LGSONIC

Research & Development Department

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Troubled Waters

The Alarming Decline of Water Quality in Ukraine's Dnieper Reservoirs

Contents

Executive Summary

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OVERVIEW

Global freshwater quality is experiencing a widespread decline, driven by factors such as climate change, pollution, and urbanization. If these trends are not monitored and addressed, they may result in the degradation of aquatic ecosystems, leading to severe consequences such as the contamination of water resources, reduced availability of water for drinking and agricultural purposes, loss of biodiversity, and significant threats to human health. In conflict-affected regions, like Ukraine, early signs of environmental changes in reservoirs may go undetected. The ongoing conflict exacerbates this issue, accelerating the deterioration of water quality due to factors such as population displacement and the destruction of infrastructure.

This report investigates temporal trends in water quality within the Dnieper Reservoir Cascade, with a particular focus on key indicators such as chlorophyll a and phycocyanin. These parameters are crucial as they serve as direct indicators of ecosystem health, signaling changes in the ecosystem and potential biodiversity loss.

KEY FINDINGS

1. Kyiv Reservoir:

- Chlorophyll a concentrations were generally below the World Health Organization's (WHO) standard of 60 µg/L despite significant external pollutant loads.
- Phycocyanin levels showed several peaks, indicating a need for real-time monitoring and intervention to maintain water usability for hydroelectric energy, drinking water, and irrigation.

2. Kaniv Reservoir:
   - Exhibited a homogeneous distribution of chlorophyll a with values lower than the WHO standard.
   - A single peak in phycocyanin was observed, suggesting good water quality potentially due to favorable inflow from the Kyiv reservoir.
3. Kremenchuk Reservoir:
   - Chlorophyll a concentrations were diluted by inflow from Kaniv but showed peaks during summer due to heavy agricultural runoff and population density.
   - Phycocyanin levels frequently approached the WHO limit, indicating consistent algal blooms.
4. Kamianske Reservoir:
   - Displayed a seasonal pattern of chlorophyll a with peaks during summer.
   - Historical averages of phycocyanin remained below standard, but blooms were noted, affecting hydroelectric generation and increasing water treatment costs.
5. Dnieper Reservoir:
   - Chlorophyll a concentrations remained within acceptable limits most of the time, with an increasing trend between 2021 and 2023.
   - Phycocyanin peaks became more frequent from 2022 onwards, posing risks to irrigation and industrial activities.

OBSERVATIONS

Chlorophyll a Trends: Concentrations varied significantly, peaking in summer. The reservoir cascade's arrangement sometimes diluted these concentrations but also contributed to pollutant loads near dams.

Phycocyanin Trends: High phycocyanin levels consistently exceeded the WHO standard, indicating a conducive environment for harmful algal blooms (HABs). This is linked to increased sediment and nutrient runoff from agricultural activities and precipitation events.

CONCLUSION

The study highlights the ongoing deterioration of water quality in the Dnieper Reservoir Cascade, particularly the lower reservoirs of Dnieper, Kamianske and Kremenchuk. Chlorophyll a and phycocyanin concentrations show concerning trends, particularly with increased algal blooms. If left unaddressed, these environmental changes may lead to irreversible damage to aquatic ecosystems, negatively impact human health, and result in the loss of water for food production or drinking purposes. These findings underscore the need for continuous monitoring and proactive measures to mitigate pollution and ensure the sustainability of water resources in Ukraine.

METHODOLOGY

Two modes of analysis were conducted to determine if the following parameters exceed the WHO acceptable limits for the quality of life of living beings dependent on water resources: Chlorophyll a (60 µg/L) and Phycocyanin (30 µg/L).

1. Traditional Evaluation:

- Sentinel-2 images covering the area of interest from 2021 to 2023 were selected and cropped to focus on the study areas. A minimum frequency of 12 images per year was analyzed.

2. Spectral Index Analysis:

- Chlorophyll a and phycocyanin water quality indices were derived from Sentinel-2 spectral bands. Specific equations correlated these spectral bands with the water quality parameters.
- Temporal averages of spectral index values for all water pixels on reservoir surfaces were calculated. Temporal trends of pixel averages were analyzed to detect seasonal variations, long-term shifts, or anomalous events.

This methodology integrates Sentinel-2 image analysis with water quality models and temporal analysis to provide a comprehensive understanding of changes in water quality across spatial and temporal scales. Through this approach, pollution hotspots were identified, facilitating targeted interventions for water quality management.

About

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Among the many environmental concerns raised due to the Ukrainian–Russian War, the water quality of surface reservoirs emerges as a critical area of interest. These freshwater sources play a vital role in the supply of drinking water, the production of hydroelectric energy, and the support of regional agriculture and aquatic biodiversity.

This report focuses on recent water-quality trends within the Dnieper Reservoir Cascade. Comprising a series of dams and reservoirs along the Dnieper River, the cascade encompasses 79% of Ukraine's total reservoir volume. It both regulates the river's flow and serves as a crucial source of freshwater for agricultural, industrial, and domestic use. As the Dnieper River is Europe's fourth largest river, spanning over 2100 kilometers, the Dnieper Reservoir Cascade supports 28 million people and diverse ecosystems along its banks. The reservoirs' characteristics are well described and can be found in Table 2.

Population displacement, industrialization, agricultural runoff, and inadequate wastewater treatment practices are likely contributing to the degradation of the river's quality. Pollutants such as heavy metals, nutrients, pesticides, and untreated sewage have been detected in the cascade, posing potential threats to human health, aquatic life, and overall ecosystem integrity.

From source to mouth, the reservoirs are ordered as follows: Kyiv Reservoir, Kaniv Reservoir, Kremenchuk Reservoir, Kamianske Reservoir, and Dnieper Reservoir (Figure 1). The Kakhovka Reservoir – once the sixth and most downstream reservoir in the cascade – has dried up after its targeted attack on June 6, 2023.

This report focuses on two key indicators – chlorophyll a and phycocyanin – to evaluate changes in the Dnieper Reservoir Cascade's aquatic health. Chlorophyll a is a pigment indicative of photosynthesis performed by aquatic plants and algae. Phycocyanin is a pigment indicative of the presence of cyanobacteria.

Figure 1 Dnieper cascade indicating the large reservoirs[1]

When infrastructure such as water treatment facilities and sewage systems is destroyed or damaged, as has occurred during the Ukrainian–Russian War, chemical and harmful effluents can leak into water bodies. Documented impacts in Ukraine of these instances, include multiple cases of water-transfer interruption, surface-water pollution due to military actions, and overflooding of mines. Specifically, there have been 12 instances of disrupted operation of water and wastewater treatment facilities, seven cases of disrupted centralized water supply, and three cases of interrupted wastewater treatment plant operations. Furthermore, the conflict has led to five instances of dam damage, including the Kakhovka Hydroelectric Station (HES), further exacerbating the water supply crisis. This pollution can promote algal and cyanobacterial blooms, thereby increasing the concentrations of chlorophyll a and phycocyanin in the water. Population displacement and the interruption of agricultural practices can beget soil erosion and nutrient loads, leading to harmful algal blooms.

In addition to the factors listed above, the cascade faces pressure from climate change. Changes in precipitation patterns, rising temperatures, and alterations in river flow regimes can increase the frequency of HABs and disrupt aquatic ecosystems. These impacts seriously threaten water quality and jeopardize water resources' reliability for various sectors, including agriculture, commercial industry, and municipal supply.

1 Khilchevskyi et al., "Large and Small Reservoirs of Ukraine."

Methodology

03

Two modes of analysis were conducted to determine if the following parameters exceed the WHO acceptable limits for the quality of life of living beings dependent on water resources: chlorophyll a (60 µg/L) and phycocyanin (30 µg/L).

The first analysis involved a traditional evaluation of images from 2021 to 2023. The second approach analyzed the averages of the parameters and their acceptable limits through representative graphs.

This report utilized a methodology that integrates Sentinel-2 image analysis with water quality models and temporal analysis to delve deeper into changes in water quality across spatial and temporal scales.

Initially, Sentinel-2 images covering the area of interest and the timeframe of analysis were selected. Subsequently, these images were cropped to focus on the study areas. Image availability was limited due to cloud cover and other obstacles. A minimum frequency of twelve images per year within the spatial and temporal scales was chosen for analysis.

Chlorophyll a and phycocyanin water quality indices were derived from the Sentinel-2 spectral bands. These indices were computed using specific equations correlating spectral bands with the water quality parameters.

Temporal averages of spectral index values for all water pixels on reservoir surfaces were then calculated. Subsequently, temporal trends of pixel averages were analyzed to detect seasonal variations, long-term shifts, or anomalous events.

Through the integration of water quality models with time series analysis, the relationships between water properties and changes observed in spectral indices over time were made clear. Consequently, areas of interest or pollution hotspots based on the findings can be pinpointed.

This methodology presents a comprehensive approach to water quality monitoring, facilitating a deeper comprehension of fluctuations in water quality across temporal and spatial dimensions.

Table 1 Information about the evaluated reservoirs.

Reservoir	Latitude	Longitude	Max length (km)	WQ status 2021	Approx volume (2019)	Application
Kyiv	50.820000	30.463611	110	Good to moderate	3.7 km³	Hydropower, Irrigation, Industrial, Drinking
Kaniv	49.926111	31.479444	162	Poor	2.6 km³	Hydropower, Industrial
Kremenchuk	49.266667	32.633333	149	Good to moderate	13.5 km³	Irrigation
Kamianske	48.800000	34.100000	114	Good to moderate	2.45 km³	Hydropower, Irrigation, Drinking
Dnieper	48.135833	35.128611	129	Moderate	3.3 km³	Irrigation

Table 2 Characteristics of the evaluated reservoirs.

Characteristics	Reservoir				
	Kyiv	Kaniv	Kremenchuk	Kamianske	Dnieper
Year of reservoir filling	1966	1976	1961	1964	1932
The Dnieper catchment area in HPP cross-section (thous. km^2)	239	336	383	424	463
Average volume of runoff in HPP cross-section (km^3)	33.1	43.9	47.8	52	52.2
Total volume of reservoir (km^3)	3.73	2.5	13.52	2.46	3.32
Useful storage of regulation (km^3)	1.17	0.3	8.97	0.53	0.85
Water table area (km^2)	922	582	2252	567	410
Average depth (m)	4	3.9	6	4.3	8
Shallow water area (%)	34	26	18	32	39
Average water mineralization (mg·dm^{-3})	285	297	305	282	330
Type of runoff regulation	seasonal	daily	annual	weekly, daily	weekly, daily

Results

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KYIV RESERVOIR

Chlorophyll a in the Kyiv Reservoir (Figure 2) was observed in large concentrations moving from the north to the south of the reservoir. This fact suggests that pollution from the surrounding drainage basin contributes to algae growth and the consequent increase in the concentrations of algal parameters.

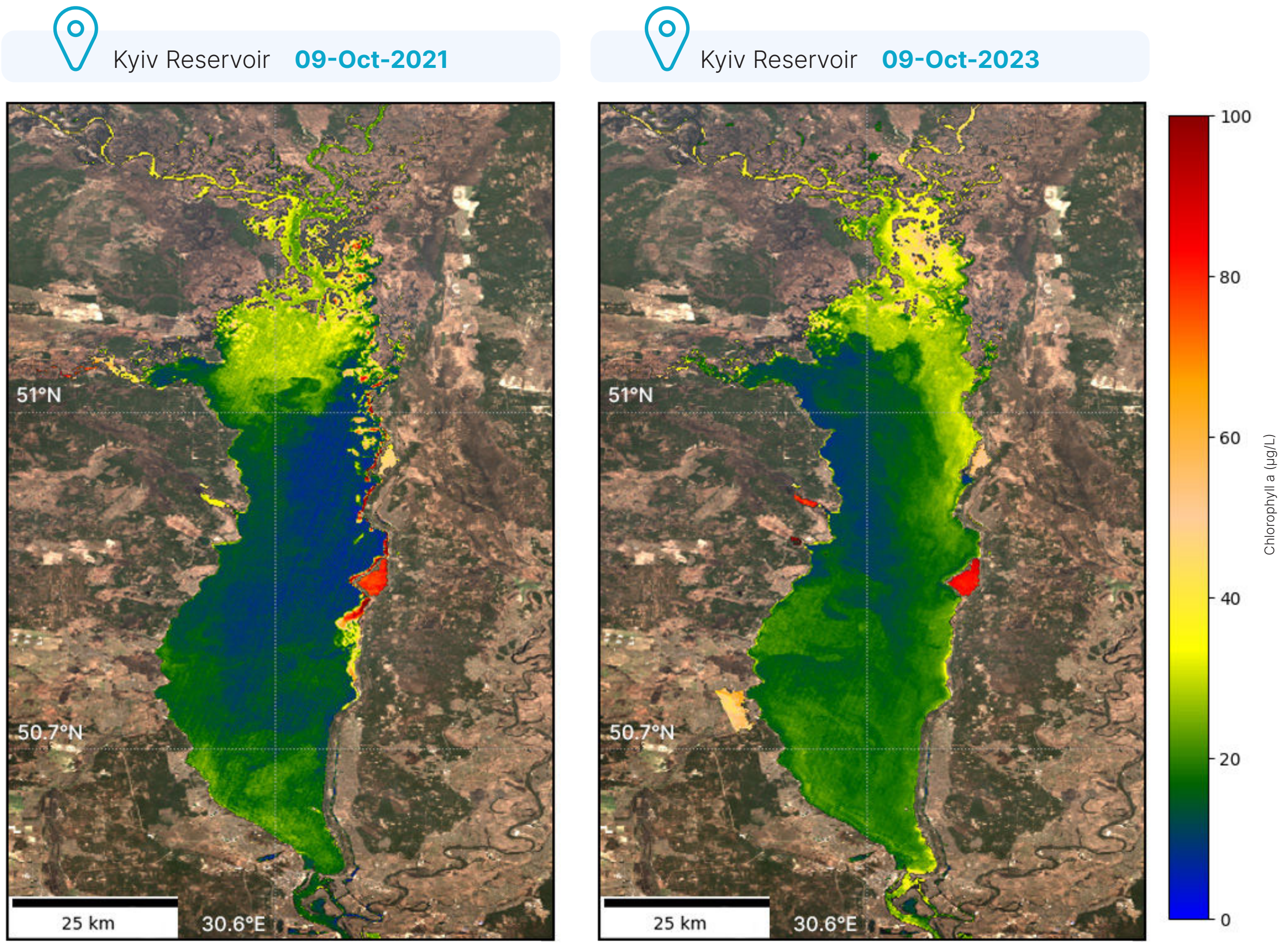


Figure 2 Kyiv reservoir area: Chlorophyll a between October 2021-October 2023.

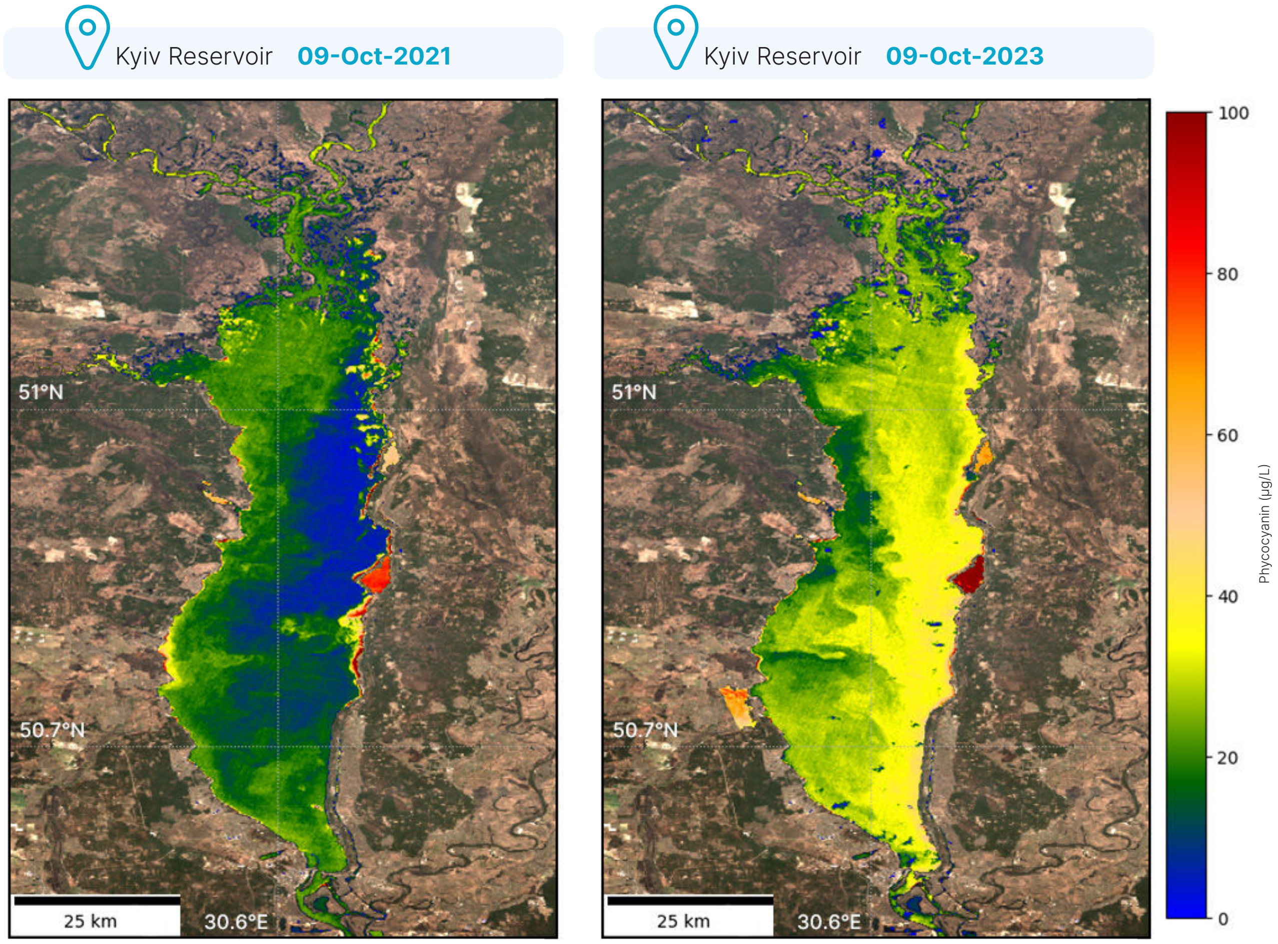


Figure 3 Kyiv reservoir area: Phycocyanin between October 2021-October 2023.

Despite the large external load, the reservoir had the potential to dilute these pollutant discharges, meaning that chlorophyll a concentrations always remained below the standard of 60µg/L, a fact that can be observed from historical averages (Figure 4).

Between 2021 and 2023, several peaks in phycocyanin were observed. There is a need for real-time monitoring and proactive intervention, lacking which the main uses of these waters may be compromised (hydroelectric energy generation, drinking water supply, and industrial and irrigation applications).

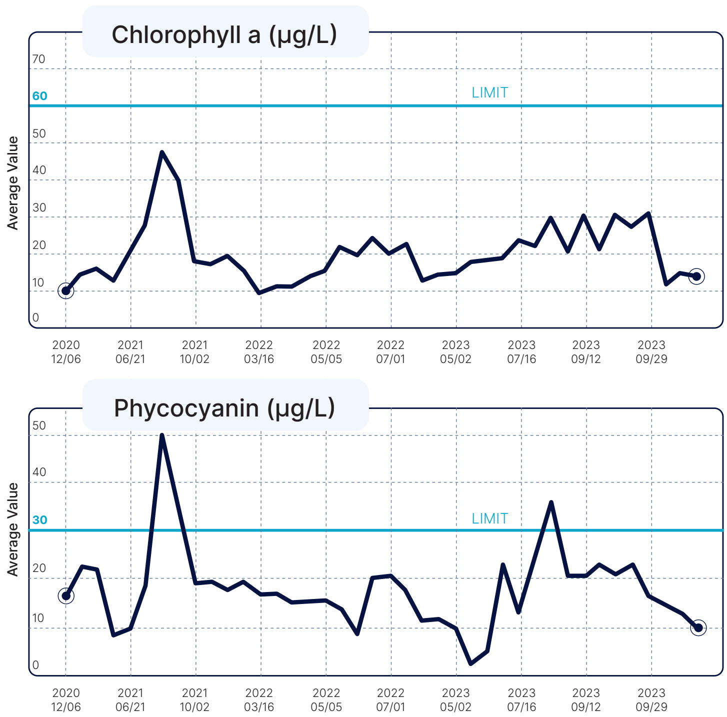
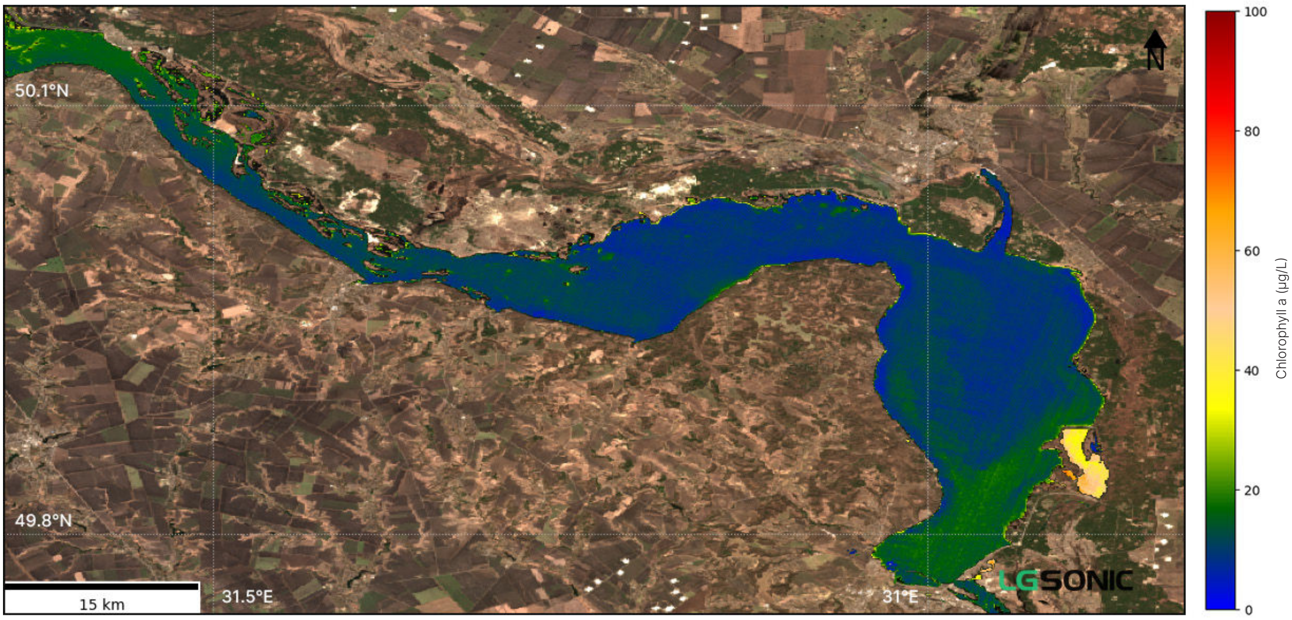


Figure 4 Temporal analysis of chlorophyll a and phycocyanin in the Kyiv reservoir.

KANIV RESERVOIR

In relation to the Kaniv Reservoir, its waters presented a more homogeneous spatial distribution of chlorophyll a (Figure 5), with relatively low values when compared to the WHO standard.

Kaniv Reservoir **14-Oct-2021**



Kaniv Reservoir **14-Oct-2023**

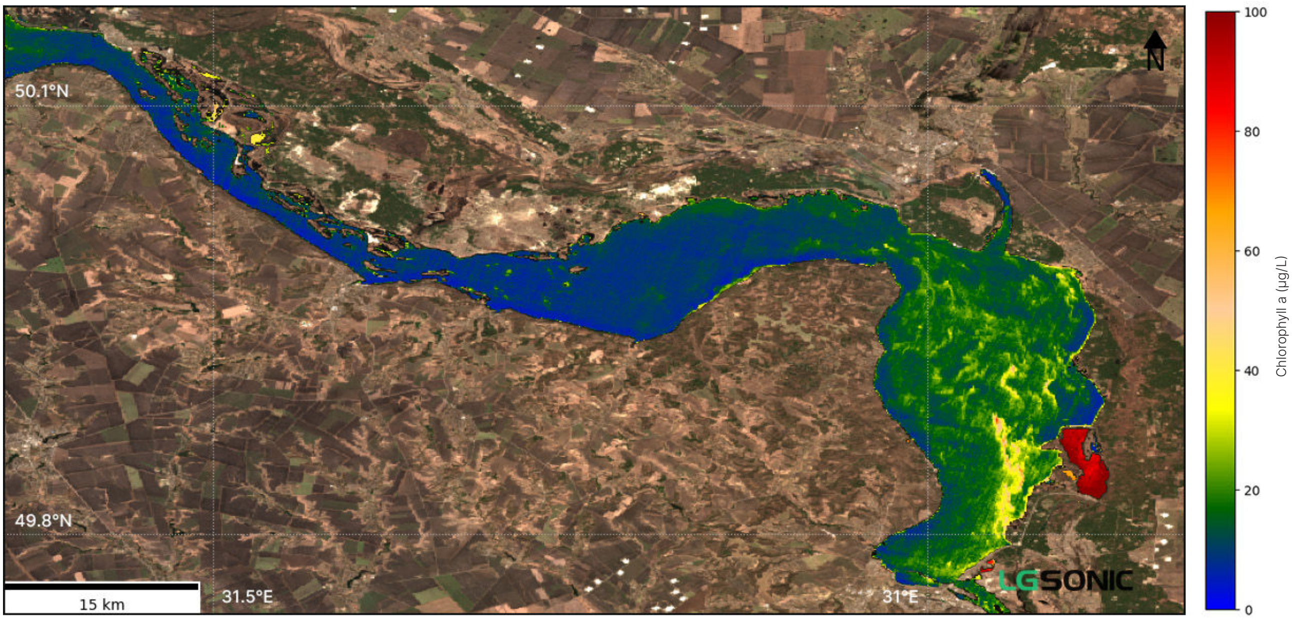
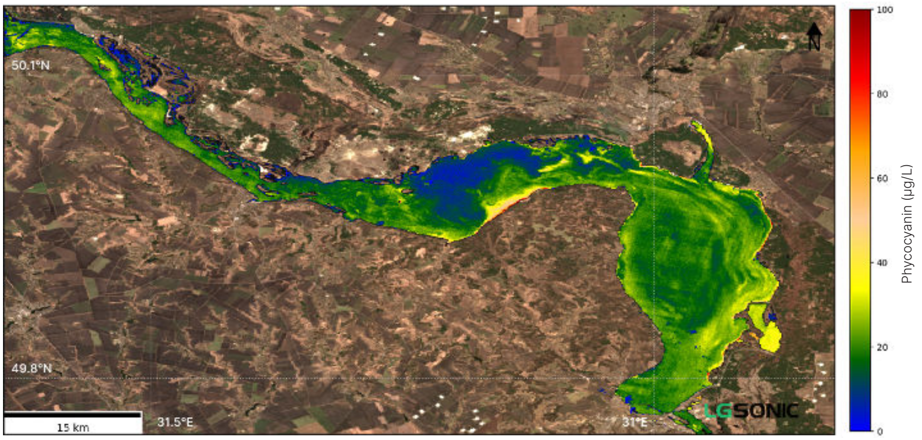


Figure 5 Kaniv reservoir area: Chlorophyll a between October 2021-October 2023.

Kaniv Reservoir
14-Oct-2021



Kaniv Reservoir
14-Oct-2023

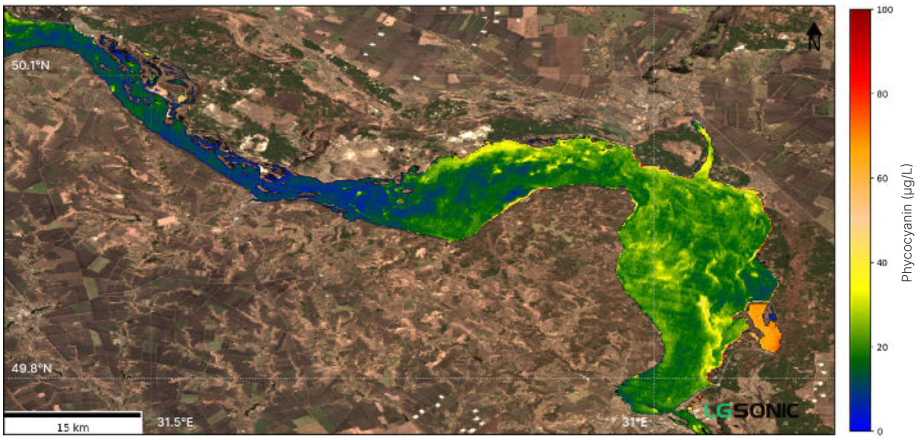
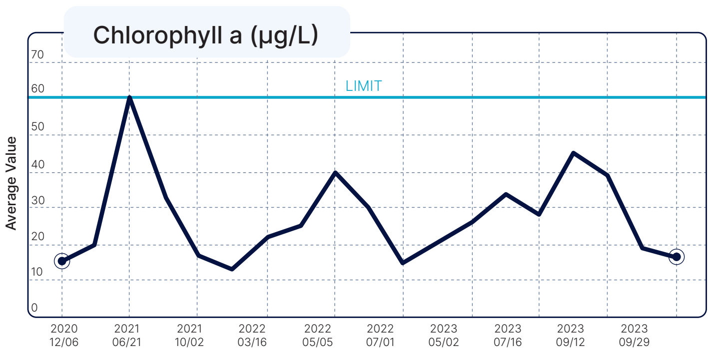


Figure 6 Kaniv reservoir area: Phycocyanin between October 2021-October 2023.



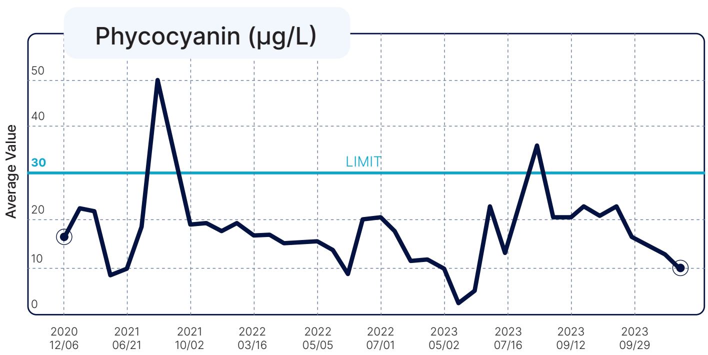


Figure 7 Temporal analysis of chlorophyll a and phycocyanin in the Kaniv reservoir.

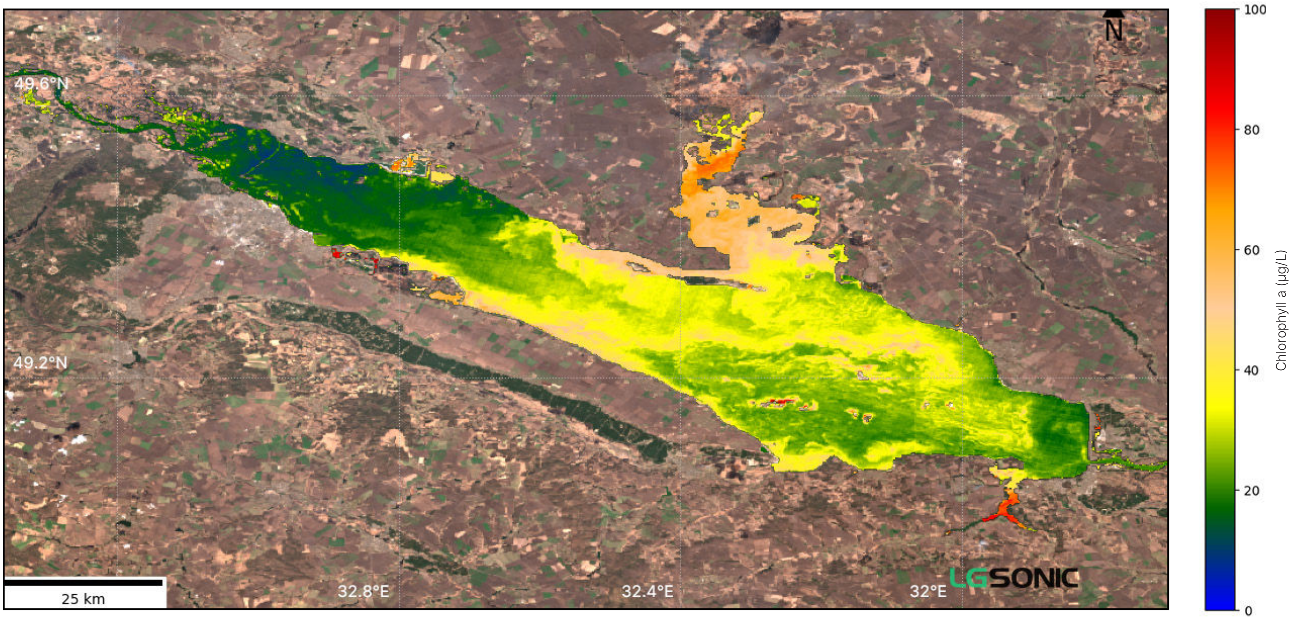
From the historical time series (Figure 7), it was observed that the highest chlorophyll a concentrations occurred at the end of summer (August 2021). Phycocyanin displayed behavior similar to chlorophyll a, with only two peaks observed between 2021 and 2023.

Generally, the reservoir shows uniformity in its algal distribution. The relatively good water quality can likely be attributed to the good influent flow from the Kyiv Reservoir upstream.

KREMENCHUK RESERVOIR

In the case of the Kremenchuk Reservoir (Figure 8), the inflow of water from the Kaniv Reservoir, which occurs from west to east, helps to dilute the Kremenchuk's chlorophyll a concentration. The main source of pollution in this reservoir is due to the heavy agricultural activity surrounding it. In addition, the higher population density and the domestic outflows contribute to increased nutrient loads. This leads to the proliferation of algae.

Kremenchuk Reservoir **11-Oct-2021**



Kremenchuk Reservoir **11-Oct-2023**

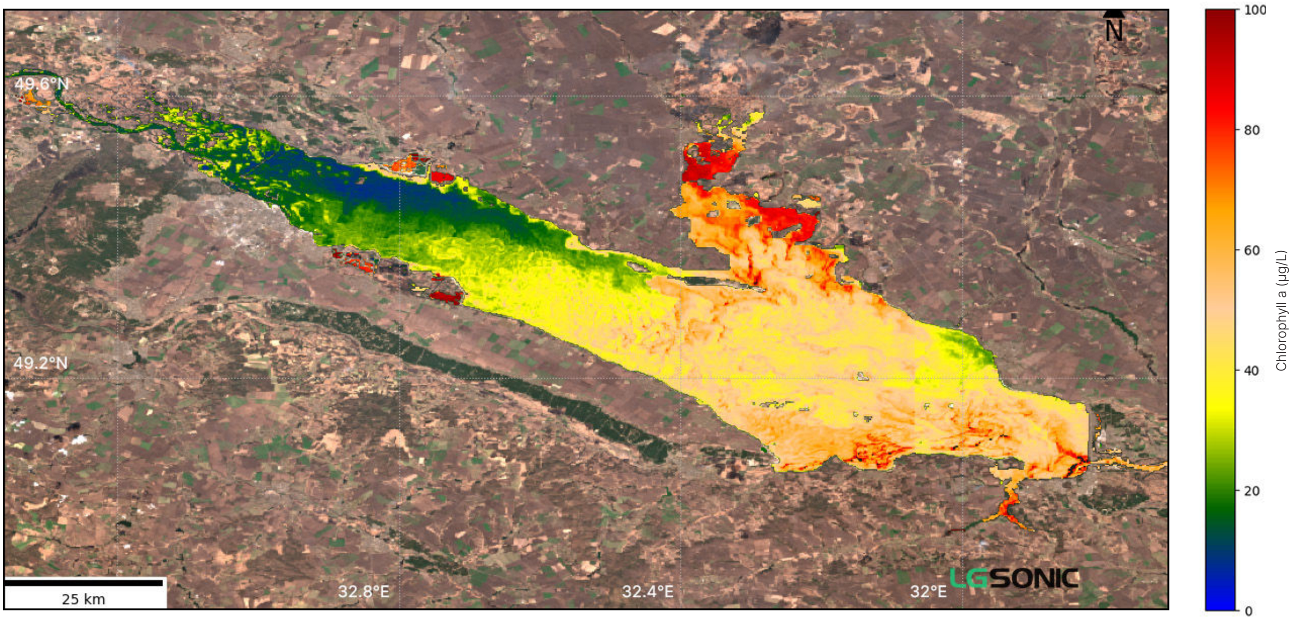


Figure 8 Kremenchuk reservoir: Chlorophyll a between October 2021-October 2023.

Kremenchuk Reservoir
11-Oct-2021

Kremenchuk Reservoir
11-Oct-2023

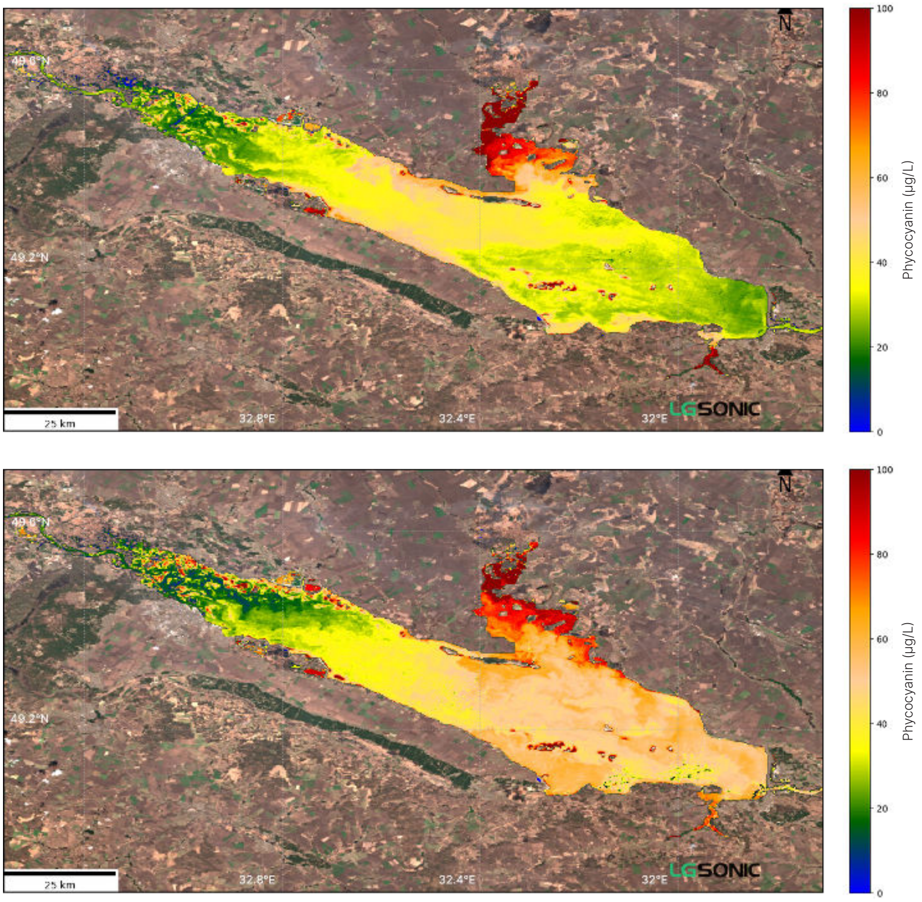


Figure 9 Kremenchuk reservoir: Phycocyanin between October 2021-October 2023.

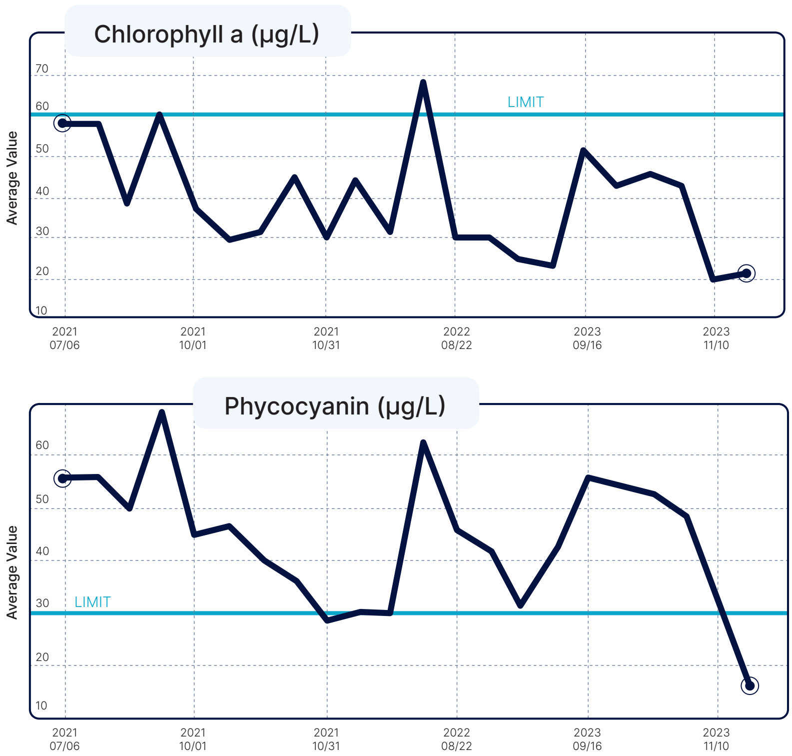


Figure 10 Temporal analysis of chlorophyll a and phycocyanin in the Kremenchuk reservoir.

Despite this, it is possible to observe in Figure 10 that its water presented chlorophyll a values lower than the standard for the analyzed period. Some chlorophyll a concentration peaks were observed that exceeded the standard, the largest of which occurred mainly in the summers between 2021 and 2023. There were also several blooms during the October months, originating in the northern part of the reservoir. Phycocyanin, in turn, presented throughout the series and almost always was observed above the limit.

KAMIANSKE RESERVOIR

The Kamianske Reservoir (Figure 11) shows a distribution of chlorophyll a from west to east, highlighting the impact of the increased load from the Kremenchuk Reservoir, which is located upstream. A seasonal behavior of chlorophyll a is observed, with the highest concentration peaks in summers between 2021 and 2023.

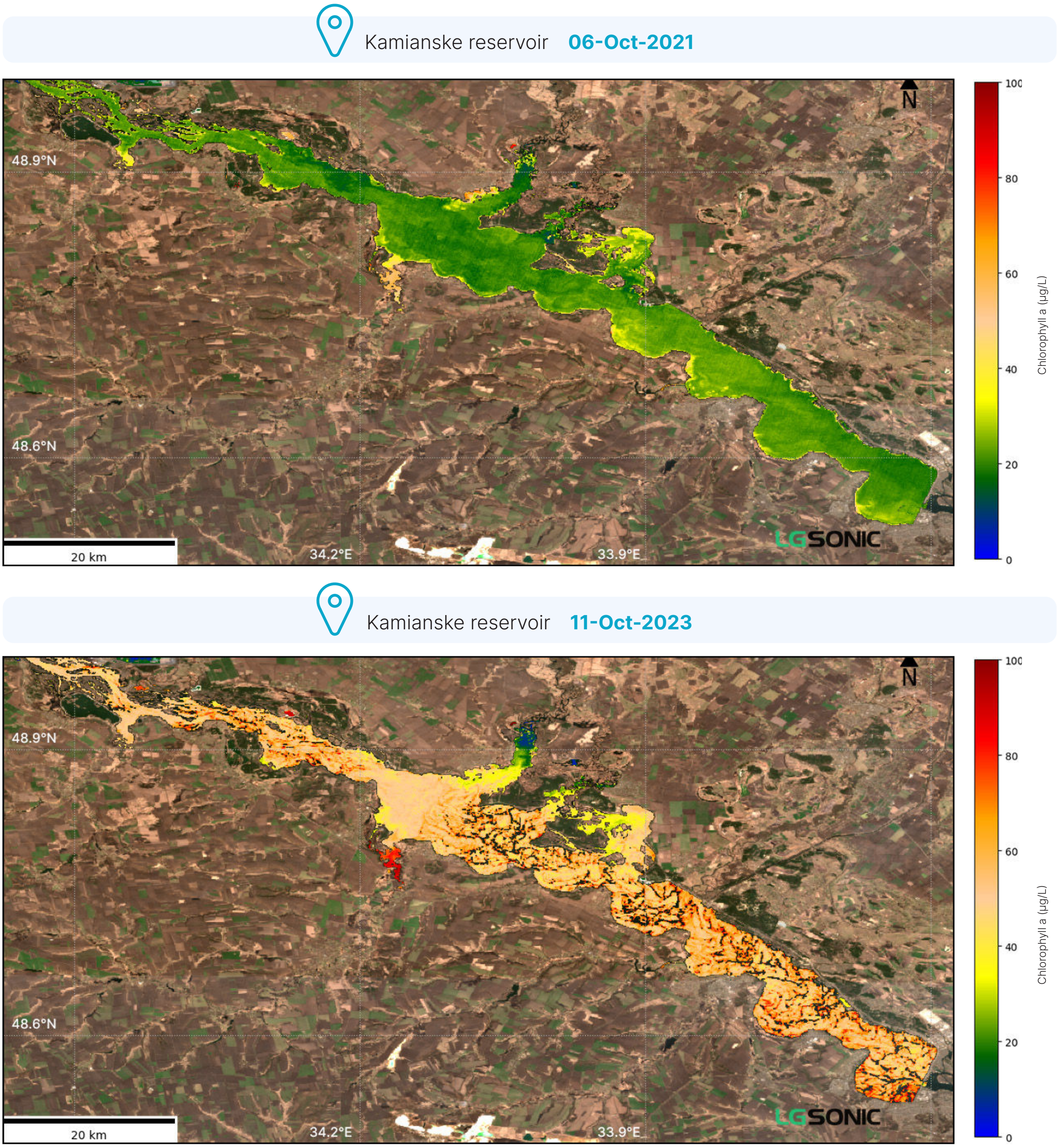


Figure 11 Kamianske reservoir: Chlorophyll a between October 2021-October 2023.

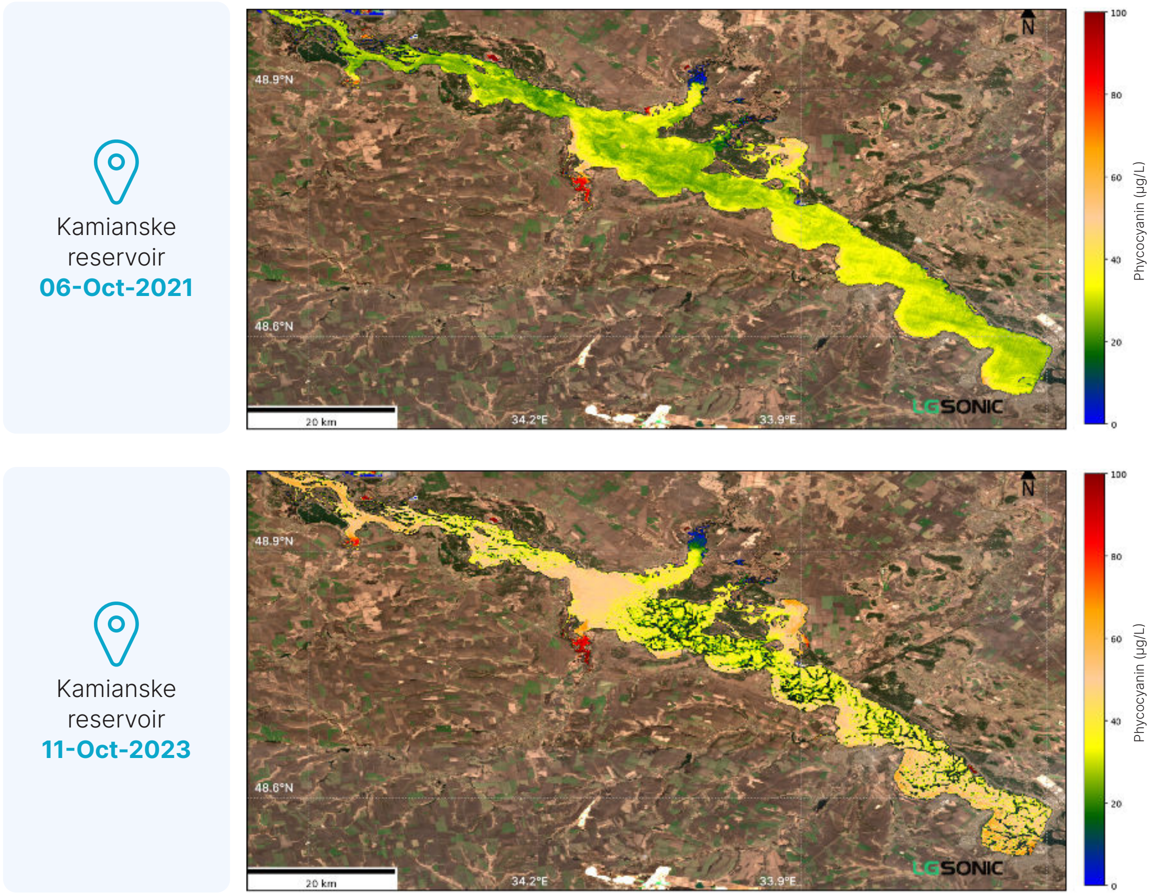


Figure 12 Kamianske reservoir: Phycocyanin between October 2021-October 2023.

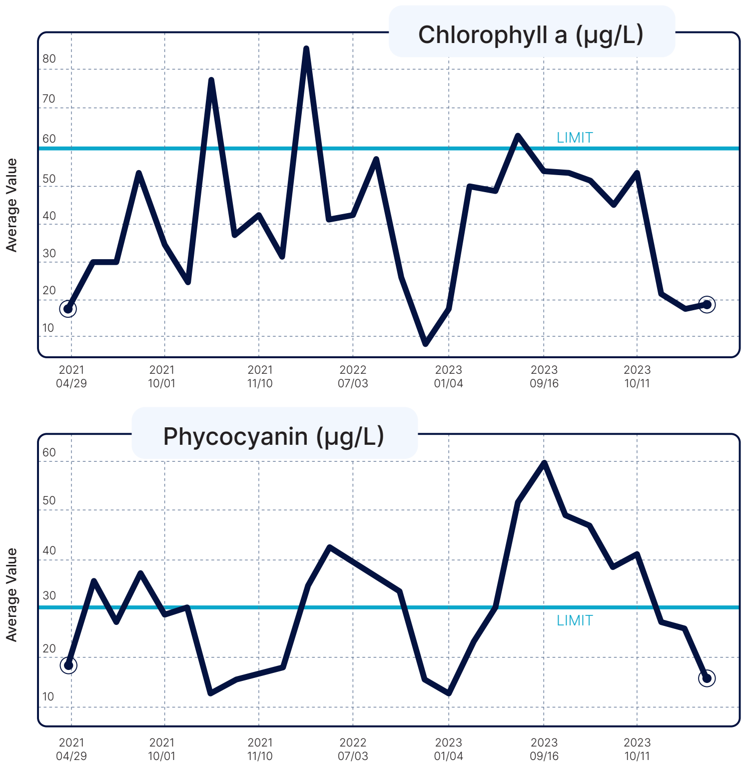


Figure 13 Temporal analysis of chlorophyll a and phycocyanin in the Kamianske reservoir.

Historically, average concentrations were below the standard value (60 µg/L), with certain blooms that exceeded this value. Phycocyanin's highest peak concentrations occurred in 2023. These conditions can affect hydroelectric power generation. Furthermore, it can obstruct irrigation and agro-related implements, increase human supply costs due to the need to remove these pollutants from the water, and pose serious threats to human health.

From the temporal analysis it can be seen that annually, blue-green algal blooms increase in intensity and duration.

DNIEPER RESERVOIR

Chlorophyll a concentrations in the Dnieper Reservoir (Figure 14), were observed moving north to south of the reservoir, mainly from September onwards. This is related to the Kamianske discharges, which are located upstream of the Dnieper and showed high concentrations of chlorophyll a.

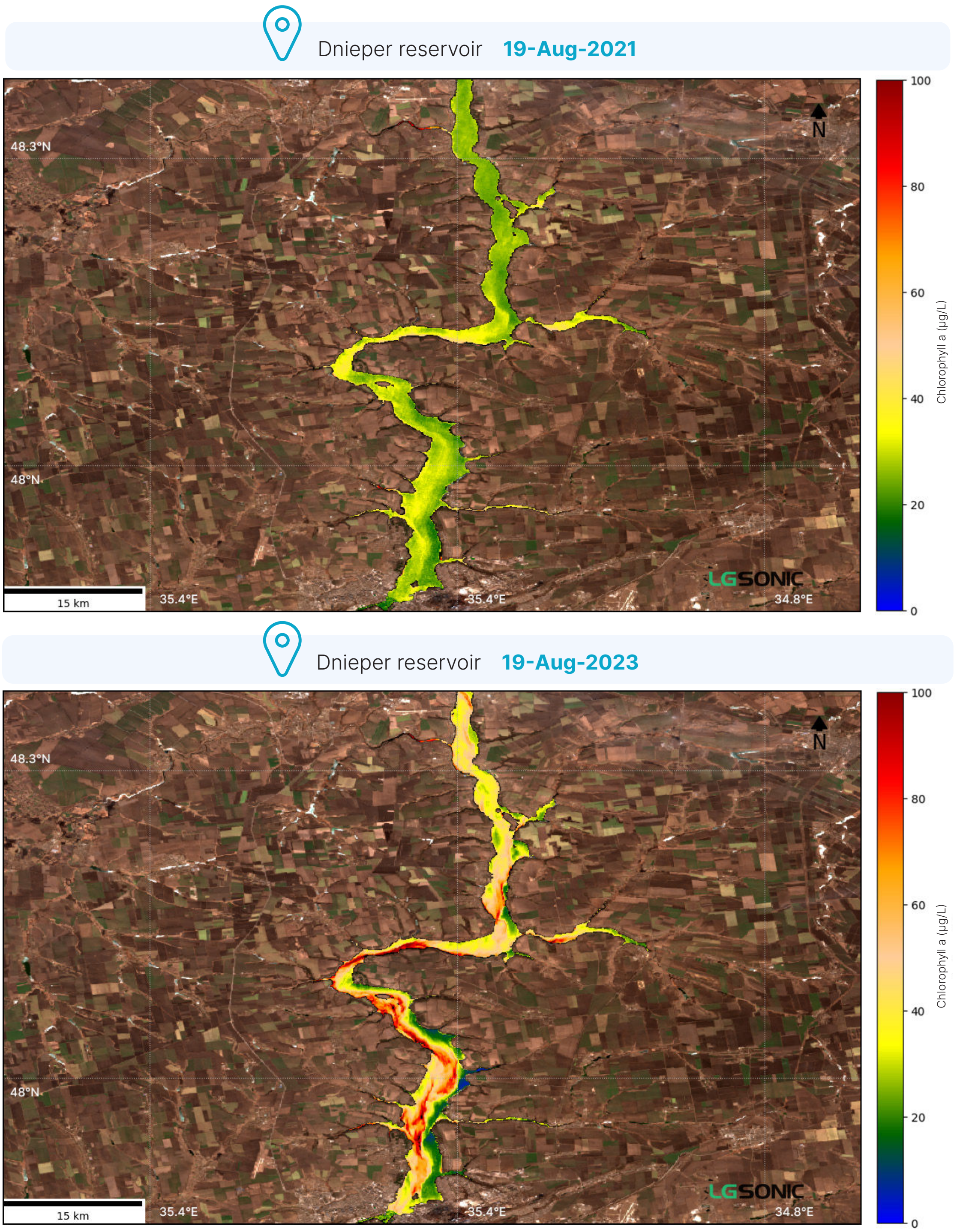


Figure 14 Dnieper reservoir Area: Chlorophyll a between August 2021-August 2023.

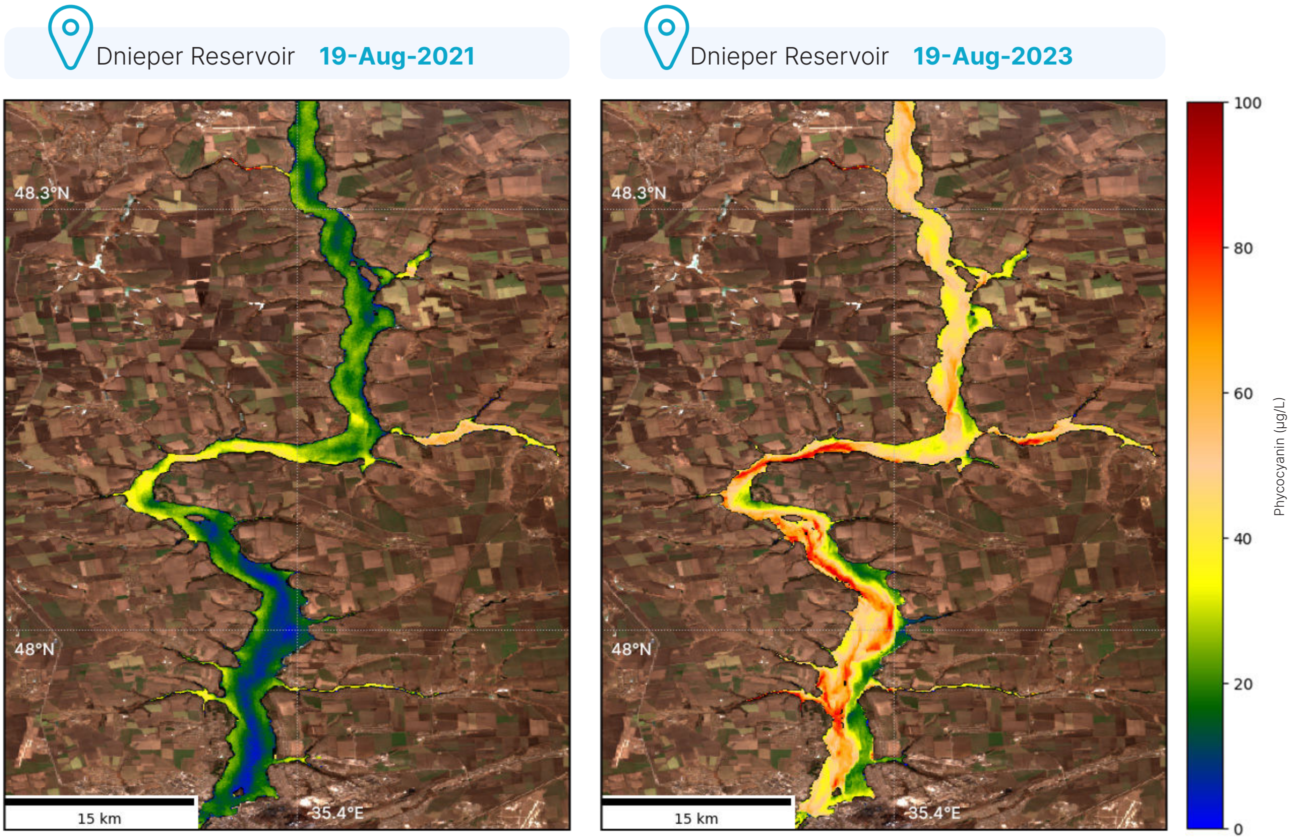


Figure 15 Dnieper reservoir Area: Phycocyanin between August 2021-August 2023.

Evaluating the historical series of chlorophyll a (Figure 16) for the Dnieper Reservoir, we noticed that the reservoir presented values within the WHO standard for aquatic environments most of the time. There is an increasing trend in the concentration values of these parameters between 2021 and 2023. From 2022 onwards, there were greater amounts of concentration peaks of phycocyanin that exceeded the standard of 30 µg/L in relation to the series studied. Such changes in the concentrations of chlorophyll a and phycocyanin indicate increased algal presence that can adversely affect irrigation and industrial activities.

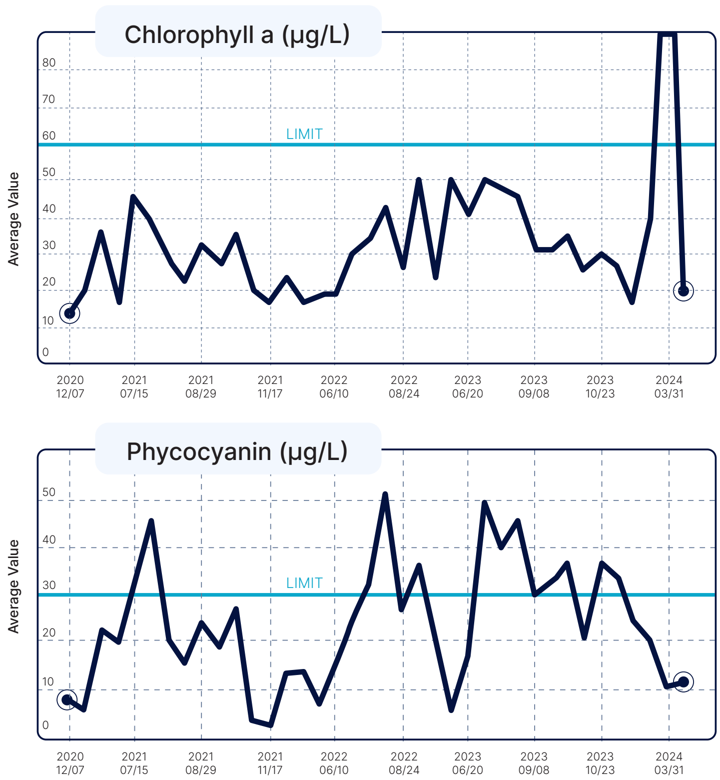


Figure 16 Temporal analysis of chlorophyll a and phycocyanin in the Dnieper reservoir.

Turbidity Analysis

05

From 2018 to 2023, the temporal variations in turbidity within the Kyiv Reservoir where investigated, using Sentinel-2 MultiSpectral Instrument (S2-MSI) imagery. Turbidity, a measure of water clarity, was analyzed across the entire reservoir area using anomaly detection techniques. The results are presented in Figure 17.

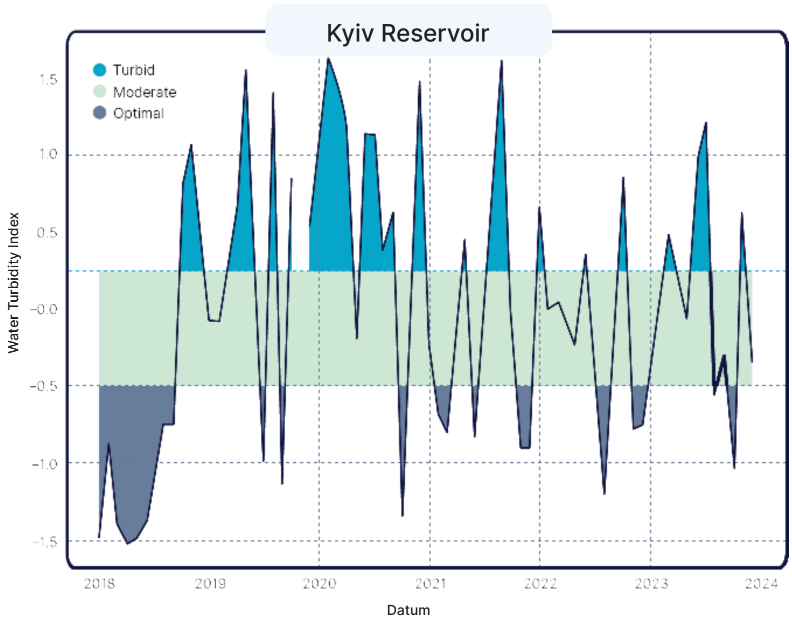


Figure 17 Temporal variation of turbidity in the Keyv reservoir..

The zero line is the reference line of normal turbidity conditions, above which the lake exhibits anomalous value. This reference line was established from the monthly climatology of S2-MSI observations.

The analysis revealed interesting temporal trends. Since the war in Ukraine began, the Kyiv Reservoir appears to exhibit a reduced dynamic range in turbidity values. This potentially indicates a decrease in nutrient influx from agricultural activities entering the lake. From an ecological perspective, such a change could serve as an early warning sign of a decline in the lake's metabolic activity. Further investigations are necessary to confirm these initial observations and elucidate the underlying mechanisms.

Observations

06

The latest satellite data from 2021 to 2023 highlights significant fluctuations in chlorophyll a concentration across various reservoirs, with the highest levels typically recorded between June and August, the peak of summer. While these concentrations generally stayed below the World Health Organization's recommended threshold of 60 µg/L, an increasing frequency of concentration peaks has been noted. The configuration of the reservoirs in a cascade sometimes aided in diluting chlorophyll a levels. Still, in certain instances, it exacerbated the pollutant load, especially downstream, as the effects were incrementally compounded.

In contrast, phycocyanin levels consistently surpassed the WHO standard of 30 µg/L during the same period, particularly in the summer months when solar energy is most abundant. These elevated levels of phycocyanin – often significantly higher than 30 µg/L – indicate a troubling trend. According to WHO guidelines, an average phycocyanin level above 30 µg/L, equivalent to 20,000 cyanobacterial cells per milliliter, triggers "alert level 1," necessitating a need for monitoring to prevent harmful algal blooms.

These findings underscore a critical need for proactive measures to address the escalating risk of HABs, which threaten aquatic ecosystems, degrade water quality, and pose serious health risks if the water is used for drinking. The surge in algal activity is largely attributed to increased sediment input from runoff during heavy rainfall and heightened agricultural activities, both of which contribute to nutrient loading in the reservoirs.

Moreover, it was observed that the Kyiv Reservoir maintained the highest water quality, while reservoirs downstream experienced increasing phycocyanin peaks, further emphasizing the need for targeted intervention.

The data from this report reveals a significant deterioration in water quality within the Dnieper Reservoir Cascade. The elevated levels of phycocyanin, particularly in the lower reservoirs, suggest that nutrient runoff from agricultural activities, the accumulation of nutrients and algal cells from upstream reservoirs, and damage to infrastructure due to ongoing conflict are all contributing factors. This deterioration poses a serious threat to both the environment and public health.

upstream reservoirs, and damage to infrastructure due to ongoing conflict are all contributing factors. This deterioration poses a serious threat to both the environment and public health.

To address this critical issue, an enhanced monitoring strategy is essential. The current report provides only a partial picture of the ecosystem's health, and comprehensive evaluation is necessary to understand the full scope of the damage. This approach aligns with the World Bank's needs assessment, which emphasizes the importance of enhanced water quality monitoring, expanded local field surveys, and monetary estimates of damage and losses. By thoroughly evaluating the deterioration and triggers within these ecosystems, we can implement targeted mitigation measures and establish a framework for the treatment and sustainable use of water resources from these reservoirs.

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