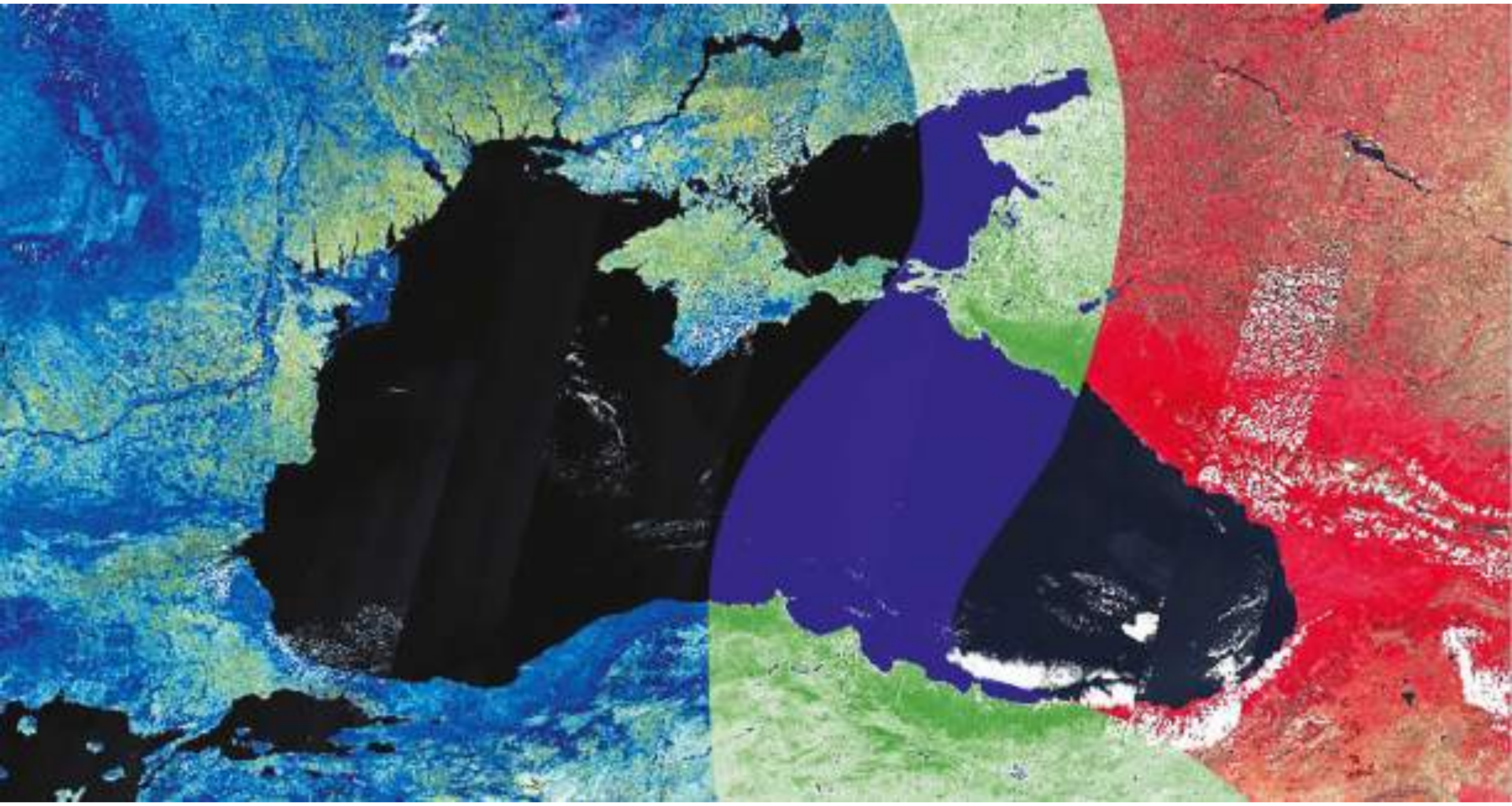
Copernicus assisted environmental monitoring across the Black Sea Basin – PONTOS



Integrated assessment on chlorophyll concentration and eutrophication dynamics

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Green Alternative

PONTOS-GE (Georgia) – The entire coastline of Georgia & Kolkheti lowland

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Executive Summary

The paper gives a comprehensive assessment on chlorophyll concentration and eutrophication dynamics on the Paliastomi Lake and its surrounding area in 2013-2021. This part of the study was prepared through remote sensing, as a result of processing satellite images that were received from Landsat 8, Sentinel – 2, in the SNAP application. On-site surveys were carried out in October 2021, July and September 2022 to validate the results obtained through remote sensing. The concentration of chlorophyll itself was measured, as well as chemical factors contributing to it such as water temperature, pH, total hardness, alkalinity, and acidity. Turbidity was also measured, and qualitative reactions were performed to determine the presence of phosphates and nitrates (nutrients). The data from sensors installed by the NGO SABUKO on Paliastomi Lake were also used in the study. The Paliastomi Lake and its surrounding area are predisposed to eutrophication caused by both natural processes and human activities.

Key words: chlorophyll, eutrophication, remote sensing, SNAP, PONTOS.

1. Introduction

Eutrophication is a gradual increase in the concentration of phosphorus, nitrogen and other plant nutrients in an aquatic ecosystem, such as lakes or other types of water (VanLoon et al., 2016). Productivity or fertility of such an ecosystem naturally increases as the amount of organic material that can be broken down into nutrients increases. Chlorophyll is essential for the existence of phytoplankton. Phytoplankton is an indicator of good water condition. Monitoring the level of chlorophyll is the best way of tracking algal growth. Surface waters with a high level of chlorophyll are usually high in nutrients, mainly phosphorus and nitrogen. These nutrients cause the algal growth that is, “blooming the water”, which, in turn, leads to changes in environmental conditions: the level of dissolved oxygen in the water decreases which can lead to the mass death of fish. High levels of nitrogen and phosphorus can also be an indicator of anthropogenic pollution, such as septic system leakage, poorly functioning wastewater treatment plants or fertilizer runoff. Thus, chlorophyll measurement can be used as an indirect indicator of nutrient levels (VanLoon et al., 2016).

The purpose of this study is to conduct an integrated study in the pilot area of the PONTOS project in Georgia (covers the Kolkheti lowland, the lower flow of the Rioni River, including the confluence with the Black Sea and the Black Sea coastline), in particular, on the Paliastomi Lake and its surrounding area of the chlorophyll concentration and eutrophication dynamics through remote sensing and data obtained as a result of in-situ. The latter includes searching for historical data, chemical analysis of water samples using analytical chemistry protocols and analysis of data obtained from sensors installed on site.

1.1. Overview of the current situation

There are more than 26,000 rivers in the country, of which 99% of the rivers are less than 25 km long. Although the number of medium-sized and large rivers is relatively small, their share in the total volume of renewable water resources is significant. The volume of renewable surface water formed during the year is about 66 billion m^3. Georgian rivers belong to the Black Sea and Caspian Sea basins. The Black Sea basin includes: the Enguri-Rioni, Chorokhi-Adjaristskali and Kodori-Bzipi basin districts. The Mtkvari (Kura), Alazani-Iori and Khrami-Debeda river basin districts are part of the Caspian Sea basin. The rivers are unevenly distributed over the territory of Georgia. 75% of Georgia's water resources are located in Western Georgia. There are about 860 lakes in the country, the vast majority of which are small (Trapaidze, 2012).

Water monitoring in Georgia is mainly carried out by the National Environmental Agency (https://nea.gov.ge/). The Agency carries out a significant part of the monitoring within the framework of the European Union project „Environmental Monitoring in the Black Sea – EMBLAS", information about which and research reports are available at https://emblasproject.org/. The main monitoring results are reflected in the "National Report on the State of the Environment for 2014-17", which is approved by the decree of the Minister of Environmental Protection and Agriculture of Georgia (30/12/2019, N 2-1294) (eiec.gov.ge/Ge/NationalReports). According to this document, "most of Georgia's rivers meet water quality standards, although water pollution is a constant or recurring problem in some rivers. The most common water quality problem in Georgia is ammonium nitrogen pollution. According to the monitoring data, the maximum concentration of ammonium nitrogen is recorded annually in 11 rivers and 4 lakes of Georgia; The state of the Black Sea waters in terms of eutrophication can be characterized as generally good. However, in two areas near the seaports of Anaklia and Poti there is an increased concentration of chlorophyll a" ("National State of the Environment Report 2014-17").

High concentrations of nitrates, nitrites and phosphates in water bodies are the main cause of intensive growth of algae, leading to eutrophication of water bodies. Sulfates are considered to be less toxic compounds. Their high concentration affects the pH level of the water. Aquatic organisms are particularly sensitive to high concentrations of chlorides. Nitrates and nitrites, sulphates, phosphates, and chlorides are found in water mainly as a result of the discharge of nutrients from fertilizer-enriched agricultural lands, as well as the discharge of municipal and industrial wastewater. The maximum permissible concentrations of these pollutants are approved by the Decree N425 of the Government of Georgia dated December 31, 2013 "on the approval of the Technical Regulations for the Protection of Surface Waters of Georgia from Pollution" (see Table N1).

Pollutants	Concentration mg/l
Ammonium nitrogen	0.390
As	0.05

Cd	0.001
Cl^-	350
Cu	1.0
Fe	0.3
Pb	0.03
Mn	0.1
Mo	0.25
Ni	0.1
NO_3^{2-}	45
NO_2^{2-}	3.3
Cl^-	350
PO_3^{2-}	3.5
SO_4^{2-}	500
Zn	1

Table 1. Maximum allowable concentrations of pollutants (MPCs)

"The problem of eutrophication is observed in the Georgian waters of the Black Sea. Chemical pollution in the coastal waters of Georgia is less expressed compared to other countries in the Black Sea basin, however, high concentrations of some pollutants have been observed at several points of the coast." The Black Sea water monitoring system operating within the framework of the EMBLAS project, pays special attention to the study of coastal waters and physicochemical parameters (transparency, nitrites, nitrates, ammonium nitrogen, organic substances, chlorophyll) and hydrobiological monitoring. In 2016-2018, a study of the Black Sea water quality was carried out at 15 points on the coast of Georgia. According to the monitoring results, the level of eutrophication of the Black Sea coastal waters of Georgia was generally assessed as good. However, moderately high levels of chlorophyll were observed in two sections – the port waters of Anaklia and Poti. The accuracy of these data is confirmed by the results of hydrobiological monitoring. The study results also indicate pollution of the Black Sea with organic substances." According to the document, "the results of the research also indicate the pollution of the Black Sea with organic substances. If the concentration of polychlorinated biphenyls (PCBs) in the waters of the Black Sea was within the limits established by the environmental quality standards (EQS) of the European Union, the concentration of pesticides – hexachlorocyclohexane, heptachlor epoxide and cypermethrin exceeded the norm established by these standards at several points. According to the recommendation of experts, these monitoring results should be taken into account and monitoring of these substances should continue. If the pollution indicators are maintained, appropriate measures will be required. In recent years, there has been an increase in the species diversity of zooplankton, which indicates an improvement in water quality. According to the monitoring results of microphytes and macrozoobenthos species, relatively poor or average condition of the coastal waters is observed only near the Batumi port."

Measurements carried out within the framework of the EMBLAS project in the surface and bottom layers of the sea revealed relatively low concentrations of inorganic nitrogen. Dissolved inorganic nitrogen (DIN) and total nitrogen (TN) were low. According to the study, compared with neighboring countries, the lowest concentration of chlorophyll is recorded in the territorial waters of Georgia. This indicates a relatively low nutrient content in the water. However, it should be noted that the highest content of chlorophyll in the coastal waters of Georgia was observed in the mixed waters of the upper layer of Anaklia, which is probably caused by the pollution of the river with ammonium nitrogen. The only area where the concentration in territorial waters is higher than concentration on the coast, is the Poti junction, which is probably the result of high anthropogenic impact in the Poti Port. Substances, the high concentration of which also indicates eutrophication, were relatively high in the Batumi water area and in the impact zone of the Chorokhi River.

The EMBLAS project used the Black Sea Eutrophication Estimation Tool (BEAST) and the Trophy Index (E-TRIX) to determine the level of eutrophication. According to the assessment of the project, the water quality of the Georgian shelf was generally good. The condition of the part of the shelf where the Poti Port is likely to have a negative impact was assessed as average. Similar results were obtained using the trophy index method (E-TRIX). According to the trophy index (E-TRIX) method, the water condition is generally good and, in some areas, it is very good.

According to the Third National Program for Environmental Protection Actions of Georgia for 2017-2022 (approved by the Decree of the Government of Georgia N1124 of May 22, 2018) “the quality of surface water in Georgia is satisfactory. The main problem is the content of ammonium nitrogen in the water. In most rivers, the concentration of ammonium nitrogen exceeds the permissible level, which is associated with wastewater from settlements and agricultural runoff. Sewage and municipal waste enter the Black Sea and cause pollution of sea water with nutrients and, consequently, enhance the process of eutrophication. This is the most serious problem of the Black Sea. Signs of eutrophication can also be observed in the coastal zone of Georgia.”

We were unable to find scientific articles related to the study of chlorophyll oncentration in our study area (Paliastomi Lake). Studies published in various scientific journals about the Paliastomi Lake can be found, but they do not address eutrophication and chlorophyll concentration (Janelidze et al., 2021, Abramia, et al., 2022, Dassenakis, et al., 2006).

1.2. How PONTOS can solve existing problems and shortcomings

Research carried out within the framework of the **PONTOS** project restores the picture of Paliastomi and its surroundings in the previous years. With the help of these data, it will be possible to find out how the eutrophication process changes over seasons and express an opinion whether it is more connected with the anthropogenic factor or a natural phenomenon.

2. Materials and methods

2.1. Description of the pilot area

The study of changes in chlorophyll concentration covered 2013-2021, the Paliastomi Lake and the water area adjacent to Poti were selected as a research site within the pilot area of the PONTOS project.
Fig. 1.

The Paliastomi Lake is a flowing lake located on the Odisha-Guria lowland. It is located near Poti. The surface area of the lake is 18,2 km^2. The basin area is 547 km^2, the maximum depth is 3,2 m, the average depth is 2,6 m. The volume of water is 52 million $m^{3.}$ It is located 0,3 m below the sea level. The Pichori River flows into the lake, and the Kaparchina River flows out. Water levels are high in spring, summer and autumn and low in winter.

Fig. 1. Pilot region of the PONTOS project

The water temperature increases in July-August (25,1°C), decreases in January (5,2°C). The lake is part of the Kolkheti National Park (Apkhazava et al., 1984) see fig. 2

Fig. 2 Pichori River. Photo Green alternative

2.2. Methodology of data collection and analysis

For our study, satellite remote sensing was used to obtain historical data, which obtains data on the spatial and temporal variations of suspended particles in estuarial and coastal zones.

In general, different satellites are used for remote sensing, such as: MODIS (250m), OrbBeew-2 (1km), Landsat8 (15m), Gaofen-1 (30m), Sentinel 2 (10m), Sentinel 3 (300m) (Schowengerdt, Robert A. (2007). Landsat8 and Sentinel 2 satellites were used for this particular study. The PONTOS platform receives data from land and sea databases (e.g. Copernicus, MODnet, Géoservices Sextant and BLACKSEASCENE) and uses the obtained images to estimate the dynamics chlorophyll concentration. This, as already mentioned, is an indicator of water pollution with nutrients.

A low concentration of chlorophyll (<2 mg/m3) 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 from 2 to 30 mg/m3 are reflected in green part (500-600 nm) and red bands (600-700 nm). In case of higher reflectance, reflecting the peak in the green part of the spectrum and the concentration of chlorophyll above 300 mg/m3 is shown in the green part of the spectrum, the blue and red bands in this case show low reflection (Schalles, 2006).

The concentration of chlorophyll a (Chl-a) was determined from satellite multispectral images Landsat 8 (2013-2015) and Sentinel-2 (2016-2021). Satellite images were selected and extracted from open access databases: Earth Explorer (USGS) and Copernicus Open Access Hub.

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 operating since 2015. The generated image data files consist of twelve spectral bands with a higher resolution of 10 m.

Sentinel-2 images can be obtained from the Sentinel Scientific Data Hub (https://scihub.copernicus.eu/) and Earth Explorer (https://earthexplorer.usgs.gov/) databases. The Sentinel-2 product is a set of elementary granules of a fixed size, taken from one orbit. A granule is the smallest indivisible part of a product (containing all possible spectral bands). Also called granular tiles, they are 100 × 100 km orthoimages in the UTM/WGS84 projection that divide the Earth's surface into 60 zones. Each UTM zone has a longitude, vertical latitude of 6° and a horizontal latitude of 8°.

Landsat is a multispectral satellite network created by NASA (US National Aeronautics and Space Administration) in the early 1970s. Satellites are updated to this day. Landsat 8 has been operating since 2013. It orbits the Earth in a sun-synchronous near-polar orbit (inclination 98.2 degrees) and has a 16-day repeating cycle with an equatorial crossing time of 10:00 +/- 15 minutes.

Landsat 8 is equipped with Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments. OLI includes 9 bands, which are measured in the visible, near infrared and shortwave infrared parts of the spectrum (VNIR, NIR and SWIR). TIRS covers 2 ranges and measures the temperature of the earth's surface in two thermal ranges using a new technology that uses quantum physics to detect heat. Both sensors provide seasonal ground coverage with a spatial resolution of 30 meters (visible, NIR, SWIR); 100 meters (thermal); and 15 meters (panchromatic) (Cao, et al., 2020).

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

To generate an image from the Copernicus open system https://scihub.copernicus.eu/dhus/#/home, it is necessary to select a specific area of study, determine the period of study, select the correct satellite platform (in our case, Landsat 8 and Sentinel-2), determine type of product, cloudiness as the latter hinders finding and downloading a good image. An image can be generated from the Earth Explorer database through same steps.

The obtained images were processed using the C2RCC processor of the ESA SNAP 8.0 application. The C2RCC processor is based on an artificial neural network (ANN) method where neural networks are trained from a database of simulated water reflectances and the TOA radiation connected to it (Asim et al. 2021). Finally, IOP generating of Chl-a and optical properties of water were performed using the C2RCC processor. The Chl-a values have been converted to mg/m^3 units and the file has been converted to GeoTIFF format. The ESA SNAP 8.0 application is focused exactly on calculating the concentration of chlorophyll in lakes and estuaries

(Schowengerdt, R., 2007). At first stage of work in SNAP, the obtained image should be transfered to its platform. Once again, the area of study of chlorophyll concentration should be marked. At the next stage, we activate the Graph Builder from the Tool section of the program and create a graph that shows the sequence of calculations.

On the final product, the centers of eutrophication and the minimum and maximum chlorophyll concentration in the study water are highlighted. Fig. 3

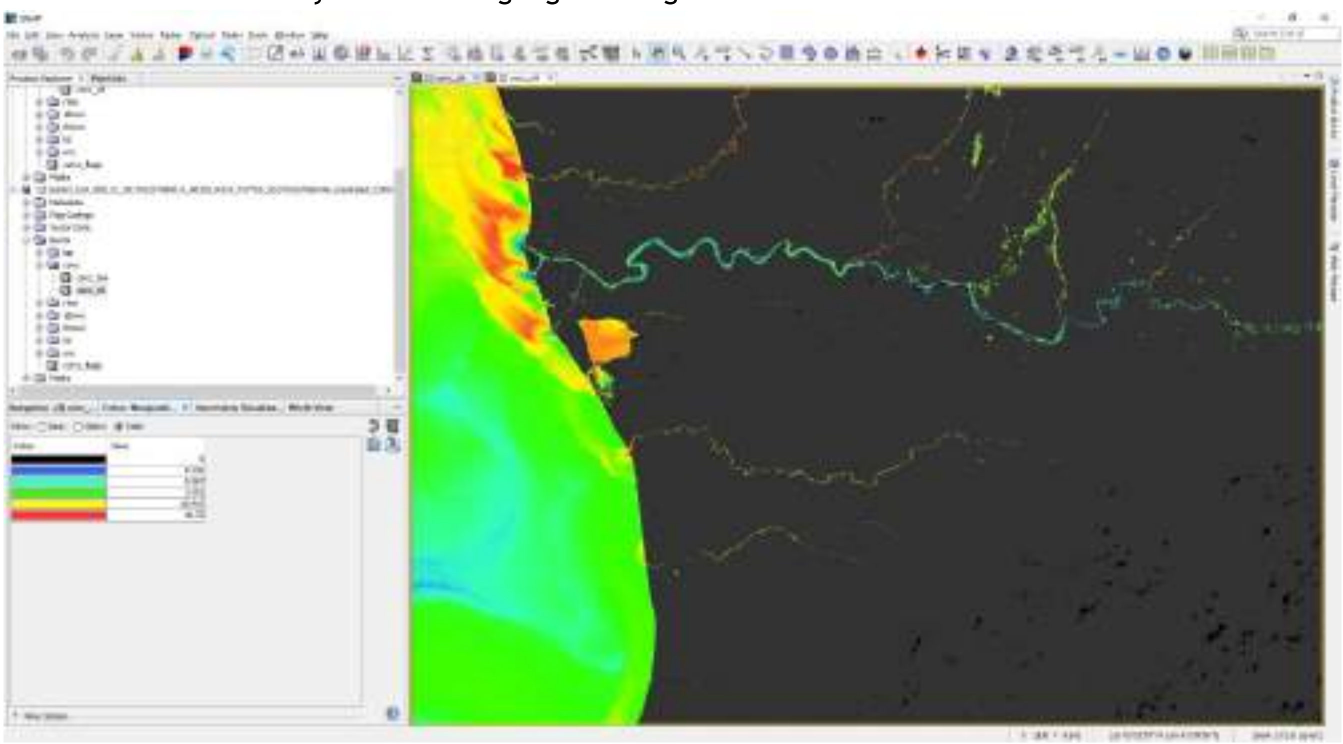


Fig. 3. Image processing steps for working in SNAP

2.3. On-site research methodology

Water quality is mainly determined by the environment, climate conditions and anthropogenic activities (Snoeyink et al. 2021). Water quality indicators used by environmental agencies include the following characteristics:

- Turbidity;
- Color;
- Temperature;
- Taste (for drinking water);
- Smell;
- PH;
- Conductance;
- 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+}, Al3+ 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, oil;

Inland waters

In different countries, the chemical and biological quality of rivers and canals is controlled by special government agencies. In Georgia water quality is monitored by the National Environmental Agency. The General Water Quality Assessment (GQA) is used to classify the aesthetic quality of rivers. The quantity, color, smell of garbage is taken into account; Also the presence of oil and foam on the river bank. The scheme is mainly used in public places. Also in places where there may be an intermittent inflow of sewage.

Coastal and marine water quality

In many countries, the quality of coastal and marine waters is vital for tourism and fishing industries and is regulated by various international agreements (Burton et al. 2002).

- International Convention on Civil Liability for Oil Pollution Damage, Brussels, 1969.
- International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND), Brussels, 1971.
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, London, 1972.
- International Convention for the Prevention of Pollution from Ships (MARPOL), London, 1973
- **The OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, 1992**

Test protocols

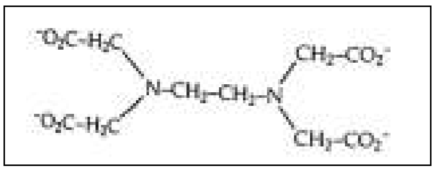
Measurement of total water hardness

Environmental chemistry uses the hardness index to determine the concentration of Ca^{2+} and Mg^{2+} ions in water (USEPA. 1978b). From a chemical point of view, the hardness index is the combined concentration of Ca^{2+} and Mg^{2+} ions. The most common type of water hardness is temporary hardness. This is caused by calcium and magnesium compounds dissolved in water.

The natural source of these salts are rocks containing calcium and magnesium salts - limestone ($CaCO_3$) and dolomite ($CaCO_3$. $MgCO_3$).

Calcium carbonate is insoluble in water, although it interacts with carbon dioxide (the latter dissolves well in water and is present in large quantities in the atmosphere). Water-soluble calcium bicarbonate is formed. The chemical reaction of this process is as follows:
$CaCO_3$(solid)+CO2(g)+H_20(liquid)↔Ca ($HCO_3)_2$(liquid)

The resulting soluble salt causes water hardness. However, the process is reversible. Calcium and magnesium ions, forming a strong complex, interact with ethylenediaminetetraacetic acid (EDTA). Therefore, the hardness can be determined by titrating a standard EDTA solution. Eriochrome Black T-EBT solution is used as an indicator. The structure of EDTA is as follows:



At the beginning of the reaction, the EBT indicator forms a complex with cations and the color of the solution changes. When we add EDTA during the titration, a new Ca^2+ and Mg^2+ complex is formed because the attraction between EDTA and cations is greater than between EBT and cations. Finally, all existing cations connect to EDTA, the color of the indicator changes from red to blue which is considered the end of the titration. Hardness is calculated by measuring the amount of EDTA consumed in the titration and corresponding to dissolved calcium and magnesium ions.

Required reagents:
NH_4OH/NH_4Cl- buffer for pH10;
0.01M EDTA
Eriochrome black T indicator;
1M HCl;

Total alkalinity

Total alkalinity refers to the ability of water to neutralize an acidic environment (VanLoon et al., 2016). The measurement is based on titrating. The alkaline environment in most natural waters is due to the presence of ($CO_{3=)}$, bicarbonate ($HCO_{3-)}$ and hydroxyl anion (OH^-). However, borates, phosphates, and silicates also have their say in the formation of an alkaline environment. Alkalinity is usually associated with calcium carbonate ($CaCO_3$).

Relationship between alkalinity and hardness

Alkalinity and hardness are linked by common ions. Alkalinity and hardness are measured by the same ions - bicarbonates and carbonates (USEPA. 1978a).

Measurement

Alkalinity measurement is based on the titration of a water sample with dilute sulfuric acid (0.1*N* or 0.02*N*). One ml 0.1 NH_2SO_4 is equivalent to 5 mg $CaCO_3$; 1 ml 0.02$NH2SO_4$ is equivalent to 1.00 mg $CaCO_3$ (APHA. 1998). A 1% solution of methyl orange is used as an indicator. 100 ml of water is poured for analysis into a conical flask with a capacity of 250-300 ml, 2-3 drops of each indicator are added and is titrated with 0.1N hydrochloric acid solution until the color of the solution changes from yellow to pink.

Formula: $\alpha \times K \times 1000/100 \times 100 = \alpha \times K/10 = 0.1 \times \alpha \times K$, where α is the amount of acid used for titration in ml, K is the correction coefficient.

General acidity of water

Required reagents: 0.1N NaOH; Methyl red 1%.

100 ml of water is placed for analysis into a conical flask with a capacity of 250-300 ml, 2-3 drops of each indicator are added and titrated with 0.1N sodium alkali solution until the color of the solution changes from yellow to pink.

Formula: $\alpha \times K \times 49$, where α is the amount of acid used for titration in ml, K-correction coefficient (APHA. 1998).

PH Measurement

PH is a measure of hydrogen ions in water and its index ranges from 1.0 to 14.0. The lower the pH water, the higher its acidity. The higher the pH of water, the more alkaline it is. PH is affected by many chemicals and organisms. A large number of marine animals choose pH 6.5 - 8.0 as their habitat. That is, having moved to a little acid-slightly alkaline region.

Water pH is an important indicator for determining how contaminated water is with nutrients, metals, algae and pesticides (Williams, 2014). The pH of the water is particularly important for the fixation of nutrients such as nitrates, phosphates, trace elements such as copper, iron, zinc and aluminium. To measure pH, we used sensor HI98103, Hanna instruments (Fig. 4).

Fig.4.pH Sensor

Water turbidity

Turbidity is caused by particles suspended or dissolved in water that absorb light, causing the water to become turbid or cloudy (Gurlin et al., 2011). Particles may include sediment, especially clay and silt, low molecular weight organic and inorganic substances, soluble colored organic compounds, algae and other microscopic organisms.

Algae that grows on water nutrients from rotting leaves or other naturally occurring decomposition processes, can also be a source of turbidity. Phosphorus composed from a variety of sources can cause algae to grow causing turbidity. Nephelometric Turbidity Unit (NTU) is taken as the measure of turbidity.

Water quality standard according to turbidity

Description	Turbidity (NTU) - desired value
1B (drinking water)	10
2A (Aquarium/Cold Waters)	10
2B (fish farming/cold/warm waters)	25
2C (fish common in local waters)	25

Turbidity was measured with a PASCO sensor (Fig. 5). Measurements of the BSB ECO Monitoring Project of the NGO Sabuko (https://www.sabuko.org/) were also used.

Fig.5 PASCO Wireless calorimeter and turbidity meter

Reactions for the detection of phosphate and nitrate ions were also carried out. These experiments are based on qualitative analysis and can be considered by the intensity of the color change of the reaction in connection with the concentration of ions present.

Phosphate detection reaction

Reagents: silver nitrate;

5-10 ml of water is placed into a test tube and silver nitrate solution is added drop by drop. In case of presence of phosphate ions, a precipitate of yellow silver phosphate is formed. (Fig. 6). The color changes due to the formation of silver phosphate which is yellow in color (Williams, 2014).

$XPO_4 + 3AgNO_3 = Ag_3PO_4 \downarrow + 3\ XNO_3$

Fig. 6. Presence of phosphate ions in water sample

Nitrate ion detection reaction

Reagents: solution of diphenylamine in sulfuric acid.

5-10 ml of water is placed into a test tube and a solution of diphenylamine dissolved in sulfuric acid is added drop by drop. In case of presence of nitrate ions, white snowflakes are formed. If they turn graysh, this means a high concentration of ions (Smith. 2019).

Determination of chlorophyll concentration in the Paliastomi Lake

There is a classic method for determining chlorophyll concentration (Smith. 2019). We used a mobile spectrophotometer that allowed us to measure the amount of chlorophyll on-site. A miniature OCEAN INSIDE spectrophotometer (Fig. 7) was used, which measures pigment absorbtion using an auxiliary program.

Fig. 7 OCEAN INSIDE Mini spectrophotometer

According to the study (Schalles. 2006), low chlorophyll concentration (<2 mg/m^3) is well reflected in the blue part of the spectrum (400–500 nm), with increasing wavelength in the near infrared the spectrum (NIR, 700–800 nm) the reflection decreases to 0; Chlorophyll concentrations from 2 to 30 mg/m^3 are reflected in green (500-600 nm) and red bands (600-700 nm). At a higher reflectivity, the reflection peak in the green part of the spectrum and the chlorophyll concentration above 300 mg/m^3 appears in the green part of the spectrum, the blue and red bands reveal low reflection in this case.

2.4. In-situ data collection

Water from the Paliastomi Lake was taken at the end of 2021, at the beginning of July 2022 and in September 2022. Several important analyses were carried out to obtain additional information about the purity of the lake and the presence of algae in it. All experiments used water samples collected on the same day from the Paliastomi Lake, which were delivered to the chemical laboratory of Ilia Tbilisi State University on the same day.

The non-governmental organization Sabuko (https://www.sabuko.org/), which installed sensors as part of the BSB ECO Monitoring project, shared with us the data on the chemical composition of the Paliastomi Lake water. We also used data obtained from the portal of the same project (BSB ECO Monitoring Project) https://bsbecomonitoring.net/ These sensors measure: ph, redox potential, water temperature, water conductivity, salt content, TDS, i.e. the total number of particles, dissolved oxygen (DO), turbidity. Each data is a certain indicator by which water quality can be discussed.

Dissolved Oxygen (DO) amount - Oxygen is transferred to the water through contact with air and is also released during algae photosynthesis. The amount of oxygen dissolved in water depends on temperature, turbidity, mineralization.

Electrical conductivity is also considered one of the important characteristics of water. It depends on the water temperature (the higher the temperature, the higher the permeability) and mineralization (Smith. 2019). Natural waters are a mixture of strong and weak electrolytes. The mineralization of water is mainly a result of: Na^+, K^+, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^-. It is due to these ions that el. conductivity of natural waters is determined. Other ions such as Fe^{3+} Fe^{2+},

Mn^{2+}, Al^{3+}, NO_3^-, HPO_4^-, H_2PO_4 do not have much effect on the conductivity (unless, of course, there are a large number of them. Then their influence also increases).

El. Conductivity has no fixed norms, however, for example, 2000 μS/cm corresponds to approximately 1000 ppt salinity. Also, for example, it can be mentioned that the conductivity of bidistillate is 0.05 μS/cm, and that of sea water 25 ^{0}C 50,000 μS/cm.

TDS, that is, totally dissolved particles provide additional information on the method for determining water transparency (Smith. 2019). 150-250 ppm is a good indicator of water transparency. That is, the particles dissolve in a very small amount and such an indicator is also good for drinking water. More than 1200 ppm is already considered contaminated. According to the data obtained, the index of the Paliastomi Lake sometimes exceeds the norm and this is mainly observed during periods of high temperature or a hot season.

Another indicator that sensors measure is the **redox potential.** It is also called the oxidation-reduction potential. Denoted by the symbol Eh, the dimension (mV) and pH, along with temperature and salinity, characterize the stable state of water. In lakes and surface waters, the index ranges from -0.5 to +0.7, although in some types of water the index can be more than -0.6. In this case, we can talk about the increased content of sulfur and hydrogen sulfide. Water with a redox indicator can be:

- Eh >+ (more than 0.1-1.15) – there is oxidizing environment in the water, water contains dissolved oxygen and Fe^{3+}, Cu^{2+}, Pb^{2+}, Mo^{2+} ions.
- Eh from -0.0 to +0.1 is transient redox environment, unstable geochemical regime, variable amount of oxygen and hydrogen sulfide, as well as weak redox reactions of various metals. It also indicates the presence of microorganisms and the process of eutrophication.
- Eh<0.0 – reducing environment. indicates the probable presence of hydrogen sulfide and metals Fe^{2+}, Mn^{2+}, Mo^{2+} in water.

3. Results

3.1. Results received through remote sensing

To determine the concentration of chlorophyll a, monthly Sentinel-2 images for 2017-2021 were selected (60 in total). Unfortunately, images of just 9 months of 2016 were cloudless and subject to processing. As for Landsat 8 images, images of only 7 months of 2013, 11 months of 2014 and 7 months of 2015 were processed. The points marked in the tables of Annex 1 are distributed on the map as follows.

Fig. 8. Sampling points where average chlorophyll concentrations were determined

The Paliastomi Lake and the Black Sea coast near the Poti port were used for our study, however, data in the table (Tables 2-10_1, see Annex 1) was also recorded from other nearby locations. Chlorophyll concentration is collected near and far from the coast. For example, near the shore of the Paliastomi Lake (Paliastomi1) and from the middle of the lake (Paliastomi2). It should also be noted here that the method described above (the SNAP program) is suitable for lakes and estuaries adjacent to the sea coast.

We received the results of the 2013 survey for May-December. In general, obtaining a clear image depends on cloud cover. Thus, not all data can be retrieved at any time.

We received remote sensing results for May-December 2013. In general, obtaining a clear image depends on cloudiness. Therefore, it is not always possible to collect data for all months.

According to the results obtained in 2013, a fairly high concentration of chlorophyll was recorded. In May, 22 mg/m^3 near the Paliastomi coast and in the inner side, the highest data near estuaries is recorded near Rioni and Old Rioni - 24 mg/m^3 and 28 mg/m^3. 3, 5 and 8 mg/m^3 on the coast of the of the Poti port (near the coast, inland and at distance) during this period.

In June, the concentration in the Paliastomi Lake slightly decreases - 16 mg/m^3, however in July it increases - 34 mg/m^3. In the following months it decreases and, for example, in December it drops to 0.23 mg/m^3.
In the port area, the concentration increases to 20 in June, 2 in July it is 2 and in the autumn months and December it is recorded at 0.92-1.80.

At the estuaries, at the confluence of the Maltakva river, 39 mg/m3 was recorded. Presumably, there were heavy rains in May 2013 and the high concentration of chlorophyll in May is associated with freshets. The increased concentration in the port area in June is associated with the an anthropogenic factor (Fig. 9, 10, 11).

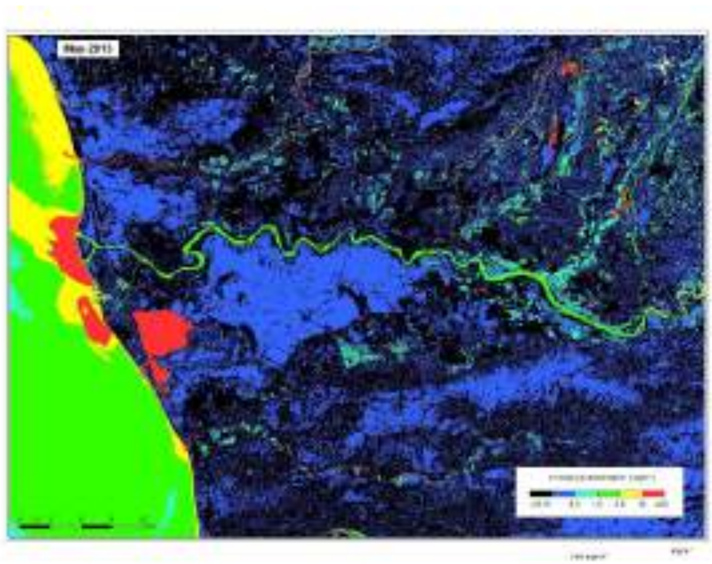


Fig. 9. Summary image of May 2013

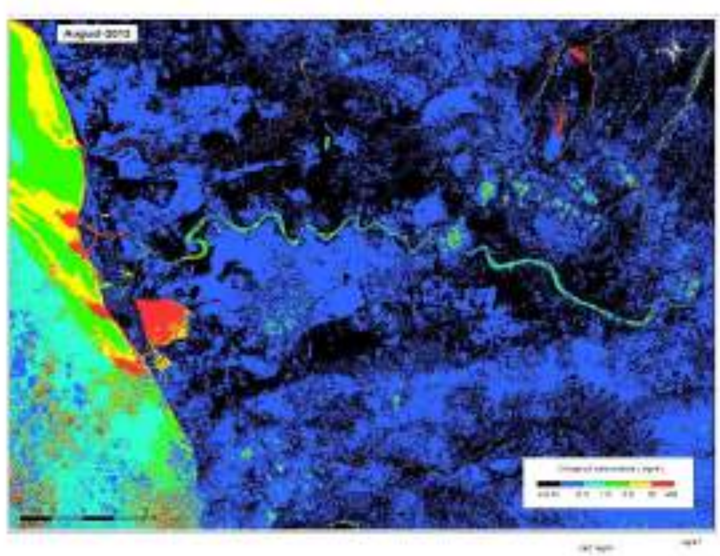


Fig. 10. Summary image of August 2013

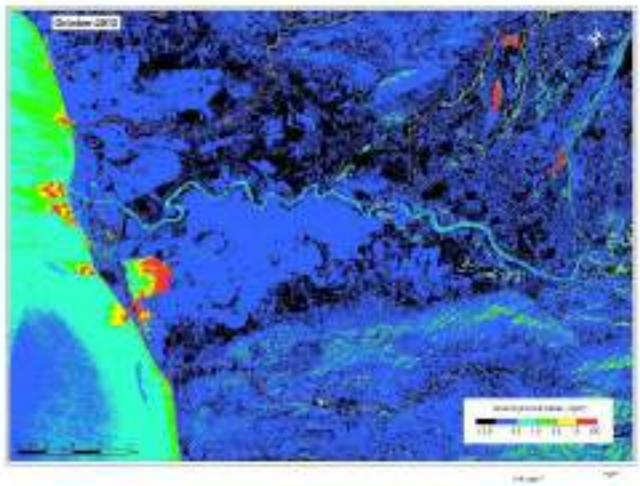


Fig. 11. Summary image of October 2013

For 2014, we have data for a relatively larger number of months (February, March-December). According to the results obtained, in 2014, in the port area in February, a rather high concentration of chlorophyll was recorded - 14 and 30 mg/m^3. Concentration is not high at estuaries 14 and 23 mg/m^3 in Paliastomi. The concentration in the port increases in November. In the remaining months, it fluctuates between 3-5 and sometimes drops even lower. In Paliastomi, the high rate persists throughout the year, decreasing only in July to 0.55 mg/m^3. (Fig. 12, 13, 14).

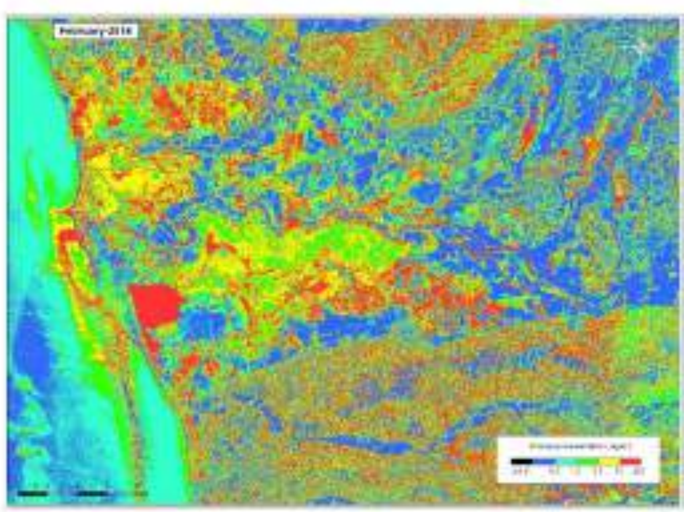


Fig. 12. Summary image of February 2014

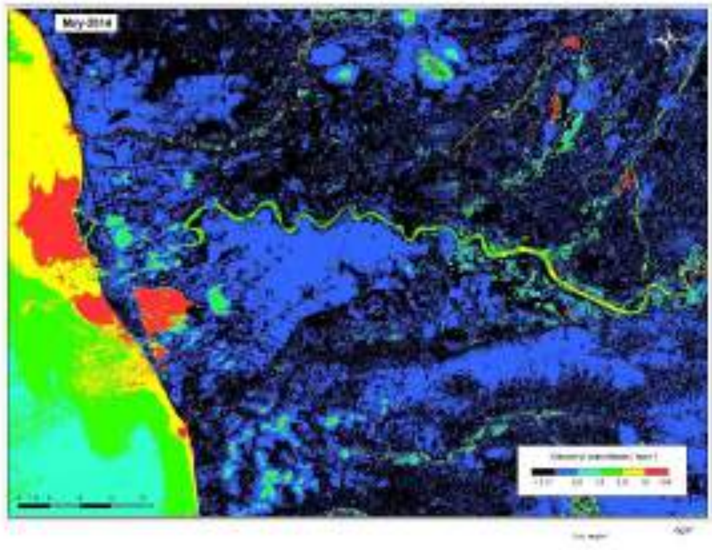


Fig. 13. Summary image of May 2014

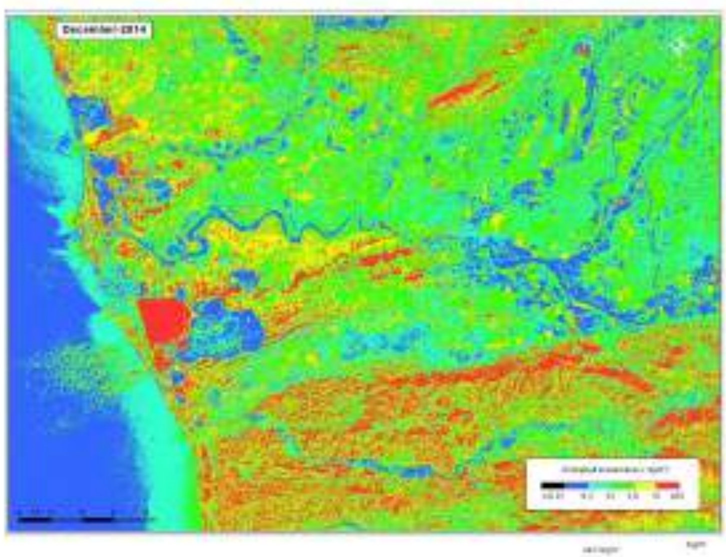


Fig. 14. Summary image of December 2014

For 2015 we have data for the following months: February, April, May-July, September, December. During this period, the concentration in the port fluctuates between 9-6, decreasing only in September-December - 1.77 and 0.81.

The highest concentration on Paliastomi was recorded in September - 39. It is the smallest in June - 0.094. At the Rioni estuary, the highest index is in May -31 (Fig. 15, 16, 17).

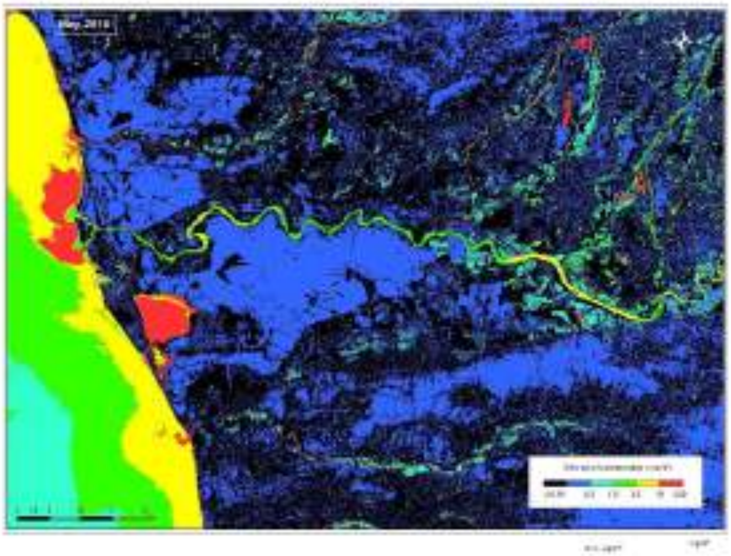


Fig. 15. Summary image of May 2015

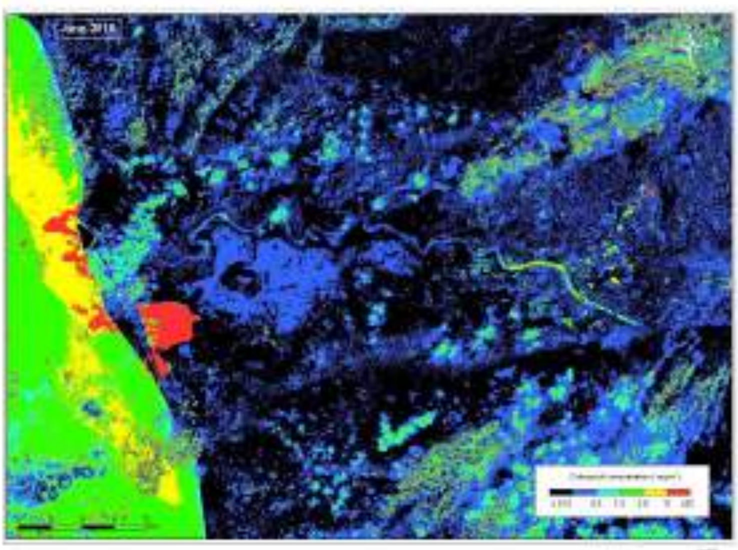


Fig. 16. Summary image of June 2015

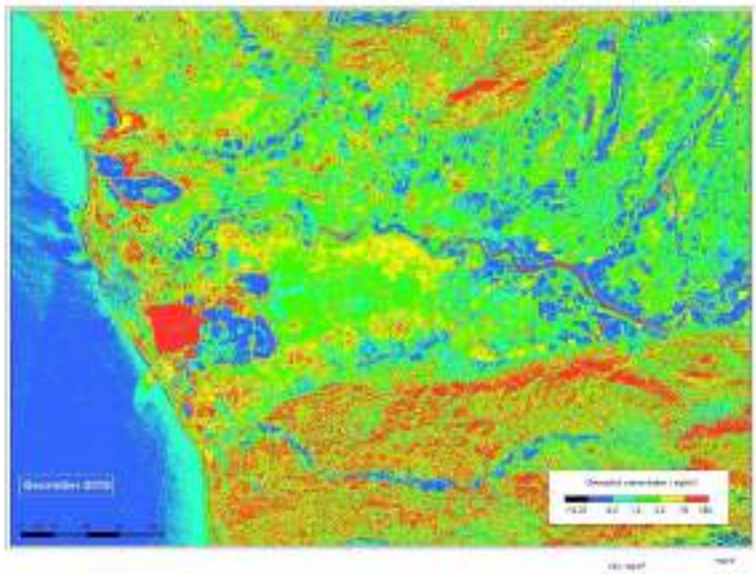


Fig. 17. Fig. Summary image of December 2015

For 2016, we have data for the months of February-September and December. From these, data of June-July could not be obtained due to cloudiness.

The highest index in the Poti port are in April and December - 10 mg/m^3. Low concentrations - 2 and 4 mg/m^3 were observed in May.

The lowest index is on the Paliastomi in February and November - 0.43, and the highest in May and August - 23 mg/m^3. In estuaries, especially in May, the highest index is recorded - 28 mg/m^3 (Fig. 18, 19, 20).

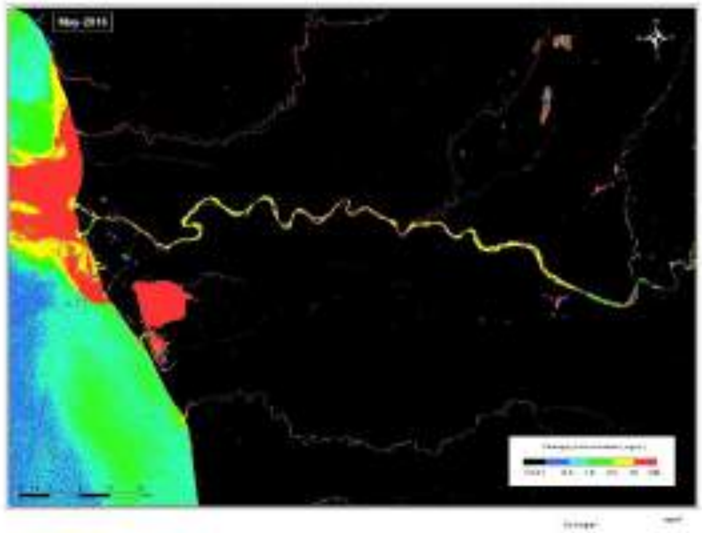


Fig. 18. Summary image of May 2016

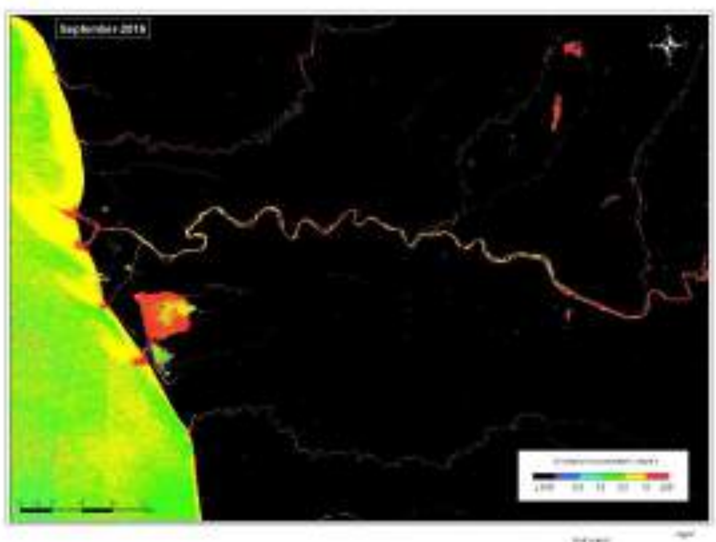


Fig. 19. Summary image of September 2016

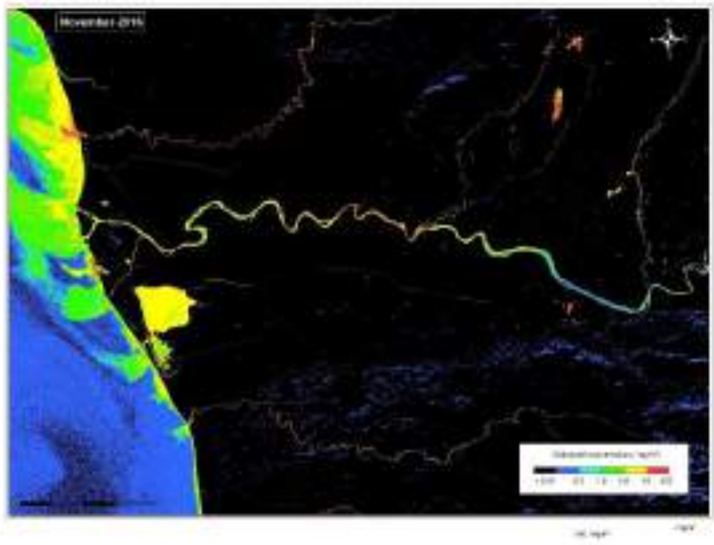


Fig. 20. Summary image of November 2016

In 2017, January, March-December are recorded. However, due to cloudiness, some failures are observed here as well. The highest index at the port is 12 mg/m^3 in June.

26 mg/m^3 is recorded on Paliastomi in May and the lowest - in August. In September, the index partially decreases. It is the smallest in December. At estuaries, the Kulevi River stands out with a high index, which in May is 36 mg/m^3. (Fig. 21, 22, 23).

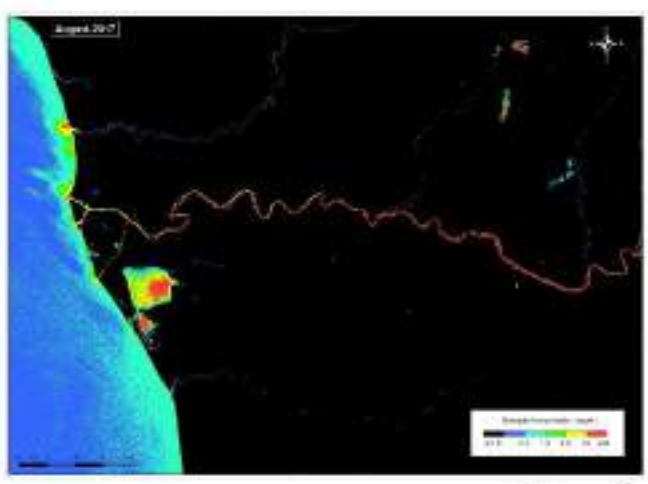


Fig. 21. Summary image of August 2017

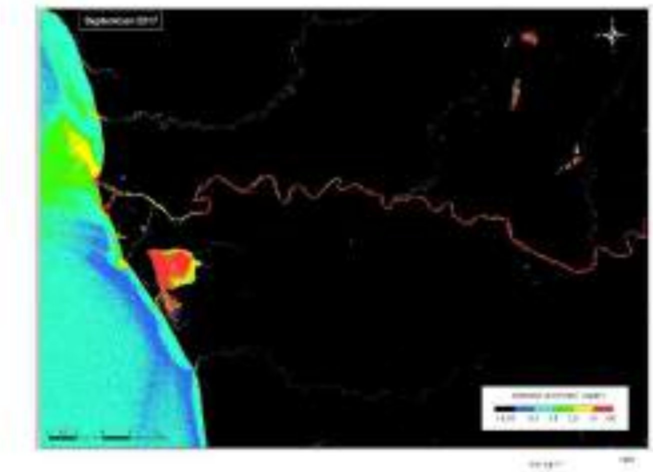


Fig. 22. Summary image of September 2017

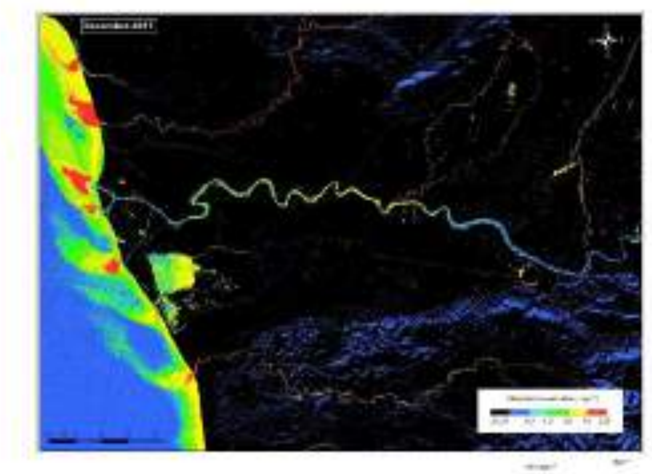


Fig. 23. Summary image of December 2017

We obtained the data for 2018 for the whole year, but in some places the data shows 0 and this is always due to cloudiness. I.E., the satellite does not see that particular place. On the territory of the Poti port we have the lowest index in July-August - 0.33 and 0.44. In May, the chlorophyll concentration on the Paliastomi is quite high. 7 in the port area and 16 on Paliastomi. In August, the index on the Paliastomi Lake decreases to 3. The index is low everywhere In November (Fig. 24, 25, 26).

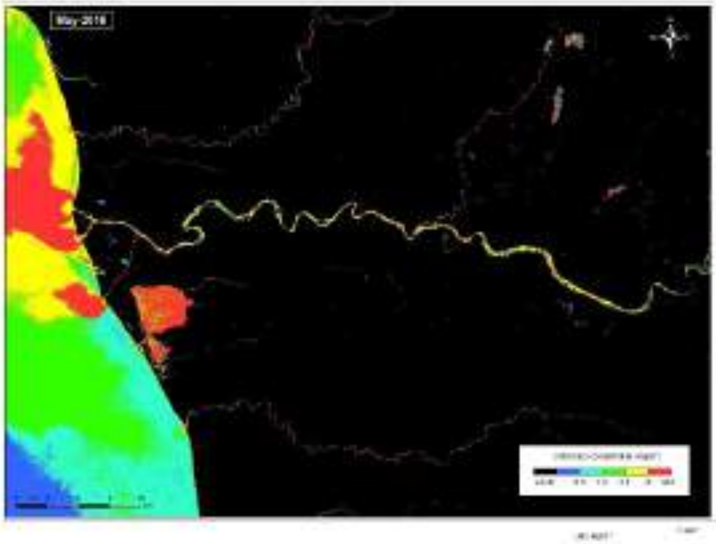


Fig. 24. Summary image of May 2018

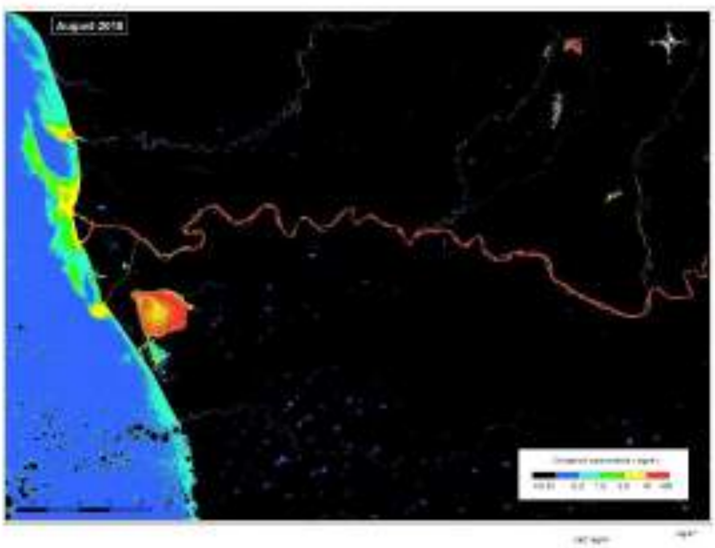


Fig. 25. Summary image of August 2018

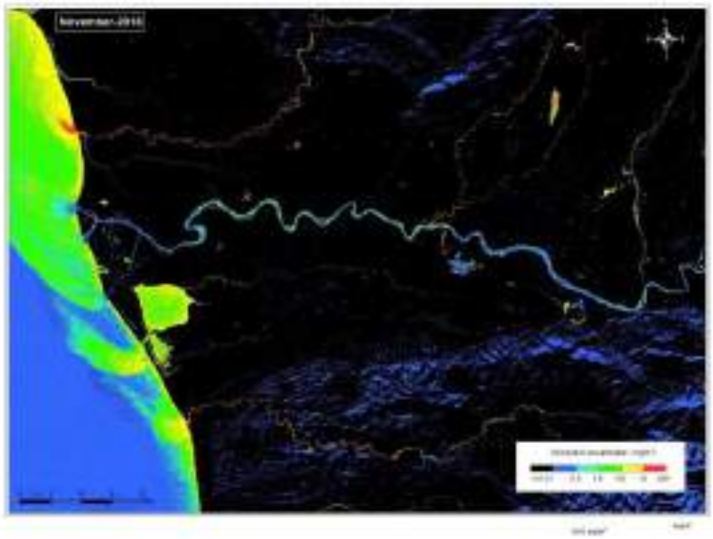


Fig. 26. Summary image of November 2018

Data for 2019 was obtained for the whole year, cloudiness is observed only in July in several places. In June, the concentration in the port area is 0.54 and 2.36. On Paliastomi - 2 and 6. A high index was recorded at the Rioni Estuary - 13 and 16. In September, the chlorophyll concentration in the port is 9. On Paliastomi - 5, in the estuaries, again Rioni shows a high index of 15. By December, almost all places have low indices (Fig. 27, 28, 29).

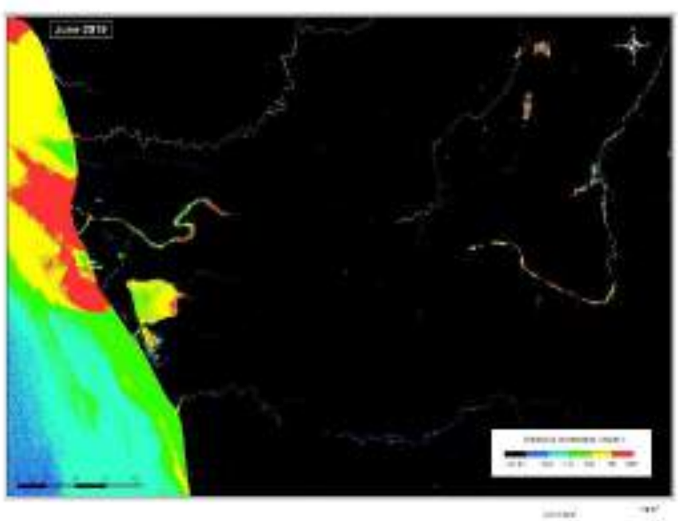


Fig. 27. Summary image of June 2019

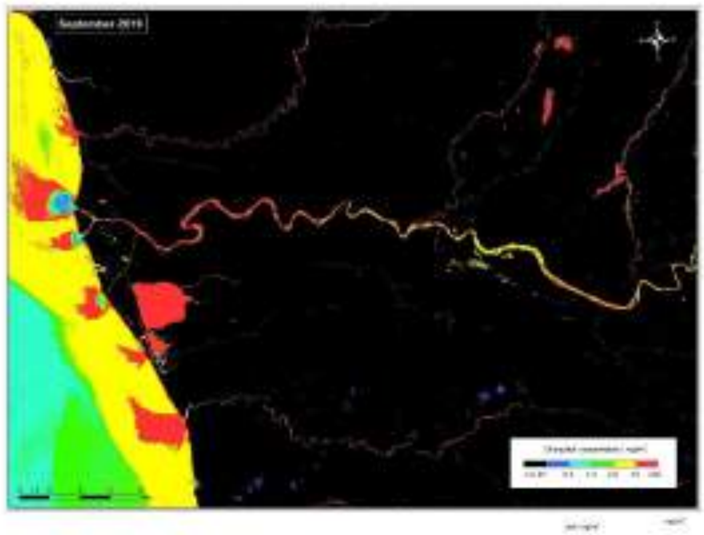


Fig. 28. Summary image of September 2019

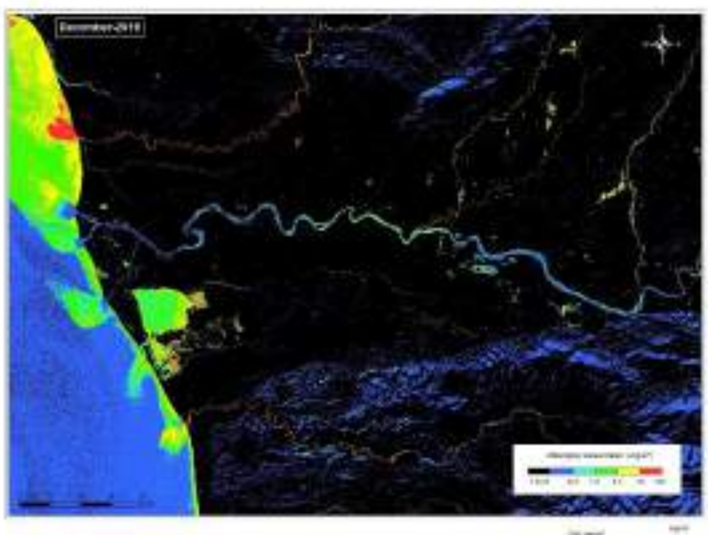


Fig. 29. Summary image of December 2019

The year 2020 is quite interesting (Fig. 30-35), because in April and early May, the COVID pandemic began in Georgia and active activities completely stopped, a lockdown was announced. The following lockdown was announced in November and December. In March, the concentration in the Poti port is on average increased-3.67; 6.86 is recorded on the Paliastomi; In April, the concentration is high -13 and this is probably due to natural phenomena. There are 2 and 9 in the port. The estuaries are almost free. The image from May 2020 shows traces of the lockdown. The rate of pollution of the coastline is significantly reduced and the concentration on Paliastomi is also decreased. Port-0.91, Paliastomi -6.24. In June, eutrophication on Paliastomi is again increased to 18. At the port, in the coastal zone, a low index is maintained - 2.99 and 0.32. The next lockdown was in November and this can be seen from the data received. On the coastline, the figures are quite low - 0.6 and 3.08. On Paliastomi - 5.10.

In December 2020, it ranges from 0.02 to 2.10 on the coastline and 4.77 on Paliastomi, which should also be attributed to natural phenomena. It should be recalled that in December the lockdown continued in Georgia in December as well.

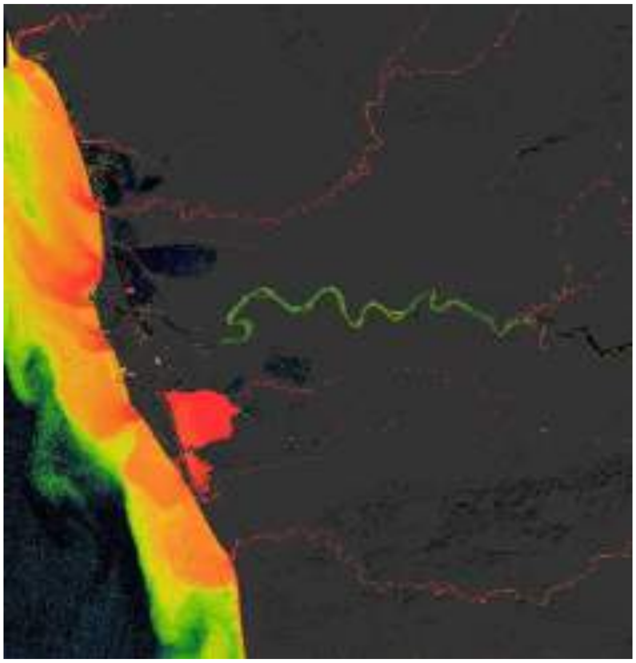


Fig. 30. Summary image of March 2020

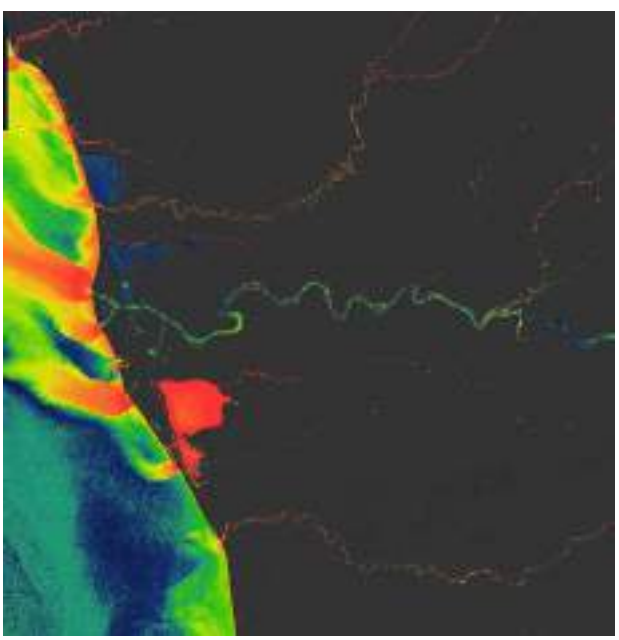


Fig. 31. Summary image of April 2020

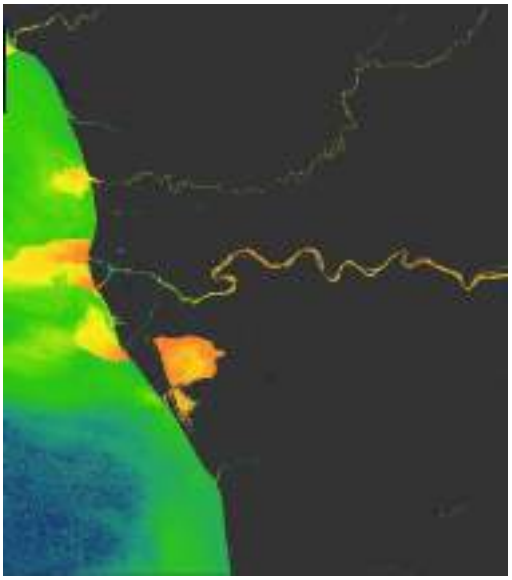


Fig. 32. Summary image of May 2020

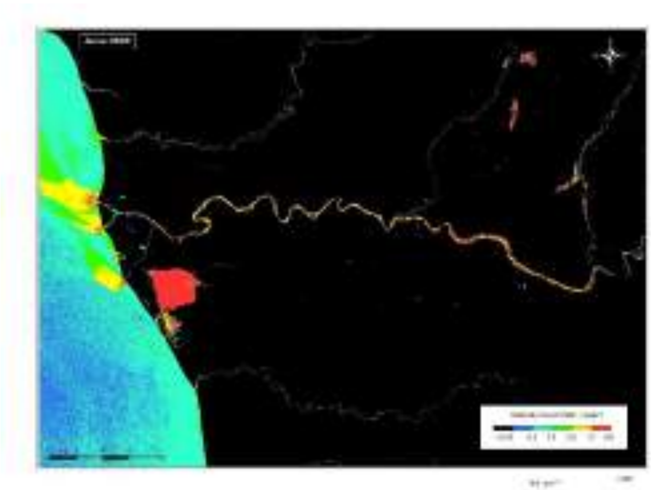


Fig. 33. Summary image of June 2020

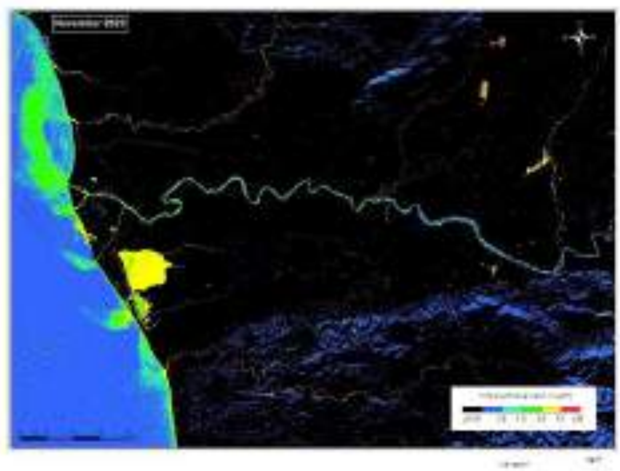


Fig. 34. Summary image of November 2020

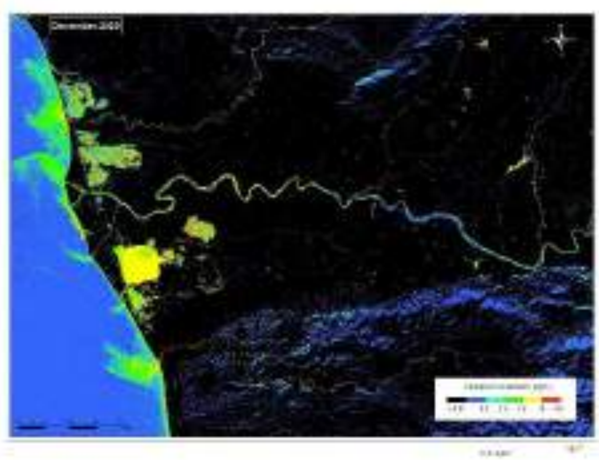


Fig. 35. Summary image of December 2020

2021 (Fig. 36, 37, 38) is the last year of satellite surveys and it is interesting in so far as we have data from on-site surveys from August of this period. Therefore, we can compare the concurring months of these two studies. The highest concentration was recorded in the month of May 2021. Coastline-6-8. On the Paliastomi lake-14-15. There are indices 15 and 11 at the estuaries, at Rioni and Kulevi (Fig. 36). In July 2021, the eutrophication rate relatively decreased to 7.02 on Paliastomi. In the coastline in the port area - 3.21, at the estuaries, Rioni -15 and 17, old Rioni-11 (Fig. 37-38). Increased concentration is not recorded in the following months either and this trend is maintained in November. Coastline - 1.33, only at the Kulevi estuary is 8.53. 8.53 on Paliastomi.

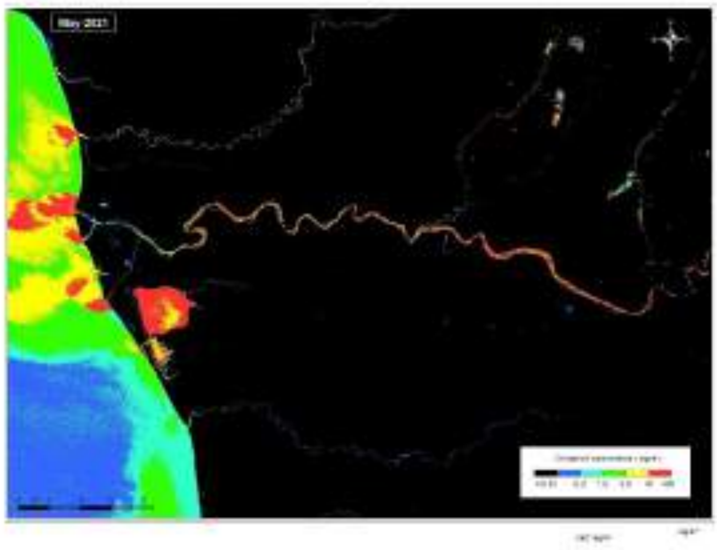


Fig. 36. Summary image of May 2021

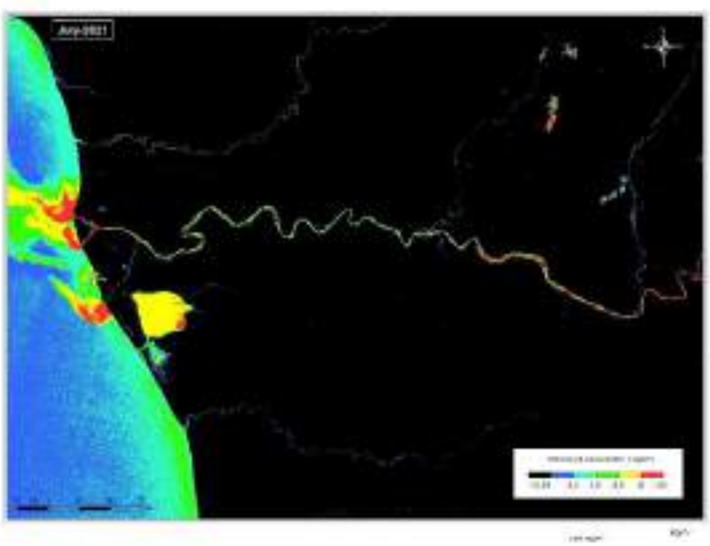


Fig. 37. Summary image of July 2021

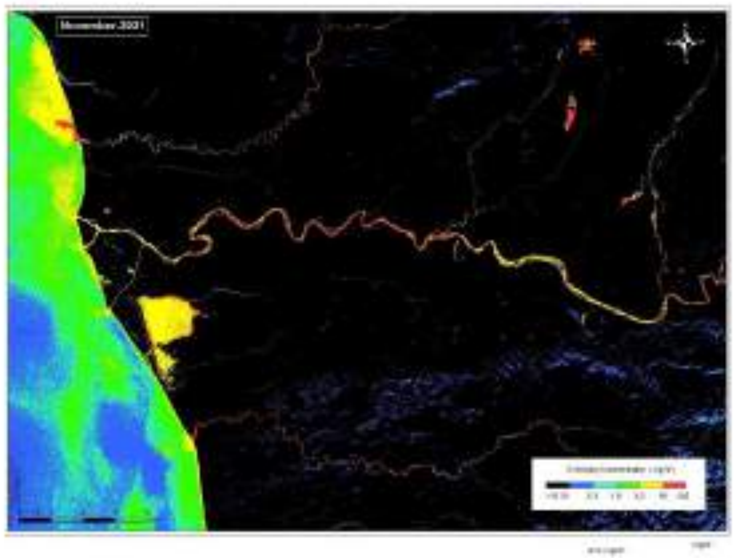


Fig. 38. Summary image of November 2021

3.2. Results of on-site studies

PH measurements of water samples taken from the Paliastomi Lake in November 2021 showed 8.3, in July 2022 - 8.9, and 8.5 in September. To obtain the average of the results, three measurements were taken with a ten-minutes interval. According to these results, an alkaline environment was observed. It is important that the water temperature was 12 C^0 in November, 24C^0 in July and 24°C in September. This pH value is the best condition for the growth of most algae causing eutrophication. However, some algae, on the contrary, stops growing in alkaline environments (Goldyn et al. 2005).

General hardness and alkalinity

Total hardness and alkalinity are interrelated, since with increased carbonate hardness, alkalinity can increase. Both data were measured using the quantitative analysis protocols described in the study methodology. The hardness of the Paliastomi water sample was 130 mg/l in November 2021, which is considered hard water in most existing sources (Williams, 2014). In July 2022, the hardness index remained practically unchanged and amounted to 125 mg/l. In September 2022, the hardness coefficient was 122 mg/l.

Turbidity

In November 2021, the turbidity of a lake water sample amounted to 350 NTU. A device showed turbidity of 190 NTU in a sample taken in July 2022 and 220 NTU in September 2022. Incidentally, the difference in the turbidity of the water was noticeable even to the naked eye.

According to the data obtained by us, in general, the Paliastomi lake can be considered a lake of medium turbidity. And in some cases, the turbidity is quite high. This can be considered as one of the characteristics of chlorophyll and eutrophication quality.

Results of qualitative analysis reactions

Reactions for the detection of phosphate and nitrate ions were carried out. We used qualitative analysis protocols as we did not have sensors to measure these ions. Both detection reactions were positive. According to the sharpness of the developed colors, a fairly high amount of phosphate and nitrate ions is observed. This indicates water contamination with nutrients. Nutrients indicate good conditions for the presence of humic substances and therefore algae. That is, the water is predisposed to eutrophication.

Determination of chlorophyll concentration

The Chl-a software for measuring with spectrophotometer (we used the "trial" version) recorded 7.64 mg m $^{\wedge -3}$ at 580 nm in November 2021. We assumed that this is not a low index for November and that the concentration of Chl-a increases with increasing temperature. According to the data of the same program, it was 10,34 mg m$^{\wedge -3}$ in July 2021 and 12.79 mg m$^{\wedge -3}$ at 580 nm in September. I.E., our assumption has been confirmed, although precipitation was also observed in the summer of 2022, especially in June-July 2022. For the full data of the on-site studies see Annex 1, Table N11.

Data from the sensors installed by Sabuko in the Paliastomi Lake starts from August 2021. See the available data in the attached tables No. 12-22 (Annex N2), where the maximum and minimum data are taken for each month.

The Sabuko study data also confirms what we have obtained from our measurements - the Paliastomi Lake can be attributed to alkaline lakes. The pH constantly fluctuates between the neutral and alkaline regions, however, 8 indicates a slightly alkaline environment. Such an environment is a good environment for chlorophyll and high eutrophication.

The amount of dissolved oxygen (DO) **-** the norm is considered 80-12% in lakes and surface waters (Williams, 2014). According to the indicators obtained as a result of the Sabuko studies, an excess amount of DO in the Paliastomi lake occurs only in certain months (08/09/2021; 02/02/2021) and only in a certain period of time. So we can say that this indicator is within the normal range.

Electrical conductivity – the index of electrical conductivity and therefore, salinity is always high. That is, there are a large number of anions and cations in the Paliastomi lake, indicated in the methodological part, including nutrients which creates good conditions for eutrophication.

TDS, i.e., totally dissolved particles

According to the results of the measurements, 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 (the metals were not measured and we can only assume). In some cases, the redox index is sharply negative, which indicates the increased index of nutrients and eutrophication. For example, in September 2021, the redox index ranges from 49.2 to 302. Compared to data measured by remote sensing as part of the PONTOS project, the chlorophyll concentration in the Paliastomi Lake is 12,5 at the shore and 14,9 in depth. The interdependence of the data is obvious. For example, in November 2021 eutrophication index was 8, 12 at the shore and 8,53 at depth. Redox is 72.04/262 (average minimum and maximum). It turns out that there is eutrophication, although not with a high concentration (fig. 39).

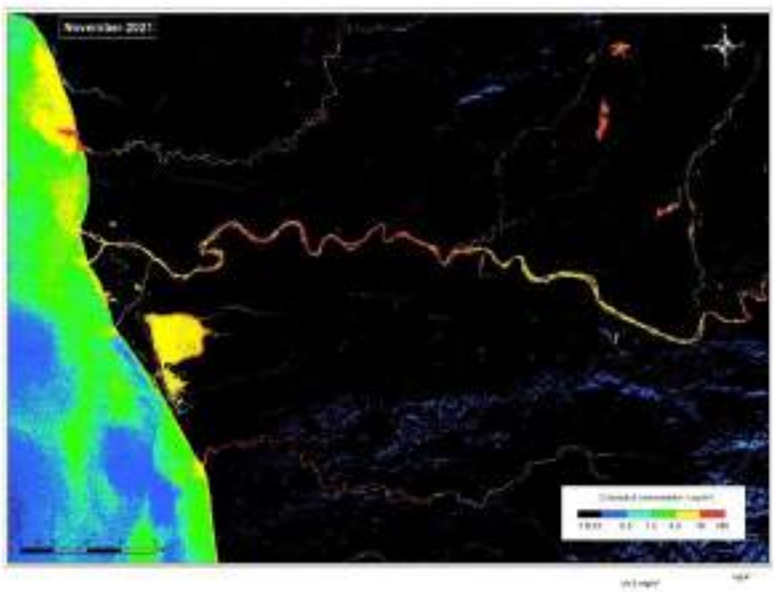


Fig.39. Summary image of November 2021 from the PONTOS project

The redox index is an indicator of various cations and anions, implying the presence of phosphates and nitrates in itself. The latter are nutrients and contribute to eutrophication. We received positive results of their presence in our detection reactions as well. For example, the maximum redox index in August 2021 is 358.7 (mV). Accordingly, the concentration of chlorophyll calculated from remote sensing data is also high: 6.812718379 on the shore of the lake and 11.02875784 in the inner part. In December 2021, the maximum redox potential was recorded -388 (mV). Chlorophyll concentration calculated by sensing: 4.042831145 on the shore of the lake and 3.147683053 in the inner part. In this case, the higher concentration near the shore is probably due to anthropogenic factors. Chlorophyll was determined directly by our group in November 2021 (which can be compared with sensing) and its number was 7,64. Data received as a result of sensing is 8.534173015. These comparisons indicate the reliability of remote sensing studies.

4. Discussion

According to the on-site studies and data obtained from “Sabuko” sensors, the water of the Paliastomi Lake tends to be slightly alkaline, and the pH value mainly ranges between 8-9. Carbonate hardness is also observed, which, in the period of our measurements, ranged 125 mg/l-130 mg/l-122 mg/l. Total hardness and alkalinity are related to each other, since with increased carbonate hardness, alkalinity can increase. The increase in alkalinity initiates the process of eutrophication. The amount of microplankton and phosphate ions increases.

The water of the studied lake can be considered as of medium turbidity, although in some periods an increase in the turbidity index is recorded (Annex 2, Tables 17, 18). Medium and high turbidity indicates the presence of humic substances and nutrients in the lake, which is confirmed by the on-site studies.

Phosphate and nitrate ion detection reactions performed using the qualitative analysis protocols (see method description above) showed positive samples. Unfortunately, it was not possible to determine their number due to the lack of proper equipment, although the intensity of the color obtained indicated their high concentration.

The same can be said from the high indicator of the redox index obtained from "Sabuko" sensors, which actually reflects the oxidation-reduction processes in lake water. Cations and anions (that is nutrients) that contribute to eutrophication participate in these processes (Annex 2, tab. 12-22). This also means the presence of heavy metal ions. We did not study metals, however, at Eh >+ (more than 0.1-1.15) oxygen and Fe^{3+}, Cu^{2+}, Pb^{2+}, Mo^{2+} ions are dissolved in water. In addition, medium and periodically increased turbidity indicates the presence of humic substances, which binds heavy metal ions and becomes more stable in water. Therefore, due to turbidity and redox indices, the presence of ions of heavy metals along with nutrients can be assumed. That is also a good condition for eutrophication.

Chlorophyll itself was determined using a mini-spectrophotometer on-site (see description in the methods), which does not give us high resolution, although the data obtained do not differ much from remote sensing data.

According to the data obtained by remote sensing, it is once again confirmed that the Paliastomi Lake and its surroundings are inclined to the process of eutrophication. High levels of chlorophyll generally increase with increasing temperature. On-site study analyses have shown that there are all conditions (pH, temperature, redox, turbidity) for a naturally developed high eutrophication index. The index of oxidation-reduction processes (redox) is also high that indicates the presence of cations and anions (nutrients). The latter can be formed in a natural way, i.e., decomposition of various plants, the metabolism of micro- and zooplankton or decomposition of bird excrement (there are a large number of them in the area). However, some of them can be brought in by rivers polluted as a result of various human industrial activities. The poaching factor should also be taken into account if it is assumed that any chemicals or biological materials are used for illegal fishing.

According to the 2020 data, the eutrophication index is decreased compared to the same periods in other years. For example, 2,9 and 1,4 in the Poti port in April-May, while in the same period of previous years 7-14 were recorded. Similar dynamics is observed in the Paliastomi Lake. Theoretically, this suggests that the reduction in industrial and commercial activities and active traffic in the Poti port pertaining to the COVID pandemic-related restrictions caused some decrease in chlorophyll concentration.

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Annex 1. Chlorophyll concentration data

Unit: mg m^-3

Location	Date						
	05_2013	06_13	07_13	08-13	09_13	10_13	12_13
Port_1	3.43199240	2.679901471	2.023494692	4.190526227	5.571074546	1.24262371	2.289011858
Port_2	5.14792632	20.04011582	1.398723048	7.142843663	5.282687951	0.92251521	1.802813807
Port_3	8.21858464	20.53151616	2.042260889	1.464115204	2.295429922	0.71740909	0.68368314
Enguri_1	8.39160623	0.745624885	0.479577094	10.11432878	33.04829489	1.82925102	0.468251114
Enguri_2	7.17532312	9.713723962	1.306155543	5.362862631	3.636739728	1.28418017	0.840545882
Kulevi_1	13.8060024	27.49929286	28.11524426	9.629354605	31.33033261	9.31629387	0.519297702
Kulevi_2	9.30063017	30.27199763	16.01717529	4.090809647	22.72232403	23.5691641	0.411408626
Rioni_R_1	11.9974107	5.433338421	24.13057196	30.48731878	0.320956611	1.16866133	1.730139306
Rioni_R_2	28.7593468	16.75289558	25.37147211	10.33165057	21.35610745	8.83225449	1.375312613
Rioni_L_1	14.9506427	6.778421819	26.48050164	30.54115822	0.455239267	4.90607100	1.844364628
Rioni_L_2	24.2700146	9.316293876	13.25262448	1.237139083	28.55666476	1.12413530	1.106772776
Maltakva_1	6.59095525	1.340716926	15.5084878	39.84270453	22.35835384	1.47042408	1.0409309
Maltakva_2	1.48284772	22.99380538	13.68911314	20.90609609	11.29925332	5.79101716	0.588229773
Supsa_1	25.4286731	0.096282989	8.457183916	9.814877126	29.58434132	23.9843551	3.766262791
Supsa_2	8.69730911	0.625581431	0.947123162	1.316559574	4.626547208	0.50188135	0.766381144
Churia_1	12.0487143	0.654607484	8.50864763	10.61189984	7.935646895	8.84725333	7.848779728
Churia_2	4.64282671	6.309619963	19.0576271	3.811657129	2.802079913	0.91438267	0.904704702
Paliastomi_1	22.7223240	16.51891118	25.62368181	0.006782817	9.689554974	6.64589938	0.232037659
Paliastomi_2	22.5939670	13.18332623	34.00246145	13.23288486	13.719621	1.95009194	0.113560897
Old Rioni _1	24.9947300	0.262044476	21.99067322	28.3169216	0.828391979	0.59584533	14.69485234
Old Rioni_2	28.2570532	2.754799314	24.17931847	22.37170855	18.73809652	8.16129276	1.472987363

Table #2. Remote sensing data on Chlorophyll concentration, 2013

Location	Date						
	02_2014	03_2014	04_2014	05-2014	06_2014	07_2014	08_2014
Port_1	30.9657974	2.776213186	4.430955588	1.670062867	9.681499159	0.98767302	2.727738113
Port_2	14.4366497	4.309443458	5.496589295	4.457907235	6.371773474	0.09149398	2.969016166
Port_3	2.37450836	16.30927761	1.05455397	15.19818919	7.555221986	0.20784590	1.821894828
Enguri_1	0.49374902	33.90679774	8.633982171	10.48811233	18.11421664	24.7403931	1.742442162
Enguri_2	0.61108766	4.745705963	1.68988103	8.15076285	4.638086886	0.63550568	0.962636907
Kulevi_1	4.34232728	30.00381472	4.642826717	24.94526174	8.225747216	21.5467080	1.003405907
Kulevi_2	0.46523262	25.05849485	5.11792864	7.841840358	9.033658131	31.3225701	0.629779421
Rioni_R_1	13.6689192	0.235160553	21.22521668	11.3980071	24.8320484	26.6698138	14.7478497
Rioni_R_2	7.99876949	21.03603719	9.665388304	25.23618954	17.77404777	27.2190884	1.903074075
Rioni_L_1	10.8494204	0.189954571	14.64724716	16.14601257	24.4450752	28.6315865	21.46779327
Rioni_L_2	13.0992431	23.42483468	11.24573111	21.95741848	7.210952268	6.62751308	2.244104889
Maltakva_1	2.95463502	15.56871959	10.51363095	8.175614291	4.032582158	2.21625583	4.550742694
Maltakva_2	1.05533263	3.147683053	5.738857713	8.798246647	4.759938546	0.71894356	1.100727605
Supsa_1	1.29830555	27.98869967	30.03437097	31.1671141	11.71581942	1.17296119	5.541815297
Supsa_2	0.74235970	6.794105395	0.752925511	8.61540965	1.968233435	0.63875145	1.066431028
Churia_1	1.40206863	22.66821792	14.45236514	13.02054132	12.70398998	0.97311413	7.752280667
Churia_2	0.93646312	30.23368017	1.490737839	8.656355657	3.99323538	0.03343756	0.962054967
Paliastomi_1	14.2175644	19.4984338	12.80083097	20.67315356	5.206078884	0.05670573	2.215054021
Paliastomi_2	23.8386115	15.98929461	13.30240769	20.2180401	20.19252519	1.19329600	2.773182534
Old Rioni _1	19.1503275	0.213701086	19.81234812	14.88640985	25.27182225	13.7855870	30.27199763
Old Rioni_2	6.10039137	16.592924	9.218941427	25.40007199	8.054964732	11.0464420	23.15074681

Table #3. Remote sensing data on Chlorophyll concentration, 2014 (02-08)

Location	Date			
	09_2014	10_2014	11_2014	12-2014
Port_1	6.88467904	3.296024293	14.52061625	0.373366835
Port_2	12.9617949	0.892709552	11.31716731	0.389840398
Port_3	4.37316458	0.565976173	6.046253263	0.358788569
Enguri_1	0.76407381	1.682943651	3.354415806	0.338268349
Enguri_2	0.08795275	0.637987686	2.414889679	0.376359985
Kulevi_1	12.3973723	3.797750336	3.276704818	2.160198033
Kulevi_2	4.50071355	2.231280643	3.035893062	0.268136119
Rioni_R_1	33.7473071	0.987090512	0.277930771	12.02071008
Rioni_R_2	4.06579249	0.98961484	4.635820076	0.758114454
Rioni_L_1	26.6625401	17.72674343	3.252307535	2.321711049
Rioni_L_2	0.62519984	0.851934243	5.420277004	0.424746561
Maltakva_1	3.07056983	1.261631231	23.32176309	4.218241575
Maltakva_2	1.06584679	1.6769982	3.688405451	0.926001435
Supsa_1	9.07594748	5.725145498	32.61392135	2.717239527
Supsa_2	0.90470470	1.236551499	9.438251222	0.66971311
Churia_1	0.25319365	5.547002675	10.30211159	4.229124332
Churia_2	5.54430521	0.947123162	2.381337189	0.40840517
Paliastomi_1	16.8737250	14.36862914	7.939223328	8.600637153
Paliastomi_2	23.2465538	25.98091542	1.550754618	12.11413872
Old Rioni _1	26.903495	16.51891118	21.00349441	1.975013227
Old Rioni_2	2.59520864	0.840159939	17.50829529	0.282555531

Table #3-1. Remote sensing data on Chlorophyll concentration, 2014 (09-12)

Location	Date						
	02_2015	04_2015	05_2015	06-2015	07_2015	09_2015	12_2015
Port_1	9.59735255	6.129133741	4.107627762	6.245197057	2.479432974	1.39537777	1.773412471
Port_2	4.90834275	4.898636456	8.802048516	3.99323538	3.25576339	1.23792254	0.817015967
Port_3	5.11296415	6.919414621	3.080509238	7.74555478	1.402068633	0.22891638	0.325606854
Enguri_1	11.2546863	17.76818871	10.92778679	13.17345827	9.328148158	14.0983916	0.408968253
Enguri_2	5.98089594	6.989115216	8.534173015	3.176517801	1.226760019	1.01409414	0.532185152
Kulevi_1	6.15808962	15.448265	36.35028483	0.214982736	3.972748162	1.08182034	1.173743054
Kulevi_2	3.94612085	7.728320719	10.23943175	1.214622758	1.196230014	1.09526854	0.33323877
Rioni_R_1	13.8876756	0.102682538	1.98418731	8.648756865	11.65176041	4.80739228	2.172405909

Rioni_R_2	6.11767782	14.47324824	28.95545031	20.90609609	6.137882447	6.44313274	0.123583137
Rioni_L_1	13.8724142	0.090076851	1.242623716	5.073048192	10.10201285	18.1022729	1.566563511
Rioni_L_2	3.31900997	9.561328658	31.57145015	19.56725622	3.343833239	0.55096917	0.283295764
Maltakva_1	12.9765877	16.29781456	9.383193479	7.282859884	11.5561242	16.3940705	6.91313661
Maltakva_2	4.03053248	11.09928826	5.185795069	1.836807231	1.213252715	0.70245466	2.054043065
Supsa_1	33.5720566	11.6654252	33.00873666	26.96942498	6.023354279	12.5932575	0.931231712
Supsa_2	4.51882864	2.212450173	14.57854249	4.582665352	0.998937575	1.01331667	0.588229773
Churia_1	14.5574382	17.13390242	16.03403429	0.165415482	14.64724716	0.02092764	23.39720101
Churia_2	5.71974406	4.390848409	7.110579368	1.211687023	1.105407626	1.019148	0.752925511
Paliastomi_1	21.3757765	29.92742932	24.07480357	0.094508191	16.01155578	37.8070680	8.398985381
Paliastomi_2	25.0514584	5.259700716	22.54666158	12.6992772	15.03105662	29.9885370	11.12145245
Old Rioni _1	16.5018164	0.084240365	18.3127442	12.47828112	9.908643963	15.9557970	3.825565874
Old Rioni_2	5.69793257	14.38950758	3.789979746	14.88640985	1.241056583	15.9225182	0.165234209

Table #4. Remote sensing data on Chlorophyll concentration, 2015 (02, 04, 05, 06,07,09, 12)

Location	Date						
	02_2016	**03_2016**	**04_2016**	**05-2016**	**06_2016**	**07_2016**	**08_2016**
Port_1	3.27670481	7.981093229	8.73468034	4.795423985	4.964323241	0	3.259219386
Port_2	7.35185816	0.203458668	10.2560033	2.99170735	0	8.27230974	0.693832661
Port_3	0.01148352	2.406851512	5.93304015	9.589299699	1.531397174	9.23438820	1.739465357
Enguri_1	12.6557943	19.57357267	26.78664469	7.158977914	7.704363627	0.36831799	6.563594216
Enguri_2	10.3021115	25.21485484	27.52886415	2.854852167	7.133205688	26.8816668	2.475208521
Kulevi_1	4.68466892	22.17076365	37.67549707	13.51750162	27.18225095	0	9.733866553
Kulevi_2	5.59515041	26.31349167	25.67183238	16.1684983	8.593251271	31.8916447	3.401035036
Rioni_R_1	2.05524139	0.037366824	2.142991438	1.951287892	0	0	21.99723688
Rioni_R_2	1.89988802	10.76703157	22.20424962	21.65230953	0	0	9.52149655
Rioni_L_1	1.49882686	0.05722772	0.775805507	3.995284325	0	0	19.97667955
Rioni_L_2	5.30340046	13.30734348	22.10401638	28.36177086	0	28.9554503	5.622136735
Maltakva_1	3.43199240	16.9428163	16.1684983	7.96026242	14.13990415	14.7372927	9.187839286
Maltakva_2	5.42027700	7.78675436	7.104085287	0.608419187	3.974796701	3.70393104	2.385354498
Supsa_1	1.08104093	23.17113467	14.52578403	6.636705986	25.33583401	20.7635242	1.707923334
Supsa_2	0.04199971	4.047136017	6.963576145	3.205565788	5.401827224	6.96043634	0.571488937
Churia_1	5.99504743	23.92179538	17.89298096	9.253856801	8.283056378	20.0082877	2.773182534
Churia_2	5.68443183	25.64322079	25.96660288	0.730456093	5.401827224	6.63378091	1.903074075
Paliastomi_1	4.26588725	10.50087135	17.79791877	23.28755596	12.72819757	15.6017537	23.25335077
Paliastomi_2	0.43734786	4.39969135	3.233201243	16.10104471	7.807357297	16.1403913	16.55288624
Old Rioni _1	7.21745007	0	0.690385009	1.978403458	9.292798709	0	20.912647
Old Rioni_2	2.69039448	0	24.6557829	29.28055947	0	24.9522970	8.945932045

Table #5. Remote sensing data on Chlorophyll concentration, 2016 (02, 03, 04, 05, 06,07,08)

Location	Date	
	09_2016	**11_2016**
Port_1	8.186356068	10.47110125
Port_2	8.663743618	9.94535387
Port_3	3.85543533	0.03292632
Enguri_1	11.58792841	8.700898174
Enguri_2	6.166839915	2.757829192
Kulevi_1	10.18505036	11.3980071
Kulevi_2	5.935744648	16.2865681
Rioni_R_1	17.86932211	2.649036986
Rioni_R_2	8.611821954	3.308228312
Rioni_L_1	18.07838631	0.239204311
Rioni_L_2	8.8134545	1.339145204
Maltakva_1	12.56434905	2.090804114
Maltakva_2	13.15350869	5.480618387
Supsa_1	7.494757237	8.919303668
Supsa_2	3.281991819	0.086714611
Churia_1	7.014448496	5.388768732
Churia_2	3.950216914	2.843930668
Paliastomi_1	12.93242557	7.414796256
Paliastomi_2	7.921762509	7.024080254

Old Rioni _1	19.32402395	2.903613927
Old Rioni_2	8.723278296	0.72258844

Table #5-1. Remote sensing data on Chlorophyll concentration, 2016 (09, 11)

Location	Date						
	01_2017	03_2017	04_2017	05-2017	06_2017	07_2017	08_2017
Port_1	3.20556578	8.026759987	4.986432939	5.160548054	12.66050646	3.11561126	0.497530869
Port_2	4.32465103	7.535064995	4.028482844	9.091173512	3.347292783	7.37828965	0.757153435
Port_3	1.21246985	7.827962326	2.065827841	3.678805353	6.277301087	1.50158936	0.308878189
Enguri_1	0	8.938323625	8.563710184	24.86743918	5.92451089	20.5572656	1.472987363
Enguri_2	0	3.082132115	6.452106979	27.24842755	8.442632834	6.97006524	0.970591439
Kulevi_1	11.1214524	7.666962671	5.788315236	29.82050236	30.87291608	30.1262683	9.569380605
Kulevi_2	11.8674792	3.919909947	2.980360927	36.04117731	34.87659153	16.5074424	3.632860828
Rioni_R_1	0	0.070157864	0.179032242	1.661345733	7.175323127	29.0534106	10.67211216
Rioni_R_2	0	12.90305877	13.35219805	2.961116335	14.17604319	13.1189750	0.535219249
Rioni_L_1	0.07877172	0.059666051	2.188620445	4.194631761	12.55963827	31.5326269	7.207598648
Rioni_L_2	3.15600753	8.154342962	12.78626016	3.94427768	13.12884147	4.56206910	0.693449556
Maltakva_1	5.62483564	8.079804891	11.07286396	8.915499863	3.974796701	9.92073855	3.911720419
Maltakva_2	9.79854569	4.395372619	1.392032803	12.81540241	3.152758859	5.39933979	0.298115817
Supsa_1	5.27253995	12.74747922	16.2190956	26.42960116	9.90440038	3.90168914	0.325606854
Supsa_2	0.45090514	5.589961316	1.804801052	12.98623562	2.833010781	0.36663563	0.781770137
Churia_1	0	7.883480116	5.584564845	13.46725824	10.13110486	16.3205246	0.767919513
Churia_2	0	4.689410578	2.119790965	12.2268458	11.40248699	10.0937317	0.52081324
Paliastomi_1	6.114761909	5.11792864	1.802813807	19.47360775	10.2101154	12.3686953	0.60060697
Paliastomi_2	7.444594129	2.194827233	0.265735739	26.96214814	13.90809687	13.0059609	8.026759987
Old Rioni _1	0.120716333	1.451106446	0.222862117	0.180305223	12.12825164	29.8433033	9.450111432
Old Rioni_2	0.343114369	14.57854249	18.34294331	7.718023022	15.58512837	6.89095606	0.33156289

Table #6. Remote sensing data on Chlorophyll concentration, 2017 (01-08)

Location	Date			
	09_2017	10_2017	11_2017	12-2017
Port_1	2.58513317	1.903074075	9.056704888	7.388149946
Port_2	11.2190802	3.110537769	10.50087135	5.986514763
Port_3	0.41610321	0.417042375	2.872046669	1.053386012
Enguri_1	7.45466768	0	10.11432878	11.96022084
Enguri_2	0.44054745	6.566726937	8.301179365	15.55231147
Kulevi_1	6.90372000	9.312483694	17.94681475	17.18049484
Kulevi_2	0.65135864	2.696247038	7.165473917	12.6557943
Rioni_R_1	10.1268576	1.145804138	0.528583026	0.864487522
Rioni_R_2	2.47802479	3.995284325	4.246374682	10.71084218
Rioni_L_1	11.8674792	8.919303668	0.093621271	0.641615891
Rioni_L_2	0.39452532	3.022715818	6.756885315	8.949736347
Maltakva_1	5.76898745	9.994591521	5.323908924	3.219382375
Maltakva_2	0.24711558	4.404215909	8.058543217	2.307265035
Supsa_1	0.64887466	20.57668765	15.00410643	15.81686507
Supsa_2	0.25264086	5.949892024	7.263150695	4.971761596
Churia_1	1.25006863	7.315573274	9.990558776	5.033351028
Churia_2	0.47296900	1.64847137	4.800376247	11.14361833
Paliastomi_1	7.05926141	13.43226391	5.576470515	5.446401046
Paliastomi_2	14.9506427	9.713723962	8.132863193	3.570412172
Old Rioni _1	13.2079973	3.807771211	0.28422116	0.326723294
Old Rioni_2	1.20581637	4.437744341	6.46108169	13.7348759

Table #6-1. Remote sensing data on Chlorophyll concentration, 2017 (09-12)

Location	Date						
	01_2018	02_2018	03_2018	04-2018	05_2018	06_2018	07_2018
Port_1	0	8.523203068	6.023354279	4.147837872	7.451309776	2.25432623	1.580599047
Port_2	0.33826834	10.09373177	6.152256362	9.806817327	5.050510309	3.342001771	0.333424999
Port_3	0	3.025959243	5.308371935	0.68770396	1.51777359	1.257123292	1.158500435
Enguri_1	4.27656927	10.98039805	11.3350824	3.336711082	12.04401119	7.69406716	9.191647494
Enguri_2	5.81034777	8.125914322	5.624835641	0.768496431	4.149889812	1.843171275	1.760902706
Kulevi_1	0	13.99022321	10.82323224	7.963628874	11.12571498	11.46563938	21.00349441
Kulevi_2	0	13.23288486	4.738693409	12.02990206	8.877465256	2.454492608	2.575260675
Rioni_R_1	1.95009194	0	0.823185257	5.885407173	4.966802645	11.88606811	17.78598312
Rioni_R_2	0	0.235528057	5.899341929	3.561028079	16.67863891	12.38303354	29.32590889
Rioni_L_1	2.45449260	0	5.641030123	6.419342929	3.694329395	12.90798878	19.21213737
Rioni_L_2	0	13.59309493	8.468150585	4.049186019	23.63124952	8.294014281	11.6562441
Maltakva_1	13.8008447	7.953108889	3.531250094	2.944914092	6.49427141	3.964554411	3.570412172
Maltakva_2	12.5116779	13.05506495	0.097348473	0.756192464	1.234201271	0.331376701	0.156361337
Supsa_1	10.7885312	17.73260196	9.79451602	1.053386012	13.51750162	1.724187517	2.006131939
Supsa_2	8.33363595	13.85199509	2.836246135	0.498854776	1.292026876	0.702837962	0.176669059
Churia_1	9.17239550	12.97658776	10.01518072	1.213252715	4.920528309	0.540151067	6.207264115
Churia_2	7.22730202	4.179852563	4.682401244	1.842176838	2.869012057	1.231263728	3.931990702
Paliastomi_1	10.1725187	10.16020008	11.06838912	8.384438167	13.20799738	12.23155171	15.07935602
Paliastomi_2	9.20328406	11.25916405	4.872206026	8.147182797	13.55271922	16.20222916	15.52489413
Old Rioni _1	0	0	8.805850447	9.257877685	0.195972257	10.10604731	20.58301633
Old Rioni_2	0	2.965775112	11.05965272	0.741399462	15.80044696	8.069068529	6.175382327

Table #7. Remote sensing data on Chlorophyll concentration, 2017 (01-07)

Location	Date				
	08_2018	09_2018	10_2018	11-2018	12_2018
Port_1	0.488267331	3.929943016	7.46474177	2.42172293	4.691678389
Port_2	11.10376359	6.086230387	8.8134545	2.50297427	7.622636921
Port_3	1.151467974	3.037515029	4.39969135	0.532753995	5.249347366
Enguri_1	1.367053751	0.144080219	7.217450078	7.184963283	11.34404035
Enguri_2	0.223962427	0.172491031	3.343833239	6.732006623	11.81214679
Kulevi_1	10.29382426	25.32153531	10.20183093	13.12390824	17.46709037
Kulevi_2	6.828404996	8.37347569	7.575381046	9.677471349	20.60876828
Rioni_R_1	9.218941427	15.79483039	1.02556453	0.01875567	0.914963476
Rioni_R_2	2.653474169	11.56978466	14.19153244	0.615472552	4.154199012
Rioni_L_1	5.799331104	16.10666543	12.82033113	0.179759617	7.79348162
Rioni_L_2	1.292811646	6.318586974	10.04405079	2.901994771	7.107437042
Maltakva_1	4.654367952	13.41208472	10.36523119	2.484864821	7.848779728
Maltakva_2	0.315379741	1.028675995	14.23821923	0.976607508	7.995192034
Supsa_1	0	22.30471917	11.40248699	13.96463736	16.2528305
Supsa_2	0	9.754010748	5.033351028	5.178344638	10.47110125
Churia_1	1.120037592	8.999197936	11.57426713	6.201429068	1.561820196
Churia_2	0.296632512	0.518350577	2.568008341	5.595150419	8.578480238
Paliastomi_1	3.768307131	10.93225943	10.51788429	1.68988103	7.207598648
Paliastomi_2	8.016236805	5.443912834	12.14685599	3.173065221	9.513658006
Old Rioni _1	8.667543235	15.27951672	0.283850988	0.177032547	8.534173015
Old Rioni_2	1.028675995	2.990086331	12.54036764	1.799634389	6.903720004

Table #7-1. Remote sensing data on Chlorophyll concentration, 2017 (08-12)

Location	Date						
	01_2019	02_2019	03_2019	04-2019	05_2019	06_2019	07_2019
Port_1	8.24723635	14.15022923	11.50170198	5.997961139	2.480841187	2.363864934	3.861369366
Port_2	8.11159615	12.09532248	5.290351219	7.091307279	7.61927613	0.546223374	5.496589295
Port_3	5.86315579	5.512561988	6.735142398	6.012114183	3.490474021	11.179002	5.995047436
Enguri_1	15.5359040	8.843450722	14.67891148	5.295529344	0.588610461	11.24125359	18.03626202
Enguri_2	14.8277904	4.884181633	9.087366914	1.46766382	0.676983797	13.76538768	3.764422922
Kulevi_1	20.7700734	5.456976435	27.75090848	34.58712382	11.60159031	11.38904751	36.03292691

Kulevi_2	18.0542838	9.339791321	25.06553135	11.11250132	4.626547208	4.469018901	37.17506386
Rioni_R_1	0.07366908	11.64257973	0.082651248	2.067026438	6.000666769	13.22280092	0
Rioni_R_2	0.51664592	12.82525992	9.553276972	4.514299611	13.43226391	16.17411992	10.64189798
Rioni_L_1	0.06893051	10.78853126	4.183957695	2.84858222	2.800665088	14.49951522	0
Rioni_L_2	3.26267552	5.728054044	10.97613766	3.887565157	20.07172785	10.59466834	32.49575681
Maltakva_1	2.47098434	12.5836211	6.443132748	4.979200379	3.097145283	5.147926326	11.44302246
Maltakva_2	9.25385680	5.483314649	8.15076285	0.867192226	1.073832426	2.08121186	2.773182534
Supsa_1	6.95101726	14.7213501	23.36298963	1.279473045	5.428155175	4.030532481	27.52886415
Supsa_2	15.7285174	6.404528175	9.822937179	0.167772729	2.460123455	1.426874845	7.759216974
Churia_1	3.69228661	10.58190496	16.50181646	8.101068717	2.57808124	3.88961199	21.47435086
Churia_2	3.06063166	4.130808283	6.809581222	0.106244548	2.959495957	3.642456292	20.19884928
Paliastomi_1	8.75706379	13.63347526	18.13224142	9.133684685	4.831332325	6.536446372	8.207841247
Paliastomi_2	6.20726411	12.01600732	12.19390638	5.052991355	2.207443105	2.751769565	17.86932211
Old Rioni _1	0.80410483	13.66891923	0.355240866	2.493315268	1.343271126	13.35713456	0
Old Rioni_2	1.33757355	11.50618344	13.03533673	1.431207798	19.29898879	22.19746472	36.18746663

Table # 8. Remote sensing data on Chlorophyll concentration, 2019 (01-07)

Location	Date				
	08_2019	09_2019	10_2019	11-2019	12_2019
Port_1	1.60413413	9.446299159	7.928704585	8.319303874	7.001886098
Port_2	3.690448149	9.045075509	1.755740941	6.995395866	5.178344638
Port_3	0.795437641	9.253856801	0.414225132	1.642728669	0.033267118
Enguri_1	13.89283461	7.728320719	1.996754462	2.521290059	8.611821954
Enguri_2	1.218341748	8.983977869	1.083768965	7.57202106	10.6461533
Kulevi_1	10.73659425	26.77187443	9.537386252	8.534173015	17.47294558
Kulevi_2	2.890864014	11.19669545	10.92352719	6.195802615	15.41006382
Rioni_R_1	14.8917981	0.18194242	7.615915396	1.616599271	0.160342743
Rioni_R_2	9.048881424	0.39115196	9.195455763	2.238894698	0.062806669
Rioni_L_1	15.10092017	1.218341748	10.73659425	7.126710813	0.105709949
Rioni_L_2	4.224812167	17.11656695	6.464212516	1.813347166	3.501481764
Maltakva_1	10.68913568	12.14685599	6.303781242	5.552397746	0.341623004
Maltakva_2	1.607101684	13.39705842	2.856470304	3.468462544	0.023276425
Supsa_1	2.794601864	15.09013795	29.85105142	12.81540241	8.552738777
Supsa_2	0.497530869	30.51811538	8.854858764	5.223881472	1.62906811
Churia_1	1.007097715	10.35694192	2.723296214	7.165473917	6.383664561
Churia_2	0.915544294	6.218934842	0.396399897	8.727078914	7.911244658
Paliastomi_1	5.092901261	15.51388455	13.11897508	6.794105395	2.74126743
Paliastomi_2	5.280202659	13.9850629	7.981093229	4.93767266	0.851934243
Old Rioni _1	10.72808091	1.907654378	15.15483573	3.917862503	0.01328831
Old Rioni_2	2.269761826	15.13866029	7.104085287	4.179852563	1.36941323

Table # 8-1. Remote sensing data on Chlorophyll concentration 2019 (08-12)

Location	Date						
	01_2020	02_2020	03_2020	04-2020	05_2020	06_2020	07_2020
Port_1	5.34732127	8.85105602	3.674924736	9.041269655	4.047136017	2.990086331	1.434556335
Port_2	7.85929437	8.468150585	3.580001247	2.959495957	0.910898146	3.85543533	0.742359704
Port_3	0.02580312	2.924261205	0.055488489	0.204737906	10.3063616	0.327095473	3.065499187
Enguri_1	0.35468082	7.880114972	0.650976473	8.949736347	8.062121764	6.458159638	1.893317452
Enguri_2	0.02630964	7.827962326	0.027662165	2.924261205	10.37798443	4.640353738	1.510470124
Kulevi_1	8.88507167	11.551642	1.652432302	5.105310942	10.93225943	2.397407985	9.355669261
Kulevi_2	2.66678742	11.36195707	0.031394428	0.894450401	11.49273927	0.852899628	0.673156743
Rioni_R_1	0.22983423	4.233436667	0.00534626	0.143899906	10.02770485	14.13990415	13.13377477
Rioni_R_2	0.1144544	6.464212516	2.842312805	1.448544642	14.47863067	9.713723962	5.336961342
Rioni_L_1	0.70916349	9.257877685	0.011974722	0.058098103	14.83834991	10.00711465	12.24096375
Rioni_L_2	0.05670573	5.780001907	0.135974898	3.869350174	9.802787523	5.997961139	0.377295532
Maltakva_1	1.14365606	10.72808091	3.024337514	4.169179948	0	1.561820196	0.921934226
Maltakva_2	0.00758618	7.030571508	0.072263803	0.453354668	1.147171172	0.431327565	0.377482652
Supsa_1	1.36292503	8.315510246	14.97737368	1.777583148	11.76152308	2.315089529	1.295950912

Supsa_2	0.02243647	1.731329758	0.397149822	0.647919384	2.68736749	0.594702763	0.763497024
Churia_1	4.10147448	8.839859418	1.96025836	7.36842986	9.458159758	4.044881062	0.552678045
Churia_2	1.32225368	7.434730944	0.163421897	1.654412905	11.13914239	0.645817956	0.581569261
Paliastomi_1	4.81936173	12.006602	3.037515029	13.93883833	6.248115344	14.31633057	0.233139673
Paliastomi_2	2.74126743	11.29029673	6.862711226	13.70436674	6.735142398	18.50048755	13.04520069
Old Rioni _1	0.26407442	8.512233663	0.001756175	0.701496465	11.09928826	4.302867847	12.3402348
Old Rioni_2	1.01156744	5.85483835	1.871421884	2.177409901	12.89834317	4.733949849	0.444501111

Table #9. Remote sensing data on Chlorophyll concentration, 2020 (01-07)

Location	**Date**				
	08_2020	**09_2020**	**10_2020**	**11-2020**	**12_2020**
Port_1	5.112964156	5.501775039	2.535382613	6.187050745	5.107793017
Port_2	6.512225803	6.725944284	5.208769823	3.085377968	8.125914322
Port_3	7.049627809	0.840159939	0.041655836	0.062457407	0.025128367
Enguri_1	4.649833764	1.167097893	0.04045312	0.075778923	0.047688808
Enguri_2	5.198627333	1.46766382	0.06858	0.038223179	0.050456791
Kulevi_1	35.06189941	9.164568222	1.127648086	2.652062307	8.953540712
Kulevi_2	25.69340192	4.337805193	0.148229786	0.14859083	1.554508671
Rioni_R_1	0	22.5129369	7.59218184	1.337573552	1.350541793
Rioni_R_2	0	10.67636794	2.553707437	2.101597422	0.418357339
Rioni_L_1	0	20.77662266	5.198627333	0.746201151	0.688086942
Rioni_L_2	3.891454175	1.693845739	0.870476946	1.036456241	0.041827763
Maltakva_1	4.435481379	8.129283443	5.006066206	3.169612786	3.247022383
Maltakva_2	14.44181639	1.326181209	0.121970241	3.964554411	0.464855362
Supsa_1	24.38203024	3.970699663	5.768987455	7.845415156	5.339447657
Supsa_2	9.609220384	0.485621842	0.081592488	1.02478672	3.169612786
Churia_1	19.87554634	4.622014066	3.092072953	3.368663598	5.611341609
Churia_2	14.54688653	0.624436712	0.111774703	1.371182942	0.671434842
Paliastomi_1	13.79074451	17.40832562	13.59803483	6.386585309	6.524335655
Paliastomi_2	5.871473685	16.55288624	10.29807414	5.10034693	4.778917869
Old Rioni _1	0	25.15085488	4.82658523	1.669072195	2.890864014
Old Rioni_2	10.83196139	5.555095357	0.147146854	1.127648086	0.505854808

Table #9-1. Remote sensing data on Chlorophyll concentration, 2020 (08-12)

Location	**Date**						
	01_2021	**02_2021**	**03_2021**	**04-2021**	**05_2021**	**06_2021**	**07_2021**
Port_1	0	15.04722763	8.95734514	8.428082717	3.313720686	4.698688256	0.598892615
Port_2	1.19994682	10.58190496	12.18920102	9.637408747	6.685812727	4.322390319	3.217553578
Port_3	0.05984036	9.383193479	8.048018434	0.079652804	8.652556229	0.689044435	1.286533995
Enguri_1	0.75388632	15.53590402	6.213099373	7.538424349	11.28134041	3.705974073	0.560465474
Enguri_2	0.03565639	9.438251222	3.917862503	10.10604731	9.118244422	2.209846443	0.612803344
Kulevi_1	3.07706073	15.52489413	19.42983847	9.880001135	10.87561115	12.70398998	0.67794069
Kulevi_2	2.64762521	8.129283443	12.64615601	4.350960885	12.56434905	5.110481984	0.534650306
Rioni_R_1	2.10399622	0.193418418	0.020258378	1.060589213	10.2812875	12.74747922	17.53757473
Rioni_R_2	3.58551031	3.527579503	6.509302865	7.484681599	13.01089249	15.57973067	13.78064454
Rioni_L_1	1.99675446	14.38434167	0.011483521	1.601364603	15.05261812	12.64122989	15.79483039
Rioni_L_2	0.04337631	7.79348162	5.035831749	4.703430453	3.301312488	11.07712578	1.18899329
Maltakva_1	1.56735411	12.66543287	10.24346832	3.320637507	3.488639527	4.059641645	1.432783542
Maltakva_2	3.30131248	9.617273878	7.707725853	0.663975237	0.995246924	0.267212798	1.00768068
Supsa_1	4.34006621	19.83762648	17.60850384	7.488040087	0.872022862	2.776213186	0.508883007
Supsa_2	0.04751601	10.84942048	9.296820242	1.161431112	1.056500678	0.872602608	1.24928488
Churia_1	5.60864295	22.06397174	8.571095088	3.85543533	3.365203206	6.117677828	0.624818276
Churia_2	0.22708109	9.505607868	8.999197936	5.697932573	1.873610999	2.304657097	0.791394192
Paliastomi_1	4.18190511	16.70721432	15.76718071	8.991587779	14.63130829	9.673443603	7.171970146
Paliastomi_2	1.01837065	14.45236514	13.56775219	6.342153778	15.24154741	4.130808283	7.024080254
Old Rioni _1	4.15419901	0.79293446	1.796455188	4.759938546	8.968758794	12.87883846	14.63130829
Old Rioni_2	0.45844377	12.40208081	6.088937537	6.621454391	11.19669545	11.60607326	8.61920845

Table #10. Remote sensing data on Chlorophyll concentration, 2021/01-07

Location	**08_2021**	**09_2021**	**10_2021**	**11-20201**	**12_2021**

Port_1	3.851343096	7.615915396	8.247236358	3.483136267	3.292566803
Port_2	5.22139725	9.064317157	3.831498136	3.642456292	5.178344638
Port_3	0.667991549	0.301639802	0.633787597	1.55253281	2.345393928
Enguri_1	10.32314981	12.12825164	1.364497824	1.339931056	8.005714153
Enguri_2	4.00573457	9.343813635	0.217913322	1.608882317	12.17508538
Kulevi_1	5.360168673	13.69426921	9.745952878	12.73783826	9.762280933
Kulevi_2	0.514184019	2.674050285	8.689708943	6.850159399	10.50087135
Rioni_R_1	9.106612011	9.414532521	0.224145832	5.305886179	0.067178624
Rioni_R_2	6.787831797	5.961127627	4.759938546	4.252741564	4.063742174
Rioni_L_1	10.26875134	14.2020741	2.789953736	4.028482844	0.04285989
Rioni_L_2	5.488707325	7.988247727	0.095395431	1.149319496	2.171205017
Maltakva_1	12.07672117	7.69406716	8.348179774	3.262675523	0
Maltakva_2	0.817015967	3.327758343	6.530390906	0.255405259	4.578133872
Supsa_1	0.47712225	9.573406677	8.468150585	8.03033799	4.261368247
Supsa_2	0.418169477	3.212473796	0.201083762	2.357238823	1.786918883
Churia_1	1.064483619	11.89995704	8.556325524	7.322074683	4.534681641
Churia_2	0.757730041	4.424167234	3.987088789	7.123568213	9.53357263
Paliastomi_1	6.812718379	14.90235931	7.158977914	8.129283443	4.042831145
Paliastomi_2	11.02875784	12.05341763	10.40753173	8.534173015	3.147683053
Old Rioni _1	8.240073071	15.3772612	7.204454684	4.608003617	12.71362996
Old Rioni_2	0.209309112	7.869599255	1.344057071	3.673086604	1.755740941

Table #10-1. Remote sensing data on Chlorophyll concentration, 2021/08-12

Paliastomi lake Measured parameters	11/2021	07/2022	09/22
pH	8.3	8.9	8.5
Turbidity	350 NTU	190NTU	220 NTU
Crl a/580 nm	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 #11. Green Alternatives on-site data

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.33	8.84
Redox (mV)	36/-446	358.7
t (C)	24.02	30.06
Conductivity (µS/cm)	8220.29	12464.5
Salinity (ppt)	4.641	7.206
TDS (ppm)	4740.19	7272.56
DO (%)	4.53	139.3
Turbidity (NTU)	12.49	131.8

Table # 12. Data from Sabuko's sensors, 2021/08.

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.597	8.62
Redox (mV)	-49.2	302
t (C)	17.71	24.39
Conductivity (µS/cm)	282.184	1646.07
Salinity (ppt)	0.18	1.389
TDS (ppm)	149	2236.01
DO (%)	26.97	140.02
Turbidity(NTU)	19.5	20.89

Table # 13. Data from Sabuko's sensors, 2021/09.

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.71	8.19

Redox (mV)	-87.3 /-442	285
t (C)	11.02	18.04
Conductivity (µS/cm)	457	1118
Salinity (ppt)	0.29	0.511
TDS (ppm)	209	804
DO (%)	42	94
Turbidity (NTU)	1.92	15.42

Table # 14. Data from Sabuko's sensors, 2021/10.

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.79	8.19
Redox (mV)	72.04	262
t (C)	9.01	18.05
Conductivity (µS/cm)	432	4486
Salinity (ppt)	0.25	0.548
TDS (ppm)	235	3186
DO (%)	0.065	82
Turbidity (NTU)	1.48	18.53

Table # 15. Data from Sabuko's sensors, 2021/11.

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.71	8.09
Redox (mV)	-388	230
t (C)	7/2.54	12
Conductivity (µS/cm)	2722.02	6208.52
Salinity (ppt)	1.506	3.009
TDS (ppm)	1594	3597.99
DO (%)	0.076	25.22/100
Turbidity(NTU)	0.778	1.714

Table # 16. Data from Sabuko's sensors, 2021/12.

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.87	8.31
Redox (mV)	153	319
t (C)	2	8
Conductivity (µS/cm)	1899	2315.89
Salinity (ppt)	1.302	1.505
TDS (ppm)	951	1406.98
DO (%)	71	108
Turbidity(NTU)	41	514

Table # 17. Data from Sabuko's sensors, 2022/01

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.93	8.11
Redox (mV)	133	318
t (C)	4.94	10.05
Conductivity (µS/cm)	1246	2442
Salinity (ppt)	0.693	1.658
TDS (ppm)	771.682	1829.27
DO (%)	92.1	147.2
Turbidity(NTU)	89	1127

Table # 18. Data from Sabuko's sensors, 2022/02

Paliastomi lake Measured parameters	MIN.	MAX.
pH	7.93	8.49
Redox (mV)	300	351
t (C)	4.88	11.65
Conductivity (µS/cm)	1873.01	4237.97
Salinity (ppt)	0.671	2.263

TDS (ppm)	1761.22	2441.23
DO (%)	87	120
Turbidity(NTU)	59.43	1580

Table # 19. Data from Sabuko's sensors, 2022/03

Paliastomi lake Measured parameters	**MIN.**	**MAX.**
pH	7.98	8.19
Redox (mV)	-239	179
t (C)	10.02	19.25
Conductivity (µS/cm)	2111.14	6410.71
Salinity (ppt)	2.761	3.547
TDS (ppm)	2994.27	3029.92
DO (%)	95.7	121.8
Turbidity(NTU)	0.001	3.965

Table # 20. Data from Sabuko's sensors, 2022/04

Paliastomi lake Measured parameters	**MIN.**	**MAX.**
pH	7.28	8.67
Redox (mV)	-174.3	150
t (C)	16.02	20.17
Conductivity (µS/cm)	4823.1	5397.54
Salinity (ppt)	2.978	3.041
TDS (ppm)	2917.26	3099.36
DO (%)	68.36	92.34
Turbidity(NTU)	87.3	328

Table # 21. Data from Sabuko's sensors, 2022/05

Paliastomi lake Measured parameters	**MIN.**	**MAX.**
pH	6.55	8.03
Redox (mV)	-271.5	98.8
t (C)	22.12	28.34
Conductivity (µS/cm)	5537.73	6056.04
Salinity (ppt)	2.972	3.048
TDS (ppm)	1645	3347
DO (%)	15.03	77.28
Turbidity(NTU)	69.12	270.7

Table # 22. Data from Sabuko's sensors, 2022/06