УДК 528.2:631.445+556 https://doi.org/10.31713/vt3202430

Klimov S. V., Candidate of Engineering (Ph.D.), Associate Professor, Kozishkurt S. M., Candidate of Engineering (Ph.D.), Associate Professor (National University of Water and Environmental Engineering, Rivne)

REMOTE SENSING OF THE EARTH TO ASSESS THE RISKS OF LOSS OF FERTILITY OF DRY STEPPE SOILS DURING A WATER CRISIS

The southern part of the steppe zone of Ukraine (Dry Steppe) is situated in challenging natural and climatic conditions. The potential fertility of dry steppe soils is limited by insufficient natural water supply, which is addressed through artificial irrigation. Irrigation not only ensures optimal water-air regime but also manages the salt regime in the soil aeration zone. The Russian Federation has caused a significant water crisis. To assess the risks of fertility loss in dry steppe soils, the level of water stress was investigated using Earth remote sensing data, which is particularly relevant under the conditions of the occupation of part of the territory. A quantitative indicator of the amount of photosynthetic active biomass, the Normalized Difference Vegetation Index (NDVI), and the Normalized Difference Moisture Index (NDMI) were selected for evaluation. Calculations were carried out for a group of fields in the Skadovsk district of the Kherson region. The analysis of index data indicates that there are prerequisites for soil degradation over a significant territory of the studied area, necessitating the restoration of irrigation melioration.

Keywords: **Remote sensing of the earth; vegetation index; moisture index; dry steppe soils; water crisis; degradation; fertility; soil moisture.**

Introduction. The Dry Steppe constitutes a part of the Steppe Zone in Ukraine, encompassing the southern and southwestern regions of the Odessa Oblast, the southern areas of the Kherson Oblast, and the Autonomous Republic of Crimea. This region is characterized by elevated air temperatures during summer, low relative air humidity, frequent droughts, atmospheric and soil aridity. The annual precipitation ranges from 300 to 420 mm, with 200–250 mm occurring during the vegetation period. Precipitation is distributed unevenly, predominantly in the form of heavy downpours. The duration of drought reaches 90–100 days and recurs every 2–3 years. The annual total evaporation exceeds the annual amount of atmospheric precipitation by 2–2.5 times. These processes intensify the degradation of dry steppe soils and the desertification of lands.

The Dry Steppe of Ukraine encompasses an area of 4.7 million hectares [1]. Agricultural lands constitute 1.8 million hectares, of which arable lands cover 1.2 million hectares. The prevailing soils are dark chestnut soils, occupying 1.1 million hectares in agricultural lands. These soils have developed under conditions of arid climate, proximity of groundwater, and a depleted herbaceous cover with elevated salt reserves in the upper layers.

In order to enhance the productivity of the steppe soils, exploit saline or prone-to-salinity masses, and create optimal conditions for soil formation, irrigation systems have been implemented. These systems source water from the Dnieper River through the Kakhovka Reservoir.

The Kakhovka Main Canal was designed to facilitate the irrigation of agricultural lands and provide water supply to rural settlements in the Kherson and Zaporizhzhia regions. The canal spans a length of 130 kilometers, with a water flow rate of 530 m^3/s. The largest in Europe, the Kakhovka irrigation system provided irrigation for more than 250,000 hectares of land.

The Northern Crimean Canal supplied water to the Kherson region and the Autonomous Republic of Crimea. The primary water consumer was agriculture, which utilized 590.18 million m^3 of water annually [2]. The canal's length is 402.6 kilometers, with a water flow rate of 380 m^3/s. Until 2014, the Crimean Peninsula received over 1.2 billion m^3 of Dnieper River water annually, constituting 85% of the total water consumption.

The implementation of hydromeliorative measures over extensive areas of the Dry Steppe has led to substantial alterations in natural factors influencing soil formation processes. These changes encompass the natural water balance, moisture and temperature of the upper soil layers and atmospheric air, water evaporation rates, as well as morphological characteristics and conditions for soil formation. As a result of hydromelioration impact, automorphic soils have transformed into hydromorphic ones, subsequently affecting agrohydrological and chemical properties of ameliorated soils, as well as the formation of root systems and alterations in the nutritional conditions of agricultural crops [3].

It is imperative to note that plant water consumption is the outcome of the interaction between a complex of external and internal (biological) factors. Meteorological conditions fall under unregulated factors, whereas regulated factors include soil moisture and fertility, groundwater regime, as well as the developmental peculiarities of plants with water consumption intensity characteristic to each phase.

With the implementation of irrigation, the water deficit necessary to meet the nutritional needs of plants and maintain optimal temperature conditions was addressed. Consequently, yields of irrigated agricultural crops in the initial years of irrigation system operation exceeded yields on non-irrigated lands by 2–4 times.

Land irrigation led to new conditions in soil evolution, characterized by the presence of an agro-irrigational humus layer. This layer contributes to an increase in humus reserves, a reduction in sodium salt content, improvement of soil structure, and enhancement of its fertility.

The presence of humus stabilizes the soil's water regime and enhances its buffering action, preventing the leaching of microelements and reducing soil toxicity in the event of chemical contamination. To achieve these positive effects, it is crucial to have high-quality irrigation water.

Water in the soil is a vital component and a key factor in fertility, facilitating the flow of biological and biochemical processes. Water deficiency in the soil, and consequently in nutrients, negatively impacts plant development. In conditions of water shortage, unfavorable physiological processes occur in plants, leading to suppression, cessation of plant mass growth, and reduced yields.

Fertile soil contains practically all essential nutrients, initially present in solid form. For plants to utilize these nutrients, they must transition into the soil solution. This process is facilitated by the root system of plants, which extracts nutrients from the soil. The magnitude and depth of the plant's root system depend on the plant species and the level of soil moisture availability.

In the formation of soil fertility, microorganisms play a significant role. In the presence of soil moisture at 70%, optimal conditions are created for the proliferation of bacteria and fungi. This process positively influences soil structure, promotes the formation of humus, and facilitates its mineralization, thereby sustaining soil fertility and contributing to the preservation of ecosystem functions.

Water plays a pivotal role not only in creating conducive conditions for soil evolution but also in regulating temperature regimes. The absence of irrigation, elevated temperatures, and high levels of evaporation from fields, especially in shallow mineralized groundwater areas, contribute to the activation of secondary salinization processes and loss of fertility.

In arid steppe lands, irrigation not only ensures optimal soil-water-air regimes, but also manages the soil salinity. The leaching regime in saline or prone-to-salinization soils prevents this process and enhances their physicochemical properties.

Therefore, irrigation is not merely a measure to ensure water regimes and increase crop yields, but also a means of guaranteeing optimal conditions for soil evolution, as well as the preservation, restoration, and enhancement of soil fertility.

Full-scale military aggression by the Russian Federation has resulted in severe damage to critical infrastructure, hydraulic structures, and the hydro-technical network of irrigation and drainage systems in the southern-steppes region of Ukraine. Due to active hostilities and occupation, it is not possible to carry out meliorative measures on agricultural lands, leading to a significant reduction in irrigated land area and adversely affecting the country's food security.

For example, in 2021, the total consumption of fresh water in the Kherson region was 703 million m^3, or 11.44% of the total Ukrainian consumption [4]. In previous years, this figure was even higher. The overall water intensity of the gross regional product in the Kherson region was nearly six times higher than the national average. Currently, the agricultural sector of Kherson is facing the threat of collapse, similar to what the agriculture of Crimea experienced.

The occupation of the Autonomous Republic of Crimea since 2014 has led to a deterioration of the hydrogeological and meliorative condition of the soil, caused by the salinization of upper horizons in the conditions of a dry climate and the loss of agricultural land. From 2013 to 2015, the volume of water used for irrigation decreased by 40 times, and the area of irrigated land decreased almost 13 times [5]. Without water, Crimea is turning into a semidesert where engaging in agriculture becomes economically unfeasible.

The acute water problem escalated to a catastrophic level following the destruction of the Kakhovka Hydroelectric Power Station dam in June 2023. This incident marks the largest technogenic and socio-economic catastrophe in Ukraine and Europe. Due to the uncontrolled release of water from the Kakhovka Reservoir, 94% of irrigation systems in the Kherson region were halted.

Over the past half-century, irrigated soils have been subjected to a periodic flushing regime, resulting in the formation of complex interrelated water and soil processes. The absence of irrigation has altered the components of the water balance, which may lead to deterioration of soil salinity, activation of salt upward movement into the upper soil layers, and subsequent secondary salinization. Over time, these lands may become unsuitable not only for the cultivation of crops but even for use as low-productivity pastures. Additionally, the recent weather and climatic conditions differ from the average indicators, with an increase in air temperature during the summer period. The increased evaporation from fields, coupled with shallow mineralized groundwater, also intensifies the processes of secondary salinization.

The potential fertility can be predicted based on the meliorative condition of the soil. Changes in the soil can be identified and measures to improve soil fertility can be justified through climatic, hydrogeological, meliorative, botanical, and other materials.

Materials and method. To assess the risks of fertility loss in the arid steppe soils caused by a water crisis amid global climate change, the application of remote sensing data is advisable. This type of observation is highly informative and relevant, especially in territories under the occupation of the Russian Federation.

Soil degradation is influenced by various biological, physical, chemical, and ecological factors, including the nature of agricultural land use, climatic factors (such as precipitation, temperature, and air humidity), and others. One of the indicators of degradation processes is the soil moisture content.

To detect changes in the conditions of cultivating crops, a group of fields in the Bechterska and Chulakivska communities in the Skadovsk district of the Kherson region was selected (Figure 1). These fields are located directly near the Krasnoznamyansky main canal, which diverted water from the North Crimean Canal. Water was extracted from the canal using a mechanical water lift. The total area of the fields is 7276.9 hectares.

This group is representative of the given region, containing fields of various configurations that were irrigated by circular and frontal action machines. Irrigated soils in this region differed from non-irrigated ones due to the presence of an agro-irrigation horizon, which resulted in a reduction in salt content, increased humus reserves, improved structure, and enhanced fertility.

Fig. 1. Placement of the research object (Google Earth Pro+Google Maps)

Results and discussion. To assess the existing conditions for cultivating agricultural crops on irrigated lands, a quantitative indicator of the amount of photosynthetic active biomass or vegetation index, specifically the Normalized Difference Vegetation Index (NDVI), was chosen (Fig. 2, a–d) [6–9].

To determine indicators of plant water stress in a group of fields, the annual variation of the Normalized Difference Moisture Index (NDMI) was analyzed [5] (Fig. 2, f–k). NDMI allows for the assessment of moisture content in plants and soil moisture levels and is based on the use of a combination of spectral ranges in the near-infrared (NIR) and shortwave infrared (SWIR) regions [6; 11; 12]:

$$\mathrm{NDMI} = (\mathrm{NIR} - \mathrm{SWIR}) / (\mathrm{NIR} + \mathrm{SWIR}).$$

This formula is implemented for various satellites within their available ranges, [13]:

Sentinel-2: $\mathrm{NDMI} = (B08 - B11) / (B08 + B11)$;
Landsat 4–5 TM, Landsat 7 ETM+: $\mathrm{NDMI} = (B04 - B05) / (B04 + B05)$;
Landsat 8, 9: $\mathrm{NDMI} = (B05 - B06) / (B05 + B06)$.

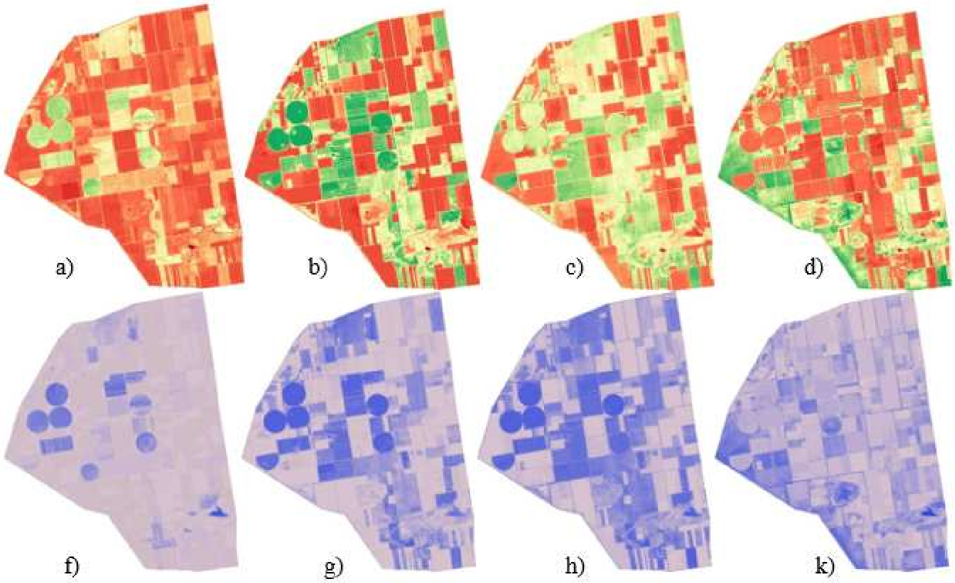


Fig. 2. Multispectral images of a field group: HDMI index (a–d); HDVI (f–k); a, f – February 23, 2022; b, g – April 24, 2022; c, h – May 9, 2022; d, k – July 3, 2022 (according to https://crop-monitoring.eos.com/)

The moisture index serves as an excellent indicator of moisture deficiency in crops [6]. SWIR channel data depict changes in moisture content in plants, while the NIR channel captures the internal leaf structure and dry matter content but not the water content. Therefore, combining NIR and SWIR allows for eliminating changes caused by variations in internal leaf structure and dry matter content, thereby enhancing accuracy in determining moisture content in plants [13].

Data analysis of satellite imagery for a group of fields revealed that over 23% of fields at the beginning of the vegetation period on February 23, 2022 (Fig. 2, a) had an NDVI index less than 0.2, amounting to 1708 hectares. At that time, the maximum daily air temperature was tmax=10° C, and the minimum temperature was tmin=0° C (Fig. 3). The low NDVI value indicates issues with plant emergence at the beginning of vegetation.

In April, based on the snapshot from April 24, 2022 (Fig. 2, b), fields with an NDVI index below 0.2 increased to 2231 hectares, constituting 31% of the selected group of fields. The maximum and minimum daily temperatures increased by 10° C, reaching tmax=20° C and tmin=10° C, respectively (Fig. 2, Table).

Table

Distribution of field groups based on HDVI and HDMI index values

NDVI	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
23/02/2022	5.81	1702.4	2699.7	1385.5	694.74	337.21	354.63	91.38	0.05	0
24/04/2022	4.75	2226.5	874.07	529.21	586.63	656.15	674.08	822.46	894.44	0.18
9/05/2022	1.08	591.27	2047.8	500.76	840.71	1413.4	1285.4	521.6	69.37	0
3/07/2022	6.55	1956.1	1846.08	768.39	756.06	673.44	582.76	440.13	88.17	0.03
NDMI	-0.8	-0.6	-0.4	-0.2	0	0.2	0.4	0.6	0.8	1
23/02/2022	0.08	0.2	48.87	4826.8	1674.5	314.22	366.72	36.04	4.2	0
24/04/2022	0	0	0.96	2856.4	1465.4	1103.5	1052.6	787.44	2.24	0
9/05/2022	0	0	0	1678.3	1585.1	1272.8	1682.5	1052.8	0.08	0
3/07/2022	0	0.01	0.3	799.8	3996.3	1484.5	797.54	183.72	9.96	0

During the mid-vegetative period, low values of the NDVI index (less than 0.5) can also indicate issues with plant development. In May 09, 2022, such fields covered an area of 3499 hectares, accounting for up to 48%, and in June 13, 2022, it was 3404 hectares, or 47%. By early July, the percentage of fields with a low NDVI index, less than 0.5, reached 69% (4968 hectares on 03.07.2022 and 5020 hectares on 18.07.2022, Fig. 2).

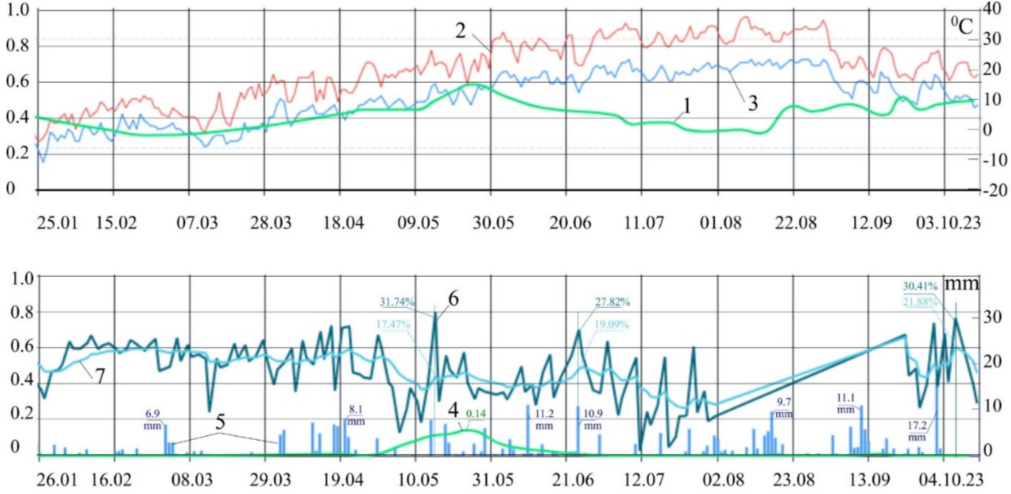


Fig. 3. Composite graph illustrating the changes in NDVI and NDMI indices across a group of fields in the year 2022: 1 – NDVI index; 2 – maximum daily air temperature, tmax, °C; 3 – minimum daily air temperature, tmin, °C; 4 – NDMI index; 5 – precipitation, mm; 6 – surface soil moisture, %; 7 – root zone moisture, %

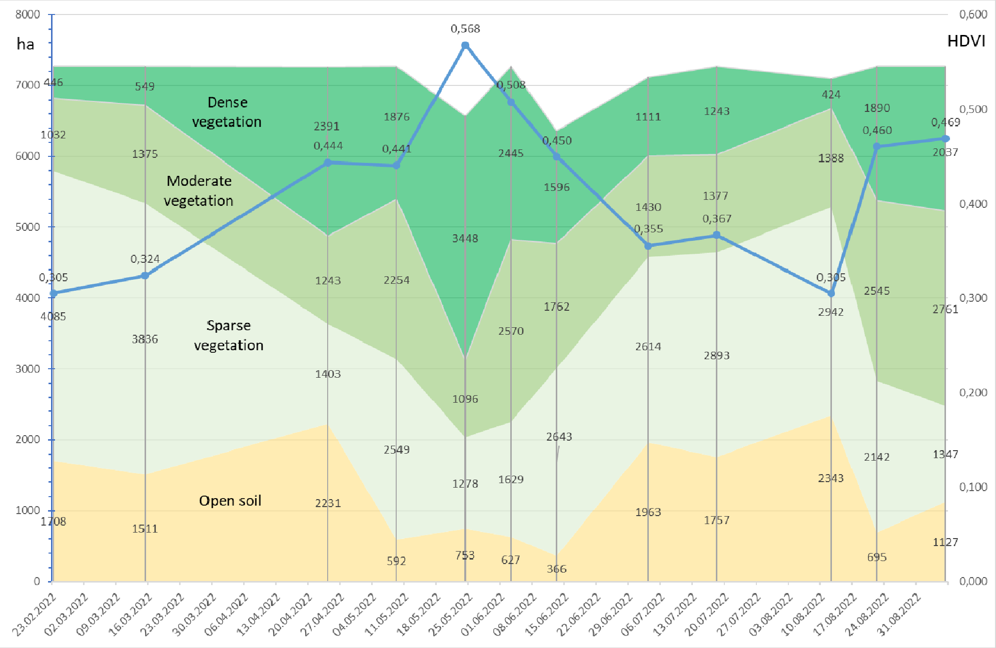


Fig. 4. Distribution of areas by NDVI index magnitude, 2022

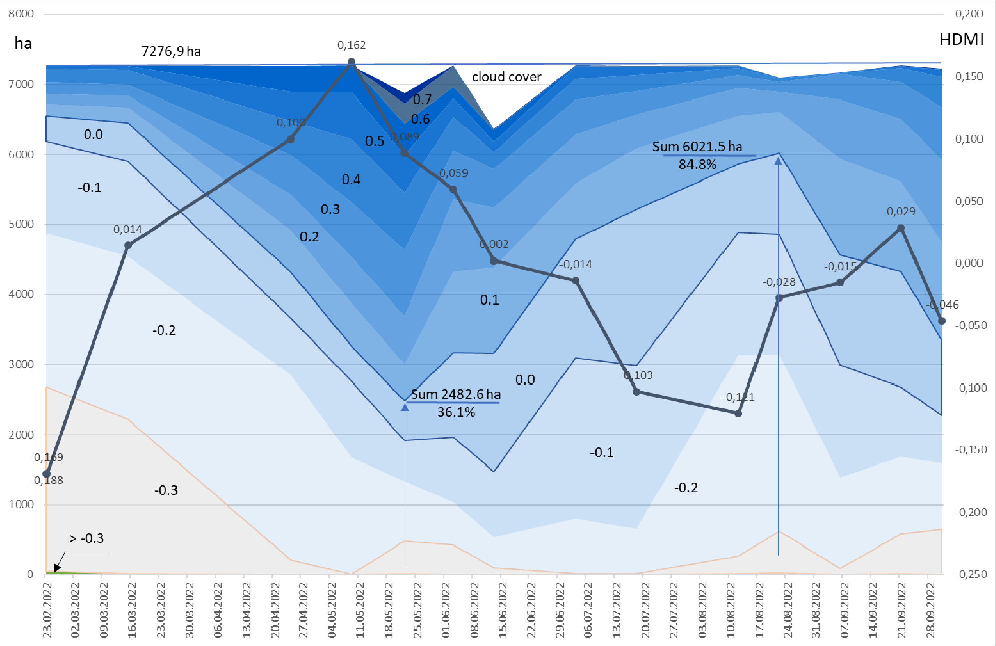


Fig. 5. Distribution of land areas in the group of fields based on the NDMI index magnitude, 2022

Precipitation distribution in the studied field group is presented in Figure 3, position 5. During the period from February 20, 2023, to

September 30, 2023, there was a total of 360.7 mm of precipitation, equivalent to 3607 m^3/ha. Throughout this period, there was one heavy rainfall event with an intensity of 38.9 mm/day on August 11, 2023. Rainfall of moderate intensity was recorded on several occasions: 17.4 mm/day on March 28, 2023, over 14 mm/day on April 5, 2023, April 11, 2023, June 11, 2023, and July 27, 2023.

The moisture content in the surface soil layer (%) varied from approximately 60% on April 4, 2023, to minimal values in mid-April, early May, and July (Fig. 3, position 6). The average value according to the remote sensing data was 16.93%.

Moisture content in the root zone (%) during the period from February 20, 2023, to September 30, 2023, showed a narrower range of variations. The maximum, around 30%, was observed in the early days of February and early April. The average value according to the remote sensing data was 17.25%. Significant periods of moisture content in the root zone falling below 15% occurred during most of May and August (Fig. 3, position 7). This implies that during a crucial period for crop development, plants did not have the necessary amount of moisture required for optimal yields.

During 2022, the primary indicator of plant water stress, NDMI (Normalized Difference Moisture Index), varied widely across the selected group of fields. However, during the vegetation period, the number of fields with low moisture content in plants and soil moisture levels was quite significant (see Fig. 5, Fig. 6, b). At the beginning of the vegetation period, with minimal vegetation cover, NDMI values below "-0.2" indicate critical moisture deficiency [14]. In March, such fields covered 4544.4 hectares, accounting for 62%, and in April, 2857.4 hectares, 39%. However, as plants grew, the overall NDMI index for the field group partially increased. In May, the number of fields with an NDMI index below "-0.2" was 1678.3–1329.9 hectares, or 23–18%. In June, such fields covered 531 hectares, or 7%.

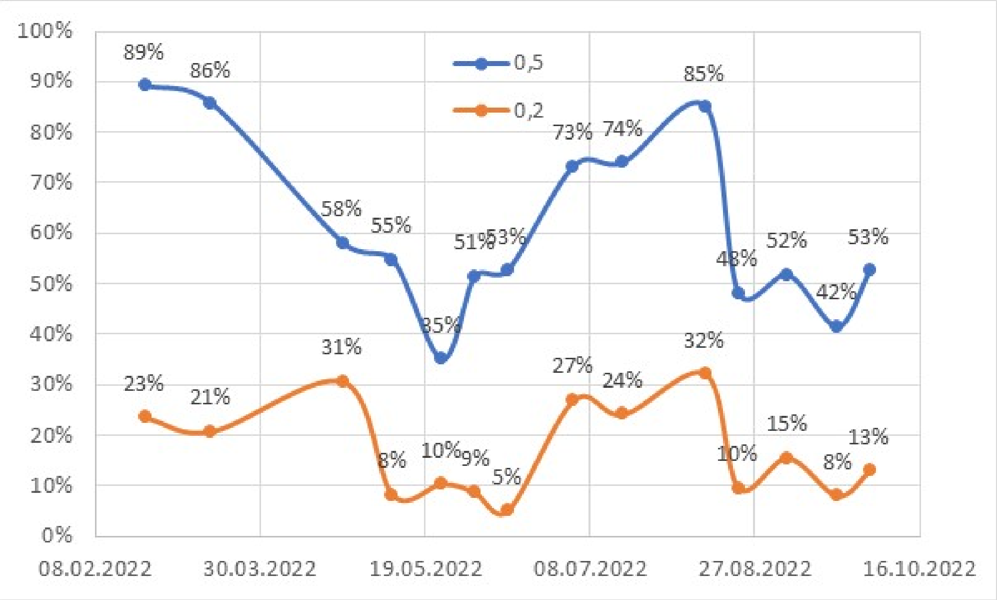
In a study [9] conducted in Romania, it was argued that for winter wheat, NDMI values in the range of -0.2 to 0.0 indicate high water stress for seven different premium wheat varieties. Values of 0 to 0.2 indicate low water stress. In these conditions, wheat plants do not receive sufficient moisture necessary for phenological development and achieving at least average yields [14]. Thus, having, as of April 24, the number of fields with an NDMI index below "0.0" at 4322.8 hectares, it can be reasonably asserted that there is a lack of water conditions for obtaining normal yields on 39% of the area.

Another factor that increases the risks of fertility loss in arid steppe soils, particularly in the Kherson region, is the low availability of irrigation equipment. According to [15], in 2021, Ukrainian agricultural enterprises had approximately 6,000 irrigation machines. This quantity could support the irrigation of 600,000 hectares, while Ukraine requires irrigation for over 2.3 million hectares of land. However, this factor can be rapidly addressed by the development of leading Ukrainian manufacturers – Variant Irrigation and Fregat, which accounted for 19.0% and 15.9% of the market share of purchased irrigation machines in 2021.

Conclusion. The southern part of the steppe zone of Ukraine is situated in complex natural and climatic conditions, and without regulation of the water-air regime, preserving soil fertility is impossible.

In order to enhance the productivity of dry steppe soils, develop saline or prone-to-salinity areas, and create optimal conditions for soil formation, irrigation systems were implemented.

The military aggression of the Russian Federation has caused serious damage to critical infrastructure and irrigation systems, leading to a reduction in irrigated areas and posing a threat to food security. The destruction of the dam of the Kakhovka Hydroelectric Station in 2023 further deepened the water crisis.



a)

b)

Fig. 6. Changes in the number of fields for the selected group in 2022 with indices: *a* – NDVI less than "0.2" and "0.5"; *b* – NDMI less than "-0.2" and "0"

The use of remote sensing allowed identifying potential risks of soil fertility loss in dry steppe soils due to the water crisis caused by the Russian Federation amidst global climate change.

Low NDVI values for the studied group of fields indicate issues with plant development. The NDMI index is significantly lower than required for normal soil-forming processes. The number of fields with an NDMI index below "-0.2" in the periods crucial for plant development in this region amounts to 1300–1600 hectares, i.e., up to 23%.

This analysis suggests that without irrigation improvements, soils will degrade. Water deficiency combined with changing weather and climatic conditions will increase the risk of secondary salinization, rendering the land unsuitable for cultivating agricultural crops.

1. Гудзь В. П., Примак І. Д., Будьонний Ю. В., Танчик С. П. Землеробство : підручник. 2-ге вид. перероб. та доп. / за ред. В. П. Гудзя. К. : Центр учбової літератури, 2010. 464 с. **2**. Водна криза в Криму під час російської окупації. *Вікіпедія*. URL: https://cutt.ly/3wPtBORF. (дата звернення: 06.07.2022). **3.** Козішкурт М. Є., Козішкурт С. М. Еволюція ґрунтів та шляхи збереження їх родючості при зрошуваному землеробстві на півдні України. *Вісник УДУВГП* : зб. наук. праць. Рівне, 2004. Вип. 2(26). С. 117–124. **4.** 6 червня 2023 року вчинено черговий злочин агресора у війні проти українського народу – російські військові підірвали греблю Каховської ГЕС / Інститут географії.

URL: https://igu.org.ua/news/377. (дата звернення: 03.12.2023). **5.** Вода як джерело життя чи зародок війни: як крадіжка воду окупантами впливає на водозабезпеченість України і Криму. URL: https://cutt.ly/wLJjgWw. (дата звернення: 10.07.2024). **6.** Geospatial Data Analytics & Satellite Imagery By EOSDA. URL: https://eos.com/. (accessed: 16.10.2024). **7.** Rouse: Monitoring vegetation systems in the Great... – Google Ac. URL: https://ntrs.nasa.gov/citations/19740022614 (дата звернення: 10.07.2024). **8.** S. A. O'Shaughnessy and C. Rush. Precision Agriculture: Irrigation. *Encyclopedia of Agriculture and Food Systems* / N. K. Van Alfen, Ed. Oxford : Academic Press, 2014. Pp. 521–535. doi: 10.1016/B978-0-444-52512-3.00235-7. **9.** N. Katsoulas, A. Elvanidi, K. P. Ferentinos, M. Kacira, T. Bartzanas, and C. Kittas. Crop reflectance monitoring as a tool for water stress detection in greenhouses: A review. *Biosyst. Eng.* Nov. 2016. Vol. 151. Pp. 374–398. doi: 10.1016/j.biosystemseng.2016.10.003. **10.** Normalized Difference Moisture Index | U.S. Geological Survey. URL: https://www.usgs.gov/landsat-missions/normalized-difference-moisture-index. (дата звернення: 10.07.2024). **11.** N. R. Falkenberg, G. Piccinni, J. T. Cothren, D. I. Leskovar, and C. M. Rush. Remote sensing of biotic and abiotic stress for irrigation management of cotton. *Agric. Water Manag.* 2007. Vol. 87, no. 1. Pp. 23–31. doi: 10.1016/j.agwat.2006.05.021. **12.** K. K. Bandyopadhyay et al. Characterization of water stress and prediction of yield of wheat using spectral indices under varied water and nitrogen management practices. *Agric. Water Manag.* Dec. 2014. Vol. 146. Pp. 115–123. doi: 10.1016/j.agwat.2014.07.017. **13.** Лубський М., Орленко Т., Пєстова І., Андрєєв А., Лисенко А. Оцінка індикаторів ризику опустелювання Олешківських пісків на основі часових рядів даних Landsat. *Український журнал дистанційного зондування землі.* 2023. Том. 10, № 1. doi: 10.36023/ujrs.2023.10.1.229. **14.** B. Mihai and R. Horoias. NDMI use in recognition of water stress issues, related to winter wheat yields in southern Romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*. Jun. 2022. Vol. 22. Pp. 105–112. URL: https://www.researchgate.net/publication/364749950_NDMI_USE_IN_RECOGNITION_OF_WATER_STRESS_ISSUES_RELATED_TO_WINTER_WHEAT_YIELDS_IN_SOUTHERN_ROMANIA. (дата звернення: 10.07.2024). **15.** TOP 10 Irrigation Equipment Producers in Ukraine in 1H 2021. URL: https://latifundist.com/en/rating/rejting-proizvoditelej-sistem-orosheniya-v-ukraine-2021. (accessed: 16.10.2024).

REFERENCES:

1. Hudz V. P., Prymak I. D., Budonnyi Yu. V., Tanchyk S. P. Zemlerobstvo : pidruchnyk. 2-he vyd. pererob. ta dop. / za red. V. P. Hudzia. K. : Tsentr uchbovoi literatury, 2010. 464 s. **2.** Vodna kryza v Krymu pid chas rosiiskoi okupatsii. Vikipediia. URL: https://cutt.ly/3wPtBORF. (data zvernennia: 06.07.2022). **3.** Kozishkurt M. Ye., Kozishkurt S. M. Evoliutsiia gruntiv ta shliakhy zberezhennia yikh rodiuchosti pry zroshuvanomu zemlerobstvi na pivdni Ukrainy. *Visnyk UDUVHP* : zb. nauk. prats. Rivne, 2004. Vyp. 2(26). S. 117–124. **4.** 6 chervnia 2023 roku vchyneno cherhovyi zlochyn ahresora u viini proty ukrainskoho narodu – rosiiski viiskovi pidirvaly hrebliu Kakhovskoi HES / Instytut heohrafii. URL: https://igu.org.ua/news/377. (data zvernennia: 03.12.2023). **5.** Voda yak dzherelo zhyttia chy zarodok viiny: yak kradizhka vody okupantamy vplyvaie na vodozabezpechenist Ukrainy i Krymu. URL: https://cutt.ly/wLJjgWw. (data zvernennia: 10.07.2024). **6.** Geospatial Data Analytics & Satellite Imagery By EOSDA. URL: https://eos.com/. (accessed: 16.10.2024). **7.** Rouse: Monitoring vegetation systems in the Great... – Google Ac. URL: https://ntrs.nasa.gov/citations/19740022614 (data zvernennia: 10.07.2024). **8.** S. A. OShaughnessy and C. Rush. Precision Agriculture: Irrigation. Encyclopedia of Agriculture and Food Systems / N. K. Van Alfen, Ed. Oxford : Academic Press, 2014. Pp. 521–535. doi: 10.1016/B978-0-444-52512-3.00235-7. **9.** N. Katsoulas, A. Elvanidi, K. P. Ferentinos, M. Kacira, T. Bartzanas, and C. Kittas. Crop reflectance monitoring as a tool for water stress detection in greenhouses: A review. *Biosyst. Eng.* Nov. 2016. Vol. 151. Pp. 374–398. doi: 10.1016/j.biosystemseng.2016.10.003. **10.** Normalized Difference Moisture Index | U.S. Geological Survey. URL: https://www.usgs.gov/landsat-missions/normalized-difference-moisture-index. (data zvernennia: 10.07.2024). **11.** N. R. Falkenberg, G. Piccinni, J. T. Cothren, D. I. Leskovar, and C. M. Rush. Remote sensing of biotic and abiotic stress for irrigation management of cotton. *Agric. Water Manag.* 2007. Vol. 87, no. 1. Pp. 23–31. doi: 10.1016/j.agwat.2006.05.021. **12.** K. K. Bandyopadhyay et al. Characterization of water stress and prediction of yield of wheat using spectral indices under varied water and nitrogen management practices. *Agric. Water Manag.* Dec. 2014. Vol. 146. Pp. 115–123. doi: 10.1016/j.agwat.2014.07.017. **13.** Lubskyi M., Orlenko T., Piestova I., Andrieiev A., Lysenko A. Otsinka indykatoriv ryzyku opusteliuvannia Oleshkivskykh piskiv na osnovi chasovykh riadiv danykh Landsat. *Ukrainskyi zhurnal dystantsiinoho zonduvannia zemli.* 2023. Tom. 10, № 1. doi: 10.36023/ujrs.2023.10.1.229. **14.** B. Mihai and R. Horoias. NDMI use in recognition of water stress issues, related to winter wheat yields in southern Romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development.* Jun. 2022. Vol. 22. Pp. 105–112. URL: https://www.researchgate.net/publication/364749950_NDMI_USE_IN_RECOGNITION_OF_WATER_STRESS_ISSUES_RELATED_TO_WINTER_WHEAT_YIELDS_IN_SOUTHERN_ROMANIA. (data zvernennia: 10.07.2024). **15.** TOP 10 Irrigation Equipment Producers in Ukraine in 1H 2021. URL: https://latifundist.com/en/rating/rejting-proizvoditelej-sistem-orosheniya-v-ukraine-2021. (accessed: 16.10.2024).

Клімов С. В., к.т.н., доцент, Козішкурт С. М., к.т.н., доцент (Національний університет водного господарства та природокористування, м. Рівне, s.m.kozishkurt@nuwm.edu.ua)

ДИСТАНЦІЙНЕ ЗОНДУВАННЯ ЗЕМЛІ ДЛЯ ОЦІНКИ РИЗИКІВ ВТРАТИ РОДЮЧОСТІ СУХОСТЕПОВИХ ҐРУНТІВ ПРИ ВОДНІЙ КРИЗІ

Південна частина степової зони України знаходиться в складних природно-кліматичних умовах. Потенційна родючість сухих степових ґрунтів обмежена недостатнім природним водозабезпеченням, яке вирішується шляхом штучного зрошення. Зрошення забезпечує оптимальний водно-повітряний режим та регулює сольовий режим у зоні аерації ґрунту. При вологості ґрунту 70% створюються оптимальні умови для розмноження мікроорганізмів. Цей процес позитивно впливає на структуру ґрунту, сприяє утворенню гумусу та його мінералізації, тим самим зберігаючи родючість ґрунту та функції екосистеми. В умовах дефіциту води в рослинах відбуваються несприятливі фізіологічні процеси, що призводять до пригнічення, припинення росту маси рослин і зниження врожаю, зупиняються ґрунтоутворюючі процеси.

Вода відіграє ключову роль не лише у створенні сприятливих умов для еволюції ґрунту, але й у регулюванні температурних режимів. Відсутність зрошення, підвищені температури та високий рівень випаровування з полів, особливо на ділянках неглибокої мінералізації ґрунтових вод, сприяють активізації процесів вторинного засолення та втрати родючості.

Військова агресія російської федерації завдала серйозної шкоди критичній інфраструктурі та зрошувальним системам, призвела до скорочення зрошуваних площ і створила загрозу продовольчій безпеці. Руйнування дамби Каховської ГЕС у 2023 році ще більше поглибило водну кризу.

Для виявлення змін умов вирощування сільськогосподарських культур було виділено групу полів у Скадовському районі Херсонської області.

З метою оцінки ризиків втрати родючості сухих степових ґрунтів досліджено рівень водного стресу за даними ДЗЗ, що особливо актуально в умовах окупації частини території. Для оцінки обрано кількісний показник кількості фотосинтетично активної біомаси Нормалізований різницевий індекс рослинності (NDVI) та Нормалізований різницевий індекс зволоження (NDMI).

Показник вологи служить відмінним індикатором дефіциту вологи в посівах. Дані каналу SWIR відображають зміни вмісту вологи в рослинах, тоді як канал NIR фіксує внутрішню структуру листя та вміст сухої речовини, але не вміст води. Таким чином, поєднання NIR та SWIR дозволяє усунути зміни, спричинені змінами внутрішньої структури листя та вмістом сухої речовини, тим самим підвищуючи точність визначення вмісту вологи в рослинах.

Низькі значення NDVI для досліджуваної групи полів свідчать про проблеми з розвитком рослин. Індекс NDMI значно нижчий, ніж необхідний для нормальних процесів ґрунтоутворення. Кількість полів з індексом NDMI нижче «-0,2» у відповідальні для розвитку рослин періоди цього регіону становить 1300–1600 га, тобто до 23%.

Цей аналіз показує, що без покращення зрошення ґрунти деградуватимуть. Дефіцит води в поєднанні зі зміною погодно-кліматичних умов підвищить ризик вторинного засолення, що зробить землю непридатною для вирощування сільськогосподарських культур.

Ключові слова: **ДЗЗ; вегетаційний індекс; індекс зволоження; сухі степові ґрунти; водна криза; деградація; родючість; вологість ґрунту.**