

## TROPHIC STATUS ASSESSMENT OF SMALL TURBID LAKES COMPARING REMOTE SENSING AND *IN SITU* DATA: CASE STUDY AT LOWER DANUBE FLOODPLAIN

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### **Abstract**

*The aim of the study was to compare in situ and remote sensing data, in order to assess the applicability of satellite images in water quality monitoring of floodplain lakes. Two indicators of trophic status were compared: chlorophyll a and total suspended matter. Two lakes on Lower Danube floodplain were selected: Srebarna and Malak Preslavets. Data were obtained in July and August 2018. Sentinel 2 MSI L1c images were analyzed in SeNtinel Application Platform (SNAP), (v. 6.0). According to in situ data, Srebarna Lake indicated status of eutrophication, while Malak Preslavets experienced hypertrophic conditions. Satellite data indicated eutrophic conditions for both lakes. Comparing the results from in situ and satellite data, chlorophyll a showed higher correlation ( $r = 0.66$ ) and comparable results. On the other hand, significantly overestimation of suspended matter according to satellite data were found, as well weaker correlation ( $r = 0.57$ ) between both methods. Remote sensing i.e. Sentinel products are emerging as a powerful tool in environmental observation. Although weather conditions could have significant impact on environmental dynamic especially in floodplain lakes, combining and comparing of different methods could improve the preciseness of the methodology as well as assessment reliability.*

### **Introduction**

Eutrophication defined as nutrient enrichment mainly compounds of nitrogen and phosphorous leading to: increased growth, primary production and biomass of algae; changes in the balance of nutrients causing changes to the balance of organisms; and water quality degradation [1], is global threat to the aquatic ecosystems. The Water Framework Directive [2] requires measures for monitoring, restoration and preservation of eutrophication process enhanced by human activity. Water quality variables as water transparency, chlorophyll a and phosphorous concentration are the most used in the trophic status assessment of inland waters [3]. However, small, shallow, polymictic floodplain lakes are often prone to dynamics of the weather conditions, or a flood process, resulting in strong fluctuation of their

state. Achieving reliable results for the environmental conditions of floodplain lakes requires high-frequency monitoring, which could be expensive. Copernicus program offers freely available data from Sentinel-2 missions. Each satellites carry Multispectral Instrument (MSI) with a wide range of spectral channels, producing images with high spatial resolution ( $10 \div 60\text{m}$ ), and a 5-day repeat cycle, providing regular long-term data array. European space agency (ESA) also developed user friendly SeNtinel Application Platform (SNAP) including large set of optical water processors, generating data about optically determined water quality parameters including chlorophyll-*a* and total suspended matter. Recent studies estimated good relationship between *in situ* and Sentinel MSI data along trophic state gradient [4, 5]. Sentinel 2 MSI L1C products are one of the newest and most precise data providers, although atmospheric conditions for example undetected clouds could significantly affect the results accuracy [6].

However, floodplain lakes due to their dynamic hydrology, wind resuspension, nutrient inflow, vegetation development, could experience fast shift in water consistent. Therefore, their optical properties are not limited to the chlorophyll produced by the algae (Case 1 waters), but interfere with higher amount of dissolved organic matter, minerals and sediments in the water, consequently defined as Case 2 waters [7]. The Case 2 Regional Coast Colour (C2RCC) processor developed as multi-mission ocean colour processor is applicable to the most of the produced satellite data, including Sentinel 2 MSI, representing good results for Case 2 waters [8]. Due to complex, inherit optical properties total suspended matter is still very often overestimated water quality parameter [9]. Hereafter *in situ* measurements are essential, considering light penetration especially in turbid lakes [10].

The aim of the study is to actualize the trophic status prerequisite of ecological state assessment of the two Lower Danube floodplain lakes, considering their importance as floodplain wetlands providing wide range of ecosystem services. The study also intend to compare and assess the reliability of the data obtained by remote sensing and *in situ* data in order of trophic state assessment of small turbid lakes.

## Materials and methods

Two small and shallow floodplain lakes at Lower Danube were investigated as case study objects – *Malak Preslavets* Lake and *Srebarna* Lake (Fig. 1). *Malak Preslavets* is a former marsh, situated on Danube floodplain at 414 river km. After its embankment in the end of 1970's was transformed into small reservoir raising the water level above 14 m a.s.l., since than flooding by the Danube did not occurred. The maximum measured depth of the lake was over 3 meters with total water surface area of 35 ha. Development of fringing reed belt along the shore (varying between 2 to 5 meters wide) and densely developed canopy of floating vegetation mainly *Nimphaea alba*, rooted in the central part of the lake, reduced its open water surface to less than 10 ha. *Srebarna* Lake is also situated on the *Danube* floodplain at

393 river km (Fig. 1). The lake was embanked and isolated from the *Danube* in 1949. Later in 1994 Srebarna was reconnected with *Danube* through inlet channel allowing flooding by the *Danube*, when the water level rises above 12 m a.s.l. at 393 rkm. The maximum depth of the lake varies between 1.8 and 3 meters according to the *Danube* flooding regime and the management of the channel facilities. The lake is characterized with open water area of about 129.66 ha, and several large adjacent pools with total area of 68.86 ha [11]. As the *Srebarna* Lake is more shallow and wider, situated in open flat area, it reflect in e greater extend the changes in the weather conditions, compared to *Malak Preslavets*, situated in a narrow valley surrounded by hills.

Five replicates were sampled from *Srebarna* Lake and three replicates were sampled from *Malak Preslavets*, resumng totally eight samples (Fig. 2). Field sampling was conducted twice (on 18<sup>th</sup> of July and replicated on 20<sup>th</sup> of August 2018), generating overall 16 samples. As shallow polymictic lakes, samples were obtained subsurface from depth of 0.5 m. Water quality parameters such as chlorophyll-*a*; transparency (*Secchi* depth); total suspended matter; turbidity; water depth and surface water temperature were measured. In order of obtaining necessary sample volume for determining the chlorophyll *a* and total suspended matter concentration between 0.1 and 0.35 litres of water were filtered, through CHMLAB GF-5 grade glass fiber filters for each method. Chlorophyll-*a* concentration was spectrophotometrically determined, extracted in 96% ethanol, following ISO 10260:1992. Total suspended matter assessment was performed according EN 872:2006. Turbidity was measured according ISO 7027-1:2016.

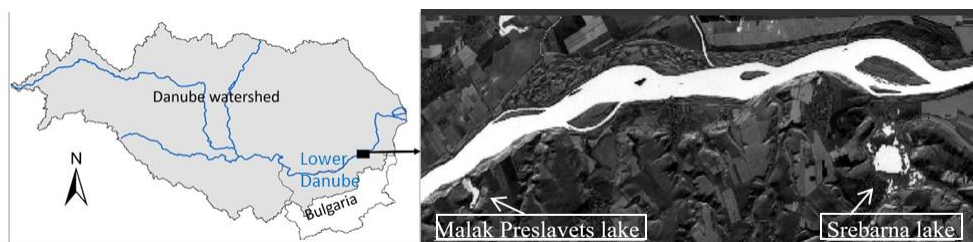
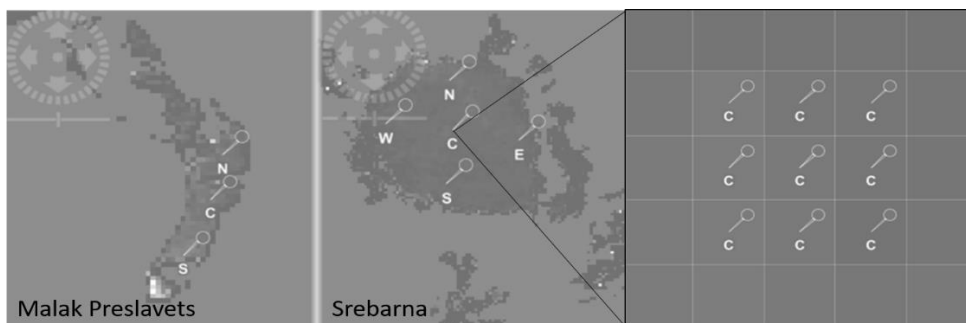


Fig. 1. Case study area: two small, shallow and turbid floodplain lakes - Malak Preslavets and Srebarna

Freely available satellite data were used for assessment of chlorophyll-*a* and total suspended matter (TSM) as indicators of eutrophication process. Sentinel 2 MSI\_L1C products from 15 and 17 of July as well as from 19 and 21 of August were selected and downloaded from [scihub.copernicus.eu](https://scihub.copernicus.eu). The mean time differences between *in situ* sampling and Sentinel-2 MSI sensing were approximately 2 days. The content of both chlorophyll *a* and total suspended matter (TSM) was determined by processing the images in SeNtinel Application Platform – SNAP (v 6.0.5) using

Case-2 Regional Coast Colour (C2RCC) MSI operator, with C2X neural networks recommended for turbid waters. Resampling by 20 m pixel resolution was performed before image processing. Atmospheric correction (AC) was automatically performed in C2RCC processor. *In situ* obtained environmental parameters such as surface water temperature, salinity and altitude were set in C2RCC operator. *In situ* GPS coordinates (Table 1) were used for match-up in pixels selection from Sentinel images, where  $3 \times 3$  pixels were extracted for each sampling station and average values calculated (Fig. 2). *In situ* and satellite data were compared for the two analyzed water quality parameters (chlorophyll-*a* and total suspended matter), based on correlation analysis. T-test comparing two samples for means was used for detecting significant differences in the two sets of data.



*Fig. 2. Images of the Malak Preslavets lake and the Srebarna lake represented in SNAP. Pins indicate the sampling sites. Three sampling sites were selected for the open water area of the Malak Preslavets: N-North, C-Center, S-South (left pane) and five sampling stations were selected for the Srebarna considering its larger open water area: N-North, E-East, S-South, W-west, C-Center (middle pane). Data from  $3 \times 3$  pixels around each station (right pane) were extracted and average values calculated.*

## Results

Higher average depth was recorded along the studied period in the *Malak Preslavets* – 2.26 (SD  $\pm$  0.58) m against 1.82 (SD  $\pm$  0.48) m in *Srebarna* lake (Table 1). Surface water temperature in both lakes registered relatively equal values 27.07 (SD  $\pm$  0.21) °C for *Malak Preslavets*, against 26.47 (SD  $\pm$  0.9) °C for *Srebarna*. Water transparency shows considerably lower values for *Malak Preslavets* 0.47 (SD  $\pm$  0.15) m and relatively higher values for *Srebarna* lake 0.89 (SD  $\pm$  0.12) m. Turbidity was higher in *Malak Preslavets* registering 22.33 (SD  $\pm$  9.5) NTU against 6.17 (SD  $\pm$  1.46) NTU for *Srebarna* lake. Total suspended matter also registered higher values for *Malak Preslavets* 18.61 (SD  $\pm$  7.35) g.m<sup>3</sup>, against 2.95 (SD  $\pm$  1.42) g.m<sup>3</sup> for *Srebarna*. Chlorophyll-*a* estimated higher concentration in *Malak Preslavets* 87.95 (SD  $\pm$  72.93) mg.m<sup>3</sup> and lower concentration in *Srebarna* lake 19.09 (SD  $\pm$  11.12) mg.m<sup>3</sup>.

In seasonal trend average depth of *Srebarna* lake decrease from 1.9 (SD  $\pm$ 0.5) m in July to 1.7 (SD  $\pm$  0.5) m in August, while the depth of *Malak Preslavets* remained unchanged. Surface water temperature (at 0.5 m depth) was also more stable in *Malak Preslavets* with 27 °C in July and 27.13 °C in august, while *Srebarna* lake reported increase from 25.86 °C in July to 27.08 °C in August. *Malak Preslavets* registered significant increase in chlorophyll a concentration, where 21.88 mg.m<sup>3</sup> was measured in July and 154.00 mg.m<sup>3</sup> in August. Increase in chlorophyll a concentration in *Srebarna* Lake was also observed, registering 9.95 (SD  $\pm$  5.45) g.m<sup>3</sup> in July and 28.23 (SD  $\pm$  6.03) g.m<sup>3</sup> in August. The increase of other measured variables: turbidity, total suspended matter and transparency also was more expressed in *Malak Preslavets* compared to *Srebarna* lake.

Table 1. In situ measured water parameters: water temperature, depth, total suspended matter, transparency (Secchi depth), turbidity and chlorophyll-a

	longitude	latitude	pin	sampling date	surface water temperature °C	CHL_a (mg.m <sup>3</sup> )	TSM (g.m <sup>3</sup> )	turbidity (NTU)	Secchi depth (m)	depth (m)	
in situ data	Malak Preslavets	26.83847	44.09422	N	18.07.2018	27	10.37	7.8	11	0.7	3.0
		26.83748	44.09187	C	18.07.2018	27	21.72	17.4	16	0.6	2.0
		26.83648	44.09043	S	18.07.2018	27	33.57	13.0	15	0.6	1.8
		26.83847	44.09422	N	20.08.2018	27	161.41	27.3	31	0.3	3.0
		26.83748	44.09187	C	20.08.2018	26.9	145.12	21.5	32	0.4	2.0
		26.83648	44.09043	S	20.08.2018	27.2	155.49	24.8	30	0.4	1.8
	Srebarna	27.07210	44.10745	C	18.07.2018	25.9	3.55	4.2	5	1.0	2.3
		27.07210	44.11105	N	18.07.2018	26.2	14.81	1.3	6	1.1	2.6
		27.06660	44.10764	W	18.07.2018	24.6	4.74	1.4	5	1.0	1.6
		27.07184	44.10349	S	18.07.2018	26.2	14.81	2.0	6	0.9	1.6
		27.07760	44.10709	E	18.07.2018	26.4	11.85	2.4	5	1.0	1.5
		27.07210	44.10745	C	20.08.2018	26.9	29.62	3.1	7	0.9	2.1
27.07210	44.11105	N	20.08.2018	26.3	17.77	2.0	5	0.9	2.4		
27.06660	44.10764	W	20.08.2018	28	33.57	5.4	9	0.6	1.4		
27.07184	44.10349	S	20.08.2018	27.2	32.58	4.8	8	0.8	1.4		
27.07760	44.10709	E	20.08.2018	27	27.64	2.8	7	0.9	1.3		

Results from the satellite data analysis also registered lower concentrations of both chlorophyll-*a* and total suspended matter in the *Srebarna* Lake, compared to higher values in *Malak Preslavets* (Table 2). Seasonal trend confirmed increasing concentrations of the chlorophyll-*a* and total suspended matter from July to August (Table 2).

Table 2. Average values of chlorophyll *a* and total suspended matter retrieved from 9 pixels matched-up to coordinates of sampling sites. Sentinel 2 MSI LIC products processed in SNAP, and C2RCC processor.

		longitude	latitude	pin	sensing date	CHL_a (mg.m <sup>3</sup> )	TSM (g.m <sup>3</sup> )	CHL_a_unc	TSM_unc
Sentinel 2 MSI C2RCC C2X	Malak Preslavets	26.83847	44.09422	N	15.07.2018	37.06	43.9	4.44	2.4
		26.83748	44.09187	C	15.07.2018	28.51	29.2	3.17	4.8
		26.83648	44.09043	S	15.07.2018	67.57	61.5	6.92	4.6
		26.83847	44.09422	N	19.08.2018	54.82	74.1	5.95	1.2
		26.83748	44.09187	C	19.08.2018	66.85	92.9	7.14	1.1
		26.83648	44.09043	S	19.08.2018	67.71	84.7	7.30	1.6
	Srebarna	27.07210	44.10745	C	17.07.2018	34.50	36.1	4.00	5.9
		27.07210	44.11105	N	17.07.2018	57.52	47.1	6.42	8.4
		27.06660	44.10764	W	17.07.2018	24.93	20.6	3.07	4.4
		27.07184	44.10349	S	17.07.2018	32.70	25.7	4.17	6.6
		27.07760	44.10709	E	17.07.2018	37.83	38.8	4.42	6.7
		27.07210	44.10745	C	21.08.2018	38.40	37.2	4.83	4.9
		27.07210	44.11105	N	21.08.2018	53.96	49.2	6.40	5.5
		27.06660	44.10764	W	21.08.2018	40.80	42.5	4.89	6.1
27.07184	44.10349	S	21.08.2018	45.78	77.6	5.47	4.1		
27.07760	44.10709	E	21.08.2018	35.65	82.5	3.78	3.5		

Satellite data reveal significant changes in concentration of chlorophyll and suspended matter in temporal scale (Fig. 3). Detailed information based on 244 pixels for the open area of *Malak Preslavets* and 2 144 pixels for the open water of *Srebarna* Lake outline well pronounced spatial heterogeneity for both lakes (Fig. 3).

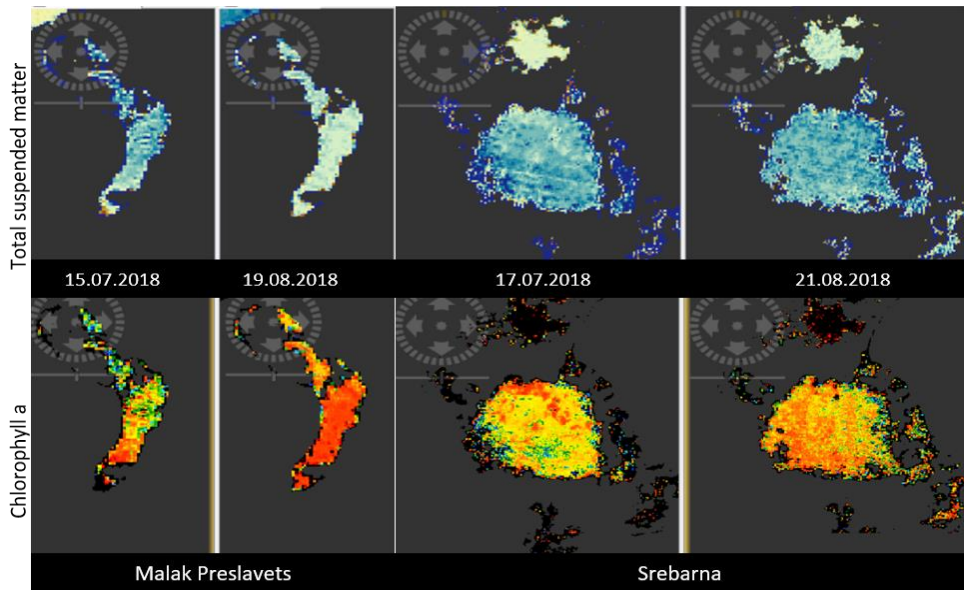


Fig. 3. Sentinel MSI images processed in SNAP representing chlorophyll a and total suspended matter retrieved by C2RCC operator using C2X neural networks. Malak Preslavets register higher concentration for both parameters chlorophyll a and total suspended matter than Srebarna lake. See the image from 19.08.2018 (on the left pane).

Correlation analysis revealed moderate relationship of concentration of total suspended matter between *in-situ* and satellite data ( $r = 0.57$ ,  $p = 0.022$ ,  $n = 16$ ). Stronger relationship was determined for chlorophyll values ( $r = 0.66$ ,  $p = 0.005$ ,  $n = 16$ ) (Fig. 4). However, less than 44% of the dispersion in chlorophyll data was explained comparing *in-situ* and satellite results, while only 32% of the dispersion was explained for total suspended matter (Fig. 4).

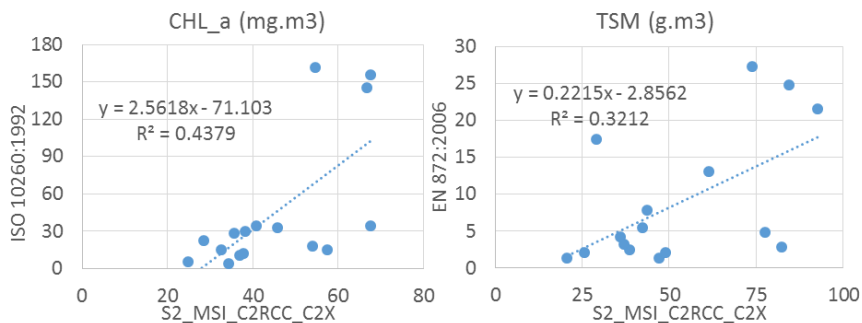


Fig. 4. Correlation between *in situ* values of chlorophyll a (left) and total suspended matter (right) against Sentinel 2 MSI data retrieved from C2X algorithm in C2RCC processor

Chlorophyll a concentration revealed similar mean values between Sentinel 2 data - 45.28 (SD  $\pm$ 14.22) mg.m<sup>3</sup> and *in situ* data – 44.91 (SD  $\pm$ 55.06) mg.m<sup>3</sup> (Fig. 5). However, *in situ* data set showed significantly higher variation, compared to Sentinel-2 data. Contrary, the total suspended matter revealed clear differences comparing the mean values obtained by the two methods. *In situ* samples registered mean values of 8.82 (SD  $\pm$ 8.98) g.m<sup>3</sup>, while the Sentinel-2 C2X data set retrieved almost six folds higher mean values of 52.73 (SD  $\pm$  22.98) g.m<sup>3</sup> (Fig. 5).

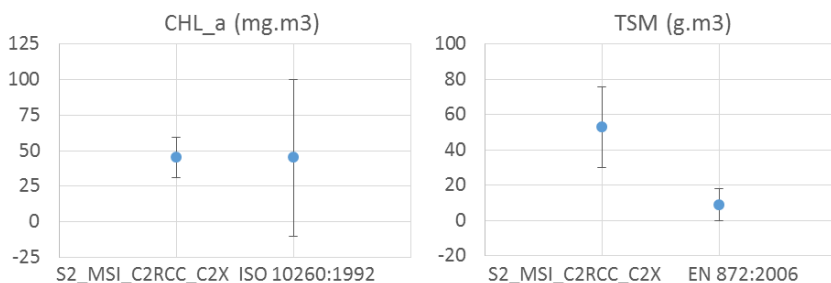


Fig. 5. Comparison between *in situ* values for chlorophyll a (left) and total suspended matter (right) against Sentinel 2 data based on C2RCC processor and C2X algorithm

T-test Paired Two Sample for Means, comparing chlorophyll-a concentration between both methods did not showed significant differences (t-stat = 0.03, one-tail p value = 0.49, t-Crit. = 1.75, n = 16). Contrary the total suspended matter registered significant differences between the two data sets (t-stat = 9.07, p < 0.001, t-Crit. = 2.13, n = 16).

## Discussion

*In situ* data showed high values of chlorophyll-a and low water transparency indicating hypertrophic conditions of *Malak Preslavets*. Due to embankment, the water level of *Malak Preslavets* was significantly raised compared to *Danube* water level and no flood process occurs. The nutrient input from the local watershed is entrapped in the lake causing progressive eutrophication. Eutrophic state was registered in *Srebarna* Lake. The result confirmed last investigations [11, 13], indicating sustainable improvement of the environmental conditions as a result of maintenance of maximum water level and water volume.

Both methods showed pronounced spatial heterogeneity, especially in *Srebarna* Lake considering its larger surface water area. However, the concentration of chlorophyll a obtained by satellite data showed lower trophic state comparing to *in situ* data. The average time differences between the date of field sampling (*in situ* data) and remote sensing date (satellite data) was about 2 days. Taking into account that water parameters can change over a short period due to dynamic weather



conditions (mainly the strength and direction of the wind) reduction in data comparability could occurred.

Comparison of total suspended matter revealed higher values retrieved by satellite data. Concentration of coloured dissolved organic matter could also affect light absorption hereafter the values of measured parameter. Considering the small depth to transparency ratio of 3.22 and its high variability ( $SD \pm 2.09$ ), bottom reflectance also may have an influence on the water-leaving signal in the investigated shallow waters [10]. High density of submerged macrophytes in *Srebarna* [11], together with the large amount of suspended matter also could affect the light attenuation and colour of the water [12]. Hereafter, due to complex optical properties of turbid waters overestimation of total suspended matter is still in concern [9], therefore *in situ* studies have important role in local data verification.

## Conclusion

Lake *Srebarna* experienced eutrophic conditions, indicating stabilization of the trophic status compared to previous years. On the other hand, in august 2018 *in situ* data revealed hypertrophic conditions in *Malak Preslavets*. The assessment of chlorophyll-*a* concentration according to both methods (satellite and *in situ*) showed comparable results. Contrary, six-fold higher concentration of the total suspended matter was determined by the satellite images and the used C2RCC operator, rather *in situ* obtained data. Nevertheless, remote sensing i.e. Sentinel 2 MSI data, emerged as valuable supportive tool for water quality monitoring, considering local validation.

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**ОЦЕНКА НА ТРОФИЧЕН СТАТУС НА МАЛКИ МЪТНИ ЕЗЕРА  
ЧРЕЗ СРАВНЕНИЕ НА НАЗЕМНИ И ДИСТАНЦИОННИ МЕТОДИ  
НА ИЗСЛЕДВАНЕ: ЧАСТЕН СЛУЧАЙ ОТ ЗАЛИВНАТА ТЕРАСА  
НА ДОЛЕН ДУНАВ**

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**Резюме**

Целта на проучването е да се оцени трофичното състояние на малки, плитки и мътни езера, сравнявайки *in situ* данни и данни от сателитни изображения. Обекти на изследване са езерата „Малък Преславец“ и „Сребърна“,

разположени заливната тераса на Долен Дунав. За оценка на трофичното състояние са използвани основни параметри за качество на водната среда като хлорофил-а, общо суспендирано вещество, прозрачност и мътност. Два от параметрите: хлорофил-а и общо количество суспендирана материя са използвани за сравнение с данни от сателитни изображения от продукти MSI L1C на сателитите Sentinel, с помощта на SeNtinel Application Platform (SNAP, v. 6.0). *In situ* резултатите индикират еутрофни условия в езерото „Сребърна“, докато в „Малък Преславец“ се регистрират хипертрофни условия. Сравнявайки резултатите от *in situ* и сателитните данни, и двата метода показват умерена корелация ( $r = 0.66$ ) и съпоставими стойности в концентрацията на хлорофил-а. Стойностите на суспендирани вещества показва умерена корелация ( $r = 0.57$ ) между двата метода. По отношение на суспендираните вещества резултатите, получени от сателитните данни, значително надценяват *in situ* резултатите. Продуктите на Sentinel 2 MSI, се очертават като перспективен източник на данни за околната среда, но е препоръчително резултатите от спътниците да се потвърдят от наземни данни.