PERIÓDICO TCHÊ QUÍMICA
ARTIGO ORIGINAL

ESTUDO SOBRE AS MUDANÇAS DE EUTROFIZAÇÃO E SUAS CONSEQUÊNCIAS NO LAGO PALIASTOMI

STUDY ON EUTROPHICATION CHANGE AND THEIR CONSEQUENCES IN PALIASTOMI LAKE

ევთროფიკაციის ცვლილებისა და მათი შედეგების კვლევა პალიასტომის ტბაში

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RESUMO

Introdução: O artigo descreve o estudo da dinâmica da concentração de clorofila no lago Paliastom e em sua área circundante. A pesquisa abrange o período de 2015 a 2022. O estudo utiliza imagens de satélite de sensoriamento remoto obtidas do Landsat 8, Sentinel-2, como resultado de processamento na aplicação SNAP. Ao mesmo tempo, foram realizadas pesquisas in situ. **Objetivos:** O objetivo deste estou foi pesquisar a concentração de clorofila no lago Paliastom e em sua área adjacente por meio de métodos de sensoriamento remoto e dados *in situ*. **Métodos:** Para a pesquisa e coleta de dados históricos, foi utilizado o sensoriamento remoto por satélite, que gerou dados sobre variações espaciais e temporais de partículas suspensas em estuários e linhas costeiras. Foram realizados estudos *in situ*, medindo-se a concentração de clorofila e agentes químicos promotores, temperatura da água, pH, dureza total, alcalinidade, acidez e outros. A turbidez total foi determinada e reações qualitativas foram realizadas para definir a presença de fosfatos e nitratos. **Resultados:** Os resultados obtidos por meio de sensoriamento remoto e estudos *in situ* foram comparados. O lago Paliastom e sua área adjacente são propensos a processos de eutrofização, causados por fenômenos naturais e atividade industrial humana. **Discussão:** De acordo com estudos *in situ* e os dados obtidos dos sensores, a água do lago Paliastom é propensa a uma reação alcalina fraca. A água do lago pode ser considerada como tendo turbidez média. Reações de detecção de íons fosfato e nitrato realizadas com protocolos de análise qualitativa mostraram amostras positivas. A intensidade da cor obtida indicou sua alta concentração. **Conclusões**: A evolução anual da clorofila-a no lago Paliastom atinge o valor máximo nos meses de verão. Em comparação com anos anteriores, foi observada uma diminuição na concentração de clorofila durante o período de bloqueio em 2020 devido à pandemia de Covid.

Palavras-chave: *Clorofila, eutrofização, Landsat 8, sensoriamento remoto, Snap Application*

ABSTRACT

Background: The article describes the study of chlorophyll concentration dynamics in Paliastom lake and its surrounding area. The research covers the period from 2015 to 2022. The study uses remote sensing satellite images obtained from Landsat 8, Sentinel-2, as a result of processing in the SNAP application. At the same time, *in situ* researches was performed. **Aims:** This study aims to research chlorophyll concentration in Paliastom lake and its adjacent area through remote sensing methods and *in situ* data. **Methods**: For our research and historical data collection, satellite remote sensing was applied, which generates data on spatial and temporal variations of

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suspended particles in estuaries and coastlines. *In situ* studies, Chlorophyll concentration and promoting chemical agents were measured, water temperature, pH, total hardness, alkalinity, acidity, and others. Total turbidity was determined, and qualitative reactions were performed to define the presence of phosphates and nitrates. **Results**: The results received through remote sensing, and *in situ* studies were compared. Paliastom lake and its adjacent area are prone to eutrophication processes. Natural phenomena and human industrial activity cause the process. **Discussion**: According to *in situ* studies and the data obtained from sensors, the water in Paliastom lake is prone to a weak alkaline reaction. The water of the lake can be considered as having medium turbidity. Phosphate and nitrate ion detection reactions performed with qualitative analysis protocols showed positive samples. The intensity of the obtained color indicated their high concentration. **Conclusions**: The annual evolution of Chl-a in Paliastom lake reaches the maximum value in the summer months. Compared to previous years, a decrease in chlorophyll concentration was observed during the lockdown period of 2020 due to the Covid Pandemic.

Keywords: *Chlorophyll, eutrophication, Landsat 8, remote sensing, Snap Application*

რეზიუმე

სტატიაში აღწერილია ქლოროფილის კონცენტრაციის დინამიკის შესწავლა პალიასტომის ტბასა და მის მიმდებარე ტერიტორიაზე. კვლევა მოიცავს 2015-დან 2022 წლამდე პერიოდს. კვლევაში გამოყენებულია დისტანციური ზონდირების სატელიტური სურათები, რომლებიც მიღებულია Landsat 8, Sentinel-2-დან SNAP აპლიკაციაში დამუშავების შედეგად. ჩატარდა ადგილზე კვლევებიც. **მიზნები**: კვლევა მიზნად ისახავს პალიასტომის ტბასა და მის მიმდებარე ტერიტორიაზე ქლოროფილის კონცენტრაციის კვლევას დისტანციური ზონდირების მეთოდებისა და ადგილზე კვლევის მეშვეობით. **მეთოდები**: კვლევისა და ისტორიული მონაცემების შეგროვებისთვის გამოყენებული იქნა სატელიტური დისტანციური ზონდირება, რომელიც აგენერირებს მონაცემებს შეჩერებული ნაწილაკების სივრცით და დროებით ცვალებადობაზე შესართავებსა და სანაპირო ზოლში. *In situ* კვლევებით გაიზომა ქოლოროფილის კონცენტრაცია და ქიმიური აგენტები: წყლის ტემპერატურა, pH, საერთო სიხისტე, ტუტე, მჟავიანობა და სხვა. განისაზღვრა წყლის სიმღვრივე და ფოსფატებისა და ნიტრატების არსებობის დასადგენად ჩატარდა თვისებრივი რეაქციები. **შედეგები**: დისტანციური ზონდირების და ადგილზე კვლევებით მიღებული შედეგები შევადარეთ ერთმანეთს. პალიასტომის ტბა და მისი მიმდებარე ტერიტორია მიდრეკილია ევტროფიკაციის პროცესებისკენ. პროცესი გამოწვეულია როგორც ბუნებრივი მოვლენებით, ასევე ადამიანის სამრეწველო აქტივობით. **დისკუსია:** ადგილზე კვლევებისა და სენსორებისგან მიღებული მონაცემების მიხედვით, პალიასტომის ტბაში წყალი მიდრეკილია სუსტი ტუტე რეაქციისკენ. ტბის წყალი შეიძლება ჩაითვალოს საშუალოდ მღვრიედ. ხარისხობრივი ანალიზის პროტოკოლებით ჩატარებული ფოსფატისა და ნიტრატის იონების გამოვლენის რეაქციები დადებითი იყო. მიღებული ფერის ინტენსივობა მიუთითებდა მათ მაღალ კონცენტრაციაზე. **დასკვნა:** ქლოროფილის წლიური ევოლუცია პალიასტომის ტბაში მაქსიმალურ მნიშვნელობას აღწევს ზაფხულის თვეებში. წინა წლებთან შედარებით, კოვიდ პანდემიის გამო 2020 წლის შეზღუდული აქტივობების პერიოდში დაფიქსირდა ქლოროფილის კონცენტრაციის გარკვეული შემცირება.

საკვანძო სიტყვები: *ქლოროფილი, ევთროფიკაცია , ლანდსეტ 8, დისტანციური ზონდირება, Snap აპლიკაცია*

1. INTRODUCTION:

Eutrophication is a gradual increase in the concentration of phosphorus, nitrogen, and other herbal nutrients in water ecosystems such as lakes or other types of water (VanLoon and Duffy, 2018). The productivity or fertility of such an ecosystem naturally increases as the amount of organic material, which can be decomposed into nutrients, also increases. Chlorophyll is necessary for phytoplankton existence. Phytoplankton is an indicator of water wholesomeness. Chlorophyll level monitoring is the best way of algal growth observation. Surface waters with high level of chlorophyll are usually rich in nutrients, mainly in phosphorus and nitrogen. These nutrients cause algae to grow or, in other words, to bloom.

Florescence of algal populations results in environmental conditions change. The level of dissolved oxygen decreases, which may become the reason for mass fish mortality. High levels of Nitrogen and Phosphorus can also indicate anthropogenic pollution, such as septic system leakage, malfunction of wastewater treatment plants, or fertilizer runoffs. Thus, chlorophyll measurement can be applied as an indirect indicator of nutrients (Williams, 2014).

This study aims to research chlorophyll concentration in Paliastom lake and its adjacent area through remote sensing methods and *in situ* data.

Paliastom is a flowing lake, with its large part located in Samegrelo, near Poti city. However, its western part belongs to the Guria region, stretching over the territory of Lanchkhuti municipality. The lake forms a part of Kolkheti National Park. Kolkheti National Park offers tourists boating routes to discover more of the lake.

The surface area of the lake is 18 2 km^2, the basin area – is 547 km^2, the maximum depth - is 3,2m, the average depth - is 2,6m, water volume - 52mln m^3. It is situated at 0,3m below sea level. The lake is fed by rainwater and affluents. Pichori River flows into the lake, and Kaparchina River flows out of the lake and joins the Black Sea. Paliastom is the third biggest lake in Georgia (after Paravani and Kartsakhi lakes). It is the lowest and rich-in-fish lake in Georgia. It is the most important place for bird-watching as this lake is one of the main stopover and wintering areas for migratory birds (Trapaidze,2012).

Paliastom lake represents a unique, relict reservoir. Until the thirties of the 20th century, it was connected to the sea by the Kaparcha River, reaching 9 km. In the thirties of the last century, Paliastom lake was directly connected to the sea to avoid Poti City flooding by lake waters during water abundance. This, in turn, resulted in sea water entering the lake and the lake water becoming salinized, thus transforming the freshwater-type reservoir into a brackish aquifer, followed by disruption and alteration of the entire ecosystem.

In many countries, coastal and marine water quality is vital for tourism and fishing industries, controlled by various international agreements (Burton and Pitt, 2002).

International Convention on Oil Pollution, Brussels, 1969;

International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, Brussels, 1971;

Convention for the Prevention of Marine Pollution by Dumping or Debris and Other Matters, London, 1972;

International Convention for Preventing Ships, London, 1973. (Amended in 1978);

Convention on Liability and Compensation for Hazardous Foodstuffs, London, 1996.

Water monitoring in Georgia is mainly carried out by National Environment Agency (https://nea.gov.ge/). The Agency performs monitoring largely through the EU project (Environmental Monitoring in the Black Sea – EMBLAS), the results of which are available on the website https://emblasproject.org/. The main outcomes of the monitoring are reflected in the "2014-2017 National Report on the State of the Environment", approved by the order of the Minister of Environmental Protection and Agriculture of Georgia. (30/12/2019, N 2-1294) (http://eiec.gov.ge/Ge/NationalReports). This document states, “Most of Georgia's waters meet water quality standards. However, water pollution is a persistent or recurring problem in some of the rivers. The most common water quality problem in Georgia is ammonium nitrogen pollution. Based on the monitoring, the maximum concentration of ammonium nitrogen is recorded in 11 rivers and 4 lakes of Georgia annually; The Black Sea water condition, in terms of eutrophication, can be characterized as generally good. However, in two sections - near Anaklia and Poti sea ports- an increased chlorophyll concentration is observed" (2014-17 National Report on the State of the Environment of Georgia).

2. MATERIALS AND METHODS:

For our research and historical data collection, satellite remote sensing was applied, which generates data on spatial and temporal variations of suspended particles in estuaries and coastlines.

Various satellites are used for remote sensing, such as MODIS (250m), OrbBiew-2 (1km), Landsat8 (15m), Gaofen-1 (30m), Sentinel 2 (10m), Sentinel 3 (300m) (Alikas, Kangro, Randoja, 2015). Landsat 8 and Sentinel 2 were used for this particular study.

Data from terrestrial and marine databases (e.g., Copernicus, MODnet, Géoservices Sextant, and BLACKSEASCENE) and obtained images are used to estimate the dynamics of chlorophyll concentration. As mentioned, this indicates water contamination with nutrients (Schalles,2006).

Low chlorophyll concentration (<2mg/m^3) is well reflected in the blue part of the spectrum (400–500 nm), with increasing wavelength in the near-infrared spectrum (NIR, 700–800 nm), the reflectance decreases to 0; Chlorophyll concentrations between 2 and 30 mg/m3 are reflected in the green (500-600 nm) and red bands (600-700 nm). At higher reflectivity, the peak reflectance in the green part of the spectrum and chlorophyll concentration above 300 mg/m^3 is displayed in the green part of the spectrum; blue and red bands, in this case, show little reflectivity (Avouris and Ortiz, 2019).

The concentration of Chlorophyll a (Chl-a) was determined using Landsat 8 (2015) and Sentinel-2 (2016-2021) satellite multispectral images. Satellite imagery was selected and extracted from open-access databases: Earth Explorer (USGS) and Copernicus Open Access Hub (Avouris and Ortiz, 2019).

Sentinel-2 is a multispectral Earth observation satellite developed by the European Space Agency (ESA) as part of the Copernicus Earth Monitoring Service. Sentinel-2 satellites have been operational since 2015. The generated image data files consist of twelve spectral channels with a higher resolution of 10m.

Sentinel-2 images can be obtained from Sentinel Scientific Data Hub (https://scihub.copernicus.eu/) and Earth Explorer (https://earthexplorer.usgs.gov/) databases. The Sentinel-2 product is a set of fixed-sized-elementary granules taken from one orbit. A granule is the smallest integral component of a product (containing all possible spectral ranges). Granules are also called tiles, and they are 100 × 100 km ortho-images in the UTM/WGS84 projection that divide the Earth's surface into 60 zones. Each UTM zone has a latitude of 6° vertical width and a latitude of 8° horizontal width. Landsat is a multispectral satellite network launched by NASA (US National Aeronautics and Space Administration) in the early 1970s. Satellites are being updated to this day. Landsat 8 has been operational since 2013.

It moves around the Earth in a sun-synchronous near-polar orbit (98.2-degree inclination) and has a 16-day repeating cycle with an equatorial crossing time of 10:00 AM +/- 15 minutes.

Landsat 8 carries the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) tools. OLI includes 9 bands measured in visible, near-infrared, and short-wave infrared parts of the spectrum (VNIR, NIR, and SWIR). TIRS covers 2 bands and measures ground surface temperature in two thermal bands through a new technology using quantum physics for heat detection. Both sensors provide seasonal terrestrial coverage with a spatial resolution of 30 meters (visible, NIR, SWIR); 100 meters (thermal); and 15 meters (panchromatic) (Brandon and Pahlevan, 2021; Asim and Brekke,2021).

Landsat 8 and Sentinel-2 images are generated from the Copernicus open system or Earth Explorer databases (https://earthexplorer.usgs.gov/).

For image generation from Copernicus open system https://scihub.copernicus.eu/dhus/#/home, the following steps have to be undertaken: select a specific research area; define the study period; choose the correct satellite platform (in our case, Landsat 8 and Sentinel-2) and type of product; determine the cloudiness, as the latter makes it difficult to find and download a good image.

An image can be generated from the Earth Explorer database using the same steps.

The received images were processed through the C2RCC processor of the ESA SNAP 8.0 application. The C2RCC processor is based on the artificial neural networks (ANN) method, where neural networks are "trained" based on the database of modeled water reflectance coefficients and associated TOA radiance [10]. Eventually, Chl-a and IOP of water optical properties were generated using the C2RCC processor. Chl-a values were reconverted into mg/m^3 units, and the file was converted to GeoTIFF format.

The ESA SNAP 8.0 application focuses on calculating chlorophyll concentration in lakes and estuaries (https://eo4society.esa.int/resources/snap/). The received image must be transferred to its platform at the first working stage in SNAP. The study area of chlorophyll concentration has to be marked once again. At the next stage, we activate the Graph Builder from the Tool section of the program and create a graph reflecting the calculation sequence. The end product highlights the centers of eutrophication and minimum and maximum chlorophyll concentrations in the water under study.

2.1 Materials

The research was conducted in two directions. For *in situ* research, was used classical analytical chemistry protocols for water quality research (Gladchi, Bunduchi, Duca and Romanciuc, 2023; Kupatadze, 2023). Data such as temperature, pH, turbidity and conductivity were measured directly on site via HANA sensors. Chlorophyll concentration was also measured at the site. We have used a mobile spectrophotometer, which allowed us to carry out *in situ* measurements of chlorophyll amount. An OCEAN INSIDE miniature spectrophotometer was used, measuring the pigment absorbance through the supporting software .

Other chemical data were analyzed in the Chemistry Laboratory of Ilia State University.

For chlorophyll analysis by remote sensing we used Landsat 8 and Sentinel-2 images and

the Copernicus open system or Earth Explorer databases (https://earthexplorer.usgs.gov/).

The free program The ESA SNAP 8.0 application was used to calculate the chlorophyll concentration. The calculations were performed at the Information Center of the Botany Research Institute of Ilia State University.

2.2. Methods

2.2.1. In situ research methodology

Water quality is mainly determined by the environment, climatic conditions, and anthropogenic activities [APHA and AWWA,1998; Kupatadze,2022]. Water quality indicators used by environmental agencies include the following characteristics:

Turbidity; color; temperature; taste (for drinking water); smell; pH; conductivity; hardness; dissolved oxygen; dissolved inorganic anions (CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^-) and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, $Al^{3+,}$ and NH^{4+}); dissolved organic substances (organic acids and phenol); presence or absence of microbiological organisms (bacteria); presence/absence of animals, algae, flora, and fauna; Presence/absence of garbage, sewage waste, oil.

2.2.2. Defining Chlorophyll Concentration in Paliastom Lake

There is a classical method for determining chlorophyll concentration (Fairooz and Mohd Zubir,2018). We have used a mobile spectrophotometer, which allowed us to carry out *in situ* measurements of chlorophyll amount. An OCEAN INSIDE miniature spectrophotometer was used, measuring the pigment absorbance through the supporting software.

According to the research (Alikas and Kangro, 2015), low chlorophyll concentration (<2mg/m3) is well reflected in the blue part of the spectrum (400–500 nm). The reflectance decreases to 0 with increasing wavelength in the near-infrared spectrum (NIR, 700–800 nm); Chlorophyll concentrations between 2 and 30 mg/m^3 are reflected in the green part (500-600 nm) and red bands (600-700 nm). At higher reflectance, the peak reflection and chlorophyll concentration above 300 mg/m^3 are shown in the green part of the spectrum, and the blue and red bands show little reflection in this case.

2.2.3. In situ data collection

Water samples of Paliastom lake were taken in late October 2021, early July 2022, and September 2022. Several important analyzes were conducted to obtain additional information about the cleanliness of the lake and the presence of algae in it. All experiments were carried out using water samples collected on one day from Paliastom Lake, which were brought to the chemistry laboratory of Tbilisi Ilia State University on the same day.

Some data about the chemical composition of Paliastom lake water was conducted by sensors installed under BSB ECO Monitoring Project (https://bsbecomonitoring.net/).

The abovementioned sensors measure pH, Redox potential, water temperature, electrical conductivity of water, salinity, TDS, i.e., total dissolved particles, dissolved oxygen (DO), and turbidity. Each data represents a certain indicator, based on which we can discuss water quality.

3. RESULTS AND DISCUSSION:

3.1 Results

3.1.1. Remote Sensing Results

It was selected Sentinel-2 monthly images of 2015-2021 to determine chlorophyll concentration. Unfortunately, only the images for 9 months of 2016 were cloud-free and, thus, subject to processing. As for the Landsat 8 images, images for 7 months of 2015 were processed.

For our research purposes, Paliastom Lake was of much importance. Chlorophyll concentration was measured near and far from the shore, e.g., near the shore of Paliastom lake and from the center of the lake. It is worth noting that the above-described method (SNAP program) applies to only lakes and estuaries near the sea coast.

For 2015, we have the data for the following months: February, April, May-July, September, and December. For this period, the concentration at the port varies between 9-6, decreasing only in

September-December -1.77 and 0.81, respectively.

The highest concentration in Paliastom was observed in September - 39. It is the smallest in June - 0.094. The highest index at the confluence of the Rioni River was observed on May -31 (Figures 1, 2, and 3).

In 2016, the lowest data in Paliastom lake was in February and November - 0.43, and the highest value - in May and August - 23mg/m^3. At the estuaries, especially in May, the highest indicator was recorded - 28 mg/m^3.

In 2017, the following months were observed: January, March-December. However, due to cloudiness, some decrease was also recorded this year.

In Paliastom, 26 mg/m^3 was recorded in May, and the lowest data was observed in August., The indicator partially decreases in September. It is the smallest in December. (Figures. 4, and 5).

The data searched for the whole year of 2018, but for some locations, the data showed 0, and this was always due to cloudiness, meaning that the satellite could not see that particular location. In May, the chlorophyll concentration in Paliastom lake was quite high - 16. In August, the indicator in the same lake was reduced to 3. The rate was low in November (Figures 6 to 9).

The data was also searched for the whole year of 2019; cloudiness was observed only in July in several locations. In Paliastomi, the recorded data in June are 2 and 6. On September -5, at the delta near Rioni River, a high indicator is observed - 15. By December, almost all locations have low values (Figures 10 and 11).

The year 2020 is quite interesting (Figures 12, 13, and 14), as this was when the COVID pandemic began, and due to the lockdown announcement, intense activities in Georgia were completely stopped in April and early May. The next lockdown was placed in November and December. In March, the concentration in Poti port was increased on average by -3.67; 6.86 was observed in Paliastom lake. In April, the concentration was high at -13, probably related to natural phenomena. There were 2 and 9 in the port. The estuaries were almost free. The image of May 2020 shows traces of the lockdown. The coastline was quite relieved, and the concentration was also reduced in Paliastom lake. Port - 0.91, Paliastom-6.24. In June, eutrophication in Paliastom lake increased again up to 18 (Fig. 15). In the coastal zone near the port, the low value remained at 2.99 and 0.32. The next lockdown was put in November (Fig. 16), also visible in the data received. On the coastline, the indicators are quite low - 0.6 and 3.08; In Paliastom lake - 5.10.

In December 2020, the indicator in Paliastom lake showed 4.77, which needs to be related to natural events. Remember that the lockdown continued in Georgia throughout December (Fig. 17).

2021 (Fig. 17; 18,19) is the last year of satellite research and is interesting regarding the data availability from field studies since August. Respectively, we can compare the corresponding months of these two studies. High concentration was recorded in Paliastom lake in May 2021: 14-15. 15 and 11 were observed at Rioni and Kulevi confluences. In July 2021, the rate of eutrophication in Paliastom lake was reduced to 7.02. At the confluences, at Rioni river, this indicator showed -15 and 17, at old Rioni river-11. Increased concentration was not recorded in the following months; this trend was also maintained in November. 1.33 was observed on the coastline, 8.53 was recorded only at the mouth of Kulevi, and 8.5 in Palistomi lake.

Detailed results were presented in Tables 1 to 7.

3.1.2. In situ study results

The pH measurements on water samples taken from Paliastom lake in November 2021 showed 8.3. 8.9 was recorded in July 2022, and 8.5 - in September. Triplicate measurements were performed at 10-minute intervals to average the results. According to these results, an alkaline environment was observed. It is essential that the water temperature was 12 °C in November, 24 °C - in July and 24 °C - in September. This pH value is the best condition for the growth of most eutrophication-causing algae. However, some species of algae stop growing in alkaline environments (Gurlin and Gitelson,2011).

3.1.3. General hardness and alkalinity

General hardness and alkalinity are interrelated, as, alkalinity can be increased due to increased carbonate hardness. Both data were measured using the quantitative analysis log sheets. The indicator of hardness of the Paliastom lake water sample, taken in November 2021, was found to be 130 mg/l, which, according to most existing literature, is considered hard water (Smith,2019). In July 2022, the hardness index did not change much and was 125 mg/l. In September

2022, the hardness coefficient was 122 mg/l.

3.1.4.Turbidity

In November 2021, the turbidity of the lake water sample was 350 NTU. A sample taken in July 2022 showed a turbidity of 190 NTU. And in September 2022, 220 NTU. By the way, the difference between the water turbidities was noticeable even with the naked eye.

In general, according to the data received, Paliastom lake can be considered a lake of medium turbidity. In some cases, the turbidity is quite high. This can be considered one of the characteristics of the quality of chlorophyll and eutrophication.

3.1.5.Results of qualitative analysis reactions

Reactions were carried out for phosphate and nitrate ion detection. Both detection reactions turned out positive. According to the sharpness of the developed colors, a sufficiently high amount of phosphate and nitrate ions was observed, indicating nutrient pollution of water. Nutrients indicate good conditions for the presence of humic material and, therefore, algae. In other words, the water is prone to eutrophication.

3.1.6. Determination of chlorophyll concentration.

According to the supporting software data, it was 10.34 mg m^{-3} in July 2021 and 12.79 mg m^{-3} in September at 580 nm. The initial assumption of the authors was confirmed. However, abundant precipitation was observed in the summer of 2022, especially in June-July 2022. The Chl-a spectrophotometer measurement Software, which we used, recorded 7.64 mg m^{-3} at 580 nm in November 2021. We assumed that this was not a low value for November and that Chl-a concentration was increased with the temperature increase.

Some Detailed results are available in Tables 8 to-12.

According to the results, Paliastom lake can be classified as alkaline. pH constantly fluctuates between the neutral and alkaline areas, although the 8 indicator shows a weakly alkaline environment. Such conditions provide a good environment for chlorophyll and high eutrophication.

The amount of dissolved oxygen (DO) - 80-12-% DO is considered the norm in lakes and surface waters (Abramia and Gverdsiteli, 2022). According to the indicators obtained from the research, the excessive amount of DO in Paliastom lake is found only in specific months (2021/08/09; 2022/02) and only in a certain period. So, it can be said that this indicator is within the norm.

Electrical conductivity -- Electrical conductivity and, therefore, salinity are always high. Large amounts of anions and cations, including nutrients, create good conditions for eutrophication in Paliastom lake.

TDS, i.e., Total Dissolved Particles-The measured results show that the TDS is quite high, which indicates a high level of dissolved oxygen in the water (which is confirmed by the measurements) and the presence of metal ions (metals were not measured, and we can only assume).

In some cases, the redox index is strongly negative, which indicates an increased rate of nutrients and eutrophication. E.g., in September 2021, redox indicators range from -49.2 to 302. Compared to the data measured by remote sensing under PONTOS project, the chlorophyll concentration in Paliastom lake is 12.5 at the shore and 14.9 - at the depth. Data interdependency is evident, e.g., in November 2021, the eutrophication rate was 8.12 near the shore, 8.53 - at depth. Redox is 72.04/262 (average of minimum and maximum taken). That is, it turns out that there is eutrophication, but not at a high concentration.

The redox index indicates various cations and anions, implying the presence of phosphates and nitrates. The latter are nutrients contributing to eutrophication. We also received positive results from their presence in our discovery reactions. For example, the maximum value of Redox in August 2021 was 358.7 (mV). Accordingly, the chlorophyll concentration calculated by remote sensing was also high: 6.812718379 - on the shore of the lake and 11.02875784 - in the inner part. The maximum value of redox was recorded in December 2021 - 388 (mV). Chlorophyll concentration calculated by sensing was 4.042831145 on the shore of the lake and 3.147683053 - in the inner part. In this case, the higher concentration near the shore was probably related to anthropogenic factors. Our group determined chlorophyll directly in November 2021 (which we can compare with the probe), and the volume was 7.64. The data obtained by sensing is: 8.534173015. These comparisons demonstrate the reliability of remote sensing studies.

3.2. Discussion

According to *in situ* studies and the data obtained from sensors, the water in Paliastom lake is prone to a weak alkaline reaction, and the pH value is mainly within the range of 8-9. Carbonate hardness was also observed during measurements ranging from 125 mg/l to 130 mg/l to 122 mg/l. General hardness and alkalinity are related because alkalinity may increase with increased carbonate hardness. An increase in alkalinity initiates the process of eutrophication. The quantity of microplankton and phosphate ions increases.

The water of the lake under research can be considered as having medium turbidity, although in some periods, an increase in the turbidity indicator is recorded. As confirmed by field studies, the average and high turbidity indicates the presence of humus material and nutrients in the lake.

Phosphate and nitrate ion detection reactions performed with qualitative analysis protocols showed positive samples. The intensity of the obtained color indicated their high concentration.

The high value of the redox index obtained from the sensors allows to say the same, which literally reflects the oxidation-reduction processes in the water of the lake.

These processes involve cations and anions, contributing to eutrophication (the same biogenic elements). It also confirms the presence of heavy metal ions. We have not examined the metals, although when Eh >+ (0.1-1.15 more) - dissolved oxygen and Fe^{3+}, Cu^{2+}, Pb^{2+}, Mo^{2+} ions are present in water, and turbidity is periodically increased, this fact confirms the presence of humic material, binding heavy metal ions and becoming more stable in water. Therefore, we can assume the presence of heavy metal ions and nutrients due to turbidity and redox indicators, which is also a good condition for eutrophication.

Based on the data obtained on anions and cations, it can be said that according to the results of chemical analysis, the water in Paliastom Lake can be attributed to sodium chloride water type. According to mineralization, the water of the lake is brackish, which is also influenced by the water of the Black Sea.

Chlorophyll was measured *in situ* using a mini-spectrophotometer (see description in Methods), which does not give us a high resolution. However, the obtained data are not much different from remote sensing data.

According to the data from remote sensing, it is confirmed again that Paliastom lake and its surrounding area are prone to eutrophication. High levels of chlorophyll generally increase with increasing temperature.

In situ research shows all conditions (pH, temperature, redox, turbidity) for high eutrophication index. The indicator of oxidation-reduction processes (redox) is also high, demonstrating the presence of cations and anions (nutrients).

The latter can be naturally formed, e.g., by the decay of various plants, the metabolism of micro and zooplankton, or by the decomposition of the excrement of birds (a large number of them live in this area). However, some may be brought in through rivers, polluted by various human industrial activities. The so-called ferries and tourist travel can contribute no less to the pollution process. These ferries are constantly anchored in the shoreline of the lake, so the chlorophyll level is higher near the shore than in the middle of the lake.

According to 2020 data, the eutrophication rate has decreased compared to the same periods of other years. e.g., 2.9 and 1.4 at Poti port in April-May, while 7-14 were recorded in the same period of previous years. Similar dynamics can be observed in Paliastom Lake. Theoretically, this allows to assume that the reduction of industrial activities, tourist travels, and active traffic in the port caused some decrease in chlorophyll concentration.

4. CONCLUSIONS:

The presented work investigated the dynamics of Chl-a concentration in Paliastom lake and its surrounding area through remote sensing. For the assessment of the condition, satellite images of Landsat 8 and Sentinel-2 were used, which have been processed in the SNAP application.

In the same research area, the so-called *in situ* studies were carried out, defining Chl-a concentration and the chemical factors contributing to its increase. The data received from "Sabuko" sensor measurements were also used. It should be noted that most of them coincide with the results obtained by sensing.

The annual evolution of Chl-a in Paliastom lake reaches the maximum value in the summer months. The first occurs in spring (May-June), and the second - in summer, around August. In general, this is the lake prone to eutrophication.

Compared to previous years, a decrease in chlorophyll concentration was observed during the lockdown period of 2020 due to the Covid Pandemic.

5. DECLARATIONS

5.1. Study Limitations

No limitations were known at the time of the study.

5.2. Acknowledgements

The authors express their acknowledgment to Project “Pontos” for participation and opportunity to conduct the research;

The authors warmly acknowledge the organization “SABUKO” for collaborating with “Pontos”.

5.3. Funding source

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5.4. Competing Interests

No conflict of interest exists in this publication.

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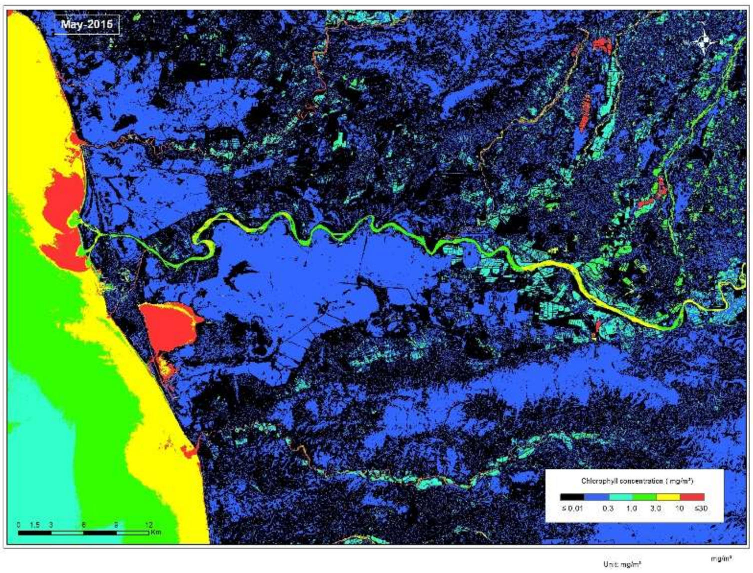

Figure 1. *Summary image of May 2015. Source: the author*

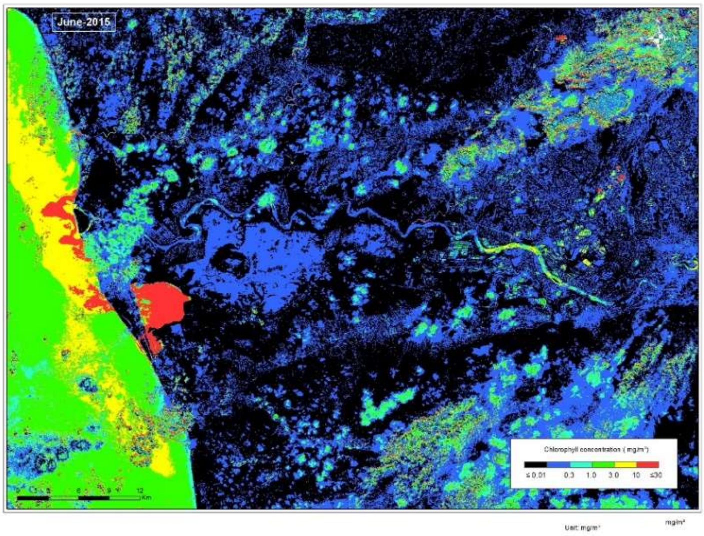

Figure 2. *Summary image of June 2015. Source: the author*

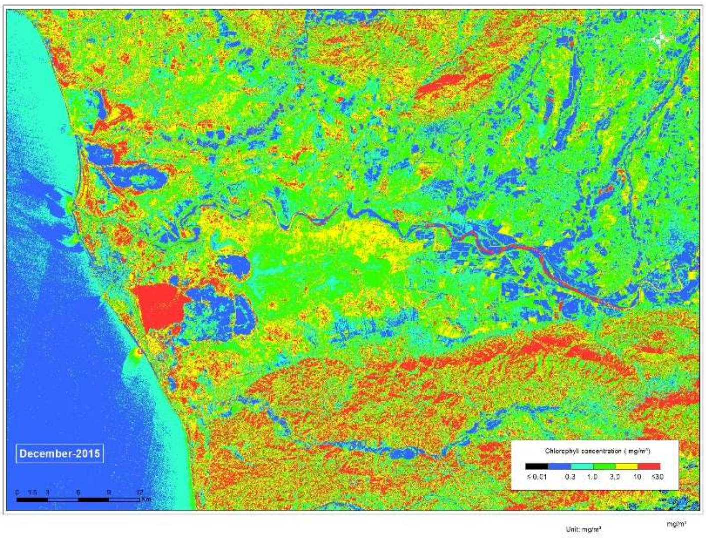

Figure 3. *Summary image of December 2015. Source: the author*

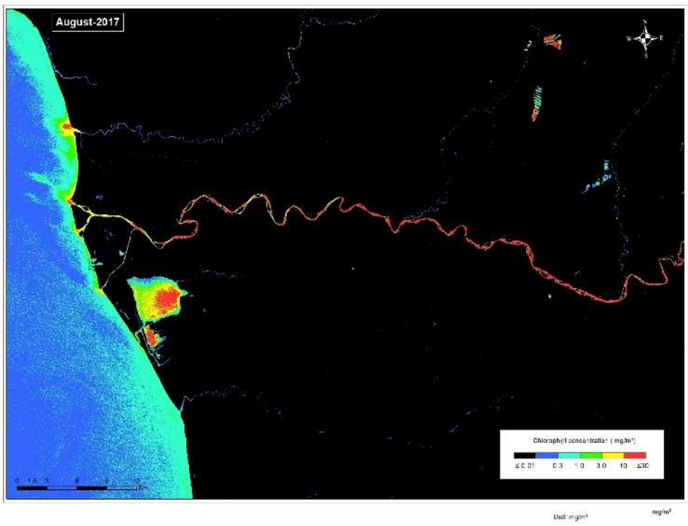

Figure 4. *Summary image of August 2017. Source: the author*

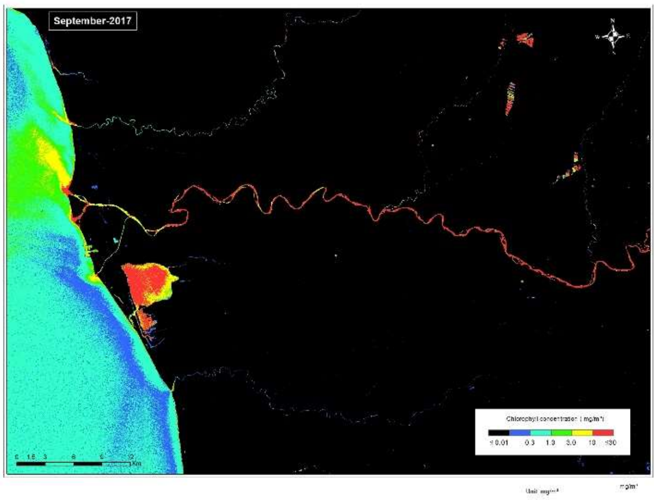

Figure 5. *Summary image of September 2017. Source: the author*

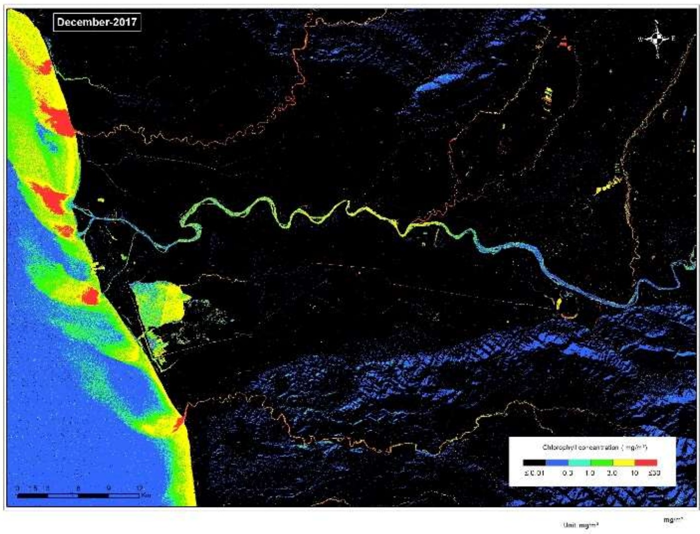

Figure 6. *Summary image of December 2017. Source: the author*

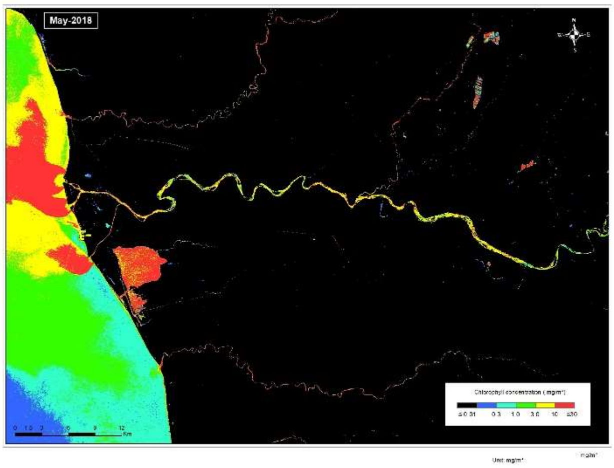

Figure 7. *Summary image of Mays 2018. Source: the author*

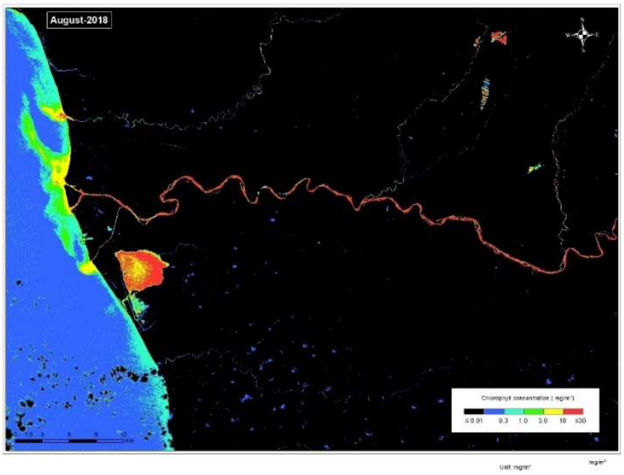

Figure 8. *Summary image of August 2018. Source: the author*

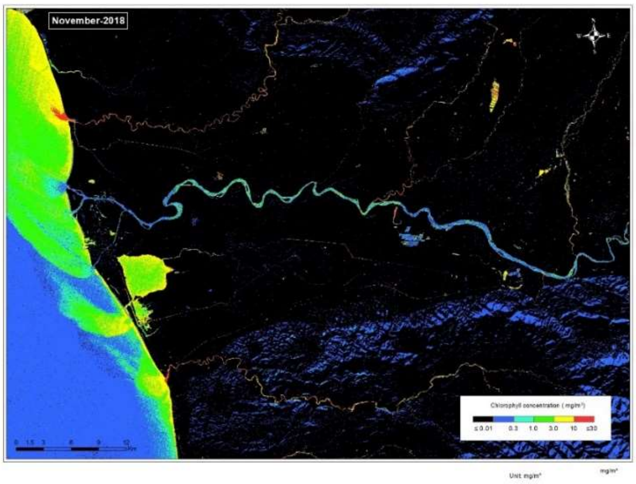

Figure 9. *Summary image of November 2018. Source: the author*

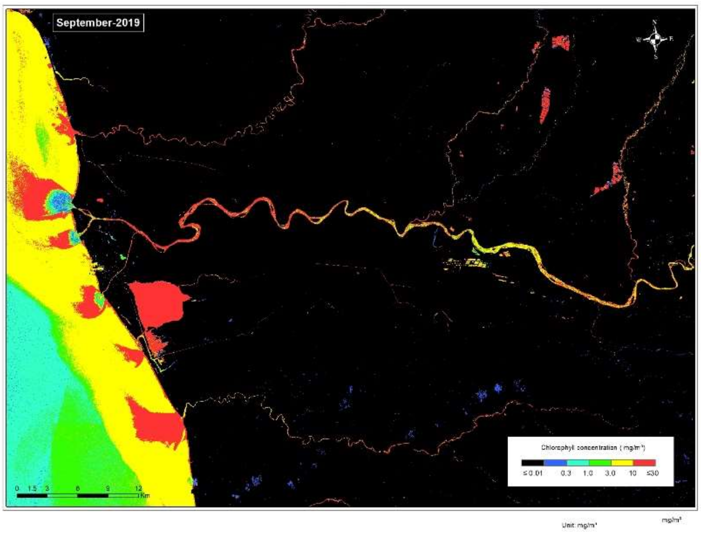

Figure 10. *Summary image of September 2019. Source: the author*

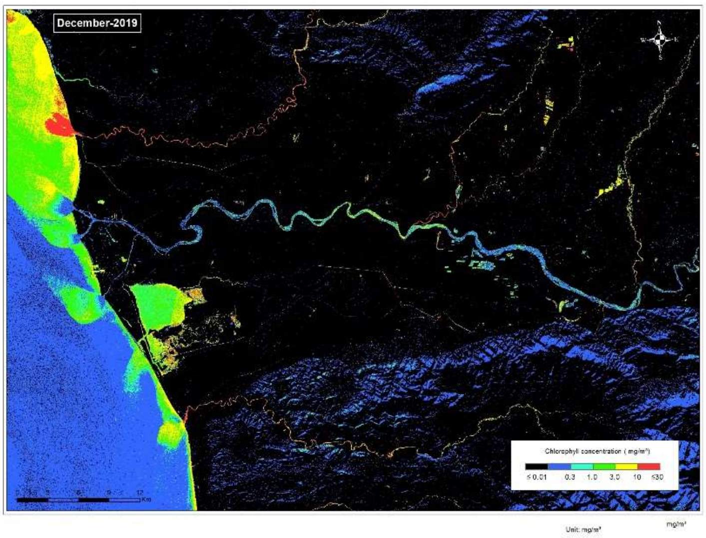

Figure 11. *Summary image of December 2019. Source: the author*

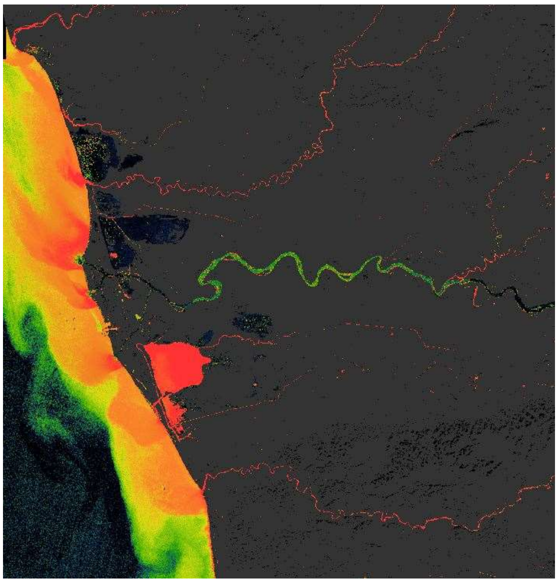

Figure 12. *Summary image of Mart 2020. Source: the author*

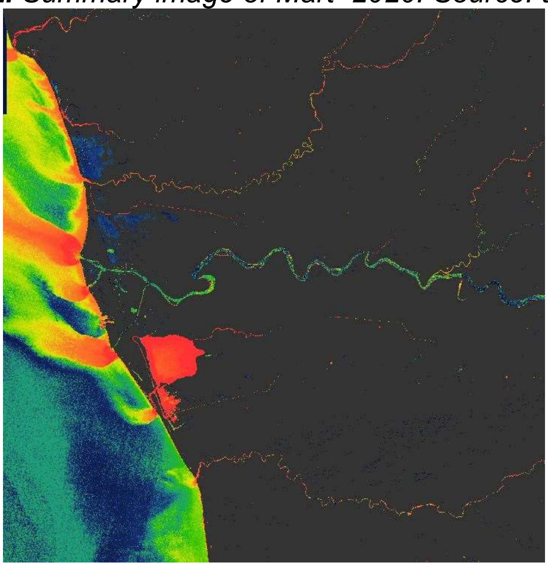

Figure 13. *Summary image of April 2020. Source: the author*

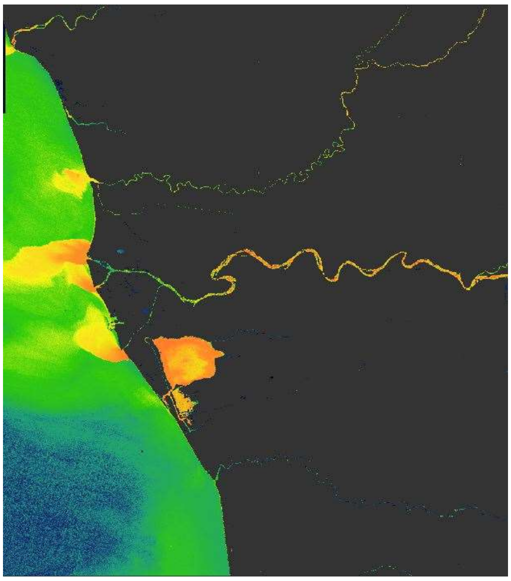

Figure 14. *Summary image of Mays 2020. Source: the author*

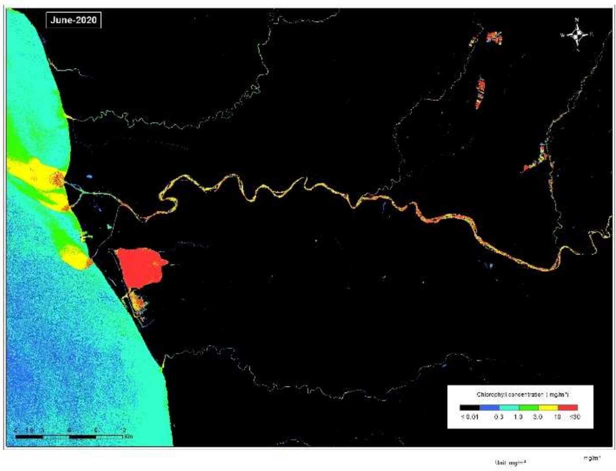

Figure 15. *Summary image of June 2020. Source: the author*

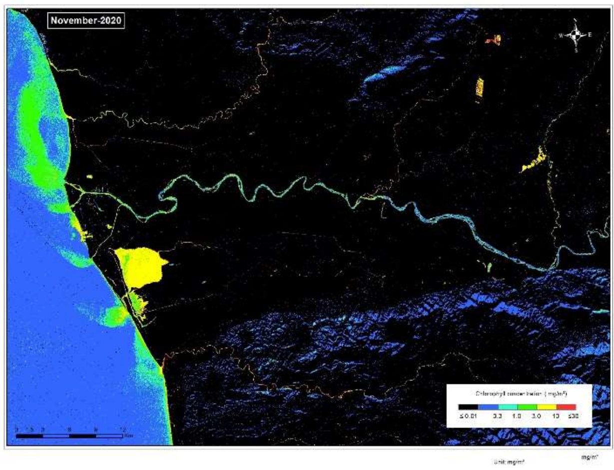

Figure 16. *Summary image of November 2020. Source: the author*

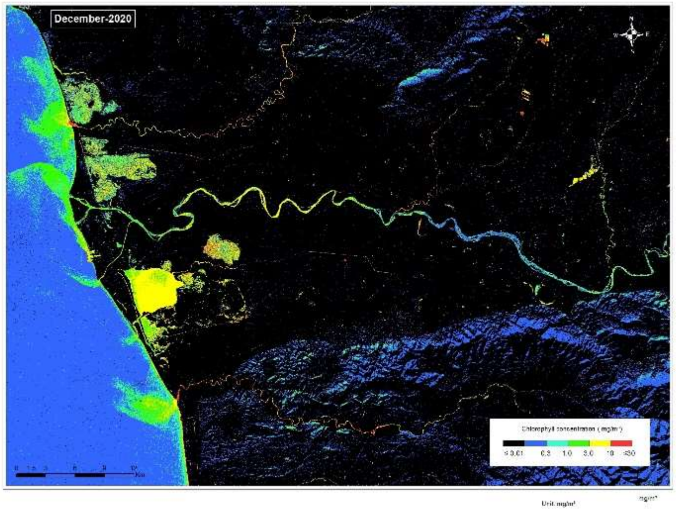

Figure 17. *Summary image of December 2020. Source: the author*

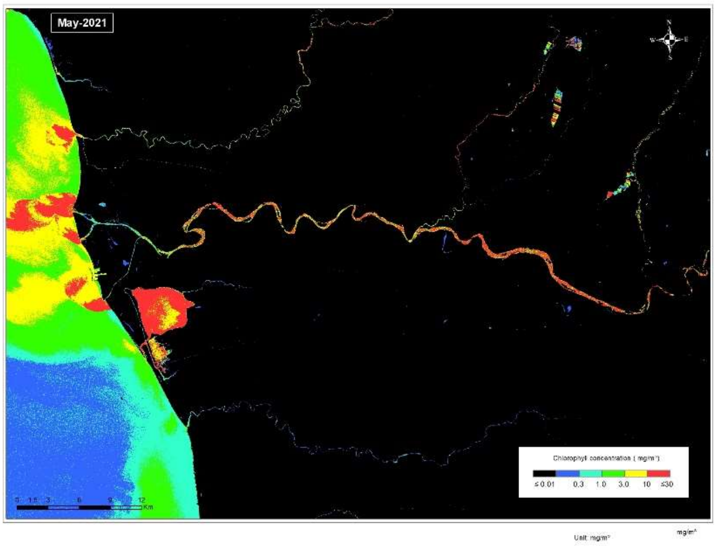

Figure 18. *Summary image of May 2021. Source: the author*

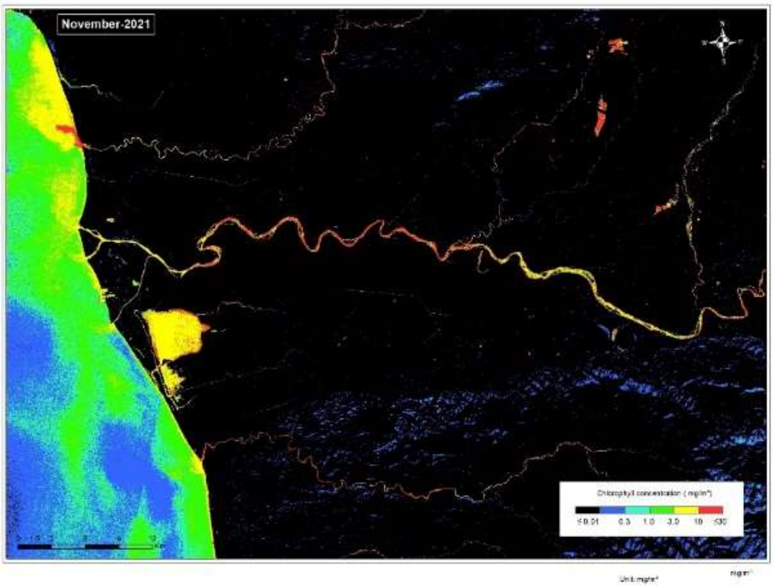

Figure 19. *Summary image of November 2021. Source: the author*

Table 1. *Chlorophyll concentration data obtained by remote sensing method in 2015 (02, 04, 05, 06,07,09, 12)*

Location	**02_2015**	**04_2015**	**05_2015**	**06-2015**	**07_2015**	**09_2015**	**12_2015**
Paliastomi_1	21.37577	29.92742	24.07480	0.094508	16.01155	37.80706	8.39898
Paliastomi_2	25.05145	5.25970	22.54666	12.69927	15.03105	29.98853	11.12145

Table 2*. Chlorophyll concentration data obtained by remote sensing method in 2016 (02, 03, 04, 05,06,07, 08)*

Location	**02_2016**	**03_2016**	**04_2016**	**05-2016**	**06_2016**	**07_2016**	**08_2016**
Paliastomi_1	4.26588	10.50087	17.79791	23.28755	12.72819	15.6017	23.25335
Paliastomi_2	0.43734	4.39969	3.23320	16.10104	7.80735	16.1403	16.55288

Table 3*. Chlorophyll concentration data obtained by remote sensing method in 2017 (01-12)*

Location	**01_2017**	**03_2017**	**04_2017**	**05-2017**	**06_2017**
Paliastomi_1	6.11476	5.11792	1.80281	19.47360	10.21011
Paliastomi_2	7.44459	2.19482	0.26573	26.96214	13.90809
	09_2017	10_2017	11_2017	12-2017	
Paliastomi_1	7.05926	13.43226	5.57647	5.44640	------
Paliastomi_2	14.95064	9.71372	8.13286	3.57041	------

Table 4*. Chlorophyll concentration data obtained by remote sensing method in 2018 (01-12)*

Location	**01_2018**	**02_2018**	**03_2018**	**04-2018**	**05_2018**	**06_2018**	**07_2018**
Paliastomi_1	10.1725	10.160200	11.068389	8.3844381	13.20799	12.2315	15.079356
Paliastomi_2	9.20328	11.259164	4.8722060	8.1471827	13.55271	16.2022	15.524894
	08_2018	09_2018	10_2018	11-2018	12_2018	------	------
Paliastomi_1	3.76830	10.932259	10.517884	1.6898810	7.207598	------	------
Paliastomi_2	8.01623	5.4439128	12.146855	3.1730652	9.513658	------	------

***Table 5**. Chlorophyll concentration data obtained by remote sensing method in 2019 (01-12)*

Location	**01_2019**	**02_2019**	**03_2019**	**04-2019**	**05_2019**	**06_2019**	**07_2019**
Paliastomi_1	8.75706	13.63347	18.13224	9.133684	4.831332	6.53644	8.207841
Paliastomi_2	6.20726	12.01600	12.19390	5.052991	2.207443	2.75176	17.86932
	08_2019	09_2019	10_2019	11-2019	12_2019	------	------
Paliastomi_1	5.09290	15.51388	13.11897	6.794105	2.74126	------	------
Paliastomi_2	5.28020	13.98506	7.981093	4.937672	0.851934	------	------

***Table 6**. Chlorophyll concentration data obtained by remote sensing method in 2020 (01-12)*

Location	**01_2020**	**02_2020**	**03_2020**	**04-2020**	**05_2020**	**06_2020**	**07_2020**
Paliastomi_1	4.81936	12.0066	3.037515	13.93883	6.24811	14.3163	0.23313
Paliastomi_2	2.74126	11.29029	6.862711	13.70436	6.73514	18.5004	13.04520
	08_2020	09_2020	10_2020	11-2020	12_2020	------	------
Paliastomi_1	13.7907	17.40832	13.59803	6.38658	6.52433	------	------
Paliastomi_2	5.87147	16.5528	10.29807	5.100346	4.77891	------	------

Table 7. Chlorophyll concentration data obtained by remote sensing method in 2021 (01-12)

Location	**01_2021**	**02_2021**	**03_2021**	**04-2021**	**05_2021**	**06_2021**	**07_2021**
Paliastomi_1	4.18190	16.7072	15.7671	8.99158	14.6313	9.67344	7.1719
Paliastomi_2	1.01837	14.4523	13.5677	6.34215	15.2415	4.13080	7.02408
	08_2021	09_2021	10_2021	11-20201	12_2021	------	------
Paliastomi_1	6.81271	14.9023	7.15897	8.12928	4.0428	------	------
Paliastomi_2	11.0287	12.0534	10.4075	8.53417	3.1476	------	------

Table 8. *Some parameters In situ research*

Paliastomi Lake	**11/2021**	**07/2022**	**09/22**
pH	8.3	8.9	8.5
Turbidity	350 NTU	190NTU	220 NTU
Crl a/580 nm ზე	7,64 mg m^-3	10,34 mg m^-3	12,79 mg m^-3
Hardness	130 mg/l	125mg/l	122 mg/l
Alkalinity	Weak alkalinity	Weak alkalinity	Weak alkalinity
Acidity	Weak acidity	Weak acidity	Weak acidity
PO_3^{2-}	positive	positive	positive
NO_3^-	positive	positive	positive

Table 9. *Some other parameters In situ research, 2021-08,09,10*

21/08	**min**	**max**	**21/09**	**min**	**max**	**21/10**	**min**	**max**
pH	7.33	8.84		7.597	8.62		7.71	8.19
Redox (mV)	36/-446	358.7		-49.2	302		-87.3 /-442	285
t (C)	24.02	30.06		17.71	24.39		11.02	18.04
Conductivity (μS/cm)	8220.29	12464.5		282.184	1646.07		457	1118
Salinity (ppt)	4.641	7.206		0.18	1.389		0.29	0.511
TDS (ppm)	4740.19	7272.56		149	2236.01		209	804
DO (%)	4.53	139.3		26.97	140.02		42	94
Turbidity (NTU)	12.49	131.8		19.5	20.89		1.92	15.42

Table 10. *Some other parameters In situ research, 2021-11,12; 2022-01*

21/11	**min**	**max**	**21/12**	**min**	**max**	**22/01**	**min**	**max**
pH	7.79	8.19		7.71	8.09		7.87	8.31
Redox (mV)	72.04	262		-388	230		153	319
t (C)	9.01	18.05		7/2.54	12		2	8
Conductivity (μS/cm)	432	4486		2722.02	6208.52		1899	2315.89
Salinity (ppt)	0.25	0.548		1.506	3.009		1.302	1.505
TDS (ppm)	235	3186		1594	3597.99		951	1406.98
DO (%)	0.065	82		0.076	25.22/100		71	108
Turbidity (NTU)	1.48	18.53		0.778	1.714		41	514

Table 11. *Some other parameters In situ research, 2022-02, 03,04*

22/02	**min**	**max**	**22/03**	**min**	**max**	**22/04**	**min**	**max**
pH	7.93	8.11		7.93	8.49		7.98	8.19
Redox (mV)	133	318		300	351		-239	179
t (C)	4.94	10.05		4.88	11.65		10.02	19.25
Conductivity (µS/cm)	1246	2442		1873.01	4237.97		2111.14	6410.71
Salinity (ppt)	0.693	1.658		0.671	2.263		2.761	3.547
TDS (ppm)	771.682	1829.27		1761.22	2441.23		2994.27	3029.92
DO (%)	92.1	147.2		87	120		95.7	121.8
Turbidity (NTU)	89	1127		59.43	1580		0.001	3.965

Table 12. *Some other parameters In situ research, 2022-05, 06*

22/05	**min**	**max**	**22/06**	**min**	**max**
pH	7.28	8.67		6.55	8.03
Redox (mV)	-174.3	150		-271.5	98.8
t (C)	16.02	20.17		22.12	28.34
Conductivity (µS/cm)	4823.1	5397.54		5537.73	6056.04
Salinity (ppt)	2.978	3.041		2.972	3.048
TDS (ppm)	2917.26	3099.36		1645	3347
DO (%)	68.36	92.34		15.03	77.28
Turbidity (NTU)	87.3	328		69.12	270.7