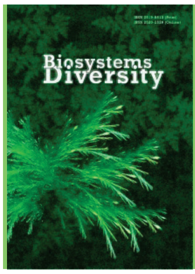

Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers.,
2024, 32(2), 285–295
doi: 10.15421/012431

Characteristic of the dried-up zone formed as a result of the breach of the Kahovka dam

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Article info

Received 28.04.2024
Received in revised form 20.05.2024
Accepted 15.06.2024

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Dovhanenko, D. O., Yakovenko, V. M., Brygadyrenko, V. V., & Boyko, O. O. (2024). Characteristic of the dried-up zone formed as a result of the breach of the Kahovka dam. Biosystems Diversity, 32(2), 285–295. doi:10.15421/012431

The explosion at the Kahovka dam led to formation of new dried-up areas at the bottom of the Kahovka Reservoir, which have specific relief and mechanical composition of soil. Vegetation that has been forming in those dried-up areas for over one year now is already undergoing the first stages of succession and is characterized by high spatial non-uniformity. The study consisted of three main stages: analysis of dynamics of outflow from the reservoir and development of a scheme of hydrographic network at the site of the reservoir's bed, analysis of soil cover, and analysis of formation of vegetative cover. We analyzed the possibility of combined use of the data of ground monitoring and remote sensing of the course and consequences of the drying. According to the reports of the Ukrainian Hydro-Meteorological Center of the State Service of Ukraine, a chronology of the emptying of the Kahovka Reservoir was created. The hydrological regime of the newly formed territory was identified using a series of satellite images. The dataset was compiled from Level-2 images from Landsat 8 and 9. Sentinel 2 was used as an additional resource. The images were processed using the Sentinel Application Platform (SNAP). We found the effect which the debris of the Kahovka dam has had on the flood level in the area. We observed recovery of the streambed network of the Dnipro River to its state before construction of the Kahovka dam. The hydraulics of the formed floodplains is complex. There are streams with signs of yet uncompleted meandering and many arms. Clustering of spectral characteristics and interpretation of the normalized NDCI and NDWI indices revealed that the spatial non-homogenous structure of the soil cover of dried-up bed of the reservoir is formed by four types of soil: eutric relictigleyic fluvisols, eutric gleyic fluvisols, eutric fluvic gleysols, eutric fluvic subaquatic gleysols. The soils are characterized by diverse granulometric composition (sand, sandy loam, loam, and clay) and various degrees of soil moisture. In the reservoir's bed, the commonest soils were found to be eutric gleyic fluvisols. We determined the effect of granulometric composition and soil moisture content on the intensity of overgrowth of the reservoir's bed. We analyzed the general dynamics of the overgrowth of the reservoir's bed.

Keywords: drying; remote sensing; soil cover; overgrowth; hydrographic network; the Dnipro River; water reservoir; plant successions.

Introduction

Since the outbreak of the war (February 24, 2022), Ukraine lost one third of its volume of freshwater. Supply of drinking and technical water ceased in the south and the east of our country (Hapich et al., 2024). In the morning of June 6, 2023, the Kahovka dam on the Dnipro River had been ruined. The dam's breach inundated the areas downstream, while drying-out the areas above. Below the dam, numerous towns and villages were submerged (Dovhanenko et al., 2024), the area accounting for 2,500 km^2 of land. Around 17 thou people of the area had to evacuate. The flood affected 120 thou ha, where 48 objects of the nature-reserve fund are situated (Marchelek-Myśliwiec et al., 2023; Nepsha et al., 2023; Vyshnevskyi & Shevchuk, 2024a, 2024b). At the same time, above the dam, a large area had been drained. This mostly affected aquatic biotopes and biotopes typical of excessively wet areas (Nepsha et al., 2023; Dovhanenko et al., 2024).

Two months after the dam's ruination, there emerged shallow water bodies that had no aquatic connection with each other, occupying an area of about 300 km^2. According to Novitskyi et al. (2024), those areas continue to dry-up, shrink, and overgrow with vegetation. This affected 40 species and subspecies of fishes. Negative effects of numerous hectares drying-up due to the dam's breach will hinder the socioeconomic development of the entire south of Ukraine.

The catastrophe at the Kahovka dam, due to military actions, deprived numerous irrigation systems of water, particularly 94% of in Kherson, 74% in Zaporizhzhia, and 30% in Dniprovetrovsk oblasts (Dorosh et al., 2023). According to the UN estimates, 700,000 people have no access to drinking water. The system of water provision that utilizes surface water cannot meet the demand during periods of crisis, and, furthermore, has not been completed (Sanina & Lyuta, 2023). The dam's breach stopped the water distribution to the Ukraine's south and Crimea. This affected 7500,000 ha of agricultural lands that relied on irrigation (Hapich & Onopriienko, 2024). Therefore, our objective was to designate areas above the Kahovka dam and provide a general characteristic of natural components of the dried-up landscapes.

Material and methods

In this study, we used a series of satellite images from Landsat 8/9 and Sentinel-2 for the respective post-catastrophe period (June 2023 to April 2024). Repositories with the images (GloVis, Earth Explorer, Copernicus Browser) are generally accessible and free. From the technical standpoint, the proposed sensors are almost identical and mutually supportive characteristics (Table 1), which were perfect for the conditions of our study (U.S. Geological Survey (USGS). Landsat missions. www.usgs.gov/landsat-missions).

The bulk of the collection was comprised of Landsat 8/9 satellite images, and the Sentinel-2 (L2A) images were used as a complementary source. In both cases, the preference was given to the Level-2 images for a quicker preparation stage. In general, all stages of work with the images were carried out using the official software of the European Space Agency – SNAP (ESA). Sentinel – 2 Sentinel-2 user handbook. https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi/document-library/-/asset_publisher/Wk0TKajiISaR/content/sentinel-2-user-handbook). The pre-analysis stage included procedures such as limiting the study region (Subsetting), unification of the spatial resolution (Resampling), composing combined image (Mosaicking), and distinguishing the territory of water reservoir (Masking). At further stages, we performed quantitative and qualitative analysis of the soil cover, designation of the water area, and estimation of moisture at the water-reservoir bed, and analysis of the vegetation cover.

Table 1
Characteristics of sensors and their satellite images (USGS, ESA)

Characteristic	Landsat 8/9	Sentinel-2
Number of spectral bands	11	13
Spectral ranges, μm	0.43–12.51	0.44–2.19
Spatial resolution, m	15 (panchromatic), 30 (multispectral), 100 (thermal)	10, 20, 60
Radiometric resolution, bit	12	12
Orbital altitude, km	705	786
Revisit period, days	16	5
Swath width, km	185	290

To analyze the soil cover, using the resource Copernicus Browser, we identified dates when the water at the reservoir dropped to the natural level, soil begun to dry-up, and active overgrowth of the bed had not yet started. Preliminary findings suggest it was the interval between late June and the second decade of August 2023. Considering significantly non-homogenous conditions of the soil cover, we used image clustering by the K-mean method. To facilitate the performance of the algorithm, the water area and the existing vegetative cover were removed from the region of analysis. For this purpose, we used the normalized indices SAVI (Soil-Adjusted Vegetation Index) (Huete, 1988) and NDWI (Normalized Difference Water Index). Estimation of the mentioned indices was performed by the means of SNAP in the semi-automatic regime. The output values of normalized indices for respective time periods were then used to analyze the parameters of vegetative cover and dynamics of water surface. Post-classification analysis of the results was carried out using the means and tools of QGIS.

Quantitative and qualitative characteristics of the soil cover of the reservoir were identified according to the granulometric composition and moisture level. The granulometric composition was determined through the normalized index of clayey particles (NDCI – Normalized Difference Clay Index) (Shabou & Mougenot, 2015):

$$NDCI = \frac{B7 - B6}{B7 + B6},$$

where B6 – reflectance in SWIR1 1.6 μm (band 6 for Landsat 8/9 sensors), B7 – reflectance in SWIR2 2.2 μm (band 7 for Landsat 8/9 sensors).

In such a variant, negative values of the index correspond to the content of clayey/dusty particles, positive – to the content of sandy particles. For convenience, we used the inverted version of this index ($NDCI_{inv}$):

$$NDCI_{inv} = \frac{B6 - B7}{B6 + B7},$$

In this case, content of clayey particles are reflected in positive values, while such of sandy particles – in the negative values of the index.

Besides differentiating water surface and land, the normalized water index (NDWI) can assess the degree of water cover (Normalized Difference Water Index (NDWI). NDWI: Index formula, value range, and uses in agriculture. www.eos.com). The NDWI values correspond to the following ranges (0): 0.2–1.0 – water surface, 0.0–0.2 – flooding / water content, –0.3–0.0 – moderate drought, non-aquatic surfaces, –1.0– -0.3 – drought, non-aquatic surfaces.

Soils of the dried-up areas were classified according to the World Reference Base for Soil Resources 2022 (IUSS Working Group WRB, 2022). Ongoing military actions leave no opportunity to gather actual data in the field, and therefore we identified dried-up areas that are uniform by conditions of soil formation and properties based on the satellite images from Landsat 9. During the classification of soils, we took into account granulometric composition, current moisture pattern, and effect of being flooded after the dam's breach. Therefore, classification identification of soils and the model of soil cover of the bed of the Kahovka Reservoir are of inferred nature.

Results

Elements of hydrological regime and hydrographic network. The water level in the reservoir started to plummet in the morning of June 6, 2023. In the first half of that day, the intensity of the level drop was the greatest (16 cm/h), further stabilizing at the level of 6.3 cm/h (Fig. 1).

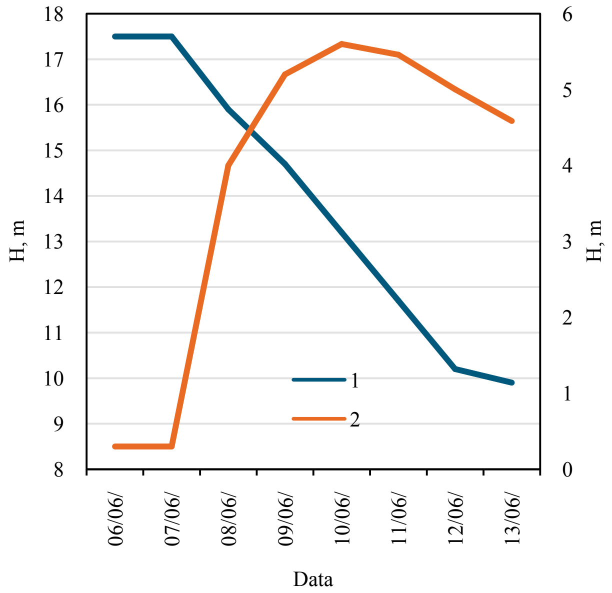

Fig. 1. Dynamics in changes in the level of the Dnipro in the area of the city of Nikopol (*1*) and the city of Kherson (*2*) after the dam's breach (according to the Hydrometeorological Service of Ukraine)

The existing satellite images (Fig. 2) suggest that the reservoir was drained to the pre-construction water level (except the streambed water and non-discharge areas of the reservoir's bed) in late June (June 30, 2023), that is the 18.2 km^3 reservoir took about 24 h to drain. At the same time, in spring of 2024, the reservoir has been filling again, with maximum flooding of the area occurring on March 24.

From early July to late September, water bodies that emerged in the hollows of the reservoir bed and had no hydraulic connection with the river streambed had gradually disappeared through evaporation and percolation into the soil. The area of exposed land (according to our estimates) is 1,969.14 km^2.

The water level in the "newly formed streambed" is quite dynamic due to regular water discharges from the dam of the Zaporizhzhia hydropower plant, and partly, side tributary. The general dynamics of water surface in the reservoir's bed is presented in Figure 3.

The spring flood of 2024 in the area of the water reservoir occurred due to partial blocking of the Dnipro River valley by fragments of the Kahovka dam. At the same time, river spills below the hydropower plant sluice gate (Fig. 4) were of much lower intensity than those above the sluice gate (Fig. 5).

The final variant of the scheme of the hydrographic network of the Dnipro in the area of the water reservoir is as follows (Fig. 6). In general, the Dnipro has returned to its old streambed. In the upper (wide) and lower (narrow) parts of the current, there are multiple arms. We can distinguish 8 large bends of the main streambed of the Dnipro. The length of the Dnipro's main streambed reaches 237.5 km. The tortuosity coefficient equals 1.35. The average width of the main streambed accounts for 570 m. The widest area of the streambed (1,200 m) is located behind Khortytsia island, while the narrowest (>100 m) is in the midstream region (Fig. 6c).

The floodplain is two-sided: 7 right-bank and 5 left-bank floodplain sites. The widest floodplain areas (maximum width of 22.5 km) are located in the upper reach. In the middle and lower reaches, the floodplains are narrower – 0.5 to 6.0 km. Percentage of lakes in the floodplain area (in the driest period) is 3% (the general area of lakes accounts for 68 km^2).

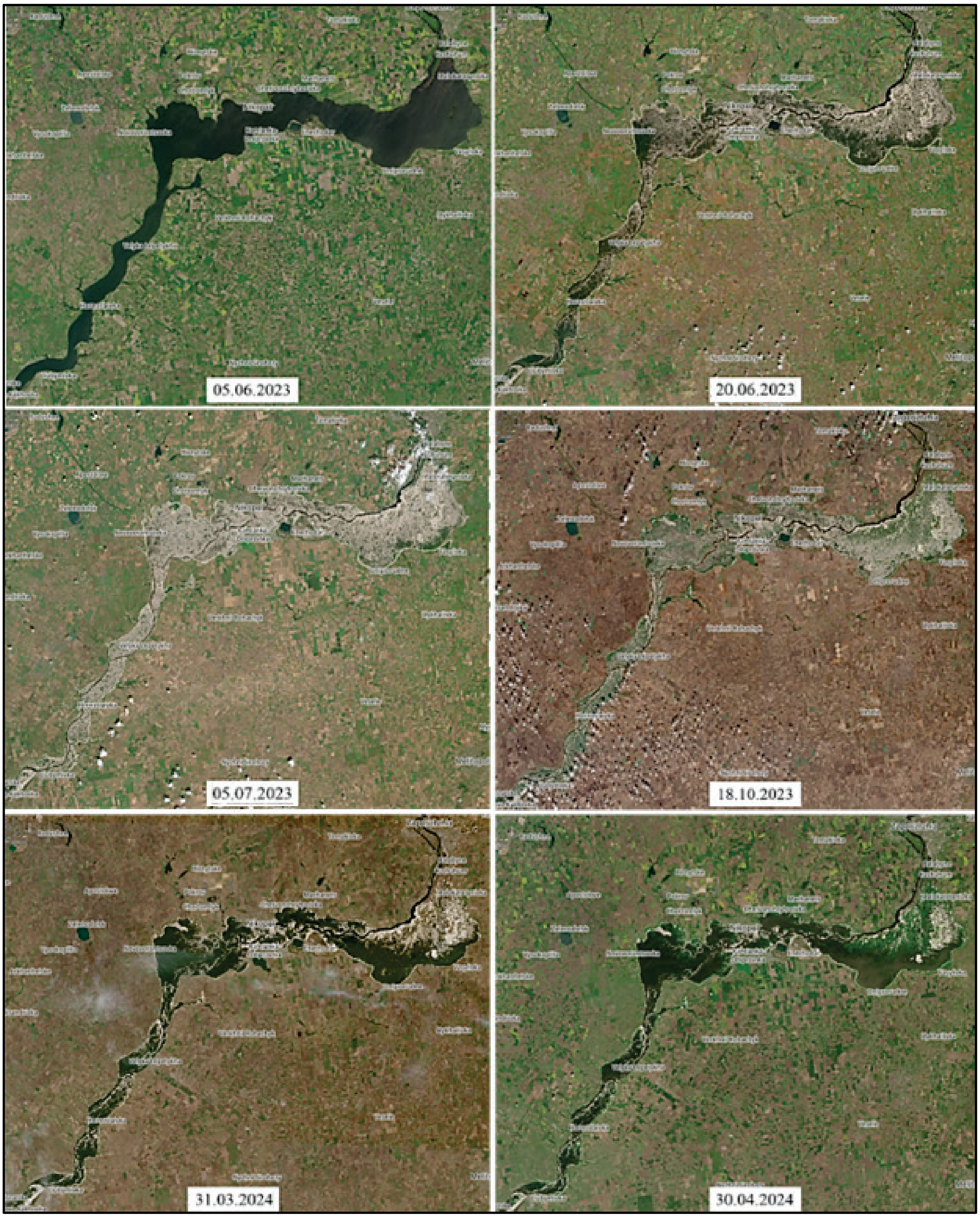

Fig. 2. Dynamics of the events at the Kahovka Reservoir from June 5, 2023 to April 30, 2024 (Sentinel-2 L2A)

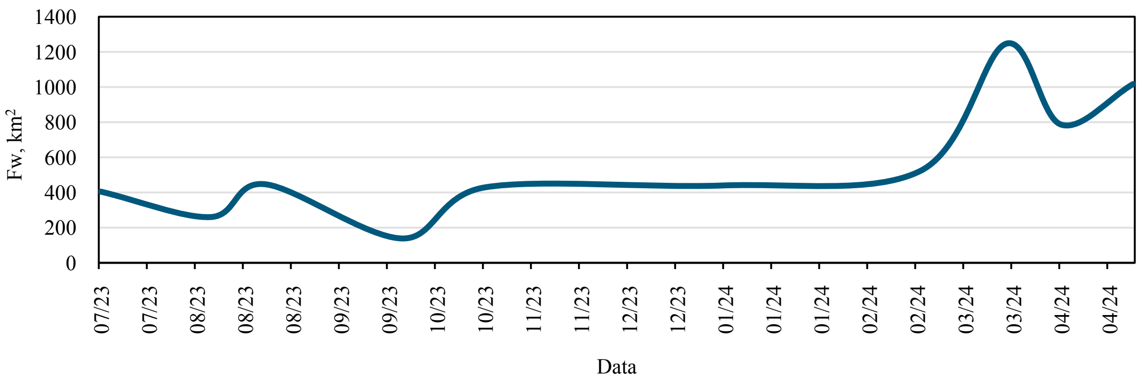

Fig. 3. Dynamics of the area of the water surface within the area of the Kahovka Reservoir (July 4, 2023 – April 4, 2024)

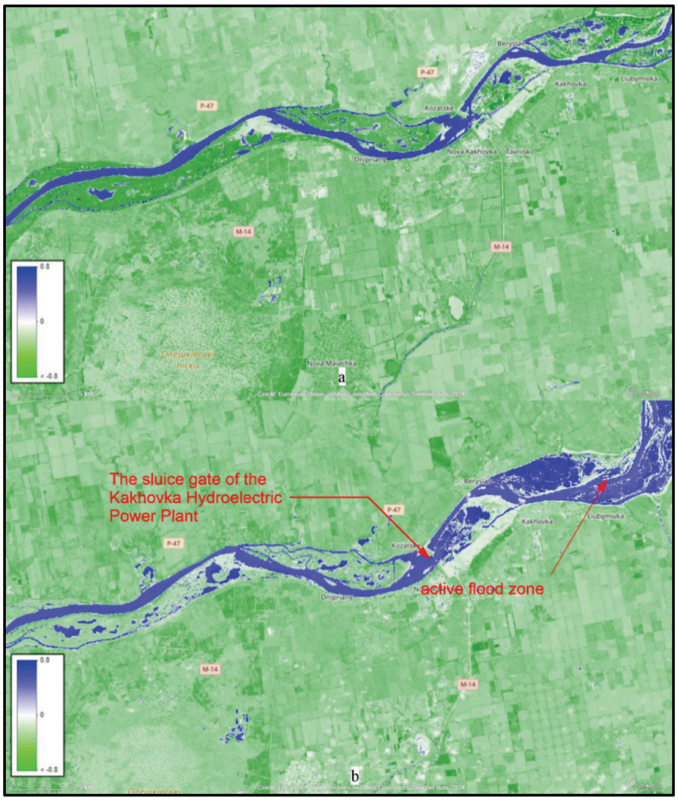

Fig. 4. Dynamics of the water level (according to NDWI) in the area above and below the outlet of the Kahovka dam: *a* – autumn baseflow (October 1, 2023); *b* – spring freshet (March 24, 2024)

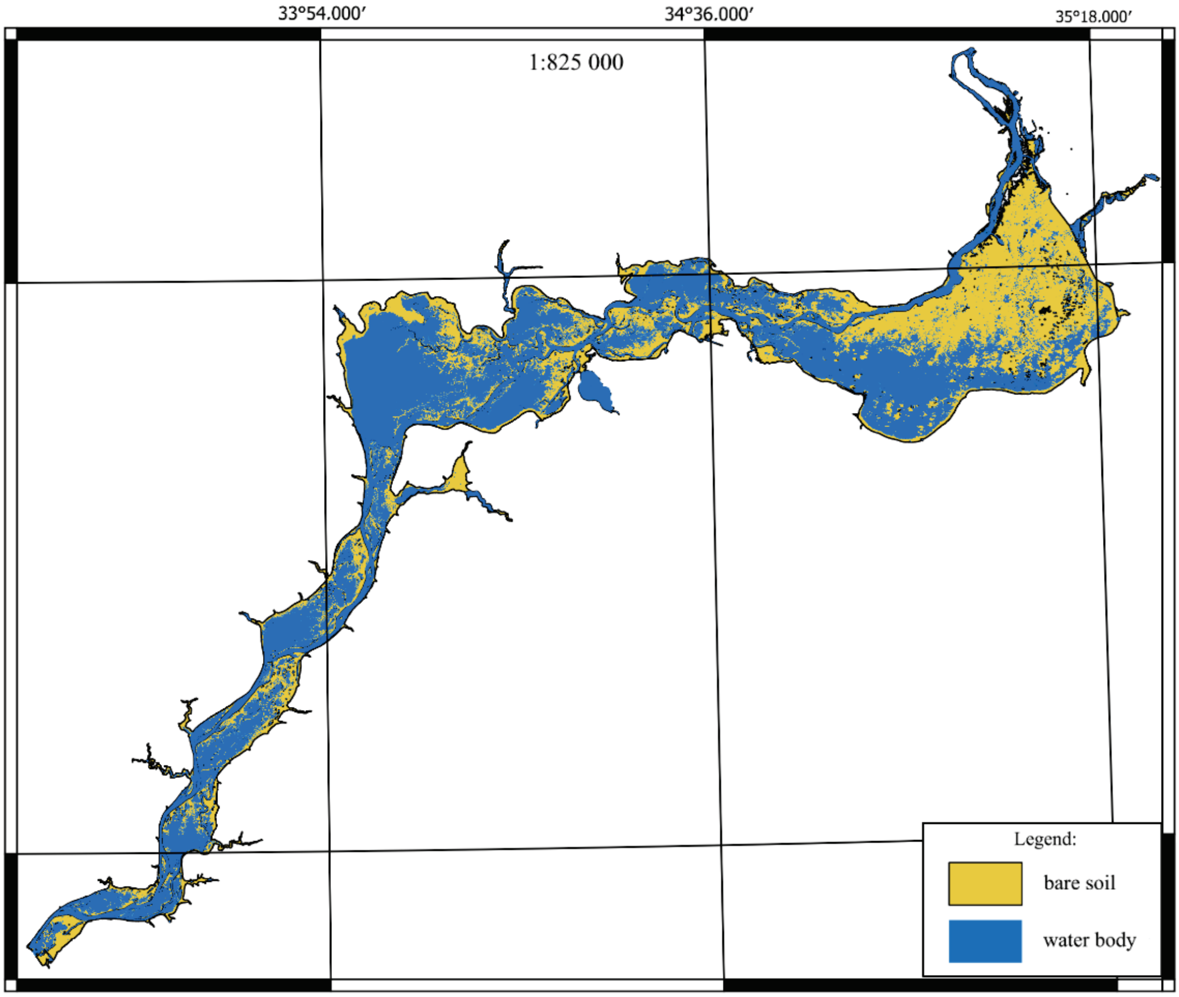

Fig. 5. Maximum area of flooding during the spring flood (March 3, 2024)

Considering the arrangement of the flooded and dried-up areas, we may assume the existence of a complex hydraulics in the floodplain sites of the upper and central parts of the reservoir. Depressions in the form of limans are adjacent to the flanks of the river-bed valley, which never dried-out during the monitoring period. Elevated floodplain sites are adjacent to convex (alluvium) parts of bends. Along the valley flank (formerly the reservoir's water edge), there formed narrow mound strips, which correspond to the accumulative plain of the reservoir. In the lower (narrow) part of the valley, those mounds are present only on the side of floodplains. From protuberant (washed-out) part of bends, those strips were shaped by the newly-formed current. The newly formed (old) streambed of the Dnipro River mostly comprises light-fraction soils. Along the entire length of the streambed, there are single sites of fluvial deposits, indicating slight overload of the current with alluvial deposits and lack of water.

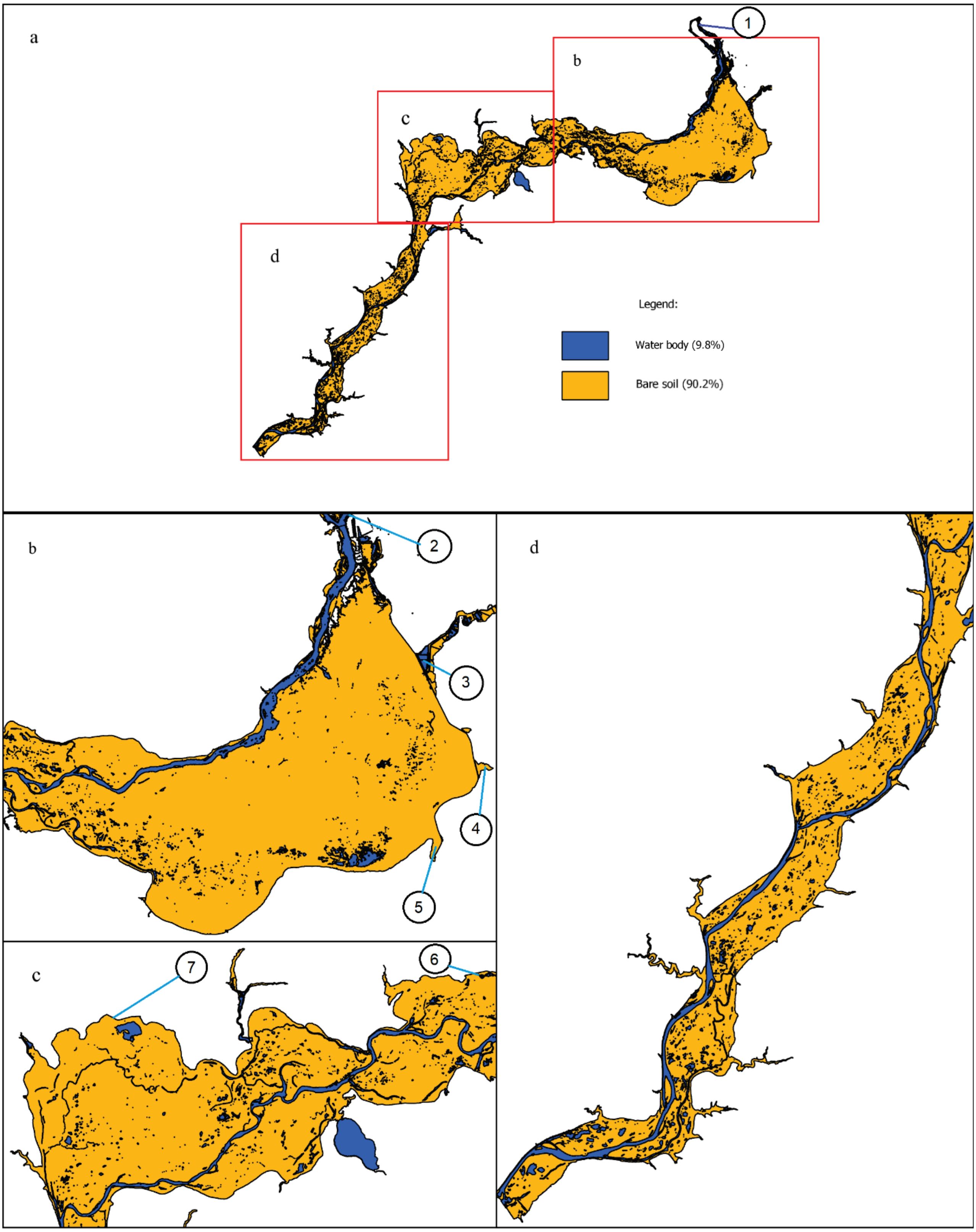

Fig. 6. The general view of the hydrographic network within the bed of the Kahovka Reservoir: *a* – general view; *b* – upper reach; *c* – middle reach; *d* – lower reach. Mouths of the rivers: *1* – Kapustianka; *2* – Mokra Moskovka; *3* – Kinska; *4* – Yanchekrak; *5* – Karachokrak; *6* – Tomakivka; *7* – Bazavluk

The tributaries in the given area have not yet formed a sufficient hydraulic connection with the streambed of the Dnipro. Those rivers flow into the reservoir only in case of high water content. Within the water area of the Kahovka Reservoir, seven small rivers (In Fig. 6, numbers show streambed areas of the rivers) and over three dozen ravines and gullies fall into the Dnipro. The water regime of the mentioned rivers will obviously change. At the first stage, as mentioned, the rivers will be establishing a hydraulic connection with the newly formed floodplain and the streambed of the Dnipro. This means that the lengthwise profile of rivers, first the mouth areas, and then such of the middle reach will be releasing water until a new erosion basis forms (the streambed of the Dnipro). The level of water drop in the profile of the mouth area will depend on the position of the streambed of the Dnipro and newly formed limans within the valley's bed (the reservoir's bed) and range several centimeters (for example, the Mokra Moskovka and Kapustianka rivers) to ten meters (the Bazavluk River). This stage can last up to dozens of years. The second stage of transformation of water content of the tributaries will depend on the degree of drainage of the groundwater horizons. As of now, the influence of Kahovka Reservoir on water-bearing horizons within its water area had disappeared, and therefore the level of groundwater has been gradually declining. Most likely, the level of groundwater in the adjacent areas (except the areas of the dam of Zaporizhzhia Hydropower Plant) will settle at the regular (or lower) water level in the Dnipro. In the area of the dam of the Zaporizhzhia Hydropower Plant, feeding of groundwater by filtration through the bed remained at the same level. The groundwater level in the area of influence of the Dnipro Reservoir will decrease proportionately to decline in the level of groundwater in the lower canal level. Therefore, one may expect decrease in baseflow in the first ten years after drainage of water reservoir. On the third stage, once streambed processes stabilize, the flow recession could increase due to deepening of the channel carving by erosion and facilitated drainage of underground horizons. Obviously, the abovementioned is a highly generalized picture of hydrological and hydrogeological regimes of the studied area. The proposed scenario of hydrological regime in the area can be elucidated by a multi-level monitoring network, which seems hardly possible in the near future.

Characteristics of soil cover of the reservoir's bed. As mentioned, study of the superficial layer of soil cover of the reservoir's bed was possible from the moment when the water dropped down to the natural level and to the moment of formation of the initial plant cover, i.e. the period from early July 2023 (images as of July 4, 2023) to the first decade of August 2024 (images as of August 5, 2024). For initial differentiation of the superficial layer of soil cover of the reservoir's bed using satellite images, we employed the method of clustering of spectral parameters (K-mean). After post-clustering analysis of the results, we distinguished four main types of spectral curves of soil cover (Fig. 7).

We precisely identified the spectral curve of the first type (Fig. 7) as sandy soil. The pattern of the rest of the spectra indicates content of sandy and clayey fractions in various proportions. We should note that in the places into which the side tributaries feed, soils were observed to have somewhat lowered coefficients of reflection in the nearer infrared spectrum (1,610–2,190 nm), which may suggest presence of a greater amount of dusty particles. Spatial distribution of soils in the reservoir's bed is presented in Figure 8.

As we can see, soil No. 1 (sandy fraction) and 2 (sandy loam) are located along the steams, which is typical for alluvial deposits of light granulometric composition. Soil No. 3 occupies quite large areas that prior to flooding were floodplains and limans. Soils № 4 and 5 are mostly localized near the residual water bodies.

In order to elucidate the preliminary findings of our study regarding the granulometric composition of soil surfaces, we used $NDCI_{inv}$. The values of index close to 0 indicate heightened content of sandy fraction. Increase in the index points to heightened content of clayey and dusty particles. So as to mitigate the effect of soil moisture, we determined averaged $NSCI_{inv}$ parameters for the period from June 1, 2023 to August 21, 2024. Using the zonal statistics, we determined distribution of NSCIinv for the main soils of the bed (Table 2).

Table 2
$NDCI_{inv}$ of the found soil types according to the results of statistical analysis

No.	$NDCI_{majority}$	Conditional granulometric composition
1	0.03	Sand
2	0.08	Sandy loam
3, 4	0.13	Loam
5	0.19	Clay or clay loam

The degree of water coverage of soil was measured using NDWI. As a period of surveying the area, we chose late August, because this is when the reservoir's bed was observed to become dried-up the most. All soils were in moderately dried state. Conditionally moderately dry throughout the summer-autumn season were sandy and sabulous soils ($NDWI_{mean}$ = –0.24). Compared with sandy soils, loamy and clayey soils had somewhat higher levels of moisture ($NDWI_{mean}$ = –0.10), but not high enough to suggest backlogging. Eventually, according to the level and regime of moisture, all present soils will correspond to the current conditions of moisture and also have features of relict origin. The areas of distribution of soils within the reservoir's bed are as follows: loamy – 564.6 km^2, clayey – 559.3 km^2, sandy loams – 539.2 km^2, and sandy – 306.1 km^2.

Therefore, since the dam breach, the benthic deposits in the zone of dried area of the reservoir's bed should be considered as soil that forms the structure of the soil cover of territories adjacent to the reservoir. The key factor for classification identification of bed soils at the level of reference groups is water regime, which determines processes and regimes of soil genesis, properties of particular soil profiles. All soils of the dried-up area of the bed had undergone the stage of being long flooded, and therefore are characterized by presence of fluvial material as a soil parent material and have features of hydromorphism in the morphological structure and properties. Depending on the current water regime of particular areas of the bed, hydromorphological properties of soils correspond to the current conditions of moisture or have a relict nature. Based on particular data regarding moisture, there can be identified gleysols and fluvisols as the main components of soil cover of dried reservoir's bed (Fig. 9).

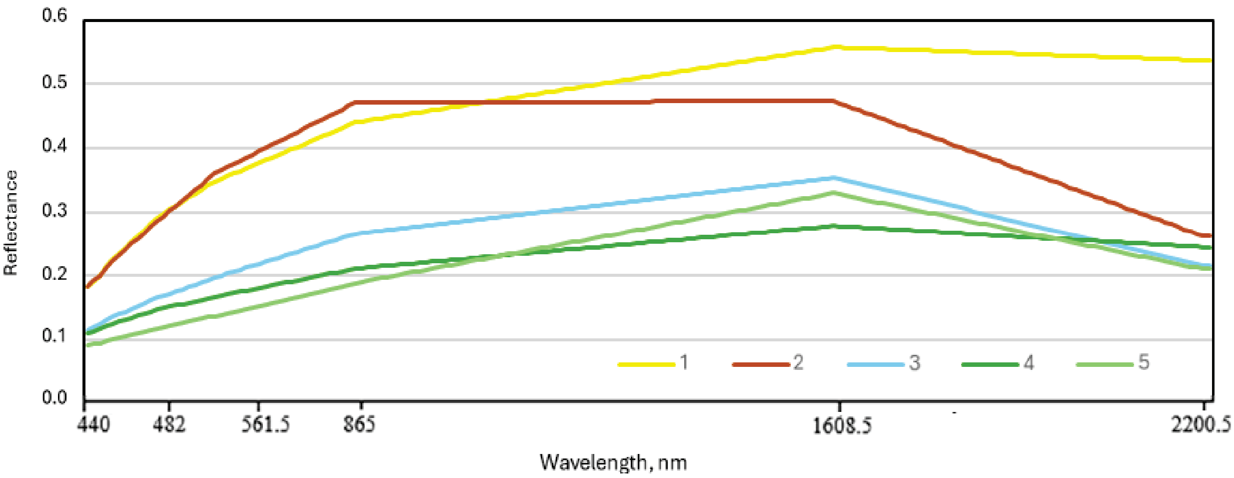

Fig. 7. Spectral curves of the main types of soils in the reservoir's bed

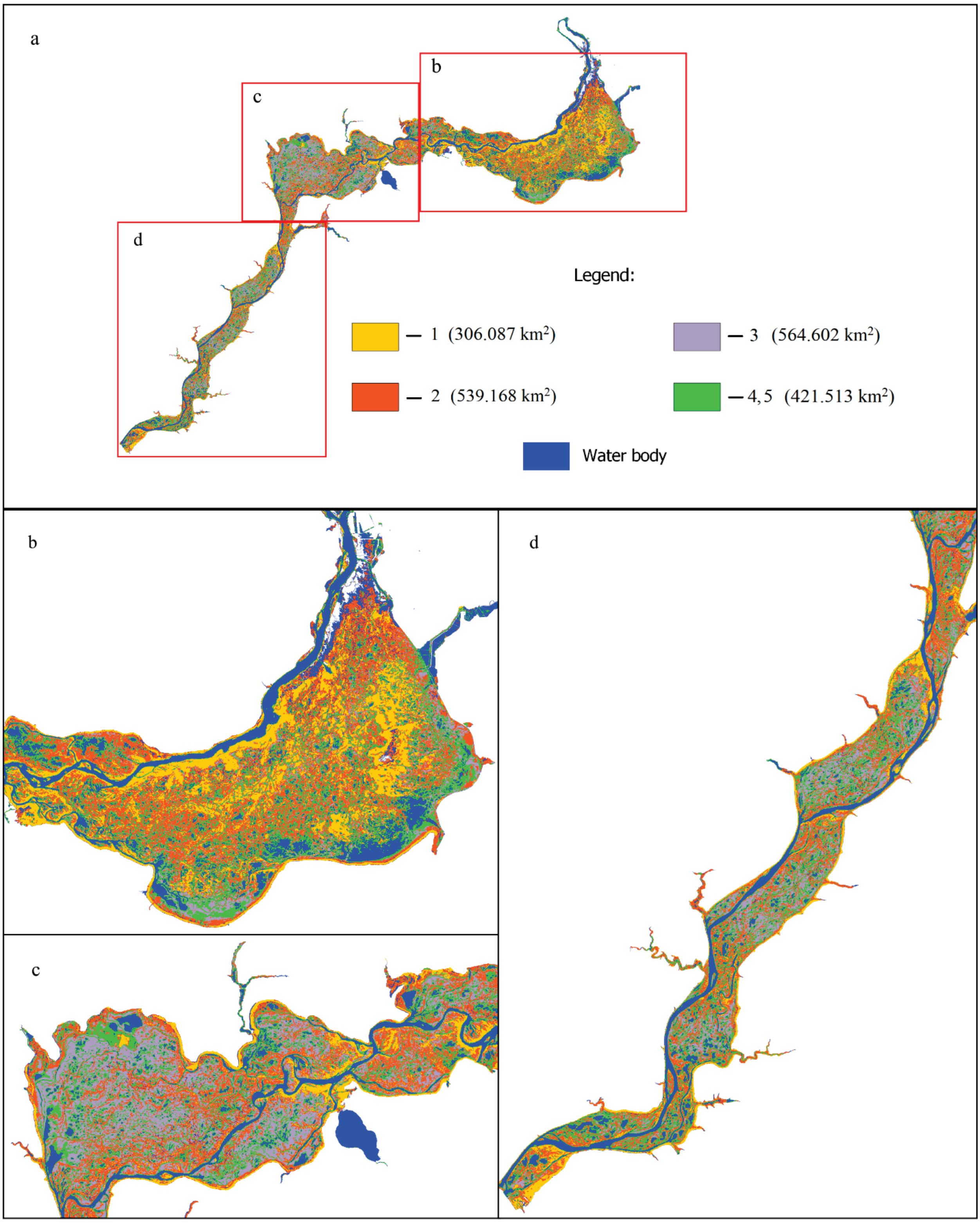

Fig. 8. Distribution of soils by granulometric composition of the superficial layer within the bed of the Kahovka Reservoir (according to the results of K-mean algorithm): *a* – general overview; *b* – upper reach; *c* – middle reach; *d* – lower reach

Gleysols. The reference soil group gleysols is formed under the influence of groundwater, which results into gley properties manifesting starting from a 40 cm depth from the soil surface and significant redox conditions in the lower part of the profile. At the second level of classification, gleysols of the bed in the conditions of moisture are characterized by principal qualifiers fluvic (presence of alluvium material in the layer starting from a depth ≤ 75 cm from the soil surface) and eutric (saturation with bases). By granulometric composition, gleysols of the bed are mostly loam (the supplementary qualifier loamic), with participation of areas of clayey composition (the supplementary qualifier clayic). Alluvial depositions are covered by up to 200 cm thick water layer are classified as subaquatic gleysols.

Fluvisols. The reference soil group fluvisols is identified in presence of fluvial material of a thickness of ≥ 25 cm starting from a depth of ≤ 25 cm from the soil surface. Non-uniformity of relief of the bed and granulometric composition of alluvial deposits causes various patterns of moistening of the profile of fluvisols, as reflected by the qualifier gleyic (the property gleyic, starting from a depth of ≤ 75 cm from the soil surface and presence of redox conditions) for the areas with moderate drought or relict and gleyic (the property gleyic, starting from a depth of ≤ 75 cm from the soil surface in the absence of redox conditions) for the drought areas. By granulometric compositions, fluvisols are mostly sand and sandy loam (the supplementary qualifiers arenic and loamic, respectively).

Characteristics of vegetative cover. From the moment when the water level in the reservoir fell to its natural level there were four and a half months left until the end of vegetation period. Starting from the first decade of August, the reservoir's bed started to become overgrown by indigenous plants (*Salix alba* L., and plants of the genera *Schoenoplectus*, *Chenopodium*, *Typha*, *Phragmites*, *Carex*, and other). Willow and poplar spread especially fast. The bed has been overgrowing in the direction from the bank line and streambed areas of side tributaries towards the central area. As we can see in Figure 9 (August 2023), in the upper part of the bed (closer to the city of Zaporizhzhia), there formed "overgrowth centers". This was conditioned by two main factors: presence of large groups of higher vegetation on the banks at the moment water-level drop and emergence of large areas with relatively dry soils of loamy granulometric composition.

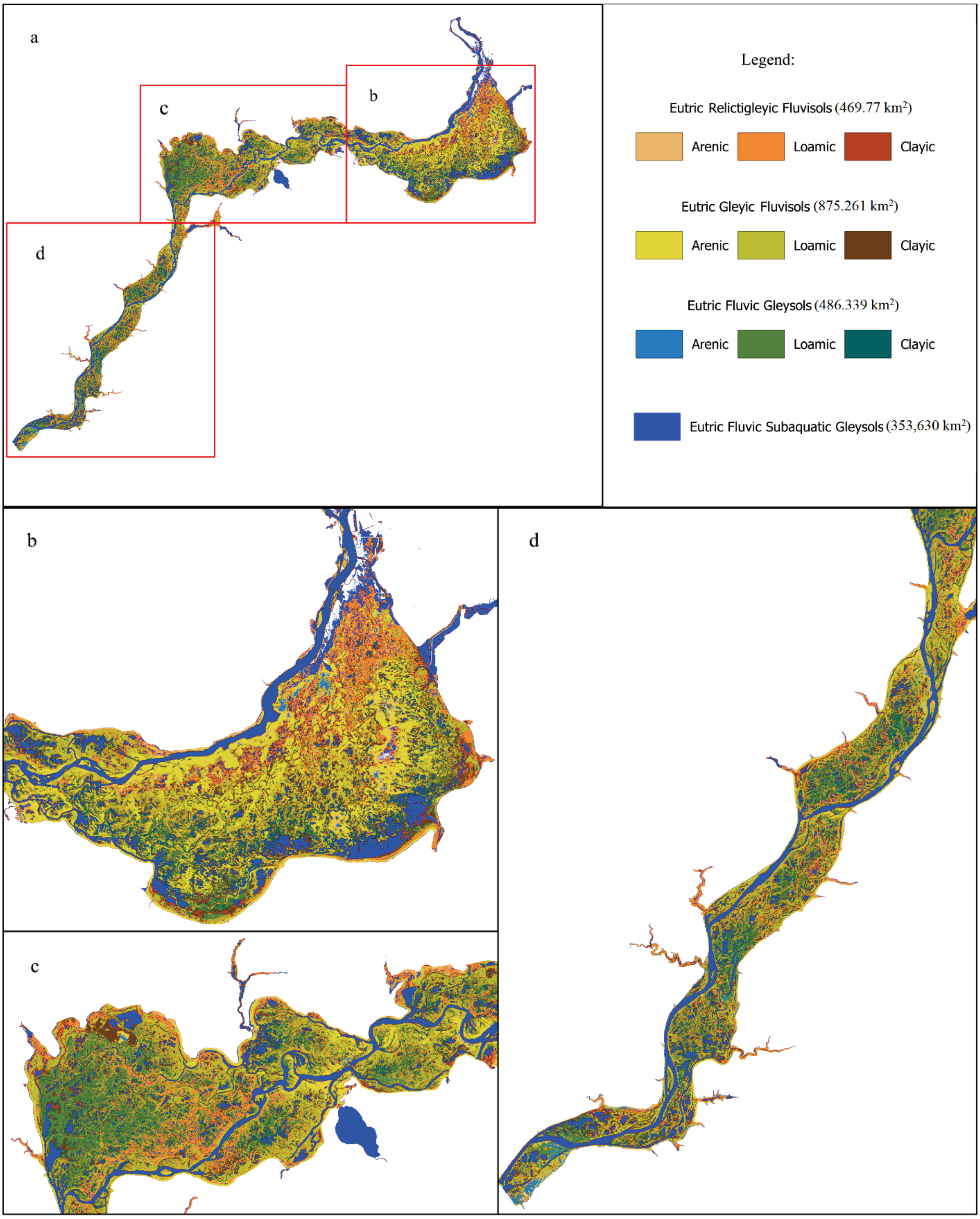

Fig. 9. Cartographic model of the soil cover in the bed of the Kahovka Reservoir (taking into account the granulometric composition and moisture degree): *a* – general view; *b* – upper reach; *c* – middle reach; *d* – lower reach

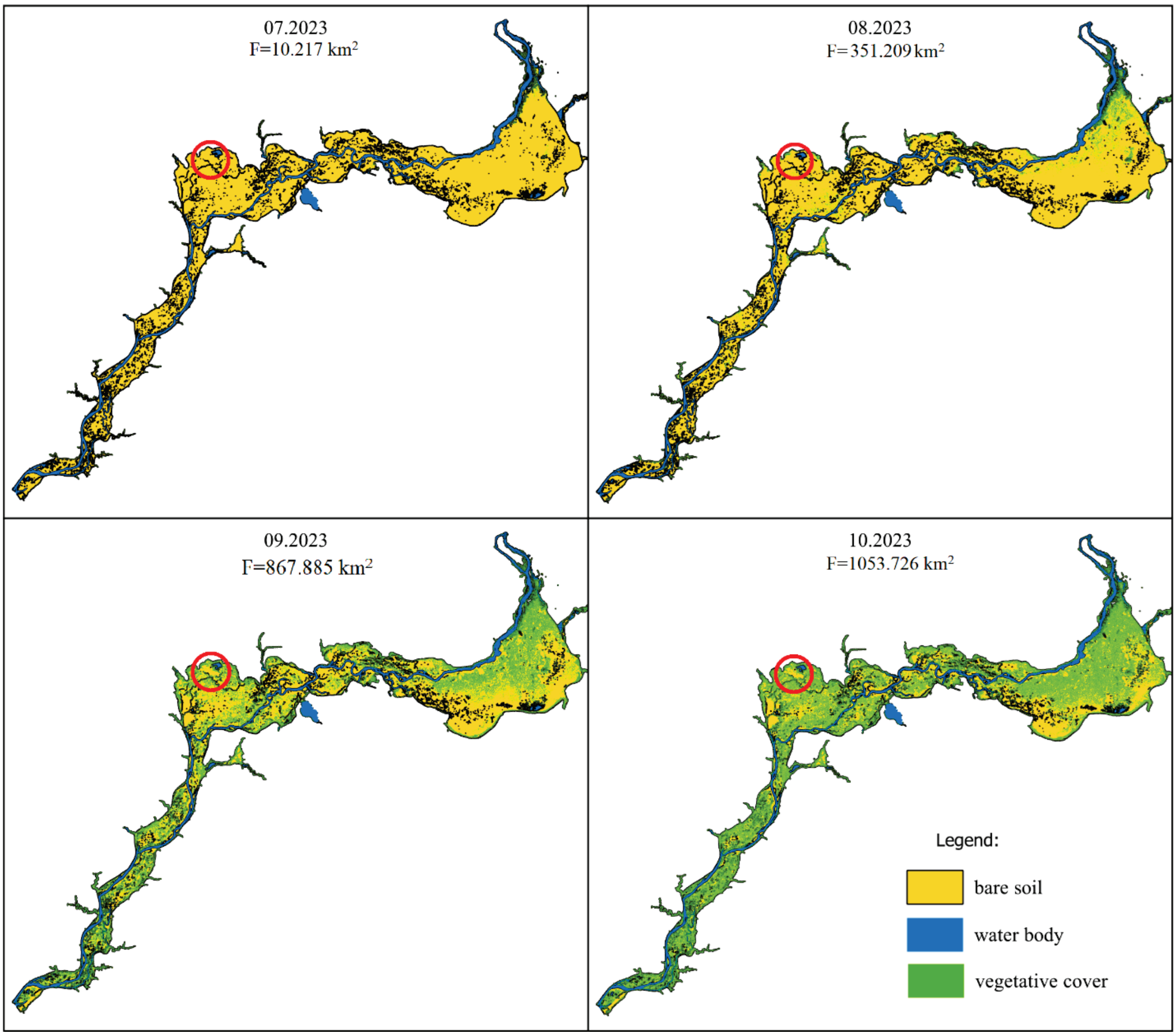

Fig. 10. Dynamics of overgrowth of the reservoir's bed during July–November 2023

It has to be noted that there are some areas of the bed that had not been covered by any vegetation at all throughout the period. Mostly, those are lowlands (former limans) adjacent closer to the walls of the bed of the valley (the reservoir's bed) of the Dnipro and are characterized by heightened moisture (backlogging) on the surface, or periodic flooding. We should separately mention the elongated area of accumulative plain near the Hrushivka village (Dnipropetrovsk Oblast) (red circle in Fig. 10). There were observed no manifestations of vegetative activity throughout the monitoring. Soils with the poorest vegetative cover during the entire vegetation period were sandy and clayey. Both are insufficiently moistened.

The intensity of overgrowth (Fig. 11) between July and November 2023 was 175 km^2 per month on average. The dynamics of gain of vegetation-covered surface during the mentioned period were relatively non-uniform. Until early August, the soil cover of the reservoir's bed remained too wet to undergo intensive overgrowth. In this period, the area covered by vegetation increased by only 12%. The greatest gain in vegetative cover was observed from late August to late September (71% of the general area), when the surface of reservoir's bed was characterized by moderate moistening. In November, the vegetative season ended. There occurred no significant gain in the vegetative surface in that period. The general area of vegetative cover accounted for 1,054 km^2 (54% of the bed's area).

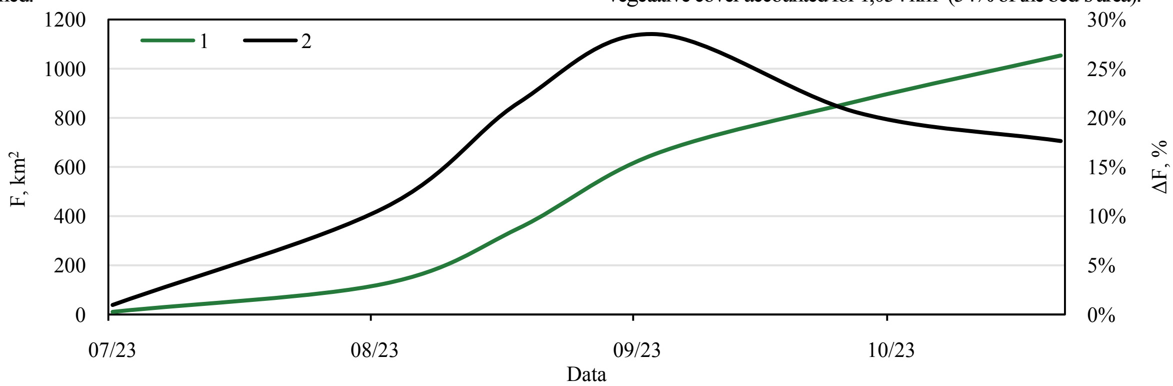

Fig. 11. Dynamics of the area of the vegetative cover of the reservoir's bed from July 2023 to October 2023:
1 – general dynamics (the left ordinate axis); *2* – intensity of overgrowth (the right ordinate axis)

The degree of moisture, as one of the main factors that limited the overgrowth of the reservoir's bed, is indicated by the pattern in which the vegetation has spread. The vegetation cover emerged more intensively in the areas that were characterized by moderately moistened soils. Furthermore, against the background of intensification of overgrowth in September, the overall productivity of vegetation (considering that the temperatures were declining) was notably lower than in August (SAVI08 = 0.93, SAVI09 = 0.42). That is, against the background of fast expansion into new territories, the rates of phytomass production in those areas decreased.

Due to lack of field studies and closeness to the frontline, it was not possible to precisely identify the species differentiation and dominating plant groups at this stage of plant expansion in the reservoir's bed.

Discussion

We may state recovery of the relict hydrographic network of the Dnipro in the area of the Kahovka Reservoir. Special attention should be paid to the peculiarities of the regulation of the current of the Dnipro travelling through the cascade of reservoirs located above this area. The regime of capacity of the current in spring in the region of the Velykyi Luh (name of the area existing prior to construction of the power plant) will be a factor determining the transport capacity of the streambed network and the general water regime in the areas uncovered from beneath the water. Therefore, in the coming decades (if the Kahovka dam will not be repaired), we should expect an active rearrangement of the streambed network in this area of the Dnipro current. The relief of the newly formed floodplain is complex and corresponds to the rivers with free meandering. There is a quite ramified system of currents that are hydraulically connected to the main streambed of the Dnipro. In the river's main streambed, there are forming sites of fluvial deposits, which may suggest some overloading of the current by solid alluvial deposits. Rivers that fed the reservoir have not yet formed a sufficient hydraulic link with the Dnipro's streambed. The lengthwise profiles of the rivers' balance will be developing in the coming years.

Fluvisols are the main component of the soil cover of the upper part of the bed (Fig. 9b). In the central area, gleysols increase in presence, while in the lower parts they dominate (Fig. 9c, 9d, respectively). The spatial connection between those soils has a non-homogenous pattern as a result of varying water content in respective areas as a result of the bed's relief and granulometrically varying benthic deposits. In the upper, the widest, part of the bed, there distinctively manifests a granulometric differentiation of fluvial deposits that is typical for river valleys – the lightest deposits (sand and sandy loam) along the river's streambed and heavier (loam and clay) deposits dominating farther away from the streambed. Such conditions in which the soil cover of the dried-up area of the reservoir's bed has been forming correspond to the floodplain conditions where the most important factors of soil genesis are periodicity of deposition of alluvial material, non-homogeneity of the relief, and high groundwater level.

In our opinion, the leading factors that will determine the functioning and evolution of the soil cover of the reservoir's bed are (1) benthic deposits characterized by the variety of granulometric composition, chemical properties, content of organic matter and nutrients, stratification (Rzetala et al., 2013; Skordas et al., 2015; Luvai et al., 2022); (2) the bed's relief, which to a high degree determines the formation of diverse soil and vegetative cover in the reservoir's former water area (Yakovenko et al., 2023); (3) water regime with variability, periodic flooding, and different levels of groundwater (Gerrard, 1987; Bullinger-Weberand & Gobat, 2006; Kawalko et al., 2021); (4) overgrowth process characterized by intensity, differentiation of the plant cover by species composition and density of groups, and intensive influx of plant foliage on the surface and into the soil.

Different plant groups form a diversity of microclimatic conditions (Belova & Travleev, 1999; Kunakh et al., 2022), which in turn creates a variety of ecological conditions for other biotic components of ecosystems (Yakovenko & Zhukov, 2021; Kunakh et al., 2023; Yakovenko et al., 2024), in particular, for pathogens of animal diseases (Boyko & Brygadyrenko, 2019; Boyko et al., 2020). Therefore, peculiarities of benthic deposits as a parental material, varying water regime, and intensive overgrowth lead to the differentiation of conditions of soil formation and variety of soil at the level of reference groups. Evolution of soil cover will further diversify the soils both at the level of reference groups and second level of classification.

Since the water level in the reservoir had fallen to the natural level and until the end of 2023, vegetation covered 54% of the territory of previously submerged land. In the lower and central parts of the reservoir, the dynamic water regime (including periodic flooding) will lead to formation of a non-homogenous vegetative cover, represented by significant diversity of plant associations. There was found correlation between the degree of overgrowth of the Dnipro's floodplain and granulometric composition and moisture content of the soils. The least prone to overgrowth were sandy (eutric relictigleyic fluvisols) and excessively wet clayey soils (eutric fluvic gleysols).

Study of species composition of the plant groups in the exposed territories is currently significantly limited due to the ongoing military actions. On-spot field surveys near the reservoir's banks provide no complete picture of the vegetative cover in the central parts of the bed. As of now, the flora of the Velykyi Luh of the Dnipro is gradually recovering.

Conclusion

In the place of the Kahovka Reservoir, a new ecosystem is starting to form. Study of the stages of this succession is currently hindered by ongoing military hostilities in the region. The only available method of monitoring this complex ecological process is remote sensing of Earth. In our study, we performed analysis of abiotic and biotic components of the initial stage of succession order: hydrographic network and water regime of the territories, soil cover, and pioneering plants. The main source of data was satellite images from Landsat 8/9 and Sentinel 2. In the first half of year after the decline of the water level in the territory of the Kahovka Reservoir, there were signs of phases of river water regime: flood, freshet, and water recession. Phases of the highest water level are directly subordinated to the regime of regulation of the current by a cascade of reservoirs located above the breached dam. In spring 2024, the maximum level of flooding of the reservoir's bed occurred in March–April. The flood came in two waves, peaking in late March, which can be explained by the regime of capacities of the superficial flow from the Dnipro Reservoir. The flooded area accounted for 1,246.23 km^2 (63% of the area of exposed land). The intensive pattern of flooding of the formed floodplain is also due to presence of debris of the Kahovka dam in the lower sluice gate.

The hydrographic network of the area is quite well developed. There is a clear main current and individual arms that partly dry-out during baseflow periods. Hydraulic connection between some tributaries and the main streambed of the Dnipro is expressed poorly. Overload of the current by solid materials provokes the formation of alluvium on the entire length of the main streambed of the Dnipro. The widest area of the river's streambed (over 1,200 m) is in the upper reach, below Khortytsia Island. In the middle reach, there are areas of the streambed that are up to 100 m wide. The river's floodplain is two-sided. The widest areas (B_{max} = 22 km) are located in the region between the city of Zaporizhzhia and the place where the river bends southwest. Floodplain lakes occupy 3% of the general area of the floodplain. Most of them dry-up during baseflow periods. The relief of floodplains is complex. There are limans, residues of oxbow lakes, and meander scars of floodplains, ramified network of temporary streams, etc. The areas of the floodplain along the streambed are formed by light washed-out soils. It is expected that the position of the streambed of the Dnipro in such areas will be unstable.

Interpretation of the results of clustering of the spectral characteristics of the surface of the reservoir's bed revealed four types of soil according to granulometric composition: sands, sandy loam, loam, and clay (clay loam). By the conditions of soil moisture, all soils were conditionally divided into gleysols and fluvisols. Accordingly, we identified gleysols and fluvisols as the main components of the soil cover of dried-up area of the bed. The commonest are eutric gleyic fluvisols. The key factor for classification identification of soils of the bed at the level of reference groups is water regime that determines the processes and regimes of soil genesis, properties of particular soils. All soils of the dried-up area of the bed had undergone the stage of being flooded for a considerable period, and therefore are characterized by presence of fluvial material as a parental material and have signs of hydromorphism in the morphological structure and properties. Depending on water regime in particular areas of the bed, hydromorphic properties of soils correspond to the modern conditions of moisture and are of relic nature.

Because the water level in the reservoir plummeted in the middle of vegetation season, once the soil cover was dry, newly formed floodplains started to be actively overgrown by pioneering plants. The start of the overgrowth stage was identified as the first decade of August 2023. Formation of the plant cover had been occurring in non-uniform manner. The general mechanism of how the vegetative cover spread was from the periphery to the center. The initial sites of overgrowth of the bed were groups of hydro- and hygrophyte vegetation of banks and shallow-water areas. During August, the most intensive overgrowth occurred in the reservoir's upper area (between Khortytsia Island and the city of Nikopol). There was found a connection between granulometric composition, soil moisture content, and intensity of overgrowth. The plants first overgrew excessively wet (flooded) areas, then moving to soils with moderate moisture content. The intensity of vegetative-cover formation peaked in late September 2023. The general area of overgrowth in late 2023 was 1,054 km^2. The zones of the reservoir's bed (currently floodplains) where no overgrowth occurred throughout the vegetation period were classified as continuously flooded or backlogged areas with clayey soils. There was found a floodplain area (formerly the accumulative plain of the reservoir) near the Hrushivka village (Dnipropetrovsk Oblast), where also no overgrowth occurred throughout the monitoring period. Soils in this area were identified as eutric gleyic fluvisols (clayic) with moderate level of water content. During the flood, this area was not flooded. To identify the reasons of absence of vegetative cover in this area, substantial field surveys should be conducted.

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