovskyi et al., 2025).

The aim of this study is to develop an integrated remote-sensing methodology for assessing the degradation of agricultural landscapes induced by explosive impacts, grounded in spectral indices and an analysis of their spatio-temporal dynamics in 2022 and 2024.

Method and Theory

To quantify the spatio-temporal dynamics of blast craters in agricultural landscapes, we applied a spectral-index remote-sensing approach using PlanetScope imagery with a 3 m spatial resolution. The analysis was conducted for two time windows: May–June 2022 (damage identification stage) and May–July 2024 (monitoring stage). The imagery was pre-processed through geometric orthorectification and atmospheric correction. Information on the spatial distribution of explosive impacts, the types of damage sources, and the initial geolocation-based identification of sites was obtained from the open geoinformation resource *Green Ukraine Interactive Map of Environmental Damage* (Green Ukraine, 2025).

Based on these data, a baseline sample of 26 test sites was compiled across Chernihiv, Sumy, and Kharkiv oblasts and assigned inventory identifiers (see Fig. 1).

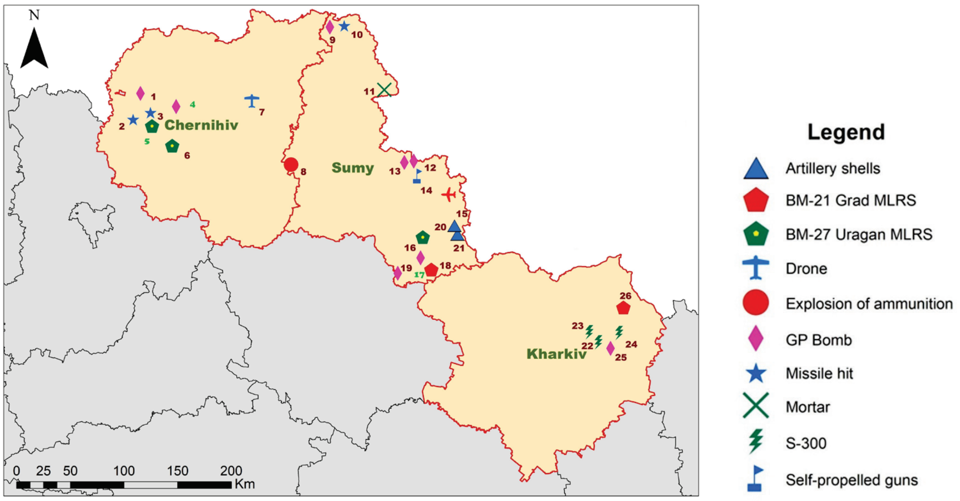


Figure 1 *Location map of the study area showing the spatial distribution of the identified damaged sites, 2022*

In the ArcGIS 10.7 environment, raster layers of indices from three groups were calculated and generated for each test field: water-related (NDWI), vegetation-related (NDVI, EVI, SAVI, GNDVI, ARVI), and soil-related (BSI, BI, IBI) (USGS, 2025). All indices were computed using established formulas as follows:

$$1)\ NDWI = \frac{Green - NIR}{Green + NIR} \qquad 2)\ GNDVI = \frac{NIR - Green}{NIR + Green} \qquad 3)\ NDVI = \frac{NIR - Red}{NIR + Red}$$

$$4)\ BSI = \frac{(Red + Blue) - (NIR + Green)}{(Red + Blue) + (NIR + Green)} \qquad 5)\ SAVI = \frac{(NIR - Red)(1 + L)}{NIR + Red + L}, \text{де } L = 0.5$$

$$6)\ ARVI = \frac{NIR-(2\cdot Red-Blue)}{NIR+(2\cdot Red+Blue)} \quad 7)\ \mathrm{IBI} = 2\cdot\mathrm{Red}\text{-}(\mathrm{NIR}+\mathrm{Green}) \quad 8)\ BI = \sqrt{\mathrm{Red}^2 + \mathrm{Blue}^2}$$

$$9)\ EVI = G \cdot \frac{NIR-Red}{NIR+C_1\cdot Red-C_2\cdot Blue+L}, G = 2.5, \quad C_1 = 6, \quad C_2 = 7.5, L = 1$$

Development of specialized indices

To increase sensitivity to multifactorial changes in soil cover under explosive impacts, three specialized indices were developed, as presented below.

Composite Degradation Index (CDI) is an integral measure of overall degradation severity that accounts for changes in vegetation and exposed soil (10).

Explosion Impact Index (EII) captures the explosive impact by detecting spectral anomalies within the crater itself and the surrounding ejecta zone formed by displaced soil material (11). Soil Recovery Index (SRI) is a recovery-oriented index that reflects the balance between surface moisture conditions and the degree of vegetation regrowth (12).

The indices were calculated using the following formulas:

$$10)\ CDI = \frac{BSI-NDVI}{BSI+NDVI} \quad 11)\ EII = \frac{(Red+RE)-2\cdot NIR}{(Red+RE)+2\cdot NIR} \quad 12)\ SRI = \frac{Green+NIR-2\cdot RE}{Green+NIR+2\cdot RE}$$

Based on the defined indices, a comparative analysis of values within the damaged areas was conducted for 2022 (the baseline year) and 2024 using the water index, which made it possible to assess interannual changes in moisture conditions, substrate exposure, and vegetation status.

The study was carried out in three consecutive stages. In the first stage, geospatial damage identification was performed through threshold-based extraction of blast-crater pixels for each spectral index; threshold values were determined by histogram analysis and visual cross-checking against reference outlines derived from a synthetic band combination of Band 2 (Green), Band 4 (Red), and Band 6 (Red Edge). In the second stage, the resulting outlines were compared by calculating the percentage of spatial overlap between the index-based mask and the visually delineated damage area. The third stage focused on change monitoring—comparing index values for 2022 and 2024 in order to evaluate whether the territory exhibited recovery trends or, conversely, a deepening of agricultural-landscape degradation.

Within the 2024 monitoring phase, for crater polygons identified as of 2022, we calculated the areas of zones exhibiting critical values of the respective spectral indices. Subsequent analysis involved determining the percentage of their spatial overlap between the two temporal snapshots in accordance with Equation:

$$P = \frac{S_{2022,2024}}{S_{ref}} \times 100\%$$

where P – is percentage of geospatial correspondence, %;

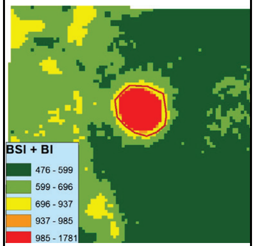
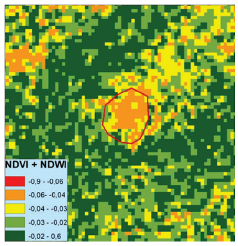
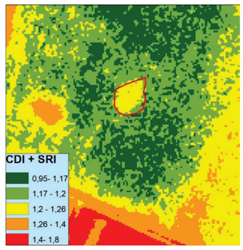
$S_{2022,2024}$ – is area of overlap between blast-crater polygons in 2022 and 2024.

S_{ref} – is reference area of the mechanically disturbed and degraded agricultural landscape site, delineated through vectorization of the blast-crater boundary and used for normalizing the spatial correspondence metric

Results

The study was conducted on test sites that differ in their distance from the state border and in the types of damage observed. Table 1 presents a summary of sites affected by explosive impacts and, in addition, reports the performance metrics of index combinations used for their identification (excerpt). The assessment indicates that no single index is universally effective, because its sensitivity is controlled by moisture conditions, soil texture, the severity of disturbance, and vegetation presence. The highest performance was achieved by the soil indices BI and IBI, which at certain sites captured more than 80% of the crater area. NDWI proved effective where a clear moisture contrast was present, whereas vegetation indices performed well under dense plant cover but lost informativeness after harvest and over degraded surfaces.

Table 1 *Characteristics of the surveyed agricultural plots with explosive damage and the effectiveness of index combinations for their identification.*

Region / settlement / site inventory number, explosive munition	Crater center coordinates (WGS 84), distance to the border, km / damaged area, ha	Index group / best combinations / percentage of overlap	Images of test sites with explosive damage	Visualization of identification results
Chernihiv Oblast, Lukashivka, (004), GP Bomb	φ = 51.39612383 λ =31.39856100 52,8 / 0.2258	exposed soil / BSI + BI / 97.5		
Chernihiv Oblast, Levkovychi, (005), BM-27 Uragan MLRS	φ = 51.29908760 λ = 31.27247571 43,3 / 0.1600	vegetation and water-related / NDWI + NDVI / 54.3		
Sumy Oblast, Okhtyrka Raion, (017), GP Bomb	φ = 50.29213592 λ =34.94536400 46,8 / 0.3516	targeted (developed)/ CDI + SRI 75.3		

The developed indices (CDI, EII, and SRI) enabled the identification of surface structural disturbances, soil exposure, and soil-moisture deficits.

The findings indicate an exceptional detectability of damage caused by higher-yield munitions—most notably aerial bombs, multiple rocket launch systems (MLRS), and self-propelled artillery systems.

To improve identification accuracy and assessment robustness, a combined approach (arithmetic integration of indices) was applied. The highest combinational performance was achieved by BSI + BI (particularly over fully denuded craters), whereas the NDWI + NDVI combination (for vegetated zones with a pronounced moisture contrast) demonstrated a moderate level of discriminative capability.

An analysis of index dynamics for 2022 versus 2024 revealed a mosaic pattern of blast-crater recovery, driven by local soil properties and agronomic practices. Some sites exhibited signs of revegetation and partial moisture restoration, while other areas retained persistent degradation signals. In places, NDVI increased, which can be attributed to natural sodding processes or the sowing of crops. Soil-index values, however, point to ongoing surface-structure disruption, exposure, and moisture deficits even under weak or absent vegetation cover. Particularly important is that EII shows a stronger capacity to detect explosive impacts even in cases of sparse vegetation, making it pivotal for spatio-temporal analysis. This supports long-term remote monitoring of agricultural landscapes and enables the combined use of indices to evaluate recovery trajectories and to inform the planning of recultivation measures.

Conclusions

This study developed and validated an integrated remote-sensing methodology for assessing the degradation of explosion-damaged agricultural landscapes. The approach combines multispectral analysis of PlanetScope imagery, threshold calibration using a "reference crater," geospatial validation, and change monitoring for 2022 and 2024. The results show that conventional vegetation metrics are insufficiently sensitive under conditions of partial cover recovery, whereas exposed-soil and moisture indicators provide more reliable crater identification—reaching, in some cases, up to 97% accuracy where a clear spectral contrast is present. Distinct degradation signatures were identified, enabling the effects of explosive damage to be typified by degree of soil exposure, moisture deficit, and biomass loss.

Monitoring in 2024 confirmed a mosaic recovery pattern: some sites exhibit evidence of partial recultivation and natural revegetation, reflected in increased CDI and SRI values, while at other locations degradation persists or intensifies. The EII index remains sensitive even when vegetation response is weak.

References

Bashir, M., & Ali, A. (2020). Soil erosion assessment using NDVI and BSI in Baluchistan region. *Journal of Remote Sensing Applications, 12*(3), 123–132.

Bonchkovskyi, O., Ostapenko, P., Bonchkovskyi, A., & Shvaiko, V. (2025). War-induced soil disturbances in north-eastern Ukraine (Kharkiv region): Physical disturbances, soil contamination and land use change. *Science of the Total Environment, 964*, 178594. https://doi.org/10.1016/j.scitotenv.2025.178594

Datsko O., Melnyk O., Kovalenko I., Butenko A., Zakharchenko E., Ilchenko V., Onychko V., Solokha, M. (2025). Estimation of the content of trace metals in Ukrainian military-affected soils. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 53(1), 14328. https://doi.org/10.15835/nbha53114328

Dindaroglu T., Tunguz V., Babur E., Alkharabsheh H. M., Seleiman M.F., Roy R., Zakharchenko E. (2022). The use of remote sensing to characterise geomorphometry and soil properties at watershed scale. Int. J. Global Warming, 7, (4), 402-421. https://doi.org/10.1504/IJGW.2022.124625

Green Ukraine. (n.d.). *Green Ukraine Interactive Map of Environmental Damage.* Retrieved 2025, from https://greenukraine.ch/map

Pereira, P., Bašić, F., Bogunovic, I., & Barcelo, D. (2022). Russian-Ukrainian war impacts the total environment. *Science of the Total Environment, 837*, 155865. https://doi.org/10.1016/j.scitotenv.2022.155865

Shelestov, A., Drozd, S., Mikava, P., Barabash, I., & Yailymova, H. (2023). War damage detection based on satellite data. In *Proceedings of the 11th International Conference on Applied Innovations in IT (ICAIIT)* (pp. 97–102) https://icaiit.org/proceedings/11th_ICAIIT_1/2_6%20ICAIIT_2023_paper_5059.pdf

Solokha, M., Pereira, P., Symochko, L., Vynokurova, N., Demyanyuk, O., Sementsova, K., & Barcelo, D. (2023). Russian-Ukrainian war impacts on the environment: Evidence from the field on soil properties and remote sensing. *Science of the Total Environment, 902*, 166122. https://doi.org/10.1016/j.scitotenv.2023.166122

Trofymenko, P., Tomchenko, O., Poralo, R., Zatserkovnyi, V., & Stakhiv, I. (2024). Remote identification of microdepression relief forms and soil cover areas of agro-landscapes of Ukrainian Polissia with signs of hydromorphism. *Visnyk of Taras Shevchenko National University of Kyiv. Geology, 1*(104), 98–106. https://doi.org/10.17721/1728-2713.104.12

United States Geological Survey. (2026). *Landsat Soil Adjusted Vegetation Index (SAVI).* https://www.usgs.gov/landsat-missions/landsat-soil-adjusted-vegetation-index