GŁUSZYŃSKIE LAKE WATER QUALITY ASSESSMENT USING SENTINEL-2 DATA

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Abstract

Traditional inland water monitoring is time and labor consuming, as well as expensive. Additionally, on its basis, only point values are obtained. Sometimes only single value represents the whole lake water quality. In the literature many remote sensing measurement based formulas for water quality parameters can be find. Ocean and marine waters are better recognized in this area. However, also for inland water some formulas can by find in literature. In this study selected formulas for 4 water quality parameters (biological oxygen demand, dissolved organic carbon, chlorophyll concentration and electrical conductivity) were applied for two-year (only vegetation season) series of Sentienl-2 images registered over the Głuszyńskie Lake, Poland. Results were validated based on measurements conducted in 2021-10-08 (one day before Sentienl-2 acquisition). Two from four validated parameters strongly correlated (R^2=0.61 for DOC and R^2=0.84 for EC) with field data. However, coefficients of this relationship shows that formulas from literature can show spatial distribution of these parameters and hotspots, but for correct quantitative estimation further analysis should be done to adapt formulas for local conditions.

Keywords: inland water, Biological Oxygen Demand (BOD), Dissolved Organic Carbon (DOC), electrical conductivity, chlorophyll

INTRODUCTION

Traditional analysis of water quality samples in the laboratory are very expensive, as well as labor and time consuming, which often makes it impossible to obtain representative results over large lakes. The development of a remote sensing analytical formulas is contributing to the efficient and regular control of potentially contaminated inland waters. The selection of data for remote monitoring of inland, sea and ocean waters is depended on the size of the research object. For larger research objects spatial resolution is less important than for smaller one. Apart from the resolution of the images, the main problem is the higher amounts of optically active substances (absorbing and scattering radiation) found over inland waters. This makes it difficult both to perform atmospheric correction and to model the water quality itself (Attila et al., 2013; Odermatt et al., 2012). Currently, there are many more developed methods for monitoring the quality of ocean waters (Gregg et al., 2004). Nevertheless, remote sensing modeling of inland waters is the subject of many studies and giving higher and higher accuracies (Dörnhöfer et al., 2016). Monitoring of inland waters is an important issue in the context of the threat to the quality of surface waters. It can be conducted with the use of satellite and aerial data, including UAV (unmanned aerial systems), with both passive and active methods.

This paper focused on applying existing formulas for water quality estimation for the Lake Głuszyńskie located in the central Poland. We analyzed Setniel-2 data registered in two-year period (2020 and 2021) for estimate spatial and temporal changes of selected water quality parameters. Results from the last satellite image (2021-10-09) were validated based on field measurements conducted day before. This work is an initial step for developing remote sensing monitoring of inland waters in Poland.

METHODOLOGY

Study was conducted in the Głuszyńkie Lake, central Poland. The Głuszyńskie Lake is located near Radziejów in the Kujawskie Lake District in the Kujawsko-Pomorskie Voivodship (Fig. 2). The neighborhood of the Lake is one of the most intensively used agricultural areas in Poland, and consequently, a lake is under pressure of agriculture source pollution, especially in north of a lake catchment. The Głuszyńskie Lake is included in State Environmental Monitoring of Surface Water. Based on monitoring results the high nitrate concentration in spring and after intensive rains in north part of the lake was identified. Currently, over 50% of the shoreline is occupied by recreational areas with holiday cottages. This creates threat to the water quality of the lake, as it develops without any legal or formal regulations for water and sewage management.

In this paper Sentinel-2 L1C products with relatively low cloud cover (less than 20%) where directly downloaded from Open Access Hub (https://scihub.copernicus.eu/dhus/#/home) and preprocessed using sen2r R package (Ranghetti et al. 2020). Package allow to calculate Bottom-Of-Atmosphere (BOA) reflectance images using Sen2Cor processor. Finally, 17 Images form vegetation season (from May to September) 2020 and 2021 were used in analyses.

Based on BOA reflectance 4 water quality parameters were calculated according formula found in literature (equation 1-4). If original formula is based on different spectral bands than registered by Sentinel-2, the closest band from Sentinel-2 was selected.

Biological Oxygen Demand (BOD) was calculated according (Słapińska et al. 2016):

$$BOD = -141.51 \cdot [(B4-B5)/(B4+B5)]+39.62 \quad (\mathbf{1})$$

Dissolved Organic Carbon (DOC) was calculated according (Potes et al. 2018):

$$DOC = 432 \cdot \exp[-2.24 \cdot (B3/B4)] \quad (\mathbf{2})$$

Chlorophyll concentration (CHL) was calculated according (Osińska-Skotak 2010):

$$CHL = 75.821 \cdot (B5/B4)-42.644 \quad (\mathbf{3})$$

Electrical Conductivity (EC) was calculated according (Abdelmalik 2018):

$$EC = 0.1252 \cdot [(B11/B8) \cdot B12]^2 + 4.1531 \cdot [(B11/B8) \cdot B12] + 10.527 \quad \textbf{(4)}$$

where: BN is reference to BOA reflectance in Sentinel-2 bands.

The same parameters were measured in laboratory based on field campaign conducted on 2021-10-08. Total 12 water samples were investigated (Fig. 2) in laboratory.

RESULTS

Based on calculation of temporal (Fig. 1) and spatial (showed only for selected date – 2020.07.01 on Fig. 2) variability of all 4 parameters has been determined.

The highest values of BOD were observed on 2020-07-01 (median equal to 61 $mgO_2 \bullet l^{-1}$), also, on 2021-10-09 (median equal to 51 $mgO_2 \bullet l^{-1}$) median BOD was above 50 $mgO_2 \bullet l^{-1}$. Besides that, dates median values varied from 25 to 50 $mgO_2 \bullet l^{-1}$ (Fig. 1). For all dates similarly to 2020-07-01 (Fig. 2) lowest BOD values were observed in the North part of the lake.

The highest values of DOC were observed on 2020-05-22 (median equal to 35 $mg \bullet l^{-1}$), also, on 2021-07-14 (median equal to 22 $mgO_2 \bullet l^{-1}$) high DOC values were observed. Besides that, dates majority of median values were lower than 10 $mgO_2 \bullet l^{-1}$ (Fig. 1). Spatial distribution depends on the date, but in most cases higher DOC values were observed in the North part of the lake.

For CHL there is no big peaks and median values varied from 25 to 50 $mg \bullet m^{-3}$ (Fig. 1). For all dates similarly to 2020-07-01 (Fig. 2) the highest values of CHL were observed in the North part of the lake.

Median values for EC varied from 1000-1100 $\mu S \bullet cm^{-1}$ with low spatial variability in all dates (Fig. 1 and 2).

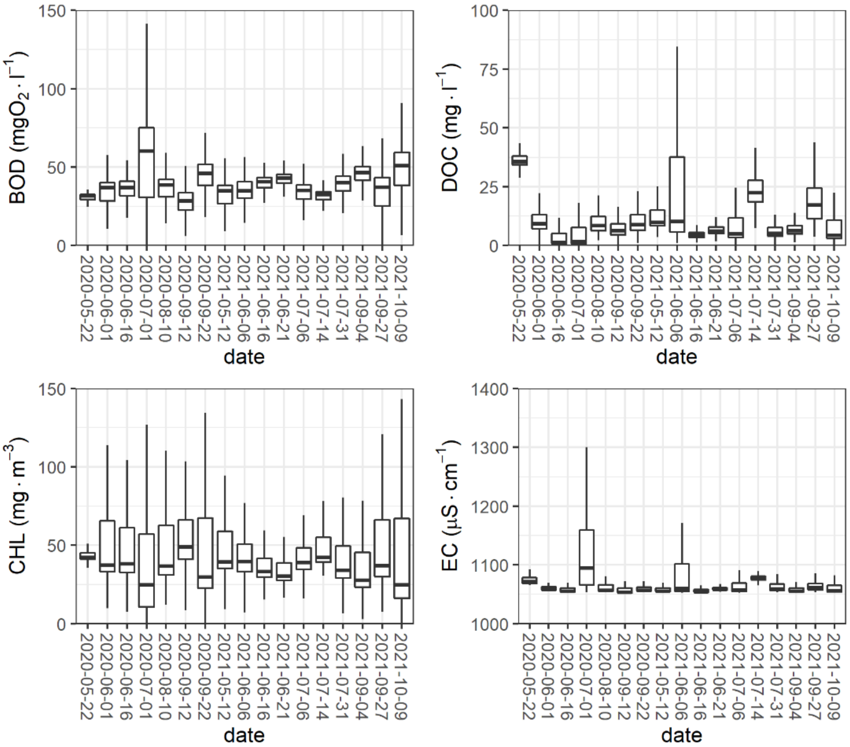

Fig. 1. Temporal changes of investigated parameters based on all cloud free pixels within Głuszyńskie Lake, boxplot shows median, the lower and upper hinges correspond to the first and third quartiles, the upper and the lower whisker is 1.5·interquartile range.

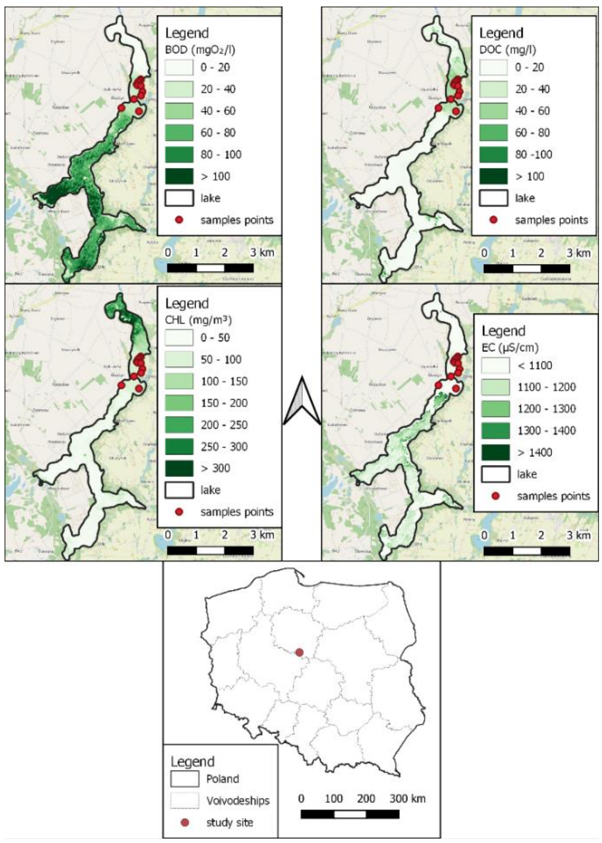

Fig. 2. Study site location, water samples points location (2021-10-08) and spatial variability of investigated parameters on 2020-01-07.

Satellite based parameters were validated against 12 ground truth samples. BOD and CHL for selected formulas don't correlate with ground truth data. Conditions before day of field measurements (air temperature near to the 0 °C) might influence obtained results. DOC and EC strongly correlated with ground truth data with R^2 equal to 0.61 and 0.84 respectively, both relationships are statistically significant.

CONCLUSION

This paper shows some potential of use free available satellite data (as an extension for time consuming field monitoring) for water quality monitoring of inland lakes. With simple workflow (data download, preprocessing using Sen2Cor processor and simple application on formulas form literature) it is possible to roughly estimate variety of water quality parameters. However, due to empirical nature of used formulas only for two (DOC and EC) parameters we can analyses its qualitative distribution. For robust quantitative analyses further work need to be done with more extensive field work to adapt used formulas (or create new one) for this region.

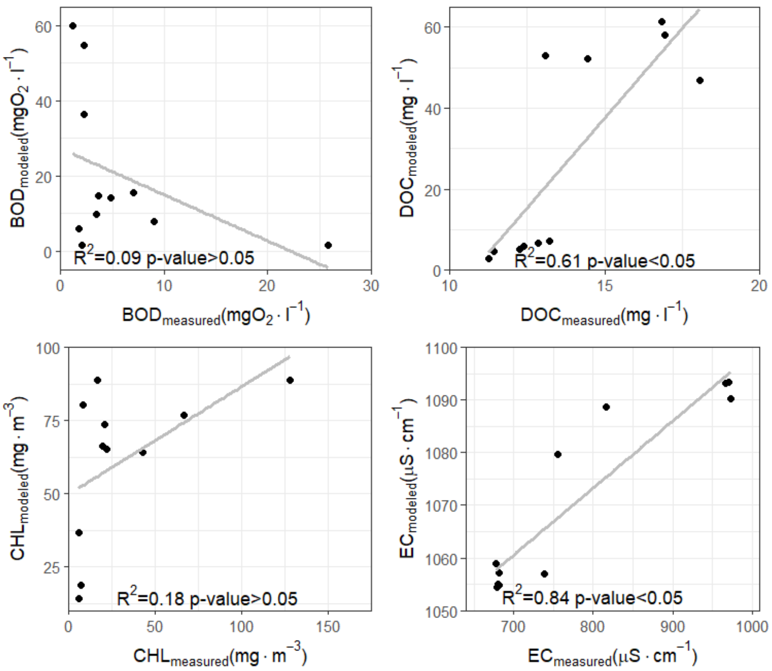

Fig. 3. Relationship between modeled (based on satellite image from 2021-10-09) and measured (based on measurement conducted on 2021-10-08) water quality parameters.

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a set of dedicated optical-analytical devices for monitoring a number of elements of animate and inanimate nature"

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