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Satellite Assisted Water Quality Monitoring: A Case Study of Artificial Lakes in Serbia

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Abstract
The present study provides comparative data on water quality parameters obtained by both, satellite and field monitoring. Two artificial lakes in Serbia were covered: the Vrutci and the Barje Reservoir (Serbia). Obtained data should be used to improve operations of municipal drinking water treatment plants, both for decision-makers and operators. Comparative data should ensure a quality of the results obtained, as well as harmonize with the proposed requirements for reservoirs intended for drinking water supply. The results of (i) satellite-assisted monitoring (with user's monitoring) of reservoir water quality, and (ii) a national reservoir status monitoring program (aligned with the Water Framework Directive, 2000/60/EC), present a true example of coupled modern water monitoring in the drinking water sector.
Keywords: *water quality, artificial lakes, satellite monitoring, field monitoring*

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I. INTRODUCTION

A historical review indicates that the first satellite photographs of the Earth were taken in 1959 by the American satellite Explorer 6, which was a challenge for the Soviets, who responded in 1962 with photographs from their satellite Kosmos. The United States responded by launching the Landsat program in 1972, the largest program to collect images of the Earth from space. Europeans later joined in with France launching satellite SPOT (Satellite Pour l'Observation de la Terre) in 1986, equipped with cameras with different types of sensors [1].

Little order in this space race was introduced by the United Nations Resolution (No. 41/65) passed in 1986. The principles of this resolution state that "remote sensing means the monitoring of the Earth's surface from space using the properties of emitted electromagnetic waves, reflected or diffracted by the observed objects, in order to improve natural resource management, land use and environmental protection" while also "remote sensing activities will be conducting for the benefit and interest of all countries, regardless of the degree of their economic, social or scientific and technological development and taking into account in particular the needs of developing countries" [2].

Half a century since the first photographs, a large number of different data today can be obtained with modern multispectral sensors from satellite imagery, and users have to download, position and analyse them against the subject of research and to interpret it in an appropriate and professional manner. Satellite technologies have become so powerful and accessible that this type of observation and analysis is becoming an integral part of multidisciplinary environmental research, to the extent that in the near future, together with terrestrial information and communication technologies, will be an integral part of information system for data management and decision making [3].

In this paper, the results of satellite assisted water quality monitoring are presented as a part of user' participation in the development of SPACE-O platform, which currently operates as a prototype - an IT product is at developing stage. Presently, testing, upgrading and adapting to actual operational conditions are being carried out to ensure that all options are in accordance with the proposed requirements in the drinking water supply sector.

The SPACE-O platform [4], including Water Information System (WIS) as its component, integrates modern satellites and *in situ*-measured water quality data. How does the whole process work? At the same time when *in situ* measurements are carried out, the satellite collects spatial and weather data from reservoirs and their catchment areas. Afterwards interpretation of satellite signals for mapping water quality is performed (based on spectral range corresponding to a certain concentration values).

A review of data analysis is necessary for preparation of the Water Quality Reports in order to improve decision-making process in reservoir management. For the Republic of Serbia, those Reports are created by the SEPA (Serbian Environmental Protection Agency), a national authority conducting water, air and soil monitoring programmes.

II. MATERIAL AND METHODS

The Water Information System (WIS) integrates modern satellite-derived and *in situ*-measured in the field data on water quality monitoring in order to improve decision-making process in reservoir management. The following water quality parameters were measured:

- Turbidity (TUR) is a key parameter of water quality linearly related to the backward scattering of light of organic and inorganic particles in water. The measurement unit is Nephelometric Turbidity Unit [NTU].
- Secchi-Disc-Depth (SDD) in [m] indicates the clarity in the water column.
- Chlorophyll-*a* (CHL). Satellite-derived chlorophyll-*a* derives from information of in-water organic absorption, in-water turbidity and spectral characteristics of the corresponding water body.

Satellite data was processed using a modern system (Modular Inversion and Processing System, MlP) developed by EOMAP [5] using data from two satellites, Sentinel-z A/B and Landsat 8 [4, 5, 6].

The sampling points for *in situ* measurements are matched with the satellite ones: A1-near the dam, B1-central part of reservoir, C1-entrance to reservoir. The sampling sites near the dam (A1 point) at the Vrutci reservoir are shown in Figure 1a, and the Barje reservoir in Figure 1b respectively.

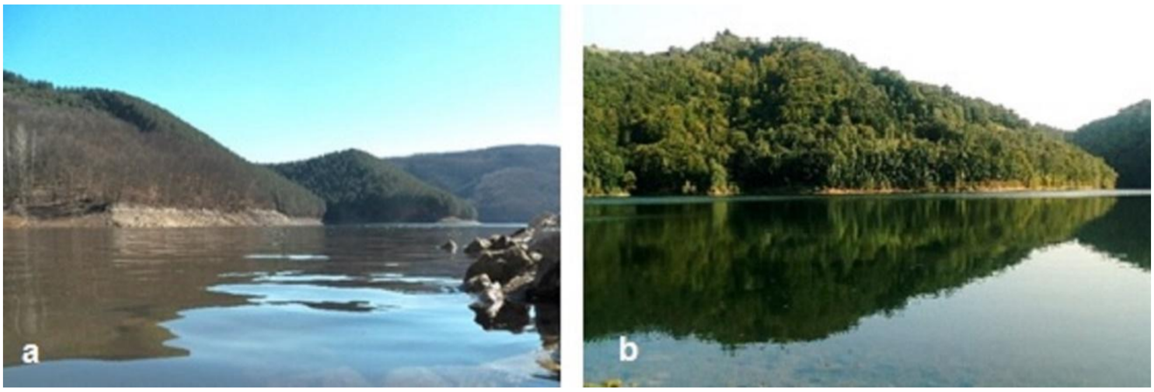

Figure 1: a) Vrutci Reservoir, b) Barje Reservoir (sampling point A1, near the dam)

III. RESULTS AND DISCUSSION

In the present study we provide data obtained by both, satellite assisted and field monitoring, for three water quality parameters (TUR, SDD, CHL) monitored in the Vrutci and the Barje reservoirs (Serbia). Also additional physical parameter (water temperature - T °C) was included.

The spectral distribution of satellite-measured parameters at sampling points (A, B, C) of the Vrutci and the Barje reservoirs are shown (Figures 2-5). The spectral range for each water quality parameter (TUR in [NTU], CHL in [µg/l], and SDD in [m]) is given as a legend.

Measuring points in the Vrutci and the Barje reservoirs are provided in the RGB („True color“) figures (Figures 2-5). Spectral distribution revealed that Secchi-Disc-Depth (SDD) is slightly variable parameter along both reservoirs. The values obtained for all other measured parameters varied in small degree along both reservoirs, particularly Turbidity-TUR (Figures 2-5).

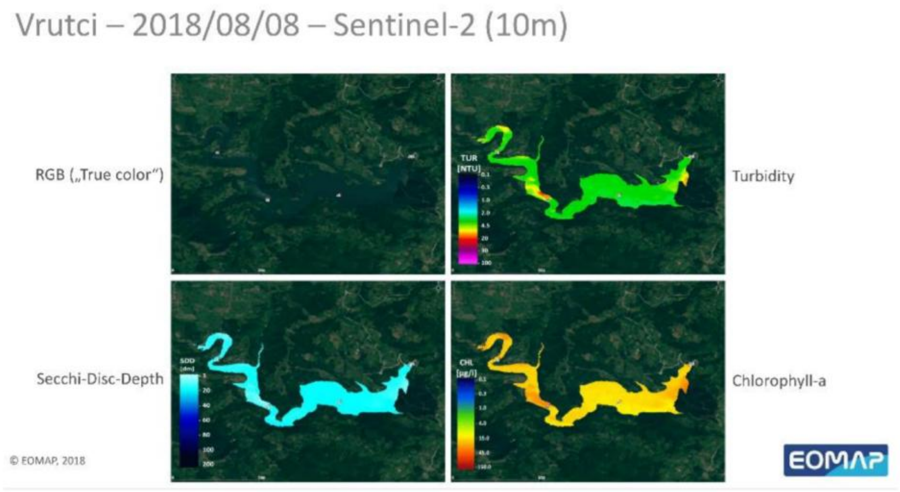

Figure 2: Map of satellite-monitored parameters in the Vrutci Reservoir (Sentinel-2, 10m) on August 08, 2018

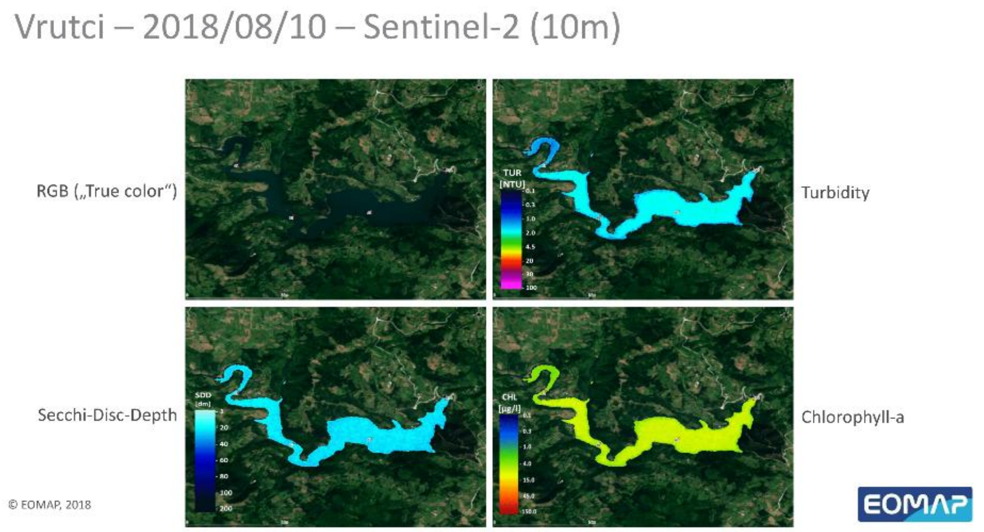

Figure 3: Map of satellite-monitored parameters in the Vrutci Reservoir (Sentinel-2, 10m) on August 10, 2018

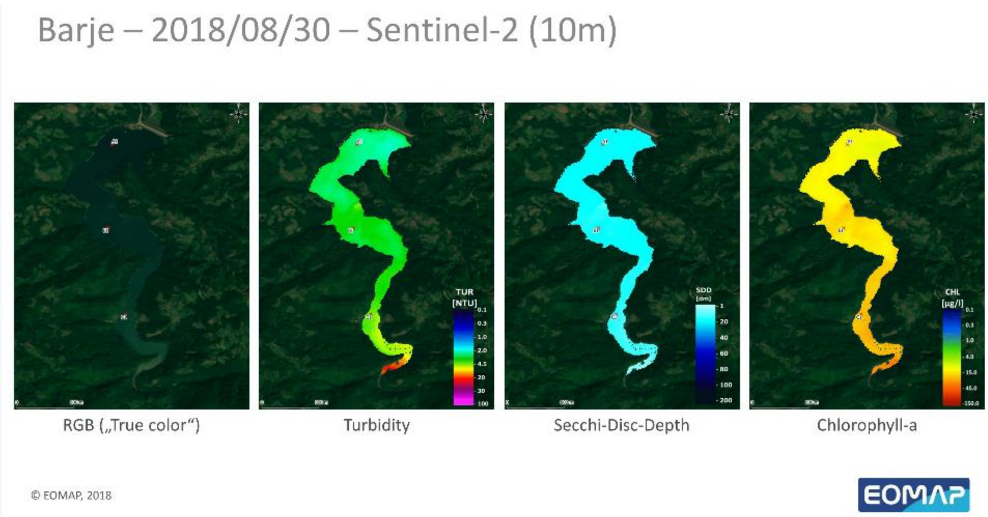

Figure 4: Map of satellite-monitored parameters in the Vrutci Reservoir (Sentinel-2, 10m) on August 30, 2018

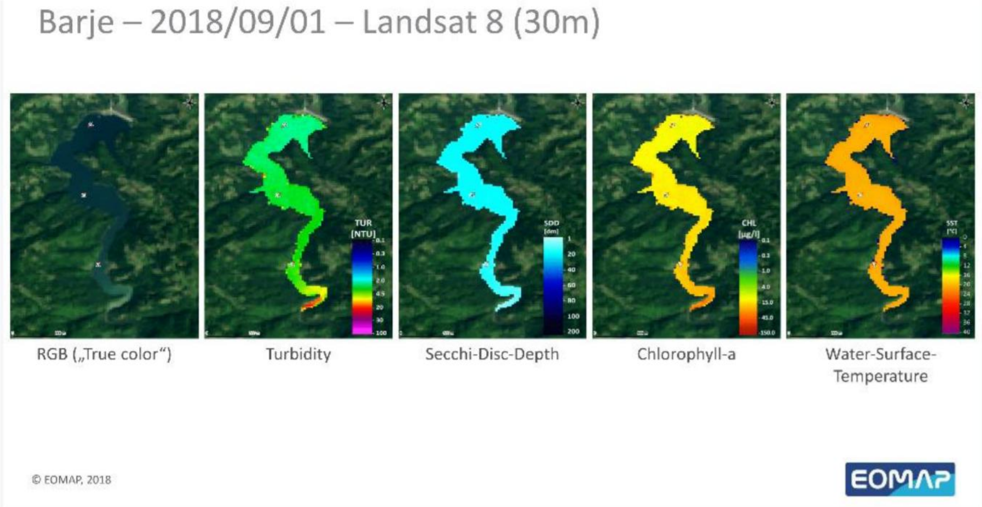

Figure 5: Map of satellite-monitored parameters in the Vrutci Reservoir (Landsat 8, 30m) on September 1, 2018

Validation plots related to *in situ*- [7] and satellite-measured parameters (TUR, SDD, CHL, CHL cal. and SST) are provided (Figures 6-10) [5]. *In situ* measurements were carried out at three different depths (50, 200 and 250 cm) at all sampling points in both reservoirs, except for the SDD (target detection method). The satellite-derived measurements are marked as followed: Parameter_Sat_1 and Parameter_Sat_2 respectively (Figures 6-10).

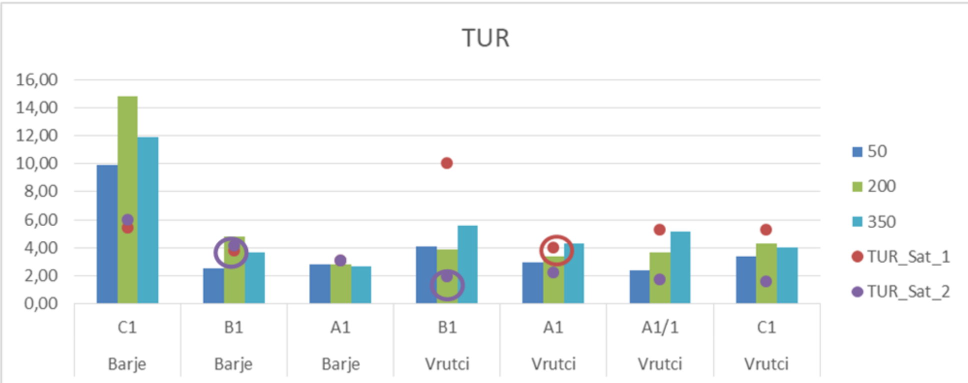

Figure 6: Validation plot for turbidity (TUR) at sampling points of the Vrutci and the Barje reservoirs

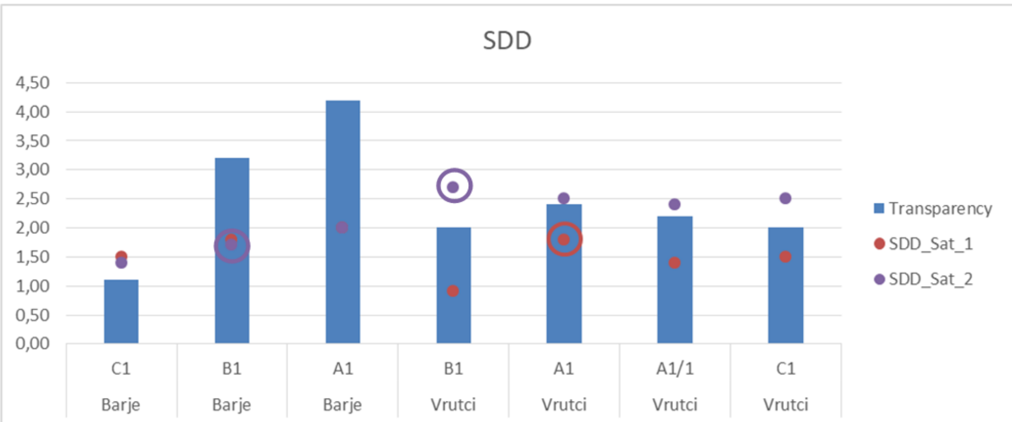

Figure 7: Validation plot for Secchi-Disc Depth (SDD) at sampling points of the Vrutci and the Barje reservoirs

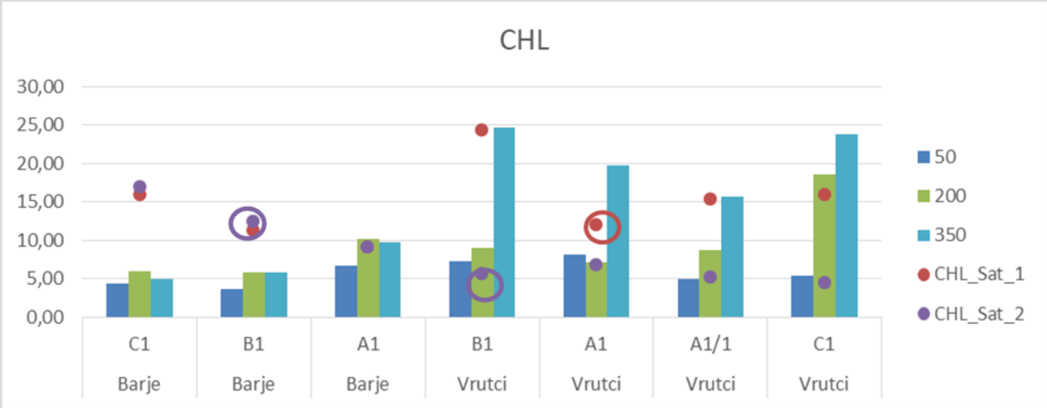

Figure 8: Validation plot for chlorophyll-*a* concentration (CHL) at sampling points of the Vrutci and the Barje reservoirs

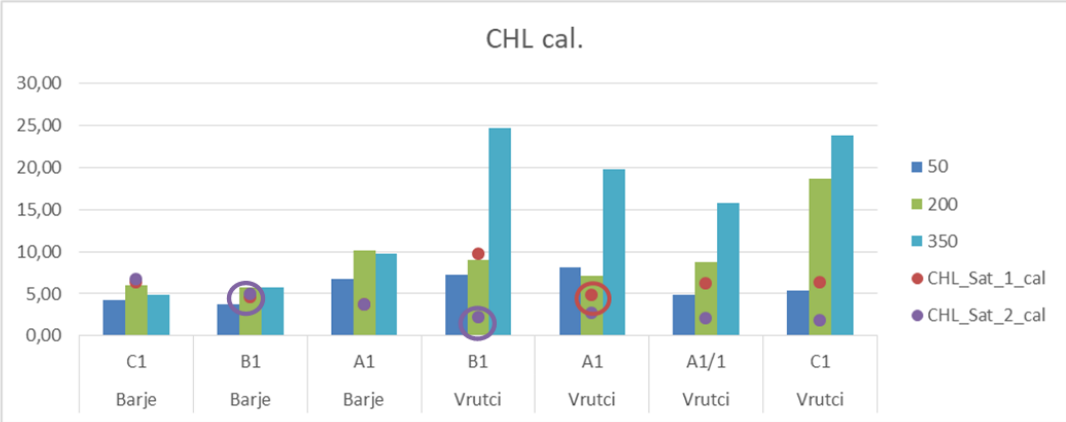

Figure 9: Validation plot for chlorophyll-*a* concentration by calibration method (CHL cal.) at sampling points of the Vrutci and the Barje reservoirs

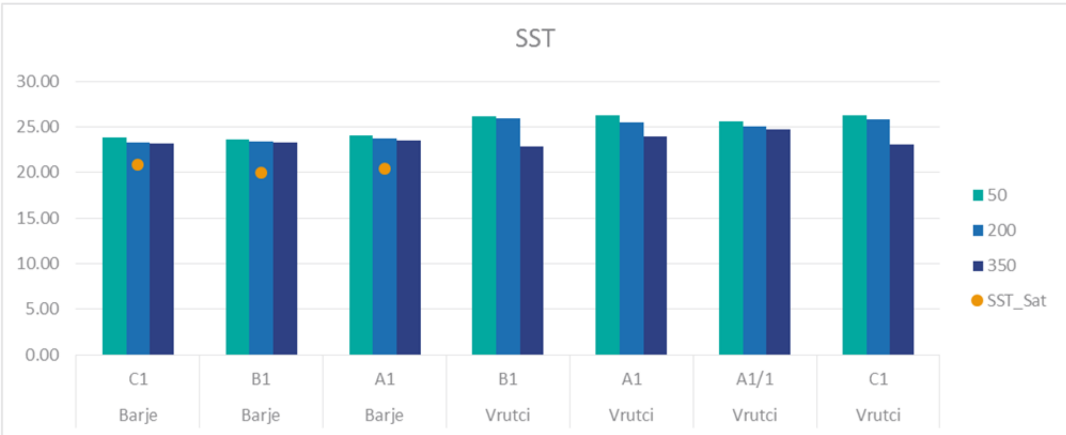

Figure 10: Validation plot for SST, surface water temperature (°C) at sampling points of the Vrutci and the Barje reservoirs

The data on *in situ* measurements [7] are provided (matched sampling locations and dates with satellite-monitored ones). Only in the Barje Reservoir, one additional sampling point was covered (A1/1) which was located nearby the sampling point A1, and regarded as a control point for measurements in vertical profile of the reservoir. Minimal (min), average (av) and maximal (mx) values of measured parameters (water temperature, turbidity, Secchi-disc-depth, chlorophyll-*a* obtained by the field monitoring at all sampling points in August 2018 are given for the Vrutci Reservoir (Table 1) and the Barje Reservoir (Table 2) respectively.

The parameters were measured in water column (in the Vrutci Reservoir 0.5-32 m, and in the Barje Reservoir 0.5-30 m respectively).

Additionally, we provided the data obtained by *in situ* monitoring [7] for parameters relevant to occurrence of algal bloom. Minimal (min), average (av) and maximal (max) values of the following parameters (TN-Total Nitrogen, TP-Total Phosphorus) as well as the percentage participation of cyanobacteria in total algal community, at all sampling points in August 2018 are given for the Vrutci Reservoir (Table 1) and the Barje Reservoir (Table 2) respectively.

Table 1: *In situ*-measured parameters of the Vrutci Reservoir

Parameter/sampl. point	A1			A1/1 (control point)			B1			C1		
	min	av	max	min	av	max	min	av	max	min	av	max
Water Temperature (ºC)	7.5	17.9	26.2	7.6	17.5	25.6	9.9	19.2	26.1	16.6	20.6	26.2
Turbidity (NTU)	1.18	3.03	8.49	1.00	4.01	15.70	2.14	3.47	5.61	2.98	3.69	4.48
Secchi-Disc-Depth (m)	2.40	2.40	2.40	2.20	2.20	2.20	2.00	2.00	2.00	2.00	2.00	2.00
Chlorophyll-*a* (mg L-1)	1.50	21.87	74.50	2.4	21.67	106.9	2.1	21.59	49.7	3.4	13.85	27.0
TN (mg L-1)	0.31	0.585	0.77	0.38	0.551	0.77	0.30	0.638	1.40	0.33	0.482	0.70
TP (mg L-1)	0.026	0.0526	0.105	0.029	0.0744	0.195	0.051	0.0937	0.252	0.029	0.0505	0.073
Cyanobacteria (%)	0.00	20.06	49.50	1.38	53.14	88.15	0.26	2.433	6.30	0.00	0.5033	1.51

Table 2: *In situ*-measured parameters of the Barje Reservoir

Parameter/sampl. point	A1			B1			C1		
	min	av	max	min	av	max	min	av	max
Water Temperature (ºC)	10.3	19.9	24.0	10.8	20.5	23.6	22.1	23.0	23.8
Turbidity (NTU)	2.47	4.75	11.60	2.53	9.02	17.30	9.89	21.09	61.40
Secchi-Disc-Depth (m)	4.20	4.20	4.20	3.20	3.20	3.20	1.10	1.10	1.10
Chlorophyll-*a* (mg L-1)	2.6	6.71	18.1	2.10	4.72	12.60	2.10	4.39	6.00
TN (mg L-1)	0.82	0.979	1.43	0.71	0.902	1.20	0.71	0.829	0.96
TP (mg L-1)	0.022	0.0716	0.157	0.032	0.0776	0.115	0.035	0.0504	0.091
Cyanobacteria (%)	1.57	36.863	77.58	0.00	37.865	84.77	0.00	26.557	44.06

Maximum values of percentage participation of cyanobacteria in the total algal community were detected at A1/1 (control point) in the Vrutci Reservoir (88.15%), B1 (84.77%) and A1 (77.58%) sampling points in the Barje Reservoir respectively, which regarded as very high, dominated by cyanobacterial taxa in algal communities.

The natural process of eutrophication is accelerated by human activities worldwide that interrupt nutrient biogeochemical cycles [8]. Control of nutrients, mainly nitrogen (N) and phosphorus (P), plays a significant role in preventing cyanobacterial blooms (harmful algal blooms (HABs)) [9]. Harmful algal blooms (HABs), specifically those caused by cyanobacteria, have become one of the most critical concerns for drinking water supply, as well as for maintaining the ecological and economic sustainability of freshwater ecosystems worldwide [10, 11]. Eutrophication is the major process stimulating the growth of algal and cyanobacterial biomass, the key factors here being the maintaining of a high availability of important nutrients, such as phosphorus (P) and nitrogen (N), and also a low N/P ratio [12, 13]. Cyanobacterial blooms are predicted to become even more common due to climate warming [11, 14].

Regarding drinking water supply, major reasons for the strong impact of cyanobacterial blooms are that large algal blooms tend to clog the treatment process. They also cause unpleasant smells, may produce toxins [15, 16, 17], and are difficult to remove [18]. Hence, to meet future challenges with respect to ecosystem services, such as the provision of clean drinking water, it is crucial to reduce the input of nutrients to aquatic ecosystems [19, 20, 21].

Early warnings related to cyanobacterial bio-volume populations support an appropriate and effective response to the occurrence of potentially harmful algal blooms. The estimated population of cyanobacteria compares with the levels of low and medium risk. Those levels are defined by the recommendation of the World Health Organization [10], and corresponds to the abundance of 20,000 cells mL^{-1} and 100,000 cells mL^{-1} of cyanobacteria, respectively. These indicators enable the optimization of water treatment processes at water treatment plants using accurate short-term forecast information on water quality, and a better understanding of environmental challenges through the integration of satellite, in-situ and modelled data [22].

Basically, the issue of risk now opens up as a central issue in the decision-making process. The decision-making process can be characterized as part of the process of managing a system, which makes decisions about the choice of management activities necessary for system operations. Planners and designers of water infrastructure systems have long recognized that risk is inseparable from the work they do. Risk is involved in engineering in many ways, in determining how much effort and resources should be considered during the development (planning and design) of an engineering systems to prevent hazards or damage, or in providing an acceptable level of risk to the system. Also, it can be used to choose which events or conditions should be considered during the system operations to prevent damage that could occur, despite the analysis conducted during the planning and design of the system [23, 24].

Therefore, the place of monitoring (as a feedback) in the concept of decision making and management of a system/process is essential, while the WIS module of SPACE-O satellite-supported platform is certainly an advanced part of the process state monitoring, i.e. presents water status feedback. The decision maker forms his/her perception of the process (process model) he/she manages, which is the process of water supply, based on that he defines what he/she should do (control algorithm) and finally takes some management action or not (control action) [25, 26].

IV. CONCLUSION

Satellite-supported environmental research becomes an indivisible part of global monitoring of the entire planet globe. The satellite-supported platform SPACE-O for water quality forecast in order to optimize decision-making process in the water supply sector and the management of the process is an example of a step forward in the future. This is particularly important for reservoirs which are intended for water supply, as it can provides various spatial and weather data.

The study provides a comparative data of water quality parameters measured in two artificial lakes in Serbia (the Vrutci - W Serbia and the Barje - SE Serbia), and it should be contribute transferability to water supply system analysis, as well as the improvement the decision-making process from the reservoirs to the drinking water treatment plant.

In this study the following satellite assisted water quality parameters were measured: chlorophyll-*a*, turbidity, Secchi-disk depth/transparency and surface water temperature. The data obtained by satellite were compared with *in situ* measurements and it had a high degree of matching. The comparative data should be used as a suitable “tool” to ensure the confidence of measurements analyzed *in situ* and in the field respectively, in terms of data validation management improvement.

The results of the conducted operational monitoring of eight reservoirs intended for water supply in Serbia in the 2012-2016 period showed that there was no reservoirs with maximum and good/better ecological potential, and that moderate ecological potential was found in three, poor ecological potential in three, and poor ecological potential in two reservoirs [27].

In this regard, we consider that three monitoring types, namely:

(1) Satellite-based monitoring, together with

(2) Local User Monitoring Programme (a water quality of the reservoirs as the source of water, and during the process of water treatment from input to output), and particularly with the

(3) National Water Monitoring Programme conducted by the SEPA and harmonized with the WFD 2000/60/EC recommendations,

represent a good example of integrated/coupled water monitoring in the drinking water supply sector.

The current state of water quality in reservoirs for water supply in the world, with a deteriorating trend under the influence of climate change, is reflected in the degree of efficiency of treatment plants and the quality of drinking water as well. Satellite-supported water quality monitoring contributes to improving decision-making in the water supply management process, and thus supports public health improvements.

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