

FUNDAMENTALS OF REMOTE SENSING PRACTICE BOOK

Part II

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OF REMOTE SENSING
PRACTICE BOOK**

Part II

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Kyiv
National Center
“Junior Academy of Sciences of Ukraine”
2022

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This Practice Book accompanies the Guidance Manual, Remote Sensing: Analysis of Satellite Images in Geographic Information Systems (S. O. Dovgyi, S. M. Babiichuk, T. L. Kuchma, O. V. Tomchenko, L. Ya. Yurkiv). It is packed with hands-on tasks aimed to introduce students to the opportunities of the Quantum GIS open-source software in different research, including climatic, hydrological, forestry, agricultural, etc. This Practice Book may be used by teaching methodology experts and heads of sections at the Junior Academy of Sciences of Ukraine, teachers, and students of schools, lyceums, gymnasiums in their education and research activities, as well as anyone seeking to master the fundamentals of remote sensing.

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Introduction






Today, everyone may access satellite imagery data over the Internet. Knowledge of where to find and how to analyze satellite images enables you to independently verify the information provided by the media or official statistics. Information concerning the environment, emergencies, and consequences of natural disasters can often be presented in speculative form. Therefore, the purpose of this Practice Book is to teach students, pupils, and other interested people how to use satellite images and processing tools, including GIS, to check and compare information, monitor processes and phenomena in time and space, critically interpret large amounts of data collected at different times and related to different subjects.

The authors at the Geographic Information Systems and Remote Sensing Laboratory (GIS and RS Laboratory) of the Junior Academy of Sciences of Ukraine, National Center (JASU) work towards creating, adapting, and testing the GIS and remote sensing methods in science education practice. In this revised and updated edition of the Practice Book, you will learn how to analyze satellite images in Geographic Information Systems.

The purpose of the educational activities at our Laboratory is the development of a scientific type of thinking in students through the formation of skills required for processing information derived from primary sources, including satellite images, and analysis of data that confirm or refute the previously formed hypothesis.

The first Practice Book, Fundamentals of Remote Sensing (Part I), mostly describes the opportunities offered by EO Browser featuring the intuitive, simple interface and a large array of available satellite images. The resource, however, has rather limited capabilities for the analysis of remotely sensed data. The second Practice Book, in contrast to the first one, is somewhat more complex in terms of the GIS use and is based on the QGIS open-source software. However, we will also continue to work with EO Browser and discover new tools, such as Giovanni.

This Practice Book will teach you how to use remote sensing in the visible and radar bands to assess the state of vegetation in the fields or forest changes, monitor water quality in reservoirs, detect oil spills in seas, etc. You will work with digital terrain models, topographic maps, and other cartographic materials, master the supervised classification, calculate various indices (vegetation, water), find correlations between different indicators, perform regression analysis, and much more. This Practice Book is supplemented by the QR-codes given at the end of each task. These are links to the YouTube page of the GIS and RS Laboratory at the JASU. In this way, you may follow the completion of tasks by one of our team members. In addition, as in the first Practice Book, we have developed color tips for different headings, such as *Definitions*, *Interesting to know*, *Additional task*, *Check yourself*, *Important!*

Definitions	
Interesting to know	
Additional task	
 Check yourself	Questions are presented in the form of a blank table
 Important!	<i>Important text is highlighted in red italics</i>

Instructions

QGIS Installation Instructions



QGIS is a free, open-source geographic information system with flexible functional modules that is supported and actively improved by a group of volunteer developers. This program enables you to visualize, edit, analyze data, design maps for printing, etc.

To download and install it to your computer, follow the link <https://qgis.org/uk/site/> or just enter **QGIS** in the Google search bar and go to the first site found. To download the installer to your computer, click the Download Now button. In the window that appears, you will see a list of all available download options. QGIS can be installed on Windows, Mac OS X, Linux, BSD, and Android. There are also different versions of this program: **Long term release** (stable version) and **Latest release** with the most recent updates. We recommend that you install **Long term release** to avoid problems with running the program. To complete the tasks given in this Practice Book, we will use **QGIS 3.16.7 'Hannover'** version.



✔ **Important!** *There are two versions of this application designed for 64- and 32-bit operating systems. You may check the type of operating system you are currently running on your computer via the Control Panel → All Control Panel Items → System. Install the version that matches the operating system of your computer.*

The *Documentation* Section on the official QGIS website contains user guides and training manuals for both beginners and experienced users. All these documents are available in different languages.

Instruction for Downloading Images in EO Browser

1. Login to EO Browser website using your login and password. Click **Login** and enter your details.

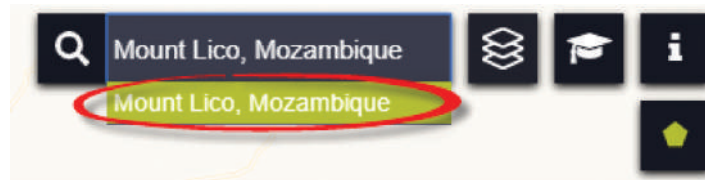
Or sign up by clicking **Free sign up** on the left-hand pane. In the tab that opens, enter your personal information and log in to the portal by clicking **Sign up**. You will receive an email from Sentinel Hub asking you to confirm that you have signed up on the site. You need to click **Verify e-mail address**.

✔ **Important!** *Check your spam folder to make sure the verification email didn't end up there!*

2. To find a satellite image of the area of your interest, you need to enter the location name in the search bar in the upper right corner of the screen and select it from the drop-down list.

✔ **Important!** *The name can be written in both English and Ukrainian*

For example, you can find a satellite image of Mount Lico in Mozambique.




3. Select the following from the settings toolbar in the left corner of your screen:

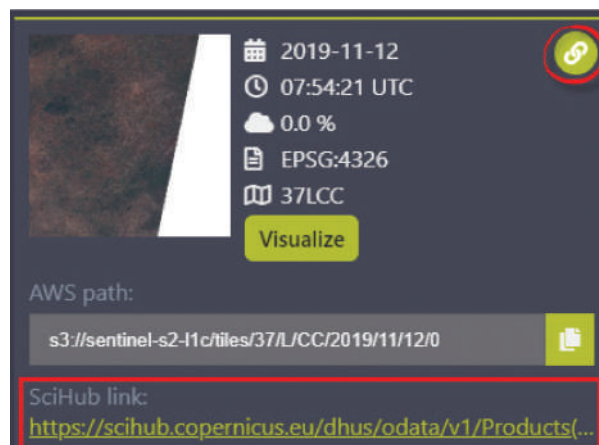
- *Data source*;
- activate *Advanced search*;
- *Max.cloud coverage*;
- *Time range*;

✓ **Important!** *Do not enter the date from the keyboard but select it from the calendar, because the input through the keyboard does not work.*

- click *Search*.

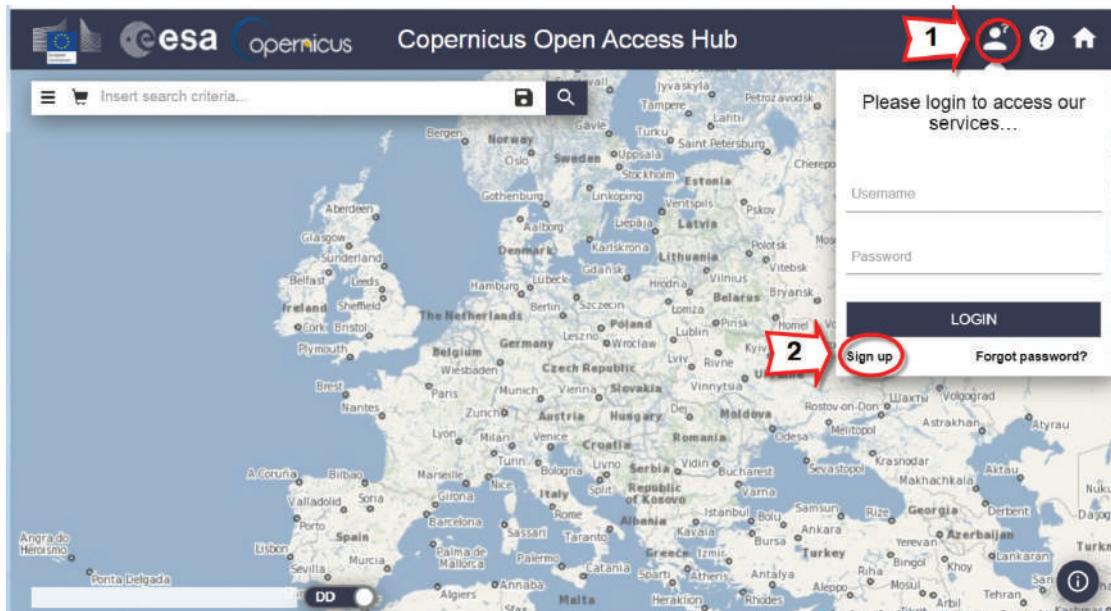
As a result, you will get a list of all available images that meet certain criteria.

4. View the images by scrolling through their list in the left sidebar, find the image that suits your purposes, and save it. Click on the  tool next to the date of the corresponding image – a link for image download in the zip format will appear.



5. Click on the **SciHub link**. To start the automatic download, you must also sign up on this resource. If you have entered the correct login, the download will start automatically. Otherwise, a login and password window will appear on the **Copernicus Open Access Hub**.

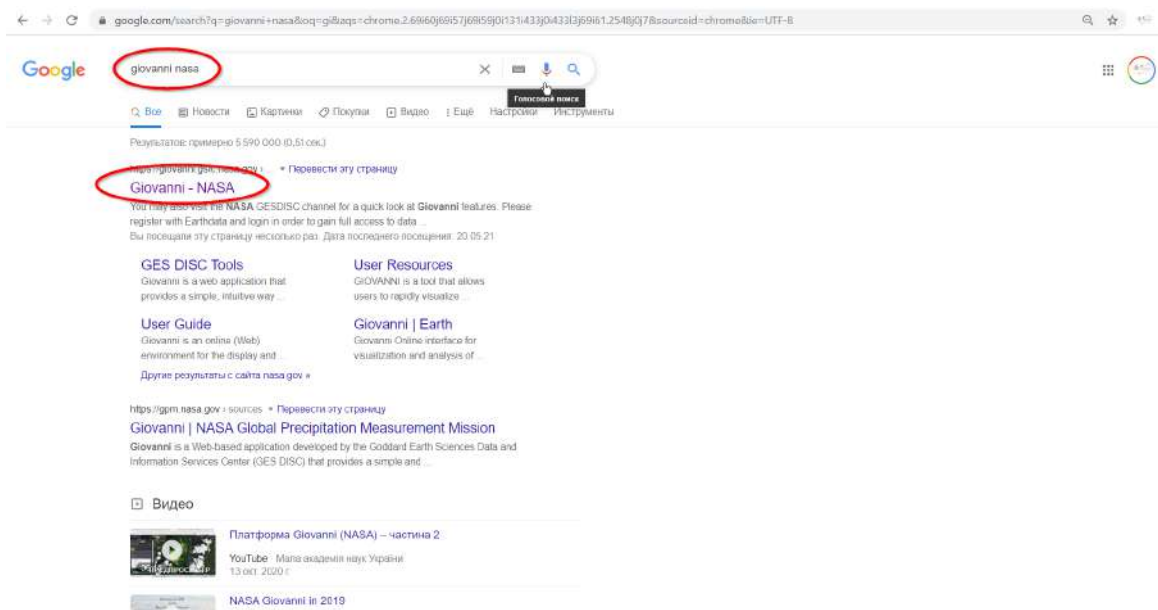
You can sign up with SciHub at: <https://scihub.copernicus.eu/dhus/#/home>. Click the **Login** button in the upper right corner of your screen and select **Sign up** from the drop-down menu.



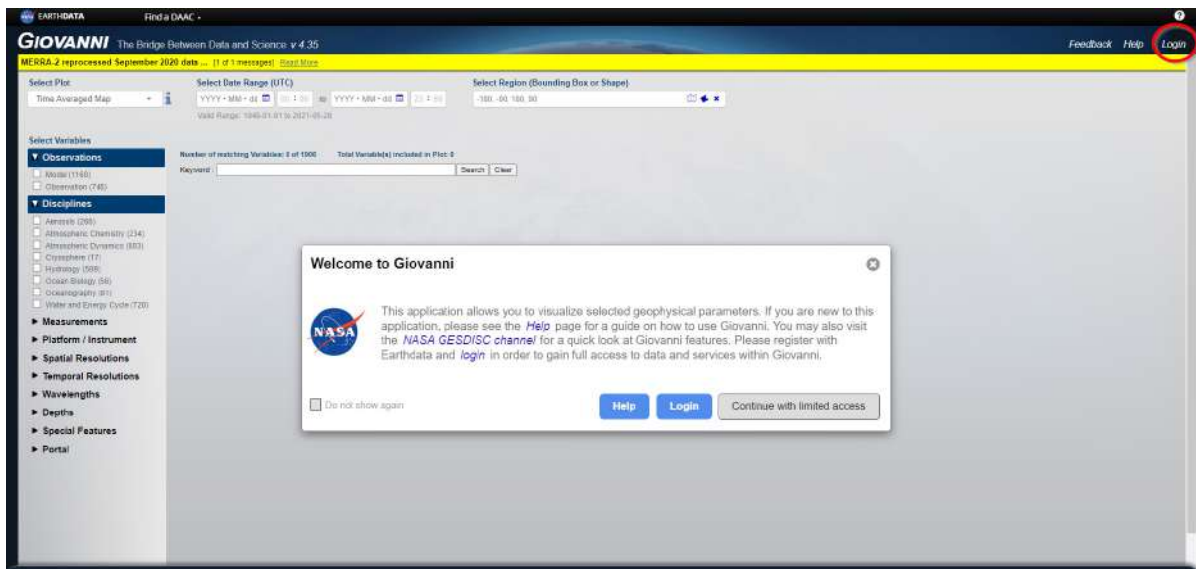
Upon signing up, return to the start page and log in: your link to image downloading on EO Browser page will activate automatically and archive download will start.

Instructions for Signing up with Giovanni Platform (NASA)

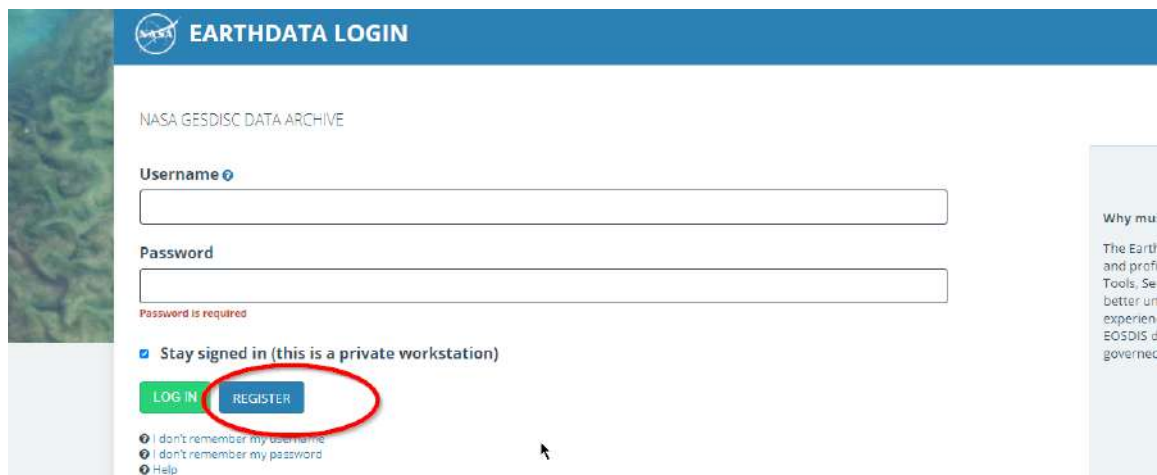
To sign up with Giovanni, simply enter the keywords “Giovanni NASA” in the search bar of a browser, or follow the link: <https://giovanni.gsfc.nasa.gov/giovanni/>.



By default, the site interface looks like this:



To get access to all the functions of the resource, we recommend that you sign up. For this purpose, click the **Login** button in the upper right corner. If you have already signed up, enter your login details in the **Username** and **Password** fields. If you have not worked with this resource before, you need to sign up by clicking the **Register** button.



You will see a registration form, where you need to enter personal data, in particular:

Username

Password that shall consist of lowercase and uppercase letters and numbers (at least eight characters)

Password Confirmation

First Name

Last Name

E-mail

Country (of residence), select from the list

Affiliation (with industry), select from the list

Study Area, select from the list

User Type, select from the list

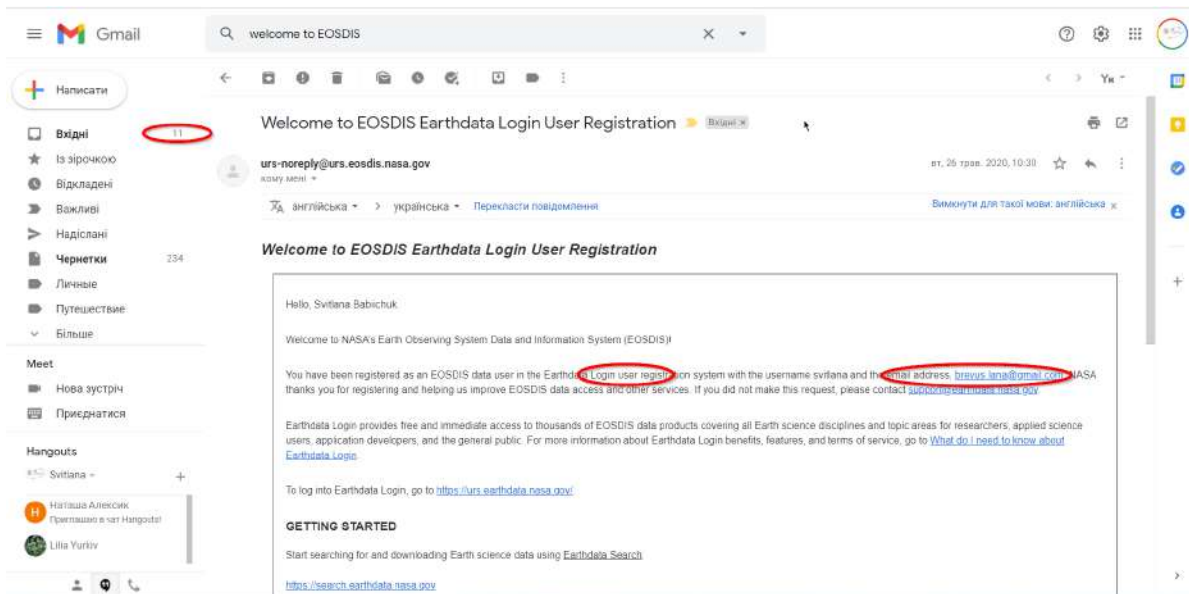
Agreements, check the box

I'm not a robot, check the box

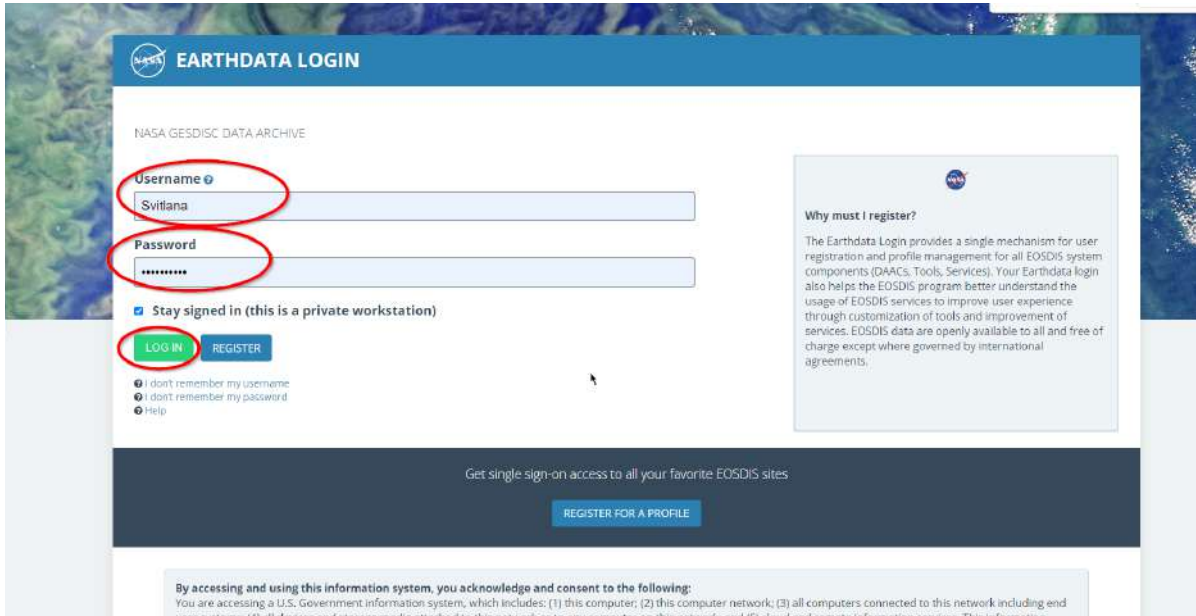
Upon entering the information and selecting all the required fields, press the **Register for earth-data login** button.

The screenshot shows the 'Register for an Earthdata Login Profile' form. Red circles highlight the following fields: 'Email', 'Password', 'Confirm Password', 'First Name', 'Last Name', 'Country', 'Organization', 'User Type', and the 'Register for earth-data login' button at the bottom.

A confirmation message with email and login will be sent to the address you provided during registration.



If your device failed to open the page to log into the resource automatically, log in again using the browser. Enter the login and password you provided during registration.



Now, you have created an account with NASA's Giovanni platform.

Data Required for the Performance of the Tasks

For your convenience, you can find all satellite images we use in this Practice Book at: <https://cutt.ly/YGZV198>. We also remind you that images can be downloaded from EO Browser, Sci-HubCopernicus, EarthExplorer USGS, LandsatLook, etc. At the end of each Task, there is a QR-code with a link to a short video tutorial on the performance of the Task.

1. Long-Term Climate Data (according to Giovanni)

1.1. Studying Changes in NO₂ and CO₂ Concentrations in the Atmosphere of Ukraine

Giovanni: an easier way to visualize Earth science data (from NASA website)¹.

Giovanni is a platform that displays geo-referenced data from NASA satellites directly on the Internet.

With a few clicks, data from various instruments on NASA satellites can be displayed in a variety of formats, including area plots, time series, meridional averages, zonal averages, and vertical profiles, among others.

You can analyze phenomena ranging from the environment surrounding a Saharan dust storm to the impact Hurricane Katrina had on ocean surface chlorophyll concentrations. Single and multiple parameters can be plotted for specified ranges and periods.

Data is accessed and displayed via a collection of interfaces, each allowing the plotting of parameters from one or more satellite instruments. Rainfall, temperature, humidity, and gas concentrations are just a few of the parameters provided.

“Giovanni is a particularly powerful tool for high school and undergraduate research and education, because it provides uncomplicated access to remote-sensing data and easy-to-use functions to analyze the data,” said James Acker, a scientist with NASA's GES DISC, which developed the product. “By manipulating imagery and conducting analyses – rather than simply looking at images – students gain a more comprehensive understanding of how remote-sensing data is used to investigate Earth's interconnected geophysical and biological systems”.

Case

Nitrogen dioxide and carbon dioxide are inorganic chemical compounds found in the air that are harmful to human health. Sources of emissions of these substances are internal combustion engines, thermal power plants, factories, etc. At the end of March 2020, the European Space Agency (ESA) published data on a significant reduction in nitrogen dioxide emissions in several major European cities (Paris, Rome, and Madrid) compared to the average monthly concentrations in 2019.² In China, at the height of the COVID-19 epidemic, the harmful emissions into the atmosphere decreased by 20-30% compared to the same period in the previous three years.³ Two weeks after the UK imposed lockdown, nitrogen dioxide pollution in some cities of the country decreased by 60% compared to a similar period in 2019.⁴ How did the pandemic affect the nitrogen dioxide concentrations in the atmosphere over Ukraine?

According to the Global Monitoring Laboratory⁵, the concentration of carbon dioxide worldwide is constantly increasing (data available since 1980). Is it possible to monitor the concentrations of this pollutant in our country with satellite observation data?

Task performance algorithm:

1. Sign up and log in to the Giovanni service under your account.

¹ URL: www.nasa.gov/audience/foreducators/9-12/features/giovanni-an-easier-way.html

² URL: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe

³ URL: http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/COVID-19_nitrogen_dioxide_over_China

⁴ URL: <https://www.bbc.com/news/uk-england-52202974>

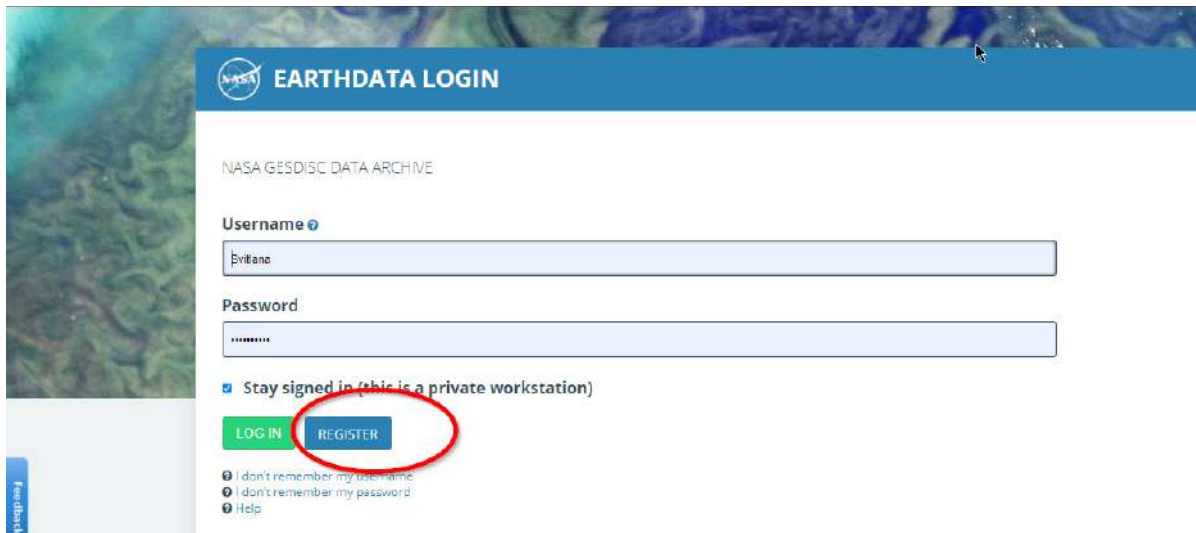
⁵ URL: <https://gml.noaa.gov/ccgg/trends/global.html>

2. Find and visually compare the average concentrations of nitrogen dioxide in the atmosphere of Ukraine from June 15, 2014, to June 15, 2015, and from June 15, 2019, to June 15, 2020.



3. Make a graph of carbon dioxide concentrations in Ukraine over the entire period available in Giovanni for this compound.

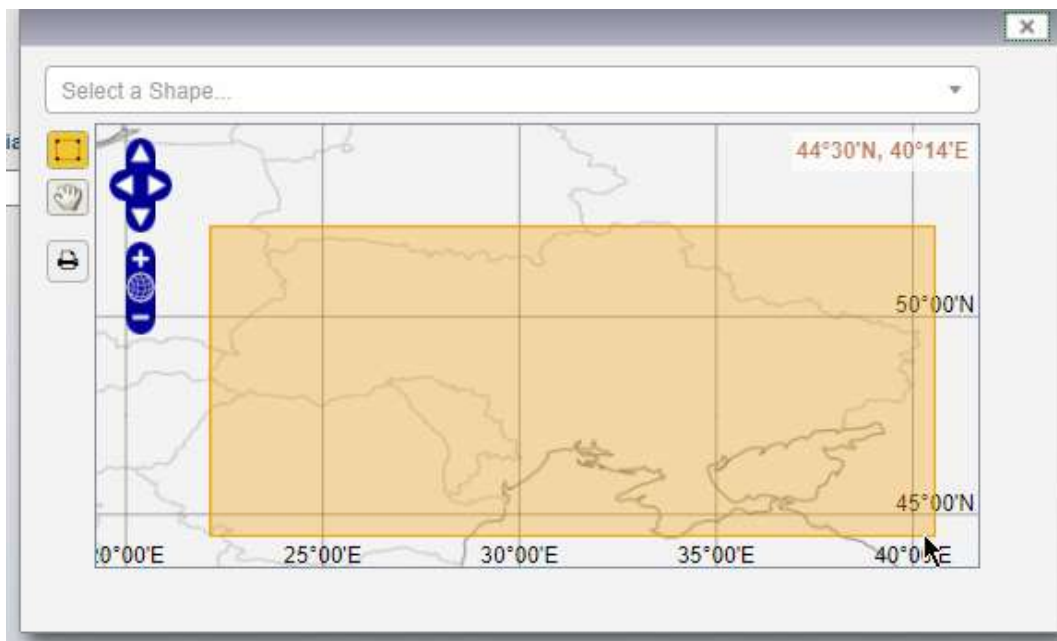
Instructions for self-guided work:

1. Signing up on the site. Official website: <https://giovanni.gsfc.nasa.gov/giovanni/>

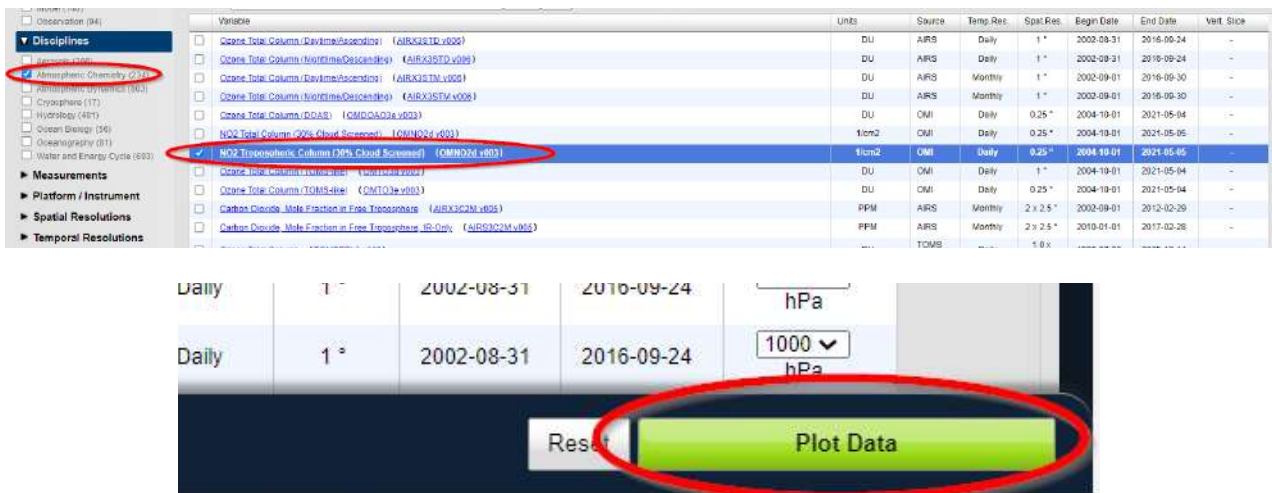


Choose a date (year/month/day): in the **Select Date Range (UTC)** field, select the time for which the program should generate an average map (June 15, 2014 – June 15, 2015). Select the display format: in the **Select Plot** field, specify the display method – **Time-Averaged Map**. You can learn more about other ways of displaying information from the user guide.

2. Choose the location for the study from the **Select Region (Bounding Box or Shape)** field. The program can process different areas under study: within the state borders of the country or rectangular- or square-shaped as specified by the user. Accordingly, if you need to display data for a certain region, your selection shall cover a larger area and include that region. You can zoom in/out on the map with your mouse wheel or the “– +” buttons, and move around the map using the  icon. Choose the territory in the north of Ukraine that includes the city of Kyiv using the tool .

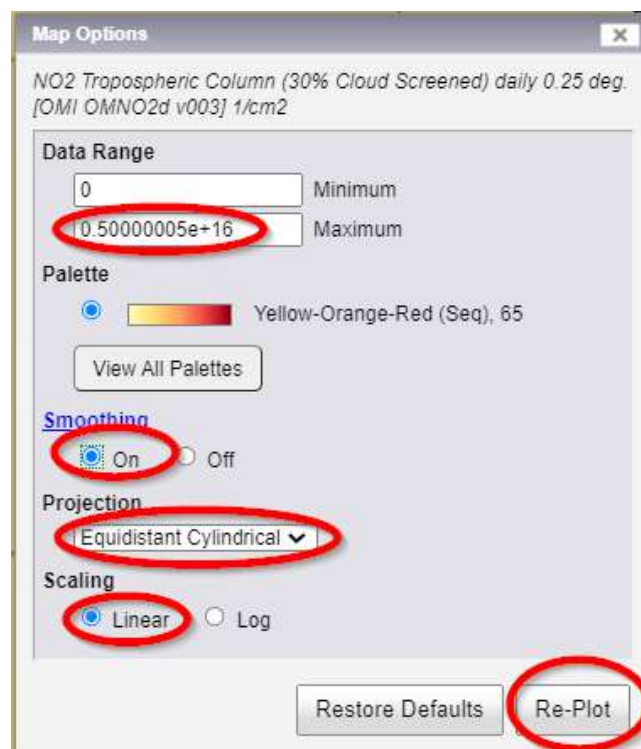


3. Select the variable to be investigated – nitrogen dioxide: choose *Atmospheric Chemistry* from the *Select Variables* panel. From a new list that appears on the screen, select *NO₂ Tropospheric Column (30% Cloud Screened)* to display the content of nitrogen dioxide in the troposphere layers); click the *Plot Data* button to display the data.

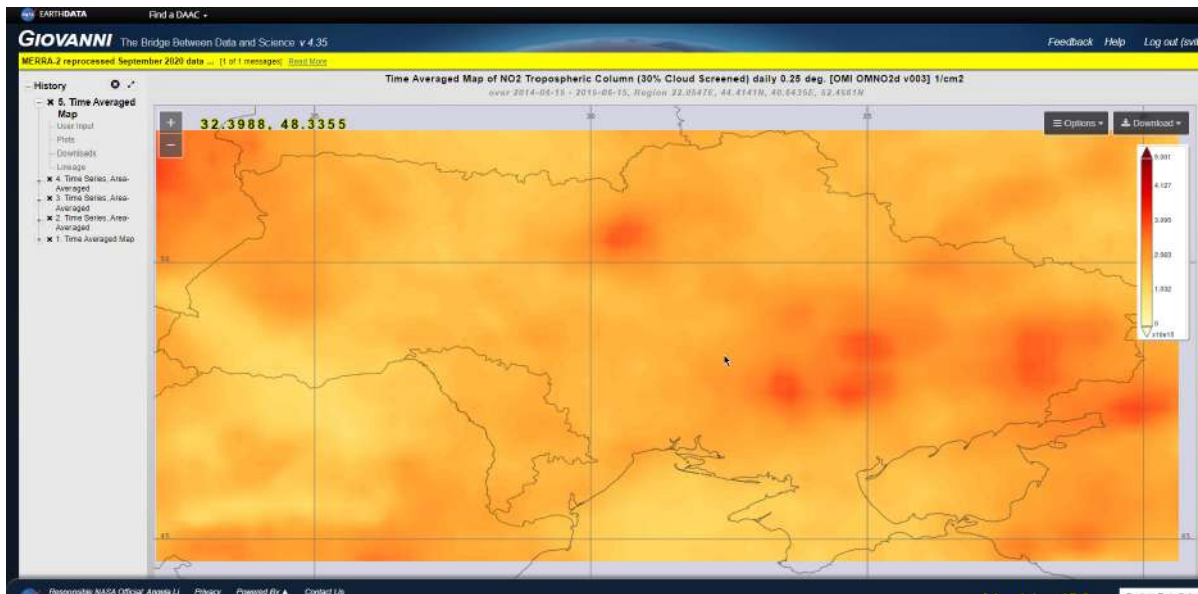


✔ **Important!** *The content of nitrogen dioxide in this data set is represented in molecules/cm². The satellite sensor estimates the number of molecules in the vertical column between the satellite instrument and the ground per area of the Earth's surface. Thus, you obtain the value in molecules/cm².*

4. As a result, you will get a map representing the average (annual) nitrogen dioxide concentrations in the selected area. The difference in values on the map remains unnoticed under the standard classification of the image because the gradation of symbols automatically sets the maximum value of 2.00000005e+16 while our area primarily falls in the range up to 0.50000005e+16; so we will change the maximum data range from 2.00000005e+16 to 0.50000005e+16. To do this, select the *Options* tool from *Options*. Set the maximum data range: "0.50000005e+16", turn *Smoothing* on, and click *Re-Plot*.

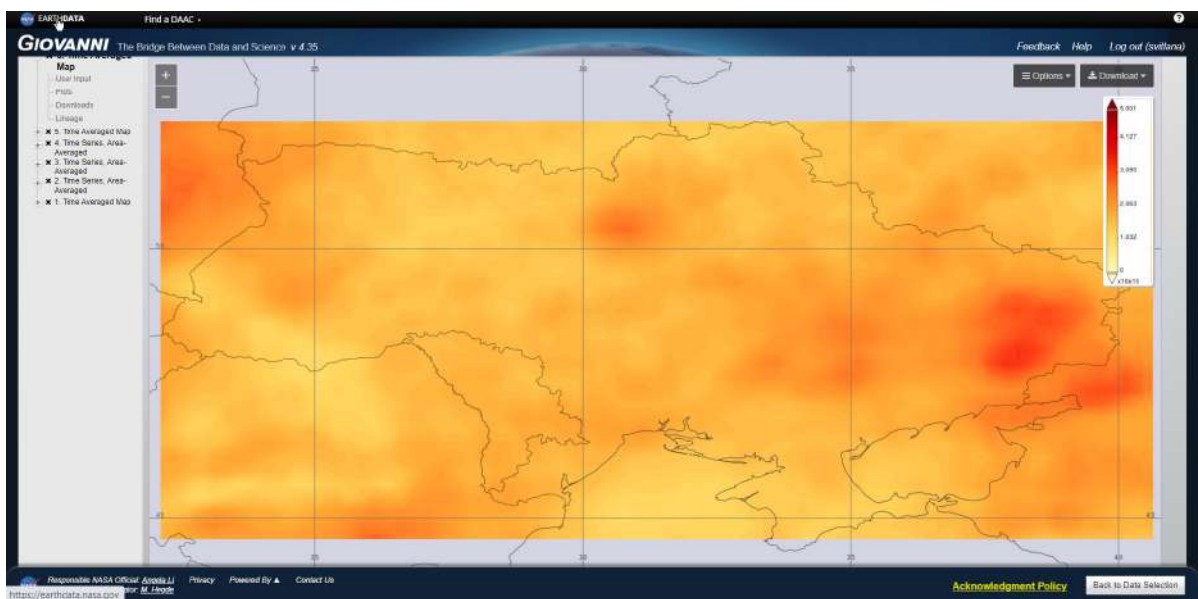


You will get a map of the average (annual) concentrations of nitrogen dioxide in the selected area.



This map will be stored at Giovanni and you do not need to save it separately. To proceed to the next Task, click the **Back to Data Selection** button in the lower right corner of your screen.

5. Using the same algorithm, determine the average nitrogen dioxide concentration in the troposphere over the same area during the period from June 15, 2019, to June 15, 2020.



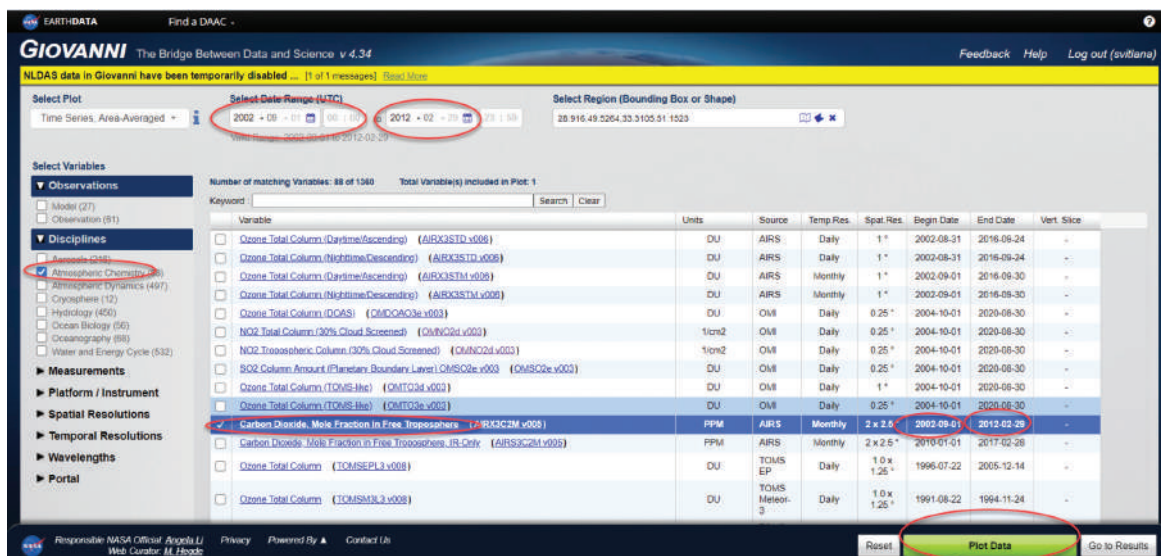
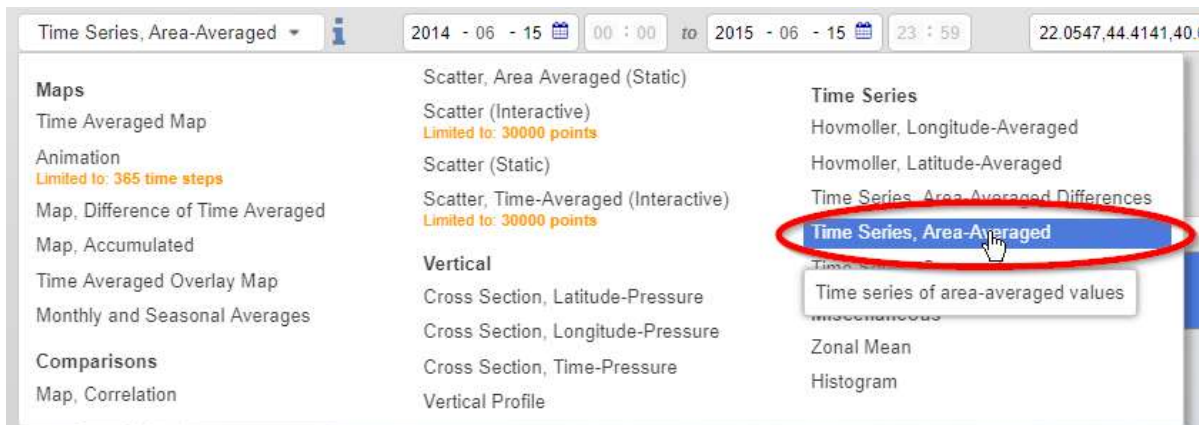
Under Layers, you can see the maps that have been created. Switching between them (left-clicking on the name of the map), you can visually compare them.

? Check yourself

<p>Why and how, in your opinion, did the concentrations of nitrogen dioxide change in 2019-2020 compared to the period of 2014-2015?</p>	
<p>What are the environmental consequences of this change in atmospheric nitrogen dioxide concentrations?</p>	

6. Now let's analyze the concentrations of carbon dioxide, a gas that contributes to global warming,¹ in the same area over the period from 2002 to 2017.

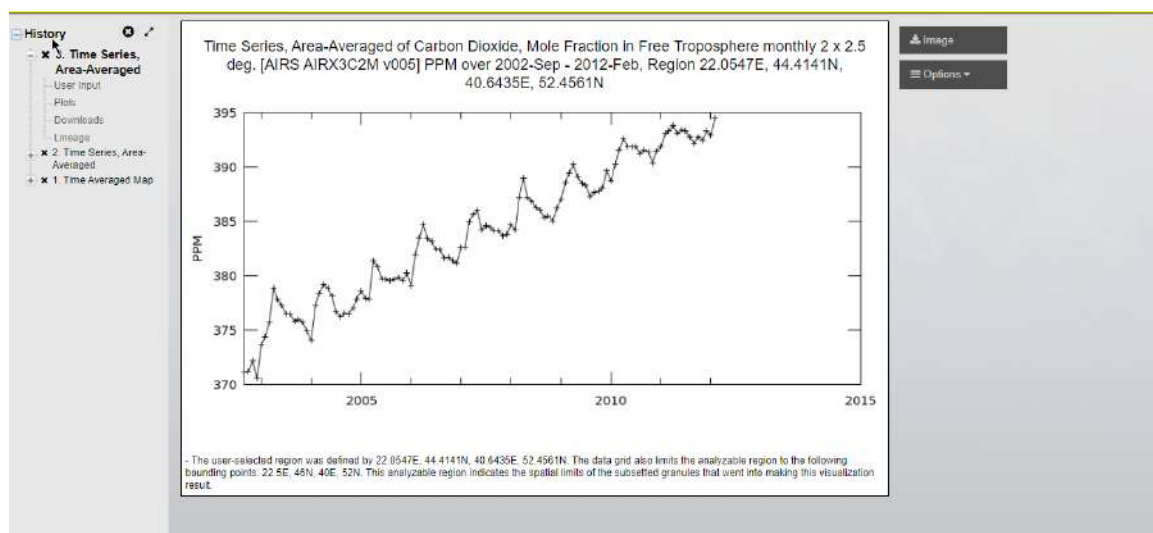
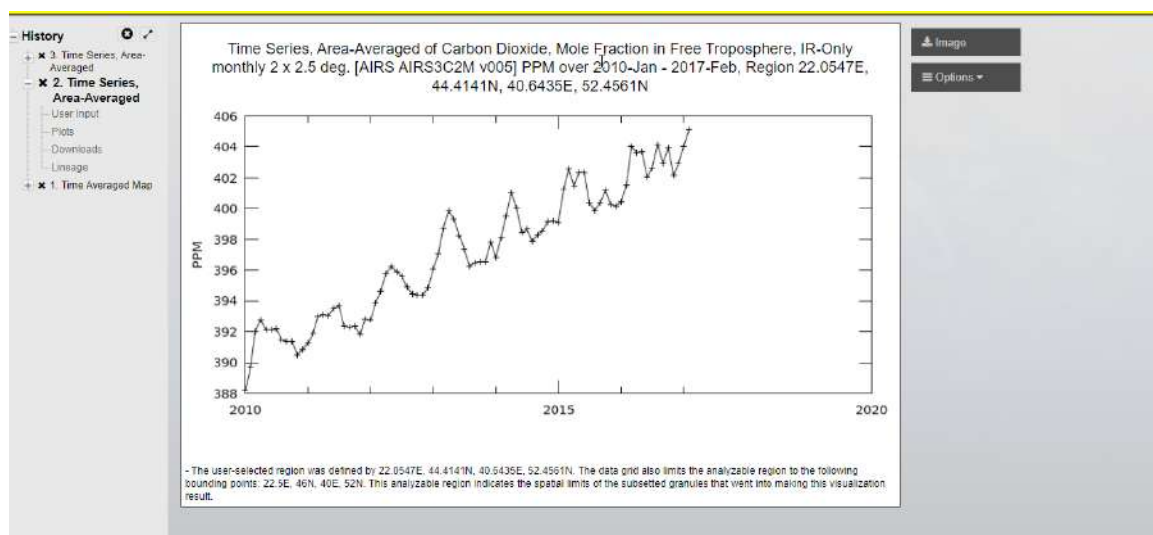
Carbon dioxide is one of the compounds that drive global climate change. Check how its concentrations have changed in the selected area over the entire period for which the data are available in Giovanni. In the **Select Plot** field, specify the **Time Series Area-Averaged** display mode; this is a standard graph of the average value for the selected period that shows the changes in the concentrations of carbon dioxide in the selected area. In the same section, **Atmospheric Chemistry**, we can see the concentration of CO₂ at different times, in particular during 2002-2012 and 2010-2017. Thus, the CO₂ concentrations for different periods (2002–2012 and 2010–2017) can be displayed as two different graphs. To do this, tick the box next to one of the two indicators, specify the appropriate time series for which information was collected, and click **Plot Data** (data visualization).



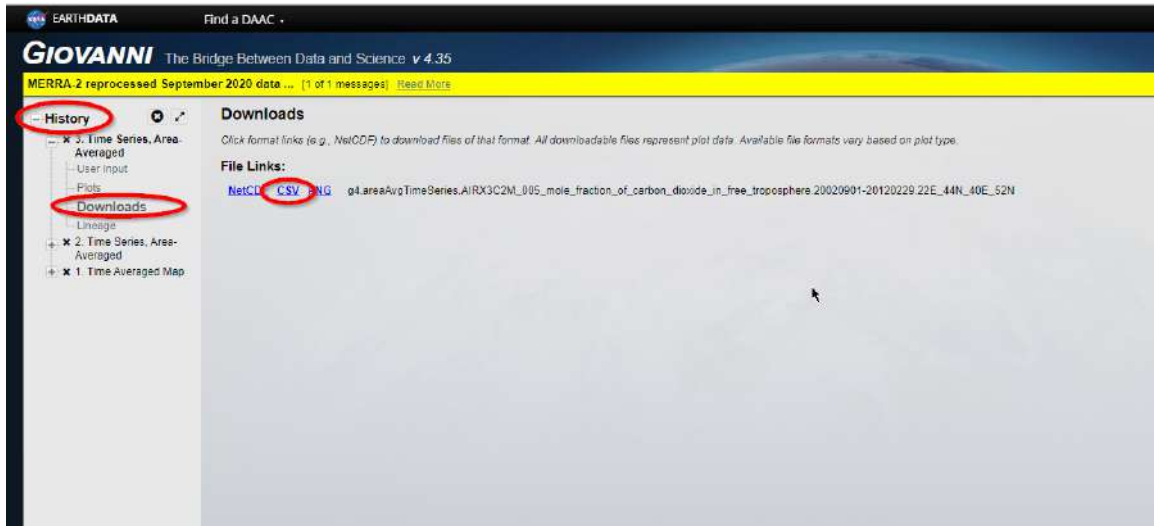
¹ URL: <https://edition.cnn.com/2019/05/13/health/carbon-dioxide-world-intl/index.html>

The screenshot shows the GIOVANNI search interface. Under 'Select Date Range (UTC)', the dates '2010 - 01 - 01' and '2017 - 02 - 28' are circled in red. In the 'Select Variables' section, the variable 'Carbon Dioxide, Mole Fraction in Free Troposphere, IR-Only (AIRS3C2M v005)' is selected and circled in red. The table below shows the selected variable with a 'Plot Data' button highlighted in green at the bottom right.

You will get two graphs for 2002–2012 and 2010–2017.

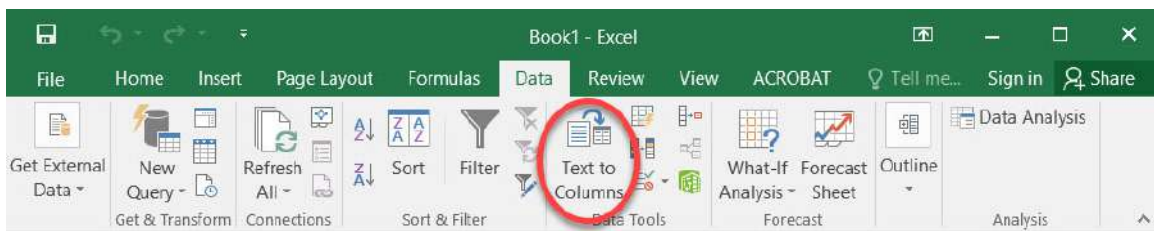


The graphs can be downloaded separately by clicking on the **Image** button and saved as a picture, or you can download different periods to your device and create a common graph in Microsoft Excel: select **CSV** under **Downloads** from the **History** tab and you will see two CSV files because we have processed two periods.

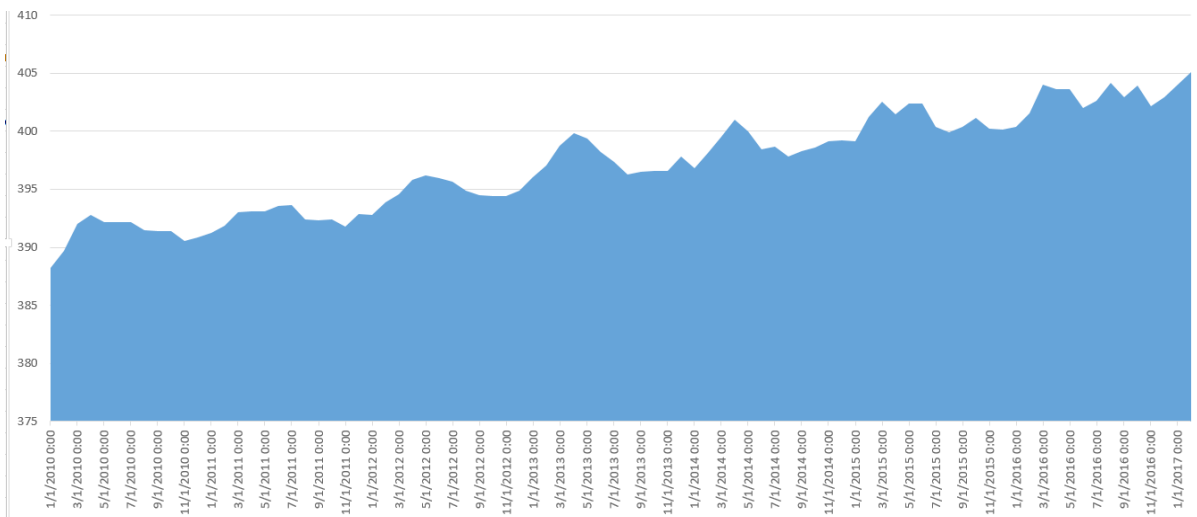


Download both CSV files and combine them into Microsoft Excel (transfer the data that is missing to display the time series from 2002 to 2017).

✔ Important! *If the files are not displayed correctly on your device (there is no automatic splitting of information into two columns: date and carbon dioxide concentration), use the Text to Columns tool from the Excel menu bar. Select the first column and in the tool dialog box, select a tab character (comma, period, space, semicolon, etc.) for splitting the information into the table columns.*



Create a graph of CO₂ concentrations from 2002 to 2017 in any format.



Graph of CO₂ concentration from 2002 to 2017

? Check yourself

How much did the CO ₂ concentration increase from 2002 to 2017?	
What trend does this graph show?	
Try to forecast the change in CO ₂ concentrations in this area by 2032.	
What other chemical compounds can be investigated with Giovanni?	



Scan the QR-code below to watch the video tutorial on the performance of this Task.

1.2. Analyzing Correlation Between Water Surface Temperatures and Water Blooms in the Black Sea and the Sea of Azov

The blooming of reservoirs is a mass development of phytoplankton, which causes a change in the color of water and impairs the oxygen supply of water. One of its reasons is the inflow of minerals, especially phosphorus fertilizers, synthetic detergents, and organic pollutants. In the marine environment, unicellular, microscopic, planktonic organisms, called phytoplankton or microalgae, form the basis of the food chain, on which almost all other marine organisms depend. About 2% of known phytoplankton species are harmful or toxic. Harmful algal blooms can adversely affect a large number of different marine organisms, especially marine mammals, sea turtles, shorebirds, and fish, causing immunological, neurological, or reproductive disorders. An example of this effect is the death of 107 bottlenose dolphins along the Florida coast in the spring of 2004 due to the consumption of fish high in brevetoxins (Wikipedia). One of the factors that cause the growth and reproduction of phytoplankton is changes in water temperature. Rising temperature is also a manifestation of global climate change. Satellite data of chlorophyll concentrations are used to analyze phytoplankton development and water blooms. The concentration of chlorophyll is an indicator of the number of photosynthetic microorganisms in the aqueous medium.

Task

Using data visualization on NASA's Giovanni portal, determine whether there is a correlation between water temperatures and chlorophyll concentrations in the Black Sea and the Sea of Azov.

Task performance algorithm:

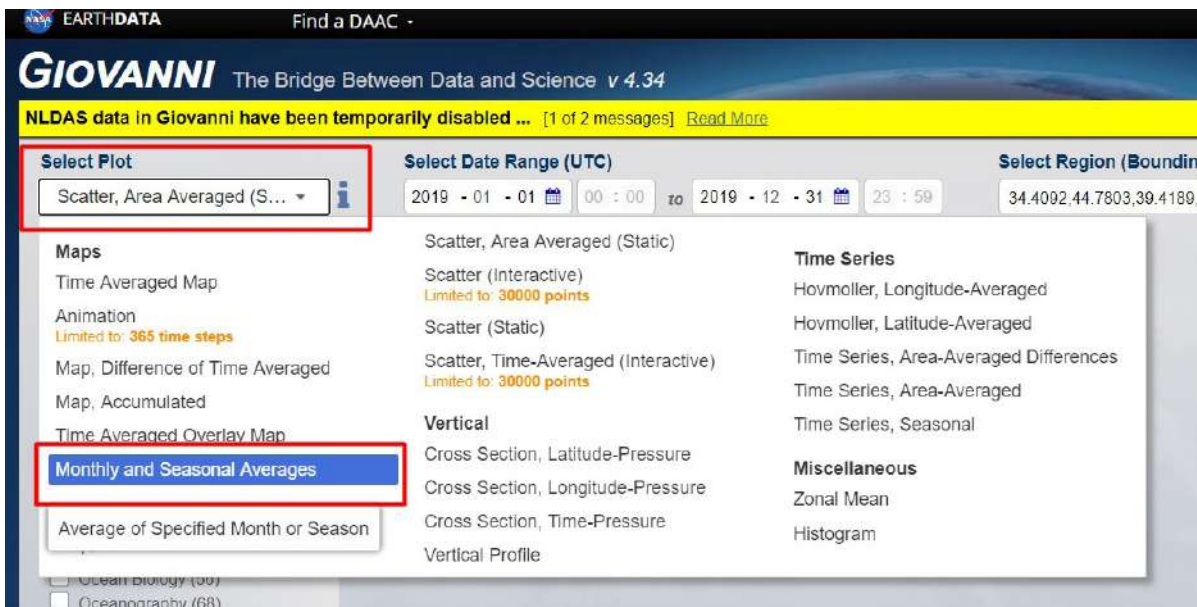
1. Create a map of the average chlorophyll concentrations in the Black Sea and the Sea of Azov during summer in 2015-2019; determine the parts of the seas with higher concentrations of chlorophyll.
2. Create a map of the average water surface temperatures in the Black Sea and the Sea of Azov in 2015-2019.

3. Create a map of the correlation between chlorophyll concentrations and water surface temperatures in 2019; determine in which sea (the Black Sea or the Sea of Azov) the correlation between these factors is higher.

Instructions for self-guided work:

Open the resource <https://giovanni.gsfc.nasa.gov>.

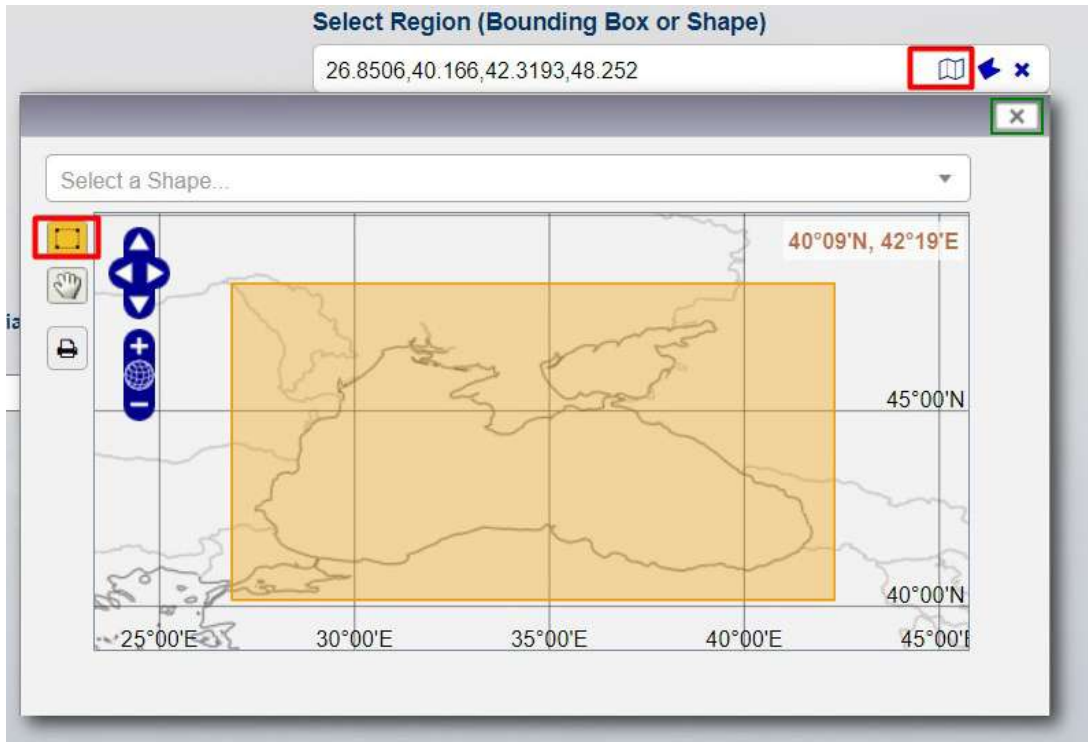
1. Sign up or log into the portal (according to the instructions given in paragraph 1 of Task 1.1).
2. First, create a map of average chlorophyll distribution in the Black Sea and the Sea of Azov. To do this, use the tool displaying the average seasonal long-term chlorophyll concentrations, i.e. create a map of average chlorophyll concentrations during summer months (June – August) in 2015-2019. The peak of water blooms in the Black Sea and the Sea of Azov is commonly observed in summer (that is why we choose summer months), and the values averaged over the five years allow us to neutralize possible extreme weather conditions, which were seen during one year only. So, in the **Select Plot** field, pick **Monthly and Seasonal Averages**.




In the **Select Seasonal Dates** dialog, specify **JJA** (from English **June, July, August** – i.e. summer months), and set the period: 2015 to 2019.

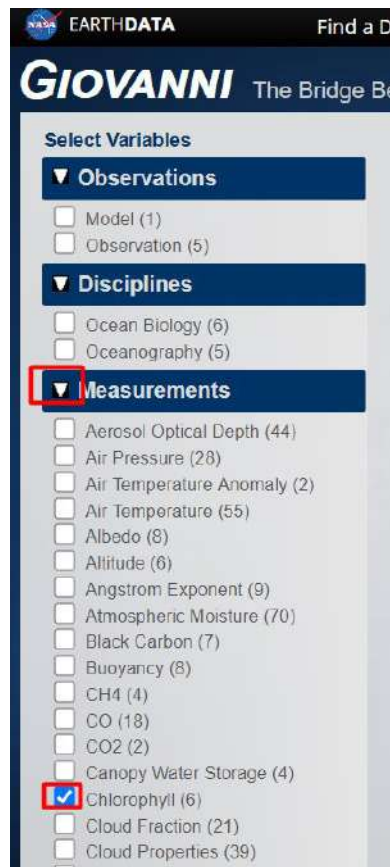


In the **Select Region** field, click the first tool  to draw a rectangle on the map, and in the window that opens, mouse over the Black Sea and the Sea of Azov.



Click on  in the upper corner of your screen to close the window.

Specify the data for analysis: in the left pane *Select variable*, expand the *Measurements* tab, and check the box next to *Chlorophyll*.



As a result, a table will appear in the center of your screen featuring a list of data sets that contain information about the concentrations of chlorophyll. This information includes the name of the variable, units of measurement, source, temporal resolution, spatial resolution, and the beginning

and ending dates of the data collection. Select the chlorophyll concentration data according to MODIS-Aqua satellite and click on the **Plot Data** (data visualization) tool.

Number of matching Variables: 6 of 1380 Total Variable(s) included in Plot: 1

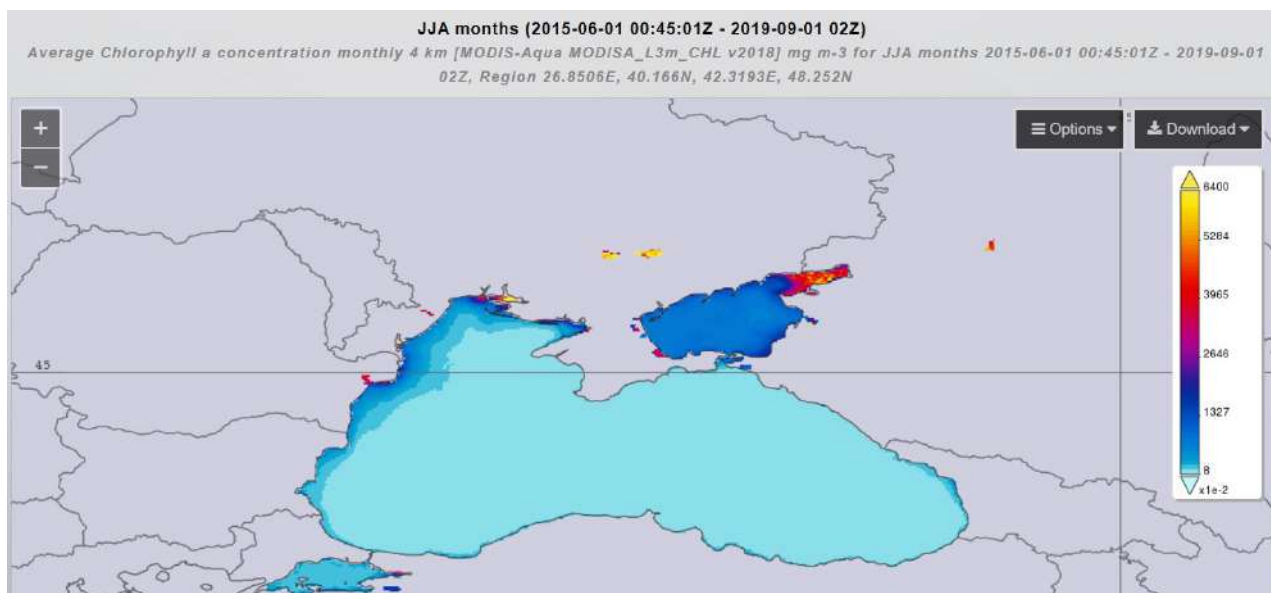
Keyword: Search Clear

Variable	Units	Source	Temp Res	Spat Res	Begin Date	End Date
<input type="checkbox"/> Chlorophyll a Concentration (OCTS_L3m_CHL_v2014)	mg m-3	OCTS	Monthly	9 km	1996-11-01	1997-06-30
<input type="checkbox"/> Concentration of Particulate Organic Carbon (OCTS_L3m_POC_v2014)	mg m-3	OCTS	Monthly	9 km	1996-11-01	1997-06-30
<input type="checkbox"/> Total chlorophyll (NOBM_MON_vR2017)	mg m-3	NOBM Model	Monthly	0.87 x 1.25 °	1998-01-01	2015-12-31
<input checked="" type="checkbox"/> Chlorophyll a concentration (MODISA_L3m_CHL_v2018)	mg m-3	MODIS-Aqua	Monthly	4 km	2002-07-04	2020-06-30
<input type="checkbox"/> Normalized fluorescence line height (MODISA_L3m_FLH_v2018)	mW cm ⁻² um ⁻¹ sr ⁻¹	MODIS-Aqua	Monthly	4 km	2002-07-04	2020-06-30
<input type="checkbox"/> Concentration of Particulate Organic Carbon (MODISA_L3m_POC_v2018)	mg m-3	MODIS-Aqua	Monthly	4 km	2002-07-04	2020-06-30

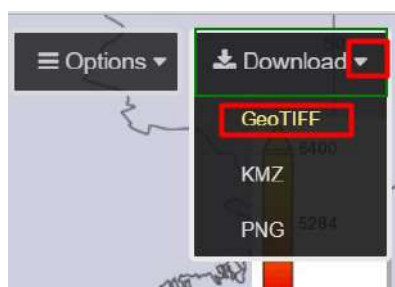
Privacy Powered By ▲ Contact Us

Reset Plot Data Go to Results

As a result, you will get a map of average chlorophyll concentrations during the summer months in 2015–2019. The map shows high concentrations of chlorophyll in the Sea of Azov as well as along the eastern coast of the Black Sea.



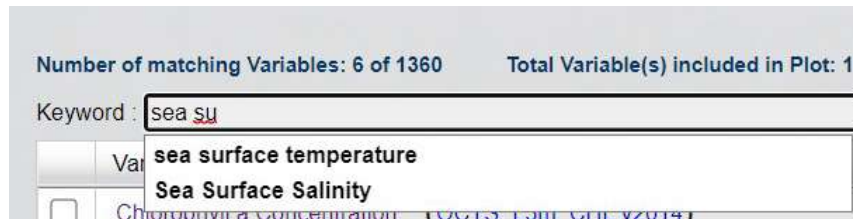
With the **Download** tool, you can download the map, namely in the GeoTiff format, and, if necessary, continue to work with it in QGIS.



3. Now let's create a map of sea surface temperatures for the same period and season. To return to data selection, click the **Back to Data Selection** button in the lower right corner of your screen.

Back to Data Selection

4. Leave unchanged the following search parameters: visualization mode, season, years, and region (these parameters should be the same as in paragraph 1.2.1; we need to specify only the variable – sea surface temperature; we will use the search bar to select this parameter; to search you can write keywords in English (the language of the program's web interface). So, enter “sea surface temperature”. All you have to do is to start writing a phrase, and a drop-down menu with possible data options will open automatically. Select the appropriate data set and click **Search**.



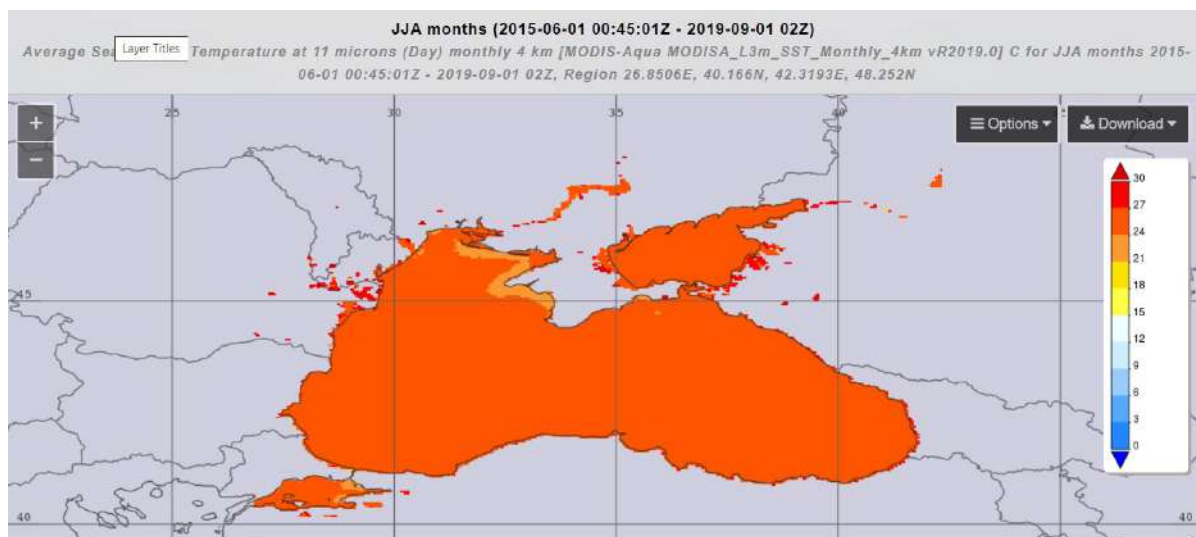
From the list of available data sets, select the *Sea Surface Temperature at 11 microns (Day)* data set with a spatial resolution of 4 km and click on the **Plot Data** tool.

Number of matching Variables: 6 of 1360 Total Variable(s) included in Plot: 1

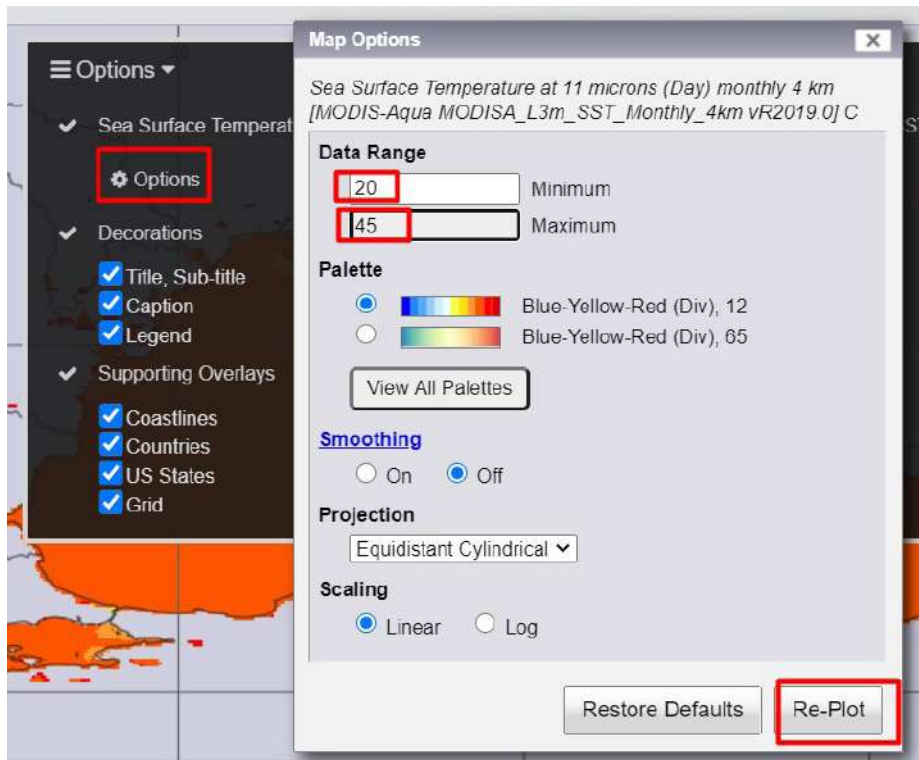
Keyword : sea surface temperature Search Clear

Variable	Units	Source	Temp.Res	Spat.Res	Begin Date	End Date
<input type="checkbox"/> Sea Surface Temperature at 11 microns (Night) (MODISA_L3m_NSST_Monthly_9km vR2019.0)	C	MODIS-Aqua	Monthly	9 km	2002-07-04	2020-07-31
<input type="checkbox"/> Sea Surface Temperature at 11 microns (Day) (MODISA_L3m_SST_Monthly_9km vR2019.0)	C	MODIS-Aqua	Monthly	9 km	2002-07-04	2020-06-30
<input type="checkbox"/> Sea Surface Temperature at 11 microns (Night) (MODISA_L3m_NSST_Monthly_4km vR2019.0)	C	MODIS-Aqua	Monthly	4 km	2002-07-04	2020-07-31
<input checked="" type="checkbox"/> Sea Surface Temperature at 11 microns (Day) (MODISA_L3m_SST_Monthly_4km vR2019.0)	C	MODIS-Aqua	Monthly	4 km	2002-07-04	2020-06-30
<input type="checkbox"/> Sea Surface Temperature at 4 microns (Night) (MODISA_L3m_SST4_Monthly_9km vR2019.0)	C	MODIS-Aqua	Monthly	9 km	2002-07-04	2020-05-31

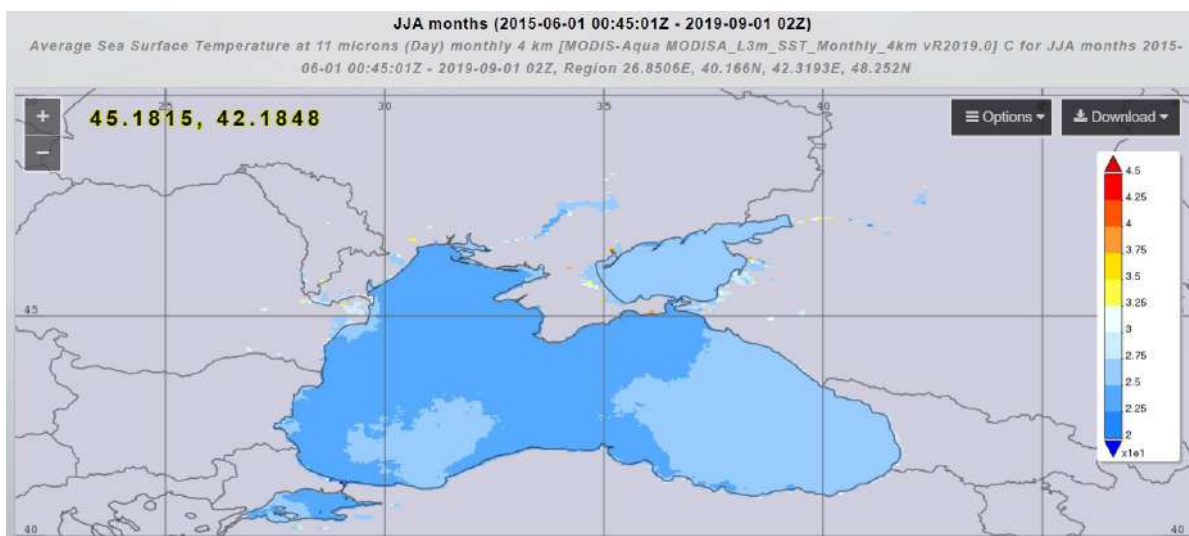
As a result, you will get a map of the sea surface temperatures in the Black Sea and the Sea of Azov.



As can be seen from the map, almost the whole area has a surface temperature above 24°C. Using the **Options** tool (as in the previous Task), you can change the scale so that the values from 20°C and above are displayed only.



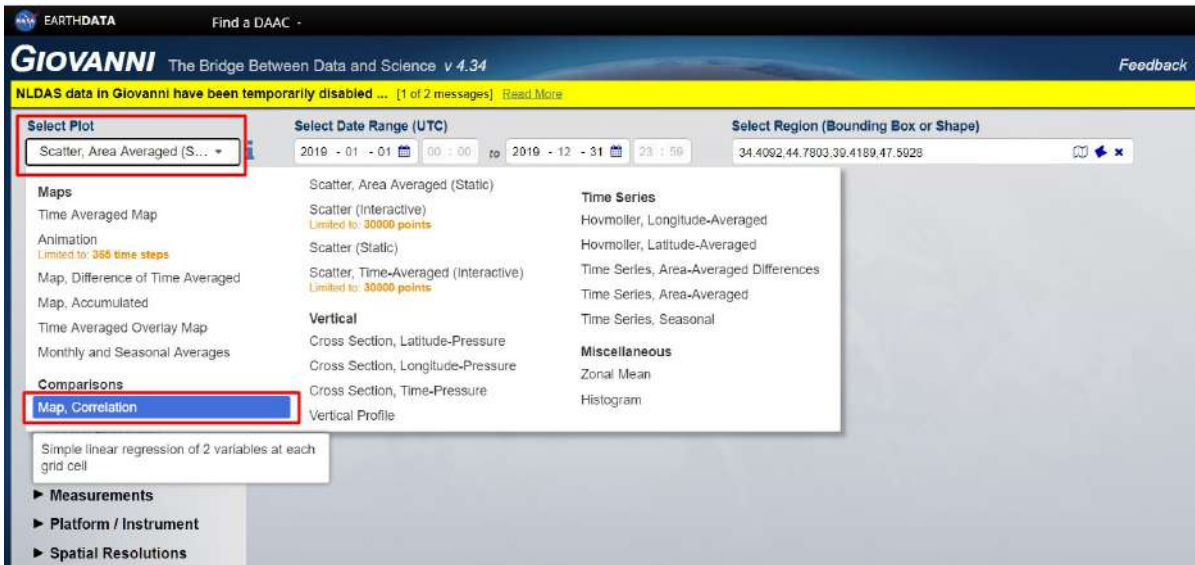
As a result, you will get a map that shows that the highest sea surface temperature is observed in the Sea of Azov, as well as off the west coast of the Black Sea.



🔍 Check yourself

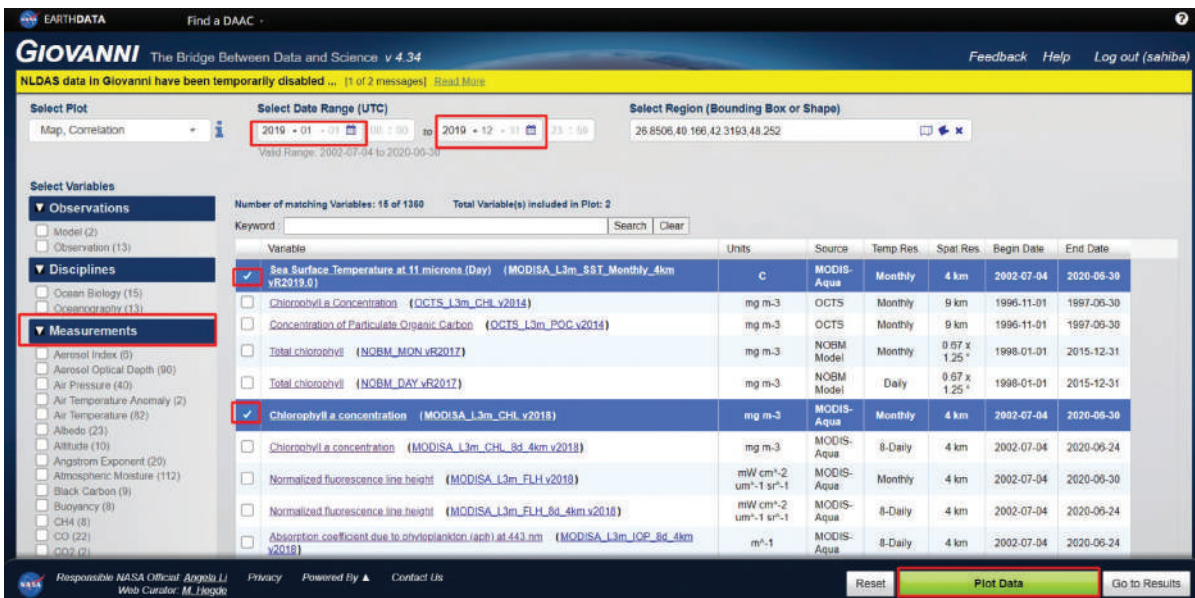
Why do you think the water temperature in the Sea of Azov is higher than that on the west coast of the Black Sea?

5. Now we will determine whether there is a relationship between temperature and chlorophyll concentration. To return to the data selection, click on the **Back to Data Selection** tool in the lower right corner of your screen. Pick **Map, Correlation** under **Select Plot**.

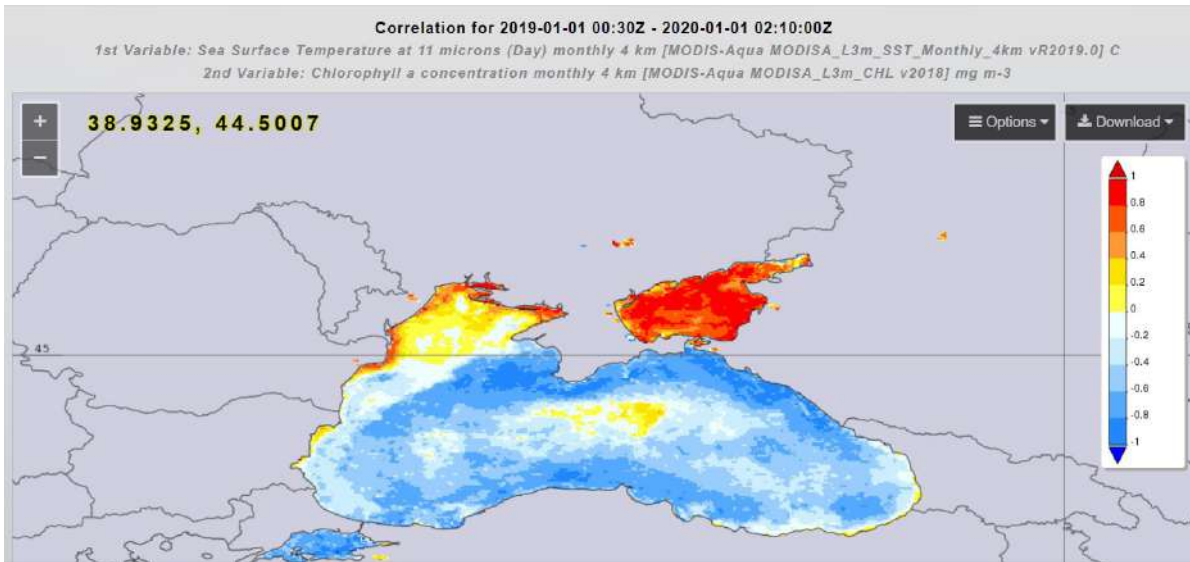


This visualization mode allows you to analyze only two phenomena over a certain period, without averaging over the season. Therefore, you need to update the data in the **Select Date Range** field and specify the period: from January 1, 2019, to December 31, 2019.

In the left sidebar, expand the **Measurements** tab again and select two variables: *Chlorophyll* and *Sea Surface Temperature*, and click the **Plot Data** button.



As a result, you will get a map that displays areas of high and low correlations between the selected variables. The map shows that in the areas with commonly high concentrations of chlorophyll (the Sea of Azov and the west coast of the Black Sea), there is a direct relationship between temperature and chlorophyll.



6. Now let's take a look at the graph of the relationship between these variables. To do this, return to the data selection tab and choose **Scatter, Area Averaged (Static)** from the **Select Plot** field and click the **Plot Data** button.

Select Plot: Map, Correlation

Select Date Range (UTC): 2019 - 01 - 01 00 : 00 to 2019 - 12 - 31 23 : 59

Select Region (Bo): 26.8506,40.166,42.0

Maps

- Time Averaged Map
- Animation Limited to: 365 time steps
- Map, Difference of Time Averaged
- Map, Accumulated
- Time Averaged Overlay Map
- Monthly and Seasonal Averages

Comparisons

- Map, Correlation

Scatter (Interactive)

- Scatter plot comparing area averaged time series for two variables
- Scatter, Time-Averaged (Interactive) Limited to: 30000 points

Vertical

- Cross Section, Latitude-Pressure
- Cross Section, Longitude-Pressure
- Cross Section, Time-Pressure
- Vertical Profile

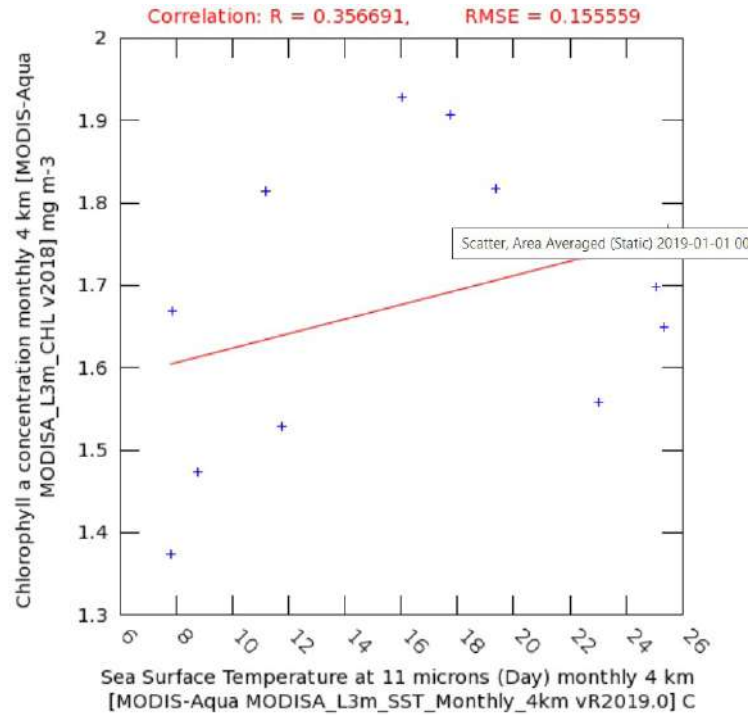
Time Series

- Time Series, Longitude-Averaged
- Time Series, Latitude-Averaged
- Time Series, Area-Averaged Differences
- Time Series, Area-Averaged
- Time Series, Seasonal

Miscellaneous

- Zonal Mean
- Histogram

As a result, a graph of the relationship between water temperatures and chlorophyll concentrations will appear. According to the graph, there is a dependence, however, the correlation coefficient is quite low (0.35) for the whole area under study. This coefficient may slightly vary, depending on the area selected for the study.

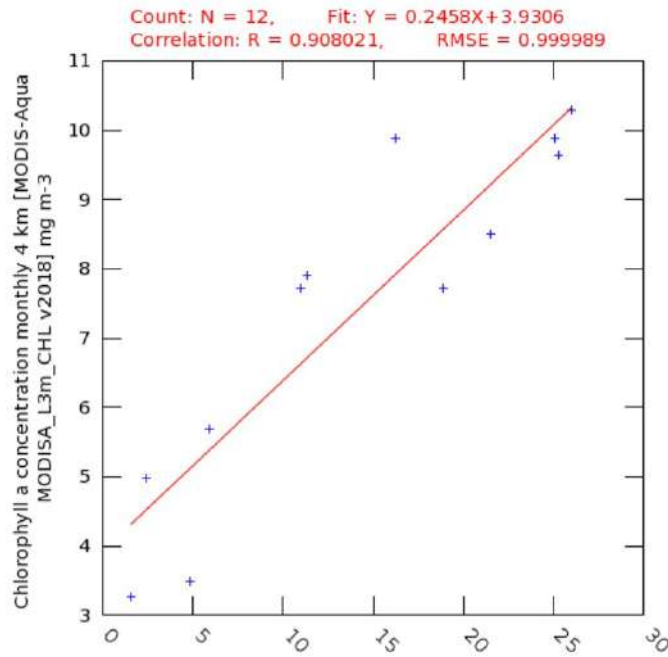


7. We will change the area under study now and draw a rectangle for the territory of the Azov Sea only, and build again a graph for the temperature-chlorophyll correlation.



The resulting correlation coefficient is 0.9, which indicates a close relationship between the water temperature in the Sea of Azov and the concentration of chlorophyll.

Scatter, Area Averaged (Static) 2019-01-01 00:30Z - 2020-01-01 02:10:00Z, Region 34.3652E,
45.1011N, 39.5068E, 47.584N



? Check yourself

Why do you think the correlation coefficient between temperature and chlorophyll was higher in the Sea of Azov than in the Black Sea?

Scan the QR-code below to watch a video tutorial on the performance of this Task.



2. Land Cover – Satellite Data for Monitoring Ground Cover

Satellite imagery is a handy tool for tracking space changes, analyzing changes in different types of land cover, such as forest, riverbed, shoreline, steppe areas, urban boundaries, or agricultural fields. In the examples below, we will discuss how satellite imagery helps to track changes in the shoreline that may result from the shallowing or such phenomena as abrasion and erosion – flooding and destruction of shores. We will also analyze how the forest cover in the highlands of the Carpathians has changed in almost a hundred years.

2.1. Analyzing the Tuzly Lagoons Coastline Changes by Comparing the Satellite Map of the Land Cover and the Topographic Map

Case

The Tuzly Lagoons National Nature Park located in the Tatarbunary District of Odesa Oblast is a system of marine lagoons, Shahany – Alibey – Burnas, separated from the Black Sea coast by a 29-km long and 60–400 m wide sandbar. It was created in 2010 to protect the unique and vulnerable Black Sea flora and fauna. The place has become a refuge for a large number of different birds: a total of 240 species were recorded in this National Nature Park. It is here that you can watch pelicans in their natural environment in Ukraine. This area is very sensitive to the influence of natural and anthropogenic factors that can lead to the drainage of estuaries and the loss of habitats for a huge number of plants and animals.

Task

Determine whether the coastline of the Tuzly Lagoons has changed in recent years.

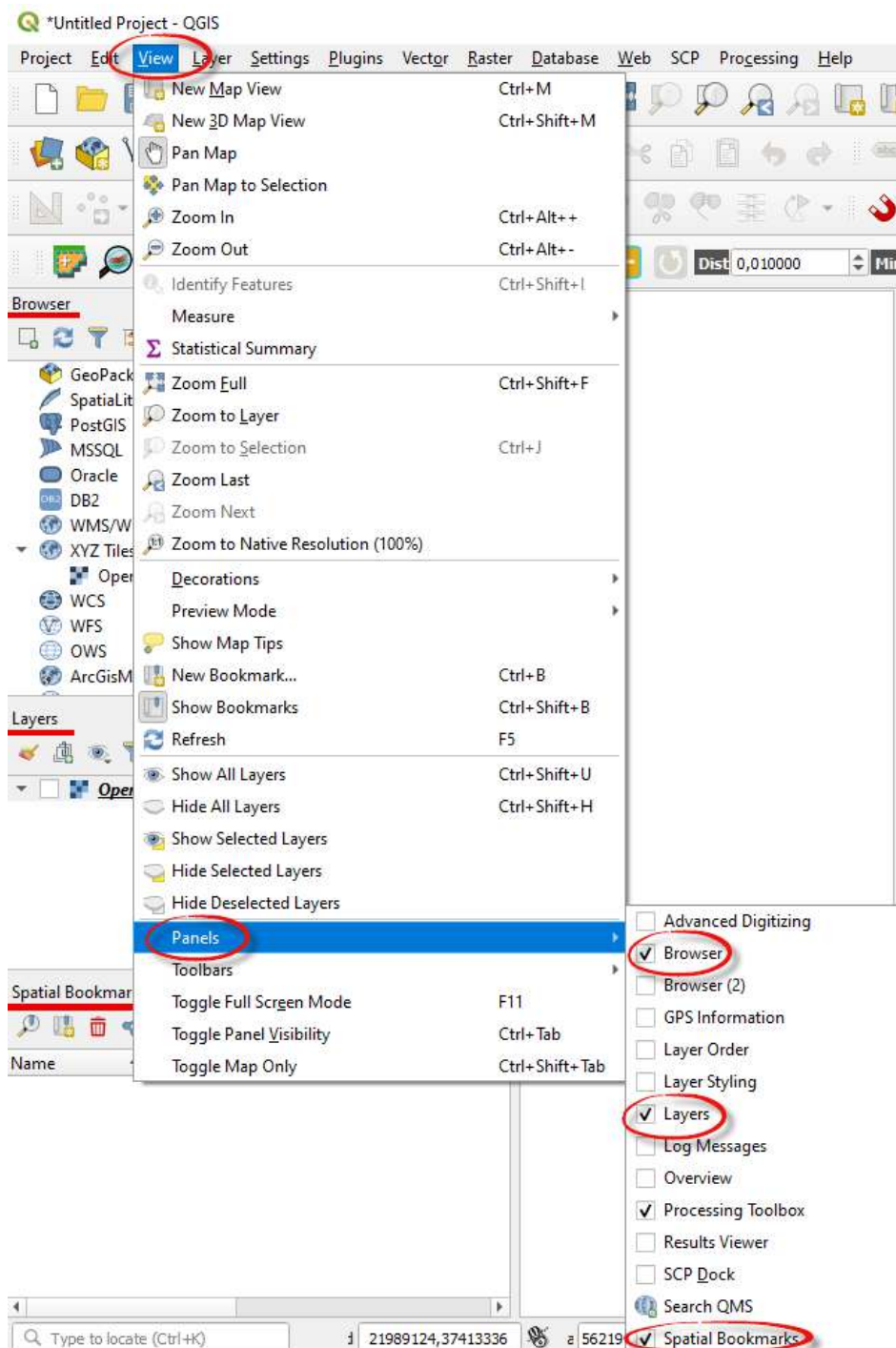
Task performance algorithm:

1. Open the OpenStreetMap layer and a topographic map of the Shahany-Alibey-Burnas lagoons in your project.
2. Using EO Browser, download a map of the land cover of the Tuzly Lagoons National Nature Park, created based on new satellite imagery of the area under study.
3. Visually compare how the land cover of the Tuzly Lagoons National Nature Park has changed using the data of new satellite surveys and previous data.

Data for the performance of this Task can be downloaded at <https://cutt.ly/YGZV198> or using EO Browser.

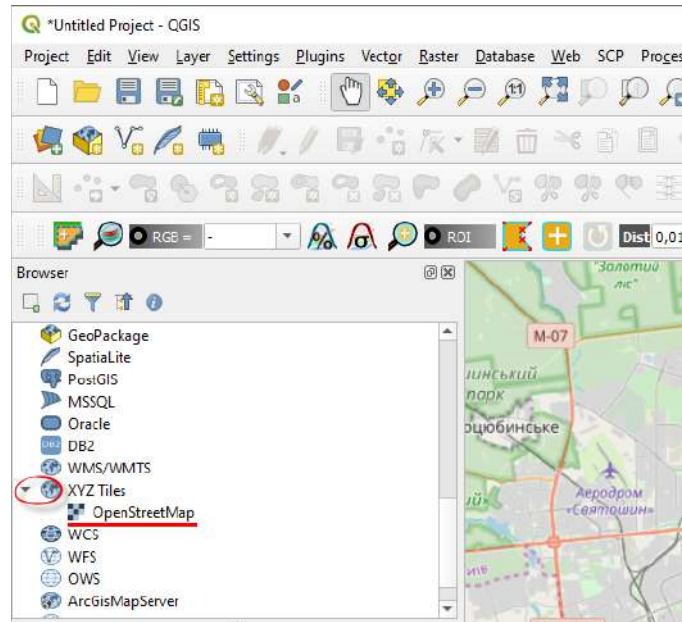
Instructions for self-guided work:

1. Open QGIS Desktop 3.10.3 with GRASS 7.8.2 and create a new project.
2. Make sure that the **Browser** panel, the **Layers** panel, and the **Spatial Bookmarks** panel are open. If they are not available, select **View** → **Panels** from the top menu and tick boxes next to **Browser**, **Layers**, and **Spatial Bookmarks Manager**.

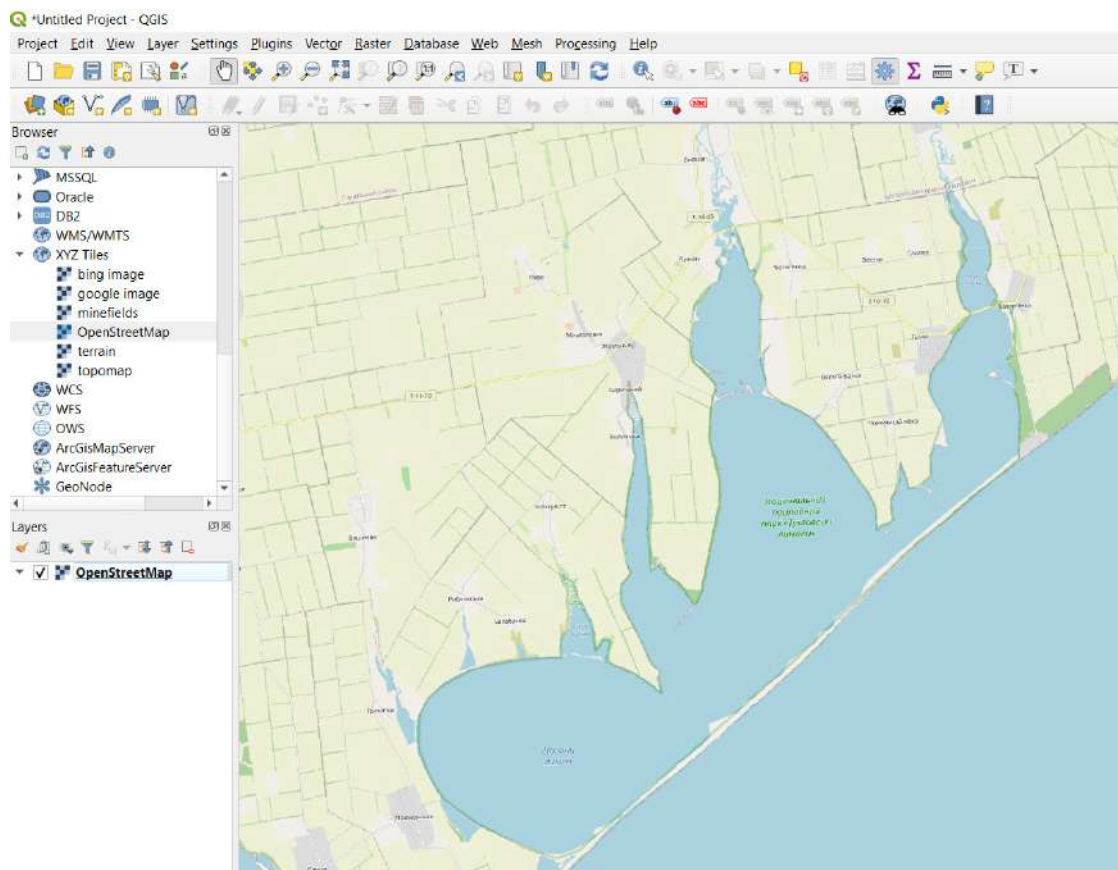


✔ **Important!** All toolbars in QGIS 3.16 are dynamic, i.e. you can change their placement in the work view of the program.

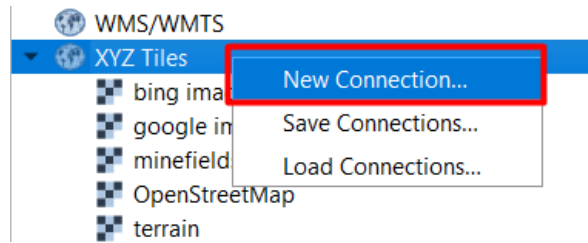
3. Add an OpenStreetMap base map to the project. In the **Browser** panel, open **XYZ Tiles** and double-click on the OpenStreetMap layer to open it in the Layers and display it in the map window.



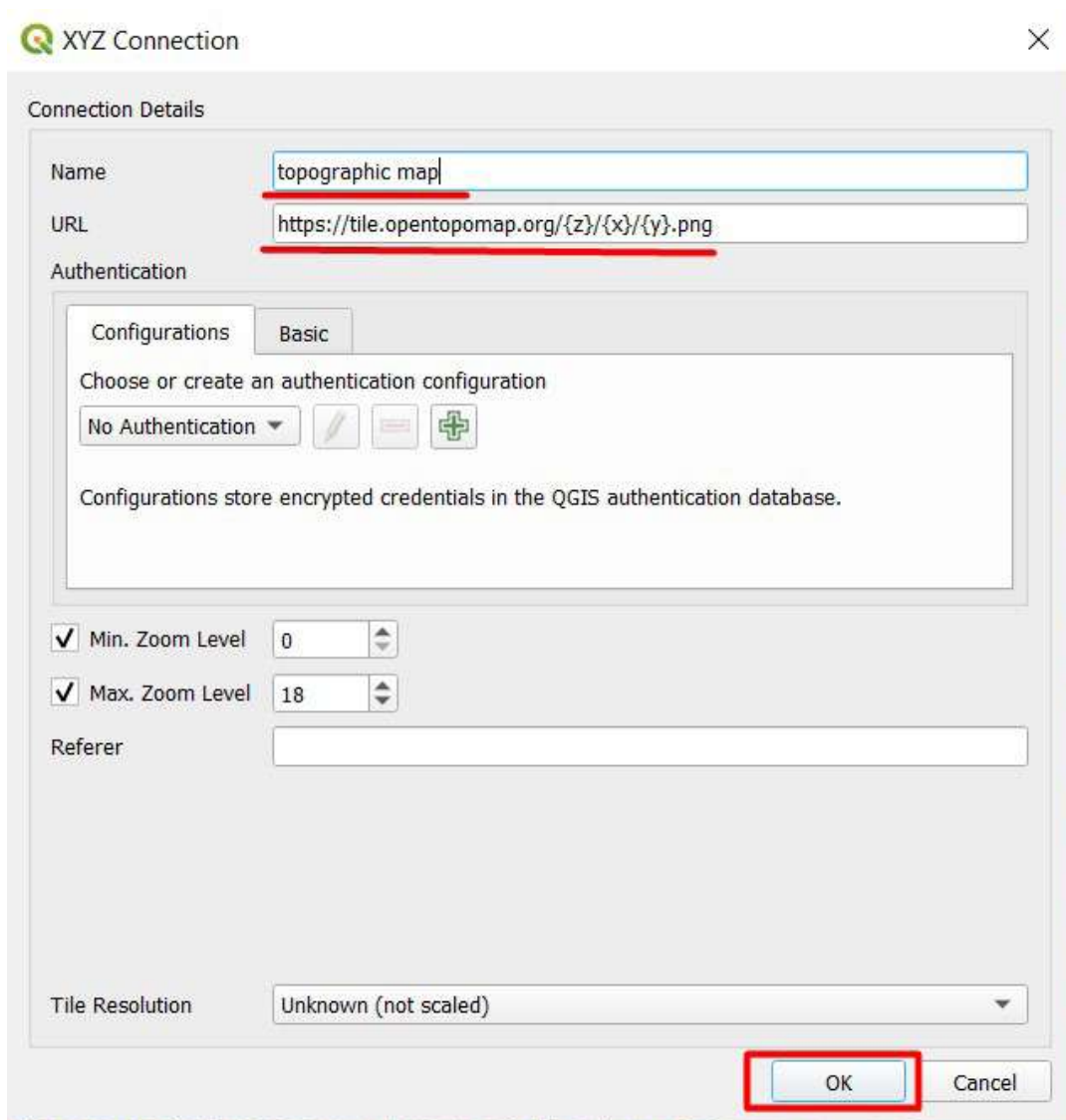
4. Zoom to Odesa Oblast, Tatarbunary District, and Shahany estuary on the map. You will see the area highlighted in green, which is delineated by the boundaries of the Tuzly Lagoons National Nature Park – a group of estuaries separated from the sea by a narrow strip.



5. Open the topographic map layer in the project. Again, use the *XYZ Tiles* tool to create a new connection to an online mapping service. The OpenStreetMap is a standard mapping service, so it does not need to be configured. Other services can be additionally connected independently. For example, the OpenTopoMap service allows you to connect a layer with a topographic map to a project. To do this, right-click on the *XYZ Tiles* menu in the *Browser* panel and select *New Connection* from the drop-down list.



In the window that opens, enter the name of the new connection in the *Name* field, e.g. “topographic map”, enter <https://tile.opentopomap.org/{z}/{x}/{y}.png> in the *URL* box and click *Ok*.



As a result, the topographic map layer will appear in the Browser panel. Double-click on its name to open it in your project.



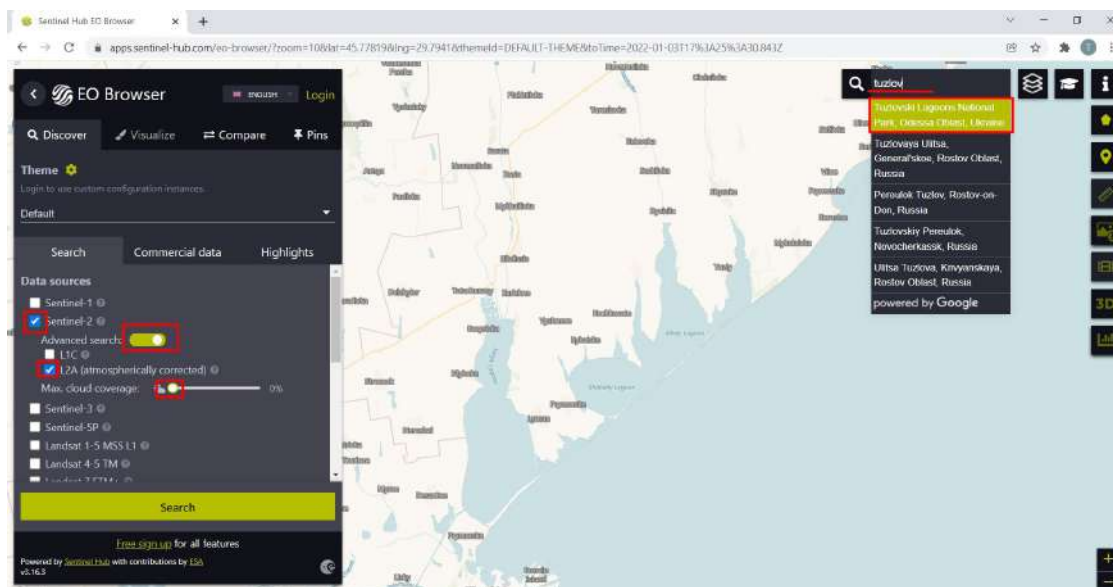
6. Have a look at the territory of the Park on the topographic map. Compare the display of the area on the topographic map and OpenStreetMap map. One of the important advantages of topographic maps over other electronic maps is that they contain terrain information that is displayed as contours. We will discuss them in more detail in one of the following sections.

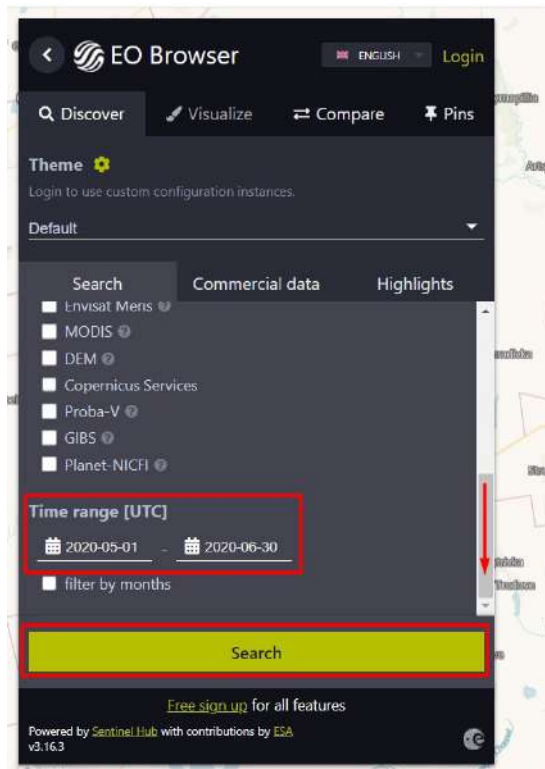
7. Download the satellite map of the land cover based on Sentinel-2 data using EO Browser (or open the data available for this Task at <https://cutt.ly/YGZV198>).

8. The land cover map was obtained by automatic classification of the Sentinel-2 satellite image according to an algorithm developed by the European Space Agency. It is distributed as one of the image bands with an L2A processing level. In fact, the ability to quickly classify a satellite image to detect certain features on the ground surface and find relevant information about the location, shape, and area of the land cover is one of the most important examples of satellite imagery use. The Sentinel-2 Scene Classification Map is the result of classifying an image into 11 classes of land cover. Let's download such a map of the Tuzly Lagoons National Nature Park area.

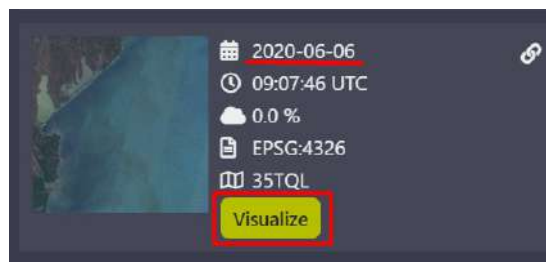
Open EO Browser and log in (see “Instructions for Downloading Images from EO Browser” in the “Instructions” section). Find the area of the Tuzly Lagoons National Nature Park on the map. In the **Search** tab, select:

- **Data source:** Sentinel-2;
- activate **Advanced search** and select **L2A (atmospherically corrected)**;
- **Max.cloud coverage:** 0 (for the analysis of land cover, it is better to use completely cloudless images unless you need data for a definite period);
- **Time range:** 2020-05-01 – 2020-06-30.

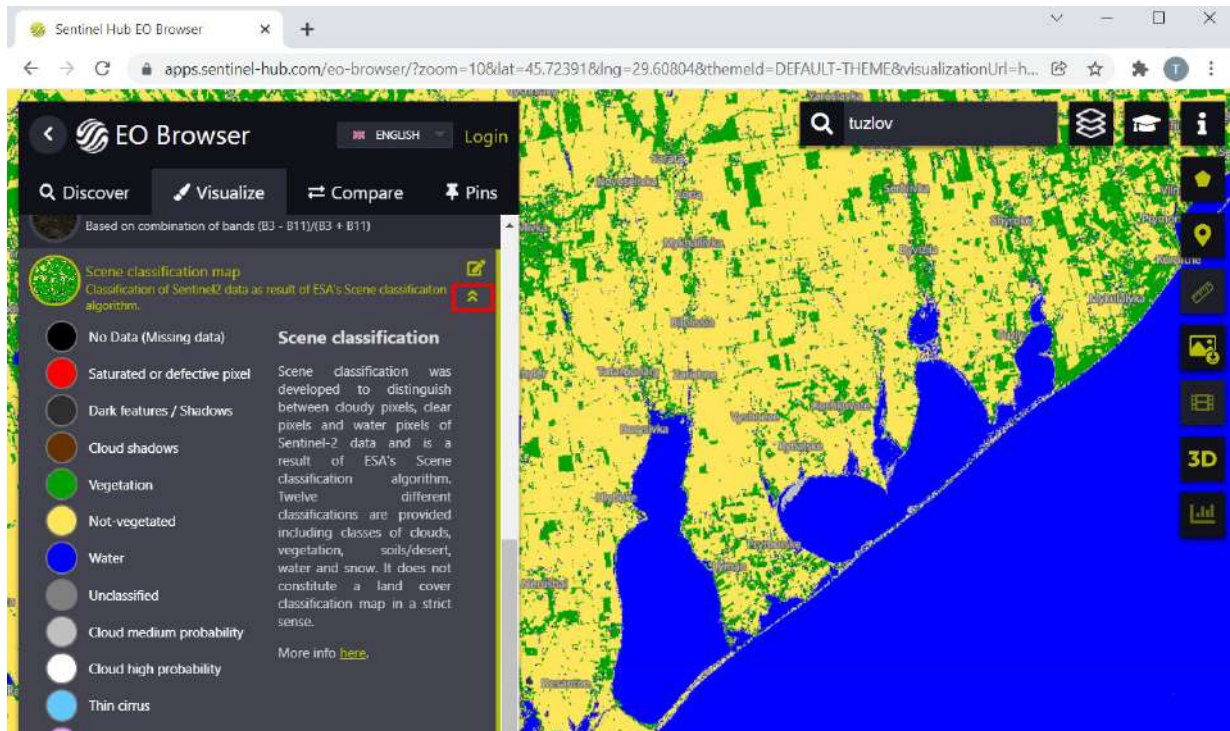




Switch to the Search tab and select the image taken on June 6, 2020, from the search results, and click *Visualize*.



Select *Scnt classification map* mode from the menu for setting up image display (visualization), click on it and expand the tab with a description of this display method.



As a result, the image will be displayed as a map of the land cover, and in the description of the display mode, we can see the colors, in which different classes of land cover appear. In this Task, we study the changes in the coastal area, therefore, the following classes are important for its performance: “water” displayed in blue, “vegetation” displayed in green, and land cover without vegetation (non-vegetated) displayed in yellow on this map.

? Check yourself

What type of land cover predominates within the area under study?	
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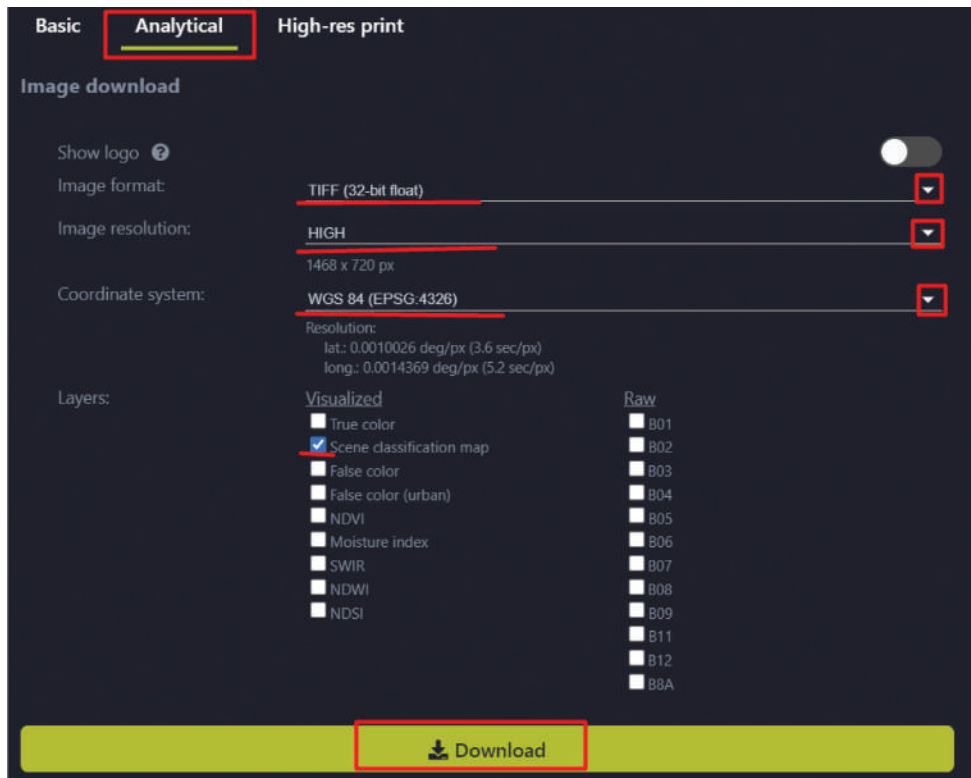
Download this map using the **Download image** tool .

Context: In the image download window, open the **Analytical** tab and specify:

- **Image format:** TIFF;
- **Image resolution:** High;
- **Coordinate system:** WGS 84;
- **Layers:** Scene classification map.

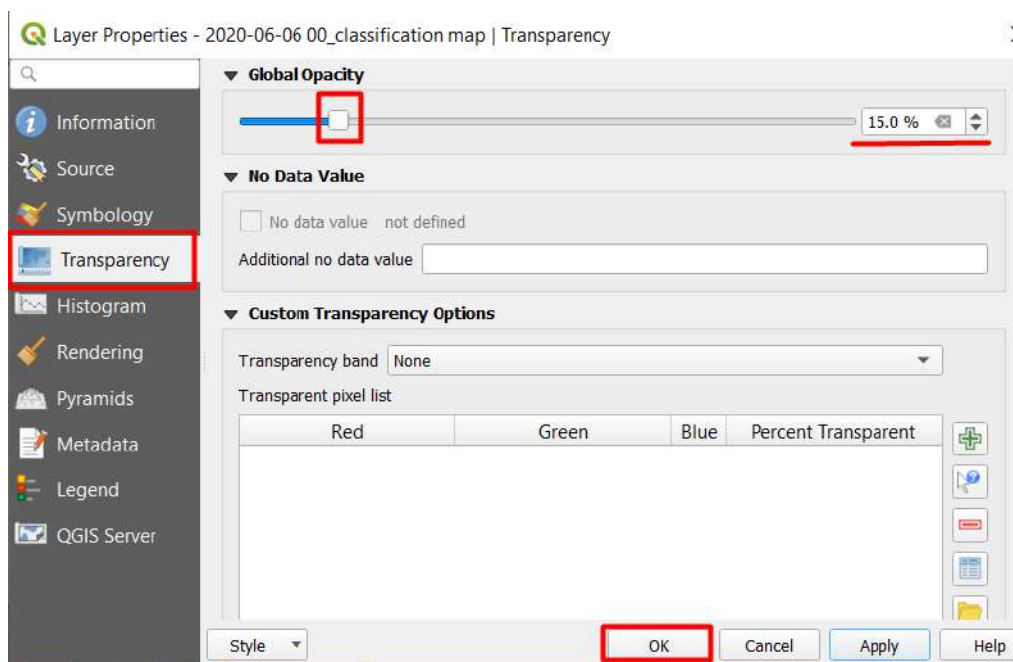
✓ Important! Note that the image will be automatically cropped along the map window, so make sure that the map completely covers the area of your interest (in this case, the National Nature Park area) before downloading.

Click **Download** and specify the path to the folder for saving the map.



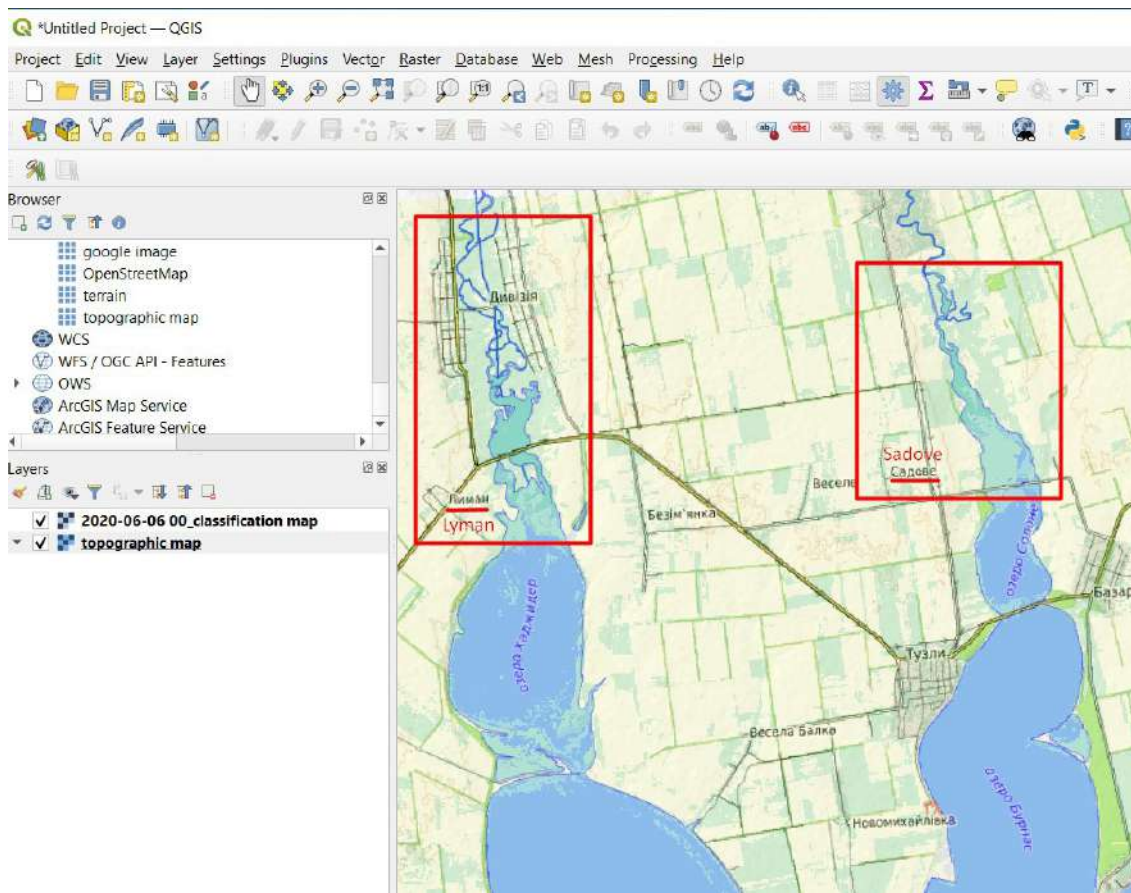
9. Open the downloaded map of the land cover in the QGIS project using the Browser menu and find the changes in the coastline by comparing the map of land cover based on satellite imagery in June 2020 and the topographic map.

10. Adjust the transparency of the land cover map so that you can see how the boundaries of the land cover types have changed. To do this, switch to the properties of the land cover map (double-click with your left mouse button on the layer in the Layers). In the Layer Properties tab, open **Transparency** and set “15” by dragging the slider or entering this value in the **Global opacity** box, and click OK.



11. By overlapping the images in this way, you can see the areas of shallowing at the lagoons: i.e. the areas displayed on the map as water bodies, in June 2020, no longer appear as such on the land

cover map, created based upon satellite images. These areas, namely, include the Solone, Ozero near Sadove settlement, and Khadzhyder Lagoon located near Lyman Town.



✔ **Important!** To see more clearly the difference in the shallowing of lagoons, you can activate the map layer display (tick the box next to the layer name in the Layers) by unchecking the layer “2020 – 06-06...”. Only the topographic map will be displayed.

❓ Check yourself

<p>What is the type of land cover in the areas that are displayed as water bodies on the topographic map and appear differently on satellite imagery taken in June 2020?</p>	
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According to the post published on the Facebook page of the Tuzly Lagoons National Nature Park on June 17, 2020, “Residents of the villages bordering the Tuzly Lagoons National Nature Park have also been affected by the drought. Currently, the condition of the reservoirs of the Tuzly Lagoons is critical. Due to the lack of proper water exchange between the lagoons and the Black Sea and as a result of the drought occurring in recent years, the area of the Lagoons has decreased by about 5 thousand hectares. These areas served as feeding grounds for waterfowl. All the inhabitants of Earth need to take care of the environment, rationally use natural resources, enhance soil fertility, and save energy resources to maintain the planet’s ecological balance.”



View of the dried-up areas of the Tuzly Lagoons National Nature Park (illustration taken from https://www.facebook.com/permalink.php?story_fbid=3287018108022144&id=432082570182393)

Scan the QR-code below to watch a video tutorial on the performance of this Task.



2.2. Changes in the Upper Boundary of the Maramures Forest Massif

Case

The upward shift of the forest upper boundary in the Ukrainian Carpathians is considered to be one of the signs of climate change. The gradual increase in temperature, especially in mountains, leads to a shift of the climatic alpine zone, where the temperature is one of the limiting factors for the growth of trees and shrubs. Such changes do not occur in a year or two, or even several decades, therefore, they are difficult to detect using satellite imagery of the Earth's surface only. However, historical topographic maps enable us to identify long-term changes that occurred even hundreds of years ago.

Task

Evaluate the changes of the forest cover, namely the upper forest boundary near Pip Ivan Mountain (Maramureş) using the topographic maps created in the early 20th century in the Austro-Hungarian Empire, the area under study belonged to at that time.

Task performance algorithm:

1. Download a topographic map of the early twentieth century capturing the area under study (https://drive.google.com/drive/folders/1evecAx26lG1n_1M1w5cKgCNhZNwvUvI).

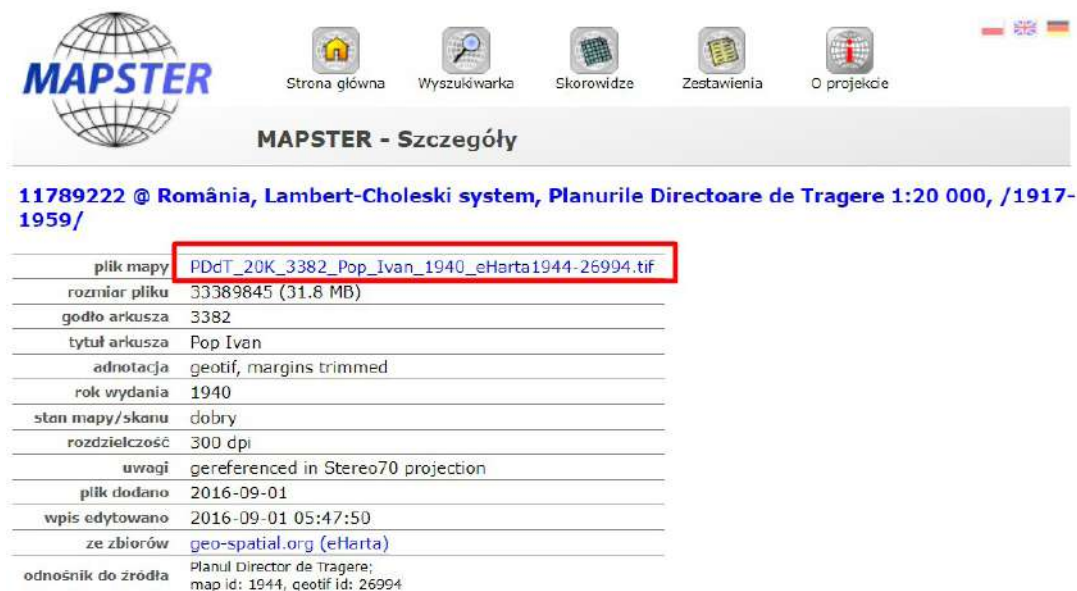
2. Vectorize the boundaries of the alpine zone (i.e. the zone of the upper forest boundary) in the area of Pip Ivan Mountain (Maramureş) on a topographic map.

3. Open a layer of satellite imagery with high spatial resolution in the project and evaluate the changes in the forest boundaries over almost 100 years.

Instructions for self-guided work:

1. Open QGIS Desktop 3.10.3 with GRASS 7.8.2 and create a new project.

2. Download a topographic map of the early twentieth century capturing the area under study. There are several online resources with open-access historical topographic maps from which you can freely download geo-referenced maps (in geotiff or geojpg formats), in particular of the Austro-Hungarian Empire, which included part of modern Ukraine. Such maps can be immediately opened in the project and compared with other cartographic data layers. For example, the site www.oldmapsonline.org/ allows you to search for the required location on the map and view and download historical maps of various scales available in the catalog. To detect the changes in the upper forest boundary, we need maps with a sufficient level of detail, in particular 1:50 000 and more. First, find a map of Pip¹ Ivan Mountain (Maramureş) area with a scale of 1:20 000 published in 1940. To do this, use the interface of www.oldmapsonline.org/ website or download the map directly from <http://igrek.amzp.pl/details.php?id=11789222>, where you need to click on the first link (on the map) and specify the path for download. As a result, you will get a geo-referenced map.



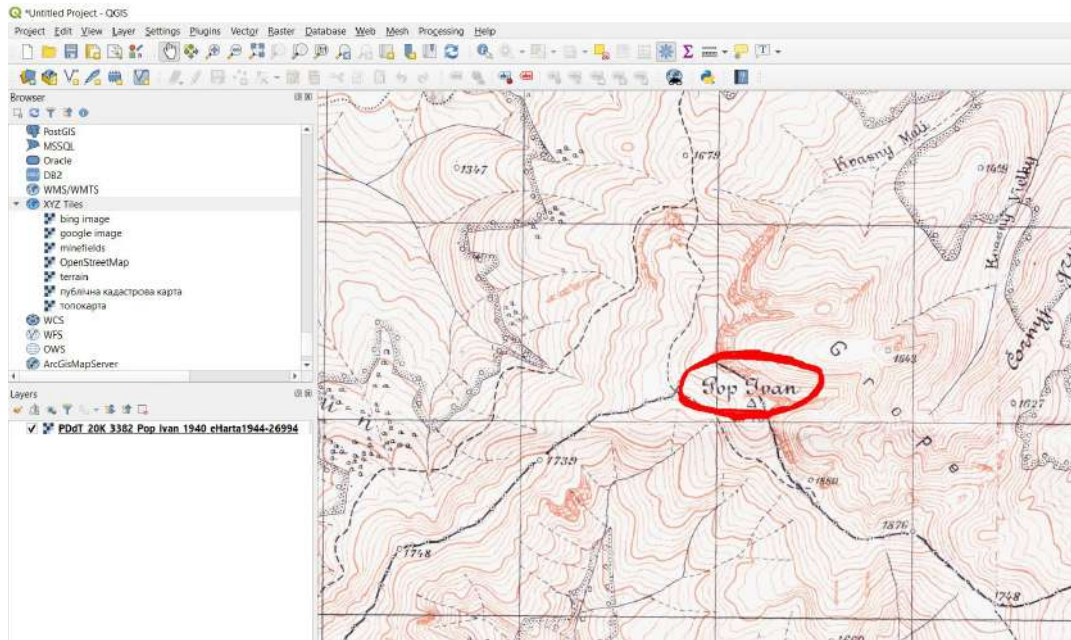
The screenshot shows the MAPSTER website interface. At the top, there is a navigation menu with icons for 'Strona główna', 'Wyszukiwarka', 'Skorowidze', 'Zestawienia', and 'O projekcie'. Below the navigation is the title 'MAPSTER - Szczegóły'. The main content area displays the map ID '11789222 @ România, Lambert-Choleski system, Planurile Directoare de Tragere 1:20 000, /1917-1959/'. Below this is a table with the following metadata:

plik mapy	PDDT_20K_3382_Pop_Ivan_1940_eHarta1944-26994.tif
rozmiar pliku	33389845 (31.8 MB)
godło arkusza	3382
tytuł arkusza	Pop Ivan
adnotacja	geotif, margins trimmed
rok wydania	1940
stan mapy/skanu	dobry
rozdzielczość	300 dpi
uwagi	gereferenced in Stereo70 projection
plik dodano	2016-09-01
wpis edytowano	2016-09-01 05:47:50
ze zbiorów	geo-spatial.org (eHarta)
odnośnik do źródła	Planul Director de Tragere; map id: 1944, geotif id: 26994

Mapstser web platform is a catalog of digital cartographic data available for non-commercial use (link to the resource: <http://igrek.amzp.pl/>).

3. After downloading the map, open it in your project and find Pip Ivan Mountain.

¹ On the digitized topographic map used in this Task, the name of this mountain is Pop Ivan.

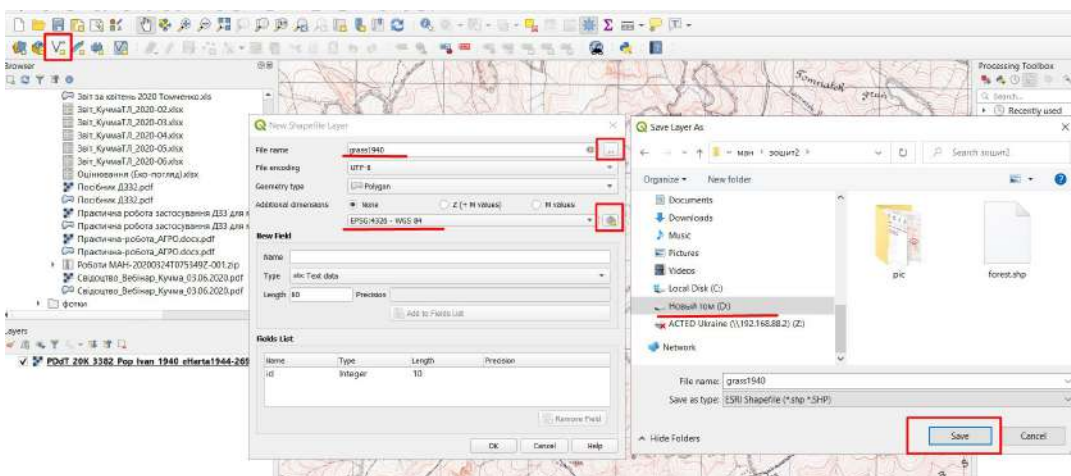


🔍 Check yourself

What is the height of Pip Ivan Mountain according to the topographic map? Find a Wikipedia page about Pip Ivan (Maramures) and see if the height indicated in this article differs. If yes, why do you think?


4. Create a new polygonal vector layer to vectorize the alpine zone (i.e. the zone of the upper forest boundary). From the toolbar, select **New shapefile layer**. In the window that opens, next to the **File name** field, click on the tool to find the required folder to save a new vector layer with selected areas of felling. Enter its name, for example, “grass1940”, and click **Save**.

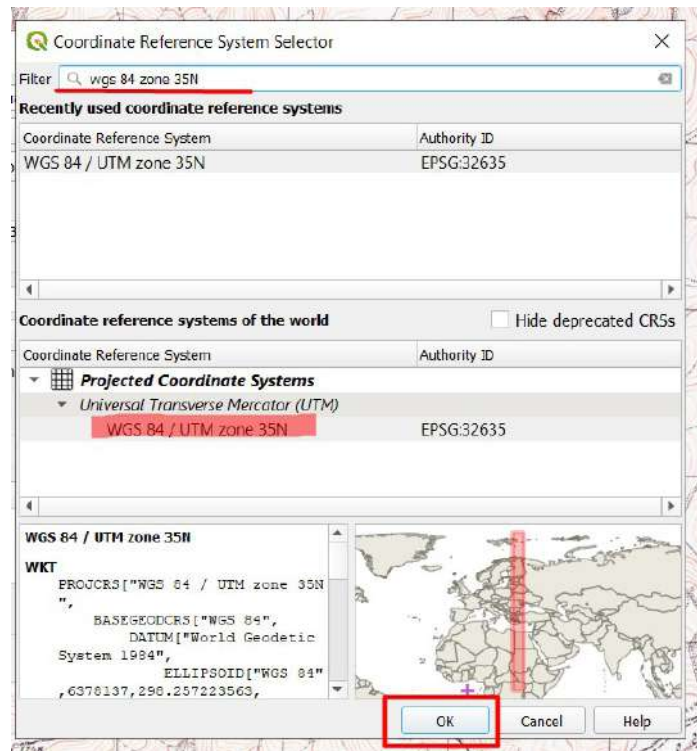
🟢 **Important!** *The name of the thematic layer should be specified in Latin without additional characters otherwise some tools may operate inappropriately (this also applies to the names of folders to which you save your files).*



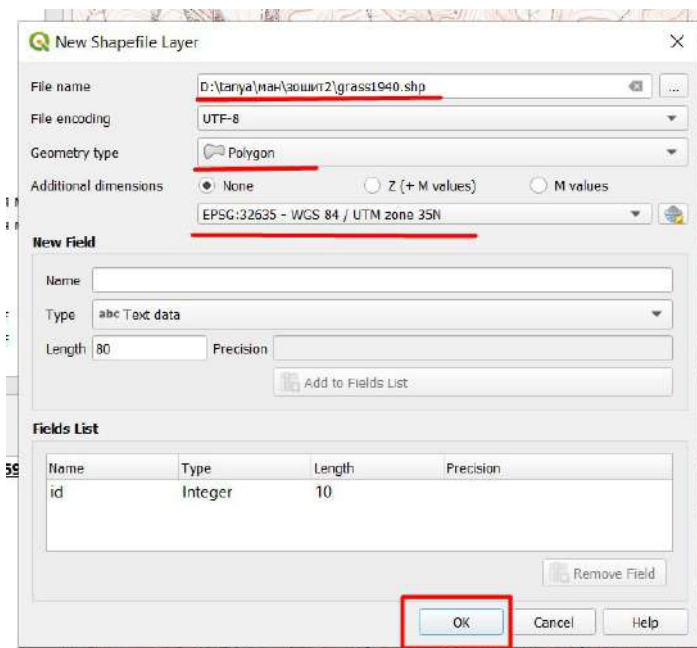
Next, select **Polygon** from the drop-down list under **Geometry type** in the **New Shapefile Layer** dialog box because the shape and area are important for forest display on the map.

Below the geometry field, there is another drop-down list containing the names of the map projections. Expand the list and select the **WGS 84 / UTM zone 35N** projection. This list contains projections

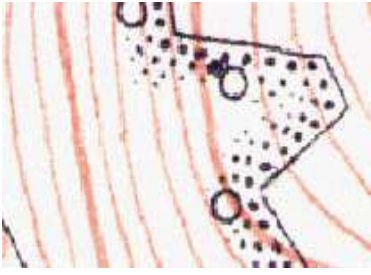
that are most commonly applied by the user; if you haven't specified a projection yet, it may be missing in the list. In this case, click on  and in the window that opens, write *WGS 84 / UTM zone 35N* in the *Filter* field.



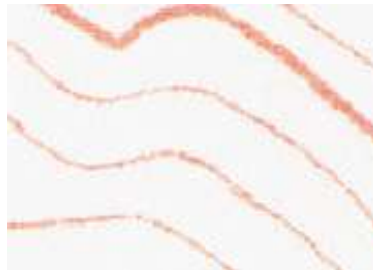
As a result, this projection will be displayed in the *Coordinate Reference System* window; you need to select it and click *Ok*.
Next, in the window to create a vector layer, click *Ok*, and a new layer will open in your project.



5. Now take a look at the map and determine how the forest boundary is marked on it. In this series of historical Austro-Hungarian maps the following symbols are used:



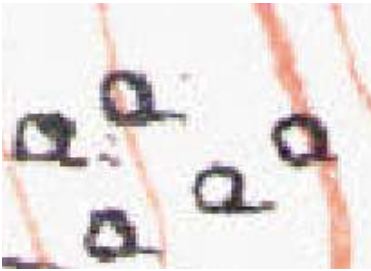
Forest boundary (the forest is located on the side of the points and circles)



Terrain isolines (horizontal)



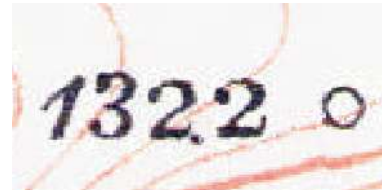
Rocks and rocky cliffs



Sparse forests



Names and height of peaks





Height symbols

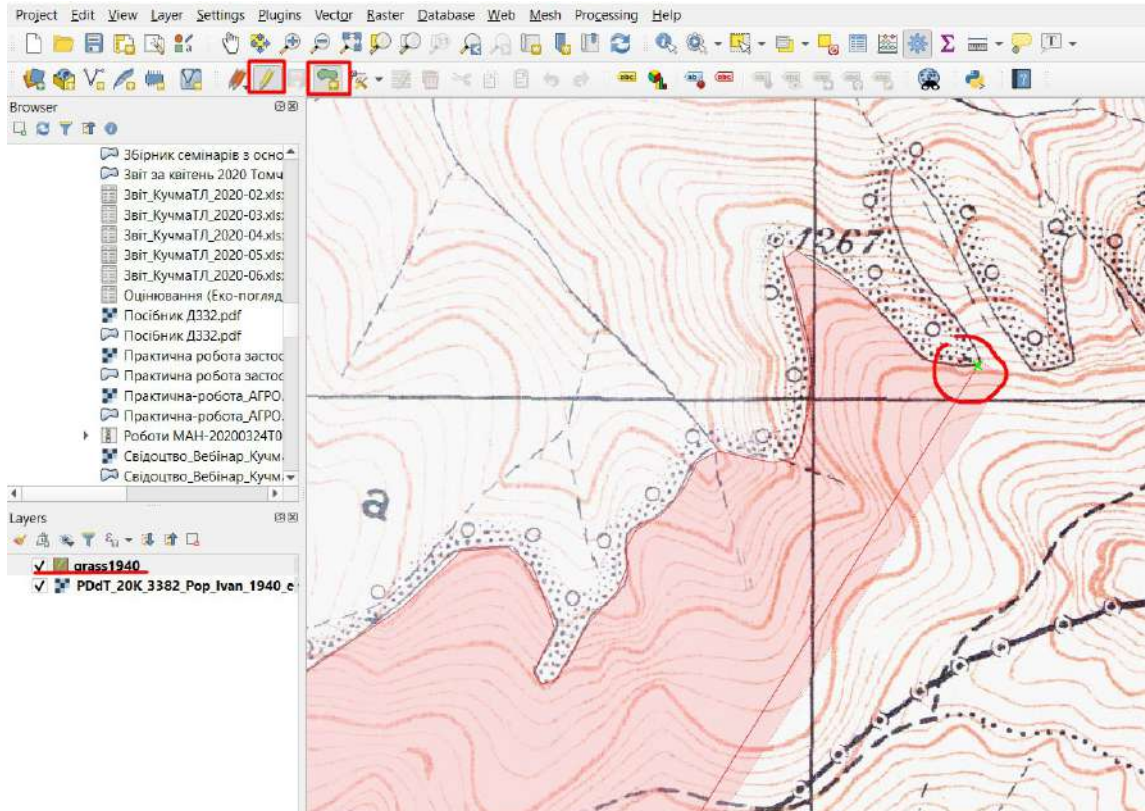


Paths, roads

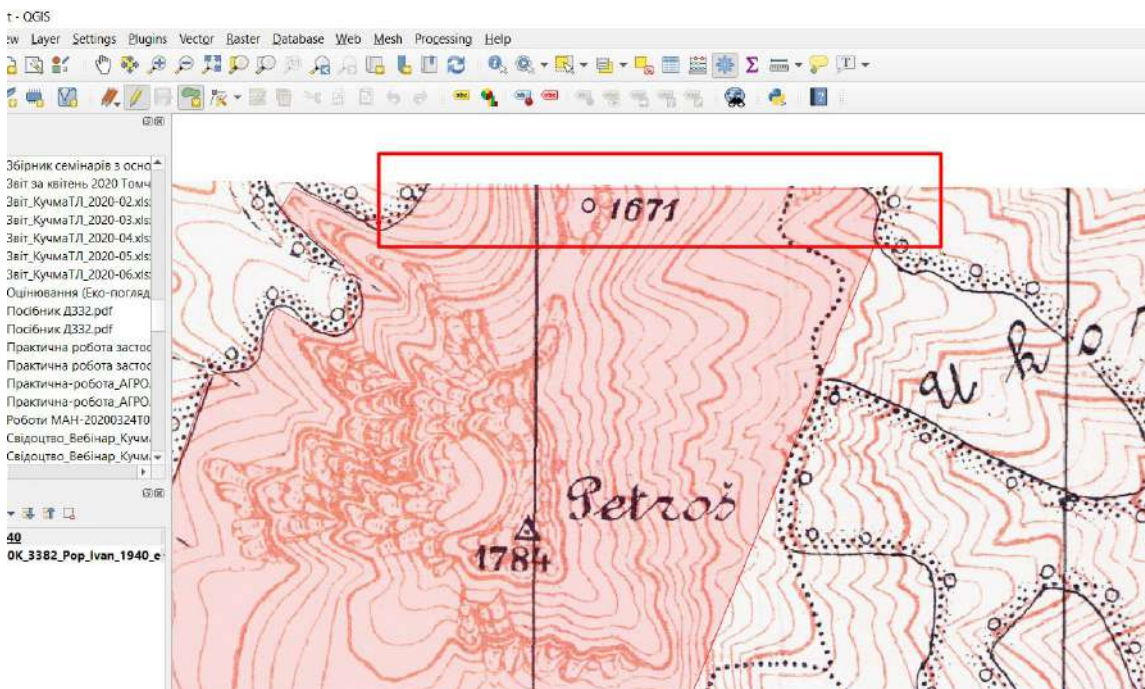
6. In QGIS, vector layers are edited with standard tools, as well as additional tools. By default, additional tools are not displayed in the top toolbar, therefore, you need to expand them first.

7. So, first activate the vector layers editing mode: select the layer you want to edit (in our case, "grass1940") in the Layers tab, left-click on it, and click on the **Toggle Editing**  tool. The icons of the tools appear grey because they are not active at first. This toolbar contains many useful tools, but first, you need to know the main thing – how to start and finish drawing the polygon.

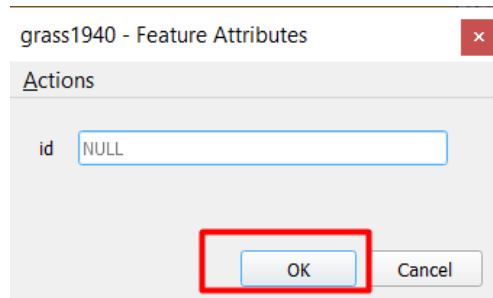
You may notice that with enabled editing mode, some tools have colored icons, i.e. they became active. One of them is a tool for digitizing polygons, **Add Polygon Feature** . Select it and start delineating the boundaries of the alpine zone (end of the forest).



You can move the map during vectorization by holding down the mouse wheel or by using the left/right/up/down keys on the keyboard. The entire boundary of the alpine zone can be vectorized as one polygon. You can also zoom in/out the map while editing with your mouse wheel. At the top and bottom of the map, the forest boundary is broken. In this example, you can simply draw a line along the top of the map and continue digitizing, as shown below.

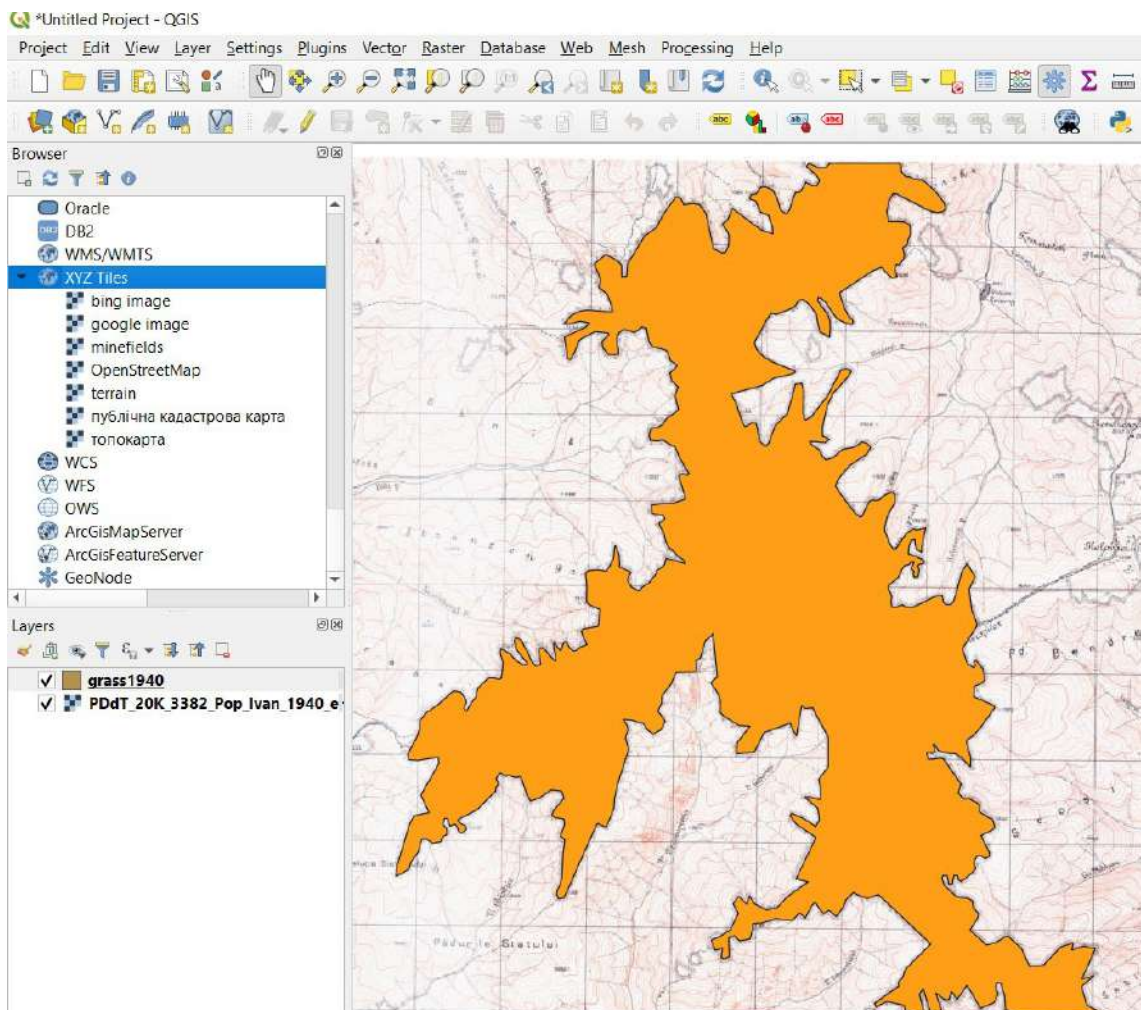


To finish digitizing, right-click, and in the window that appears, click *Ok*.

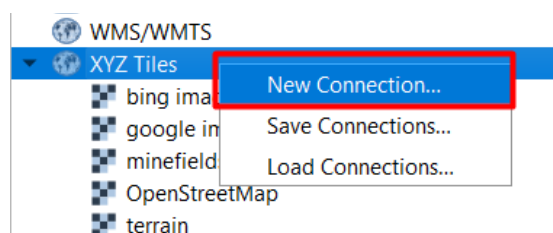


Next, click the **Save**  tool, and then click **Toggle Editing** . If changes have not been saved before selecting this feature, a window will appear asking you to save the edited data. Click **Save** if you want to save all changes.

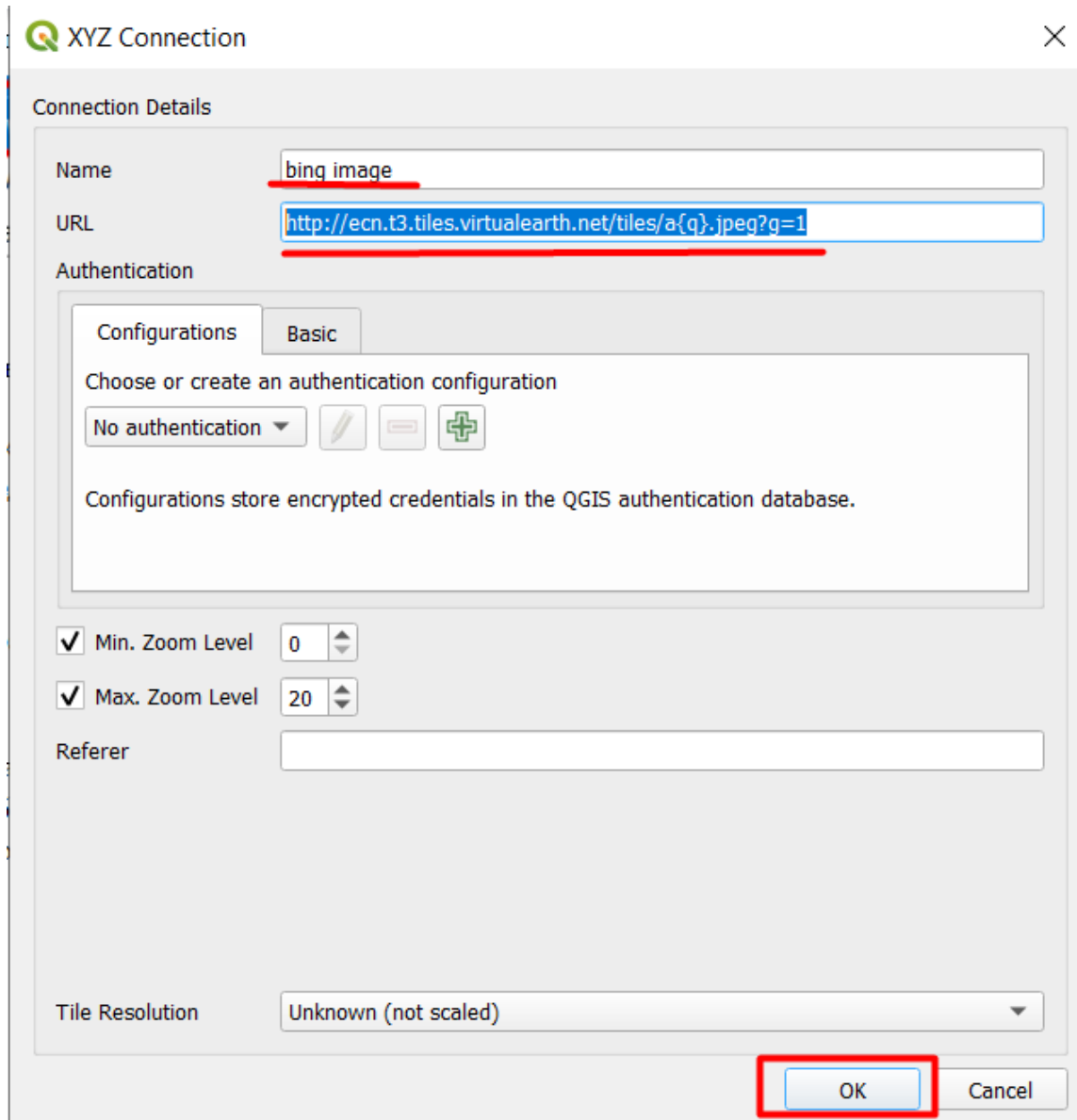
As a result, a vector layer will be created as shown in the figure below.



1. Connect a layer with contemporary satellite imagery of high spatial resolution to see how the forest boundary has changed. To do this, right-click on the **XYZ Tiles** menu in the **Browser** panel and select **New Connection** from the drop-down menu.

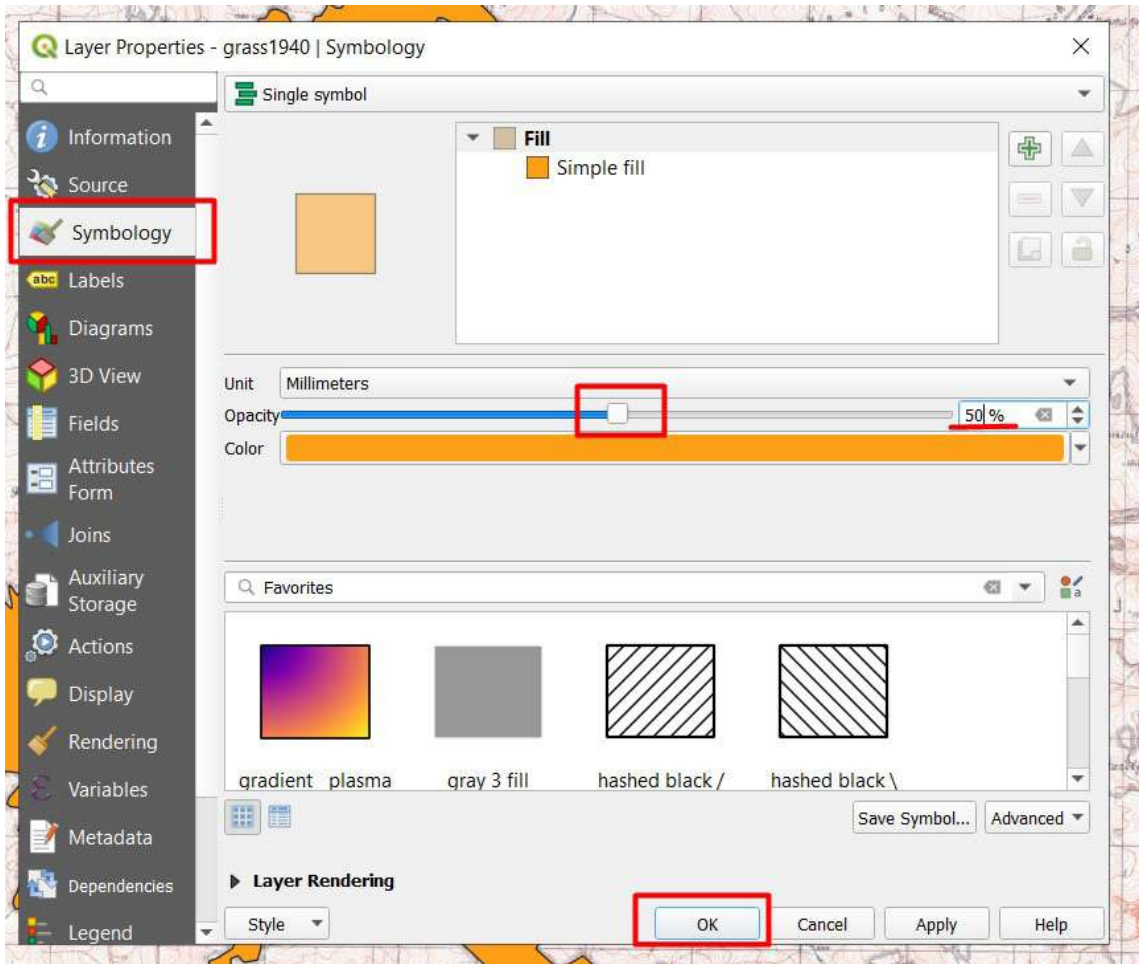


In the window that opens, specify the name of the new connection, e.g. "bing image", in the *Name* field, and enter <http://ecn.t3.tiles.virtualearth.net/tiles/a{q}.jpeg?q=1> in the URL line and click *Ok*.

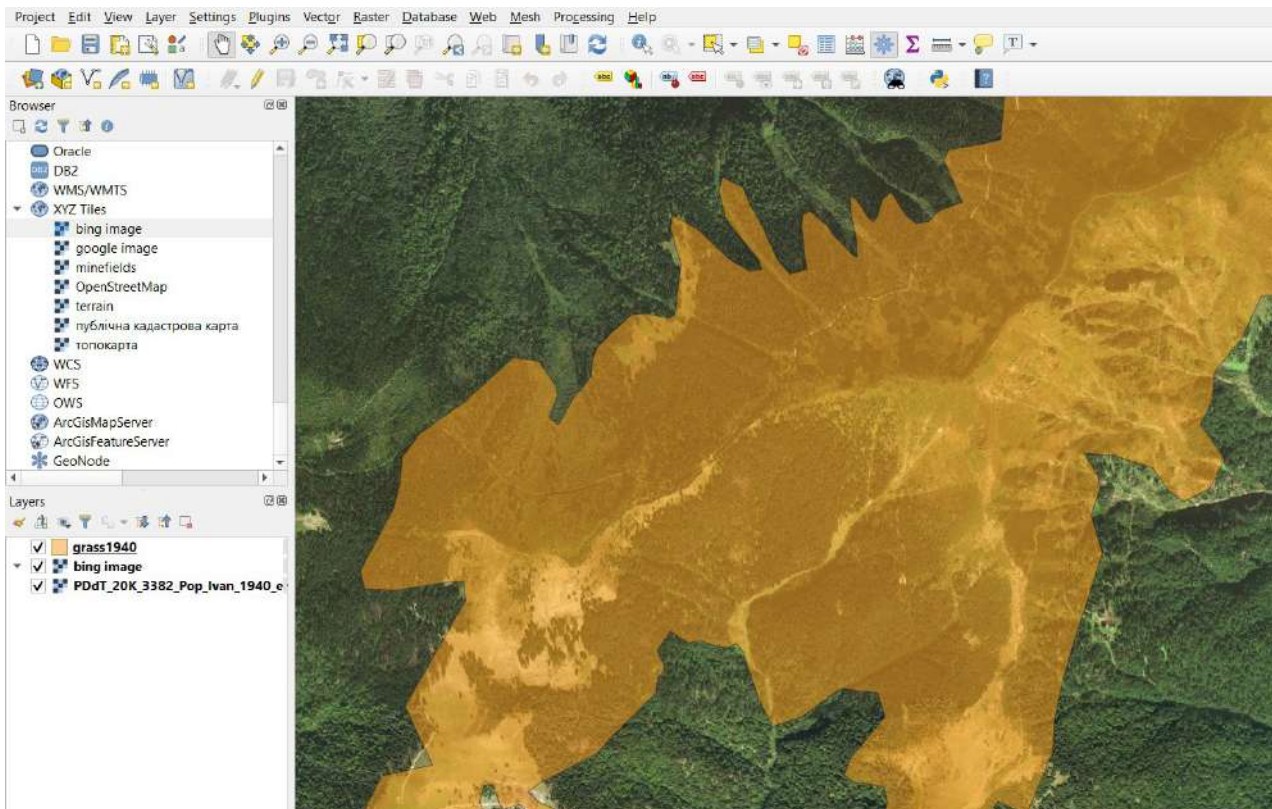


The new *bing image* layer will appear in the *XYZ Tiles* menu list on the *Browser* panel; double right-click to add it to the project.

1. Drag the "grass1940" vector layer in the Layers so that it appears the first in the list of layers and is not overlapped with other layers, and make it transparent using the *Properties / Symbology* window.



As a result, both the satellite image and the boundaries of the alpine zone must be visible at the same time.



? Check yourself

Analyze whether there is a shift in the upper forest boundary. Is the upward shift of the forest boundary occurring evenly? Why do you think so?	
--	--

Scan the QR-code below to watch a video tutorial on the performance of this Task.



3. Combination of Bands – Detecting Spectral Patterns of Features

3.1. Highlighting the Rainforest Boundaries on Mount Liko in Mozambique

Case

It's the 21st century, and probably each of you is sure that the epoch of geographical discoveries is well behind, and the world has been fully explored. Indeed, it is very unlikely that people will be able to find an area that has not been bulldozed, damaged by fire, exploited for mining, deforestation, or simply littered. However, in the spring of 2018, a researcher from Wales, Dr. Julian Bayliss, led a team of 28 people who started on an expedition to Mount Liko in Mozambique. This mountain has almost vertical inaccessible slopes, and the forest on its top is completely isolated from human impact. The scientist made his geographical discovery – he spotted a forest hidden from the human eye on the Google Earth satellite images.¹

Task

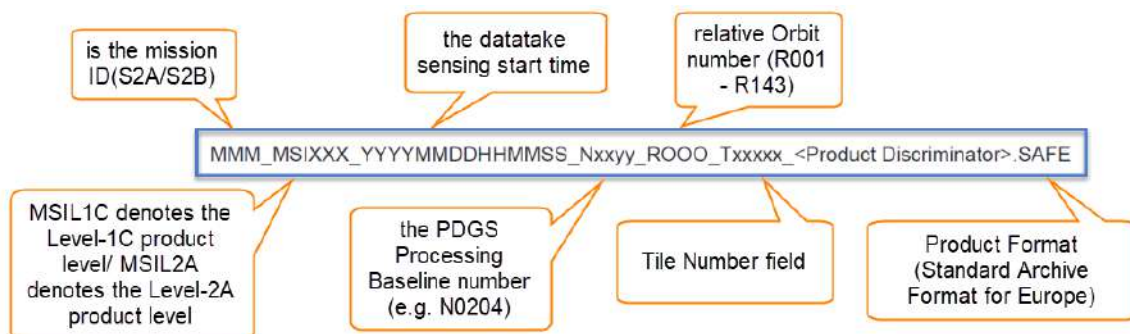
Using a satellite image, determine what type of forest is on Mount Liko (Mozambique), calculate the approximate area of forest on the mountain, and assess the value of ecosystem services it provides to the region.

Task performance algorithm:

1. Enable the *QuickMapServices* plug-in and download the *OpenTopoMap*.
2. Merge the bands in natural colors.
3. Save a map area near Mount Liko.
4. Merge bands B12, B8A, B04 (*SWIR, Vegetation Red Edge, Red*).
5. Calculate the forest area on the mountain using the *Measure* tool.
6. Calculate the cost of the ecosystem services for this forest area.

Instructions for self-guided work:

1. Data for this Task can be downloaded from <https://cutt.ly/YGZV198> or using EO Browser (Sentinel-2a image dated November 12, 2019, of the Mount Liko area).
2. The name of the Sentinel image folder may seem scary as it contains many numbers and letters, which, at first glance, are not clear and complex. The Figure below explains what is encrypted in this mysterious code; all Sentinel-2 products get their names according to a similar convention and provide details of the satellite, date of the image, height of the orbit, etc.



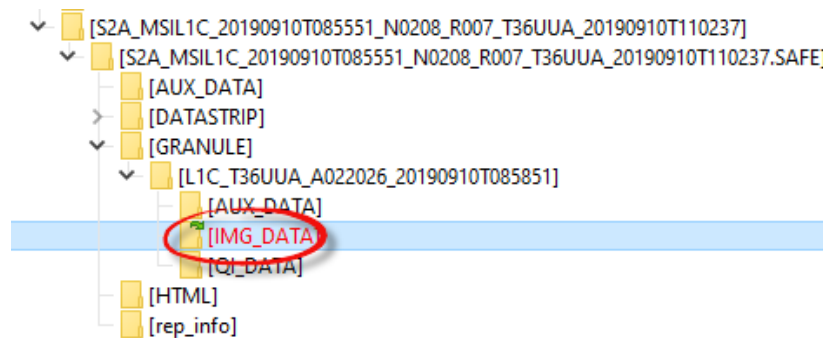
¹ URL: www.theguardian.com/world/2018/jun/17/mozambique-mount-lico-rainforest-new-species

URL: www.theverge.com/2018/8/28/17770988/google-earth-mount-lico-discovery-secret-mozambique-rainforest-expedition

? Check yourself

Interpret the name of the Sentinel satellite image that we will use in this task?	
---	--

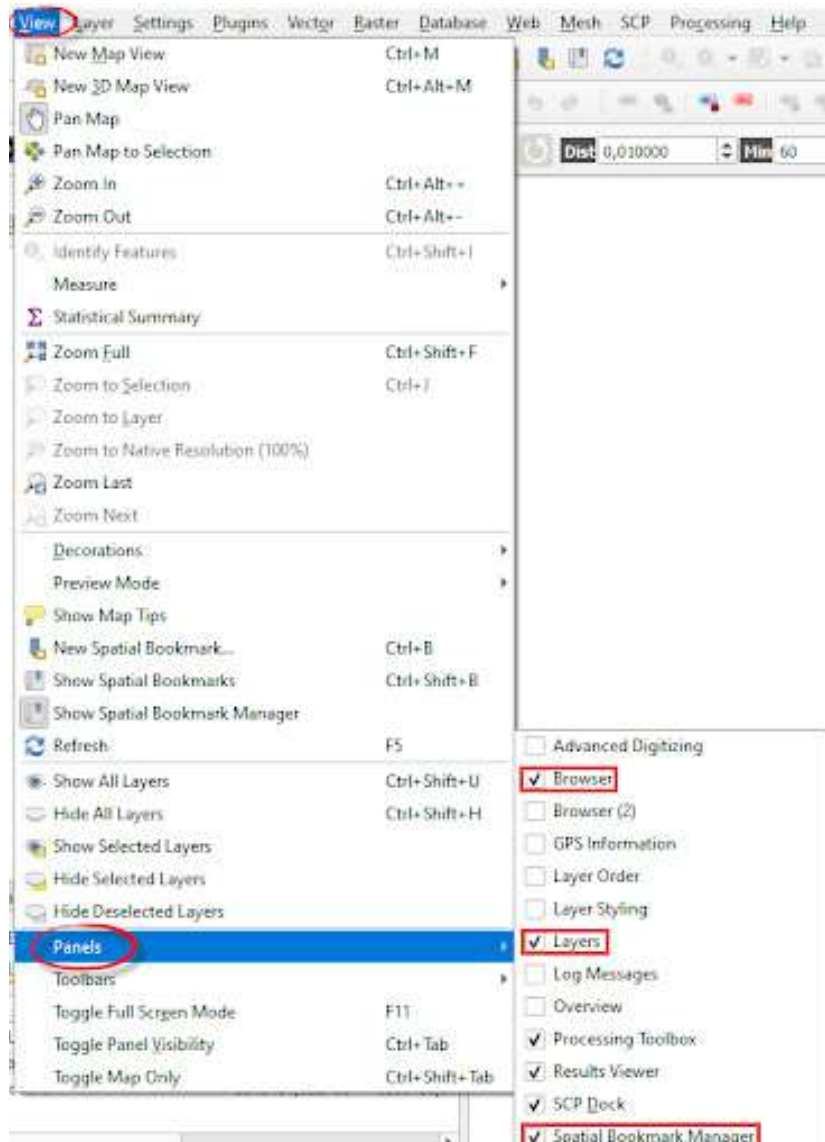
It is important to note that the Sentinel-2 image archive includes many folders and accompanying data, while the bands we will work with are contained in the “IMG_DATA” subfolder (in jpg format). The path to this folder is shown in the Figure below.



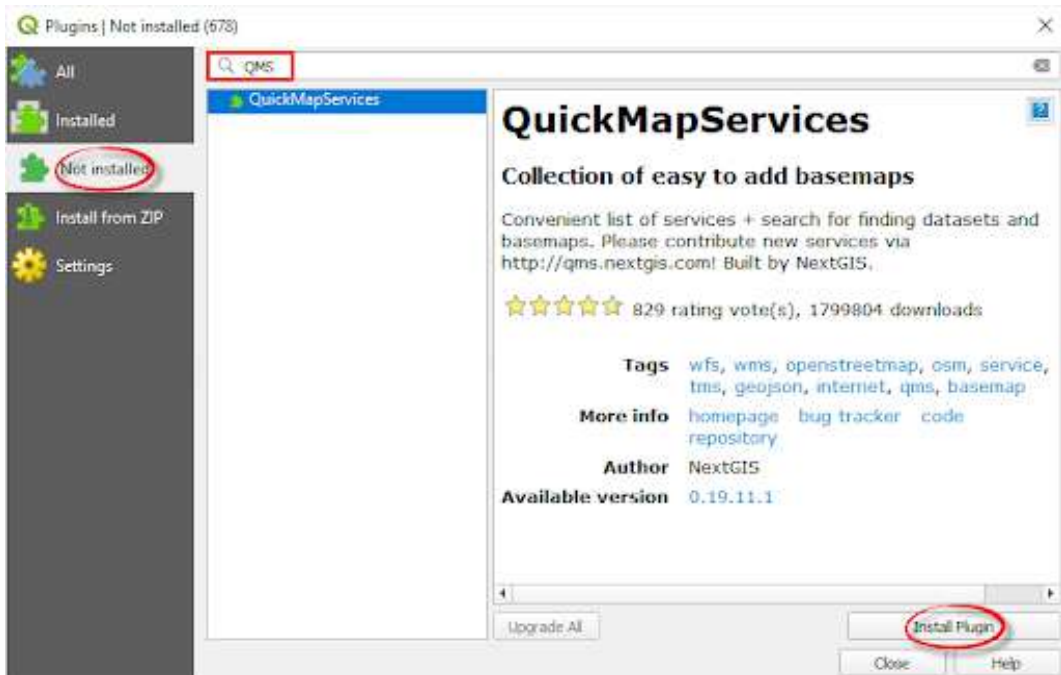
If you are interested in finding out the purposes and content of other folders, we recommend reading the Sentinel-2 User Handbook (p. 60): https://earth.esa.int/documents/247904/685211/Sentinel-2_User_Handbook.



We hope that the previous tasks did not cause any difficulties and you successfully found the right folder. So let's start performing the Task in QGIS.

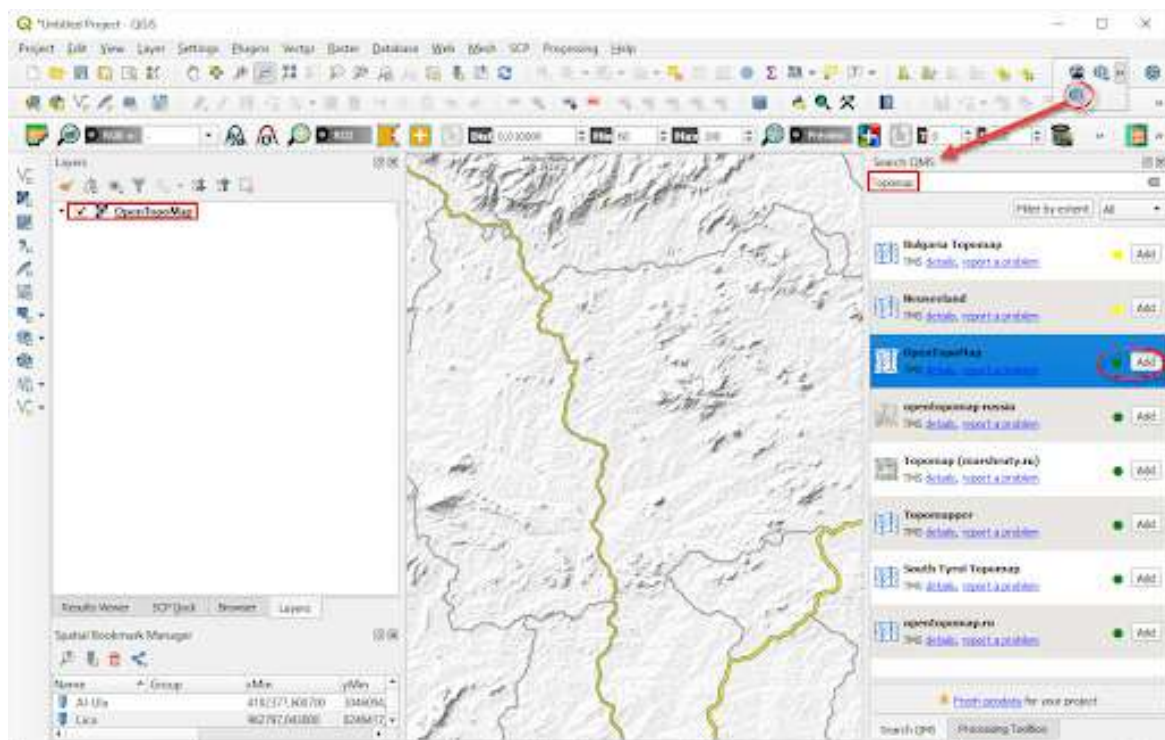
3. Open QGIS application and create a new project. Make sure that the **Browser**, the **Layers**, and the **Spatial Bookmarks** panels are open in your project. If they are not available, select **View** → **Panels** from the top menu and tick the boxes next to **Browser**, **Layers**, and **Spatial Bookmarks**.



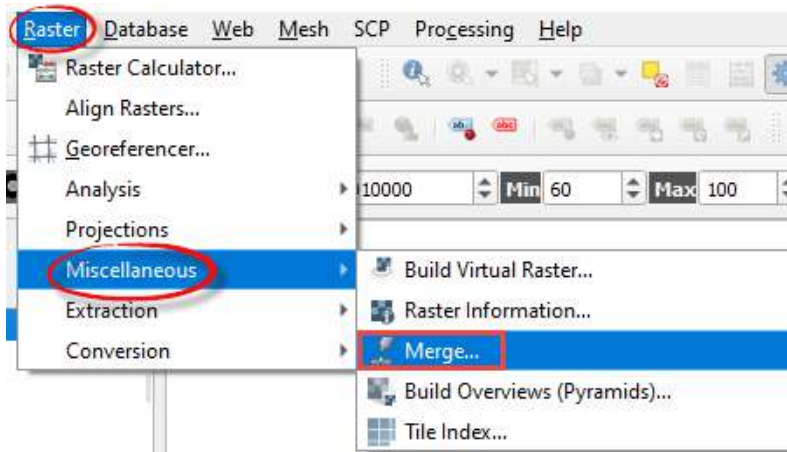
The first step is to add the *QuickMapServices* plugin. To do this, select the *Not installed* tab under *Plugins – Manage and Instal Plugins ...* from the main menu. In the search bar, start typing the plugin name, "QuickMapServices" or simply "QMS", and it will automatically appear in the list at the bottom of the window. Select this plugin from the list by left-clicking, and brief information about it will display automatically. Read this information, click *Install Plugin*, and close the dialog box. Once installed, the plugin will appear on the *Installed* tab.



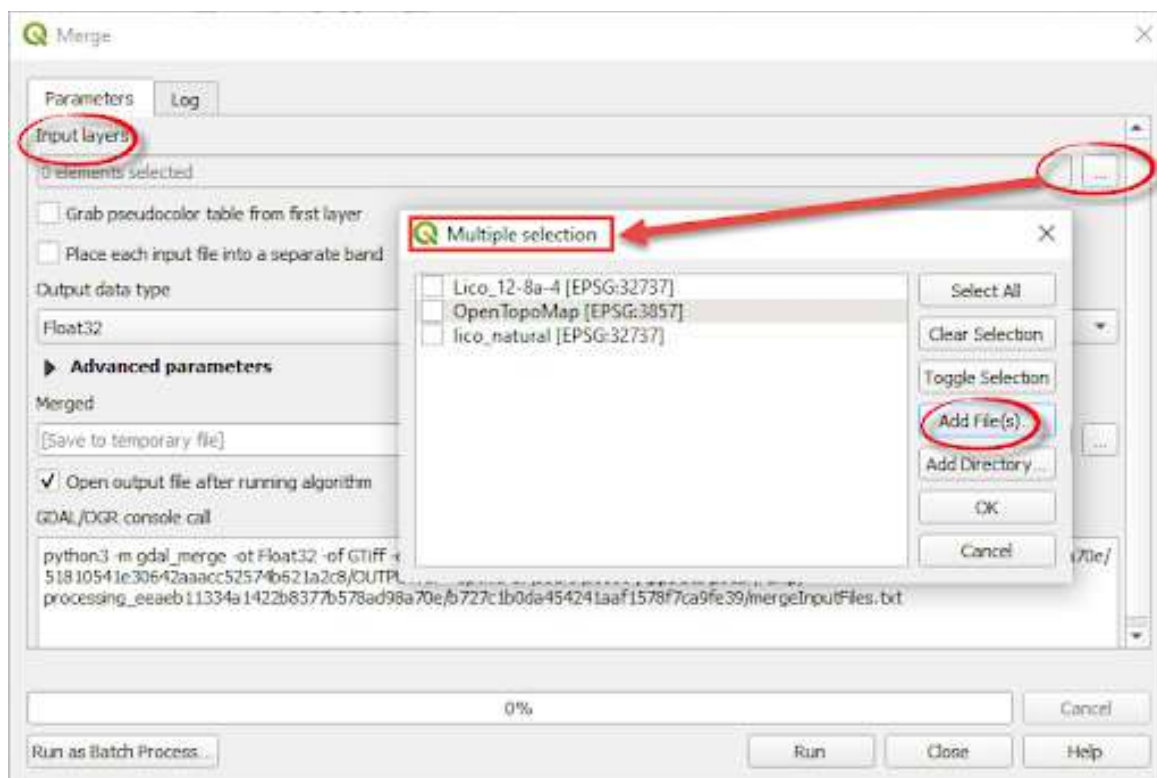
QuickMapServices plugin will now be located in the top menu **Web**, and new buttons   will be added to the toolbar. Click **Search QMS** if you have not enabled it yet, and a new panel will be added to the QGIS work window. In this panel, type “Topomap” in the search bar, and in the list that opens, select **OpenTopoMap** and click **Add**. As a result, a topographic map of the world will be added to your project as a new layer.



4. The next step is to merge the bands, i.e. combine the black and white bands of the satellite image into one color image. Click **Raster** in the top menu and open the **Miscellaneous** tab → **Merge**.

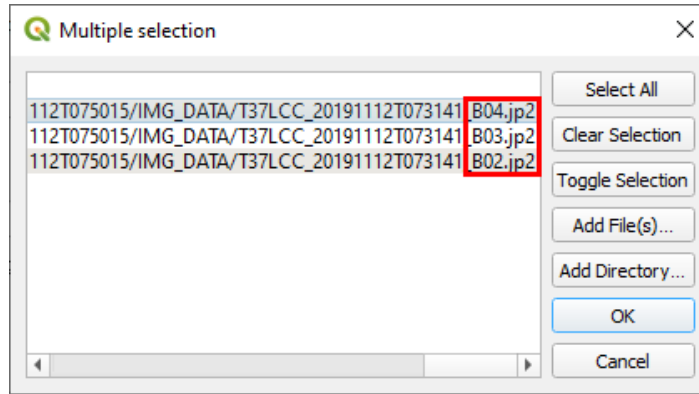


The *Merge* dialog box opens up, where you shall specify the bands you want to merge in the *Input Layers* field. To do this, click on the icon next to *Input Layers*, and click *Add files* under *Multiple selection*, find the folder that contains saved image bands, and select the desired bands.

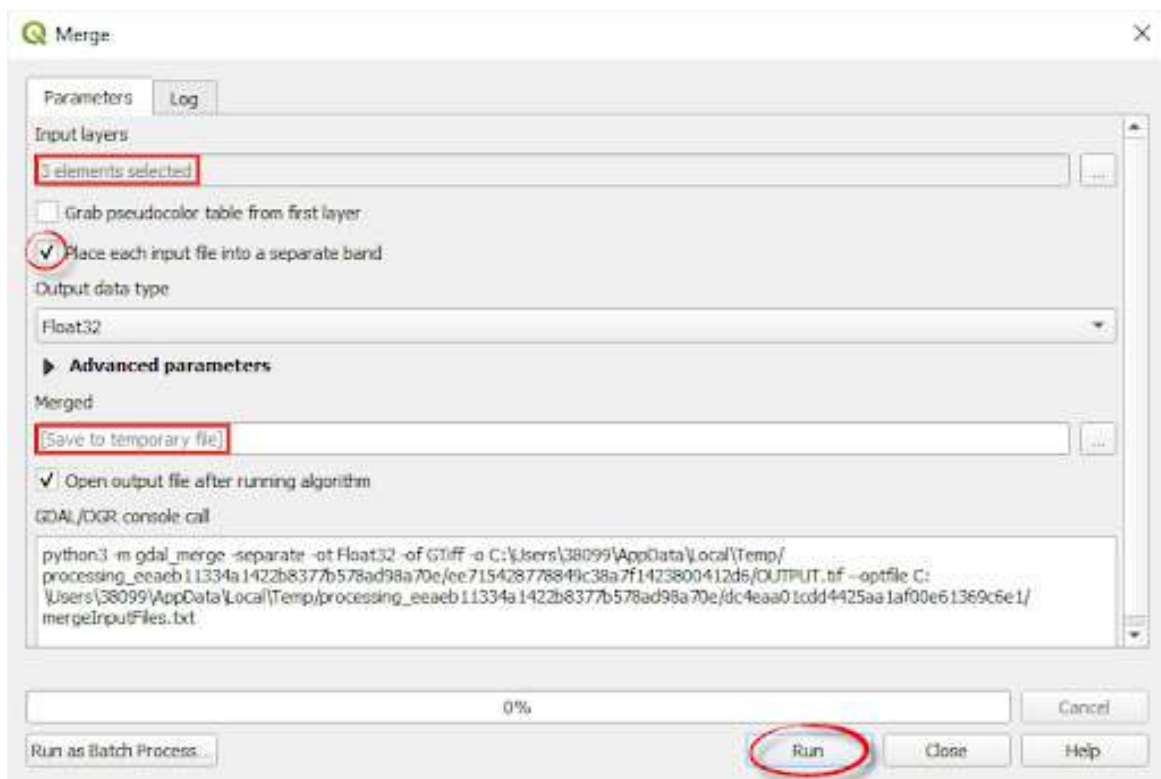


5. First, create a true-color image using B04, B03, B02 bands from the “IMG_DATA” folder of the Sentinel archive. One of the differences between the Sentinel 2a level archive and archives of other levels of processing is that all bands in the “IMG_DATA” folder are grouped according to spatial resolution into three folders: the first has 10 m resolution bands, the second – 20 m, and the third – 60 m. Bands B04, B03, and B02 are contained in the first folder “R10m”.

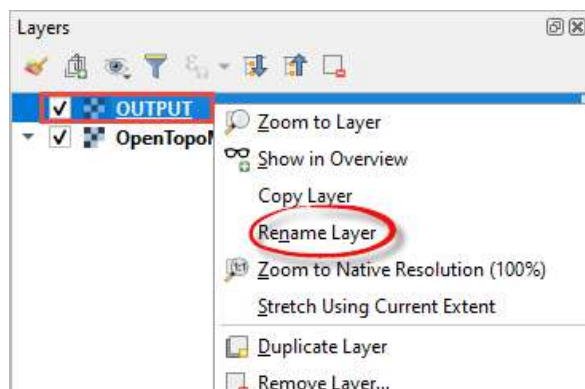
You can select three bands at once by holding down the “Shift” or “Ctrl” key on the keyboard. Then you need to click on *Open*, and the selected images will download to the *Multiple selection* window. It is important to select the bands in the following sequence: R (red – B04), G (green – B03), and B (blue – B02). Therefore, you need to drag the bands in that sequence, B04, B03, B02, and click *Ok*.





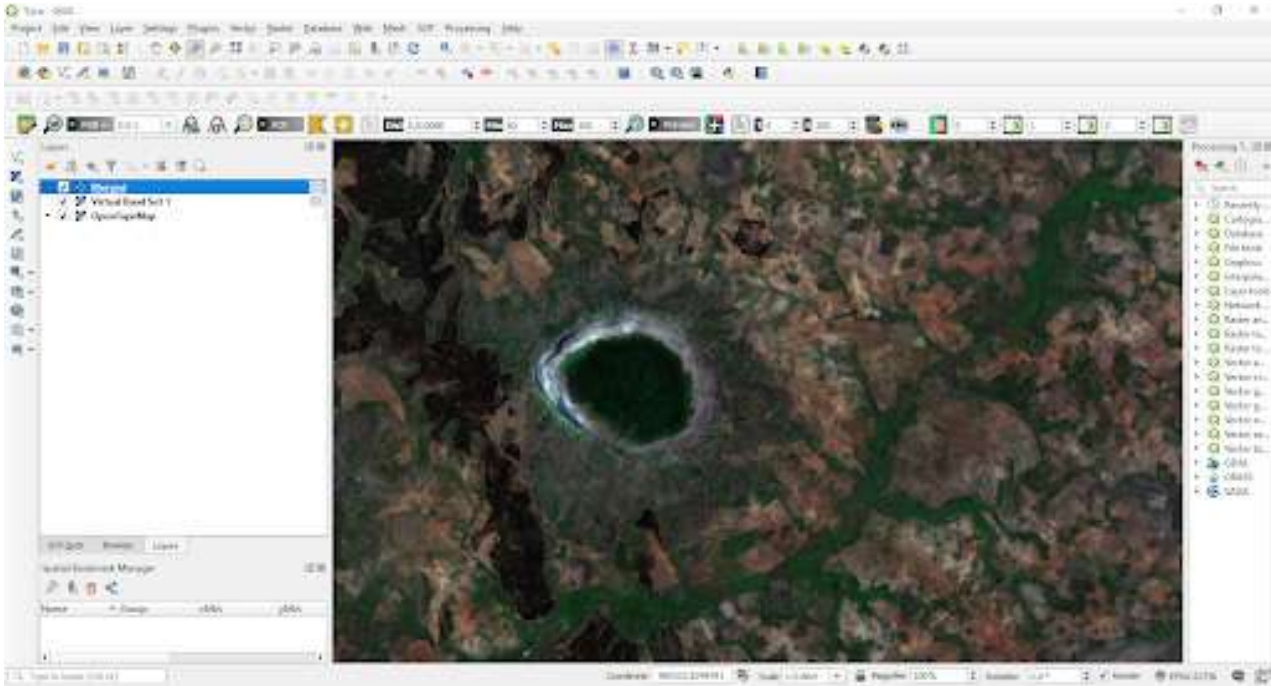
As a result, the number of selected bands (i.e. 3) will be displayed in the *Merge* window in the **Input layers** line. Next, you need to check the box next to *Place each input file into a separate band*. Leave the *Merged* field blank (in this way we create a temporary file that will not be stored on your computer but in this project only), and click **Run**.



The created band combination will appear as a raster layer named “OUTPUT” in the **Layers** panel. Not to confuse the files, change the layer name to “4-3-2”. To do this, right-click on the layer, select *Rename layer* from the menu that opens, and write a new name “4-3-2”.

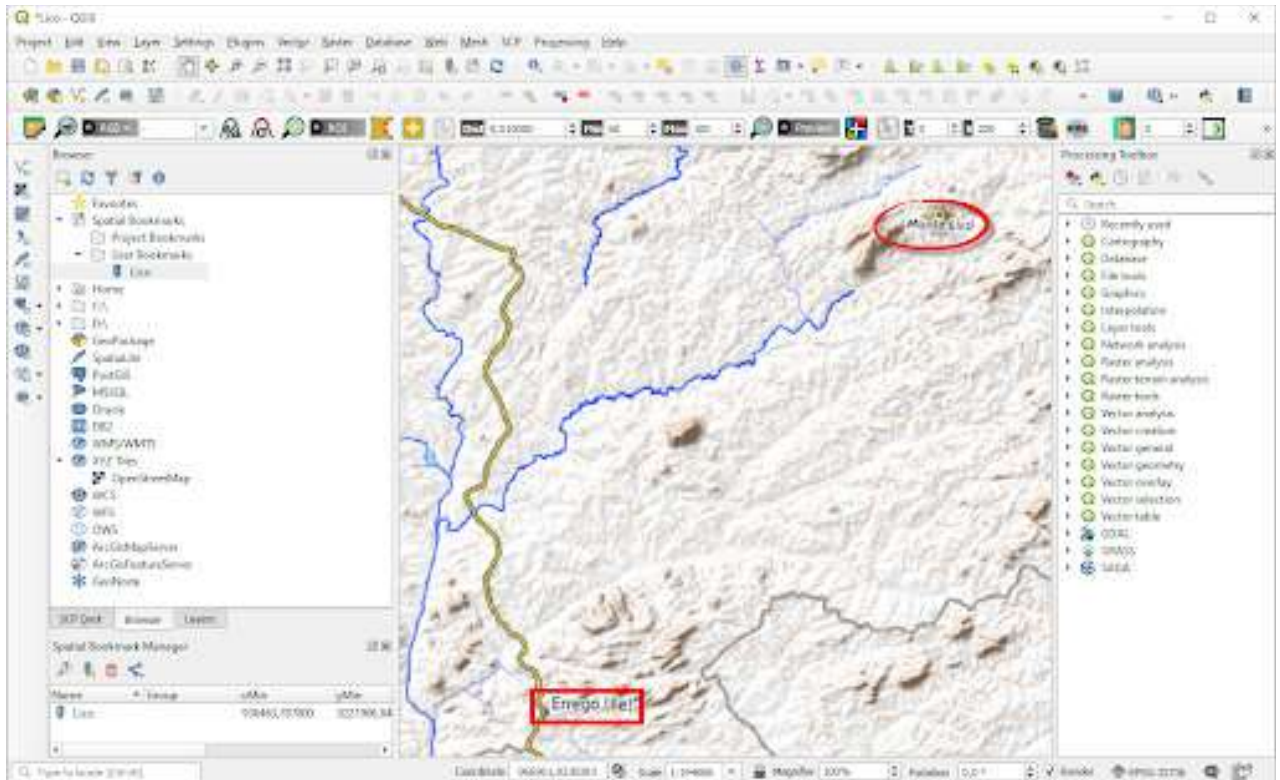


Zoom to the borders of the created raster layer, right-click on the layer name in the **Layers** panel and select **Zoom to Layer**. If you are not satisfied with the colors in the image, you can improve it with the buttons  located on the toolbar under **Raster Toolbar**. If you can't find these buttons, it means that **Raster Toolbar** is not switched on in your QGIS project. To enable it, select **View → Toolbars** from the top menu and check the box next to **Raster Toolbar**. First, select the appropriate raster layer with your left mouse button in the **Layers** panel, click the buttons  and experiment. The image should change. Leave the visualization you like best.




In a true-color image, all features look very similar to what a person would see from an airplane window, i.e. all greenery appears in shades of green, open ground in shades of brown, and bodies of water are blue.

6. Turn off the image of the created raster layer by unchecking the box next to the layer name in the **Layers** panel, and find Mount Liko on the topographic map. Use the city of **Errego (Ile)**, which is located southwest of the area under study, the transport network, and the highlands as references on the topographic map.



If you managed to find a mountain on the topographic map, turn on the satellite image again in the **Layers** panel and make sure that it is indeed a mountain with a forest.

Not to search for Mount Liko every time, we advise you to save this part of the map to bookmarks – you will be able to return to it easily in the future. To do this, find the **New Spatial Bookmarks** button  on the toolbar or use the Ctrl + B keyboard shortcut to specify the name of the bookmark and click **Save**.

Return to the created true-color combination and pay attention to the color and shape of the forest on Mount Liko. The area around the mountain looks like a mosaic of small farms, tea and eucalyptus plantations, and forests, while the forest on the mountain appears as a holistic, non-fragmented area that contributes to the development of biodiversity in the territory.

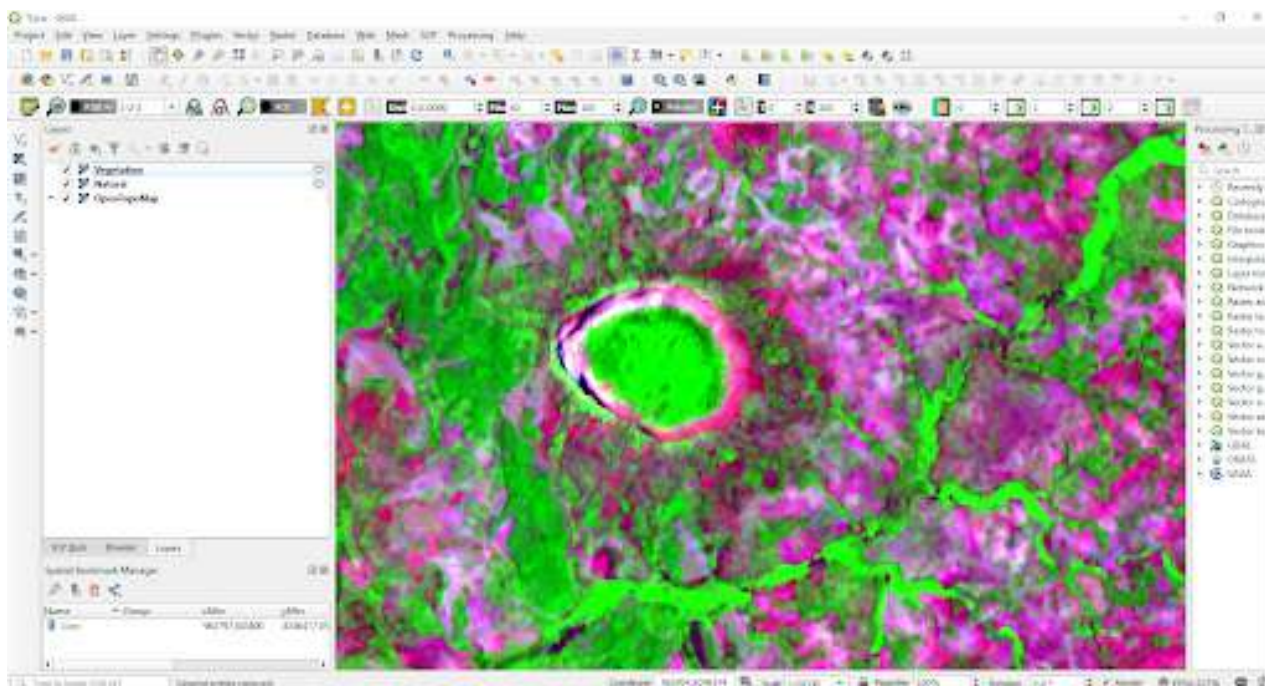
Check yourself

Specify a True color combination for the Landsat 8 satellite	
Why do you think the vegetation in True color combination is green?	

7. Let's download now another combination, namely: B12, B8A, B04 (**SWIR, Vegetation Red Edge, Red**), which is useful for the study of vegetation, because the reflectivity in SWIR is mainly due to the moisture content in the leaves or soil. Thus, healthy vegetation with high moisture content, as well as coastal areas will be bright green, while arid areas appear dark green, coniferous forest – deep green, and deciduous forest – bright green.

To download a B12, B8A, B04 image, repeat the steps described in paragraph 5 above using the **Raster – Miscellaneous → Merge** menu. However, select bands B12, B8A, B04, respectively (**remember that it is important to keep the sequence of bands**). Look for bands B12, B8A, B04 in the “R20m” folder of the Sentinel image archive. The path to this folder looks like this:

S2A_MSIL2A_20191112T073141_N0213_R049_T37LCC_20191112T100427.SAFE → GRANULE → L2A_T37LCC_A022926_20191112T075015 → IMG_DATA → R20m



Rename the added raster layer to “12-8a-4” and adjust its image using  buttons.

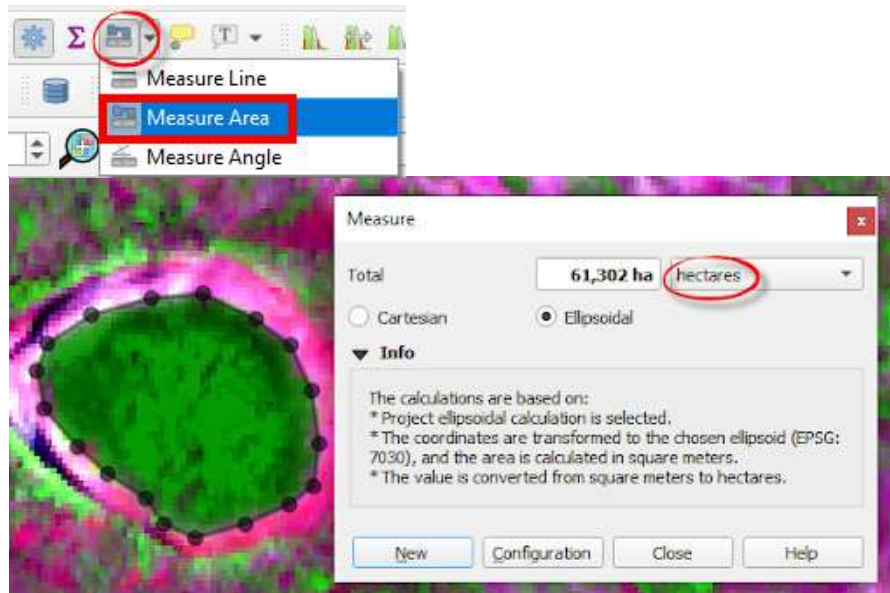
Have you noticed the color changes in the image? All deciduous vegetation appears in shades of bright green, while coniferous trees are dark green. Such appearance of vegetation in this combination of bands is due to the peculiarities of reflection and absorption of electromagnetic radiation. This is described in more detail in the *Fundamentals of Remote Sensing* Guidance Manual, and we will only remind you that photosynthetically active vegetation strongly absorbs red light and reflects near-infrared radiation. Therefore, to determine the species composition of forests, the near-infrared band is most often used, in which the crowns of deciduous trees have a much higher reflectance coefficient than those of conifers.

If you have been attentive at Geography classes, you know that the mountain area of Mozambique is covered with tropical forests, which consist of 4-5 layers, and most plants have large evergreen leaves because in this country, there is neither cold nor drought seasons, which normally cause falling leaves off trees. Thus, we have found out why the forest on the mountain is bright green – because it is deciduous.

8. Forest on Mount Liko is like a “time capsule” because it is difficult to access due to the steep slopes of the mountain. Preservation of this forest will benefit local communities that cause damage to the surrounding forests by burning and cutting them down which in the long run may lead to deforestation of the entire region. Let's measure the forest area on Mount Liko and estimate its benefits.

You can measure the area by selecting the **Measure – Measure Area** button from the toolbar. Zoom to Mount Liko and measure the area in hectares by drawing the polygon that includes the forest land. To create a polygon, left-click on the perimeter of the forest, and to complete the drawing, right-click at the last vertex.

The resulting area will depend on the accuracy of the polygon drawing and the calculation method – **Ellipsoidal or Cartesian**. We advise you to experiment with different options.



9. Having calculated the rainforest area, we can assess the value of ecosystem services it provides to the region.

Ecosystem services are benefits to humans provided by the wild nature (material assets – berries, mushrooms, water, wood; abstract services such as recreational, aesthetic support for global photosynthesis, biodiversity, etc.). These services are valued in monetary units to show that everything that nature provides us has a price. In general, it is not always easy to calculate the value of ecosystem services, because some of them are very abstract and we cannot assess all aspects, but let's try. According to the study by L. R. Carrasco, T. P. L. Nghiem, T. Sunderland L. P. (2014) <https://www.sciencedirect.com/science/article/pii/S000632071400295X>, the average value of ecosystem services per hectare of rainforest is \$ 1,312 per year, and the maximum – up to \$ 9,000 per year (the value varies depending on the condition of the forest, etc.). .

We suggest that you calculate the value of ecosystem services for the studied forest by multiplying the forest area by the average value of ecosystem services (\$ 1,312 per year). Enter the result in the Table below.

Check yourself

Specify the area of the forest massif (hectares).	
Specify the value of forest ecosystem services on Mount Liko (\$ per year).	

Scan the QR-code below to watch the video tutorial on the performance of this Task.



3.2. Delineating the Boundary between Coniferous and Deciduous Forests near Lisovychi Village, Kyiv Oblast

To see another type of forest and learn how to distinguish between coniferous and deciduous forests, consider the following case.

Forest management in Ukraine involves commercial development based on the economic assessment of the forests and their use as a source of wood for profit. Therefore, quite often instead of the native species characteristic for the felled area, the most productive tree species or even alien invasive (or simply invasive) species are planted.

Invasive species are alien species, which spread has led to threats or adverse impacts on biodiversity.

Keep in mind that not all alien species are invasive (for example, they do not include crops, most of which are not native). Invasiveness depends on specific conditions; some alien species are not able to spread widely in Ukraine or lose the competition to local flora and fauna. The threat is posed by those species only that spread rapidly on their own and occupy new territories. Invasive species are a recognized global environmental problem, but most people in Ukraine have not even heard of such a term, so you have a chance to tell them about a very serious environmental danger!

Here are just some examples of invasive species available in Ukraine: common ragweed (*Ambrosia artemisiifolia*), Sosnowsky's hogweed (*Heracleum sosnowskyi*), *Amorpha fruticosa*, *Quercus rúbra*, wild olive (*Elaeagnus angustifolia*), *Ácer negúndo*, Prussian carp, *Robinia pseudoacacia*, *Perccottus glenii*, *Asclepias syriaca*, *Rapana venosa*, sika deer (*Cervus nippon*), common raccoon dog (*Nyctereutes procyonoides*), American mink (*Neogale vison*). If Sosnowsky's hogweed is deemed dangerous because it may cause burns, and all highly allergic individuals suffer from ragweed, did you guess that acacia or deer can be dangerous for flora and fauna, and thereby for humans? In fact, this is true: invasive species have virtually no competitors in Ukraine and are spreading rapidly. At the same time, they displace local species that are disappearing and can no longer grow and propagate themselves in this area.

Unfortunately, invasive species are widely used in our country, and society does not understand the harm they cause. Therefore, it is important to take measures to control the planting of new invasive species and reduce the number of those that are already growing in Ukraine. It is necessary to apply herbicides, carry out selective felling and uprooting; it is also possible to use controlled fires to manage such species or, in the long run, adjust vegetation by planting competing species that can displace existing ones. For example, to plant oaks in an acacia plantation area, which in decades to come should squeeze them out of the stand, or plant wild pears in olive groves.

Case

The forestland near Lisovychi Village (Kyiv Oblast) belongs to the Lytvynivske and Shevchenkivske Forestry Enterprise of the Dymyri Forestry District. This forestland is dominated by coniferous trees, however, the forest cover in this area has transformed recently. There are practically no reserved areas in these forestry districts and most of them are commercial forests intended for clear-cutting. In the logged areas, new tree species are planted or self-seeded. Forestry enterprises determine independently what species to renew. Within the coniferous forest (not a native forest, planted in the 1950s and 1970s), areas of deciduous trees are gradually increasing, in particular planted with *Robinia pseudoacacia* (false acacia), which is an invasive harmful species. *Robinia pseudoacacia* is originated from North America; it has been planted in Ukraine since the 19th century. Plantings of this species in the mentioned above forestland started at the beginning of the 20th century.

Task

Download Landsat-5 image taken on August 14, 2010, and Sentinel-2 image taken on July 19, 2020, of the forestland near the Lisovychi Village (Kyiv Oblast), clip the images along the map extent, perform the classification, and identify changes in predominant forest species that occurred over 10 years.

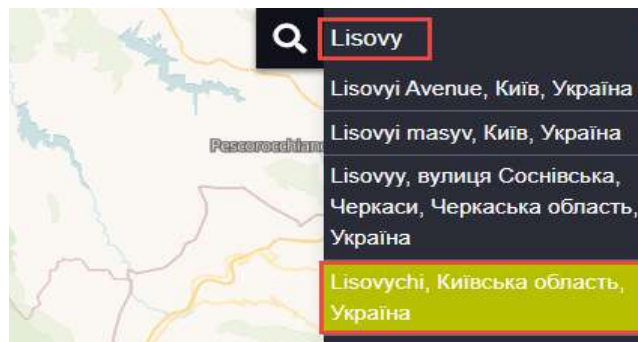
Task performance algorithm:

1. Using EO Browser, download B11, B08, B04 bands for the Sentinel-2 image dated July 19, 2020, and B05, B04, B03 bands for Landsat-5 image dated August 14, 2010.
2. Open in QGIS the B11, B08, B04 band combination for Sentinel-2 and B05, B04, B03 composite for Landsat-5.
3. Clip the raster layers along the map extent.
4. Open the **Google Satellite Hybrid** layer.
5. Install the **dzetsaka** plugin.
6. Create a polygonal vector layer, **Region of interest (ROI)**.
7. Perform the classification.
8. Change the appearance of the classified raster layer from black-and-white to colored.

The data for this Task can be downloaded from EO Browser, or at <https://drive.google.com/drive/folders/1MUPvw74QJGmqdW4Xjme7-cETvxtao64W>.

Instructions for self-guided work:

1. Open EO Browser and log in (instructions are available at the beginning of the Practice Book). Use the search bar to find the Lisovychi Village (Kyiv Oblast) on the map. The village is located southwest of Dymer, on the right bank of the Kyiv Cistern.



In the image search bar, select:

- **Data source** – Sentinel-2;
- Activate **Advanced search** and select **L2A (atmospherically corrected)**;
- **Max.cloud coverage** – 20;
- **Time range** – 2020-07-01–2020-07-20;
- Click **Search**.

As a result, you will get a list of images available for the selected period. Scrolling through the list, find the image dated July 19, 2020, and display it on the screen by clicking the **Visualize** button. The image will automatically be displayed in the **True color** combination. Take a close look at the forestland area, and zoom to it. In Appendix A at the end of this Practice Book, you can see the appearance of different types of land cover in satellite images. Pay special attention to the appearance of forests.

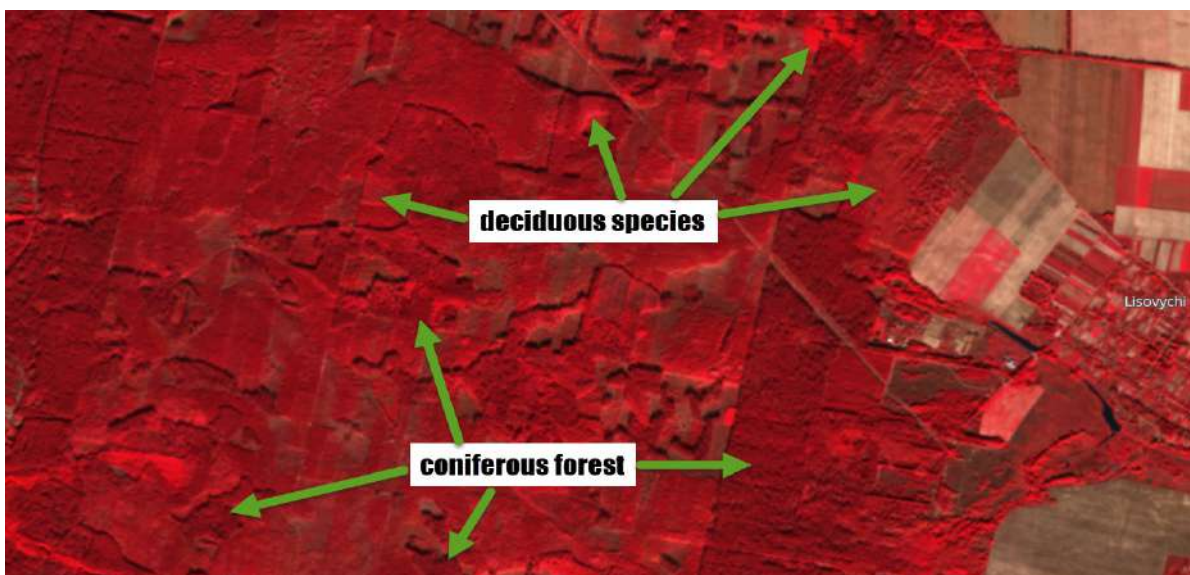
? Check yourself

Can you distinguish tree species in the image using this combination? If so, based on what?	
Specify the types of land cover from Appendix A that you found in the image	

Now change the combination to **False color** available in **EO Browser** list.



In this combination, vegetation is displayed in shades of red, namely: a coniferous forest is dark red, deciduous species are light red (see Fig. below).



False color combination is often used to monitor vegetation but there are also other useful combinations for distinguishing forest species. We will use one of such combinations in QGIS upon uploading the selected bands of an image. However, to do this, first, use the navigation buttons to adjust the screen coverage so that the names of Lisovychi and Lytvynivka villages are displayed (see Fig. below).

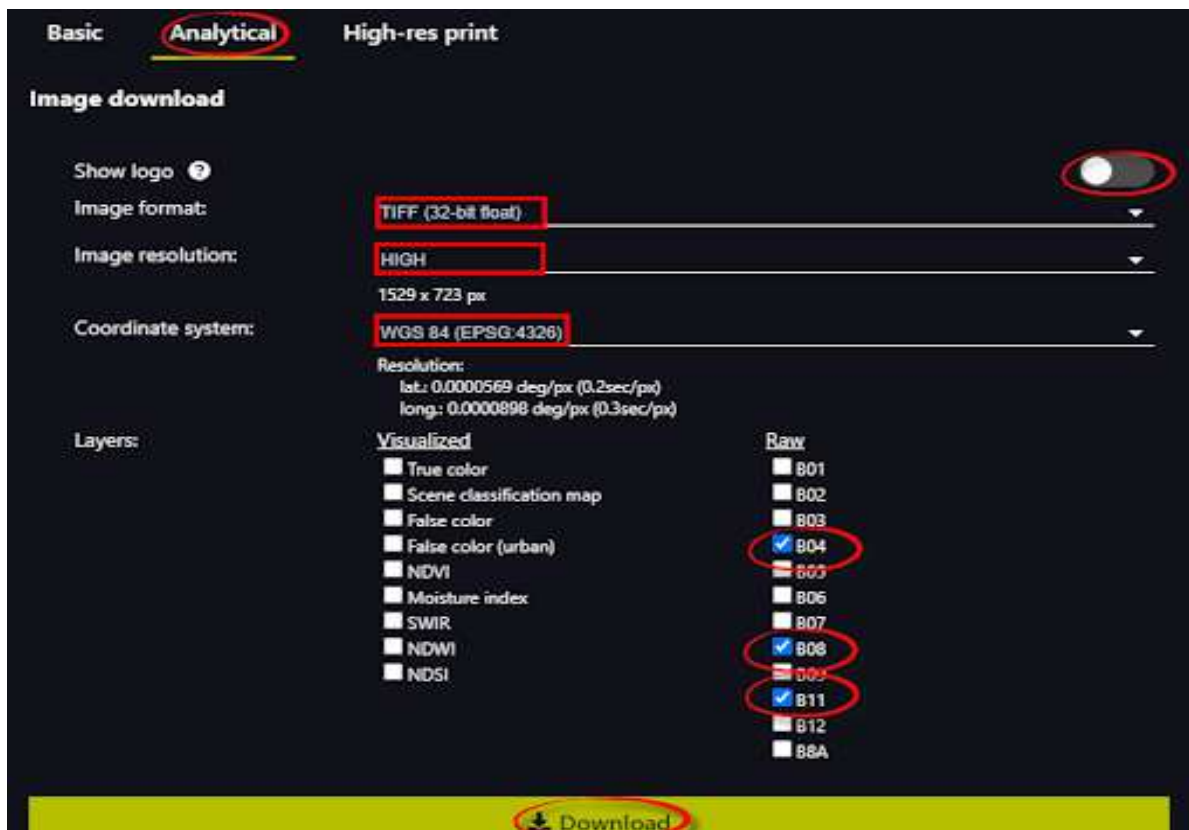
✔ **Important!** *Note that the image is automatically clipped along the map window, so before downloading, make sure that the map covers the area of interest completely.*



Download this satellite image using the **Download image** tool . Open the **Analytical** tab and specify the following:

- **Show logo** – toggle off;
- **Image format** – TIFF;
- **Image resolution** – High;
- **Coordinate system** – WGS 84;
- **Layers** – B11, B08, B04.

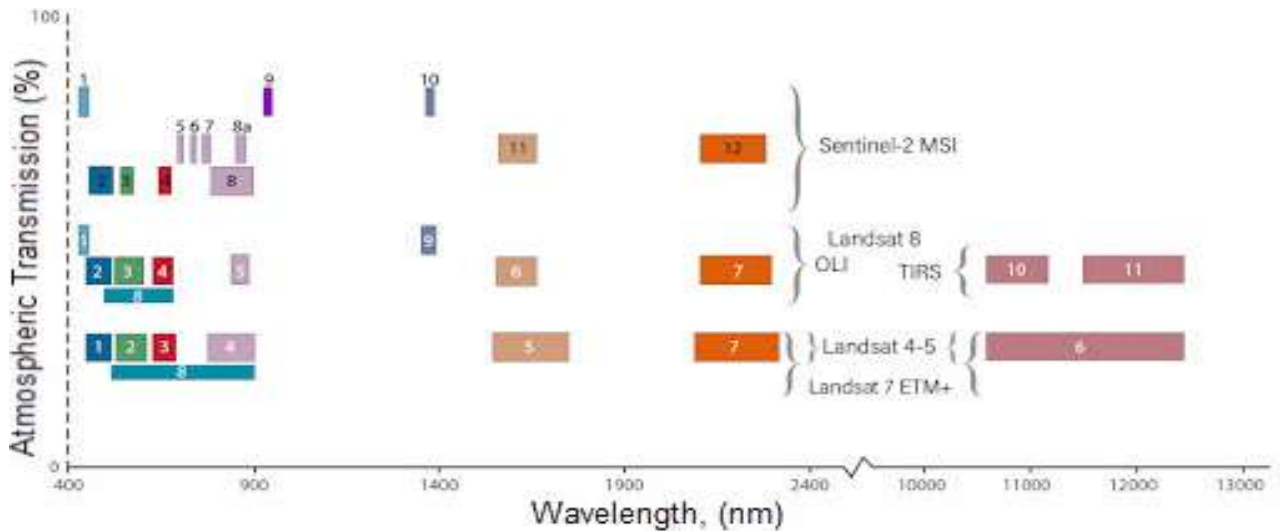
Click **Download** and specify the path to save the archive.



2. Repeat the steps described in paragraph 1, find and display the Landsat-5 image dated August 14, 2010. In the image search bar, select:

- **Data source** – Landsat-5;
- **Max.cloud coverage** – 50;
- **Time range** – 2010-08-01–2010-08-20;
- Click **Search**.

The Landsat images have a poor spatial resolution, which can be noticed at once from the image quality; however, these images are important for historical analysis of changes in the area under study. Our task is to save the Landsat-5 image bands that correspond to the downloaded B11, B08, B04 Sentinel-2 bands because we want to download an identical combination of bands for these two images in QGIS. This task is complicated by the fact that Landsat-5 has fewer bands and numerical symbols in the names of Landsat-5 and Sentinel-2 bands do not match. So we suggest that you use the band diagram from the Figure below and determine which Landsat-5 bands correspond to B11, B08, B04 Sentinel-2 bands, and, accordingly, download these bands via **Download image**.







Schematic representation of the electromagnetic spectrum bands recorded by the Earth's artificial satellites – Sentinel 2 and Landsat 5/7/8¹

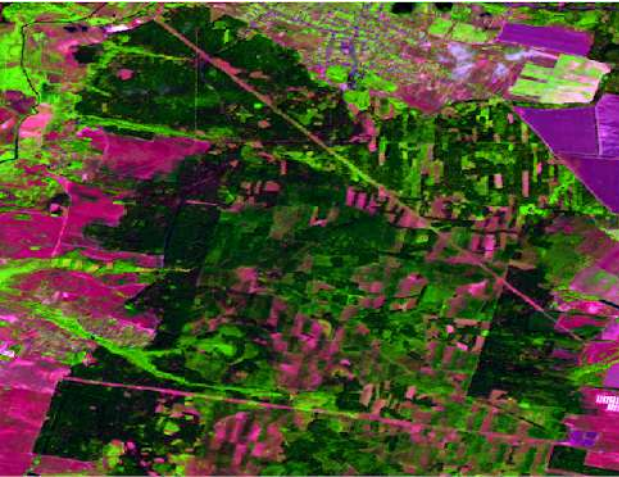
As a result, you will get two archives with **EO Browser** – one for Sentinel-2 dated July 19, 2020, and another one for Landsat-5 dated August 14, 2010. Unzip them and start working in QGIS.

3. Open QGIS and create a new project. Add a combination of B11, B08, B04 bands for Sentinel-2 to your project. Choose **Raster** → **Miscellaneous** → **Merge**. Under **Input Layers** → [...], in the **Multiple selection** window, click **Add files**, find the folder we have downloaded earlier, select B11, B08, B04 bands keeping their sequence and click **Ok**. Tick the box next to **Place each input file into a separate band** and leave the **Merged** field blank (we are creating a temporary file), and click **Run**. Rename the created raster layer: left-click on it in the **Layers** panel, select **Rename Layer** from the drop-down menu, and enter a new name, "Sentinel_11-8-4".

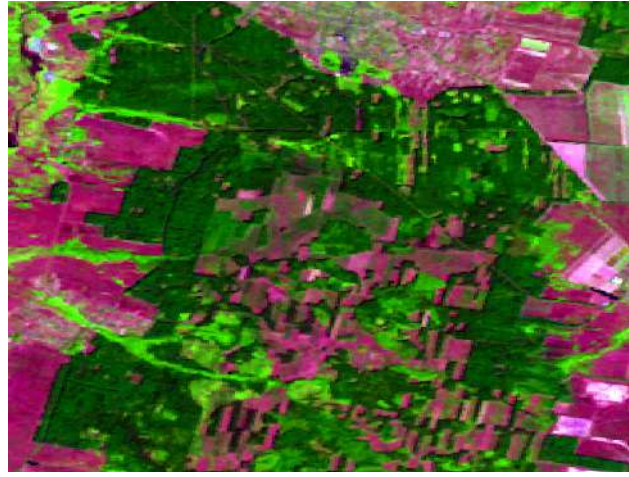
Repeat the steps and create a combination of B05, B04, B03 bands for the Landsat-5 image (we hope that these are the bands that you have downloaded before; if something went wrong, return to **EO Browser** and download these bands for Landsat-5). Do not forget to rename the created combination, for example to "Landsat_5-4-3".

If you have not changed the screen extent when searching for the images in **EO Browser**, you will get almost identical images in terms of coverage, which we will use later. With the created combination, the deciduous forests are light green, while the coniferous forests appear in shades of dark green; so both forest types can be easily recognized in the images. If you are not satisfied with the raster image and want to adjust the colors, experiment with the histogram using the     buttons from the **Raster Toolbar**.


¹ Remote Sensing: Analysis of Satellite Images in Geographic Information Systems / S. O. Dovgyi, S. M. Babiichuk, T. L. Kuchma et al. Kyiv : The Junior Academy of Sciences of Ukraine, National Center, 2020. P. 49.




Combination B11, B8, B04 for Sentinel-2
dated 19.07.2020



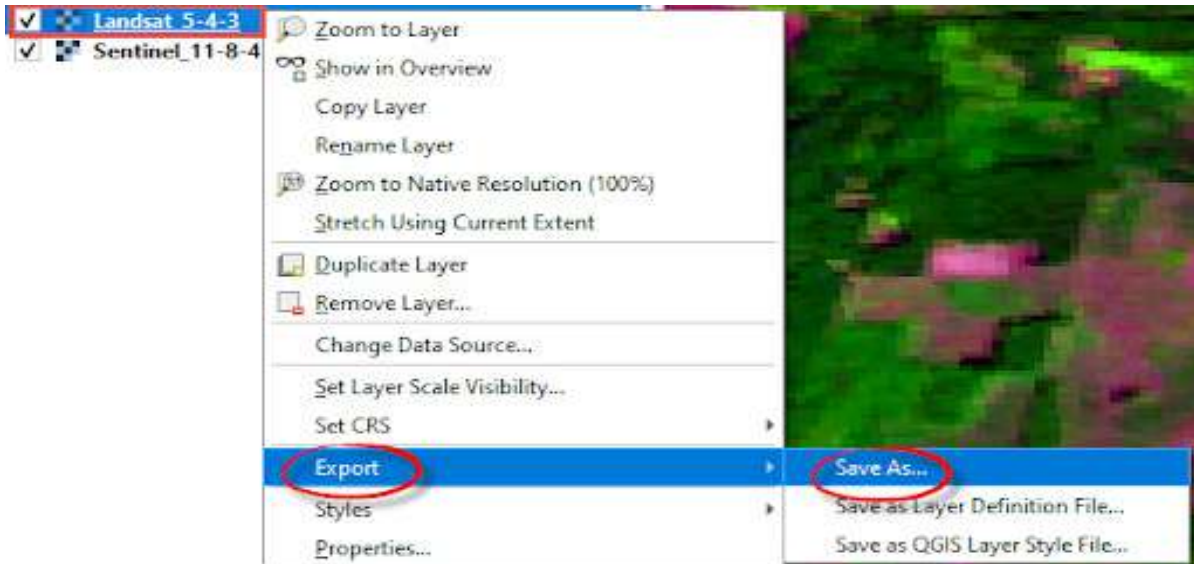
Combination B05, B04, B03 for Landsat-5
dated 14.08.2010

4. The images that we have downloaded capture a larger area than we need. So, first of all, zoom to the forest near the Lisovychi Village using the navigation buttons and your mouse wheel. We suggest that you change the scale to 1:14 000 in the **Scale** field at the bottom of QGIS work window and move the image using the  button from the toolbar so that the work window displays the forestland near the Lisovychi Village (i.e. as in Figure below).

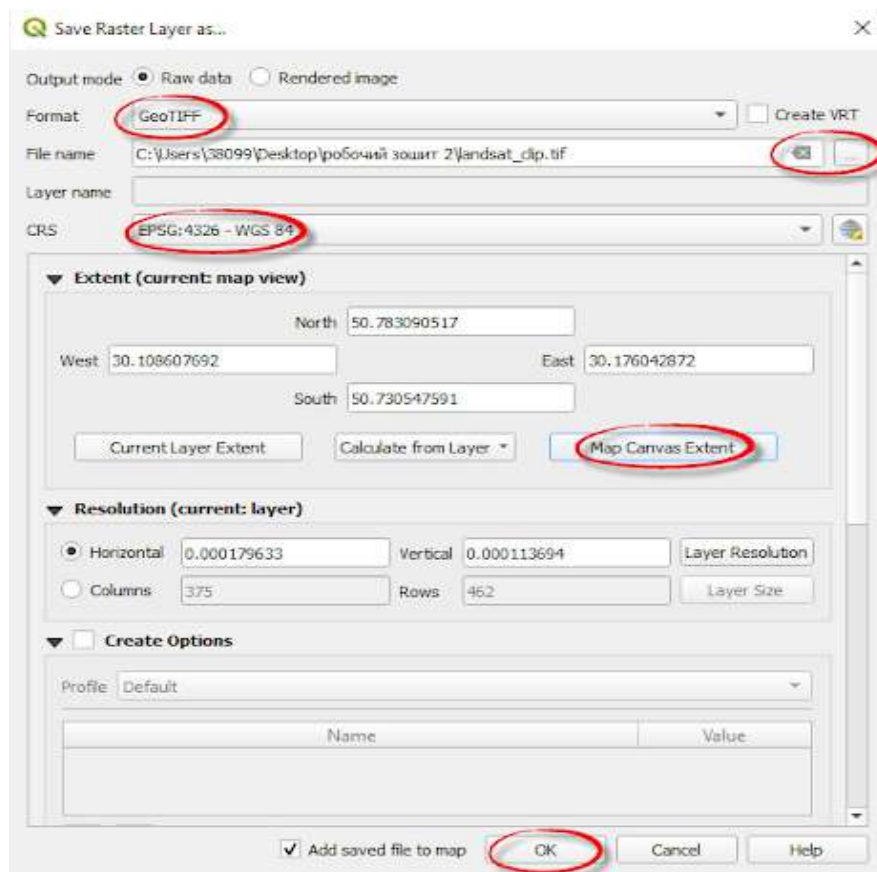
 **Important!** *Make sure the extents of the two images are the same. Uncheck the top layer in the Layers, and the bottom image should fill the extent of the work window. If this is not the case, change the coverage, experiment with the scale.*




We have experimented with the scale because now we will clip the raster layers along the map extent. Right-click on the first layer in the **Layers** tab and select **Export** and **Save As** from the drop-down list.

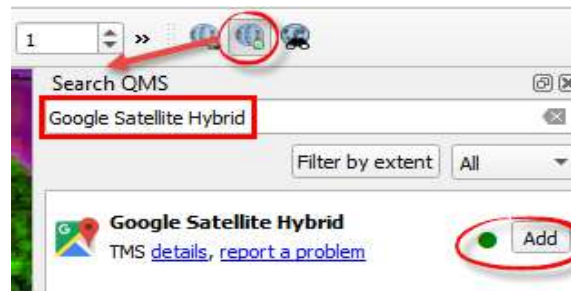


In the window that opens, make sure that the output format is GeoTIFF. Specify the name (for example, "landsat_clip" or "sentinel_clip") and the path to the directory where you want to save the source layer. Then specify the map projection (CRS) – WGS84. Select *Map Canvas Extent* under *Extent*, and click *Ok*.

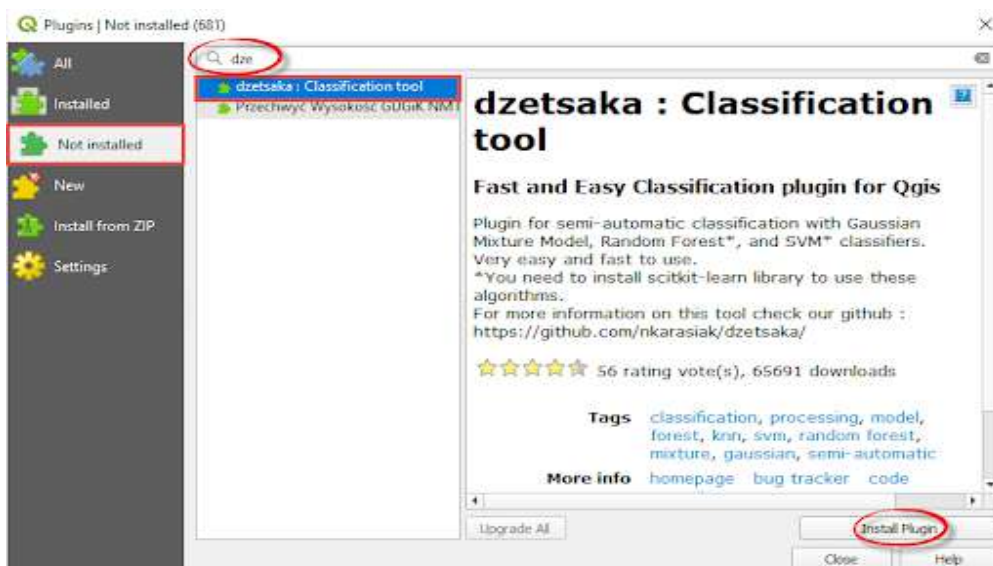


As a result, the newly created raster layer will open in your project. Repeat the clipping for the second image. We will continue to use these files, so you can delete unclipped raster layers to avoid confusion.

5. Activate the **Google Satellite Hybrid** layer with state-of-the-art high-resolution satellite imagery to check yourself when performing classification. To do this, find the **Search QMS** button  on the toolbar, and a new panel will be added to the QGIS work window. In this panel, type **Google Satellite Hybrid** in the search bar, select it from the list and click **Add**. As a result, **Google** map will be added to your project as a new layer.




6. We will use in this Task the **dzetsaka** plugin to perform the classification. This plugin must be downloaded via **Plugins – Manage and Install Plugins ... – Not installed** tab. In the search bar, start typing the name of the plugin, and it will automatically appear in the list at the bottom of the window. Select it from the list by left-clicking – a brief useful information about the plugin will automatically appear. Click **Install Plugin** and close the dialog box.




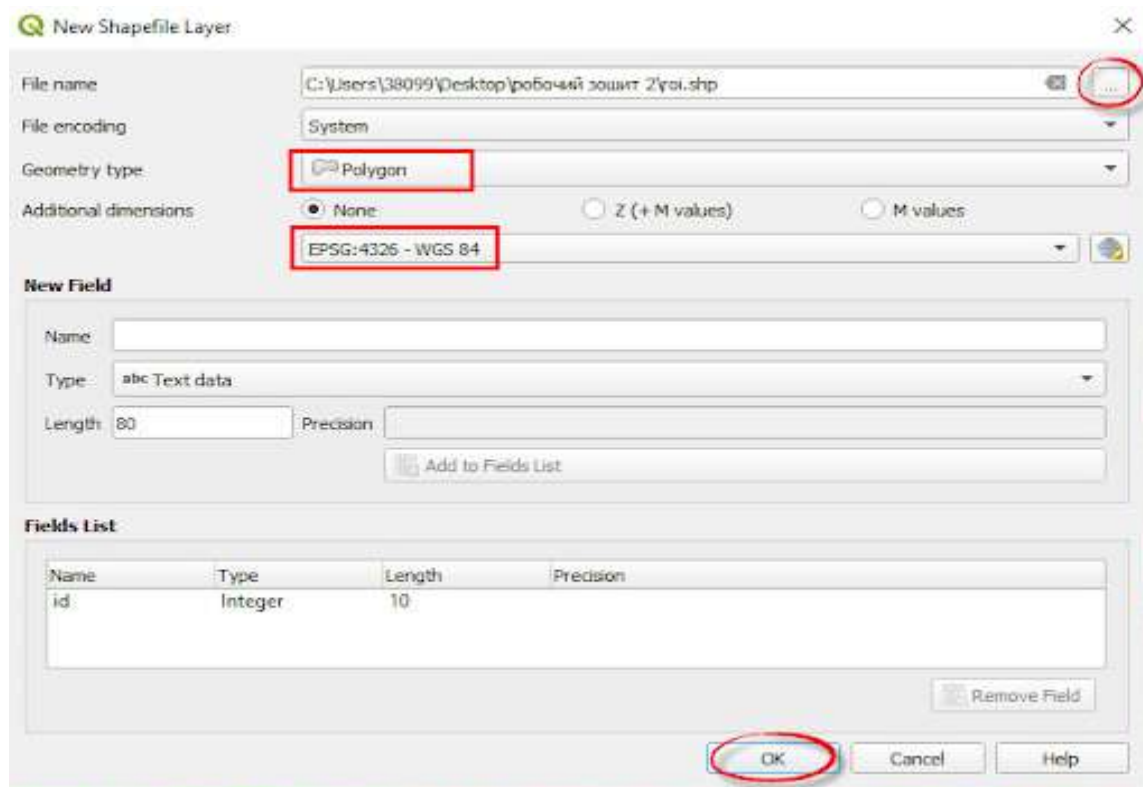
Once installed, the **dzetsaka** plugin will appear in the **Installed** tab and will be displayed in the **Plugins** menu as a separate line. This plugin is one of the simplest classification methods and is well-suited for quick analysis in QGIS, which we will perform in this Task.

7. The classification of satellite images will be carried out automatically with this plugin. To perform the classification, however, you should create a training sample (**Region of interest (ROI)**) that is essential for the accuracy of classification.

ROIs are polygons used to determine the spectral characteristics of land cover classes.

To select the **ROI**, you should create a polygonal shapefile. From the main menu, select **Layer – Create layer – New Shapefile layer**. In the window that opens, next to the **File name** field, click on the  tool to find the desired folder for saving the new vector layer. Enter its name, e.g. “roi”, and click **Save**.

 **Important!** **QGIS “doesn't like” Cyrillic, so use Latin characters to name files and avoid using extra characters and spaces (this also applies to folder names where you store your files)..**






In the *New Shapefile Layer* dialog, select **Polygon** from the drop-down list under **Geometry type**. Below the **Geometry type** field, there is another drop-down list with the names of cartographic projections. Expand the list and select **WGS 84** – the same projection as we have selected before for satellite image bands when downloading. They must match. Next, in the window to create a vector layer, click **Ok**, and a new layer will open in your project.

8. Since we need to make a quick classification of forests in the images, in this example we will identify three types of land cover only in the **ROI** layer:

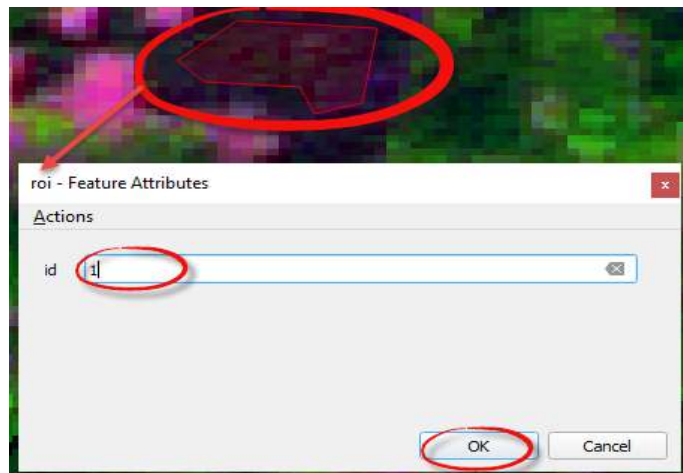
1	Coniferous forest
2	Deciduous forest
3	Open ground

Of course, you can also find other types of land cover in the image – water bodies, overgrowing areas of felling, buildings, etc.; for the current Task, however, this abbreviated set is quite suitable. In other words, the set of **ROIs** can vary depending on our needs, and the more advanced it is, the more detailed the classification will be.

To create this set of **ROI** polygons in a shapefile, you must enable vector layer editing mode. To do this, select the layer you want to edit in the Layers (in our case, the “*roi*” layer) by left-clicking on it, and click on the **Toggle Editing** tool . The **Add Polygon Feature** tool  has changed from gray to color, which means that the mode is enabled and we can start creating the first polygon by clicking this button.

First, we shall create polygons for the areas of coniferous forest (appearing in shades of dark green) in the Sentinel-2 image. For this purpose, zoom to the dark green area of the forest and draw a polygon by left-clicking. If you erroneously put a vertex, you can cancel it by clicking **Backspace**. To complete the digitization, right-click, type “1” in the window that appears (because we marked the coniferous forest as “1”), and click **Ok**. Then, click on the **Save** tool . Therefore, we have created the first polygon; to improve the classification functioning, we need to create several more such polygons for each class. Search for other areas of coniferous forest in the Sentinel-2 image, draw several polygons, and assign the number “1” to them.

✔ **Important!** *Avoid digitizing polygons along the plot boundaries not to capture pixels that belong to another type of land cover.*

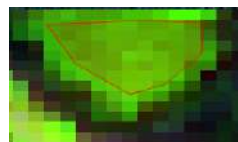


Next, we will digitize areas of deciduous forest that appear light green in the image. Be careful: we marked this type of land cover with the number “2”, so specify this number in the id field when creating a polygon. Similarly, create polygons for other **ROIs**, not forgetting to change the numerical symbols according to the specified set. In case of difficulties with the identification of features in the image, we recommend using **Google Satellite Hybrid** to check your guesses. The Figure below provides tips for you to make features’ identification easier.

✔ **Important!** *You can clip the images so that they don’t cover water bodies or, on the contrary, include additional features, such as settlements or buildings. In this case, simply remove or add these types of land cover to the ROIs list and create polygons.*





Coniferous forest



Deciduous forest

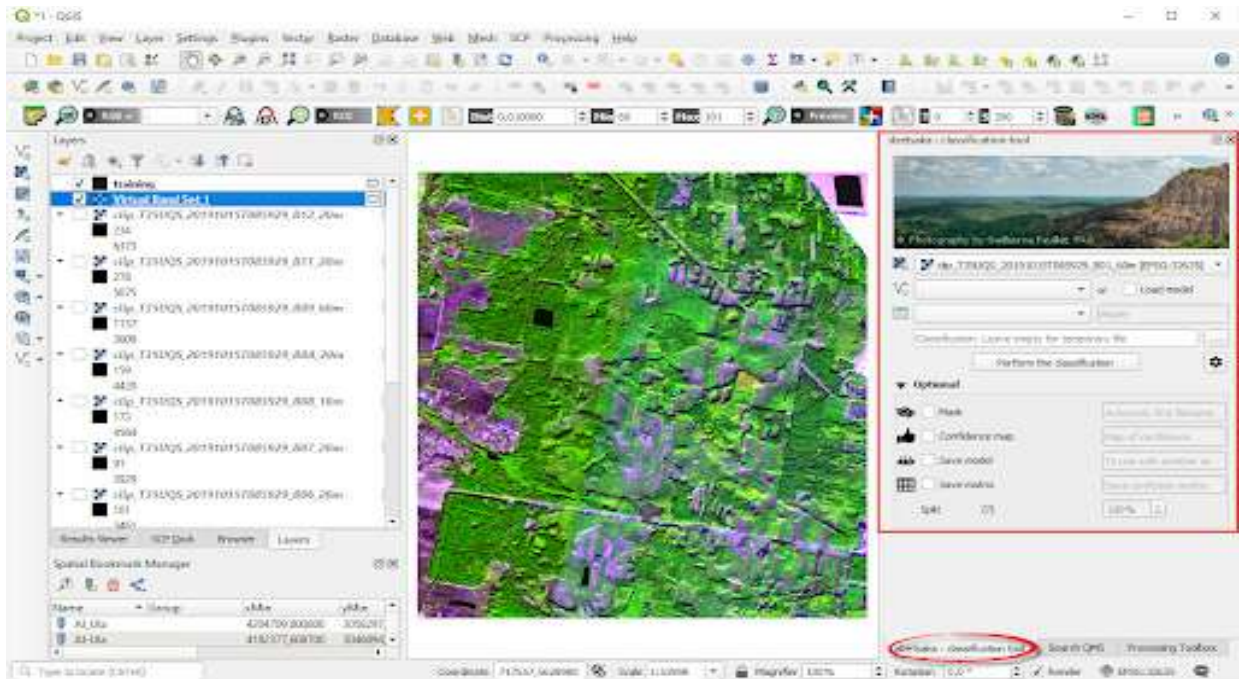



Open ground

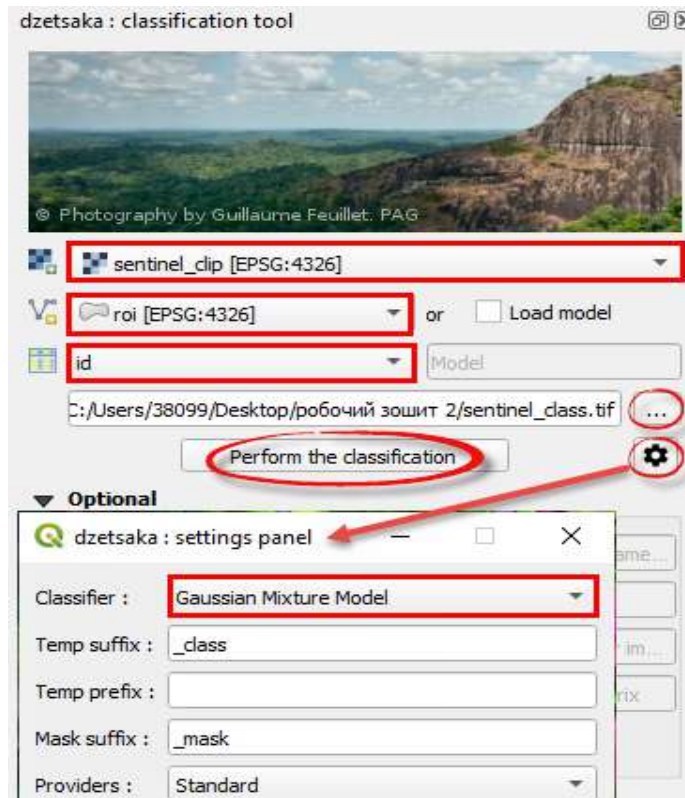
To save all changes to the shapefile, click the **Save** tool , and then click **Toggle Editing** . As a result, you will create a vector layer containing a set of data for classification (Fig. below). The next step is the performance of classification.



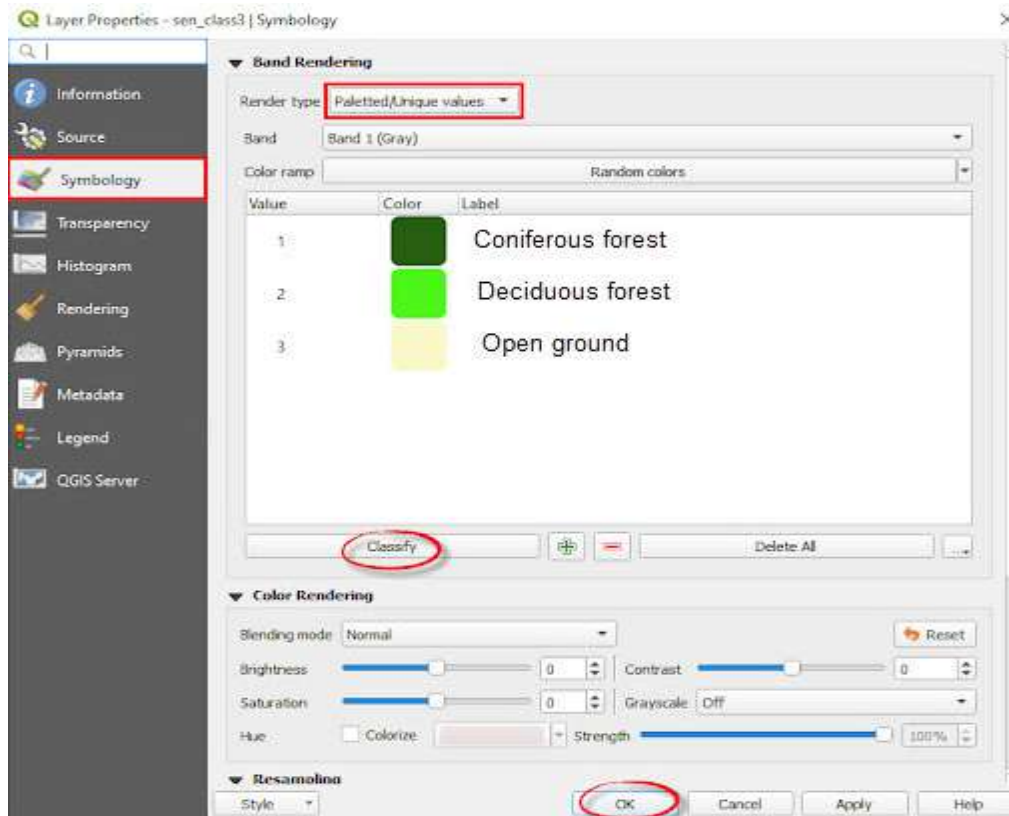
9. Go to the main menu **Plugins** → **dzetsaka** → **classification dock**. A new panel of the plugin will appear which you can move to a convenient place, for example as in the Figure below.



In the panel of the **dzetsaka** plugin, select the raster layer to be classified from the **The image to classify** field. First, we will classify the Sentinel-2 image, since we have already created the **roi** set for it in the previous sub-paragraph. Accordingly, pick the **roi** layer in the next field (*note that the coordinate systems of these two layers, which are indicated in square brackets next to their names, are the same – this is essential for a successful classification*). In the **Column name where class number is stored** field, select “id” from the created vector layer **roi** (*classification is performed only in numerical values*). By clicking on [...], specify the folder for saving the classified image and enter its name, e.g. “sentinel class”. Click on the button below , and a new dialog box opens up, where you should select the **Gaussian Mixture Model** classification method from the **Classifier** field as this method is the most suitable for quick classification. Upon selecting the classification method, close this dialog, leaving the rest unchanged. To run the classification, click the **Perform the classification** button. As a result, a new black-and-white raster layer will be added to your project in a few minutes, which is the result of classification.



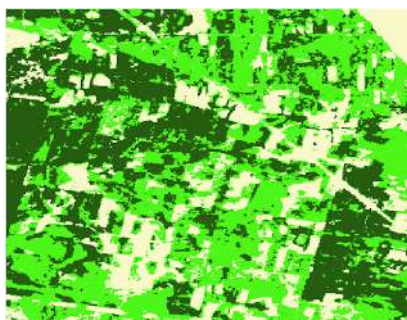
10. Change the appearance of the classified raster from black-and-white to the color image according to the values of *id*. To do this, right-click on the created “sentinel class” raster in the Layers tab of your project and select **Properties** from the drop-down menu. In the **Layer Properties** window that pops up, switch to the **Symbology** tab and select the **Paletted / Unique values** display method. This method allows you to group pixels by their values and set the display color accordingly. Click the **Classify** button to add all the unique pixel values of the raster layer. In this case, these will be the numbers 1, 2, and 3, which correspond to the *roi* classes that we have created earlier. We suggest that you change the colors for these classes. For this purpose, double left-click on the colored square in the Color column and select a hue. We recommend using the colors in the Figure below as references and highlighting the coniferous forest (marked “1”) with dark green, and deciduous (marked “2”) with light green. Choose a neutral color in the shades of brown for the open ground. In the **Label** column, enter the name of the class, double-click on the inscription in the field, and enter “coniferous forest” instead of “1”, “deciduous forest” instead of “2”, and “open ground” instead of “3”. Click **Ok** to apply the changes.



11. As a result, you will get a color raster layer, in which the forest boundary should visually match that of the Sentinel-2 image. Of course, the classification may have errors, because for a better result you need to perform a more detailed analysis and create a wider set of *roi*. In this Task, we should compare the changes in coniferous and deciduous forests that occurred during 2010 – 2020, and the result is well-suited for this purpose.

To complete the Task, repeat the steps specified in paragraphs 7-10 for the Landsat-5 image, create a new shapefile with the same types of land cover (*roi* set), perform classification, and change the raster from black-and-white to color.

✔ **Important!** *The Landsat-5 image has a poor spatial resolution, so it will be more difficult to identify the features. We recommend using Google Satellite Hybrid to check the results.*



Sentinel-2

Landsat-5

Check yourself

Describe the changes that occurred in the territory of the forestland during 2010 – 2020.	
Which forest has the larger area in the image of 2020 – coniferous or deciduous? What do you think are the causes?	

Scan the QR-code below to watch the video tutorial on the performance of this Task.



3.3. Characterizing Geological Structures in the Vicinity of the City of Al-Ula, Saudi Arabia

Case

The development of the tourism sector from scratch in Saudi Arabia underlies the Vision 2030 Program, which aims to significantly reduce the country's economic dependence on oil production. The main tourist attraction of the country is the *Winter at Tantora*, an international festival of music, art, culture, and history, which was last held from December 19, 2019, to March 7, 2020, in the city of Al-Ula.

The unique city of Al-Ula surrounded by majestic Martian-like landscapes is the main archaeological site in the north of the Arabian Peninsula and the home for many ancient civilizations. Here are located the rocks formed of red and black sandstone of unusual shapes molded by wind and time. Many of these rocks share some petroglyphs. It has not yet been possible to study the peculiarities of the geological structure of this territory using various combinations. In 2008, the region was inscribed on the UNESCO World Heritage List and became the first recognized site in Saudi Arabia.

Task

Download two Sentinel-2 images of the territory of Al-Ula (Saudi Arabia) in the bands B12-B08-B02, and B12-B11-B02 dated 14.02.2020.

Tantora is an ancient marker for the changing of agricultural seasons, i.e. a sundial located in Al-Ula's old town. It has been used by the local people not only to tell time but also to mark the changing of the seasons. At present, the local community celebrates the festival, which symbolizes the beginning of the winter season, as well as the return of agricultural activity in the region. Over the years, it has become a popular tradition that symbolizes development and progress.

Al-Ula county is located 300 km north of Medina – a place of extraordinary human and natural heritage. The Wadi Al-Qura (the Valley of Villages) is a lush oasis valley that runs through Al-Ula, sheltered by sandstone cliffs, that created ideal conditions for several civilizations to flourish. In ancient times, the Dedanites, Lihyanites, and Nabataeans all built their cities here. The Al-Ula region has always been an important trading route used from at least the first millennium BC. Al-Ula, positioned on the ancient Incense Route between Southern Arabia and Egypt, became a commercial and cultural center. Its oases and cities were important stopping-points for traders of frankincense, myrrh, and other precious commodities.


You can visit this region together with Anton Ptushkin. To watch his blog about Saudi Arabia, go at <https://youtu.be/ea5uxRmRe8Y>.

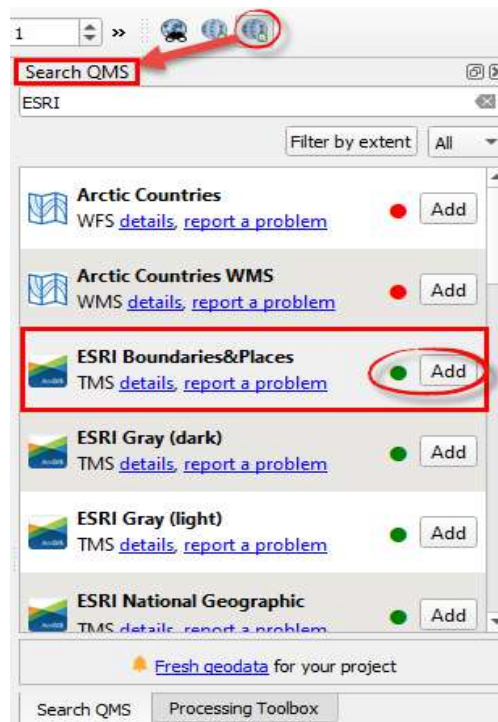
Task performance algorithm:

- enable the *QuickMapServices* plugin and download the *ESRI Boundaries & Places map*;
- merge B04, B03, B02 bands (a true-color combination) for each image, and combine two images into one raster layer;
- merge B12, B11, B02 bands (Geology combination) for each image, and combine two images into one raster layer;
- save the area in the map to bookmarks – Al-Ula Valley;
- download the AFR CGMW BRGM 10M Geologic Units map from the OneGeology portal to your project via URL as a WFS shapefile.

Instructions for self-guided work:

1. Download the data for the Task from <https://drive.google.com/drive/folders/1Q7W-c-WfD1zqR7WOjkPOxOoME64aefyd> or from *EO Browser*. In this Task, we will use two Sentinel-2 images. All jpg image feeds are located in the “IMG_DATA” subfolder. The path to this subfolder we have already specified in the previous tasks; it may look like this: S2B_MSIL1C_20200214T075959_N0209_R035_T37RCK_20200214T100110 → S2B_MSIL1C_20200214T075959_N0209_R035_T37RCK_20200214T100110.SAFE → GRANULE → LIC_T37RCK_A015362_20200214T080655 → IMG_DATA.

2. Open QGIS application and create a new project. Make sure that the *Browser* and the *Layers* panels are open in QGIS. If you do not see them, select *View* → *Panels* from the top menu and tick the boxes next to *Browser*, *Layers*, and *Spatial Bookmarks*. Also, download the *ESRI Boundaries & Places* map via the QuickMapServices module; if this module is missing, use the instructions from Task 3.1 to install it. Find  *Search QMS* on the toolbar and turn on the search field by clicking on this button, start typing ESRI in the search field. Various maps will appear automatically in the list below. Select and add *ESRI Boundaries & Places* from the list.



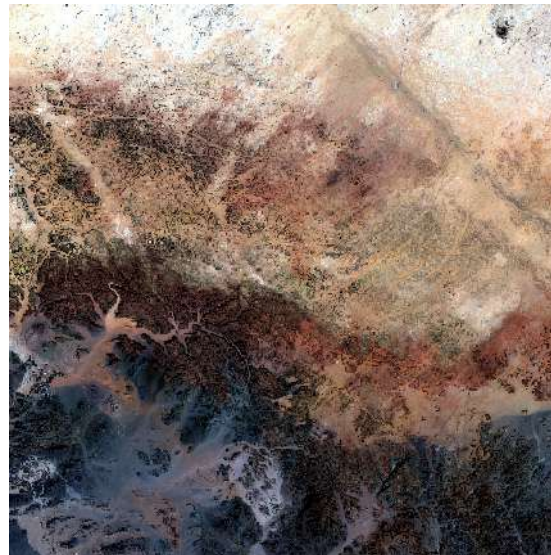
3. First, create a true-color combination for the two downloaded images to see what the area looks like with the “human eye”. In this Task, we use Sentinel-2 images, and a true-color combination of bands for any Sentinel-2 images is as follows: B04, B03, and B02.

Let's create a combination of B04, B03, B02 bands for each image (it is not essential what image will be processed first). Select **Raster** → **Miscellaneous** → **Merge**. In the **Input Layer** line → , in the **Multiple selection** window, click **Add files** and select B04, B03, B02 bands (*all image bands are stored in the "IMG_DATA" folder, the path thereto is described in the first paragraph*) maintaining the sequence, and **Ok**. Next, you need to tick the box next to **Place each input file into a separate band**, and leave the **Merged** field blank. In this way, we create a temporary file that is not stored on your computer but is available in this project only and click **Run**. Zoom to the borders of the created raster layer, right-click on the layer name in the **Layers** panel, and select **Zoom to Layer** from the drop-down box.

Repeat the steps and create the same combination for the second image.



S2B_MSIL1C_20200214T075959_N0209_R035_T37RCK_20200214T100110



S2B_MSIL1C_20200214T075959_N0209_R035_T37RDK_20200214T100110

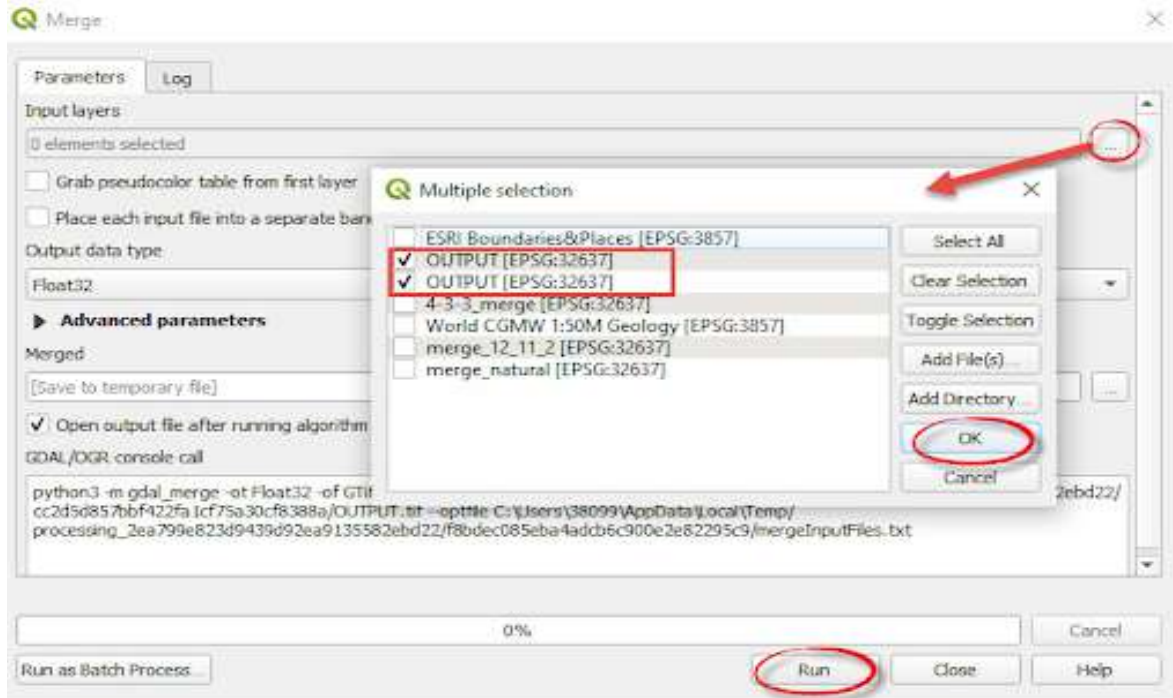
? Check yourself

Have you noticed that although the combination is the same, it is not displayed similarly in the two images? Why do you think?

4. The next step is to merge two images into one. This can be done through the main menu **Raster** – **Miscellaneous** – **Merge**. In the **Input Layers** field, select the items you want to merge, namely two files called “OUTPUT” with created true-color combinations. Leave the **Merged** field blank. In this way, we create a temporary file that is not stored on your computer but is available in this project only, click **Run**.

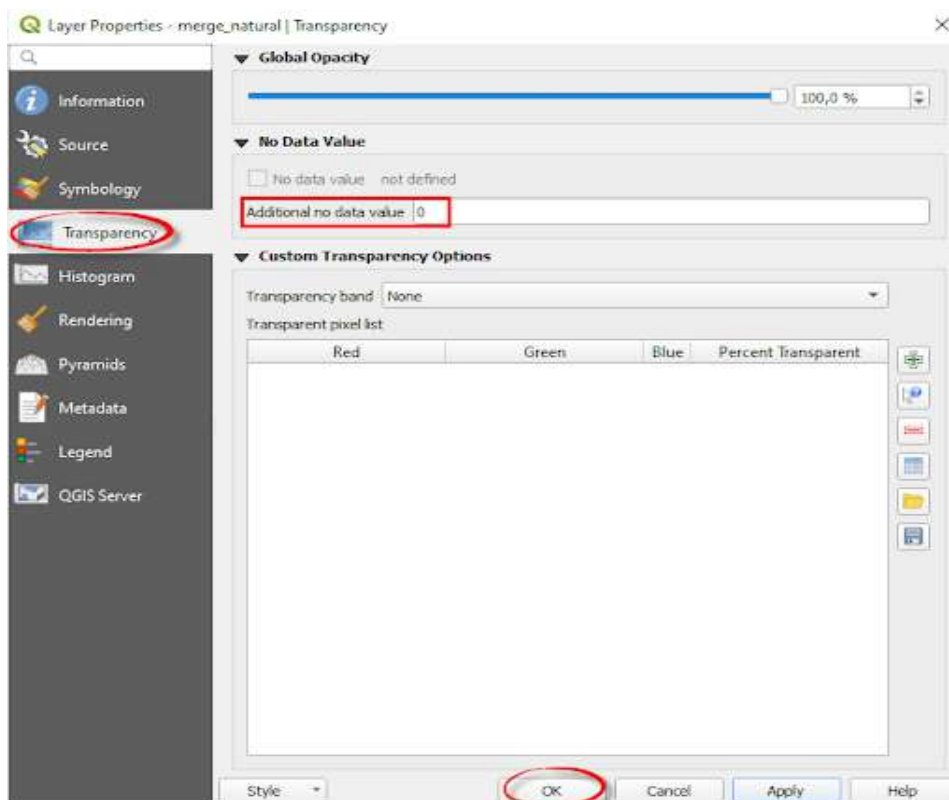
✔ **Important!** *This time, we do not check the box next to **Place each input file into a separate band** to get a fully merged raster layer.*

It takes some time to merge two raster layers, so don't panic, just wait.



We recommend renaming the created raster, for example to “merge_4-3-2”, and deleting the previously created combinations. To perform all these operations, left-click on a layer in the **Layers** panel, select **Rename Layer** from the drop-down menu; to delete, click **Remove Layer**.

Take a look at the merged raster layer. Do you notice any color changes in the image? Now the color has become homogeneous with smooth and seamless transition between the images. To remove the black background appearing to the left of the image border, double-click on the name of the merged image in **Layers**. The **Layer Properties** menu will appear. Go to the **Transparency** tab and write “0” in the **Additional no data value** field, and click **Ok**.

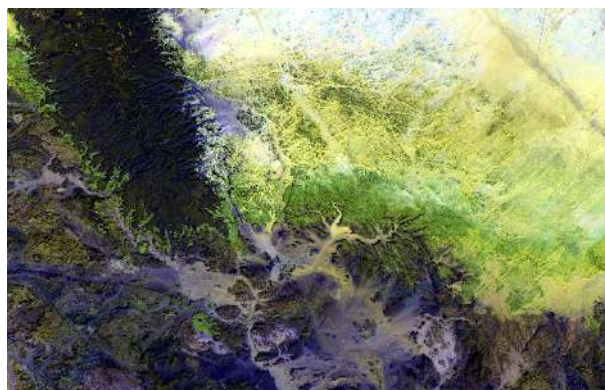


In a true-color satellite image, the desert is displayed in different shades of brown and white, and therefore does not look very impressive. Let's try to display it differently.

5. We will merge the bands for images by choosing another combination, namely "Geology" (B12, B11, B02). Each type of rock formations reflects short-wavelength infrared light differently. We can see it by comparing the reflected SWIR light. This combination uses B12 (SWIR) band to delineate different types of rocks containing anionic groups such as Al-OH, Mg-OH, Fe-OH, Si-OH, carbonates, ammonium and sulfates. Therefore, again, we should first merge the bands for each image separately, this time for B12, B11, B02 bands, and then combine them into one raster layer. To do this, simply repeat the instructions given in paragraphs 3-4; just remember that you need to select B12, B11, B02 bands for the combination. You can start merging bands with any image, since changing the order does not change the result.



B04, B03, B02 combination



B12, B11, B02 combination

Rename the created merged raster layer to “merge_12-11-2” and remove the black background. Thus, we get an image displayed in completely different colors, where the desert seems to have blossomed. The B12, B11, B02 combination simplifies to a great extent the visual interpretation of geological units because the colors mark different minerals. Yellow/brown areas are used for goethite, dark green – chlorite, light green – clay, and purple – sulfides. Cleavages appearing in satellite images mark potential mineral ores or subsurface deposits. Such surveys of the area using satellite images can help to find potential deposits before a planned on-site inspection.

6. Examine the images in more detail and compare the created true-color and Geology combinations. Using the *ESRI Boundaries & Places* map given above, find Al-Ula Valley. Pay attention to the order of the layers display. The *ESRI Boundaries & Places* map should be on top of all other layers, i.e. the first in the list. If it is displayed differently, move it – first, select it with your left mouse button in the list of layers and drag it to the top. Now the inscriptions of cities and highways are displayed in satellite images.


Use the navigation buttons from the toolbar to zoom to Al-Ula Valley and save this map area to bookmarks. Find the *New Spatial Bookmarks* button  on the toolbar, or use Ctrl + B to specify a bookmark name, such as Al-Ula, and click *Save*.

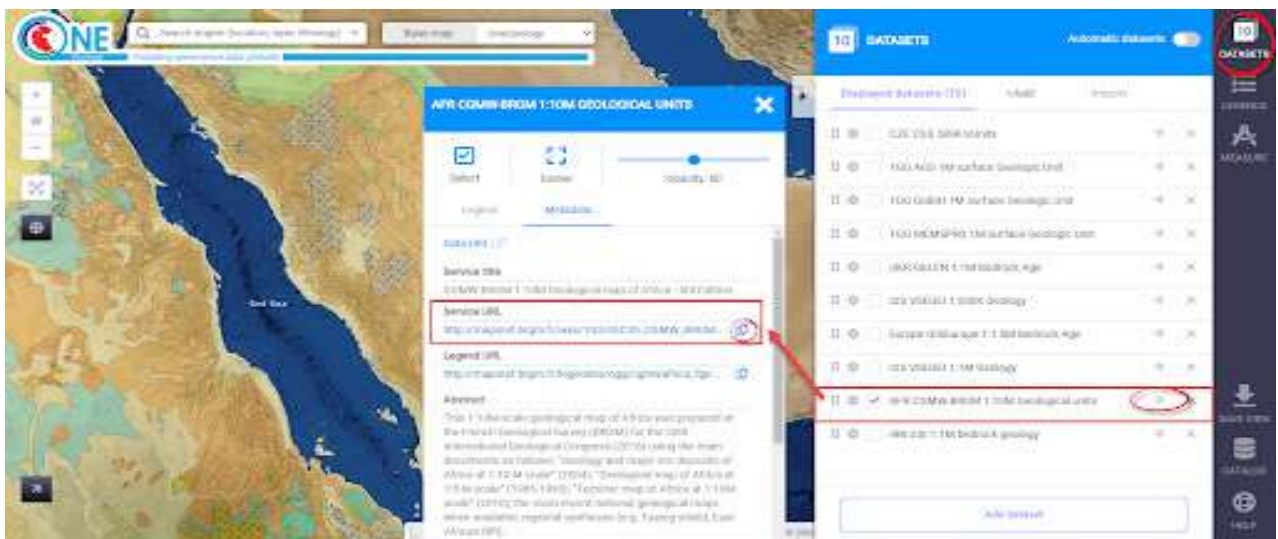
 **Check yourself**

Using the Geology combination, determine the composition of rock formations in Al-Ula valley – the cradle of many extinct civilizations.	
Analyze based on color which rock formations are the most common in the merged image in the Geology combination	

7. The last assignment in this Task will be to add OneGeology map to this QGIS project as a WFS-shapefile via URL (**Uniform Resource Locator**).

WFS (Web Feature Service) is a standard protocol that is the technological basis for remote access to the cartographic materials database. The WFS query defines a layer(s), a map area that can be displayed as a layer in the QGIS project as vector spatial data.

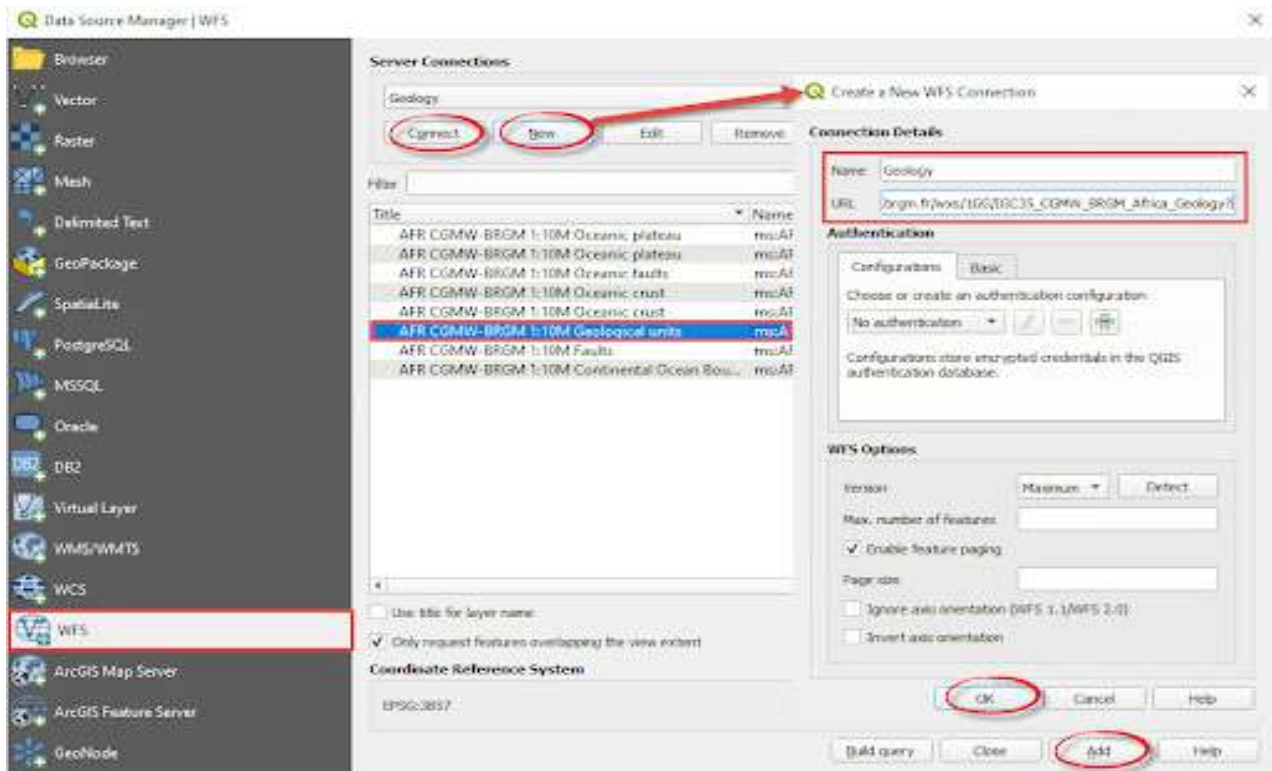
To download the OneGeology map, you must first copy the URL link from OneGeologyPortal. Therefore, go to <http://portal.onegeology.org/OnegeologyGlobal/> or just type *OneGeology* in the search bar and follow one of the first links. Using the navigation buttons, zoom to the Arabian Peninsula and open the **Datasets** tab from the right sidebar. Tick the box next to *CGMW-BRGM 1:10M Geological map of Africa* only, because this map contains data about the area under study. Click the arrow → next to the map name, and copy the **Service URL** link by clicking  in the tab that opens.



OneGeology map resource interface (URL: <http://portal.onegeology.org/OnegeologyGlobal/>).

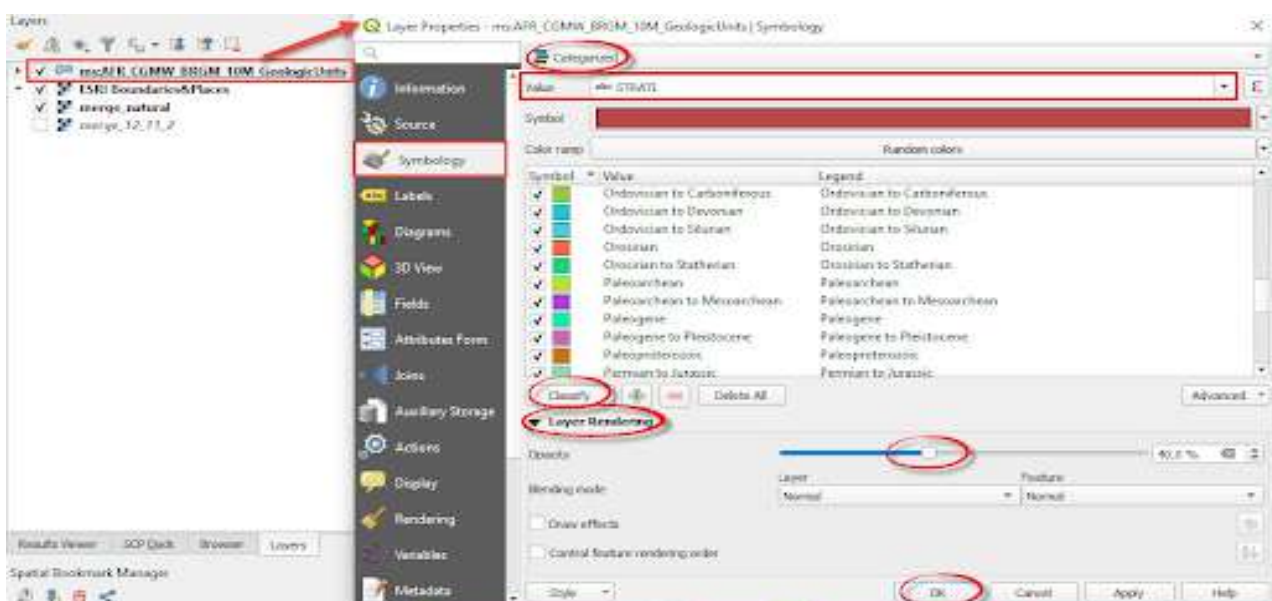
Copying the URL link http://mapsref.brgm.fr/wxs/1GG/IGC35_CGMW_BRGM_Africa_Geology from the OneGeology portal.

Return to QGIS to add the OneGeology map to your project. Select **Layer – Add Layer – Add WFS Layer** from the main menu, and click the **New** button in the window that opens to add a new WFS layer. In the new dialog box, type “Geology” in the **Name** field, specify the URL-service that we have copied from the OneGeology site in the **URL** field (see Figure below), and click OK. Return to the **WFS** dialog box and click the **Connect** button. The box below will update and display all the maps that have been downloaded to this created URL connection. Select *AFR CGMW BRGM 10M Geologic Units* from the list and click **Add**.








8. The downloaded map will appear in the list of layers in your project. Any map that is downloaded via *WFS* will be displayed as a shapefile in the list of layers. If the shapefile consists of polygons, they all will be displayed in the same color automatically after downloading. To change the display of the downloaded layer, double-click with your left mouse button on its name, and change the display mode from *Single Symbol* to *Categorized* in the *Layer Properties* dialog box under the *Symbology* tab. In the *Value* field, select the name of the column containing data for building a map (in our case, select "STRATI"), and click the *Classify* button to download all the values from the column we selected in *Value*. Click *Ok*. The polygons will be displayed in different colors (according to the parameters we specified above).

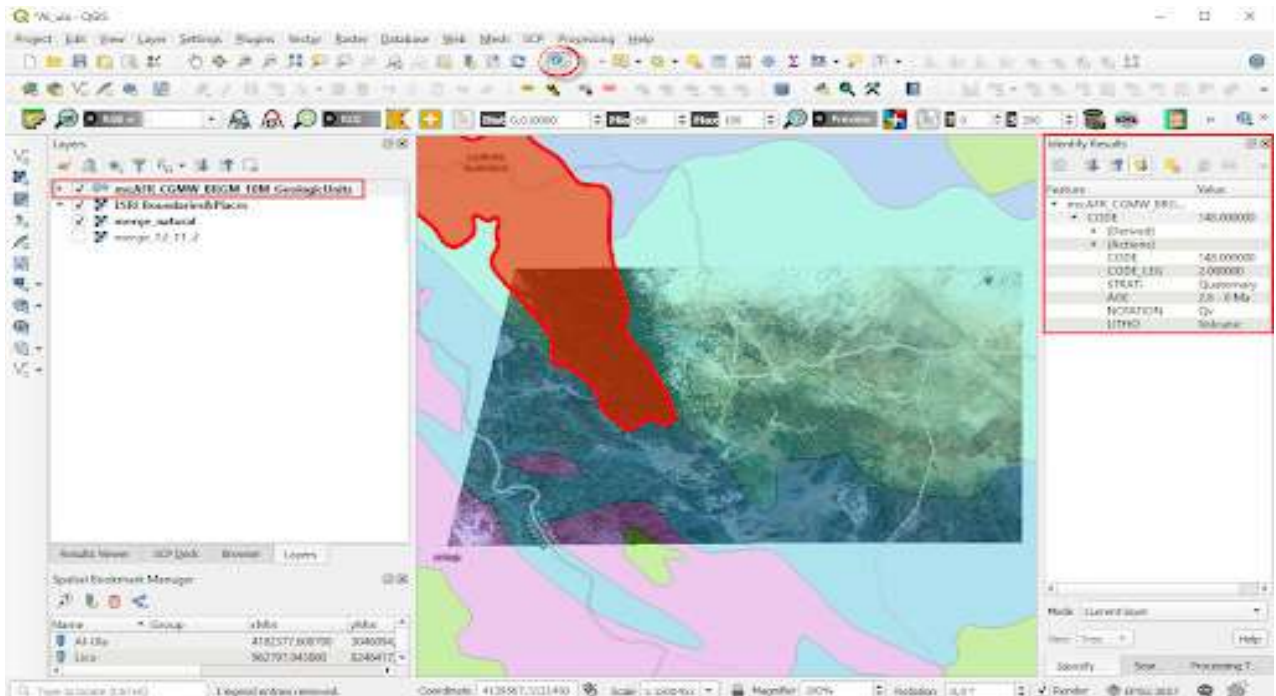
In the same dialog box, change the transparency of the displayed layer: expand *Layer Rendering* and drag the slider or change the numeric value to "40%" in the *Opacity* field.



Pay attention to the order of the layers display. The map “AFR CGMW BRGM 10M Geologic Units” should display on top of all other layers, i.e. be the first in the list. If it is not the case, move it – select it with your left mouse button from the list of layers and drag it to the top.

9. Using the **Identify Features**  button, determine the time when the geological structures within the area under study were formed (combined satellite image). To do this, select the downloaded map “CGMW-BRGM 1:10M Geological map of Africa” from the list of layers with your left mouse button, find the button  on the toolbar (under **Attribute Toolbar**). If this button is missing, enable it by right-clicking on the toolbar and checking the box next to **Attribute Toolbar**). Click , hover over the polygon you are interested in and select it with your left mouse button. All the information about the selected polygon will appear in the **Identify Results** sidebar. Pay attention to the “STRATI” field, where the era or period from the stratigraphic table is shown when this territory was formed (remember what you have learned at the Geography classes), as well as the “LITHO” field, where the origin of the sediments is indicated.

 **Important!** *If you have selected a layer other than the required source of information, the button  will either not work or will provide information about another layer that is selected from the list of layers.*



Using the data from the “AFR CGMW BRGM 10M Geologic Units” map and the **Identify Result** table, analyze the relationship, if any, between the color changes in the satellite image in the Geology combination and the boundaries of the geological units highlighted on the map.

Check yourself

Specify the names of all stratigraphic periods (“STRATI” field) that are identified within the merged satellite image. Indicate which period is the oldest and which is the youngest.	
Write how many geological units does the study area cover (merged satellite image).	
Using the “LITHO” field, determine the predominant types of sediments in the area under study.	

A few years ago, listening to music was banned in Saudi Arabia, and now citizens and visitors can enjoy the large Maraya Concert Hall (means “mirror” in Arabic) that was built in the Al-Ula Valley and earned the Guinness World Records title. It is the largest mirror-clad building in the world. Rocks and endless sands are reflected on the walls of the building, creating a mirage effect. According to the author's plan, this design makes the hall an “architectural extension of the environment surrounding it”.

? Check yourself

What are the characteristic features, in your opinion, according to which you can find the Maraya Concert Hall on a satellite image?	
--	--



Location of the Concert Hall on the satellite image [URL: http://mapsref.brgm.fr/wxs/1GG/IGC35_CGMW_BRGM_Africa_Geolog]



The Concert Hall in the image [URL: <https://experiencealulages/default.aspx>]

Scan the QR-code below to watch the video tutorial on the performance of this Task.



4. Visualization of Images on a Digital Elevation Model

4.1. Creating a Digital Elevation Model of Mount Hoverla

Case

Mount Hoverla at 2,061 meters, is the highest mountain in Ukraine. It is located in the mountainous region of Chornohora, on the border of Yaremche City Council (Ivano-Frankivsk Oblast) and Rakhivskiy District (Zakarpattia Oblast), within the reserved areas: the Carpathian Biosphere Reserve (Transcarpathia) and the Carpathian National Nature Park (Ivano-Frankivsk Oblast). The slopes of the Mount are covered with beech and spruce forests. At 1,500 meters, the subalpine belt of pastures (known as meadows) begins. The first tourist route for climbing to the top was opened in 1880. In winter, climbing Hoverla is assigned category 1B.¹ One of the most common climbing routes starts from the Zaroslyak tourist complex (climbing time – 3-4 hours).

Task

Create a 3D model of Hoverla Mount and part of the Chornohora ridge, determine the steepness of the tourist route, the differences in height on the climbing trail from the Zarosliak tourist complex.

Task performance algorithm:

1. Download the SRTM digital elevation model of the Carpathians (Chornohora ridge).
2. Based on the elevation model, create a map of the steepness of the slopes and choose the flattest trail from the various routes to Hoverla Mount.
3. Create a 3D model of Hoverla Mt. based on the SRTM digital elevation model.

Instructions for self-guided work:

1. Download the SRTM digital elevation model of the area under study from SRTM Tile Grabber (<https://dwtkns.com/srtm>) geoportal or at https://drive.google.com/drive/folders/1pb5YCqcUA_UcaV8l_FytlviVLvGtQ_xs (at this link, you can find data to this Practice Book).

SRTM, *Shuttle Radar Topography Mission*, is an international research project to create a digital elevation model of the Earth's land surfaces.

In the map window of the geoportal, you can see that the territory is divided into zones represented by squares (tiles). Using the navigation tools, select a square that covers the territory of the Ukrainian Carpathians. Once you click on it, a window for downloading the tile *srtm_41_03* shall appear. Click on **Download GeoTiff**.

¹ URL: <https://uk.wikipedia.org/wiki/Говерла>.

SRTM Tile Grabber

Note: This tool doesn't work as of January 2021, because the data paths it pointed to on external mirrors have changed. You can download tiles from CGIAR's website [here](#). This map may still be useful for finding figuring out which file name you're interested in downloading.

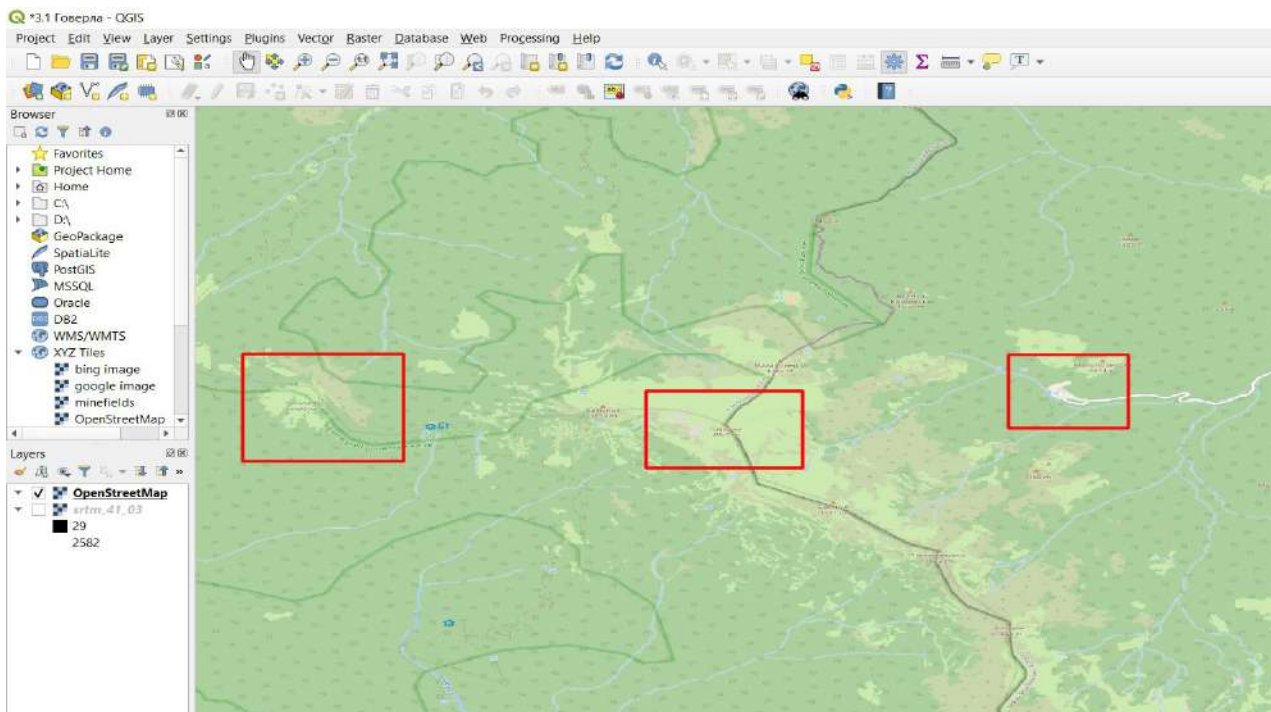
This interface attempts to ease the pain of downloading **elevation data** from the [Shuttle Radar Topography Mission](#). Click on red tiles to download their corresponding data.



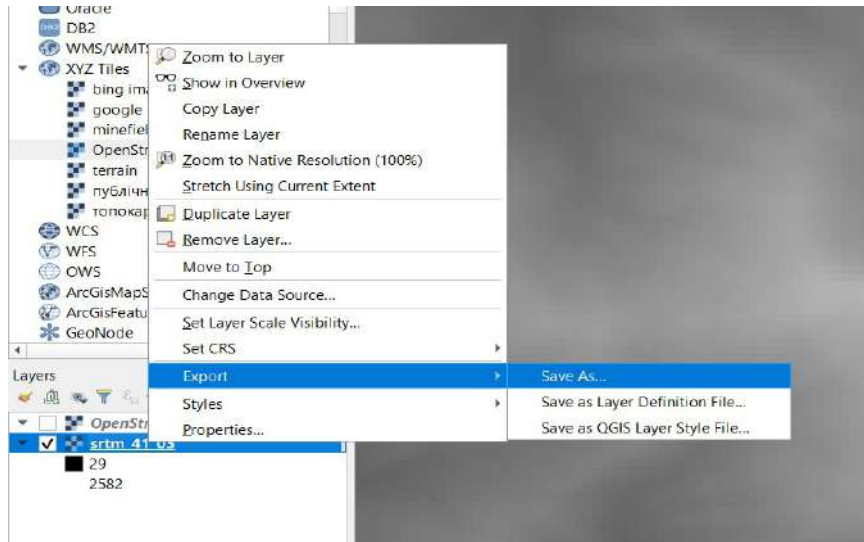
SRTM Tile Grabber web portal interface (<https://dwtkns.com/srtm>).

2. Unzip the downloaded file and add it to your QGIS project.

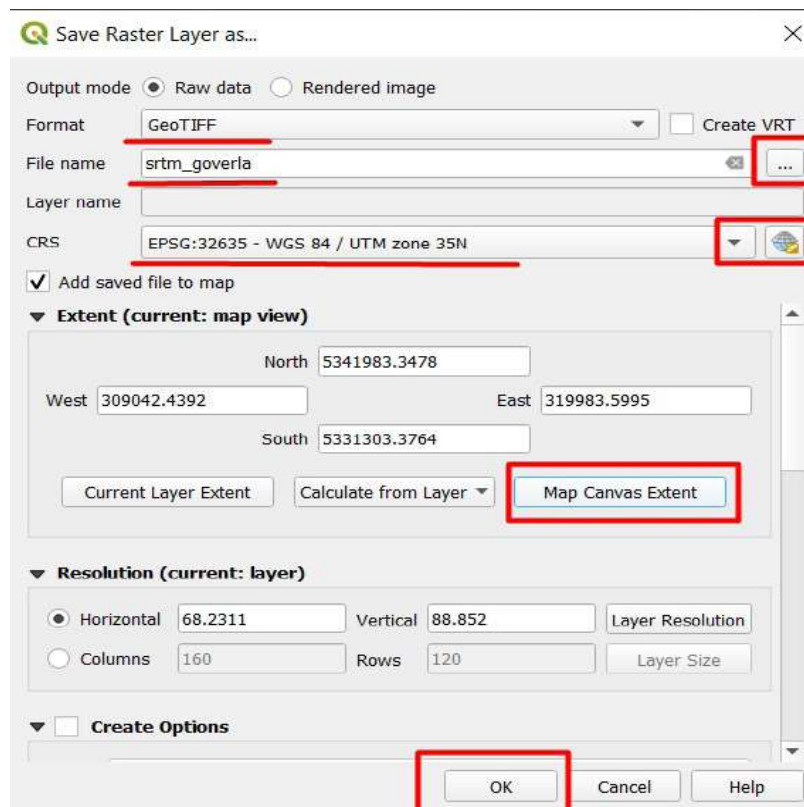
3. Add an OpenStreetMap to your project (from XYZ Tiles under **Browser**) and find Hoverla Mount on the map, as well as the Zarosliak tourist complex and the Skopeska Meadow. Zoom to the map to display these three locations at the same time.



4. Clip the SRTM raster along the map extent by right-clicking on the layer under Layers, and select **Export, Save As** from the drop-down list.



In the window that opens, check the input format (should be GeoTIF), specify the name (e.g. “srtm_goverla”) and the path to the directory where you want to save the input layer. Set the map projection (CRS): WGS84 / UTM Zone 35N (step-by-step instructions for selecting the required projection are given in Section 2.2 (4)). Select **Map Canvas Extent** under **Extent**, and click **Ok**.

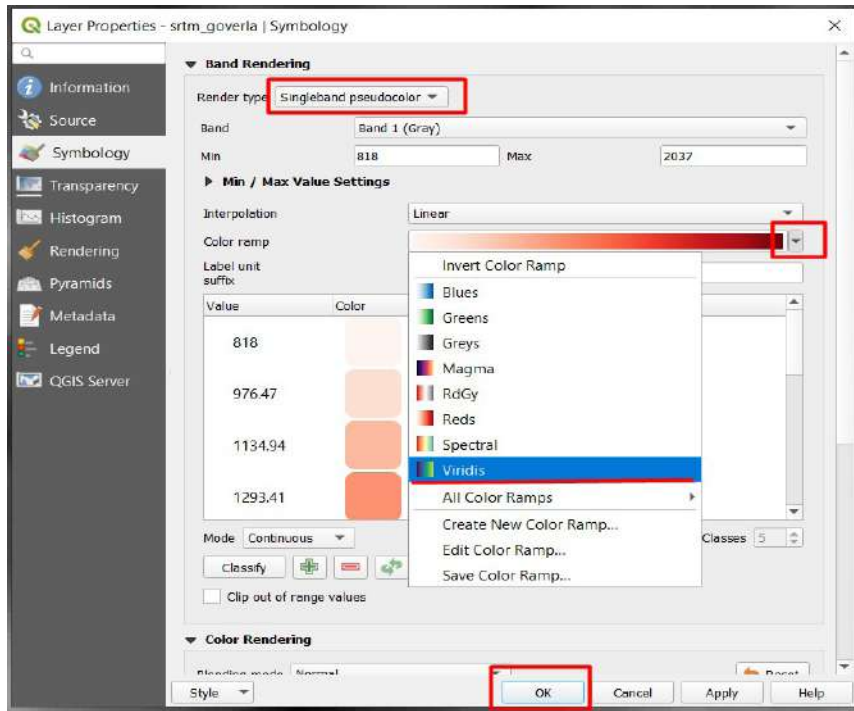


Once you hit the **Ok** button, a new raster layer will open in the project. We will use this file to speed things up.

5. Adjust the color display of terrain for better visualization of height differences. Double-click on the "srtm_goverla" under Layers to open the **Properties** window of the terrain layer. Switch to the **Symbology** tab and select the following settings from the dialog box:

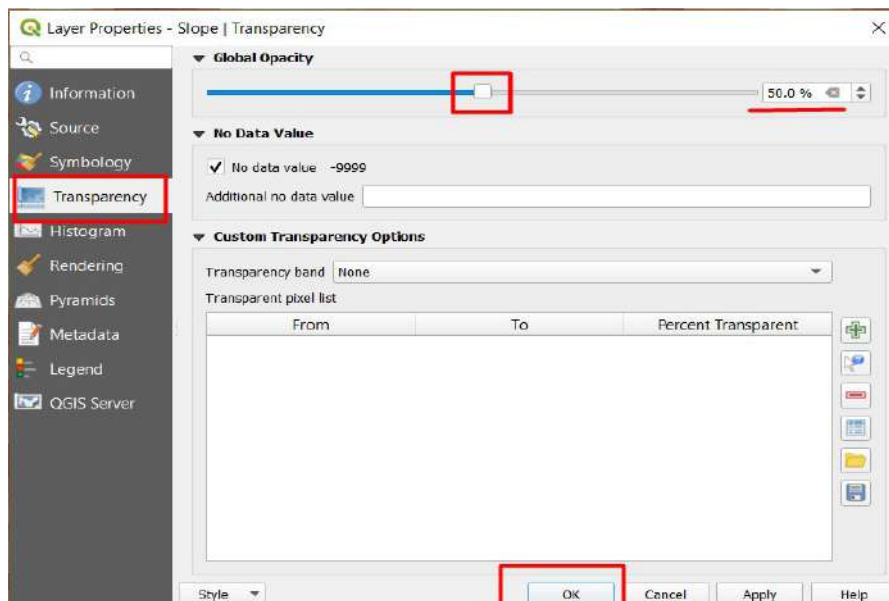
- **Render type** – *Singleband pseudocolor*;
- **Color ramp** – Select a scale from blue to yellow.

Click **Ok**.

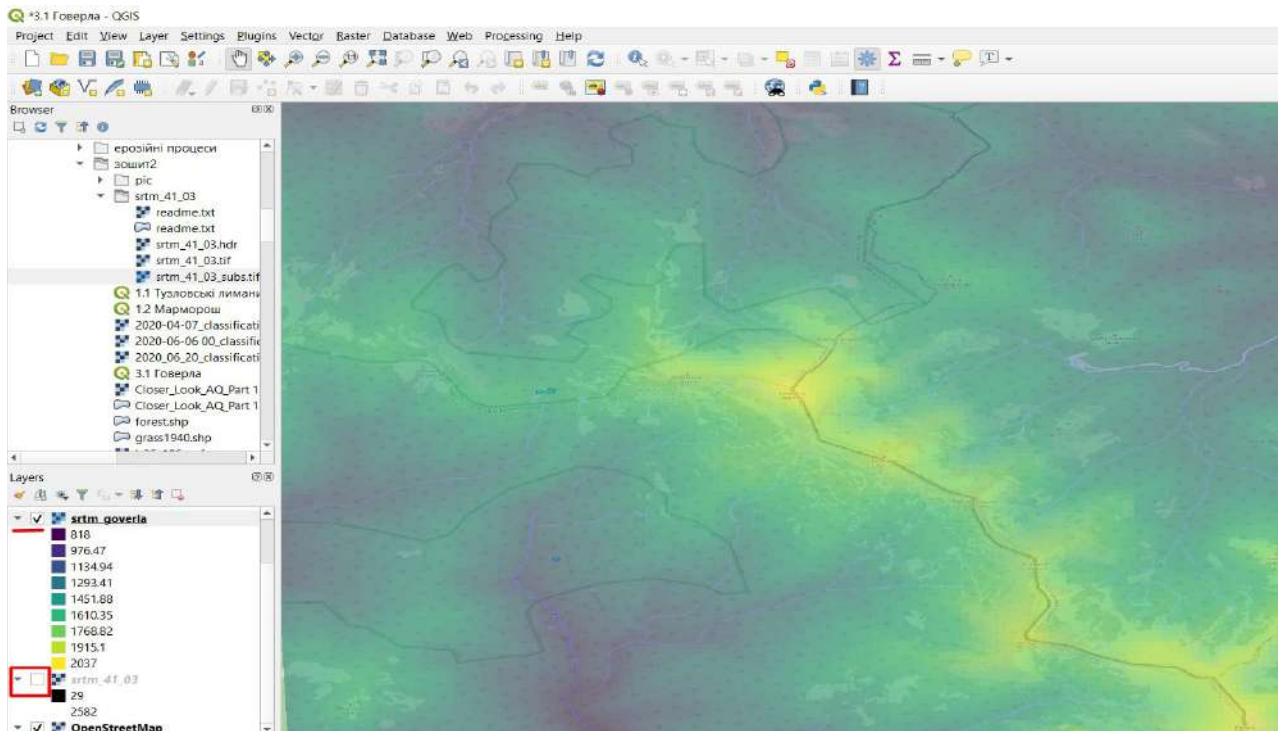


As a result, the peaks will be displayed in yellow and the lowlands in blue.

6. Make the elevation layer semi-transparent so that you can see also features on the map. Open the layer properties window again (double-click on the “srtm_goverla” layer under Layers), switch to the *Transparency* tab in the *Properties* window, and set the transparency level to 50%.



You should get the same output as in the Figure below.

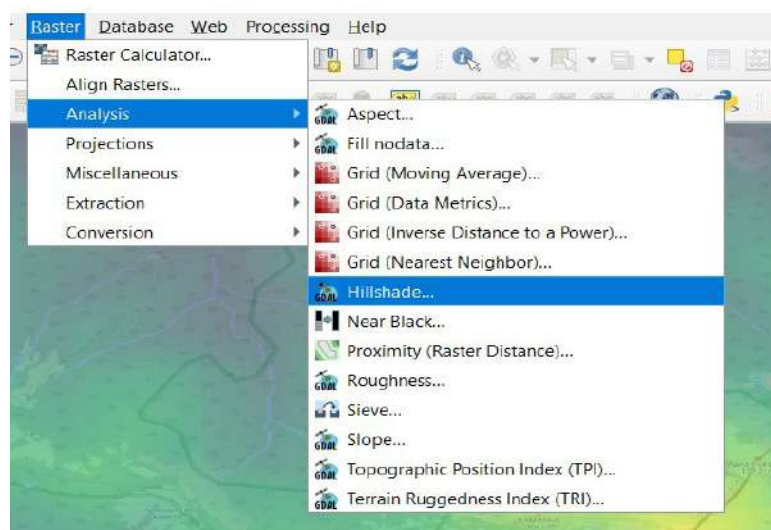


Note that the “srtm_41_03” input layer must be disabled, it can be deleted from the project (it will not be used anymore in this Task). The OpenStreetMap and “srtm_goverla” layers must be enabled. You can see from the map that the lowest parts of the area under study are located along the riverbeds. The Chornohora ridge is also well distinguished.

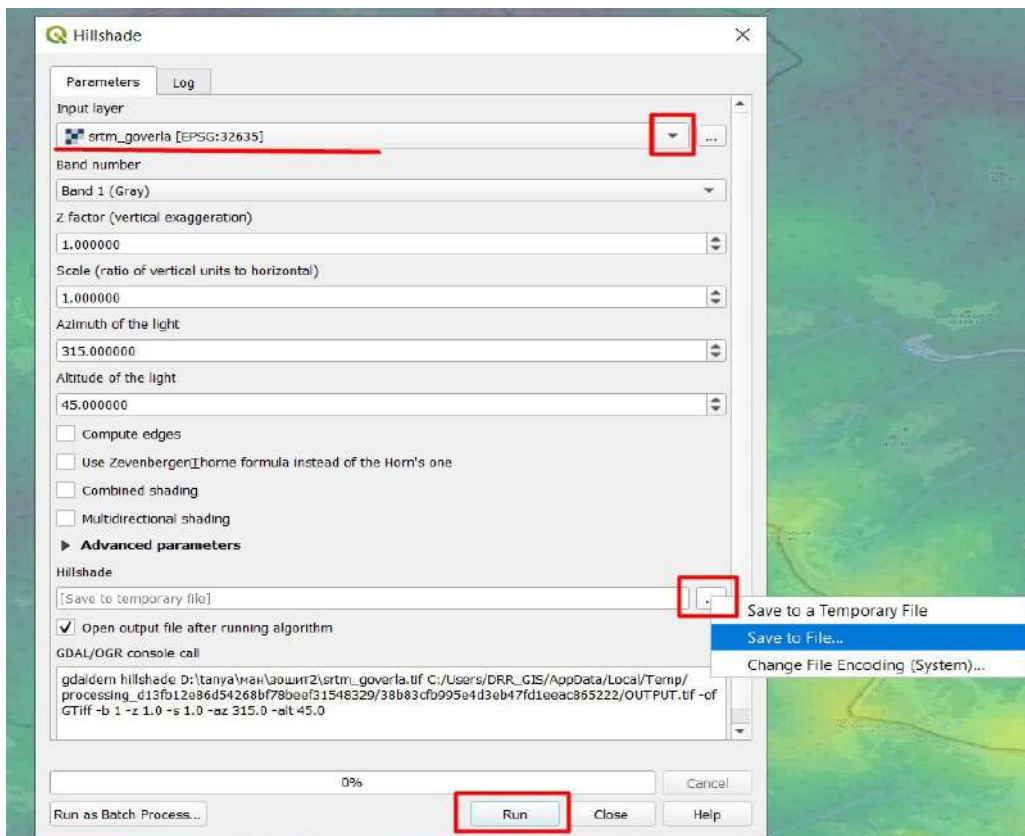
🔍 Check yourself

What other peaks of Chornohora ridge, besides Hoverla, can be identified on the map?	
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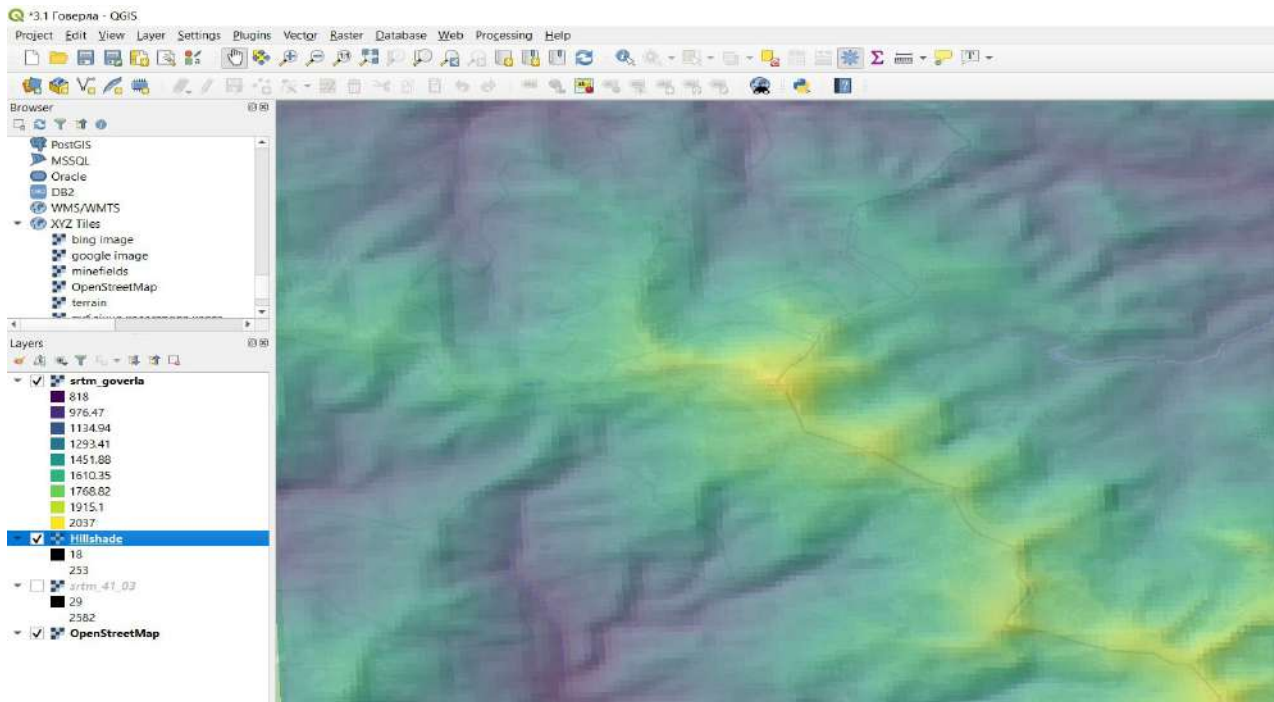
7. Another convenient way to visualize the elevation of the terrain is the **Hillshade** method, i.e. mapping the terrain in shades of grey using sunlight and shadow to create a 3D-looking image. This method allows you to enhance the topography of the landscape and is used mainly with overlapping a semi-transparent raster layer of elevations. To create a **Hillshade** layer, click on the menu items **Raster – Analysis – Hillshade**.



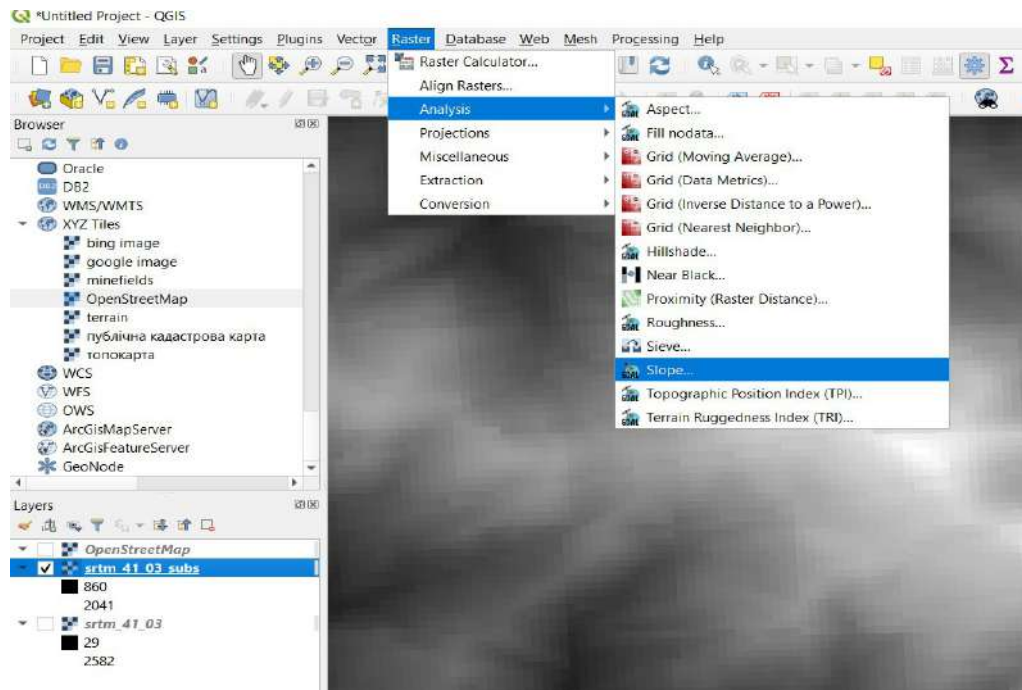
In the window that opens, specify “srtm_goverla” in the **Input layer** field, and set the name (e.g. “hillshade”) and the path to the folder where the output layer will be stored in the *hillshade* field, and click **Run**.



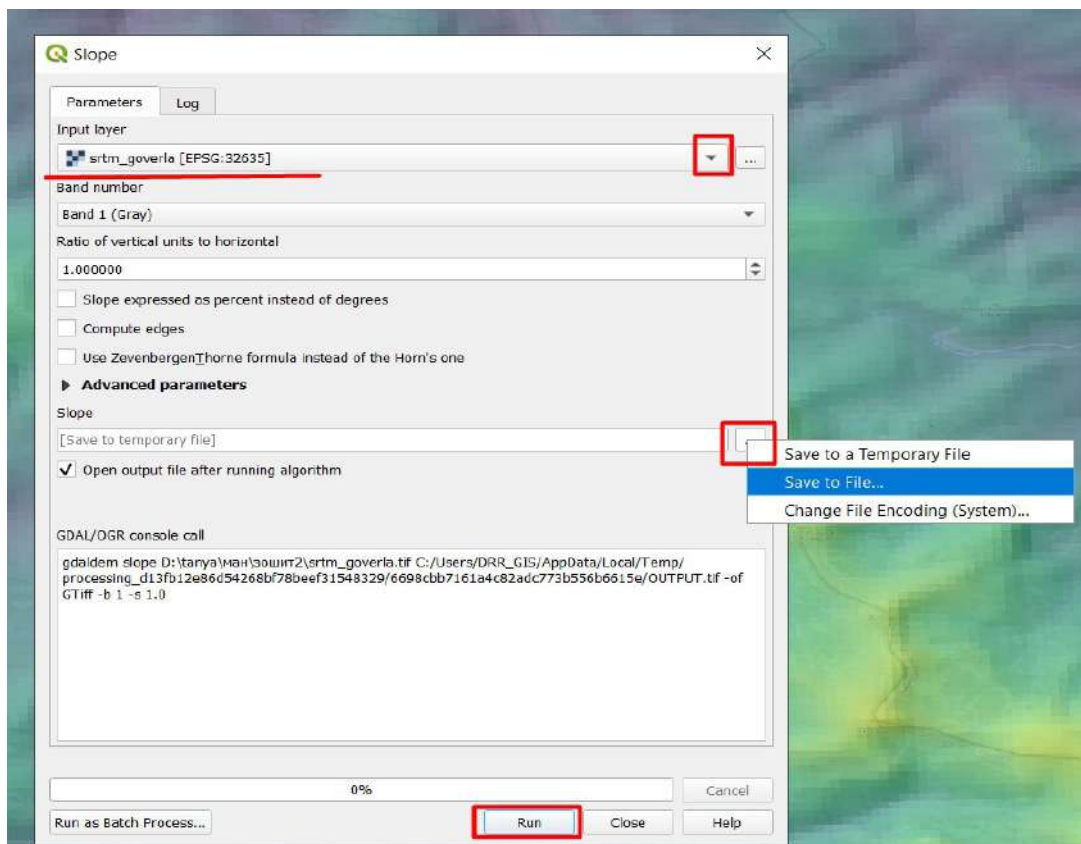
The created layer will open in your project. It is necessary to drag it with your mouse cursor to place it under the *srtm_goverla* layer. Next, open the properties of the *hillshade* layer and adjust its transparency – 50% (as described in paragraph 6 of this Task). The result should look like in the Figure below.



8. Another useful thing to know about the terrain is how steep it is. Therefore, we will now create a slope map. This will help to identify the flat and steep terrain, and therefore, choose an easier way to climb to the top. To do this, click on the menu items **Raster – Analysis – Slope**.



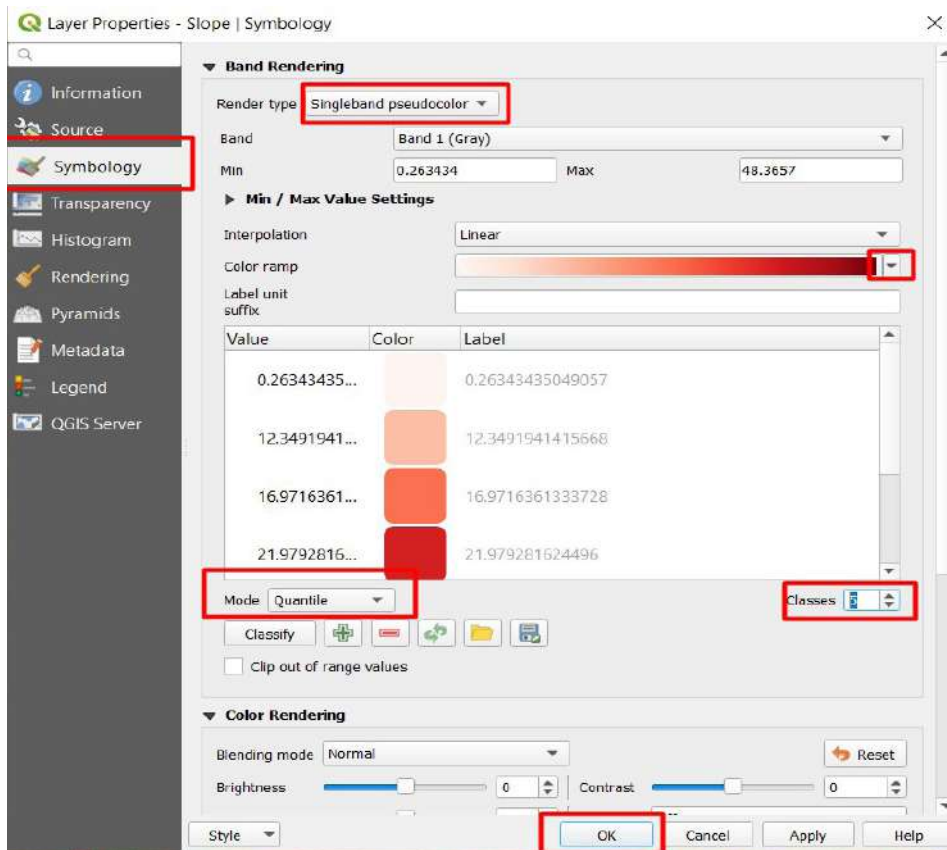
In the window that opens, specify “srtm_goverla”, the name (for example, “slope”), and the path to the source layer under **Input layer**.



9. Adjust the display of the slope map. To do this, open the layer properties window (double-click on the layer in the Layers tab) and select **Properties**. Specify the following in the **Symbology** tab:

- **Render type** – *Singleband pseudocolor*;
- **Color ramp** – select a scale with a red color gradation;
- **Mode** – *quantile*;
- Classes – 5.

To finish, click **Ok**.

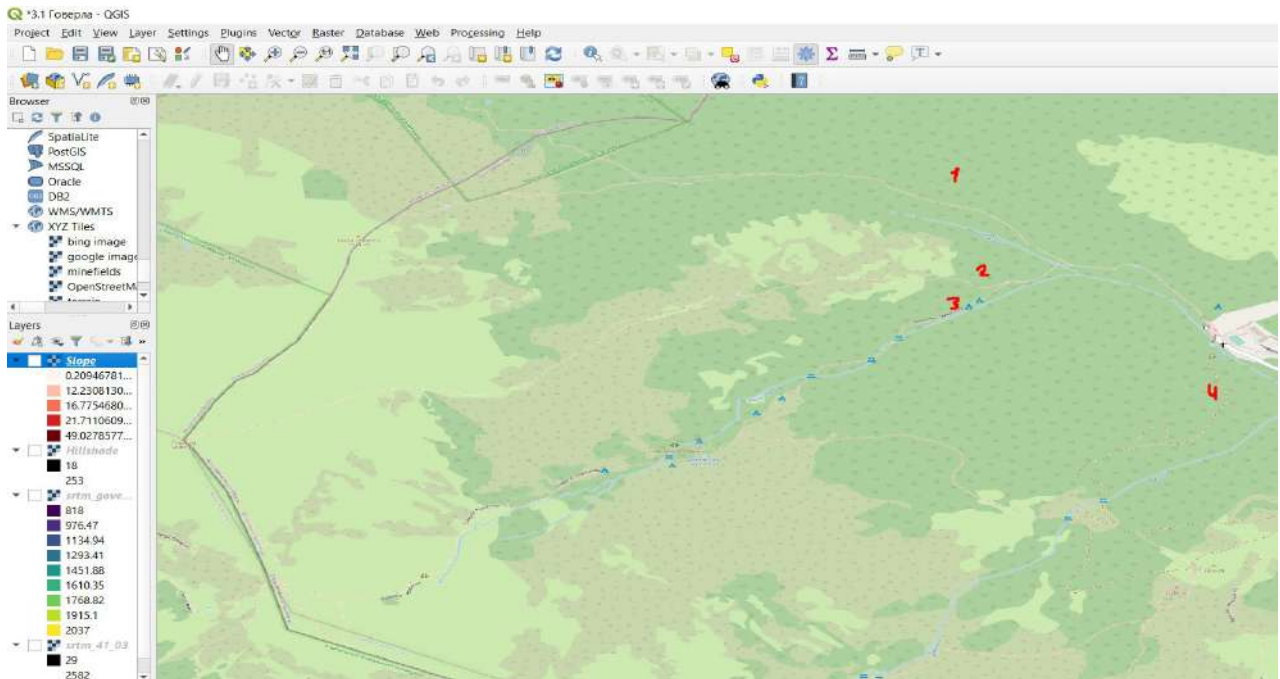


Now you see how the slope changes as you approach the summit from the side of the Zarosliak tourist complex – steepness is expressed in degrees (it is lower on gentle slopes and higher on steep slopes). You can review the slope values using the **Identify results** tool.

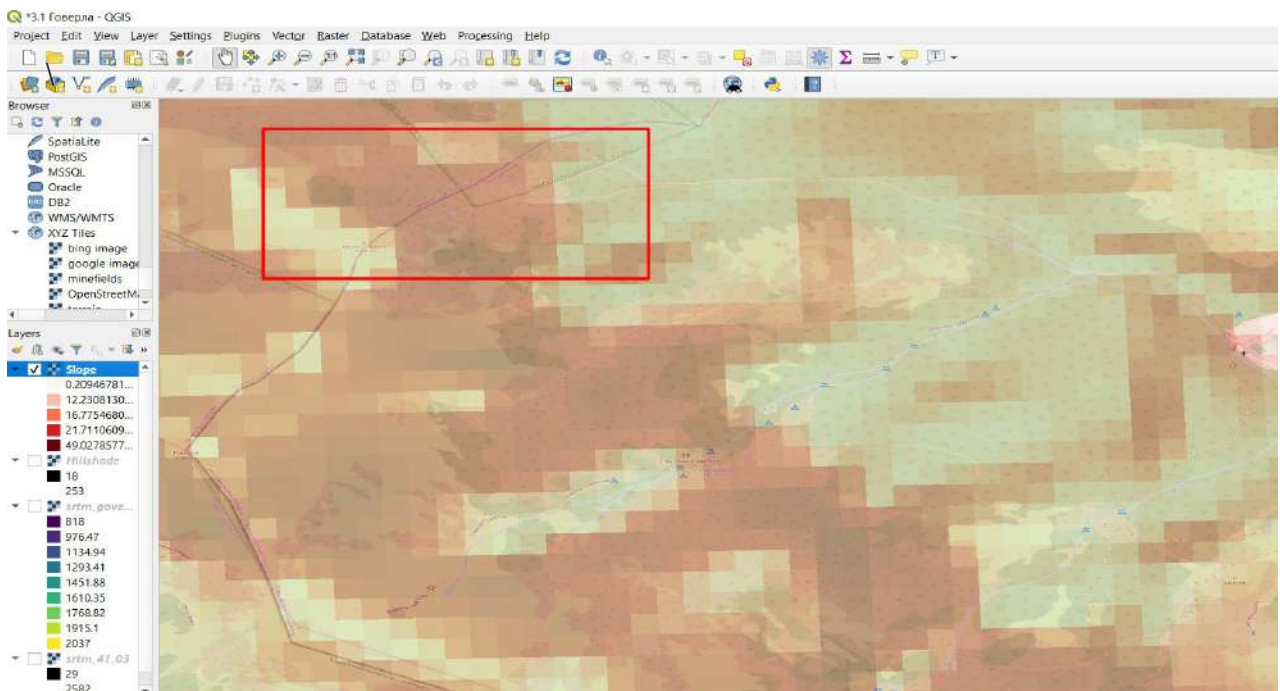
🔍 Check yourself

Analyze the slope map and determine whether the steepness of the slopes increases as we approach the summit of Hoverla.	
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10. Take a look again at the OpenStreetMap map, disable all other layers in the Layers tab and position the map so that you can see the routes to Hoverla Mount from the Zarosliak tourist complex. The climbing routes appear as dotted lines on the map, so you can see four main trails that are numbered in the Figure below.



According to the map, route 2 is the shortest one. Now enable the slope layer and analyze which trail will be the easiest, with the gentlest slope (for better visualization, you can increase the transparency of the “slope” layer to 30%). With this visualization, it becomes clear that route 1, which passes through Mala Hoverla Mount, is the flattest one, and therefore, the easier albeit longer trail. It has a sharp rise in front of Mala Hoverla Mount, almost in the middle of the route.

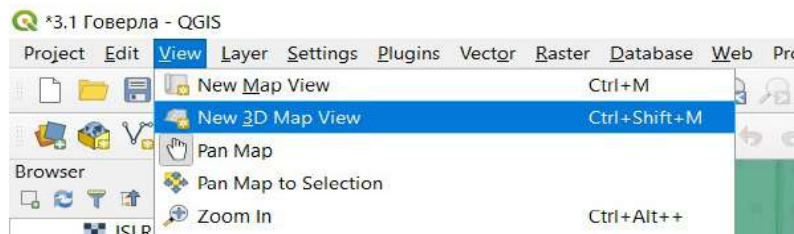


Route 1 is called Green (the easiest), and route 2 is called Blue (the most difficult). These routes are marked accordingly on the scheme of climbing routes to Hoverla Mount.

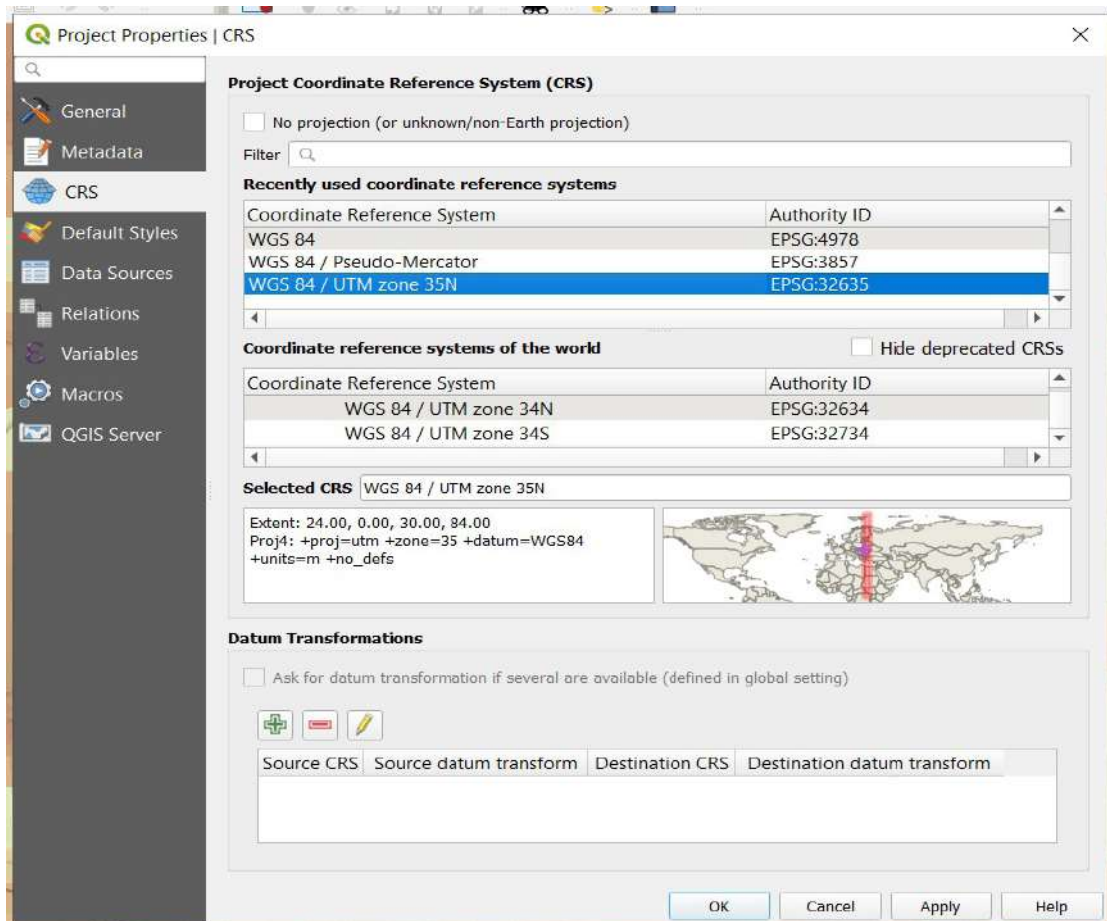


Scheme of marked routes to Hoverla Mount
(URL: <https://pohod-v-gory.com/маршруты-на-говерду>).

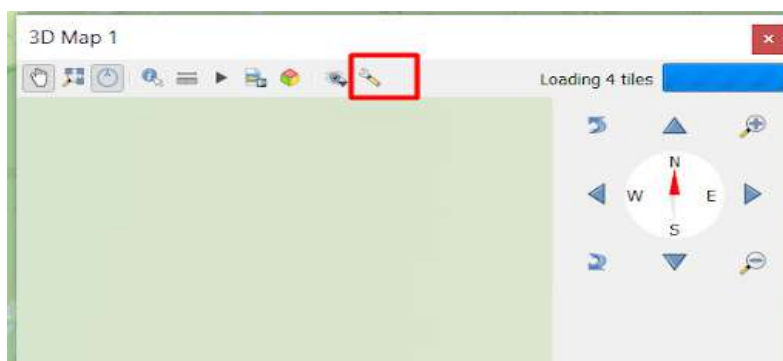
11. Let's create now a 3D-visualization of the terrain around Hoverla Mount. Leave only the "srtm_hoverla" layer (transparency 50%) and "OpenStreetMap" enabled in the project, so that the height and marks on the map can be seen at the same time. Click the **View** menu item and select **New 3D Map View**.



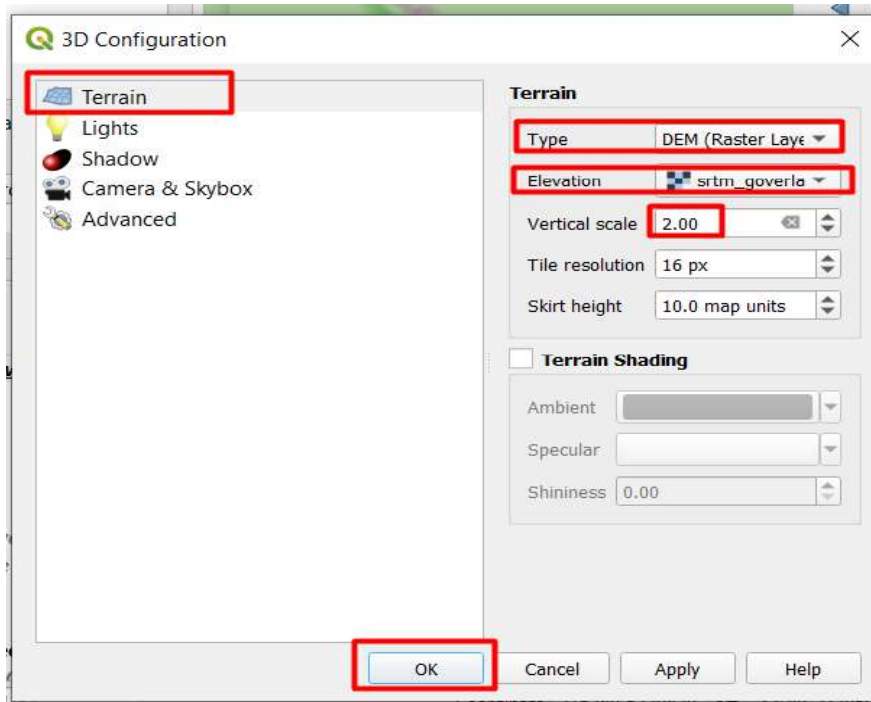
It is not possible to create a 3D visualization for a project in a geographic coordinate system – you need to change the map projection to WGS 84 zone 35N (projected coordinate system). To do this, click on the **Project, Properties** menu items and in the window that appears, open the CRS tab, enter "WGS 84 zone 35N" in the **Filter** field, select this projection from the **Coordinate Reference System** window, and click **Ok**.



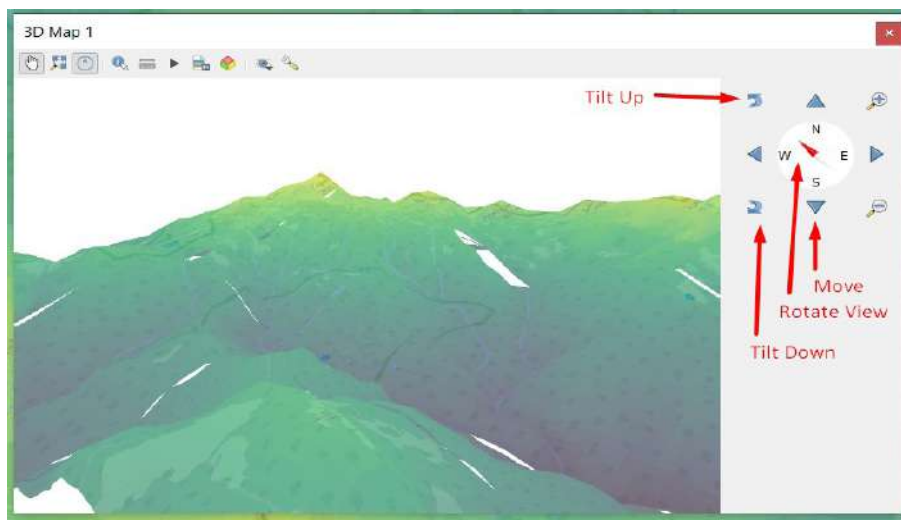
In the window that opens, click the *Configure* tool .



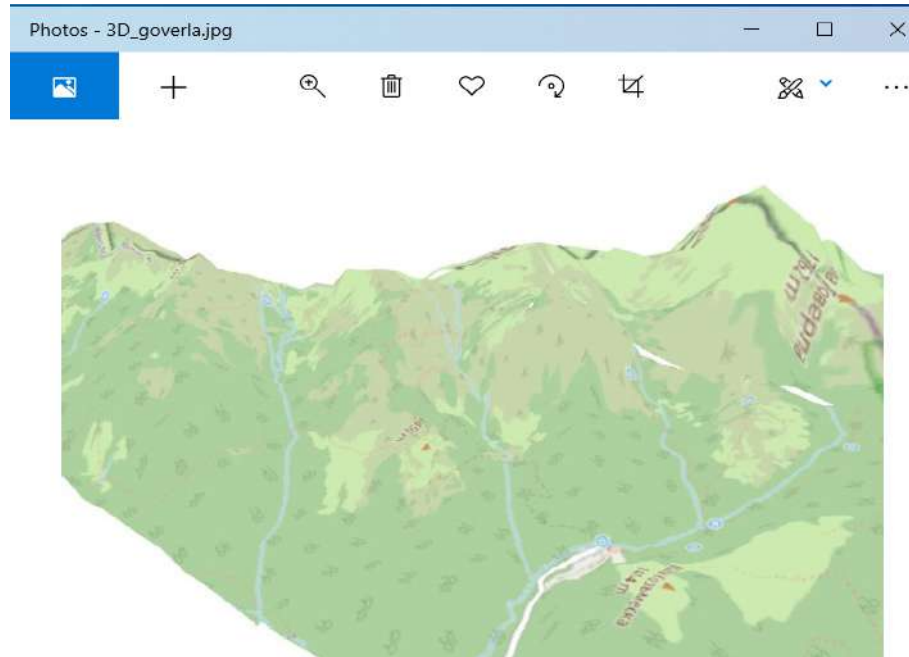
Switch to *Terrain* in the window that appears, select *DEM* (which stands for *digital elevation model*) in the *Type* field, specify the “srtm_goverla” layer under *Elevation*, and select 2 in the *Vertical Scale* field (this will increase the effect of the height difference for better visualization), and click *Ok*.



You can now rotate the 3D model by holding down the mouse wheel. Move the wheel to zoom in and view the 3D model from different angles. Note that active (enabled in the project) layers only will display, so you can add different vector and raster data to your project to display them in the 3D model. You can also enlarge the 3D visualization window by stretching the corners of the window with your mouse cursor.



12. Select the angle you like, click the *Save as image* tool , and save the selected 3D model angle as the image.



Scan the QR-code below to watch the video tutorial on the performance of this Task.



4.2. Analyzing Terrain to Determine the Growing Conditions of Rare Orchid Species in the Carpathians

Terrain (relief) is a set of forms of the earth's surface in different stages of development and in a complex interrelation with each other and the environment (Wikipedia). Terrain affects the microclimate of the region, which in turn affects the distribution of heat, light, water and other resources available to plants growing in the area. Therefore, analysis of terrain is essential for the distribution and growth studies, in particular of rare plant species, and assessment of existing risks and threats to their habitats.

Task

In this Task, we will analyze the terrain of the places where orchids grow naturally in the Carpathians: the altitudes and slopes (North-facing, South-facing, or other).

The orchid family is one of the largest groups of plants on the planet. Representatives of this family can be found on every continent except Antarctica; they grow in rainforests, savannas and steppes, hot lowlands, cold mountainous areas, at altitudes of up to 5,000 m. However, the greatest number of Orchidaceae (orchid family) species can be found in tropical and subtropical zones of East Asia, as well as in Central and South America. Approximately 70 species of orchids grow in Ukraine, and most of them are listed in the Red Data Book (Wikipedia).

We will find the places where orchids naturally grow with iNaturalist social network, which can be accessed via its website or from its mobile application. On iNaturalist, users can identify the species

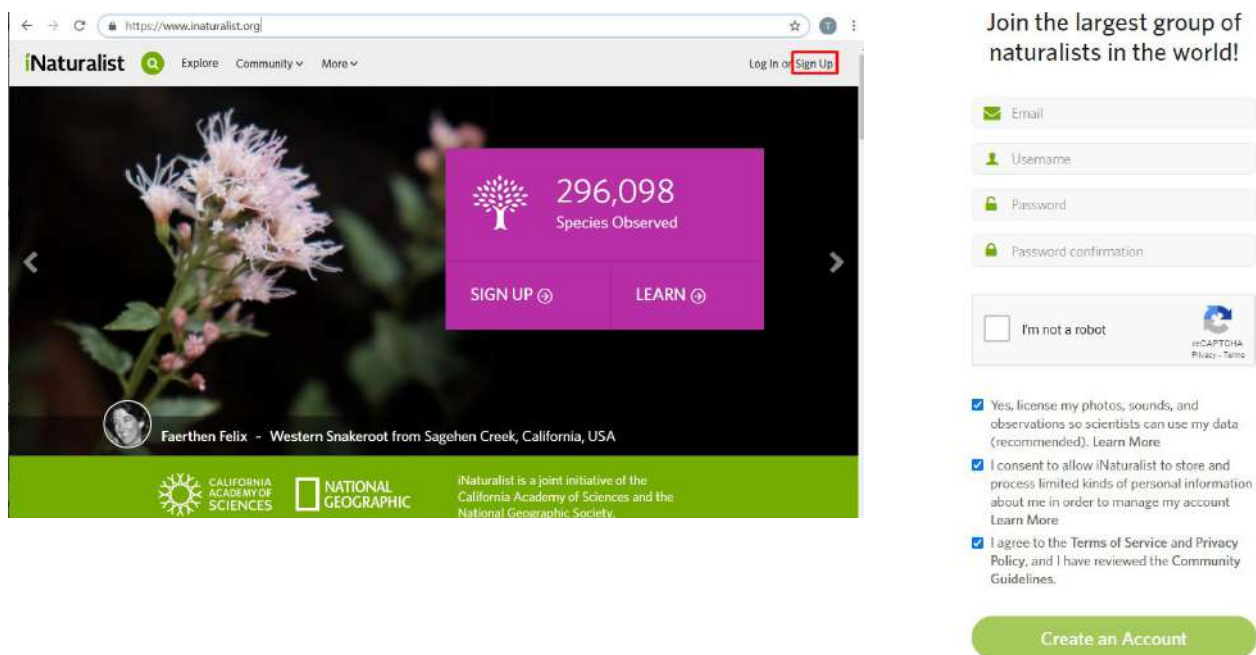
from a photo of a plant, animal, fungus, or other organisms with the help of the automated species identification tool and community of naturalists, and save the location in the database. iNaturalist provides valuable data for environmental specialists that help to understand the threats and justify conservation efforts, e.g. the creation of protected areas in the habitats of species.

Task performance algorithm:

1. Download data on the places where orchids naturally grow in the Carpathians using iNaturalist platform.
2. Characterize the terrain (altitude, slope, and aspect) in places where orchids grow.
3. Describe the conditions of growth (ecological niche) of the Orchidaceae in terms of terrain.

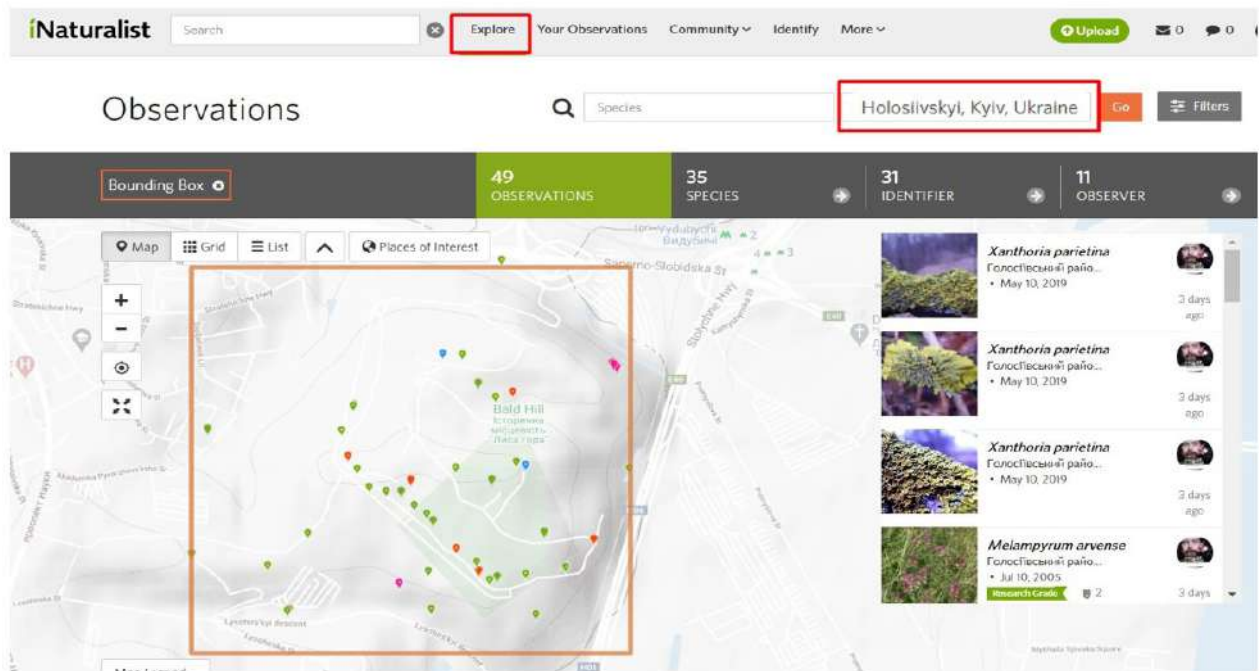
Instructions for self-guided work:

1. Go to <https://www.inaturalist.org/> and sign up. Registration is very simple: you need to specify your e-mail, invent and specify the username, password, enter the password again in the field below (password confirmation), check “I’m not a robot”, agree to other terms of use of the service, as in the Figure below.



iNaturalist interface (URL: <https://www.inaturalist.org/>)

2. Find the nearest natural area on the map and review the species that were identified and photographed in this area. To do this, click on the **Explore** menu, and in the window that appears, enter the name of the natural area near you in the **Location** field (the name of the forest, park, tract, etc.), such as “Holosiivskyi, Kyiv, Ukraine”.

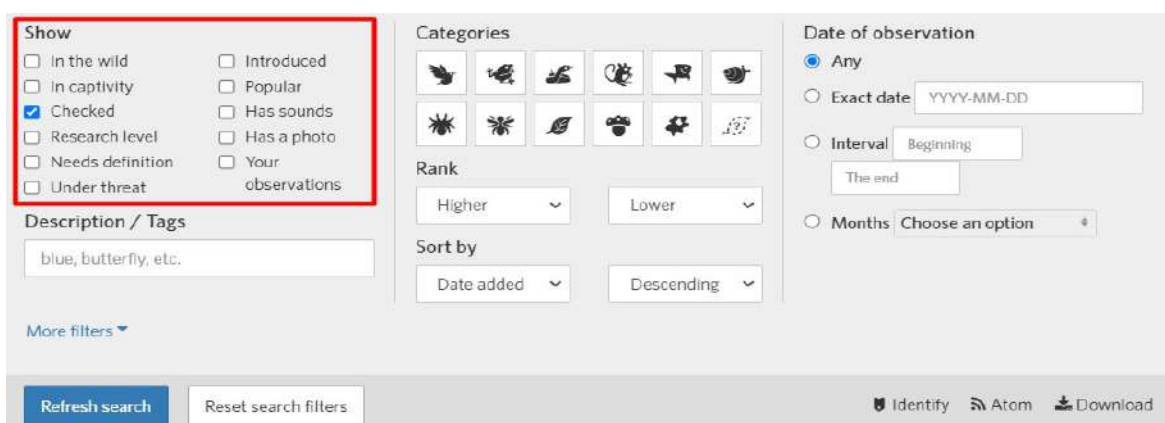


iNaturalist website interface: Search results for “Holosiivskiy, Kyiv, Ukraine”
(URL: <https://www.inaturalist.org/>)

The search area will be highlighted in red on the map, and a list of species photographed and saved by community members will be displayed on the right side of the screen. If you have already created an account before, the *Observation* tab will appear. If this is the case, check and remove the filter by clicking on the **Filter** menu item at the top of the window.



In the **Show** module of the window that pops up, tick the box next to the **Checked** item – verified results only will be displayed in the search results. Next click **Refresh search**.

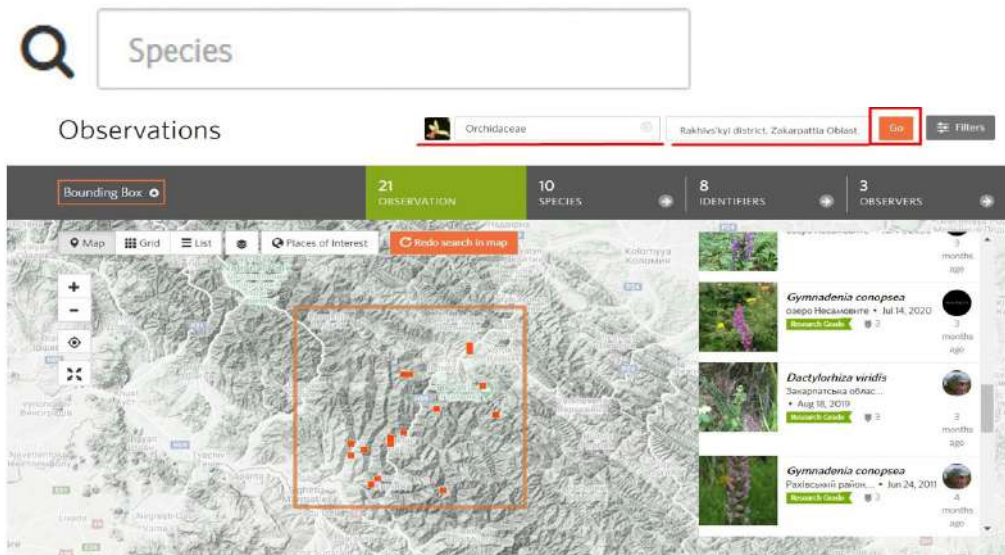


iNaturalist website interface: Search results for verified wildlife species
(URL: <https://www.inaturalist.org/>)

? Check yourself

Specify five types of species observed in the natural area that is nearest to you (e.g., forest, park, coast)

3. We will find now the area of the Carpathians on the map and search for the places where orchids grow in the database. To do this, enter *Orchidaceae* (this is the scientific term denoting plants of the orchid family) in the **Species** search bar, and pick this family from the drop-down list. Next, enter *Rakhivskyi District* (select from the list) in the **Location** field, and click **Go**.



iNaturalist website interface: Search results for the *Orchidaceae* species in Rakhivskyi District, Zakarpattia Oblast, Ukraine (URL: <https://www.inaturalist.org/>)

The search area enclosed in a square with an orange outline, as well as a list of recorded observations will display on the map. By clicking on the **Species** tab, you can review in more detail all the orchid species found in the selected area. Currently, there are 10 such species in the database (the number of species and observations may change over time).



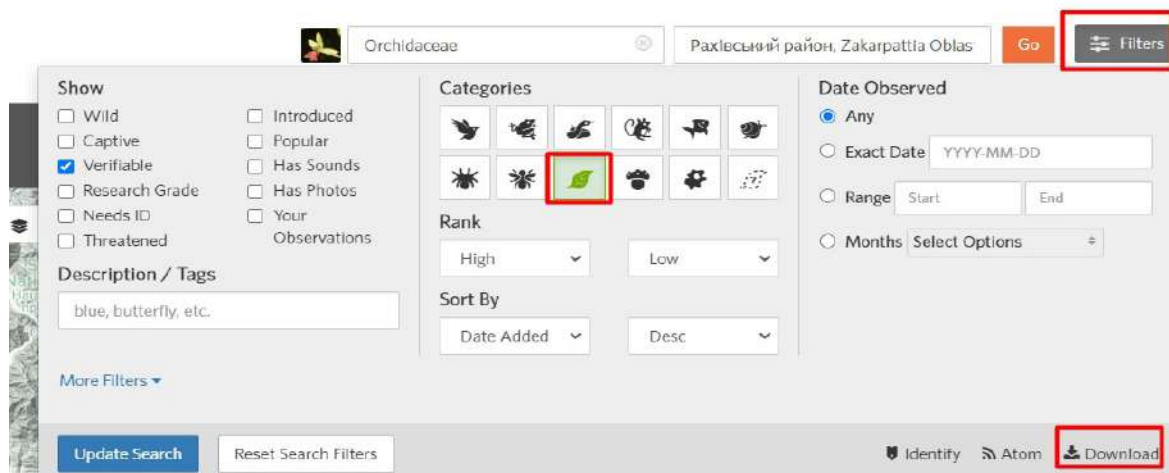
iNaturalist site interface: Search results for the *Orchidaceae* species in Rakhivskyi District, Ukraine (URL: <https://www.inaturalist.org/>)

If the list of observations is missing, check the **Filter** menu item – it should be disabled to avoid searching among your observations only (described in more detail in paragraph 2 above).

? Check yourself

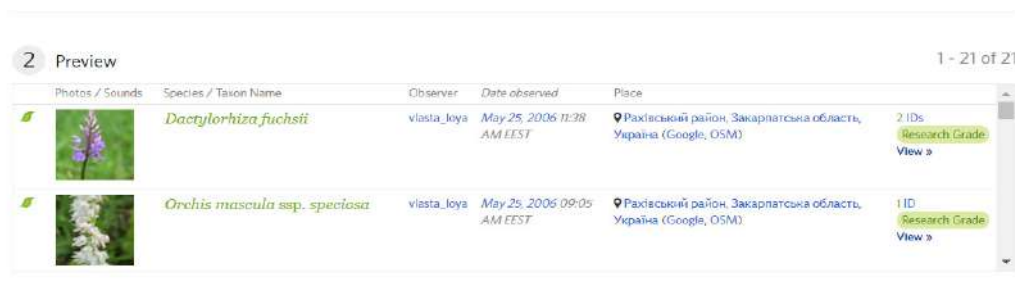
Specify the number of observations (i.e. places where orchids were found in the Carpathians) that are displayed on iNaturalist.

4. We will save these found places where orchids grow as a database that can be opened in QGIS as a vector layer of vertices. To do this, go to the **Filters** tab, and in the dialog that opens, set the following: tick the box next to **Verifiable** under **Show**, select the plant icon under **Categories**, and select **Any** under **Date Observed**. Then click the **Download** tool.



iNaturalist website interface: Search results for the Orchidaceae species in Rakhivskyi District, Ukraine, verified wildlife species (URL: <https://www.inaturalist.org/>)

In the window that opens, you can check whether the data was selected correctly by scrolling down the page and viewing item 2, **Preview**. The data you want to download should appear in this list.



iNaturalist website interface: Search results for the Orchidaceae species in Rakhivskyi District, Ukraine, verified wildlife species (URL: <https://www.inaturalist.org/>)

Scroll down and click **Create Export**.

Note: these columns will slow down the generation of your export:

<input type="checkbox"/> taxon_kingdom_name	<input type="checkbox"/> taxon_phylum_name	<input type="checkbox"/> taxon_subphylum_name	<input type="checkbox"/> taxon_superclass_name
<input type="checkbox"/> taxon_class_name	<input type="checkbox"/> taxon_subclass_name	<input type="checkbox"/> taxon_superorder_name	<input type="checkbox"/> taxon_order_name
<input type="checkbox"/> taxon_suborder_name	<input type="checkbox"/> taxon_superfamily_name	<input type="checkbox"/> taxon_family_name	<input type="checkbox"/> taxon_subfamily_name
<input type="checkbox"/> taxon_supertribe_name	<input type="checkbox"/> taxon_tribe_name	<input type="checkbox"/> taxon_subtribe_name	<input type="checkbox"/> taxon_genus_name
<input type="checkbox"/> taxon_genushybrid_name	<input type="checkbox"/> taxon_species_name	<input type="checkbox"/> taxon_hybrid_name	<input type="checkbox"/> taxon_subspecies_name
<input type="checkbox"/> taxon_variety_name	<input type="checkbox"/> taxon_form_name		

Observation Fields (All | None)

4 Create Export

iNaturalist website interface: Exporting search results for the Orchidaceae species in Rakhivskiy District, Ukraine (URL: <https://www.inaturalist.org/>)

As a result, you will get a table generated according to the specified sampling criteria as a separate file that must be downloaded by clicking on the **Download** tool.

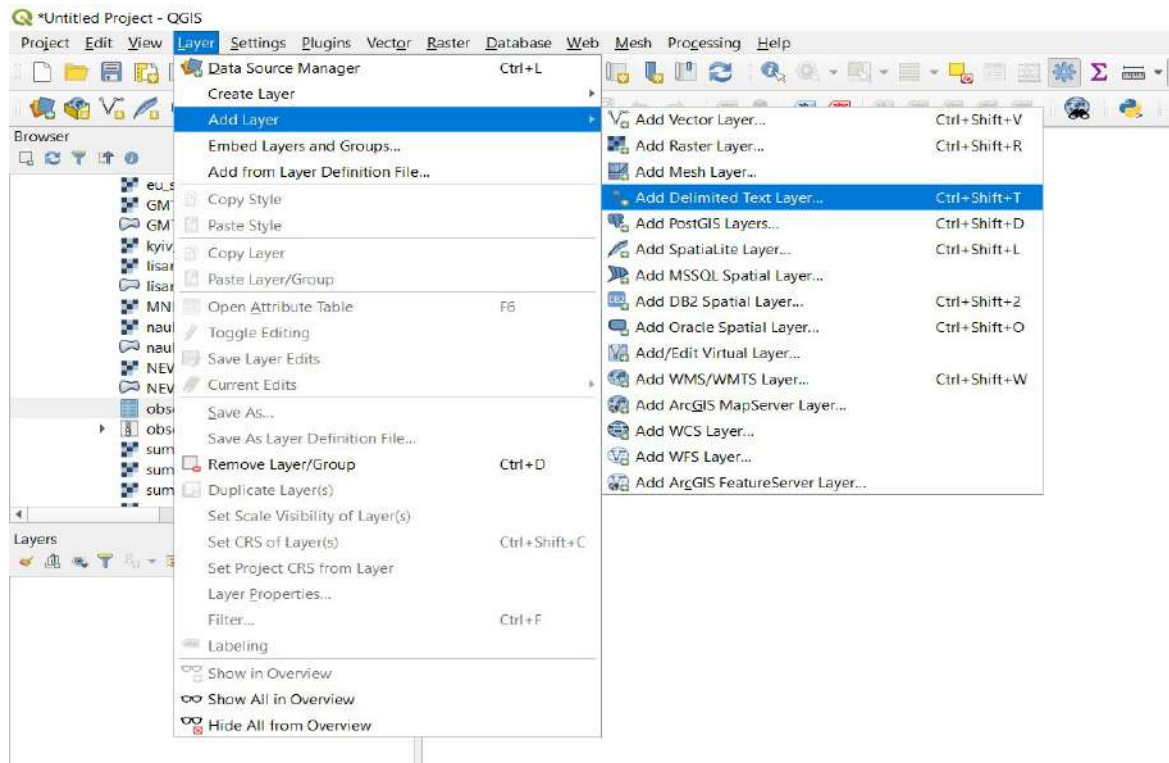


iNaturalist website interface: Export results for the Orchidaceae species in Rakhivskiy District, Ukraine (URL: <https://www.inaturalist.org/>)

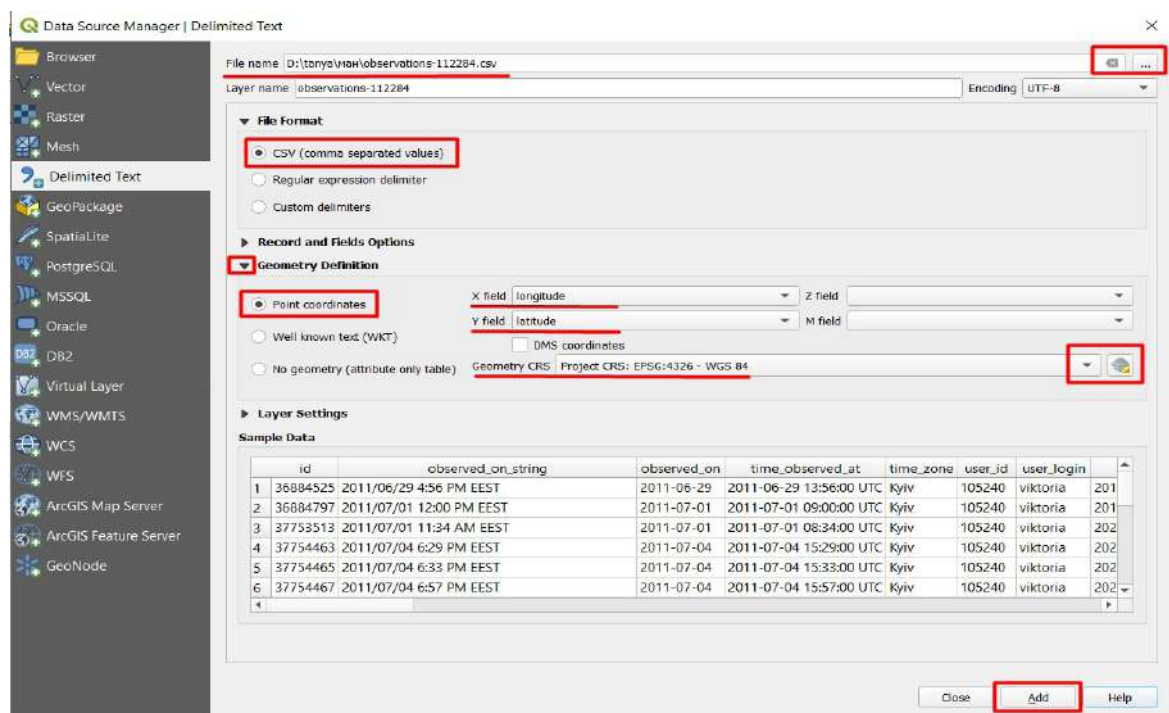
Once you unzip the downloaded file, you will get a table containing data of found orchids in csv format, which can be opened with QGIS. You can also download this “observations-112284.csv” file at <https://drive.google.com/drive/folders/1FqrxnbnmNwKjBG1T1zNxfHd66hMWovdAm>, along with materials for this Task.

5. Open QGIS, create a new project and unzip the downloaded file.

6. Next, open the table downloaded from the iNaturalist site, which contains data of found places where orchids grow as a vector point layer. To do this, select from the **Layer** menu: **Add Layer – Add Delimited Text Layer**.



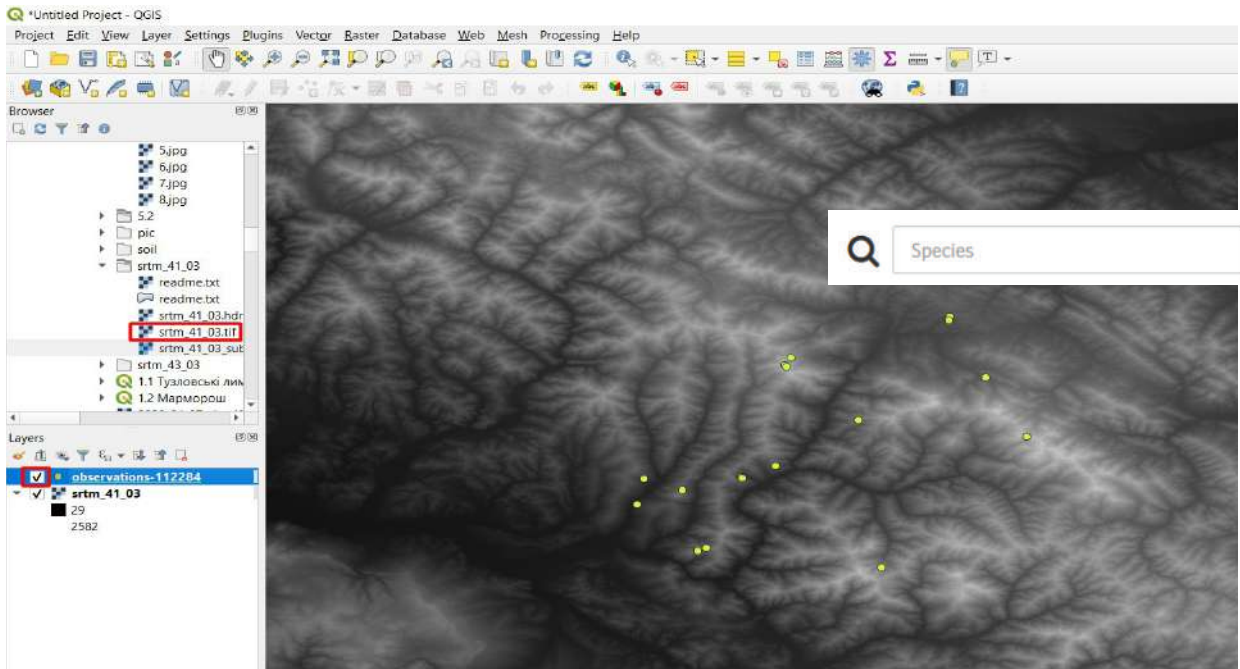
In the window that opens, specify the downloaded file containing the data of orchid locations in the **File name** field; select “scv” under **File format**; expand the **Geometry Definition** tab and select **Point coordinates, X field – longitude** (it is in this field that the longitude coordinate is stored in the downloaded table), **Y field – latitude**; and specify “WGS 84” in the **Geometry CRS** field (map projection). Click **Add**.



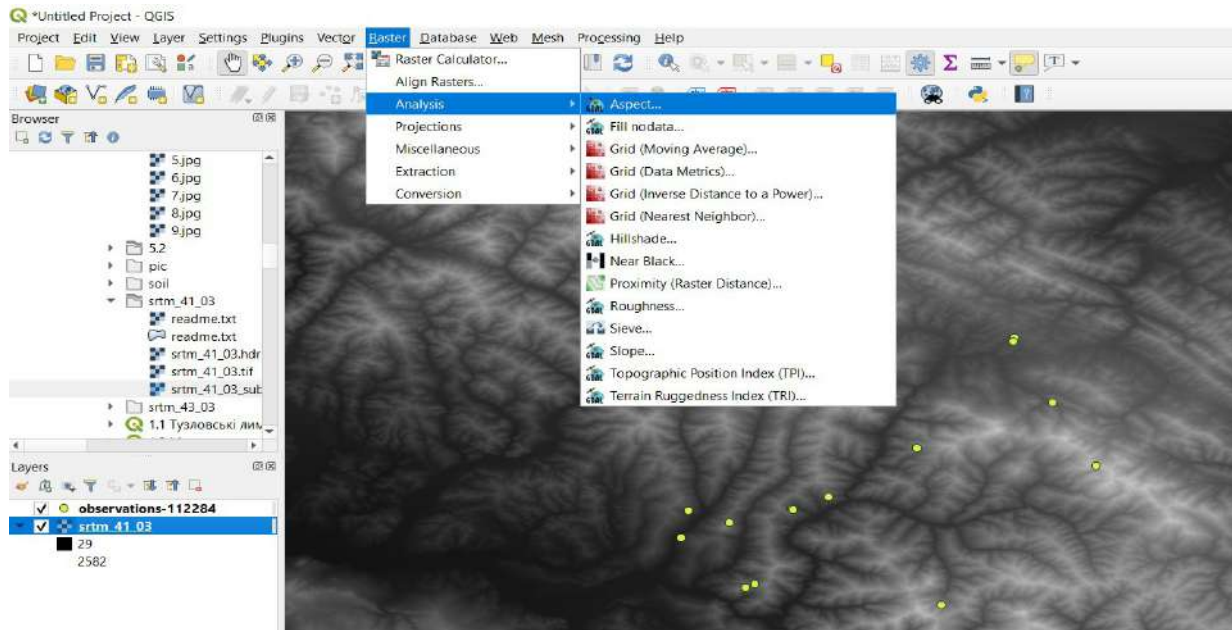
As a result, you will get a map of places where orchids grow.

7. Open the SRTM raster terrain layer of the Carpathians (we have downloaded this layer in Task 4.1; instructions for creating a layer are described in pp. 1-2). Make sure that the point layer is located above the terrain layer; if necessary, change the placement of the point layer in Layers. You can also download this

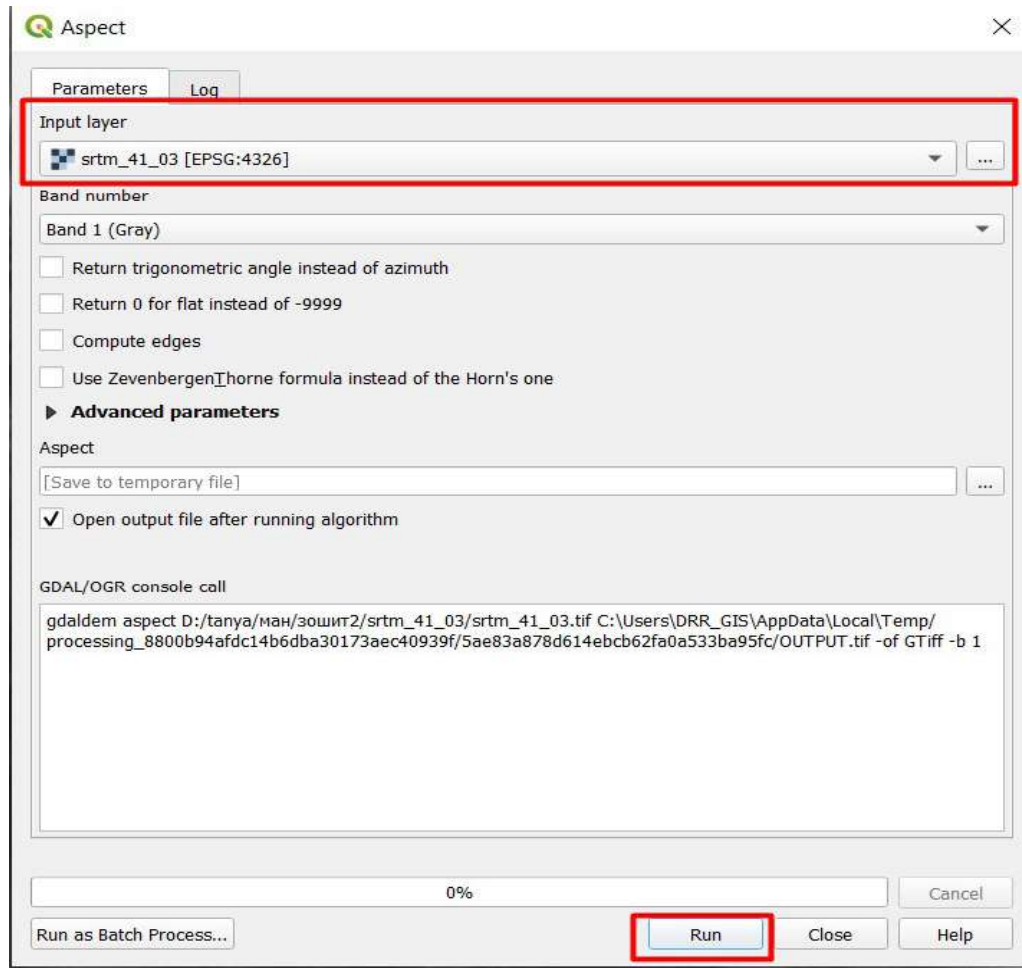
layer from <https://drive.google.com/drive/folders/1FqrxnbnwNwKjBG1T1zNxfHd66hMWovdAm>, along with materials for this Task.



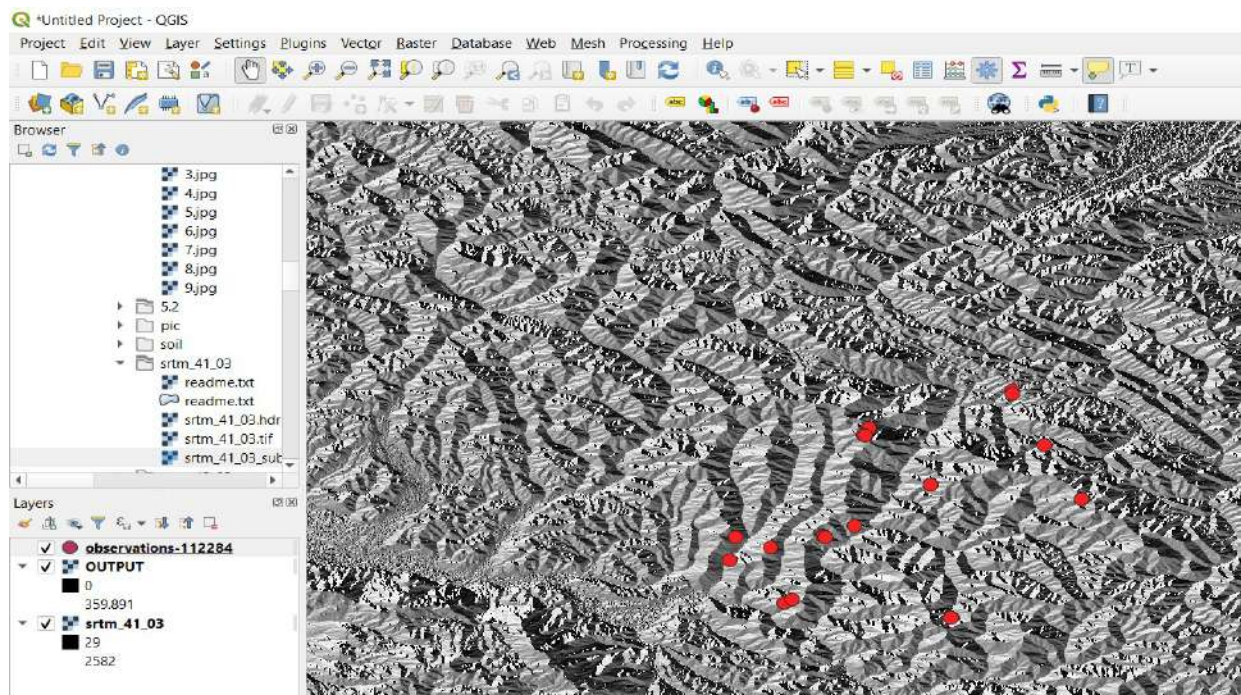
8. Create an aspect map based on the SRTM terrain layer. To do this, open the **Raster** menu – **Analysis – Aspect**.



In the window that appears, specify **Input layer – SRTM_41_03** (downloaded terrain layer), and click **Run**.



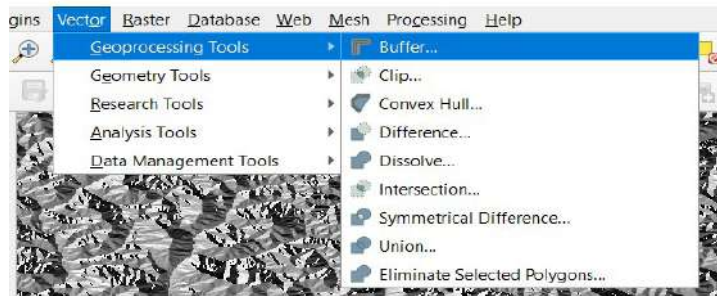
As a result, an aspect map will be created, where you can see the part of the world the slope faces (the East, West, South, or North).



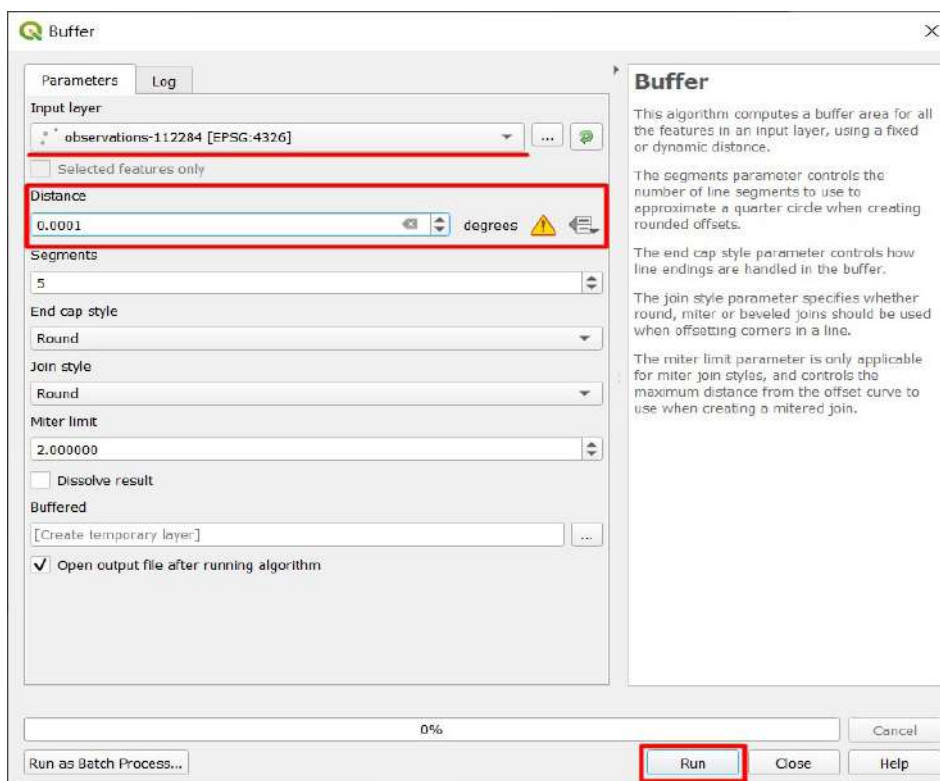
? Check yourself

Specify in which part of the aspect map the riverbed is located in the Figure above.
What are the signs of the riverbed on the aspect map?

9. Now we will review the values of altitudes and aspects at the places where the orchids were found. To do this, we will use the **Zonal statistics** tool. As far as this tool can only be used for a polygonal layer and not a point one, first, we will create a vector polygon layer from the vector point layer using the **Buffer** tool. So, open the **Vector** menu – **Geoprocessing Tools** – **Buffer**.

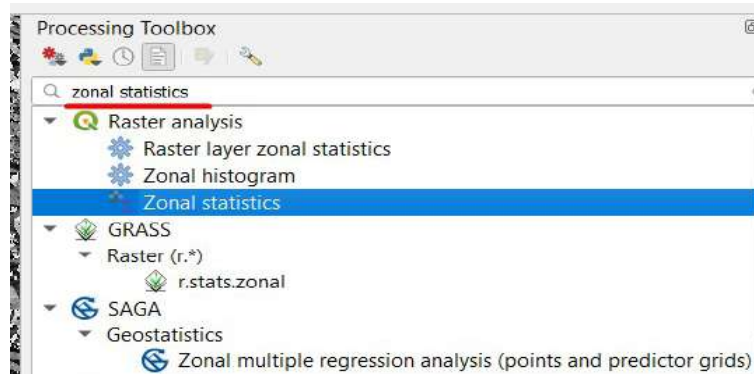


In the window that appears, specify “observations” vector point layer under **Input layer** and the minimum value “0.0001” (degrees) in the **Distance** field, click **Run**.

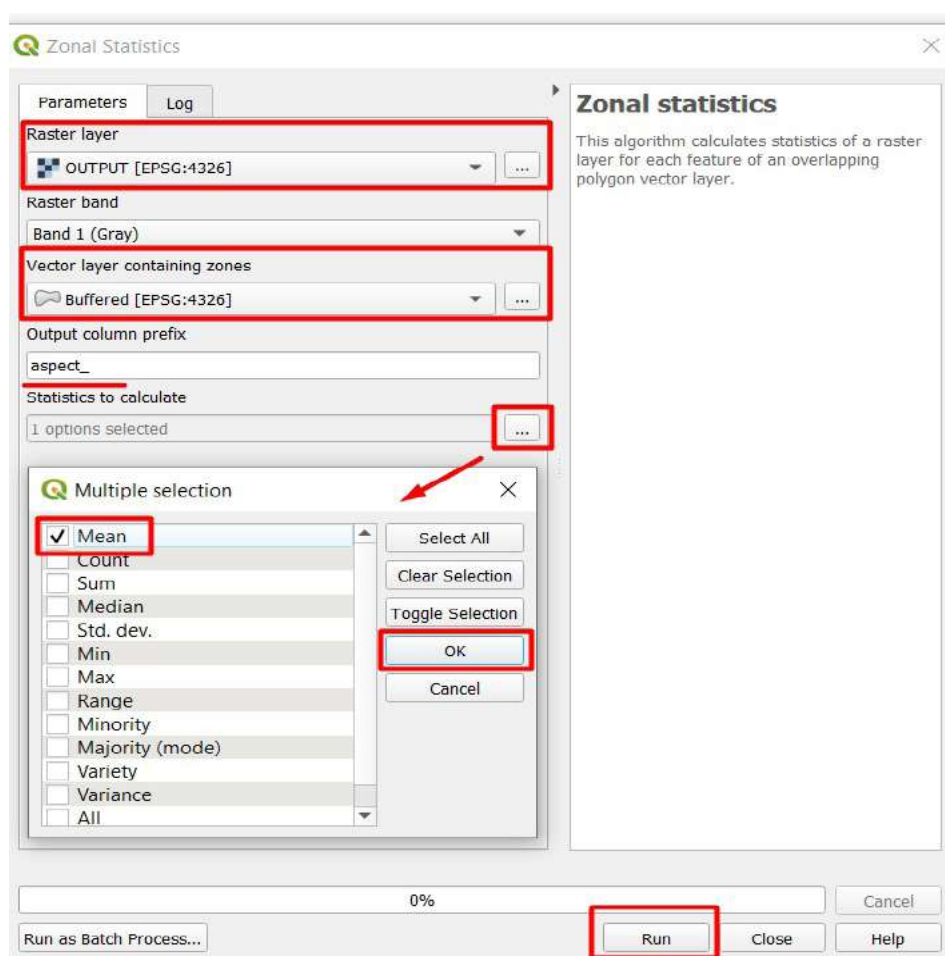


A new vector polygon layer should open in the project.

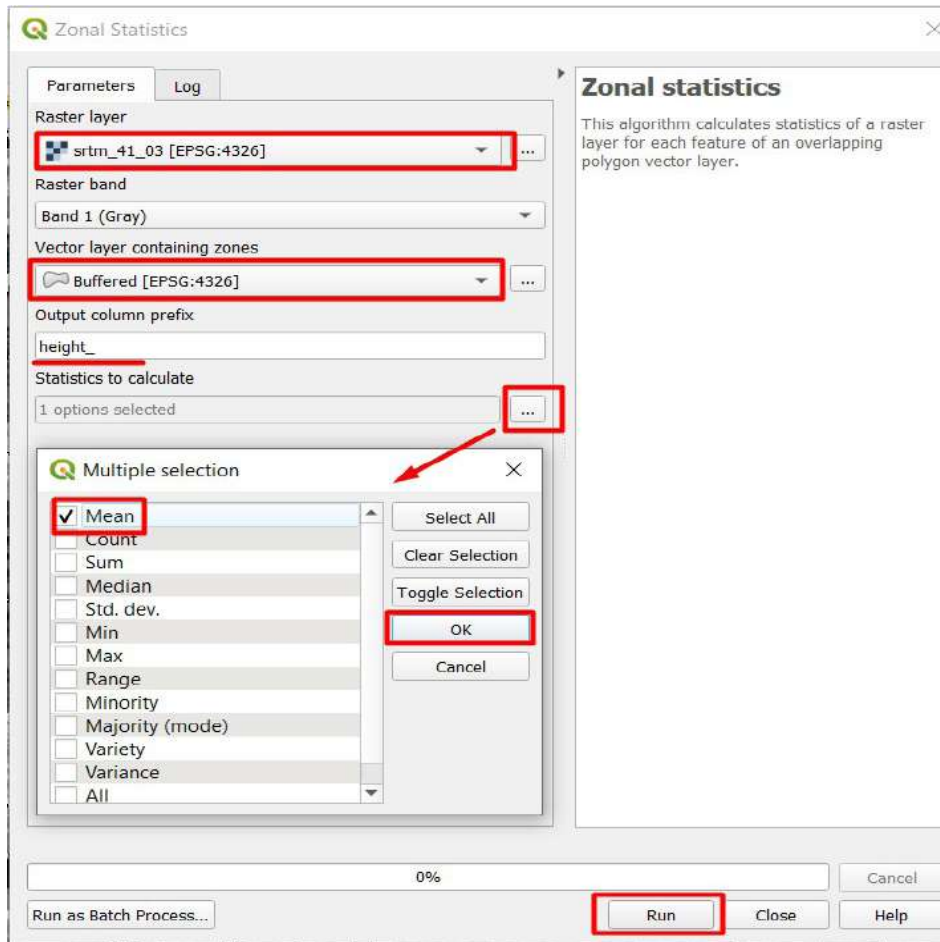
10. Type “zonal statistics” in the search bar under **Processing Toolbox** and double-click on the appropriate tool to open it.



In the dialog that pops up, select **Output** (aspect layer) in the **Raster layer** field, pick **Buffered** under **Vector layer**, and “**aspect_**” in the **Output column prefix** field (to distinguish easily this field in the Attribute Table). Next, expand the **Statistics to calculate** tab and select **Mean**, click **Ok**, and then click **Run**.

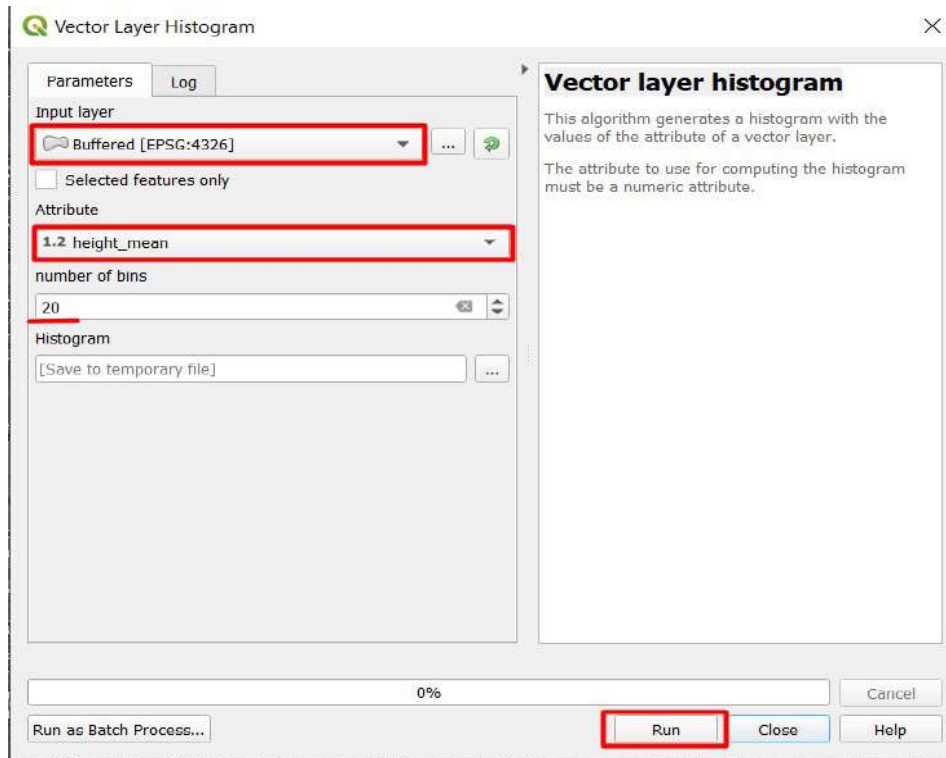


11. Do not close the **Zonal Statistics** dialogue, and calculate the values of the height at each point where orchids were found. For this purpose, select **srtm_41_03** under **Raster layer**, pick **Buffered** in the **Vector layer** field, and select “**height_**” (the field in which the height values from the terrain layer will be saved) under **Output column prefix**. Next, expand the **Statistics to calculate** tab, select **Mean**, click **Ok**, and click **Run**.

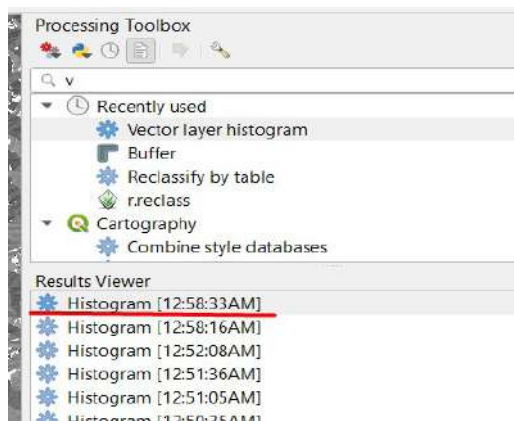


12. Open the Attribute Table of the buffered layer for which the height and aspect values were determined, drag the slider at the bottom of the Table to see the last columns (these two new columns, “aspect_mean” and “height_mean”, should appear at the end of the Table).

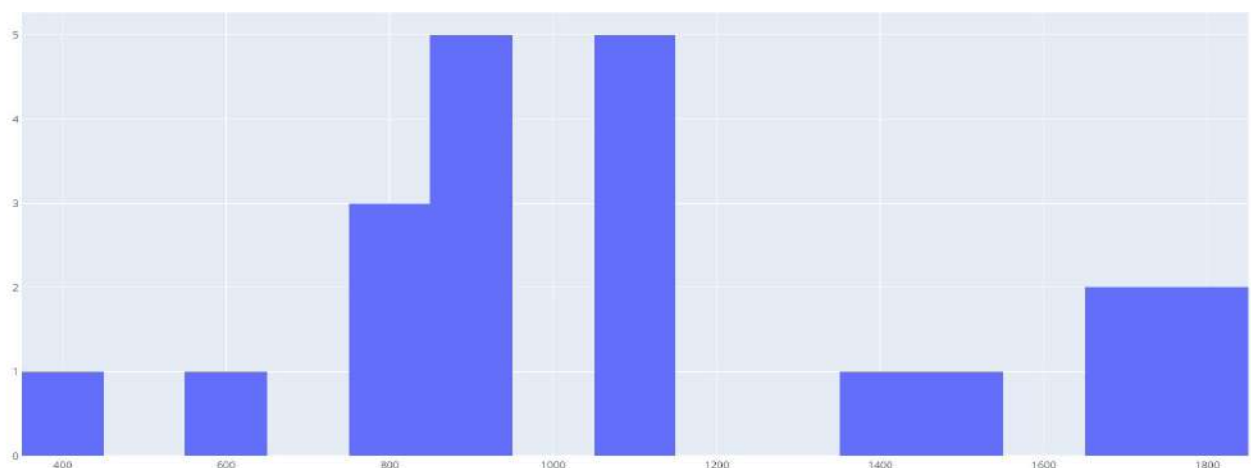
13. Therefore, to understand at what altitude and on what slopes orchids were found, we will build histograms for these values. To do this, switch to **Vector Layer Histogram** in the **Processing Toolbox** search bar, and double-click on the corresponding tool to open it. In the dialog box that appears, select a vector buffered layer with height and aspect values in the **Input layer** field, pick “**height_mean**” under **Attribute** and type 20 in the **number of bins** field, and click **Run**.



14. As a result, a link to the histogram will appear in the right-hand *Results Viewer* pane. Double click on it to open.

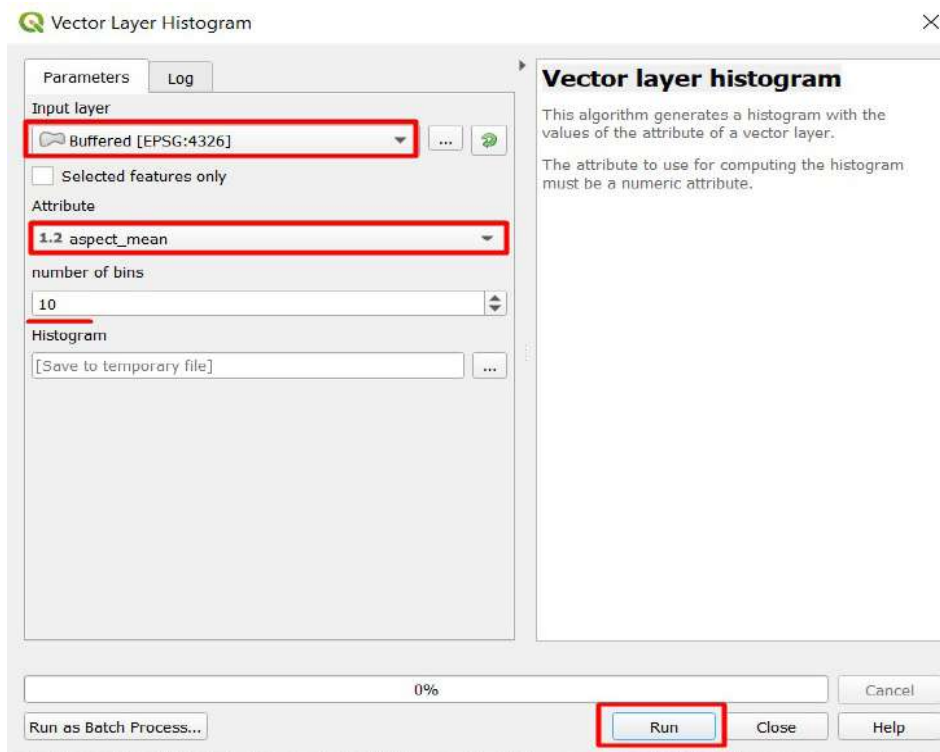


The graph that opens shows the height values on the x -axis, and the number of recorded observations at the corresponding height on the y -axis.

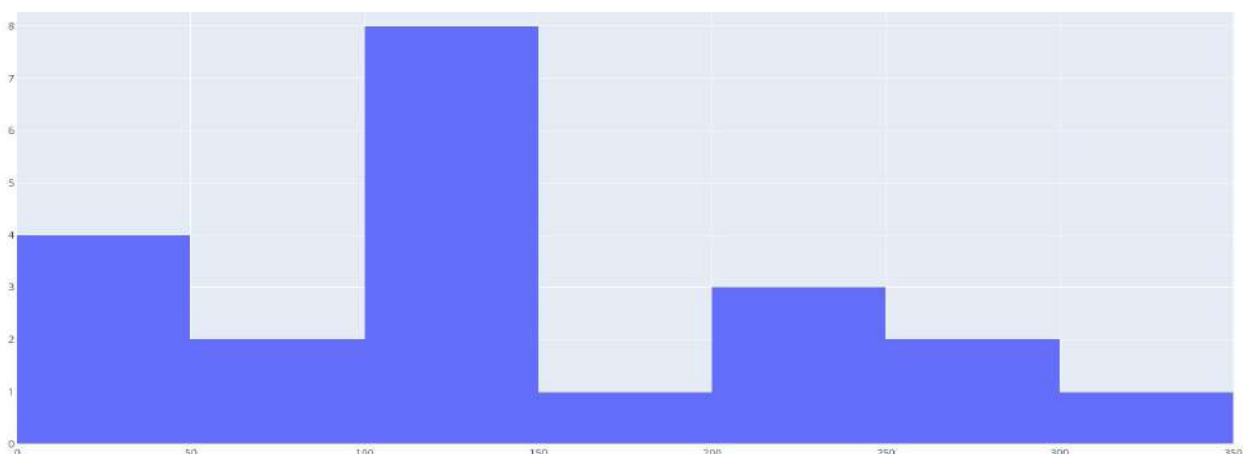


As can be seen from the graph, the largest number of observations (encounters of orchids) was recorded at the altitudes from 800 to 1,100 m.

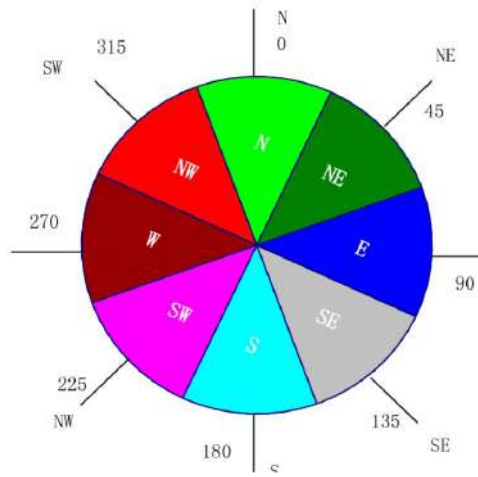
15. We will create now a histogram for the aspect values. Click the **Vector layer histogram** tool again. In the dialog box that appears, select the vector buffered layer with the height and aspect values again in the **Input layer** field, pick “aspect_mean” in the **Attribute** field, enter 10 in the **Number of bins** field, and click **Run**.



16. Open the created histogram by double-clicking on the top **Histogram** line in the **Results Viewer** panel. A graph should open with the aspect values of the slopes (in degrees) displayed on x-axis, and the number of orchid encounters on such slopes on y-axis.



The graph shows that the largest number of orchid encounters was recorded on the slopes with the aspects of 100-150 degrees, which according to the Figure below corresponds to the slopes facing the East and South-East.



17. Thus, we can conclude that the orchid encounters in the Carpathians were mostly recorded at a height of 800-1,100 m, on the slopes facing East and South-East.

Scan the QR-code below to watch the video tutorial on the performance of this Task.



5. Indexed Images: Vegetation Index for Monitoring the Dynamics of Vegetation

5.1. Regional Assessment of the Crimean Peninsula Vegetation Using MODIS Data

Case

The agriculture sector on the temporarily occupied Crimean Peninsula is constantly exposed to both anthropogenic and natural impacts. The effects of the drought are exacerbated by the inability of the occupying authorities to solve the problem of sufficient water supply on the Peninsula. “Agriculture, especially in the northern part of Crimea, is actually killed. Since the Dnipro water is not supplied, citizens have built hundreds of artesian wells and are trying to water the fields with mineral water. As a result, the groundwater level decreased by about 17 meters. Soil becomes salinized and unsuitable for agriculture,” explained Mustafa Dzhemiliev, the Commissioner of the President of Ukraine for the Crimean Tatar people.¹

The Ministry of Temporarily Occupied Territories and Internally Displaced Persons of Ukraine studied the condition of vegetation on the Crimean Peninsula in 2016 and 2018. You can get acquainted with the results of these studies in more detail on the Ministry’s official website: <https://mtot.gov.ua/na-tymchasovo-okupovanij-terytoriyi-ar-krym-zafiksovano-nachnezmenshennyaroslennosti>.

Task

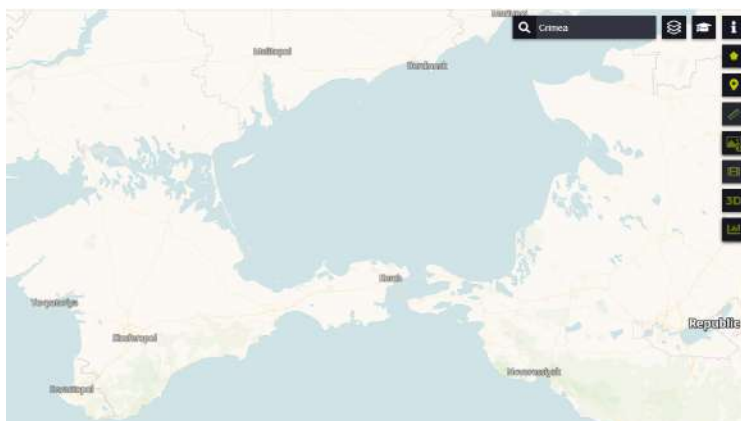
To map the changes in the Normalized Difference Vegetation Index on the Crimean Peninsula as of June 1, 2010, 2015, and 2020, using *MODIS* satellite images.

Task performance algorithm:

1. Download satellite images as of the following dates: 01.06.2010, 01.06.2015, and 01.06.2020.
2. Create a layer of Normalized Difference Vegetation Index (NDVI) for these dates.
3. Visualize the difference between NDVI for 2015 and 2020.

Instructions for self-guided work:

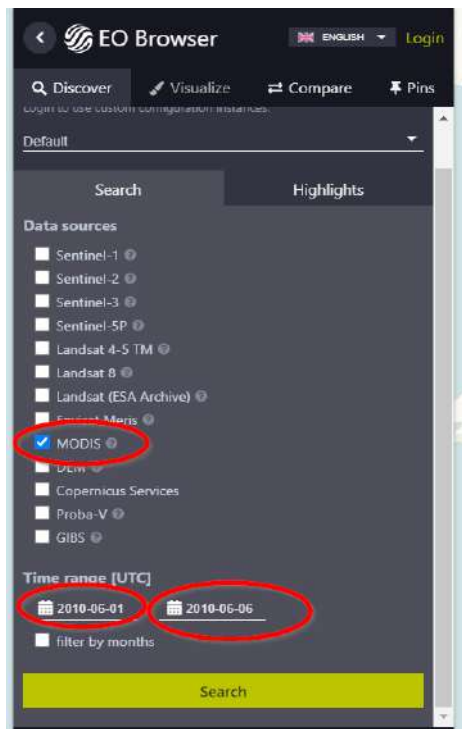
1. Open EO Browser service: <https://apps.sentinel-hub.com/eo-browser>.
2. Log in to the service from your account.
3. In the search box, enter “Crimea” and click on the highlighted line to zoom to the area.



¹ URL: ru.krymr.com. <https://ru.krymr.com/a/news-djemilevdeokkupacyja-kryma/29901555.html>

4. Set the following:

- **Data source** – MODIS;
- **Time range**: from 01.06.2010 to 06.06.2010.



Select an image dated June 1, 2010 (there are two of them in the search results list, you can choose any) by clicking on **Visualize**.



5. Download the bands required for the NDVI display.

NDVI is the Normalized Difference Vegetation Index (NDVI), first used in 1979.

$$NDVI = (NIR - Red) / (NIR + Red),$$

where NIR is the near infrared region of the spectrum; Red – visible red region of the spectrum.

The NDVI index depends on the activity of biomass and chlorophyll and provides data ranging from -1 to +1. Red waves are absorbed by chlorophyll only therefore, the more red light absorbed, the more active chlorophyll in the leaves of plants.

Plant cells are filled with water and function as a mirror for the infrared waves. When the osmotic pressure¹ is high, the plant reflects most of the infrared spectrum. Thus, the more infrared spectrum the plant reflects, the more biomass and the better the health of the plant.

In MODIS:

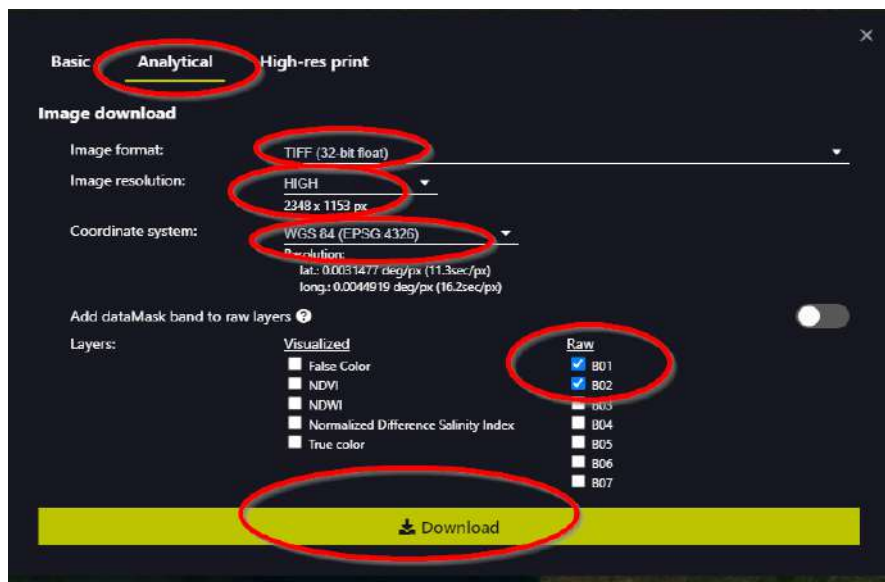
NIR = B2 (0.841–0.876 μm);

Red = B1 (0.62–0.67 μm).

Use the tool  to download the required image.

In the download settings panel, select:



- **Analytical** tab;
- **Image format:** TIFF (32-bit float);
- **Image resolution** (Spatial resolution): HIGH;
- **Coordinate system:** WGS 84 (EPSG 4326);
- **Layers:** B01 and B02.



Once you have selected the required settings, click **Download**. An archive document with satellite images  will be downloaded. Unzip it.

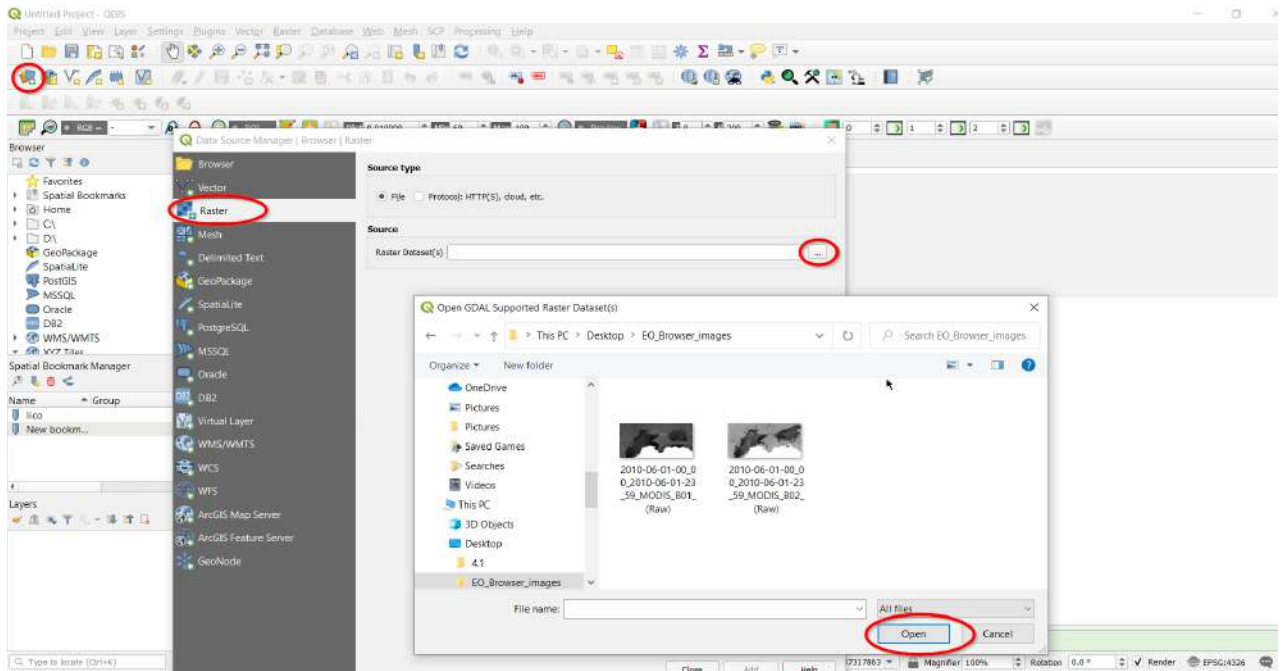
Create a “MODIS” folder and save to this folder the unzipped satellite images.

6. Open B01 and B02 bands in QGIS:

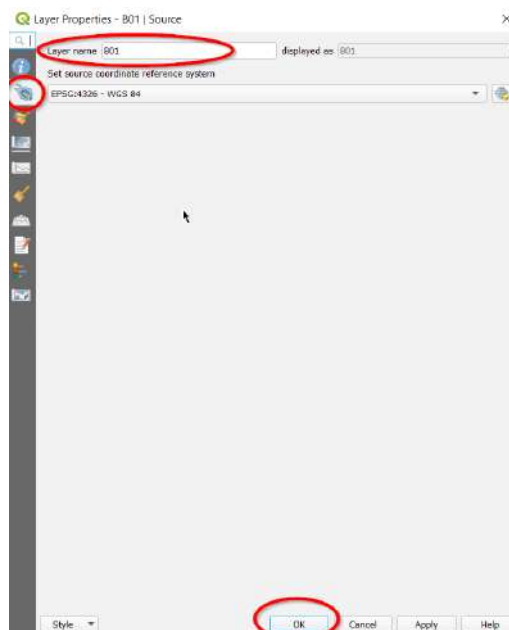
- open  (Start → Programs → QGIS 3.16 → QGIS 3.16 with GRASS);
- use the **Open Data Source Manager** tool .

In the **Raster** tab, specify the path to the images in the MODIS folder → **Add**.

¹ Osmotic pressure is a phenomenon caused by the presence of a semi-permeable membrane that separates solutions. For living cells, the cytoplasmic membrane functions as the semi-permeable membrane, creating the osmotic pressure. URL: https://stemua.science/Research_works/Osmotic-pressure-cells.

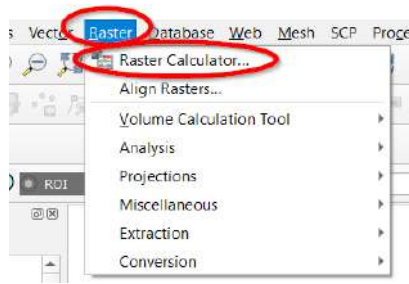


As a result, you will see bands in the **Layers** panel
 Rename the bands, leaving only the band names B01 and B02 (right-click on the layer name in the **Layers** → **Properties** → **Source** → **Layer name** → B02 / B01 → **Ok**).



7. Create the NDVI layer.

To create a layer of Normalized Difference Vegetation Index, use the **Raster Calculator** tool. Click the **Raster** tab in the menu bar. This tab contains the **Raster Calculator** tool.



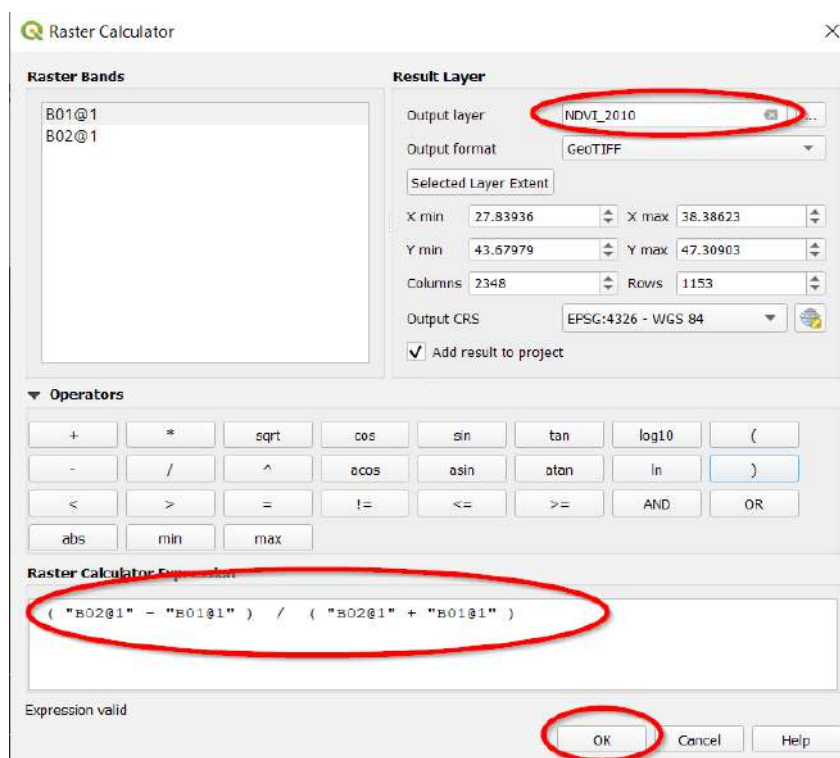
In the *Raster Calculator Expression* dialog, enter the NDVI formula, substituting the names of the corresponding layers from the MODIS.

✔ **Important!** *The formula should be entered with the mouse cursor only, by clicking on the operation symbols and the names of the layers (the keyboard should not be used for this purpose to avoid incorrect processing).*

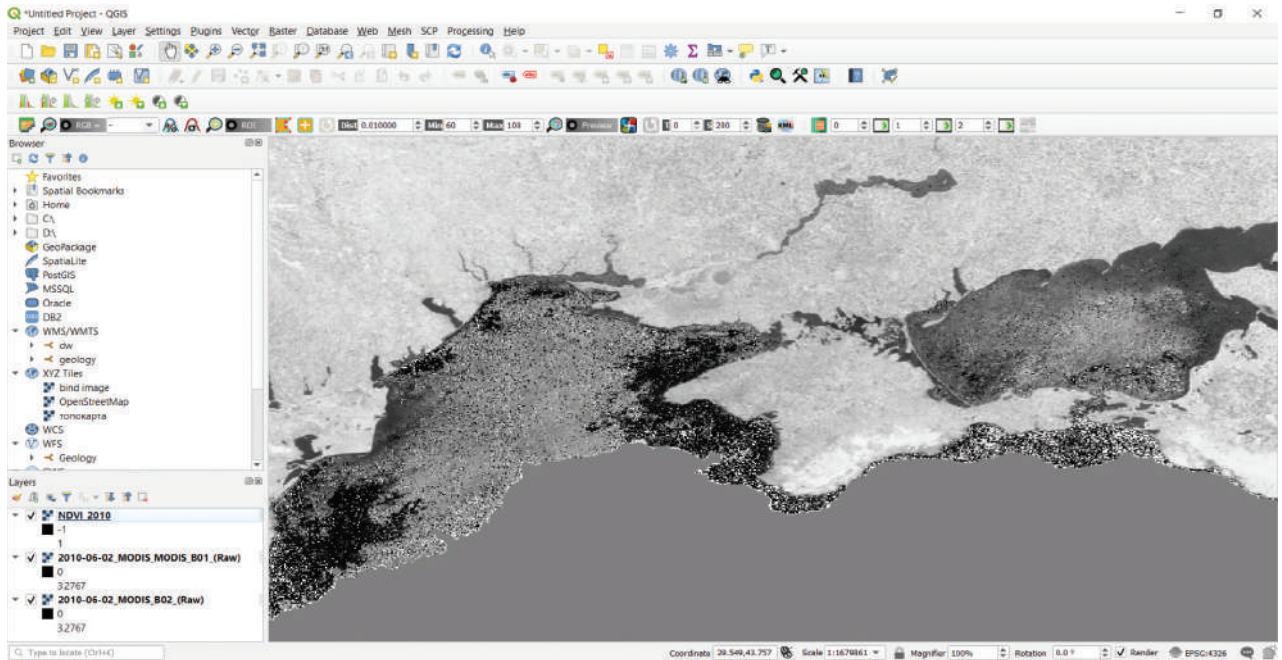
$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}),$$

where NIR is B2, Red is B1.

In the *Output layers*, specify the name of the layer, “NDVI_2010”, and the path for saving the created layer (“MODIS” folder).



As a result, a new layer will be created and displayed in the Layers tab.



8. Since the layer is displayed in shades of gray, you need to change the shades of gray to green for better perception. To do this, select for the NDVI 2010 layer → **Properties** → **Symbology**, and set the following parameters:

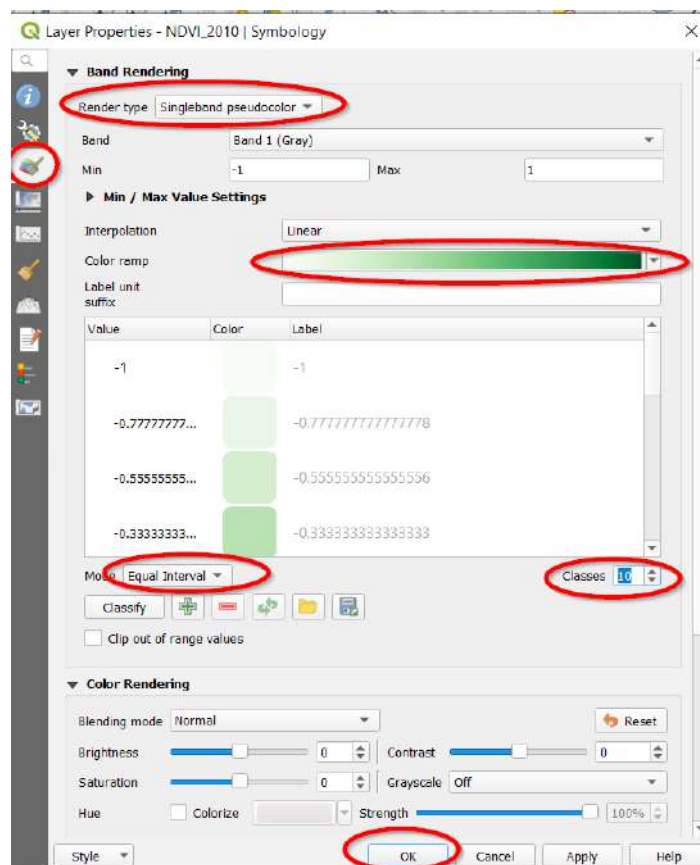
Render type: *Singleband pseudocolor*;

Interpretation: *Linear* (For a continuous color scale);

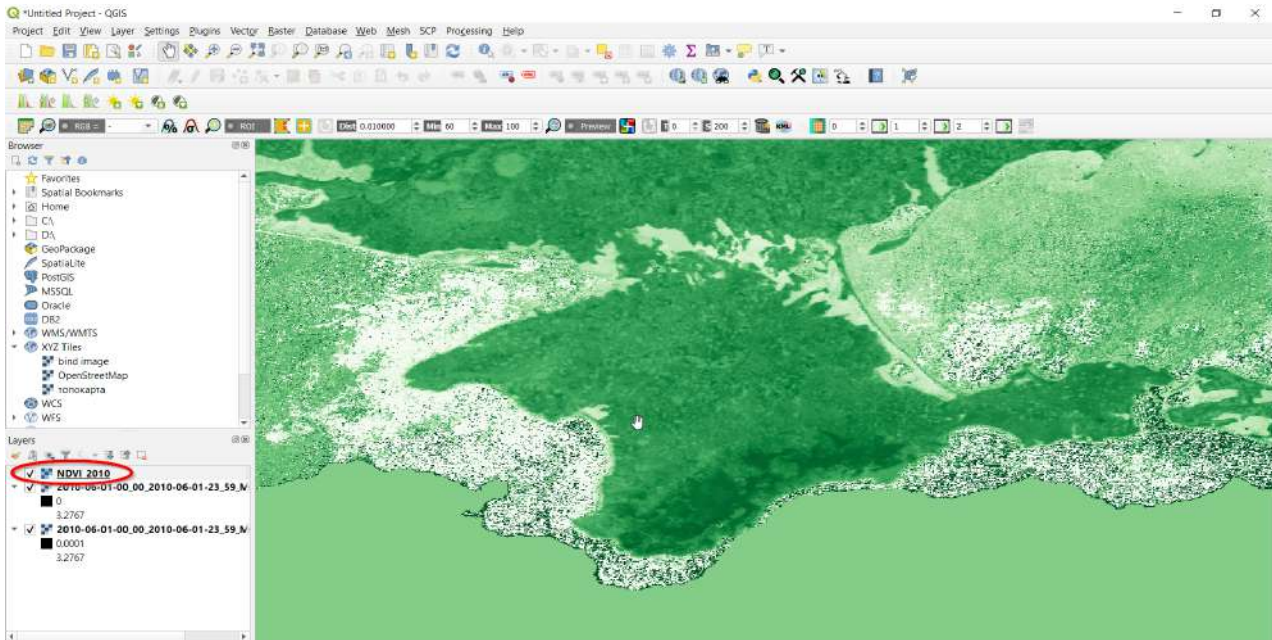
Color ramp: *Greens*;

Classes: *10*;

Mode: *Equal interval*.

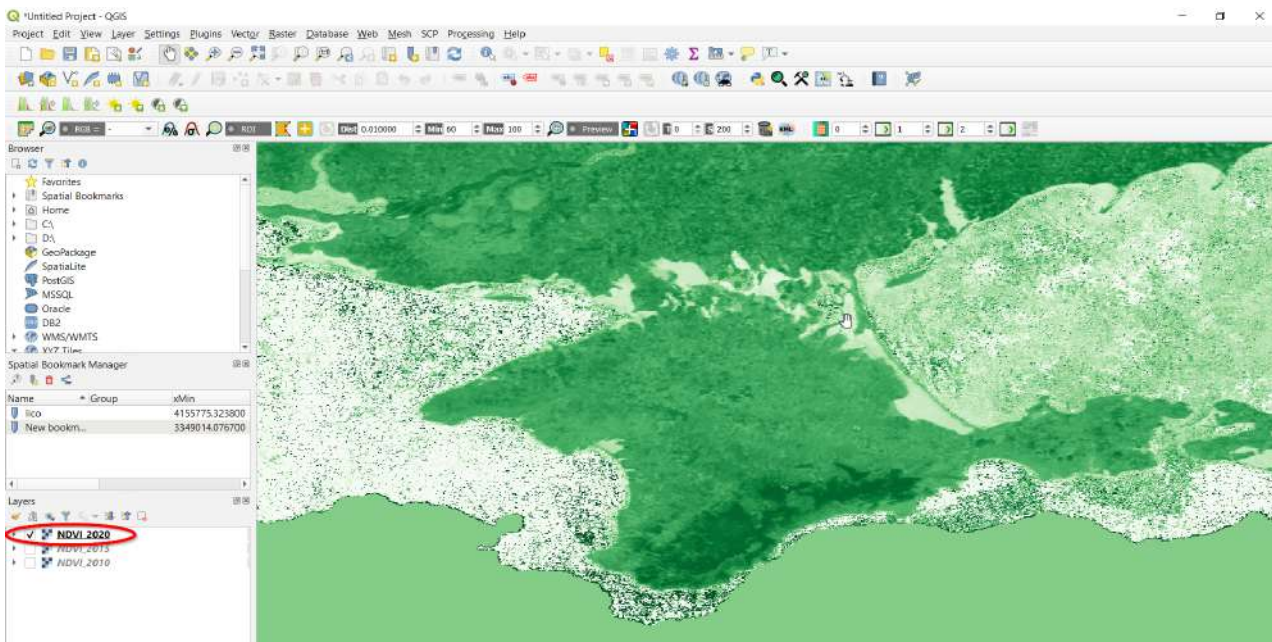


As a result, the NDVI layer will be displayed in shades of green.



9. Using the same algorithm, create the Normalized Difference Vegetation Index layers for 01.06.2015 and 01.06.2020 (name the layers “NDVI_2015” and “NDVI_2020”, respectively).

Leave the NDVI layers for 2010, 2015, and 2020 in your project only, and delete the rest of the layers, as we will not use them.



10. Visually compare the Normalized Difference Vegetation Index values in 2010 and 2020 by unchecking each of the layers in the Layers tab. You can also use the mouse cursor to zoom in and out of a certain area.

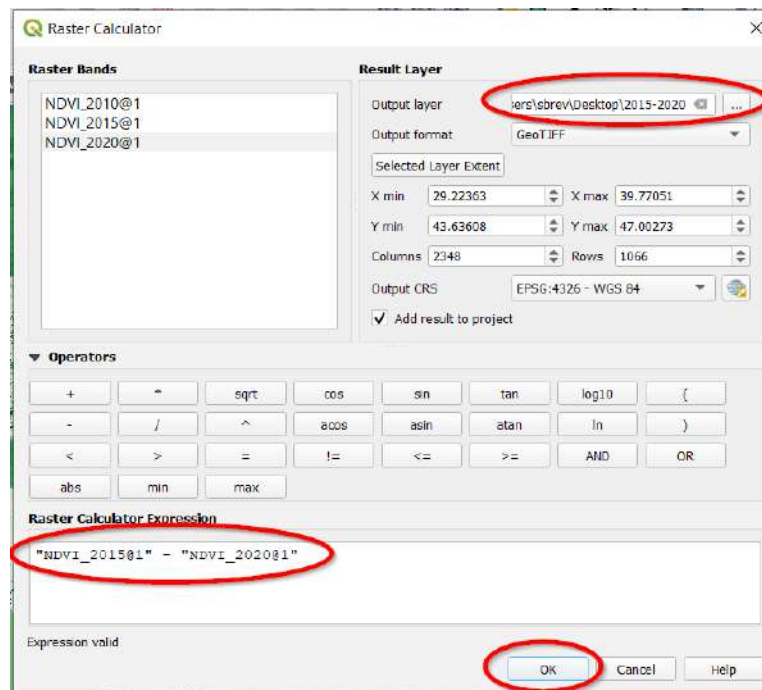
? Check yourself

Track the differences in NDVI between the areas located at various altitudes above sea level in 2020, 2015, and 2010.	
Compare the NDVI values on the land and in the waters of the Black Sea and the Sea of Azov in 2020, 2015, and 2010.	

11. Visualize the differences between the NDVI values in 2015 and 2020 on the map.

✔ **Important!** *Comparing values for the same date in different years is not a fully representative sample for research. It is better to compare the average values (monthly, seasonal or annual) to exclude random, single, force majeure factors that occurred on a chosen day and may “blur” or “distort” the research results.*

Using the *Raster Calculator*, find the difference in NDVI between these layers (2015 and 2020). Name the created layer as “2015-2020”, and save it to the “MODIS” folder.



You will get a new layer, displayed in shades of grey. Visualize it in color. Select the following in the settings panel:

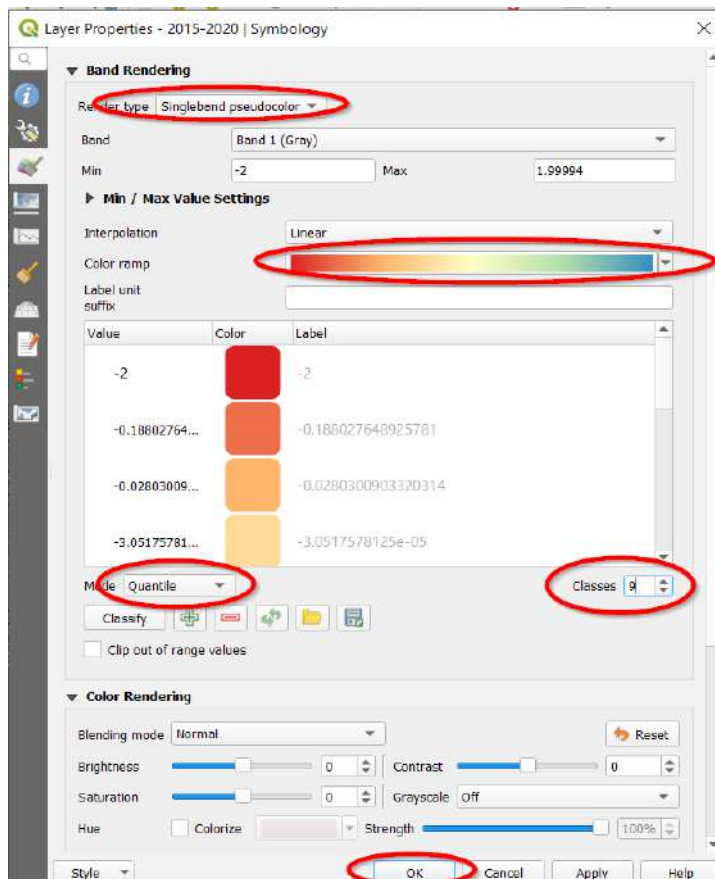
Render type: *Singleband pseudocolor;*

Interpretation: *Linear* (for a continuous color scale);

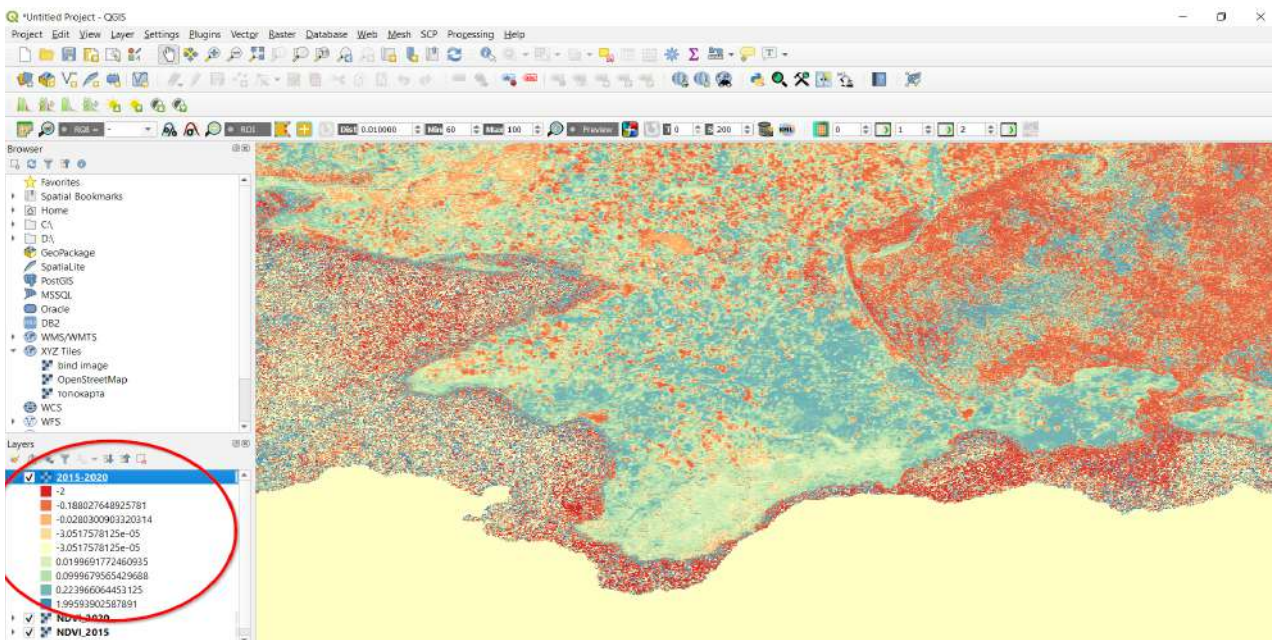
Color ramp: *Spectral;*

Classes: *9;*

Mode: *Quantile.*



You will get a map where the values close to “0” indicate negligible (if any) changes in the NDVI, the values close to “+2” (appear bluish) stand for the territories with higher NDVI values on 01.06.2015, compared to 01.06.2020, and the values close to “-2” (appear reddish), on the contrary, indicate the territories with higher NDVI values in 2020 compared to 2015.



? Check yourself

Why do you think the NDVI values in 2015 and 2020 differ?	
How has the vegetation rate changed in the Sea of Azov? Think about the potential causes of such changes	

Additional Task

Create a map of the Normalized Difference Vegetation Index as of June 1 of the current year and compare it with that as of June 1, 2015.

Scan the QR-code below to watch the video tutorial on the performance of this Task.



5.2. Assessing Vineyards in Crimea Using Sentinel-2 Data

Case

There are 250 hectares of vineyards belonging to the Alma Valley production farm located near the settlements of Vilino and Pishchane.¹ All vineyards are equipped with a drip irrigation system. According to the Alma Valley website, the first seedlings of European varieties were planted in the Alma River valley in 2008. The company's winery began operating in 2013, and the commercial sale of wines started in the summer of 2015. In 2017, the company announced the purchase of 1,000 hectares in Sevastopol and the construction of a new production complex there,² as business at Alma Valley was successful. In 2020, water scarcity led to reduced yields, and threatened the planting of new vineyards on the Peninsula. How do Alma Valley vineyards appear on the satellite images taken in 2017 and 2020?

Task

Compare the Alma Valley's vineyards on the Crimean Peninsula in August 2017 and 2020 according to the NDVI index using Sentinel-2 satellite images.

Task performance algorithm:

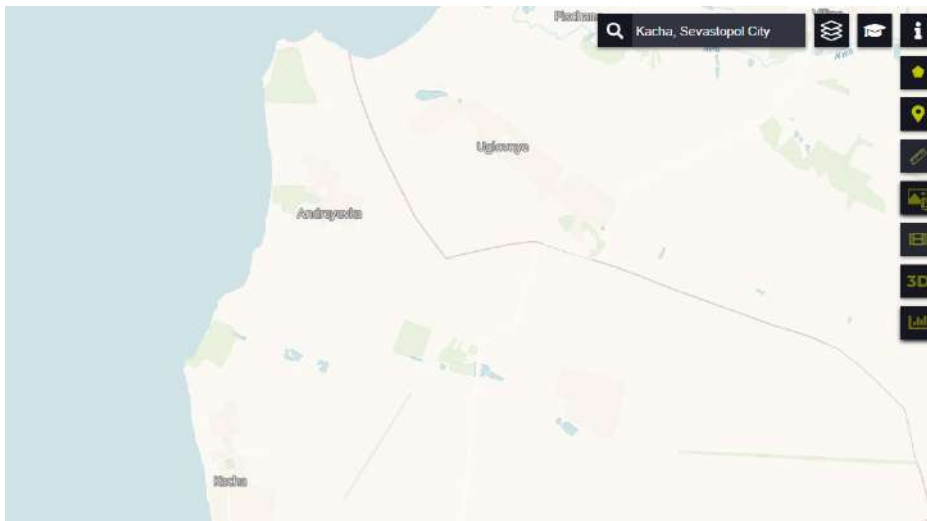
1. Download satellite images dated August 24, 2020, and August 25, 2017, from EO Browser.
2. Create a Normalized Difference Vegetation Index (NDVI) layer for the specified dates.
3. Visualize the difference between *NDVI* values as of these dates in the Alma Valley's vineyards.

¹ URL: <http://alma-valley.ru/>

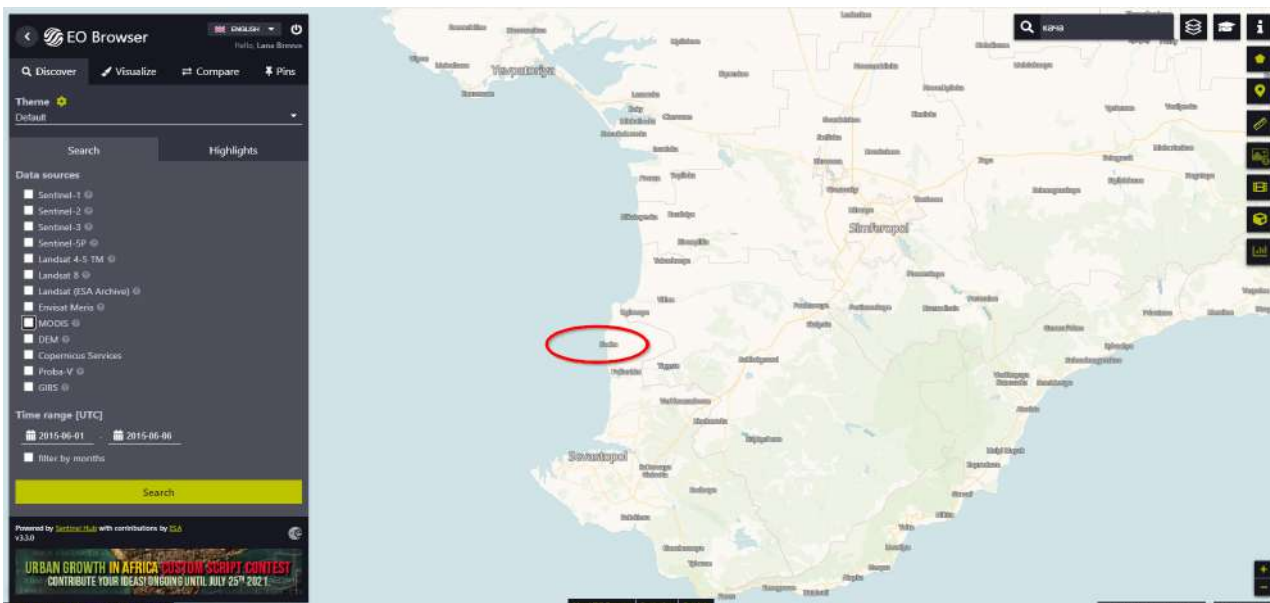
² URL: <https://www.forbes.ru/biznes/372873-novyy-hozyain-massandry-chto-zhdet-legendarnyy-brend-posle-privatizacii>

Instructions for self-guided work:

1. Open EO Browser at <https://apps.sentinel-hub.com/eo-browser>.
2. Log in to your account.
3. In the search bar, enter “Kacha, Sevastopol City”, and click on the first highlighted line to zoom to the area of interest.

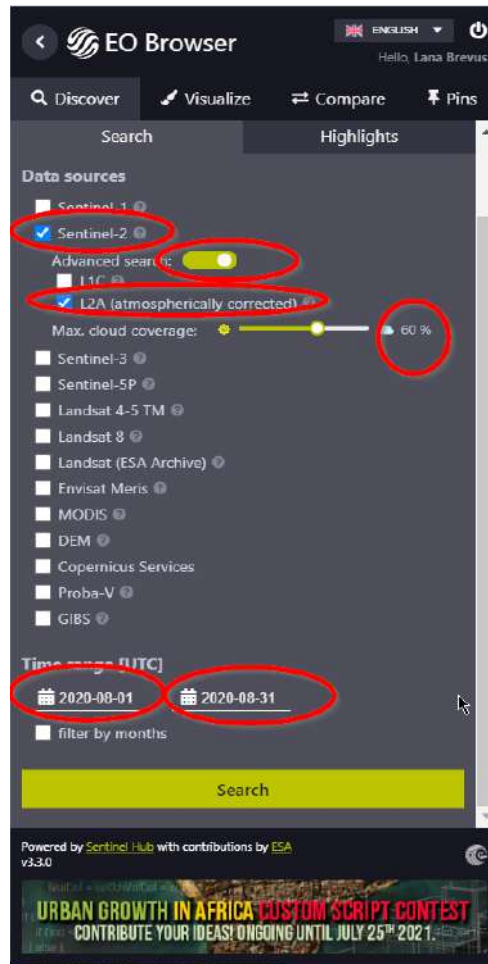


Using the navigation buttons, zoom to the southwestern part of the Crimean Peninsula. The places where the vineyards grow are located close to Kacha urban-type settlement.

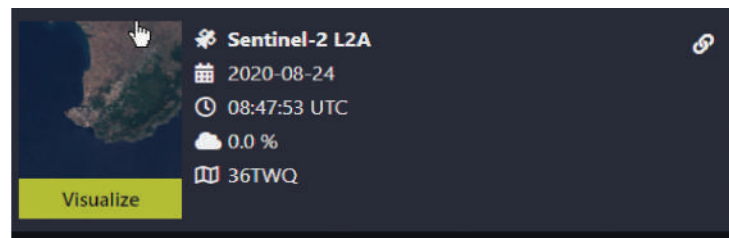


4. In the *Discover* tab, select:

- **Data source** – Sentinel-2;
- **enable Advanced search** and select **L2A (atmospherically corrected)**;
- **Time range** – 01.08.2020 – 31.08.2020;
- **Max. cloud coverage** – 60%.



5. Select the image taken on August 24, 2020, from the list of search results.



6. Zoom to the vineyards of Alma Valley company, which are located closest to the barns where the grapes are stored (landmark: vineyards between the settlements of Vilino, Kocherhino, and Vidradne).


✔ **Important!** *When downloading, the part of the image you see on your screen will be saved.*



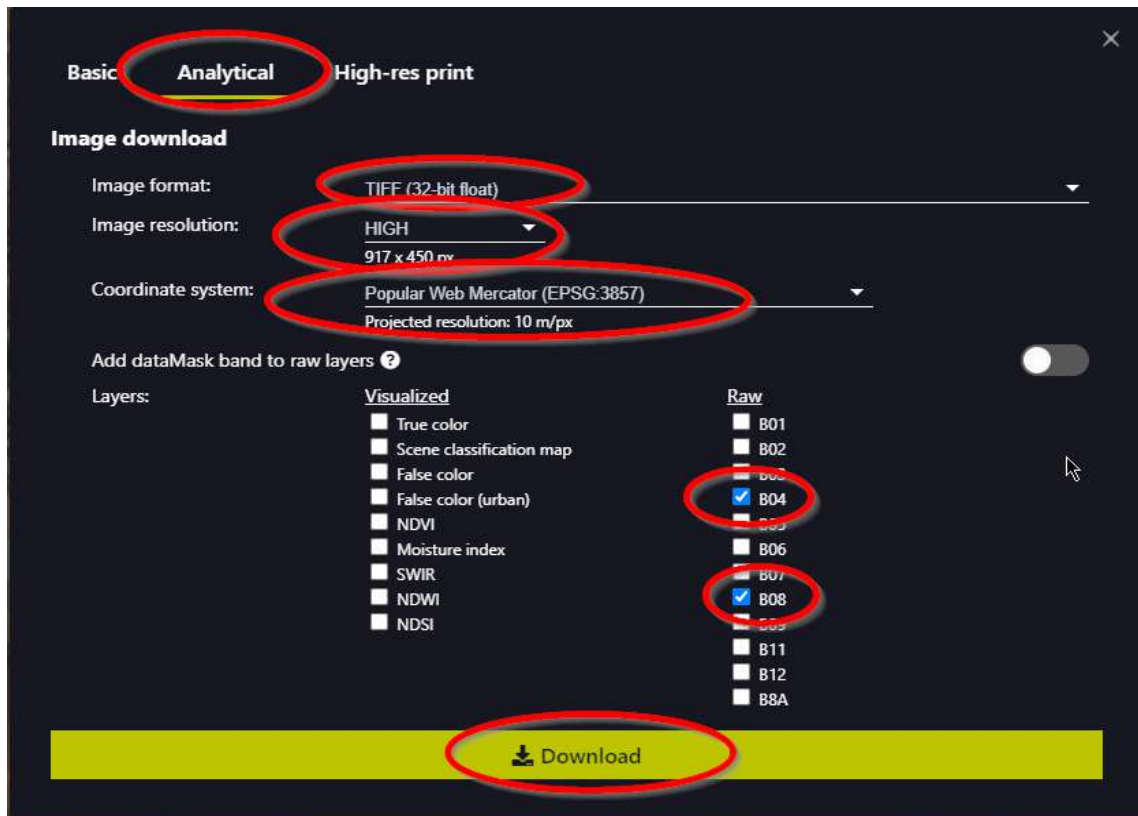
Additional task

Find this area in Google Earth: the image resolution will allow you to see the Scythian burial mound of the 2nd century BC near the company's winery.



7. Download the Sentinel bands required for the NDVI display: NIR = B8; Red = B4.
Using the Download image tool , download the required image bands. In the download settings panel, select:

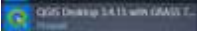
- **Analytical** tab;
- **Image format – TIFF (32-bit float);**
- **Image resolution – HIGH;**
- **Coordinate system – WGS 84 (EPSG 4326);**
- **Layers – B08 and B04.**



Once you have selected the required parameters, click Download. The downloaded zip file containing satellite images will look like  ED_Browser_image...zip

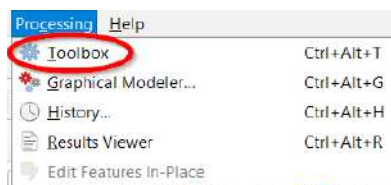
Create a “Sentinel” folder for saving unzipped satellite imagery.

8. To open B08 and B04 bands in QGIS:

- click  (Start → Programs → QGIS 3.16 → QGIS 3.16 with GRASS);
- press Ctrl+L to open the **Data Source Manager** dialog box. Under **Raster**, specify the path to the images in the “Sentinel” folder → **Add**;
- as a result, appropriate spectral bands will be loaded to your project;
- rename the bands, leaving only the band names, “B08” and “B04” (right-click on the layer name in the Layers → **Rename layer**).

9. To create the NDVI layer:

- use the **Toolbox** item from the menu of the **Processing** tab;



- in the **Processing Toolbox** dialog, go to **SAGA** → **Image analysis** → **Vegetation Index (Slope Based)**. Specify the following: **Near Infrared Reflectance** – B8; **Red Reflectance** – B4;
- in the **Normalized Difference Vegetation Index** field, specify the path, **Save file to**, for saving the generated layer entitled “NDVI_2020” (“Sentinel” folder, which we have created) → **Run**;

✔ **Important!** All the layers that we create must be named using Latin characters; otherwise, the result may be incorrectly processed by the program.



- the “NDVI_20” layer that you have created will display in the Layers tab in shades of grey.

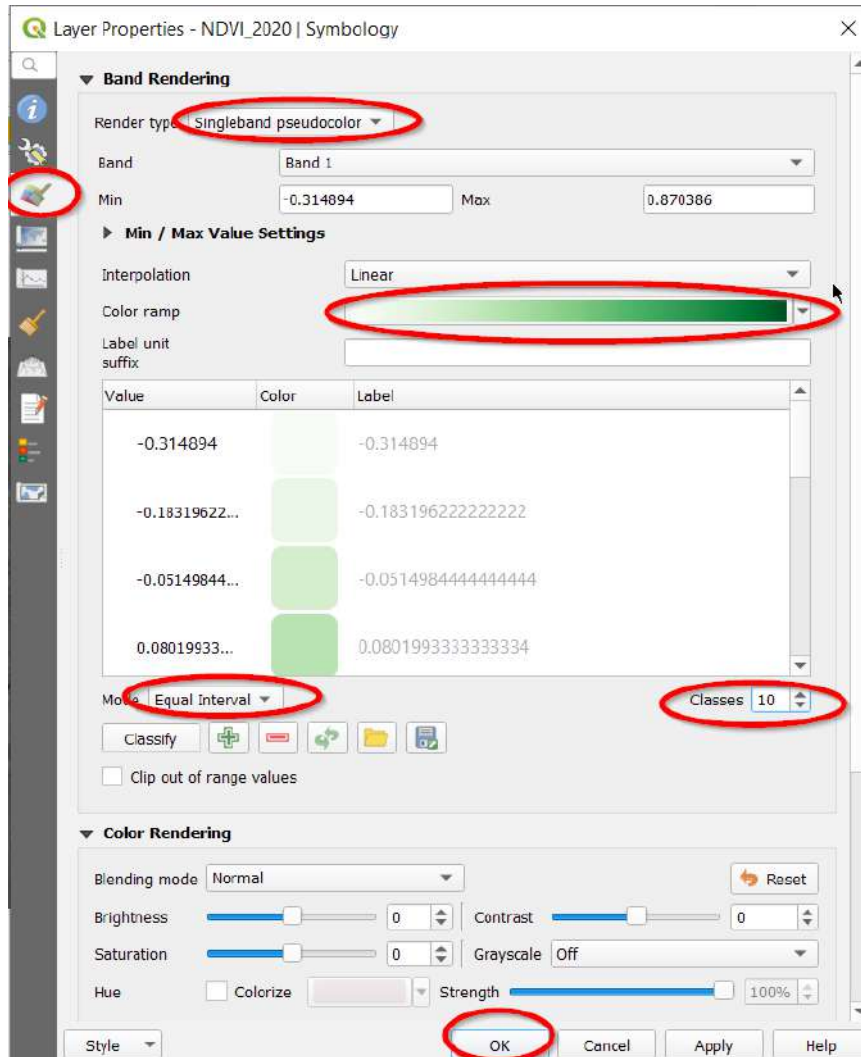
✔ **Important!** If the **Vegetation Index (Slope Based)** module works incorrectly or shows an error (due to the old version of the program), you can use the **Raster calculator** to determine the **NDVI** as in the previous task.

10. Display the created layer in green gradations:

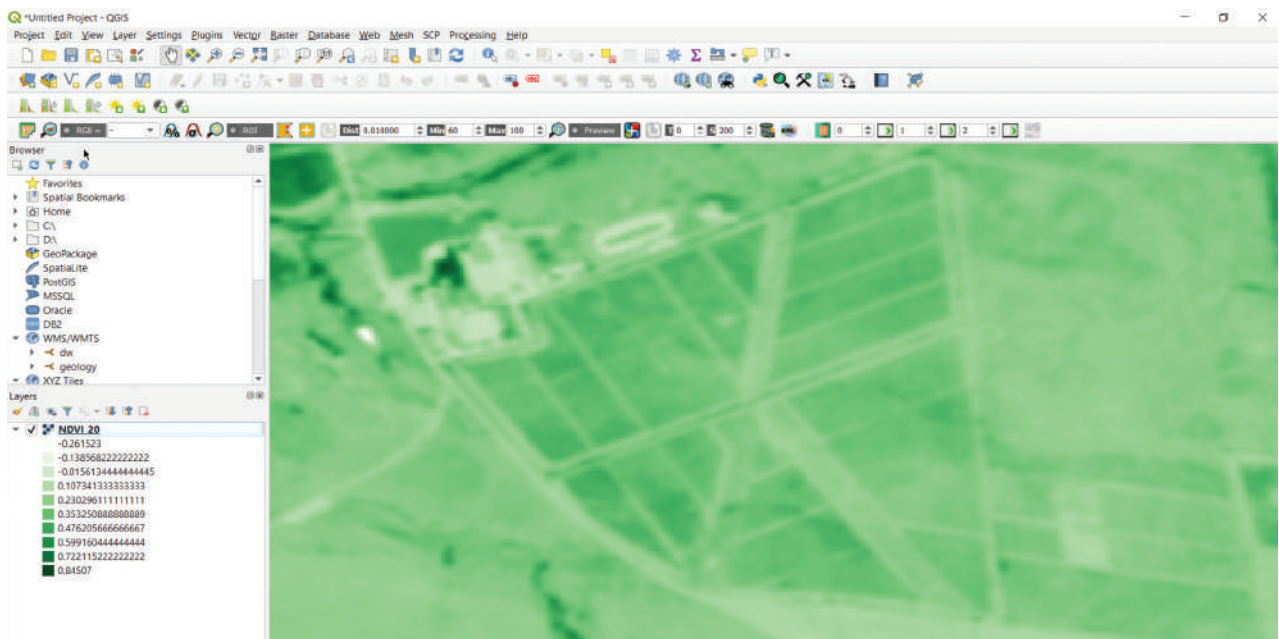
NDVI layer → **Properties** → **Symbology**

In the settings panel, select:

- **Render type** – **Singleband pseudocolor**;
- **Interpretation** – **Linear** (for a continuous color scale);
- **Color ramp** – **Greens**;
- **Classes** – **10**;
- **Mode** – **Equal interval**.

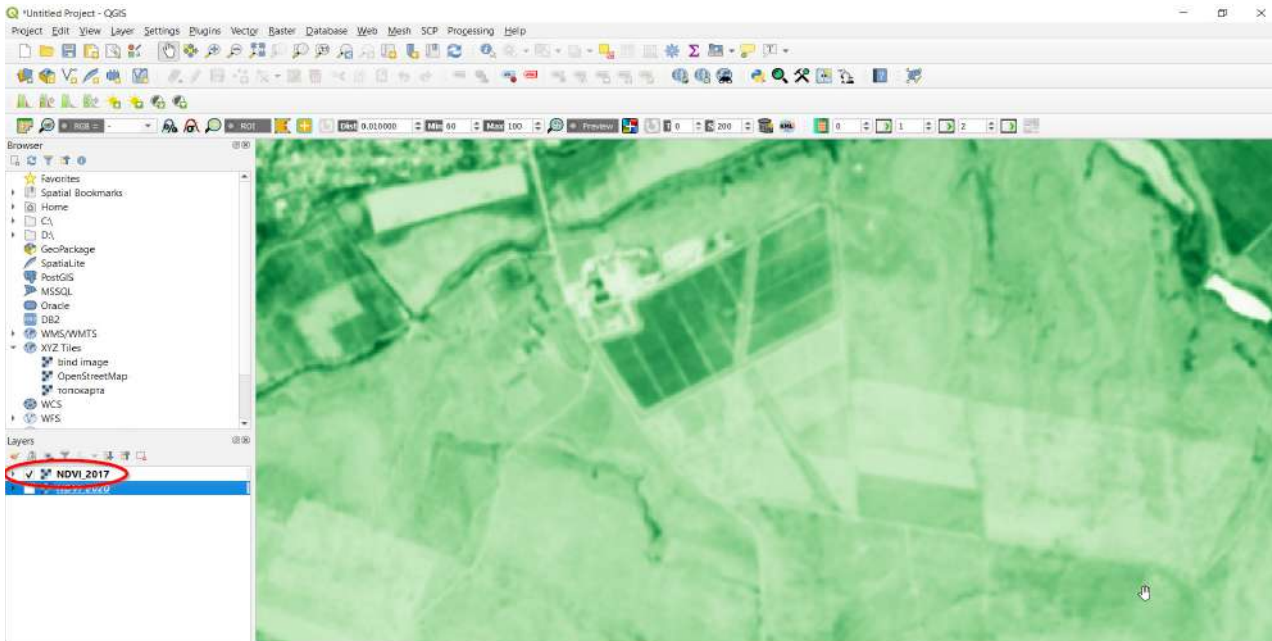


11. As a result, you will get the NDVI map of the Alma Valley vineyard fields as of August 24, 2020.



12. Using the same algorithm, calculate the vegetation index for the vineyard in 2017 (name the layer as "NDVI_2017") in QGIS:

- download appropriate bands (to display the NDVI index) of the satellite image dated August 25, 2017, from EO Browser;
- create a layer “NDVI_2017” in QGIS.



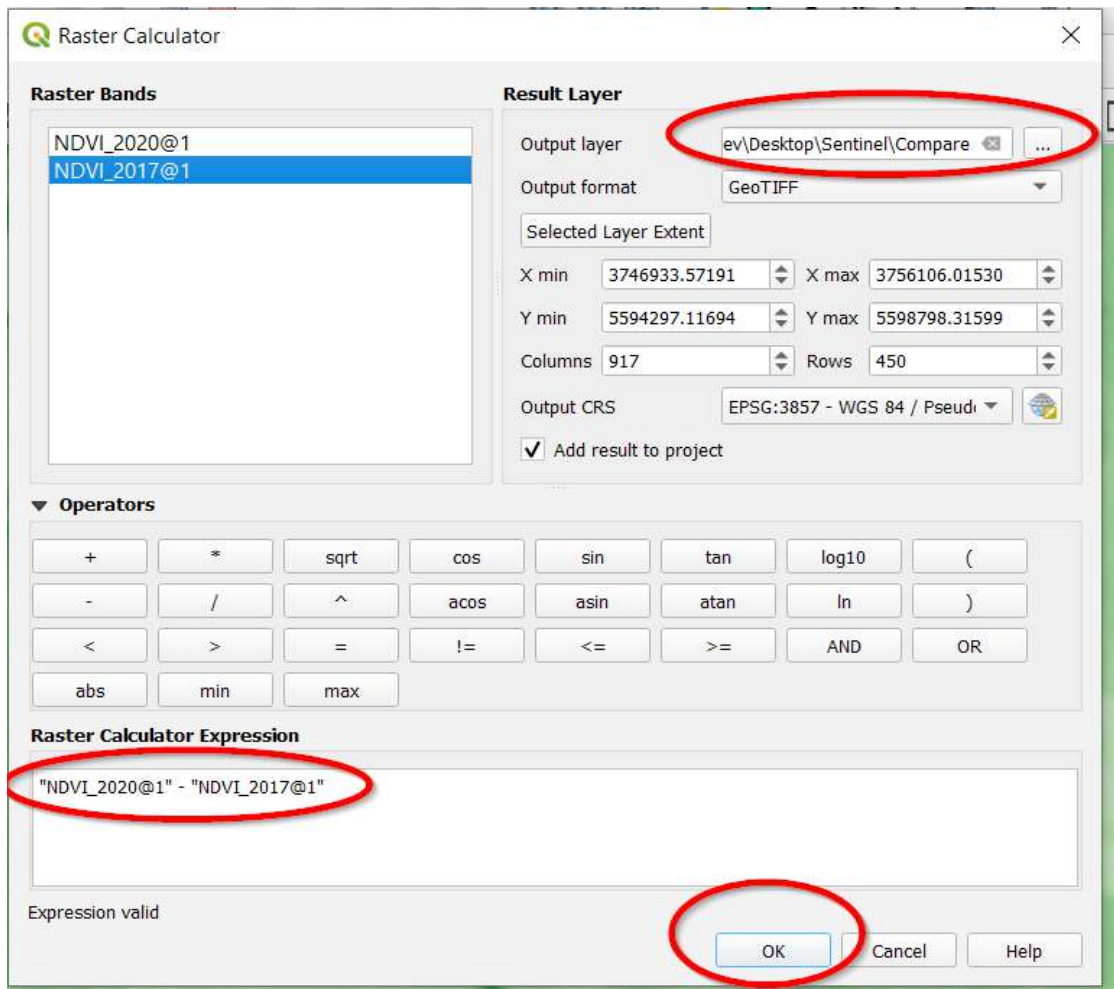
13. Visually compare two NDVI layers: as of 2020 and 2017.

🔍 Check yourself

Why do you think the NDVI index in the fields of Alma Valley company has changed?	
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14. Compare two NDVI layers (2020 and 2017) using the **Raster Calculator** tool:

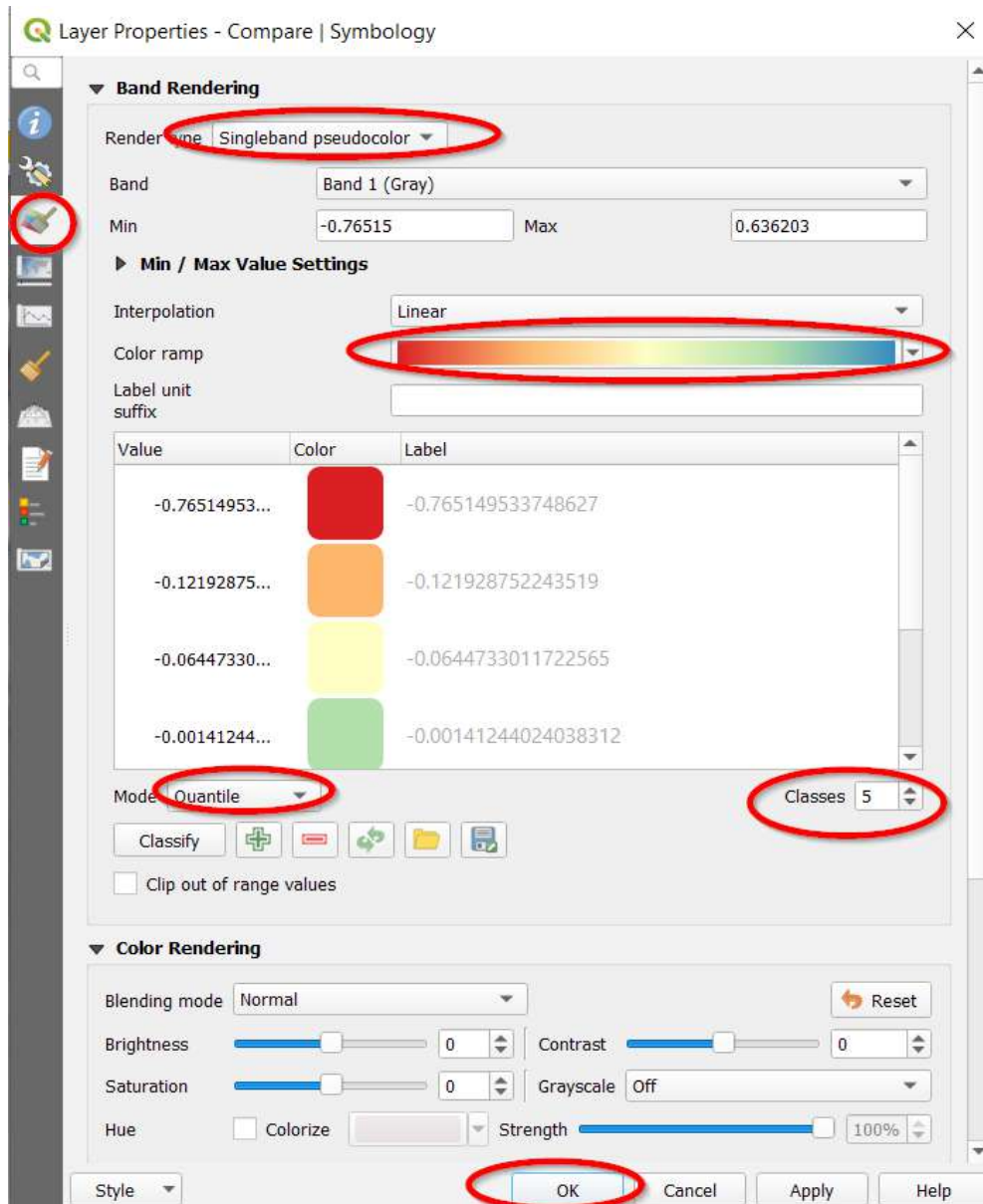
- open **Raster calculator** tool from the menu bar under **Raster** tab;
- assign “*Compare*” name to the file and specify the path for saving the resulting layer to the “Sentinel” folder;
- in the expression field, specify that the NDVI value of 2020 should be subtracted from that of 2017;



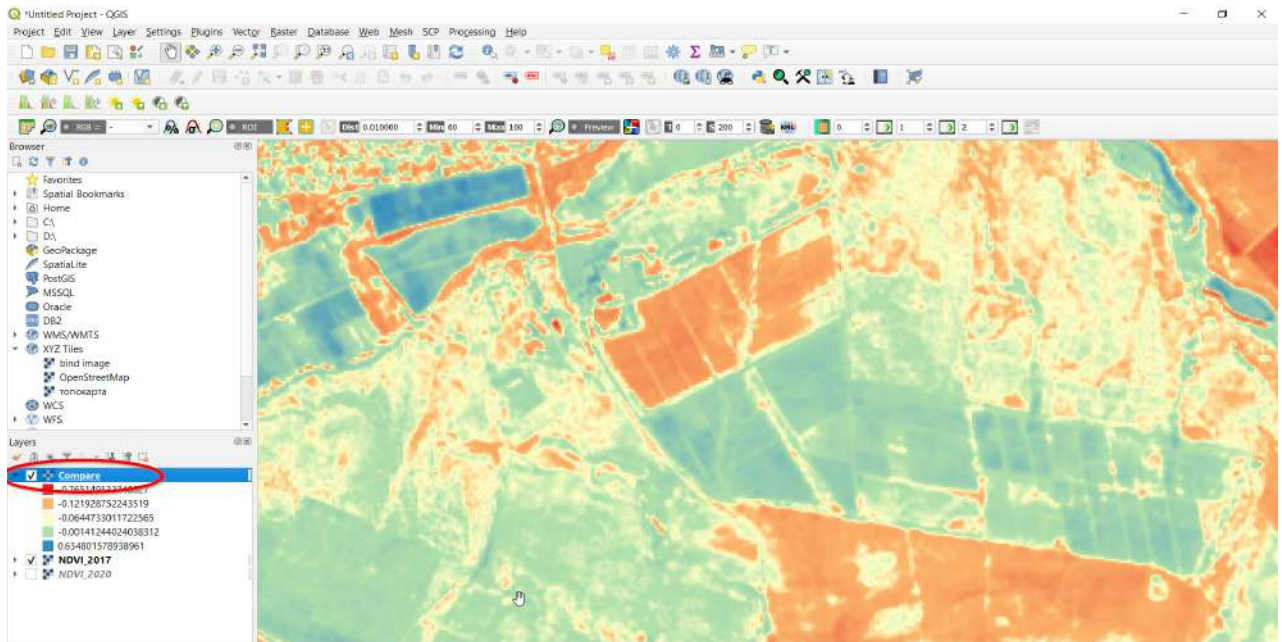
- the resulting layer (representing the difference of the value for the selected two years) will display in the Layers tab;
- change the display from grey to color. Adjust the “compare” layer to see the area of the vineyards: **Properties** → **Symbology**.

In the settings panel, select:

- **Render type** – **Singleband pseudocolor**;
- **Interpretation** – **Linear** (for a continuous color scale);
- **Color ramp** – **Spectral**;
- **Classes** – **5**;
- **Mode** – **Quantile**.



Thus, we have determined the difference between NDVI_20 and NDVI_17 layers. The areas where the vegetation index was lower in 2020 than in 2017 appear red on the resulting map, and blue are areas where the vegetation index was higher in 2020 compared to 2017).



Therefore, there are different trends in the NDVI changes in the same field of Alma Valley company equipped with drip irrigation system observed over three years.

? Check yourself

Hypothesize about possible causes of the decrease in the NDVI values in the northern part of the field and the increase in the NDVI values in the southern part of the field that occurred over three years (hint: look for the answer in Google Earth, namely – in the historical images of this area).

Scan the QR-code below to watch the video tutorial on the performance of this Task.



6. Water Indices to Identify Water Dynamics and Wetlands

6.1. Investigating Changes in the Hydrological Regime of Bondarivske Swamp

Case

The Polissia region is substantially dehydrated, primarily due to the past land reclamation (large-scale drainage of swamps), and current massive deforestation. In the spring of 2020, large fires occurred. The Polissia swamps are an extremely important source of water for Ukrainian rivers. Due to the destruction of swamps, our rivers are drying up and the climate is changing. For the first time in 120 years, Ukraine finds itself in a situation where most rivers have low water levels. This is caused by the abnormal autumn and winter temperatures in 2019-2020.¹

Task

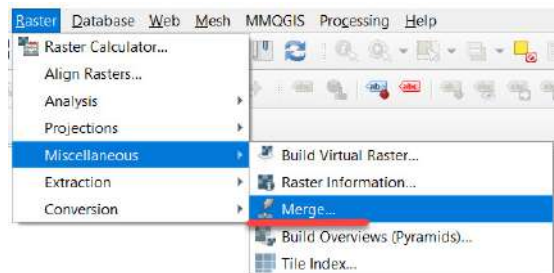
Investigate changes in the hydrological regime of Bondarivske Swamp in the springs of 2018 and 2020.

Task performance algorithm:

1. Download satellite images as of April 8, 2018, and April 5, 2020, from Google Drive or EO Browser.
2. Create a merged false-color satellite image as of these dates.
3. Calculate the MNDWI water index for both Sentinel-2 images.
4. Visualize the difference in soil moisture distribution histograms of in Bondarivske Swamp as of these dates.
5. Select the MNDWI threshold values and create a map of the wetland area for two years.

Instructions for self-guided work:

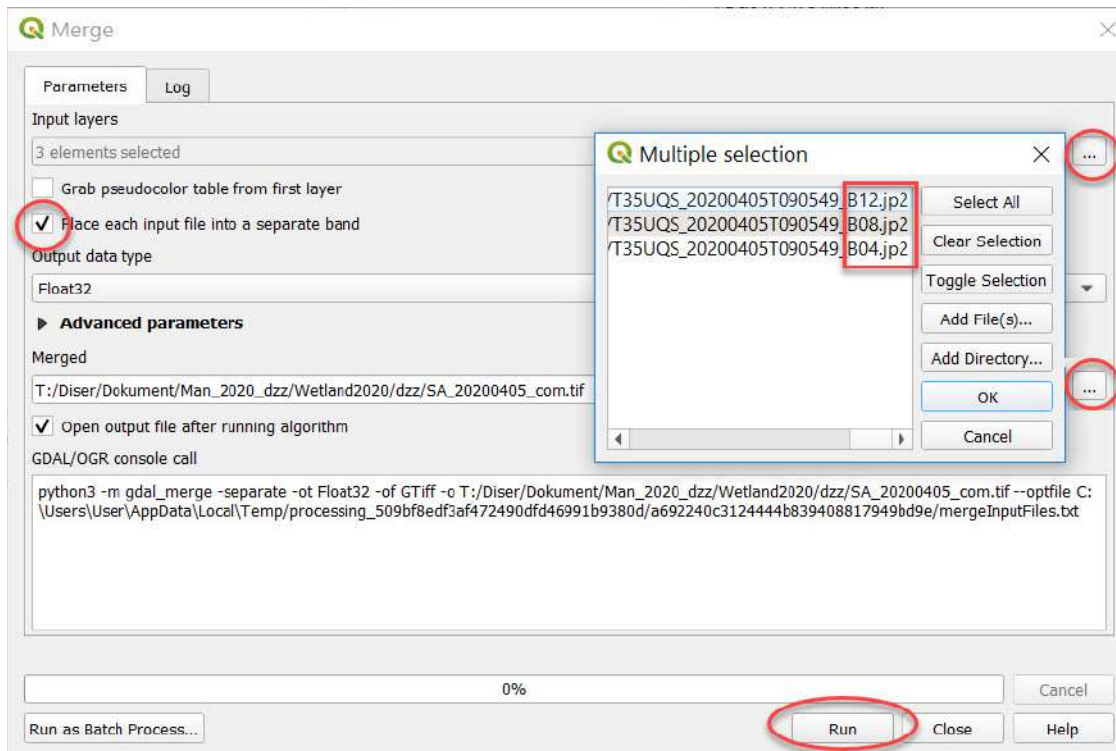
1. Download the Sentinel-2a satellite images taken on April 8, 2018, and April 5, 2020, of Bondarivske Swamp area (near Otrokhy Village, Kozeletskyi District, Chernihiv Oblast) from: https://drive.google.com/drive/folders/1NfwGVGXwfyGtMMLJmMVTslaeytx_RURh?fbclid=IwAR1o-maWbqTc1TSRg-jIkP6cAmXRNRM22C1-ng-9fwu0Md3nXIvAAcr6btus.
2. Unzip the downloaded archive. Satellite image bands can be found in the internal archive files, in the GRANULE and IMG_DATA folders.
3. Open QGIS Desktop 3.10.4 and create a new project.
4. First, merge the bands for Sentinel-2a image taken on April 8, 2018. To merge black-and-white bands of the satellite image into one color image, click on **Raster** in the top menu, expand the **Miscellaneous** tab → **Merge**.



¹ URL: <https://greenpost.press/news/osushennya-bolit-nam-shhe-dobryache-gyknetsya-ekspert-i2447>

A **Merge** dialog box will pop up, in which you need to specify the bands you want to combine in the **Input Layers** field. To do this, click on the icon [...] next to the **Input Layers** field and pick **Add files** from the **Multiple selection** dialog, find the folder where the image bands are saved and select the desired bands.

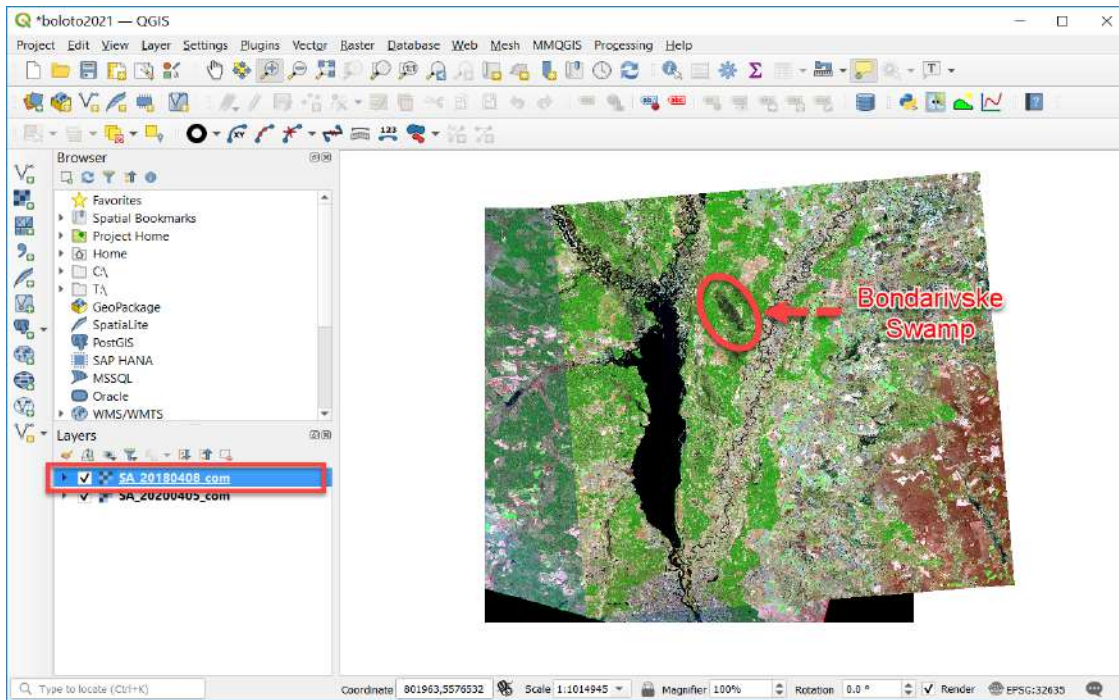
5. Create a merged false-color satellite image using B12, B8, B4 bands (this combination will help you to roughly determine the content of water in plants and soil, since it is reflected in the SWIR wavelength). You can select three bands at once by holding down the “Shift” or “Ctrl” key on the keyboard. Then you need to click **Open**, and the selected images will be downloaded to the **Multiple selection** window. It is important to select bands in the following sequence: R (B12 – SWIR), G (B8 – NIR), and B (B4 – red). Therefore, you need to drag the bands in a way so as to display them in the following sequence, B12, B8, B4, and click **Ok**.



As a result, the selected bands (i.e. three bands) will be displayed under **Input layers** in the **Merge** dialog. Tick the box next to **Place each input file into a separate band**, click on the icon [...] next to the **Merged** field, select **Save to file**, find the path to the folder, name the file, and click **Run**.

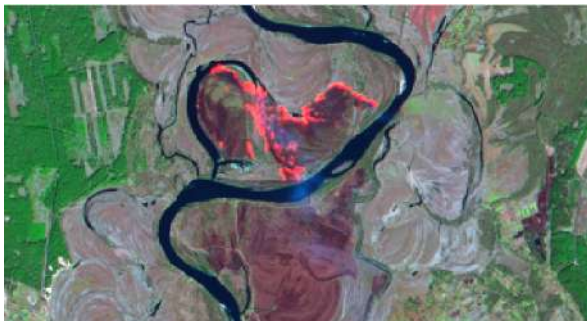
🟢 **Important!** *It is better to use Latin characters to name the files. Cyrillic is not always correctly processed by programs.*

You will get a merged satellite image as of April 8, 2018. To perform a comparative analysis, however, it is necessary to develop an appropriate algorithm for the zipped images as of the two dates that you have previously downloaded. Therefore, repeat all the above steps for the next satellite image taken on April 5, 2020.



If you did everything correctly, a large image will be displayed on the screen showing the Kyiv Cistern on the left and the Desna River in the center. Bondarivske Swamp is located between them (the top of the Cistern and the Desna River). With this combination of bands, the bodies of water appear blue, the forest is green, open ground (fields, felling sites, and meadows) appears light brown and pink.

🔍 Check yourself

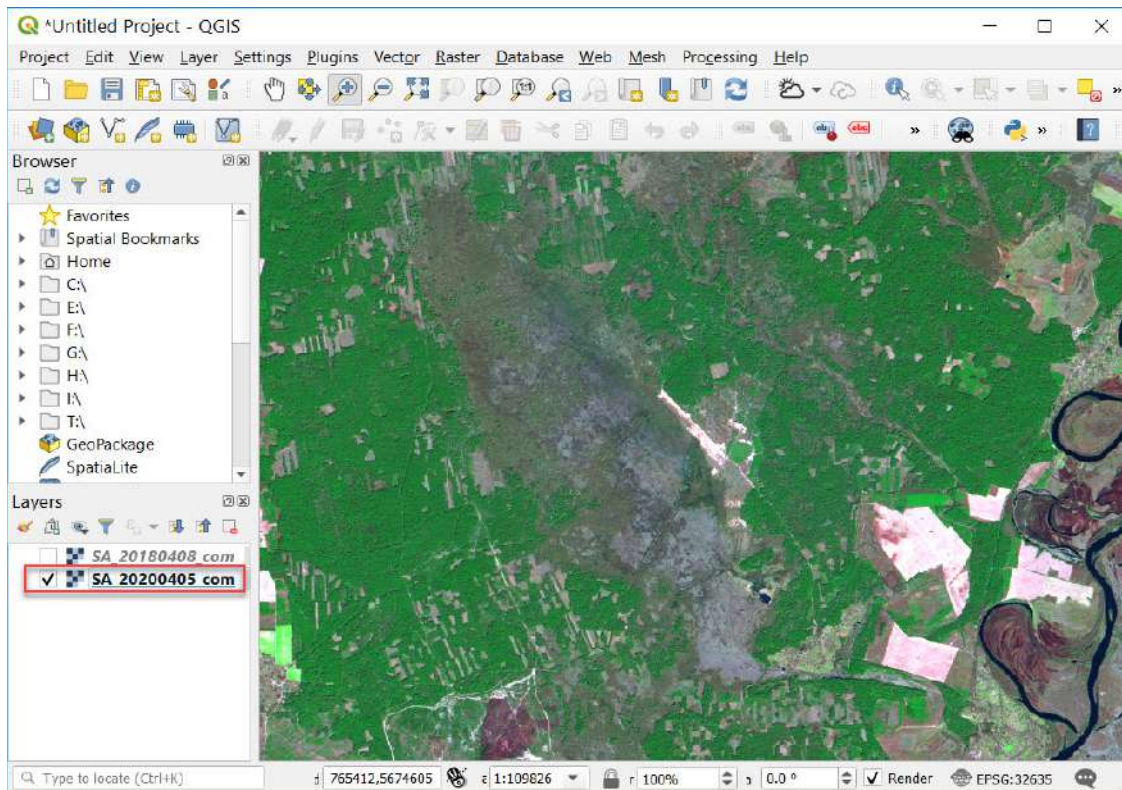
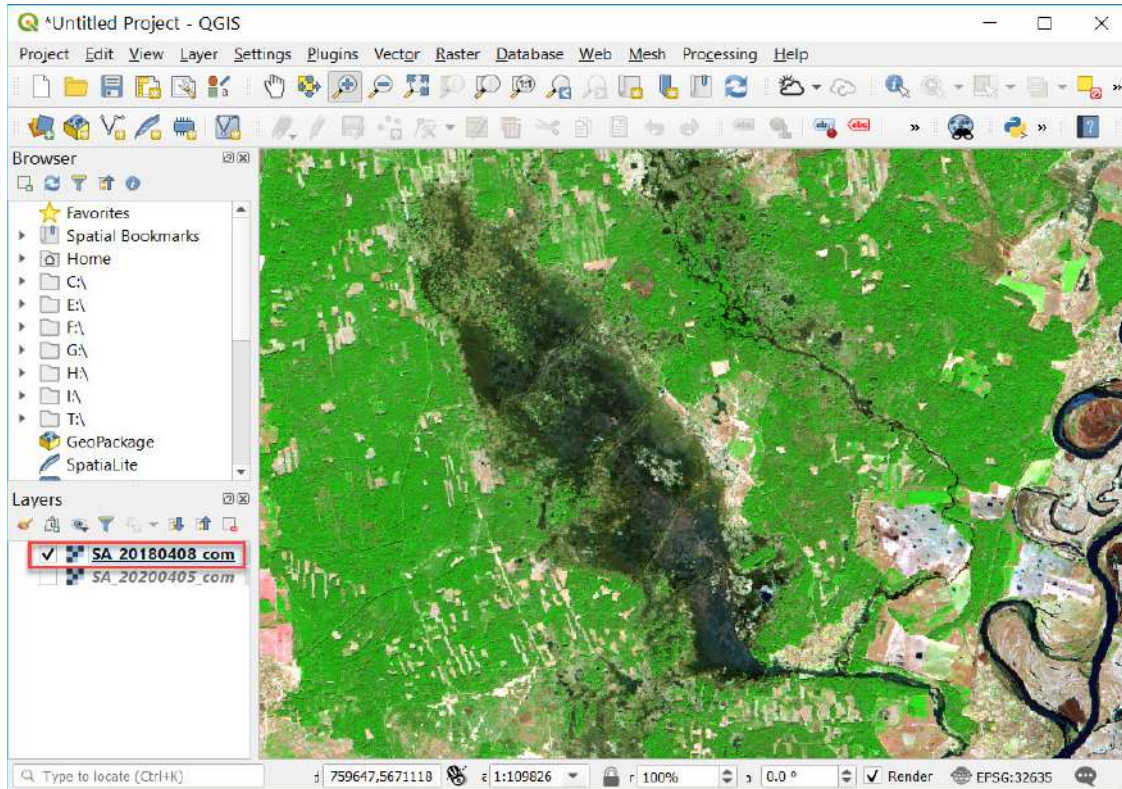


Take a closer look at the Desna floodplain in front of Bondarivske Swamp, as well as upstream and downstream in 2020. Why do you think it contains some dark areas? Specify the potential causes.



Take a closer look at the upper eastern part of the 2018 image and specify what types of land are affected by the water-abundant spring period. Do you think the effects of these water flows on natural and agricultural landscapes are the same?

Zoom to Bondarivske Swamp and visually compare its appearance in two satellite images taken in 2018 and 2020.



Visually comparing these two images, you can conclude that the swamp humidity levels in these years differ significantly.

6. Calculation of the **MNDWI** water index for two Sentinel-2 images.

Modified Normalized Difference Water Index (MNDWI) is a standardized differentiated moisture index used for monitoring droughts and enhancement of open water features.

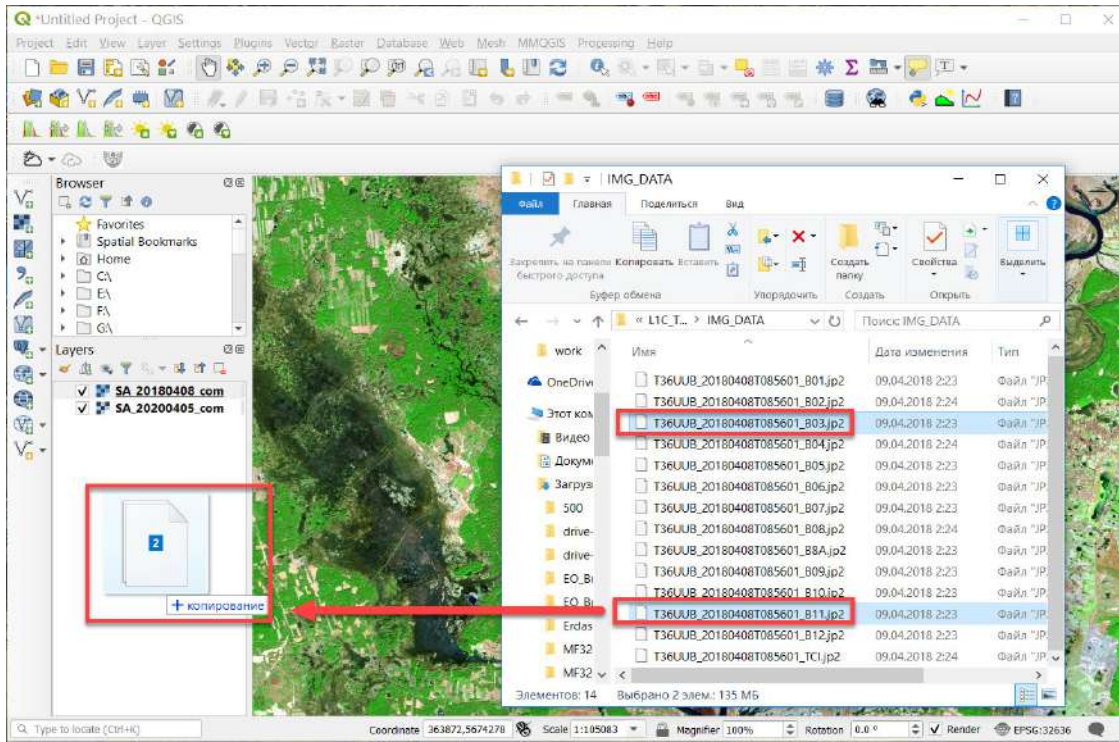
The water index formula:

$$\text{MNDWI} = (\text{Green} - \text{SWIR}) / (\text{Green} + \text{SWIR})$$

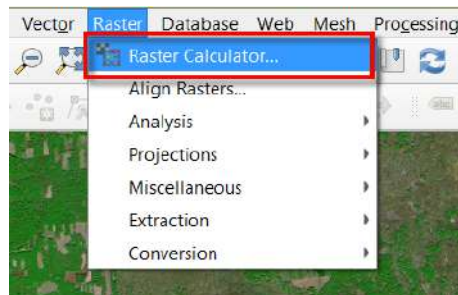
where: Green – the green band of the range; SWIR – the medium infrared band.

For Sentinel-2, the MNDWI formula will look like this: $(B3 - B11) / (B3 + B11)$.

First, add bands 3 and 11 from the 2018 image to your project. You can do this quickly by simply dragging them from the Explorer window to the corresponding QGIS **Layers** window.



Next, we will use the raster calculator. For this, open the **Raster** tab → **Raster Calculator**.



In the corresponding field of the **Raster Calculator** window, enter the formula $(\text{Green} - \text{SWIR}) / (\text{Green} + \text{SWIR})$, where Green and SWIR are the bands you have selected from the menu at the top of the raster calculator dialog.

We can simply enter now the MNDWI formula in the **Raster Calculator**, substituting the values of the bands:

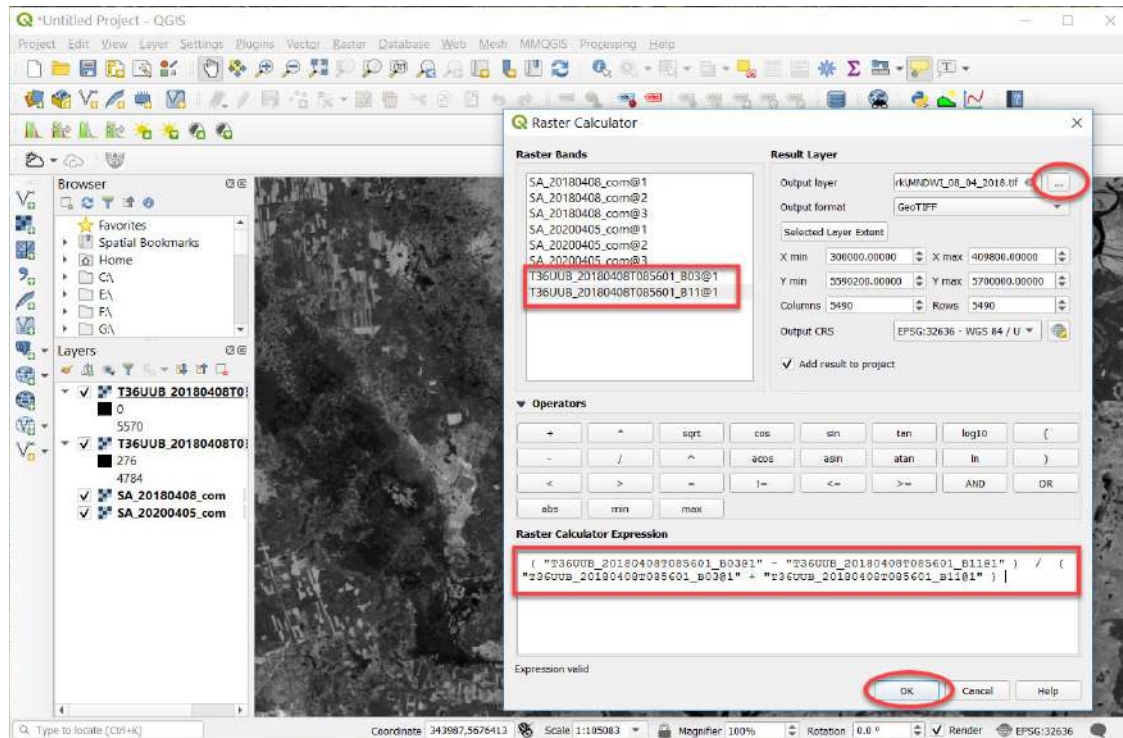
$$(\text{Band3} - \text{Band11}) / (\text{Band3} + \text{Band11})$$

First, select the appropriate bands from the **Raster Bands** menu at the top of the window in the **Raster Calculator** dialog, and use the appropriate **Operators** to select the -, +, / symbols. To add layers to the expression box, double-click the desired layer with your left mouse button.

✔ **Important!** Do not enter the band names from the keyboard because the formula will not run.

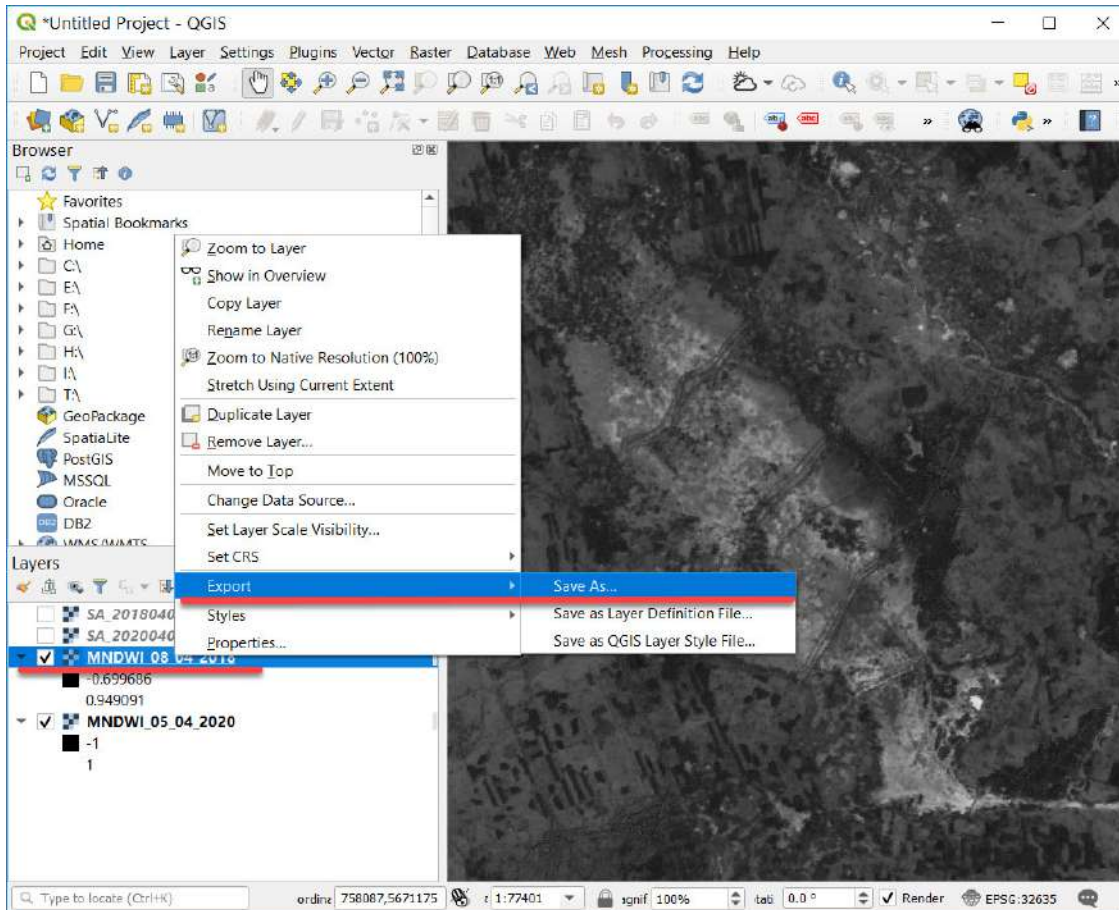
Note that the Ok button at the bottom of the calculator will not be active until you enter a name and specify a location of the **Output layer**. Select the desired folder by clicking [...], and write the name of the source layer, for example: "MNDWI_08_04_2018.tif", where the numerical symbols indicate the date of the image.

✔ **Important!** *If a file for some reason is not saved, check the paths and file names for Cyrillic characters and spaces – you should avoid using them.*



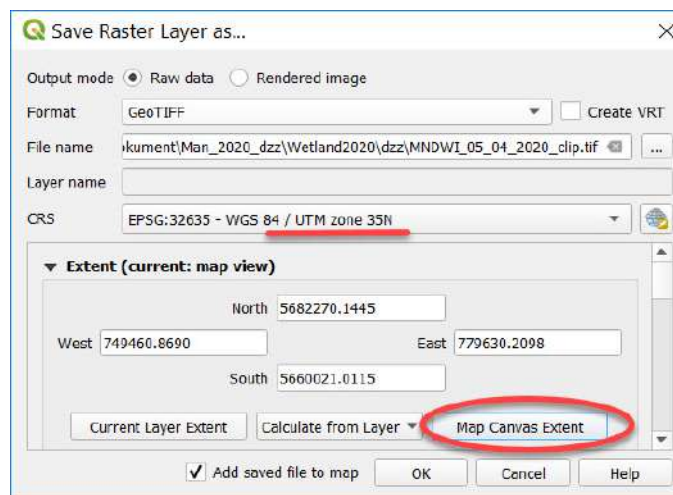
Repeat now all the above steps for the 2020 image to calculate the water index for 2020. As a result of calculation with the raster calculator, you should get two water indices of Bondarivske Swamp area as of April 8, 2018, and April 5, 2020, which will automatically open in your project as black-and-white raster layers with values ranging from 1 to -1.

Next, you need to immediately clip the resulting index images along the map window to avoid processing by the program any extra areas of the image and building a stretched histogram. To do this, place Bondarivske Swamp in the center of your screen, and right-click on the water index in the project, and select the following from the context menu: **Export** → **Save As**.

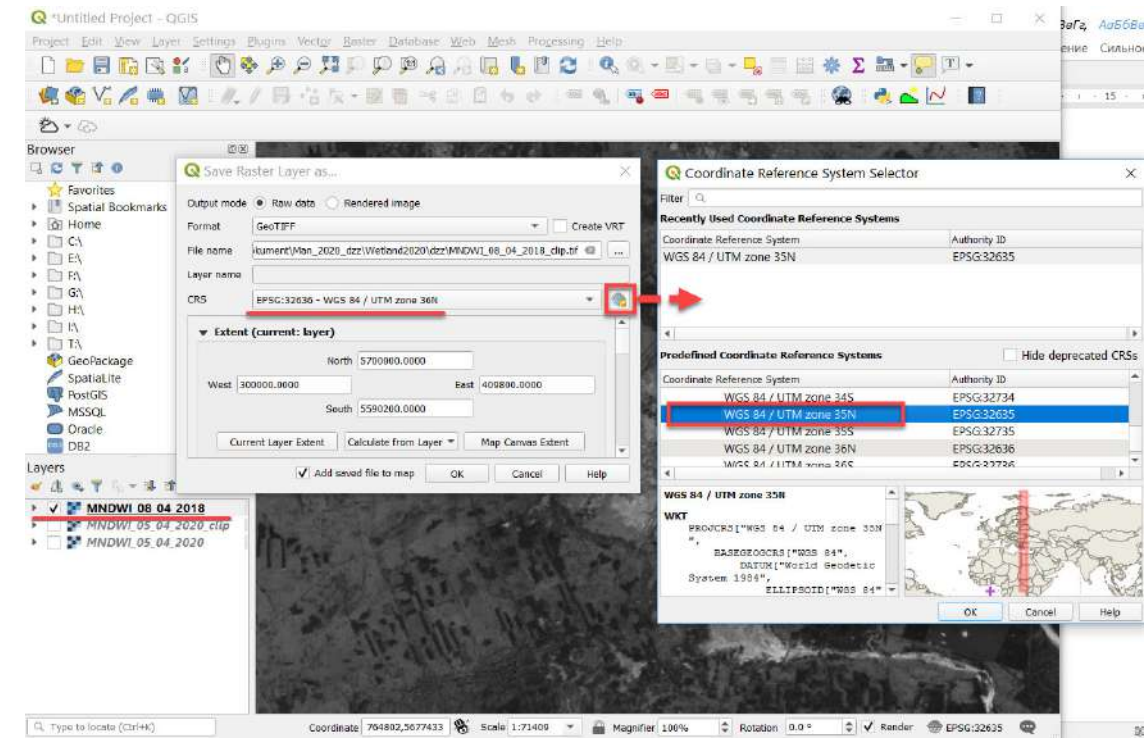


In the **Save Raster Layer** as dialog, click on the icon  next to **File Name**, and specify the path to the folder where the image will be stored, as well as its name.

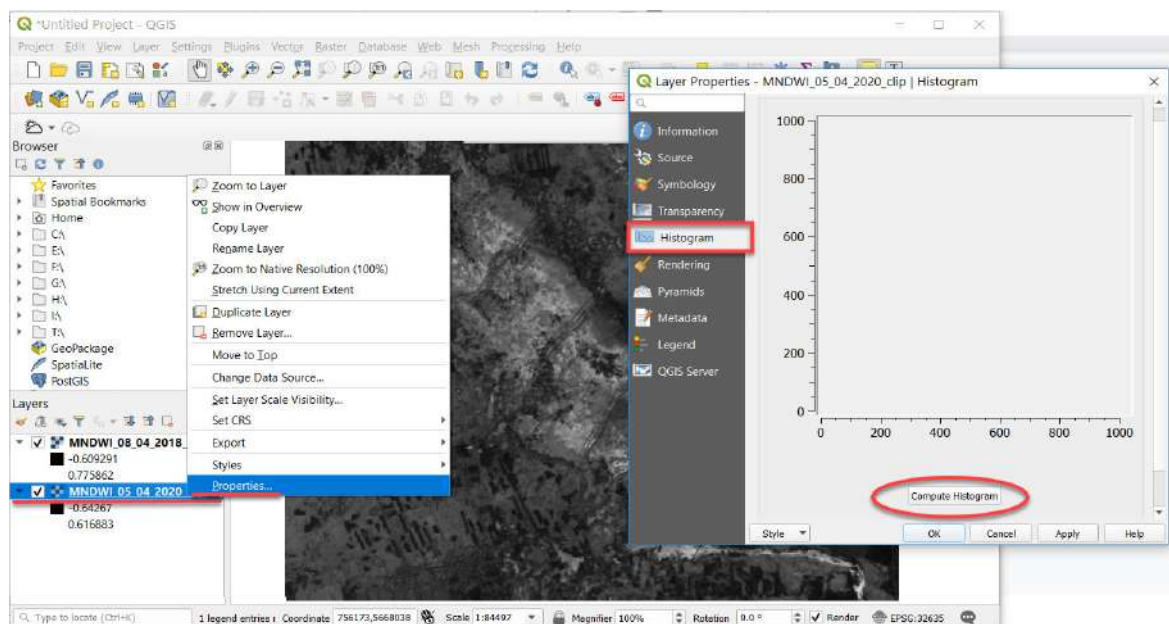
In the **Extent** block below, select **Map Canvas Extent** and click Ok.



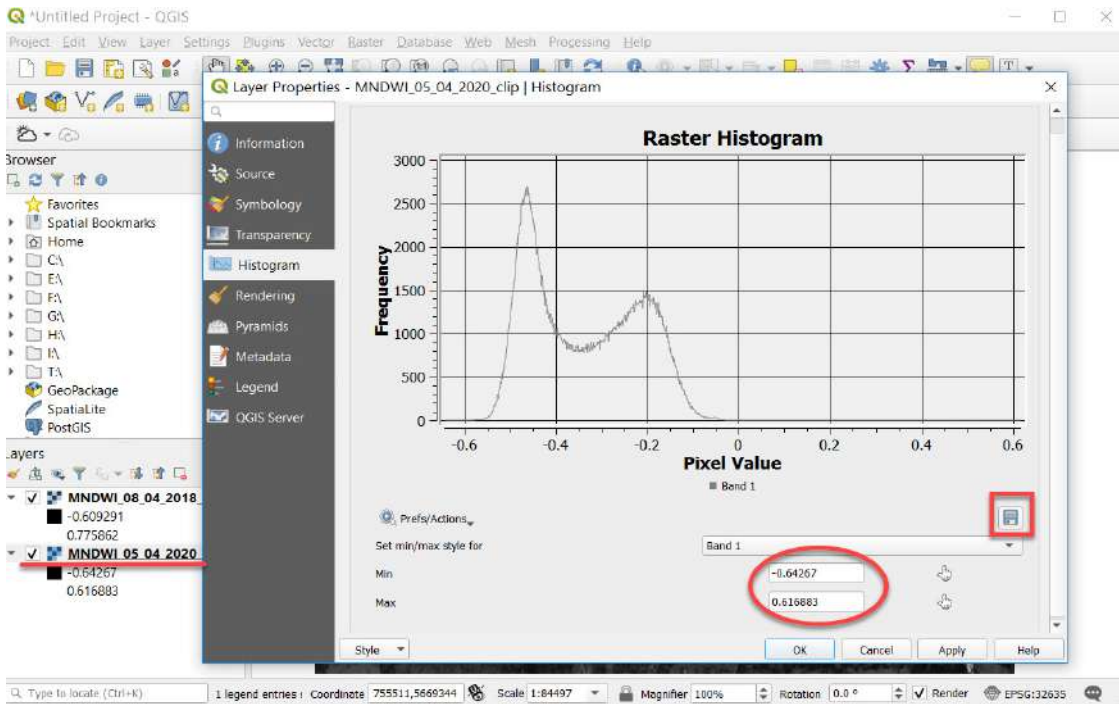
Important! If you have images with a geographical projection in different areas (in our case, the image as of April 5, 2020, has a projection of WGS 84 zona 35N, and the image dated April 8, 2018 – WGS 84 zona 36N), the image with the area that differs from that of the project, should be assigned a similar area when clipping the image on the desktop – otherwise the image will look rotated.



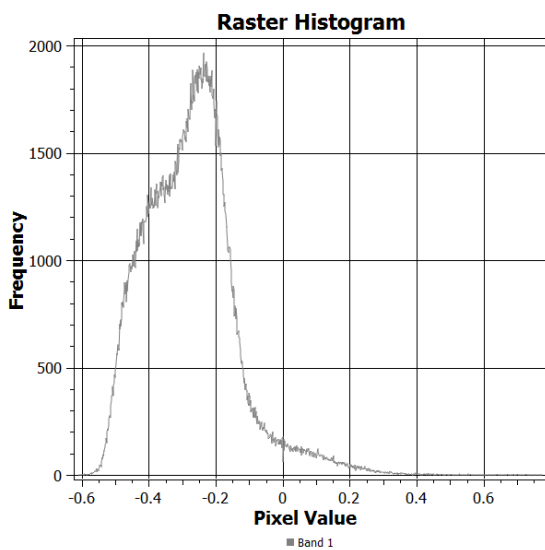
To check the correctness of index calculation, we can open the *Properties* tab of the created **MNDWI** layer by right-clicking on it and go to the *Histogram* tab. The tab that opens will initially be without a histogram. We need to calculate it by clicking the *Compute histogram* button.



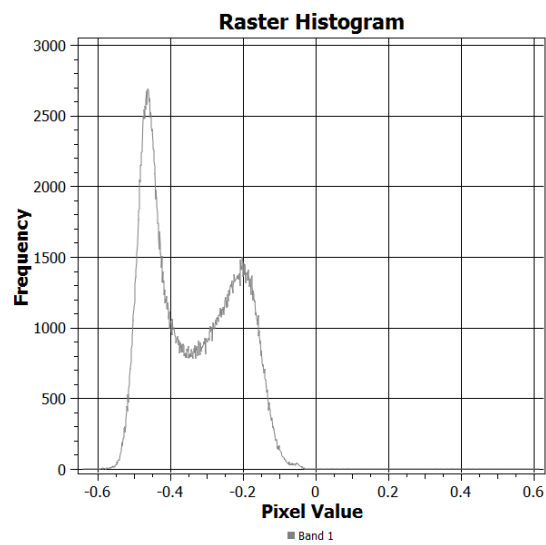
If the pixel value in the calculated histogram is between -1 and 1 (in our case the value for Bondarivske Swamp ranges from -0.64 to 0.61), your calculation is correct. The more wet the area, the closer value to +1.



Save the resulting histograms for comparison to your computer by clicking *Save plot*.



2018



2020

🔍 Check yourself

Compare two histograms of soil moisture distribution and describe the difference between them.

7. Selecting MNDWI threshold values and creating humidity maps of Bondarivske Swamp.

To create the Swamp moisture color map, you need to perform the following steps.

To access the raster display tools, right-click on the obtained humidity index first for 2018 – “MNDWI_08_04_2018_clip.tif” under Layers, and select *Properties* from the drop-down menu. In the *Layer Properties* dialog that appears, go to the *Symbology* tab and select the *Singleband pseudo-*

color display mode that allows you to group pixels into a given number of classes where the threshold values of each class can be modified. Next, select **Interpolation – Discrete**, and change Color ramp to make the index map look the way we need. We suggest that you choose shades from light blue to blue (Blues).

The table that appears at the bottom of the page has three columns:

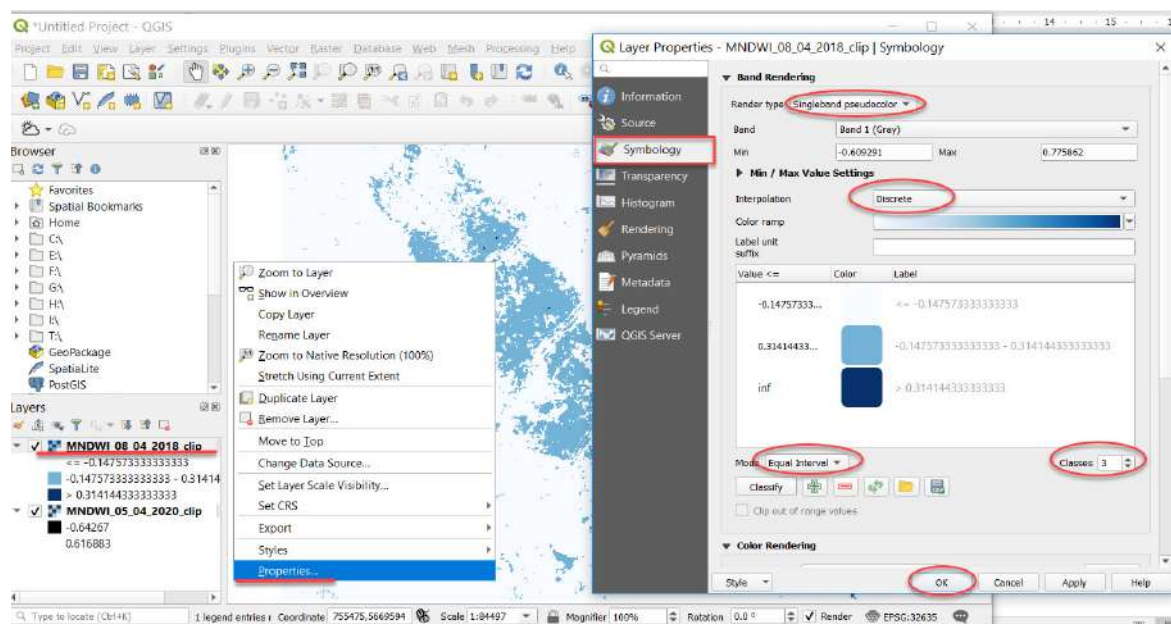
Value – the upper limit of the range;

Color – you can manually select the color of the range;




Label (name) – a text field, where you can label digital limits of the range or provide a short text description.

Using the **Classify** button, run the classification for the raster layer. You can also change here the number of **Classes** (in our case, there are three classes), and the range they cover by selecting the **Value** that best reflects the specified classes.

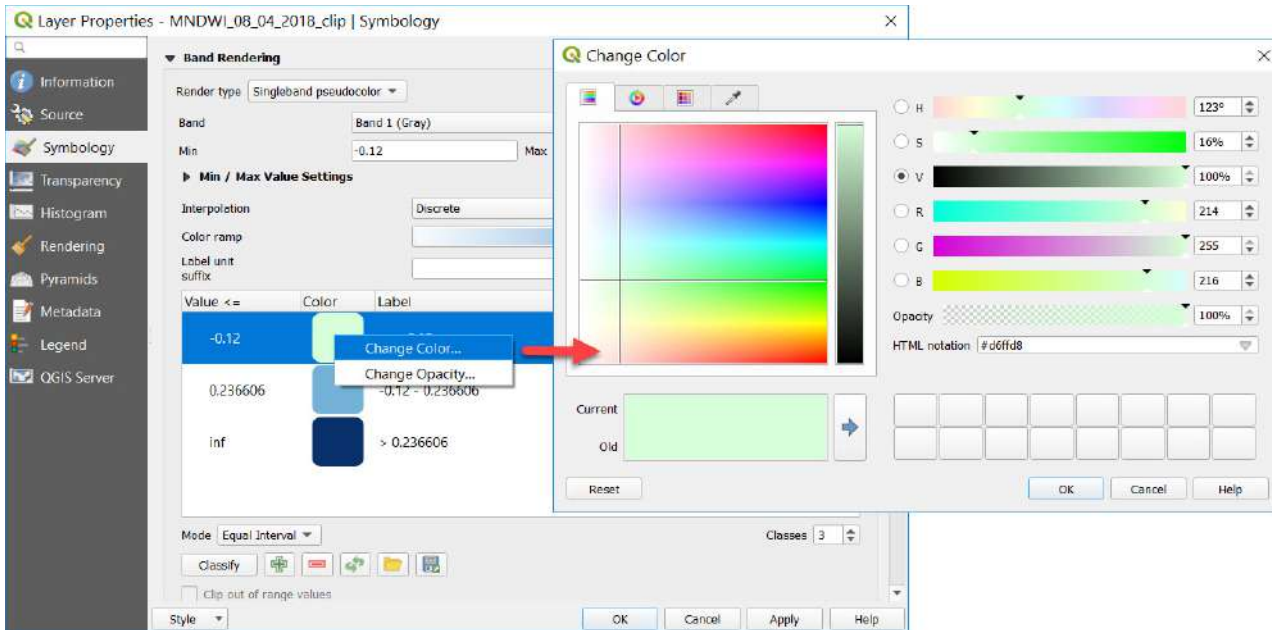
✔ **Important!** *If the character next to Classes cannot be edited, change the Mode from Continuous to Equal Interval, and specify three classes.*



Next, adjust the range for the land and change its color to light green. To change the values of the first range manually, double-click on the Value field with your left mouse button, and write the value -0.12; the second range will have the value 0.24. Therefore, you change mostly the upper limit between the first and second classes, and all other threshold values can be left unchanged. The main tip: make sure there are three classes: the first is just land, the second is a wet part of the swamp and the third is open water area.

	Value <=	Color	Label
1	-0.12		<= -0.12
2	0.24		-0.12 - 0.236606
3	inf		> 0.236606

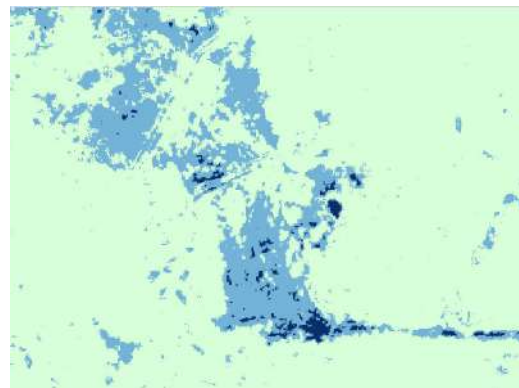
Now change the color of the land class from blue to green: click on the blue color of the first class, and a drop-down window, Change Color, will appear, in which you can choose a convenient display color (in our case, it is green).



If you analyze in detail the ranges of MNDWI values on the scale, you will see that according to the classification, the water index of open water areas will be represented by positive numbers, while all other values indicate drier areas or open surfaces. Using these threshold values, you should get the moisture content map for 2018 as shown below; however, it may differ visually within the threshold ranges, depending on the size of the humidity index fragment you have selected when clipping its part for Bondarivske Swamp.

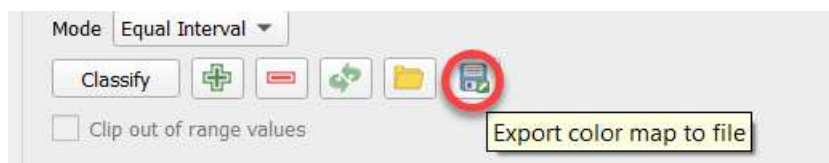


Satellite image



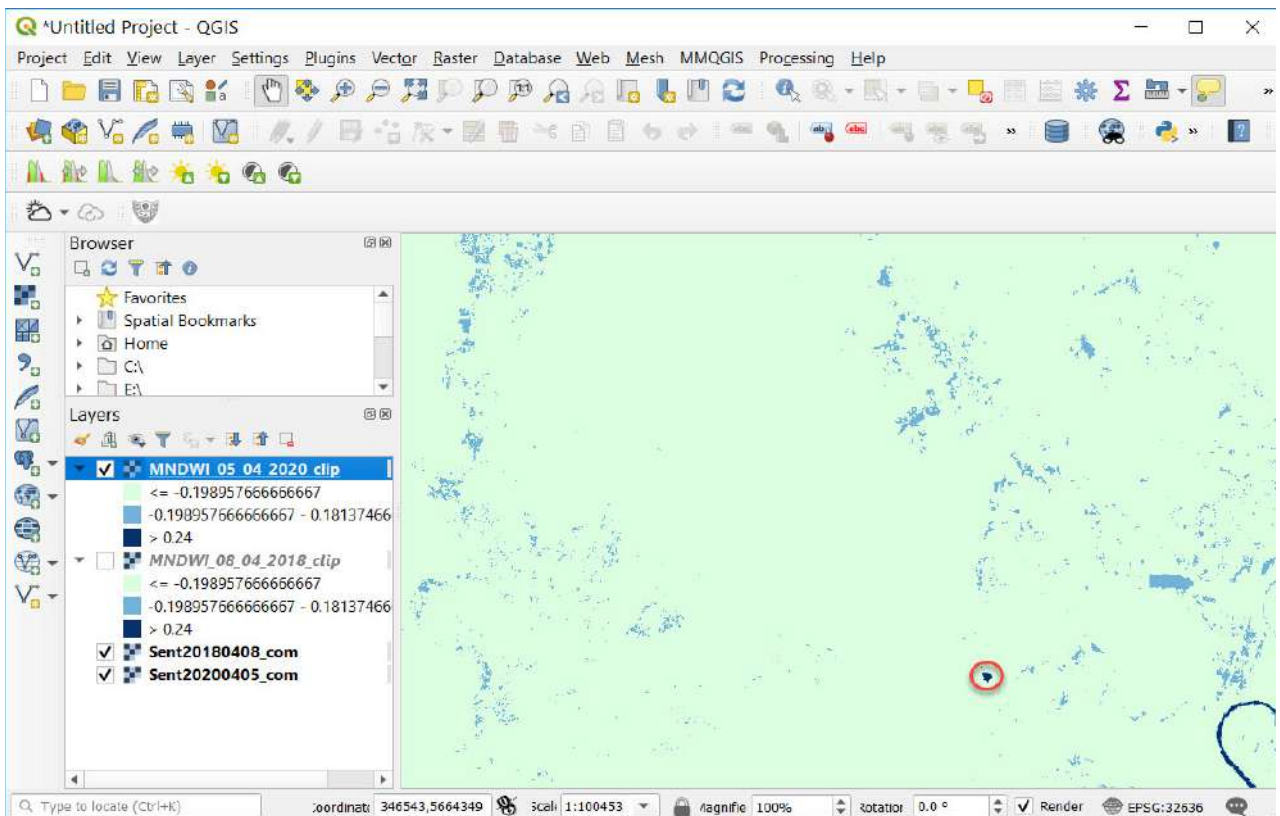
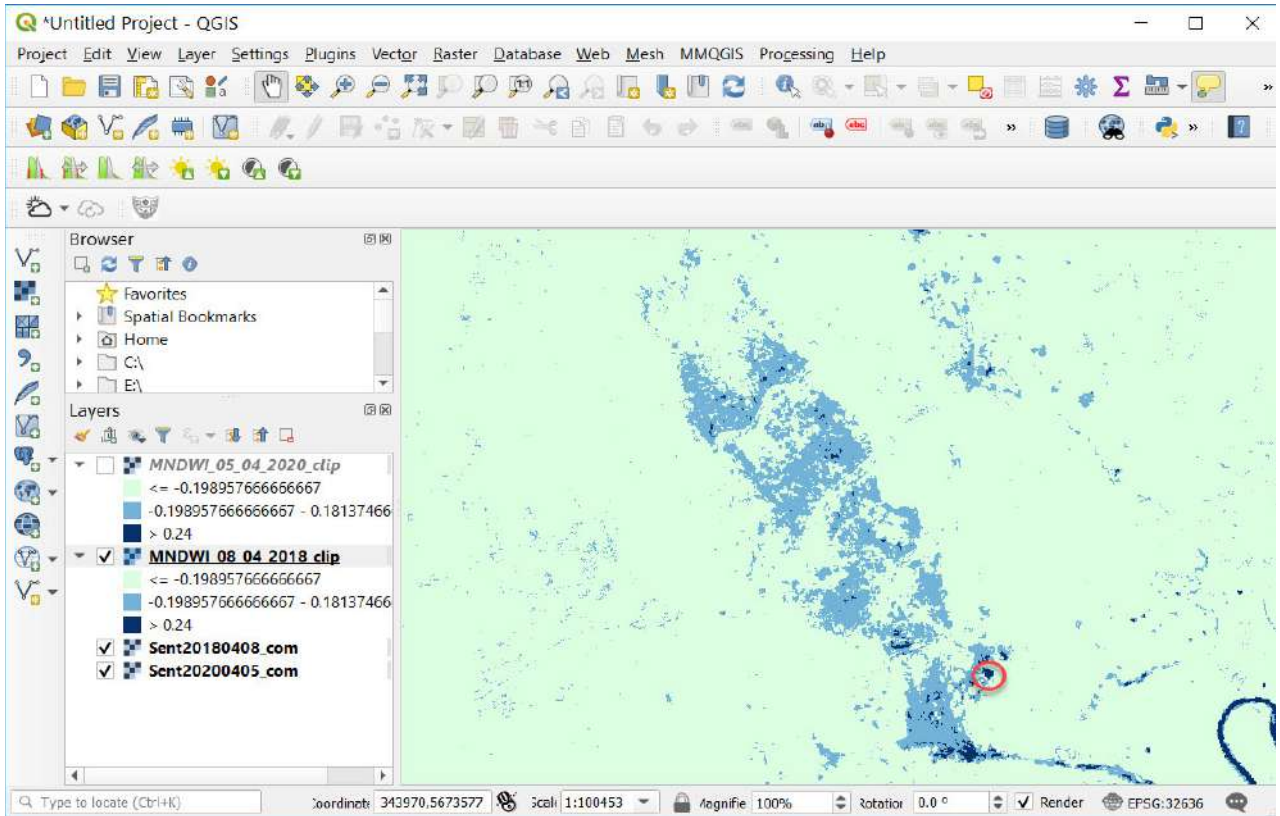
Moisture content map

Save the settings of the created 2018 moisture content map to be able to use these styles for another case study, namely, for 2020. To do this, click **Export color map to file** and apply these settings to the 2020 water index.



For this, go to the **Symbology** tab in the **Layer Properties** dialog that appears, and select **Load color map to file**.

As a result, you will get two thematic maps, where open water appears dark blue, the wet area is blue, and the rest of the area is green. The only thing that remains unchanged on both moisture content maps is a small lake near Bondarivske Swamp, enclosed in a red circle.



? Check yourself

Why do you think the moisture level in Ukrainian swamps changes? Why are swamps important for the ecosystem of our region in general?

Scan the QR-code below to watch the video tutorial on the performance of this Task.



6.2. Studying the Scale of the Flood on the Dniester River in the Summer of 2020

According to a leaflet prepared by the Zoï Environmental Network in the framework of the UN-ECE/OSCE/UNEP climate projects in the Dniester River basin within the International Environment and Security Initiative (ENVSEC) 1, the basic definitions are as follows:

- **flood** is a phase of the river water regime, which occurs annually in certain climatic conditions during the same season; it is characterized by high and prolonged rise and fall of water levels in rivers, lakes, reservoirs;
- **freshet** is a significant increase in the water levels in rivers within the annual cycle, which occurs irregularly; it takes place during heavy rains or thaws.

Case

The freshet in Western Ukraine in the summer of 2020 was a natural disaster that occurred due to intense thunderstorms, resulting in a sharp rise in the water level in the Dniester River. The freshet peak was observed on June 24-25 and exceeded the scale of a similar natural disaster in 2008, which caused losses amounting to UAH 3-4 billion.¹

Task

Create thematic maps of the flooded area during the freshet on the Dniester River in Halytskyi District of Ivano-Frankivsk Oblast based on the water index according to the Sentinel-2 satellite image.

Task performance algorithm:

1. Download Sentinel-2 satellite images dated June 25, 2020, and July 2, 2020, from Google Drive or EO Browser.
2. Create a merged false-color satellite image for these dates.
3. Visually compare the obtained images.
4. Measure the width of the Dniester River during the freshet.
5. Calculate the NDWI water index for both Sentinel-2 images.
6. Choose the NDWI threshold values and create a map of the Dniester River floodplain during and after the freshet.

¹ URL: <https://suspilne.media/43479-velika-voda-pricini-ta-naslidki-zatoplen-na-zahidnij-ukraini/>

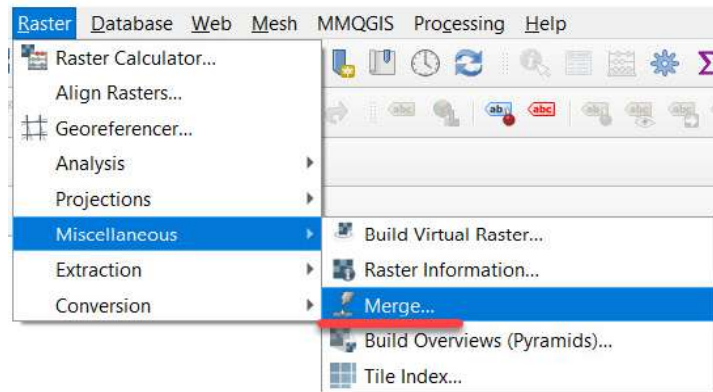
Instructions for self-guided work:


1. Download Sentinel-2 images dated June 25 and July 2, 2020, of the Halytskyi District of Ivano-Frankivsk Oblast from the *USGS Earth Explorer* website or from: <https://drive.google.com/drive/folders/1dReNsDzfaRTaczAZ8BTM43x8hnlzdsv4?fbclid=IwAR33GWqZD97t-j8hoFYBYOryZSt-94myqfO-SJAGUqmowblSlfP6LVWZybgk>.

2. Unzip the images. Satellite image bands can be found in the internal zipped files, in the GRAN-ULE and IMG_DATA folders. Launch QGIS and create a new project called “Freshet”.

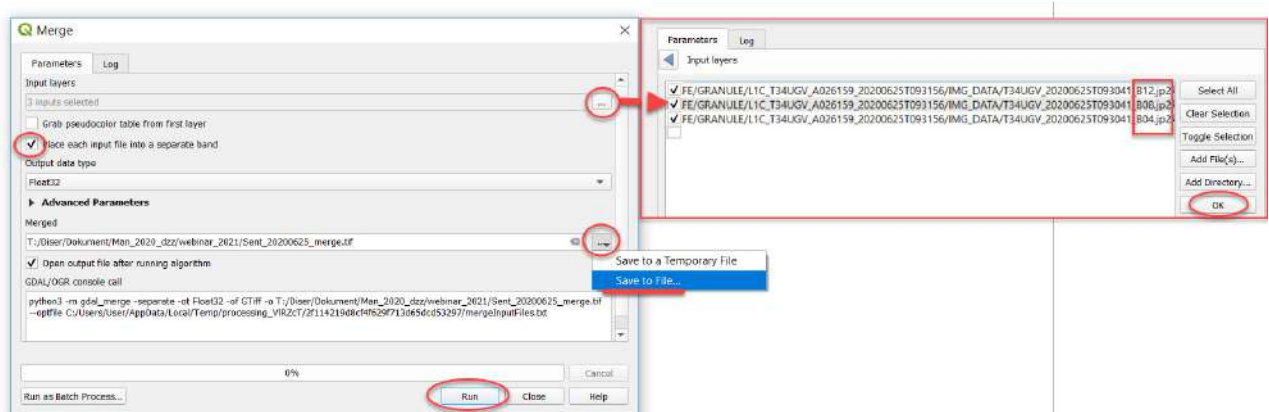
3. Let's start creating a merged image.

Create merged image via **Raster** → **Miscellaneous** → **Merge** first for one image taken on June 25, 2020, and then for another one taken on July 2, 2020.

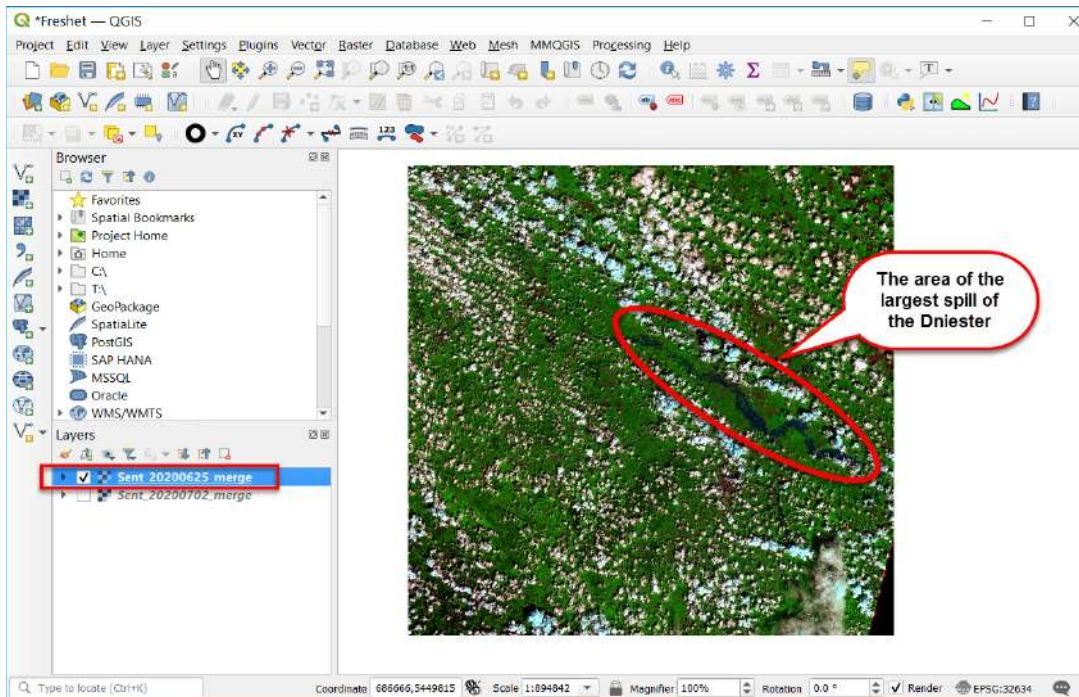


Under **Merge**, open the bands synthesis dialog, and specify the bands you want to merge in the Input Layers field. For this, click on the icon  next to the **Input Layers** field, click **Add files** in the **Multiple selection** dialog, find the folder with the saved image bands, and select the desired bands, namely: 12-8-4. You can select three bands at once by holding down the “Shift” or “Ctrl” key on the keyboard. It is important to select bands in the following order: R (B12 – SWIR), G (B8 – NIR), and B (B4 – red). You should drag the bands in a way as to display them in the following sequence: B12, B8, B4, and click Ok


 **Important!** Pay attention to the sequence of the bands when creating a merged image. If the bands are displayed in a different order, change their positions using the mouse.

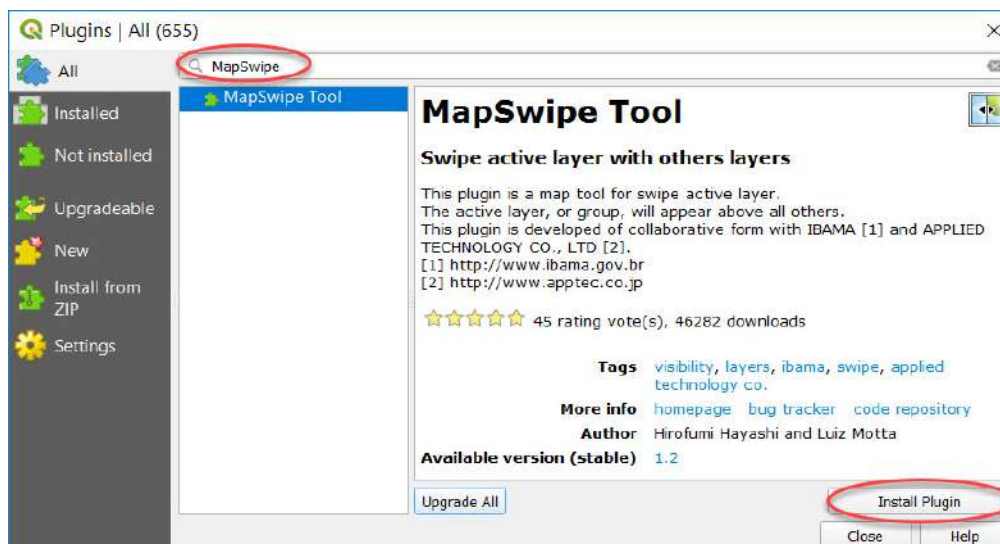


Upon completion of the **Merge** operation, the synthesized image in the 12-8-4 bands combination will be added to the project as a new layer called “Sent_20200625_merge”. Not to confuse the names, we suggest that you immediately give the name of the layer according to the date of an image. Upon completion of the same operations, add the next image to your project, named “Sent_20200702_merge”.



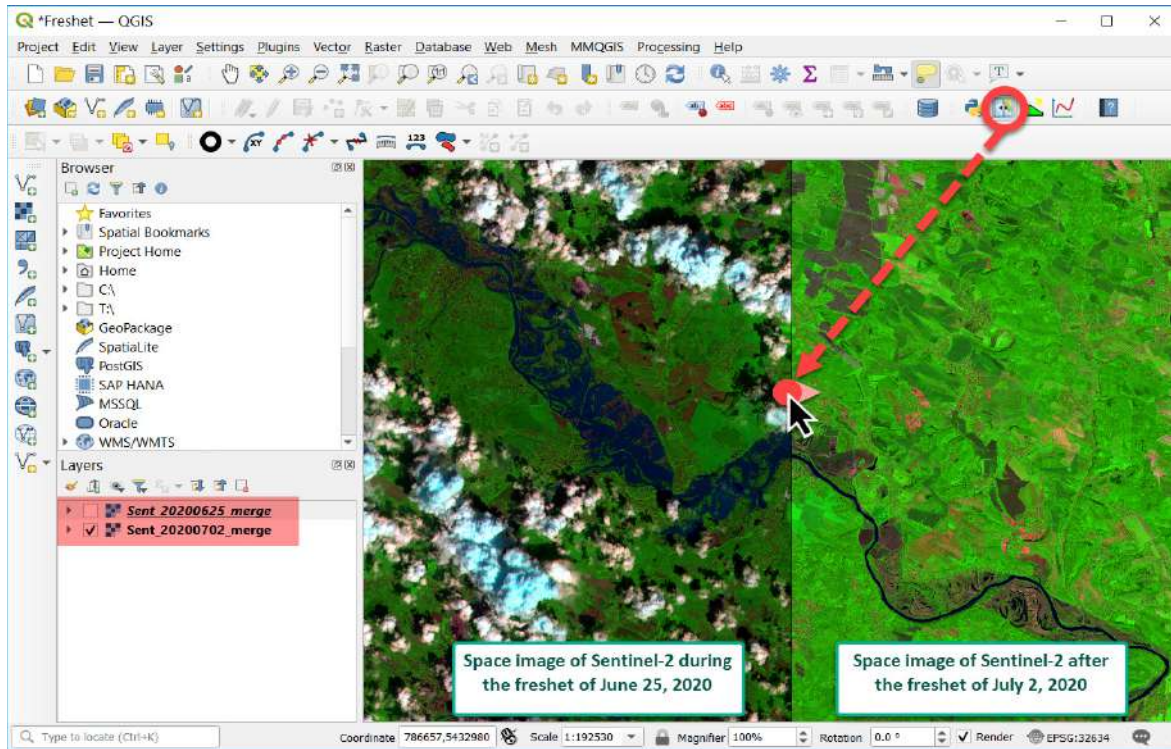
4. Visual comparison of two images using the *Swipe* tool.

To make it easier to compare two images, use the *Swipe* tool from the *MapSwipe Tool* plugin. For this purpose, select the following from the top menu: **Plugins – Manage and Install Plugins ... – Not installed** tab. In the search bar, start typing the name of the plugin, “MapSwipe Tool” or simply “MapSwipe”, and it will appear automatically in the list at the bottom of the screen. Select it from the list by left-clicking, and brief information about the plugin will pop up, which is worth reading. Click **Install Plugin** and close the dialog box. Once installed, the plugin will appear in the **Installed** tab, and an icon  will be displayed on the toolbar.



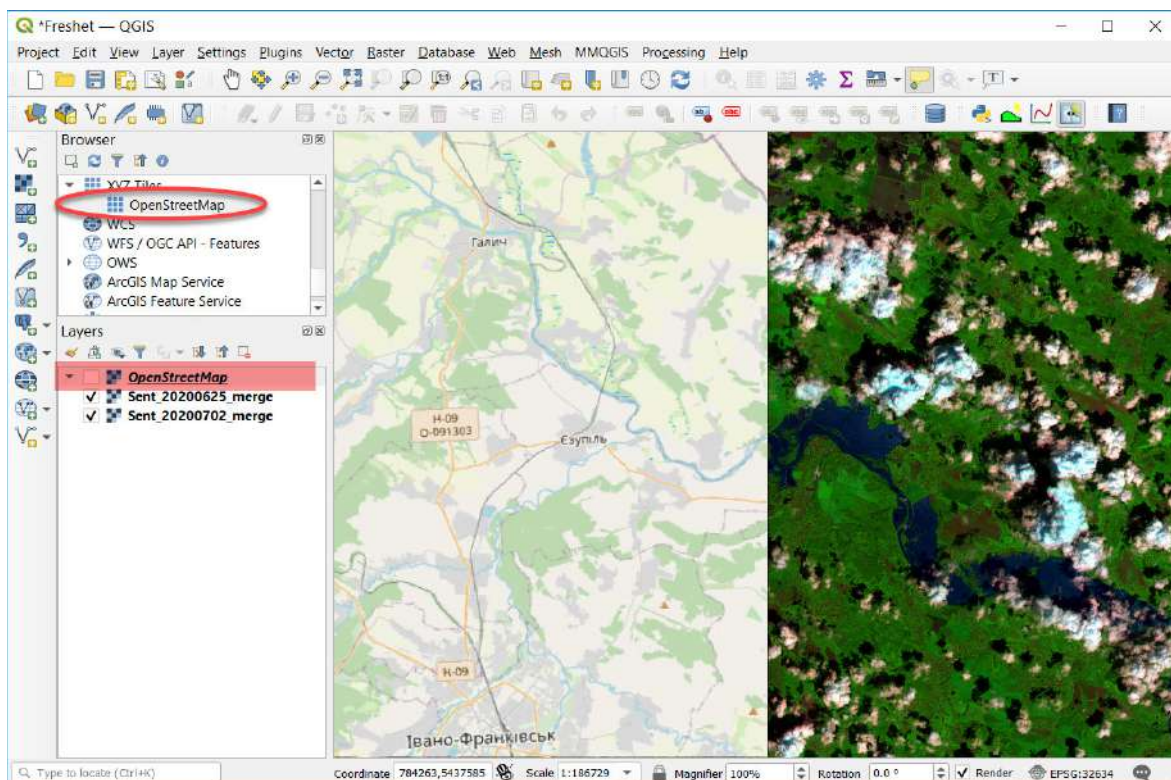
To use the *Swipe* tool, press and hold down the mouse button as you scroll over the image. You will notice that the mouse cursor changes depending on its position. This allows you to select the direction in which you want to temporarily swipe the layer. By holding down the mouse button and moving the cursor over the image, you can close the top layer in the selected direction.

Your Sentinel satellite images that were merged using the *Swipe* tool should look as in the figure below; you can visually compare the scale of the flood now.



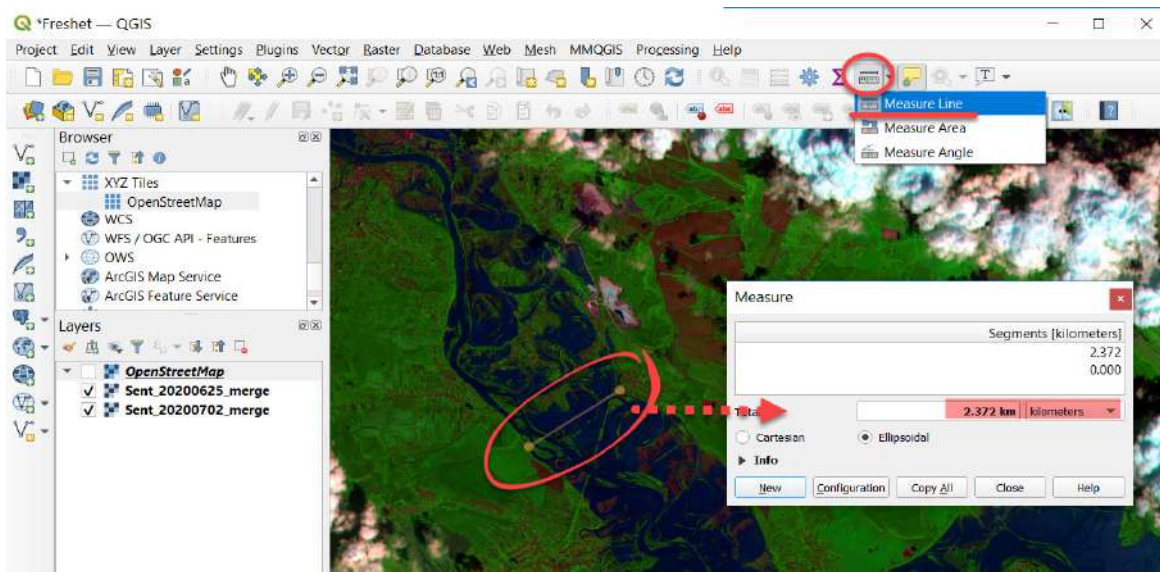
5. Measuring the width of the Dniester River during the freshet.

Add an OpenStreetMap (OSM) to your project for your guidance and identification of the extent of flooding near different settlements. For this purpose, expand *XYZ Tiles* from the *Browser* panel and double-click on the OpenStreetMap layer to open it in the Layers tab and display in the map window.



With the *Measure Line* tool, measure the width of overflow. Select the *Line* measurement type and a new *Measure* dialog will open. Hover over the image captured on June 25, 2020, find the appropri-

ate settlement, and click once on the right bank of the Dniester River, and the second time – on the left bank. The respective values for the width of river overflow will appear in the *Measure* window. You will need these values to complete the Task, i.e. to verify the following statement. For your convenience, use kilometers as units of measurement.



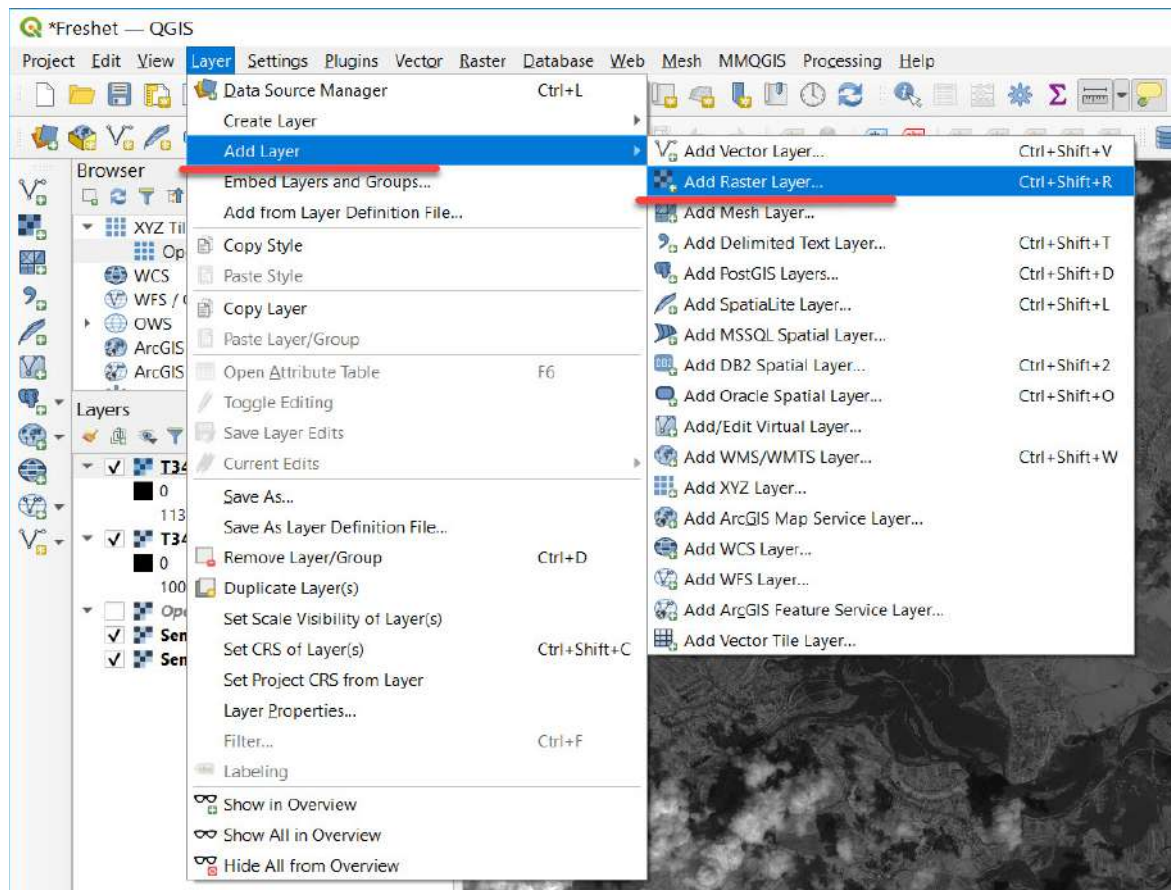
? Check yourself

Calculate the Dniester River overflow width near the following settlements:	Width of overflow, km
Petryliv	
Dovhe	
Yezupil	
Dubivtsi	
Halych	

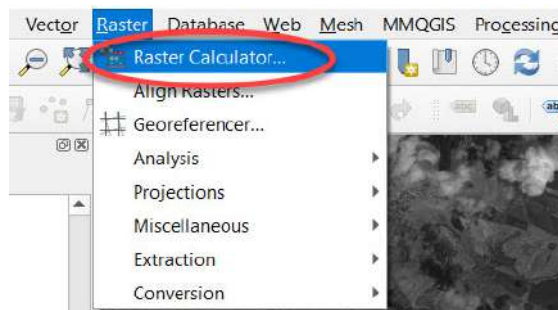
6. Calculating the NDWI water index for Sentinel-2 images before and after the freshet.

Water index formula: $NDWI = \frac{NIR - SWIR}{NIR + SWIR}$. For Sentinel-2, the NDWI formula will be as follows: $(B3 - B8) / (B3 + B8)$.

First, add the required bands (3 and 8) to your project using the *Add Layer* → *Add raster Layer ...*, or simply drag them from the Explorer window to your GIS project window.



Expand the **Raster** tab → **Raster Calculator** from the main menu.



In the corresponding field of the **Raster Calculator** window, enter the formula for calculating the water index: $NDWI = (NIR - SWIR) / (NIR + SWIR)$, where NIR and SWIR are the bands you select from the menu at the top of the calculator window. For the Sentinel-2 image, we substitute the bands' values:

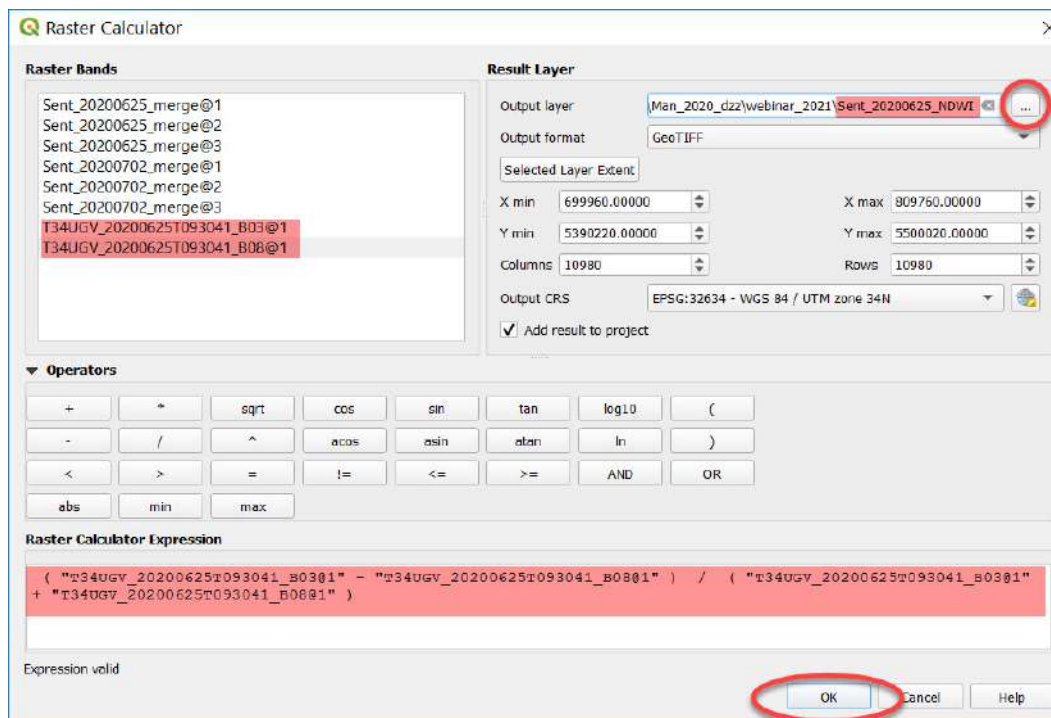
$$(Band3 - Band8) / (Band3 + Band8).$$

For this purpose, select the appropriate bands under **Raster Bands** in the **Raster Calculator** dialog box, use appropriate **Operators** to select characters for the formula: -, +, /. To add layers to the expression window, double-click the desired layer with your left mouse button.

✔ **Important!** *Do not enter the file names from the keyboard since the formula will not run.*

Note that the Ok button at the bottom of the calculator will become active after you specify the name and location of the **Output layer**. Select the desired folder by clicking , and write the name of the source layer, for example: "Sent_20200625_NDWI.tif", where the digital characters indicate the date of the image.

✔ **Important!** If the file is not saved for some reason, check the paths and file names for Cyrillic characters and spaces – you should avoid using them.



As a result of calculation with the raster calculator, you will get two water indices for the Dniester River area as of June 25 and July 2, 2020, which will automatically open in your project in the form of black and white raster layers with values ranging from 1 to -1.

5. Selecting NDWI thresholds and creating maps of the Dniester River during the freshet illustrating high water levels.

To create a color map of the Dniester River water level during the freshet, you need to perform a series of steps using the image captured on June 25, 2020.

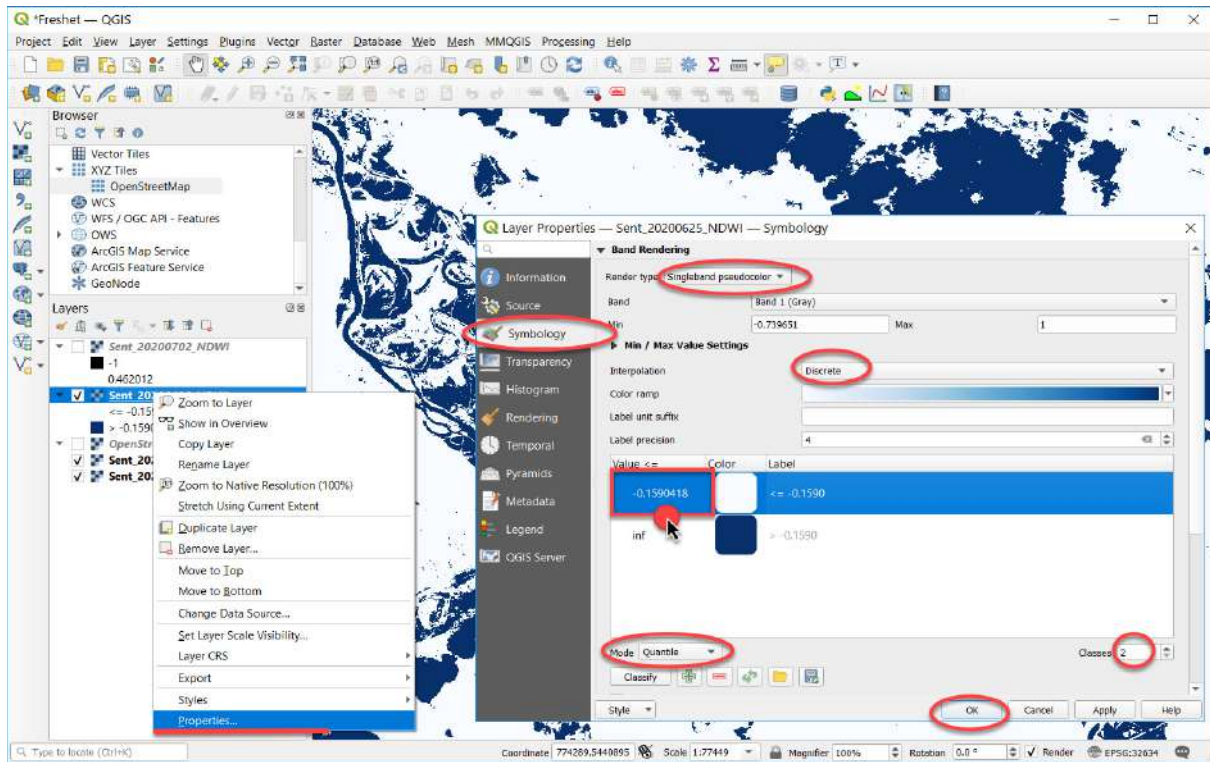
To access the raster display setting tools, right-click on the NDWI layer under Layers and select **Properties** from the drop-down menu; next, go to the **Symbology** tab in the **Layer Properties** dialog that appears, and select the **Singleband pseudocolor** display mode. This mode allows you to group pixels into a given number of classes, and change the thresholds for each class. Next, select **Color Interpolation – Discrete (Discrete scale)**, and change the **Color ramp** so that the index map has the appearance that we need. We suggest that you choose shades of blue. The table that appears on the page below has three columns:

Value – the upper limit of the range;

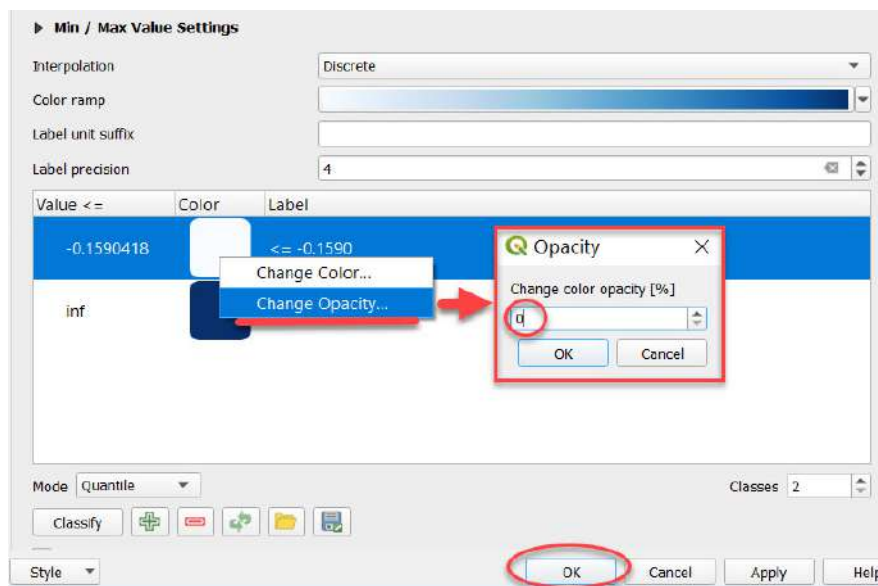
Color – you can manually select the color of the range;

Label – a text field, where you can specify the digital limits of the range, or make a short text description.

To select the water index thresholds for only two classes, water, and land, change the **Mode** from **Continuous** to **Quantile**, and write “2” in the **Classes** field. As a result, you will get a map where not only water but also clouds are displayed as one class. This is characteristic for the clouds display; therefore, to reduce the number of clouds, change the **Value** settings from - 0.3590418 to - 0.1590418.



By editing the *Value*, you can best display the scale of the flood under study. Once we have set the threshold values, we shall make the land class transparent: right-click on the color designation of the first class and select **Change Opacity**, and replace 100% with 0%. While doing this, the OSM base map should be open in the background.



As a result of all transformations, you will change the appearance of the water index from a black-and-white gradient raster to a raster with two classes: ≤ -0.1590418 (land), and > -0.1590418 (water).

Sent 20200625 NDWI
 -0.739651
 1





Sent 20200625 NDWI
 <= -0.1590
 > -0.1590

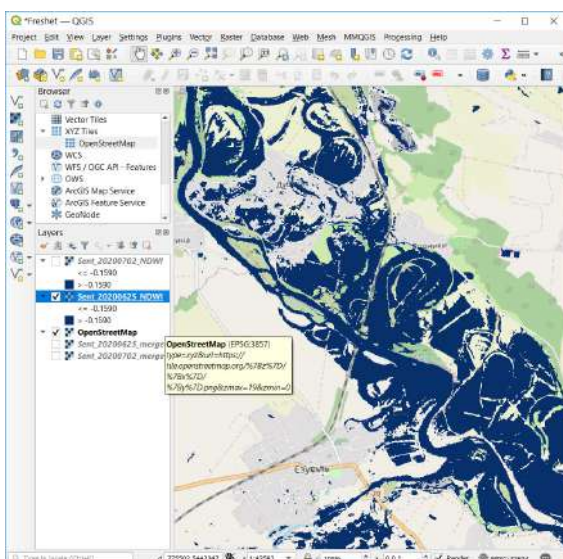


Water index before setting the threshold values

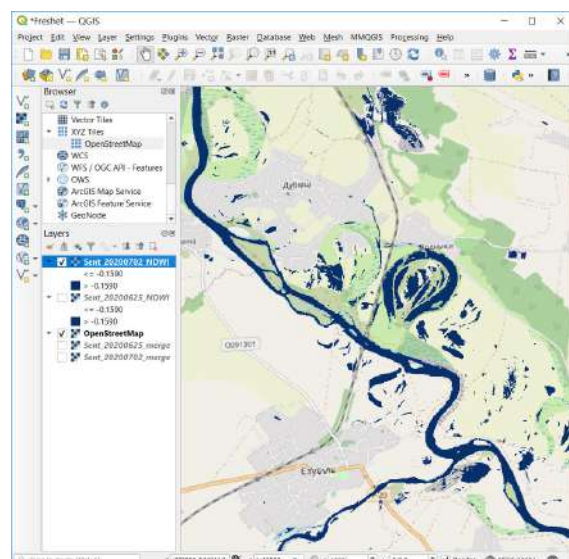
Water index upon setting the threshold values

To quickly assign the already selected values (that we have set for the image taken on June 25, 2020), to the next image taken on July 2, 2020, according to the image dated June 25, 2020, select **Style**  → **Export color map to file** on the bottom left-hand side of the screen from the **Layer Properties** window under **Symbology**. For the image captured on July 2, 2020, click **Style** → **Load color map to file**  and select a style file that was previously downloaded to your computer. In this case, we have used the same style template for two raster layers to make it easier to compare them. As a result of all transformations, we have obtained thematic raster layers that can be further converted into vector layers, and based on which, the area of flood in the reservoir can be calculated.

You can compare the results by superimposing them on the OSM map or overlapping two water index images.

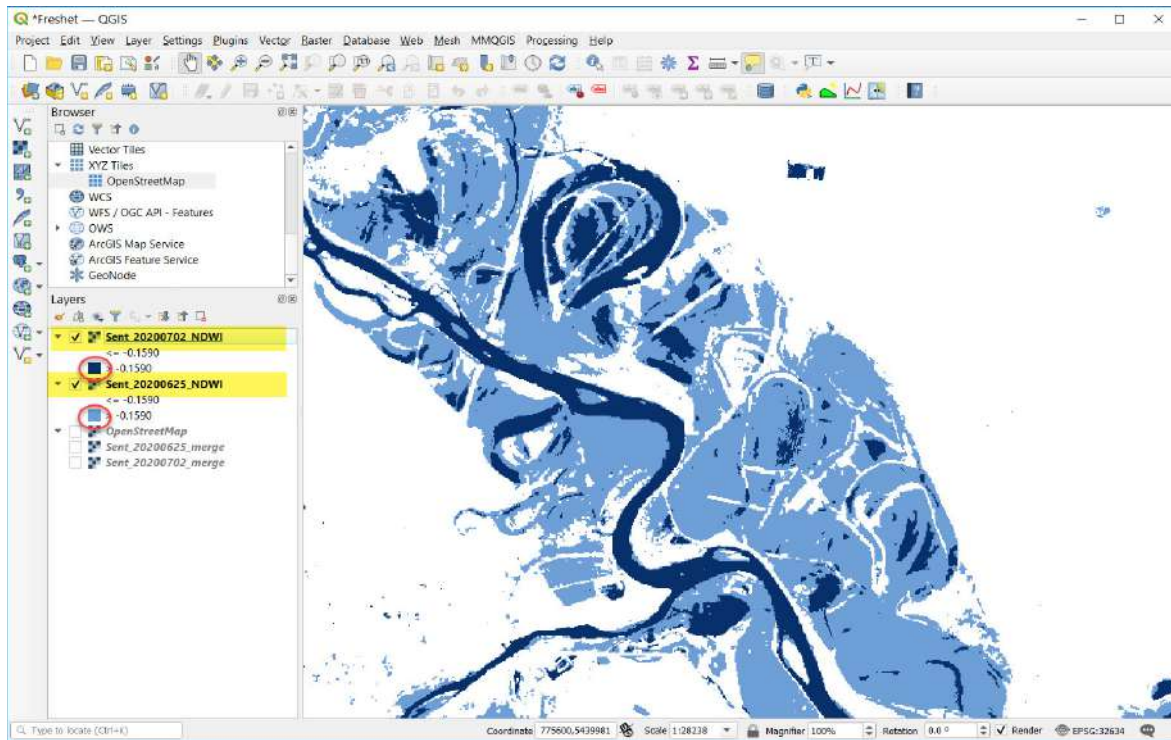


June 25, 2020



July 2, 2020

To make the water appear differently on the map in different months, change its color to blue in the image taken in June: go to the **Layer Properties** window and select **Change Color** under **Symbology**.



? Check yourself

What do you think are the main causes of abnormal heavy rainfalls? And why do the Carpathians and Zakarpattia suffer from floods most often?

Scan the QR-code below to watch the video tutorial on the performance of this Task.



7. Applications of Radar Imagery

7.1. Detecting Ships Operating in the Area of Tokyo Bay

The term “quarantine” derives from the Italian “quaranta giorni”, meaning 40 days – the length of time ships from infected ports had to sit at anchor in Venice during the 14th-century bubonic plague epidemic. This system, which was used by Italian cities, was later adopted by other European countries.¹

Case

Cruise ships carrying a large number of people often become the settings for outbreaks of infectious diseases because of the crowded semi-enclosed environments and limited medical resources. Outbreaks of COVID-19 on cruise ships pose a risk for a rapid spread of disease beyond the voyage.

The *Diamond Princess* was the first cruise ship to experience a major COVID-19 outbreak on board. In early February 2020, an elderly passenger who disembarked in Hong Kong was tested positive for the coronavirus. The liner was then quarantined off the coast of Yokohama (Japan). From February 4, 2020, for approximately a month, people remained on board, some confined to their cabins, often without windows. The infection spread four times faster on the cruise ship than in Wuhan (the city where the first COVID-19 outbreak was recorded). A major outbreak aboard the ocean liner eventually led to nearly 700 infections and 14 deaths from coronavirus. In February 2020, the *Diamond Princess* had the second-highest COVID-19 infection rate in the world.²

Task

Identify Singapore in the radar (Sentinel-1) and multispectral (Sentinel-2) images taken on January 31, 2020. Using *EO Browser* scripts, experiment with the radar image of Yokohama Port taken on February 4, 2020 (a time when *Diamond Princess* cruise ship was under quarantine), download the processed image and animation, create a map layout in QGIS.

Task performance algorithm:

1. Run scripts in *EO Browser*.
2. Download data from *EO Browser* (image and animation).
3. Open the image and vector layer in QGIS.
4. Download the image from **Bing**.
5. Create a map layout.

Instructions for self-guided work

In this Task, we will use radar imagery acquired by the Sentinel-1 satellite. The Sentinel-1 mission is a constellation of two satellites that monitor Earth day and night and deliver radar data.

Unlike multispectral images, radar images do not show a clear picture due to the presence of granular noise – flashes, vortices, speckles, and waves. To generate a clearer image and reduce granular interference, it is necessary to stitch together and filter several images. The SNAP software (<http://step.esa.int/main/download/snap-download/>) has been specifically developed for Sentinel-1 images' preprocessing and offers a series of toolboxes for the performance of the above-mentioned operations. However, to make our work with radar data easier, we will use *EO Browser* for downloading Sentinel-1 images that have already undergone script processing.

¹ URL: <https://time.com/5799525/coronavirus-covid19-quarantine-ships-history/>

URL: www.theguardian.com/world/live/2020/feb/20/coronavirus-live-updates-diamond-princess-cruise-ship-japan-deaths-latest-news-china-infections

Imaging radars, although complex systems, have some advantages, namely:

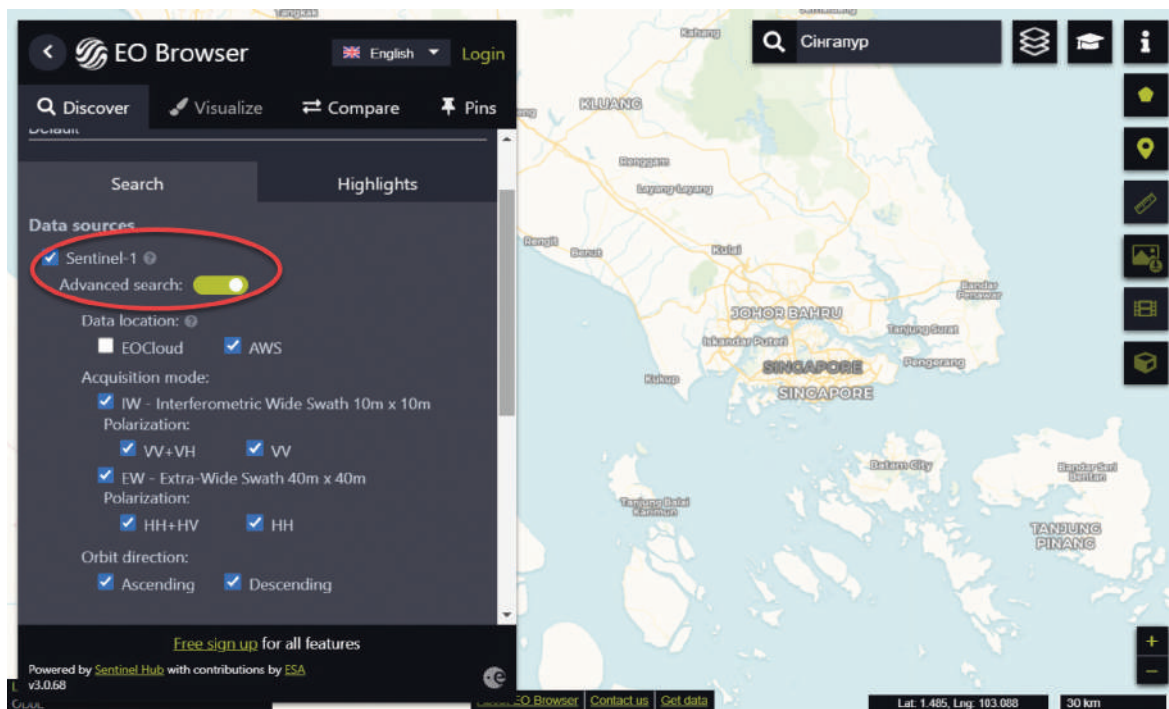
- can operate under any weather conditions;
- independent of sunlight as they have their own source of energy;
- sensitive to water, biomass, ice, and surface roughness;
- can measure distances accurately;
- sensitive to anthropogenic (man-made) features.

1. We will start our work in *EO Browser*: go to *EO Browser's* website, enter your login and password.

Using the search bar, identify the location of Singapore, one of the largest port cities in the world, on the map.

First, let's compare Sentinel-2 multispectral data and Sentinel-1 radar data. In the **Search** tab.

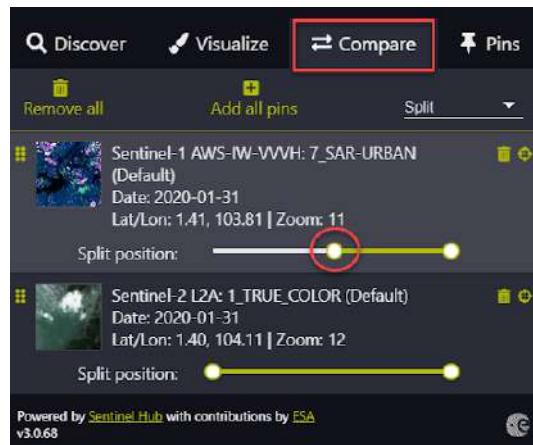
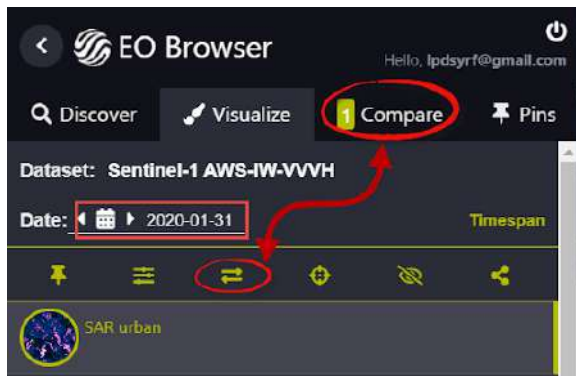
- select **Data sources**: Sentinel-1;
- turn **Advanced search** on. Leave unchanged all default settings (don't uncheck the boxes): **Data location, Acquisition mode, Polarization, Orbit direction**;
- set the **Time range**: 2020-01-30 – 2020-02-01;
- click the **Search** button.



In the list of search results, select the Sentinel-1 image taken on January 31, 2020, and click **Visualize**. The Sentinel-1 image will be automatically displayed as a **SAR urban** product. Leave it unchanged and click the **Add to compare** button – the image will be added to the **Compare** tab.

Return to the **Search** tab and select the next data source – Sentinel-2. Toggle the **Advanced search** on and tick the **L2A (atmospherically corrected)** box. Set the **Time range**: 2020-01-30 – 2020-02-01. Click the **Search** button.

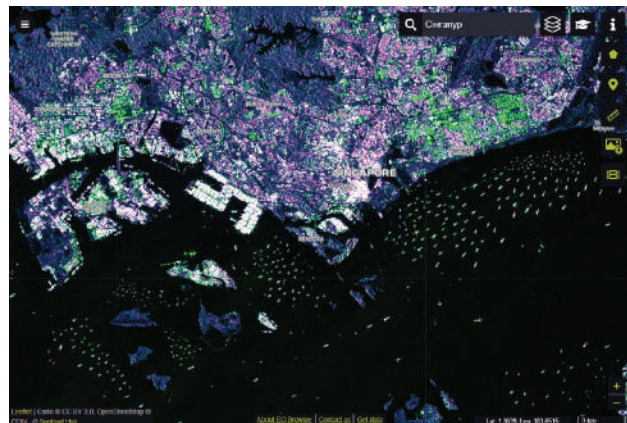
Download the Sentinel-2 image taken on January 31, 2020, click **Visualize**, and add this image to the list for comparison by clicking the **Add to compare** icon.



Switch to the *Compare* tab and compare the Sentinel-1 and Sentinel-2 images taken on the same date (January 31, 2020) by dragging the slider next to the top image.



Sentinel-2 True color



Sentinel-1 SAR-urban

View of Singapore as of January 31, 2020 (Sentinel-2 and Sentinel-1 images)

Check yourself

What is the most obvious difference between Sentinel-2 and Sentinel-1 images? Why do you think the images differ?	
What coastal area of Singapore has the largest number of ships?	

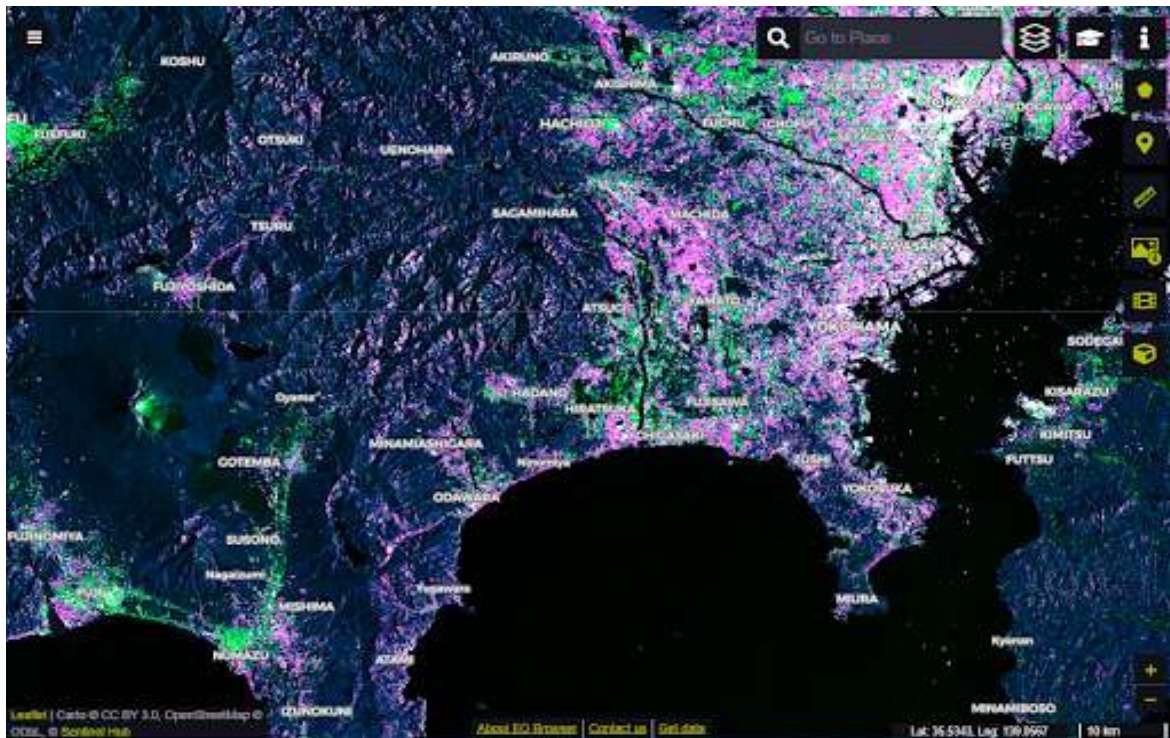
2. EO Browser makes your work with radar data much easier due to the availability of numerous custom scripts. After all, good visualization can help you focus on specific aspects, and create images that are more understandable to people who do not work with satellite imagery. Therefore, the next step will be to experiment with scripts and download images of Yokohama port, where the *Diamond Princess* ocean liner was kept under quarantine for more than a month.

Using the search bar, identify Yokohama Port (Japan) in the map:

- set *Data sources*: Sentinel-1;
- turn *Advanced search* on and leave all default settings unchanged: *Data location*, *Acquisition mode*, *Polarization*, *Orbit direction*;

- set **Time range**: 2020-02-20 - 2020-03-01;
- click the **Search** button.

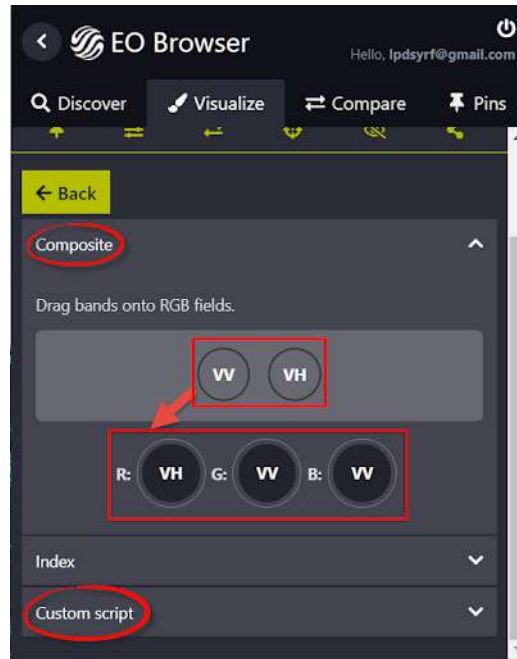
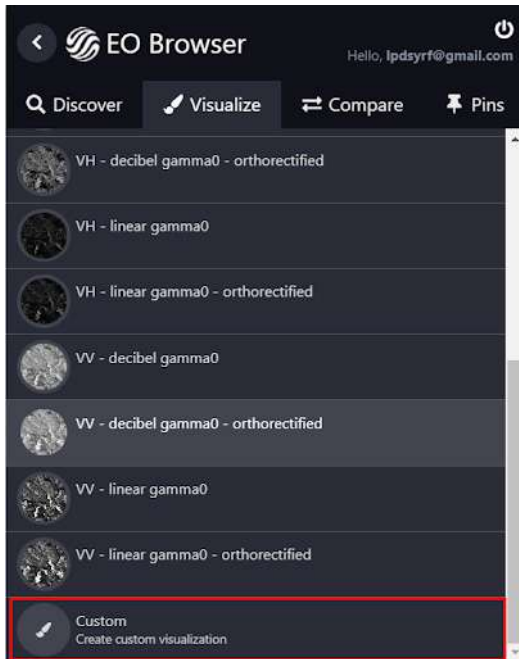
In the search results window, select the Sentinel-1 image taken on February 27, 2020 (Sentinel-1 AWS-IW-VVVH, 2020-02-27, 20:43:21 UTC), and click **Visualize**. The Sentinel-1 image will automatically be displayed as the **SAR urban** product. **SAR urban** combination is well suited for detecting urban areas and individual buildings and making mountain terrain more distinctive. It uses VH and VV polarization to highlight different buildings. You've probably noticed already the ships, which can be distinguished with this combination (dots, dashes, and crosses in a black background) in the image of the bay.



In fact, **SAR urban** is not well suited for our purpose because we have to investigate water surfaces. Let's try out other scripts for visualization.

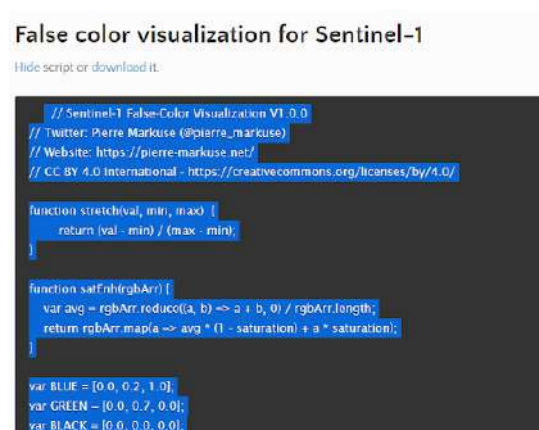
✔ **Important!** Please note that a color radar image is the product of post-processing; initial data is black-and-white and contains two polarizations – VV and VH, which need to be further processed and calibrated. EO Browser simplifies this procedure and allows us to use already processed data (try out different polarization options from the left-hand sidebar in EO Browser).

3. Let's proceed to visualization options using scripts. Select **Custom** from the left-hand sidebar: you can create your own band combination under **Composite** by dragging the bands onto **R, G, B** fields. As you change the band composite, the image in EO Browser window will change accordingly.



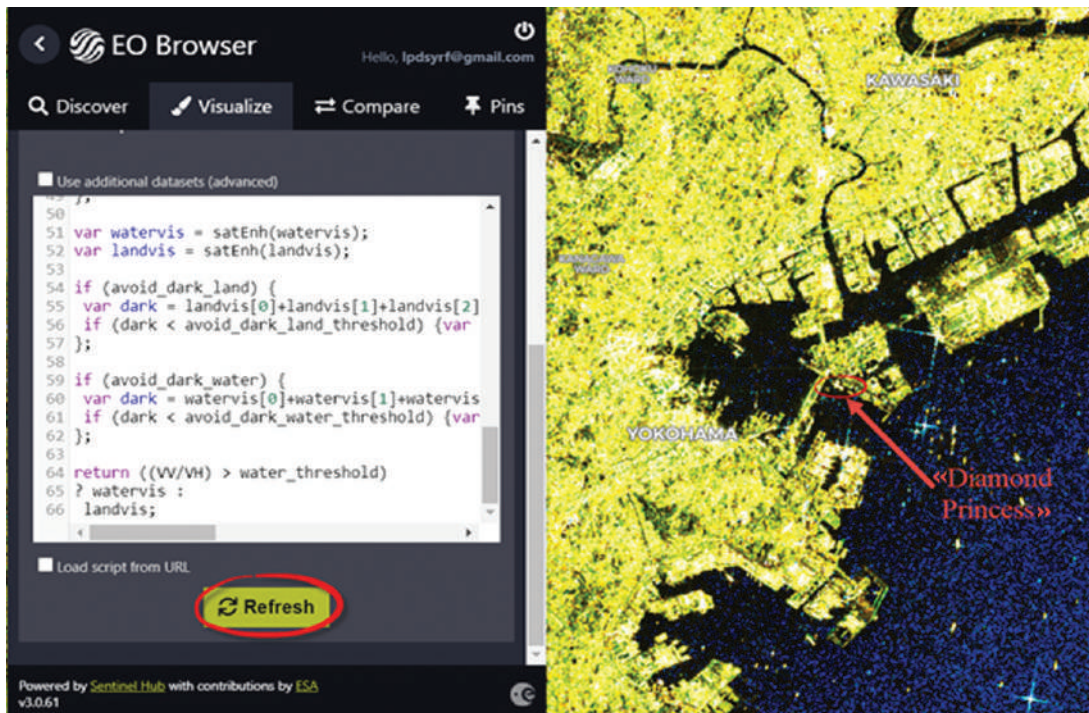
However, of our interest is the **Custom script** tab. Switch to this tab, and a script window with the code description of the image scene will appear on your screen. This does not mean, however, that we will learn a programming language now and write our own script – we will use the scripts from a repository of Sentinel-1 custom scripts available at: <https://sentinel-hub.github.io/custom-scripts/#sentinel-1> (select Sentinel-1 section).

Go to the page using the above-mentioned link and you will notice that all scripts for Sentinel-1 are grouped into several categories. Select **SAR false color visualization 2** under **Other available scripts**. The page provides brief information about the script and indicates its author; you can also view the examples of radar images produced with this script. Click the **Show script** button and copy the whole text that appears in a black background.



The interface of a web platform that provides a collection of custom scripts for EO Browser (source: <https://sentinel-hub.github.io/custom-scripts/#sentinel-1>)

Return to EO Browser, replace the existing script with the one you just copied, and click **Refresh**. The resulting image will be displayed in blue and yellow shades (blue for water, yellow for land). If you zoom to Yokohama port, you can see yellow spots and dots on the water surface – these are the ships. On February 27, 2020 (the date of the image), the *Diamond Princess* liner was anchored at the port, and you can see it in the image.



4. Save this image using the  **Download image** image tool. The part of the image you see on the screen will be saved during downloading. To do this, open the **Analytical** tab in the image download dialog, and perform the following settings:

Show logo - turn this function off;

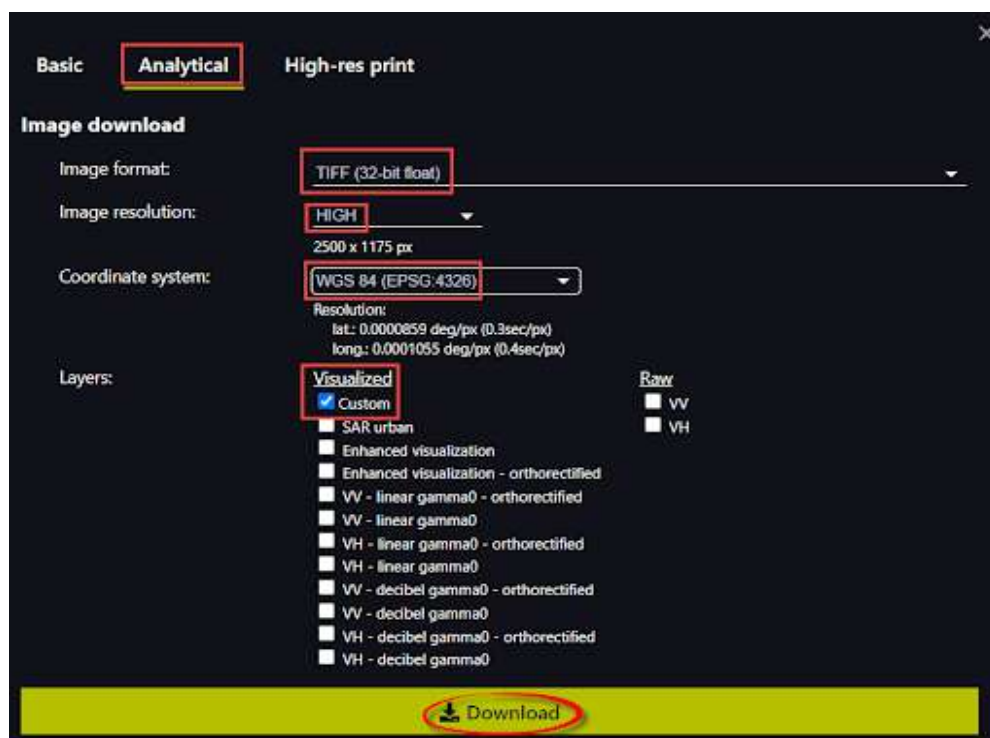
Image format - TIFF;


Image resolution - High;

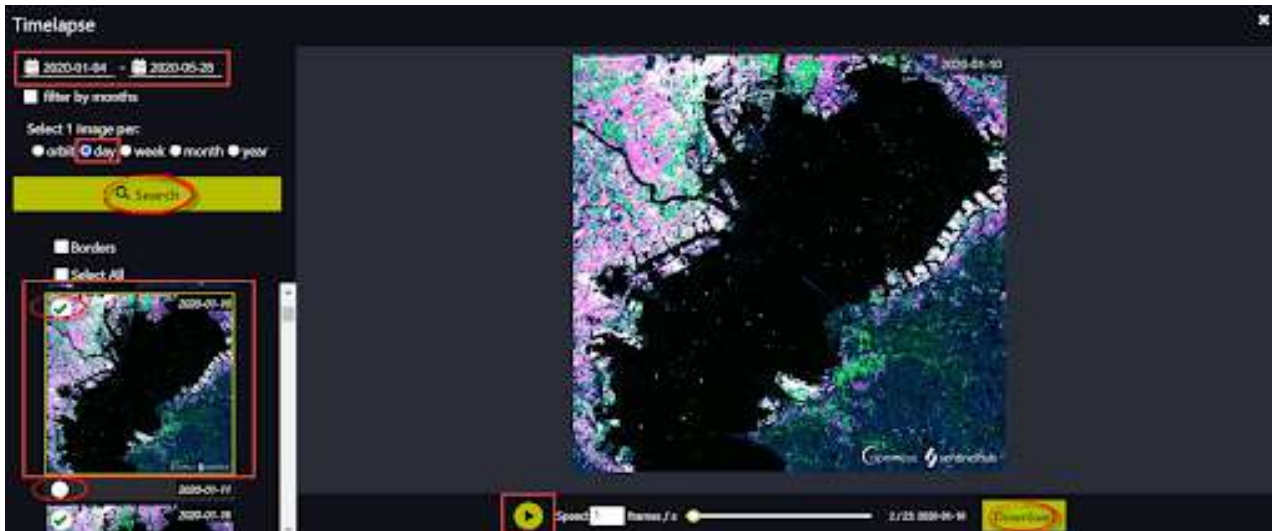
Coordinate system - WGS 84;

Layers - Custom.

Click the **Download** button and specify the path to save the archive to your computer.



5. You can also save a short video demonstrating the movement of ships from early January through the end of May 2020. First, select the visualization mode from the list in the **Visualize** tab or from the collection of scripts. In our example, we have used **SAR urban**. To save the animation, first, click the  icon on the right-hand sidebar, zoom to the map to display the ships present in the bay, click the selected area of your screen (navigate by the video playback arrow) – a new dialog box will appear where you can select images. Set the time range, for example from early January 2020, to the end of May 2020, and image frequency – 1 image per day, and click **Search**. In the list of downloaded images below, uncheck the incomplete images or the ones you don't like. Check the boxes next to the images you want to see in your animation. By clicking the video play button located on the bottom panel under the animation, you can play the video. You can also change the playback speed. If you are satisfied with everything, click the **Download** button.



With this animation, you can see the movement of ships during the selected period. You can also add any images from the **Pins** library to the animation. The advantage of this type of animation is that you can use the images from different libraries, and add already processed images, terrain models, etc. Moreover, this animation may be used to demonstrate the outputs of your images' processing: view the images before and after processing, with/without application of scripts, and many more.

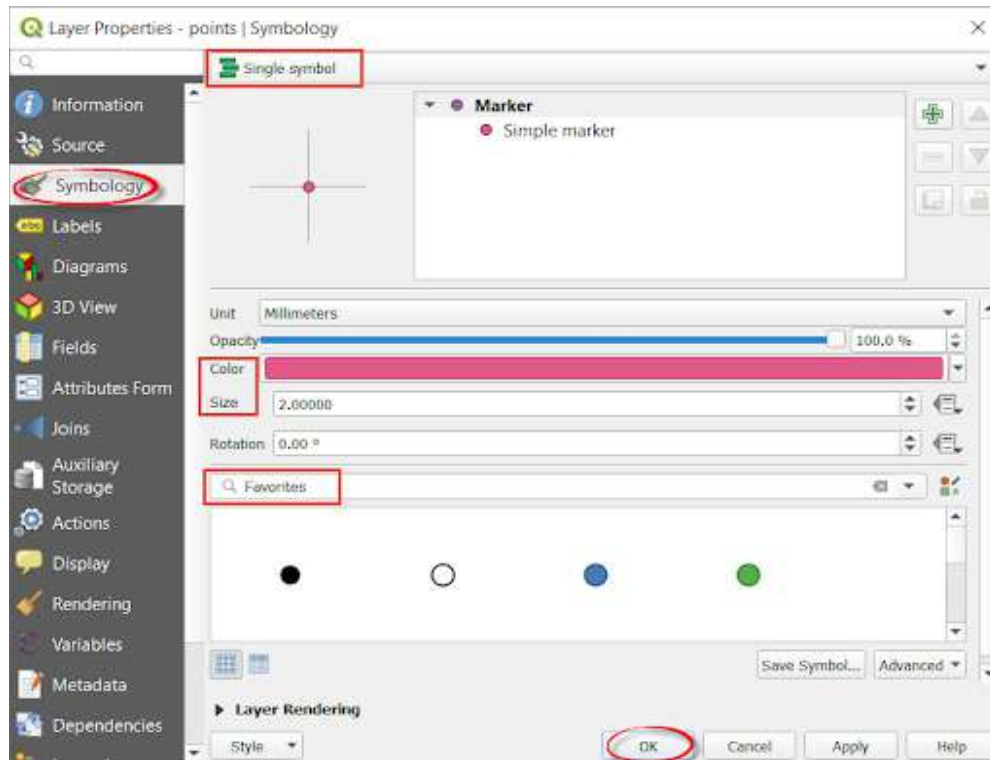
Unfortunately, such animation cannot be added to a static map layout, which creation is discussed below. However, you can add it to your presentations and use as illustration of your research results.

6. We will proceed with our work in QGIS. Download the image that was saved with EO Browser to your project. You can open the image simply by dragging it to the map view window, or using the tools from the main menu: **Layer – Add Layer – Add Raster Layer**. Click the three dots button next to **Raster dataset(s)**, specify the path to the file you have previously downloaded, and click the **Add** button.

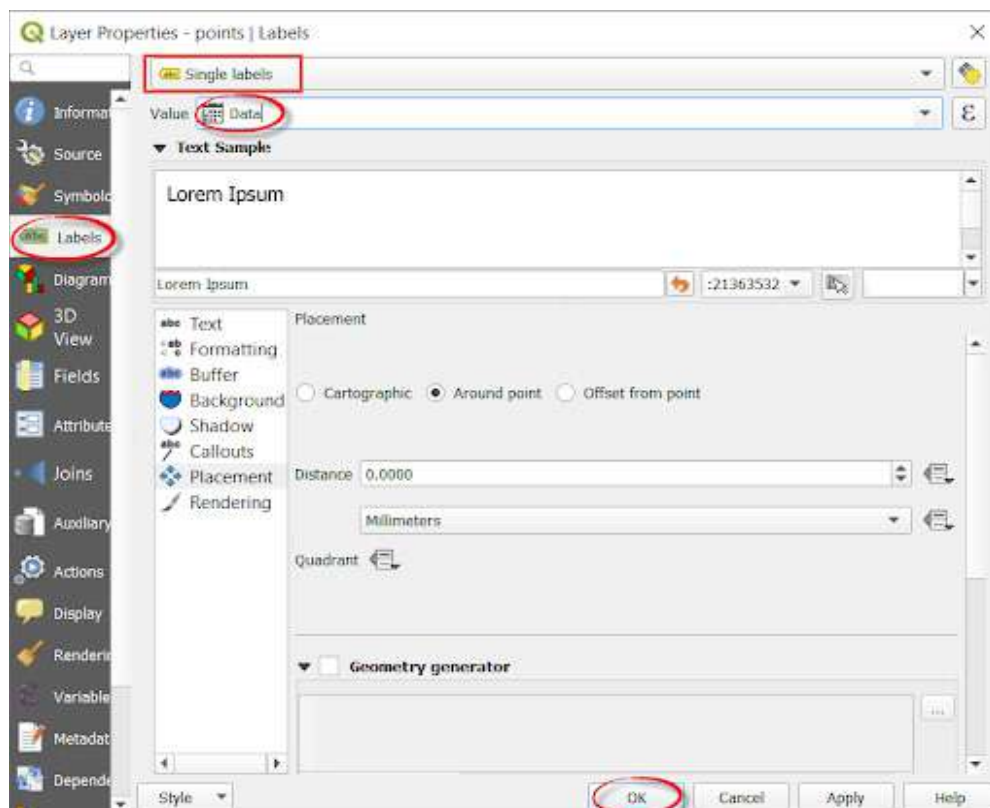
Export an image displaying all the ports where the Diamond Princess liner moored to your project. Select **Add Layer – Add Vector Layer** from the **Layer** menu. Click the three dots button next to **Vector Dataset(s)**, specify the path to the file (first, download it from <https://drive.google.com/drive/folders/17oU03XEHk7a-Jo362AwllpT503hWs5Kk>), and click the **Add** button.

Adjust the points display and label them. To access the shapefile settings tools, right-click on the vector layer, select **Properties** from the drop-down list, and switch to the **Symbology** tab in the **Layer Properties** dialog box that appears.

In the **Favorites** module at the bottom of your screen, you can choose the symbol for a shapefile features display. Color and size settings can be made in the module located above the **Favorites**.

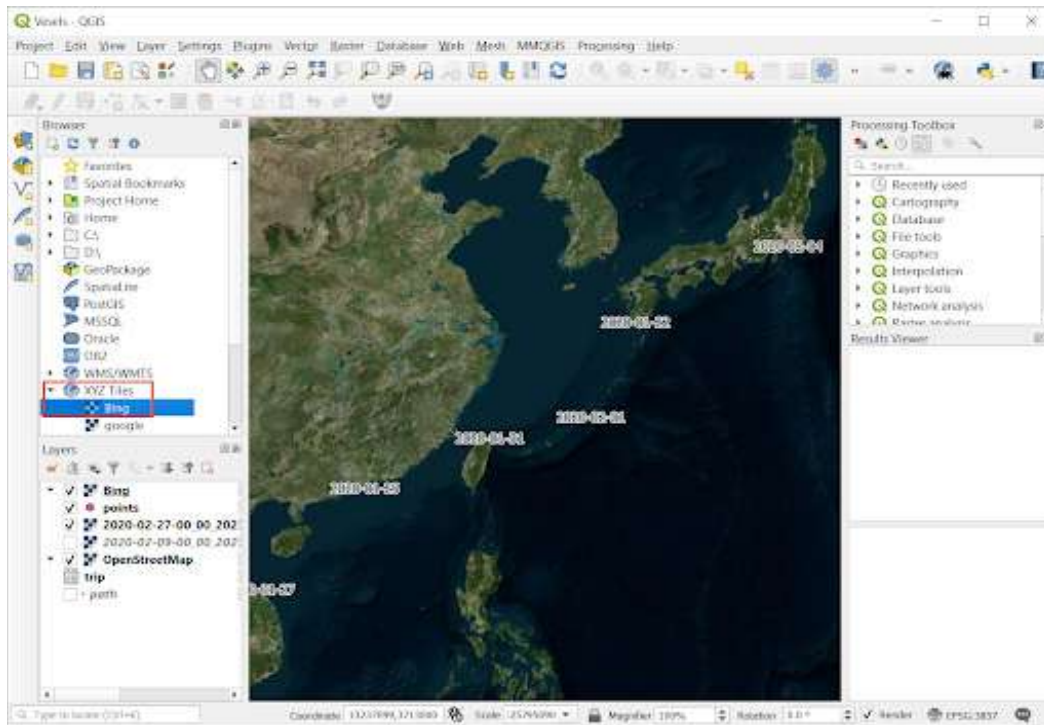


To add labels, go to the **Labels** tab and switch to **Single labels** in the drop-down menu. Select the value for the labels from the **Value** list (in our case it is *Data*), and click the **OK** button. In this window, you can also customize the labels display by adding a shadow, highlighting, changing the size, and many more.



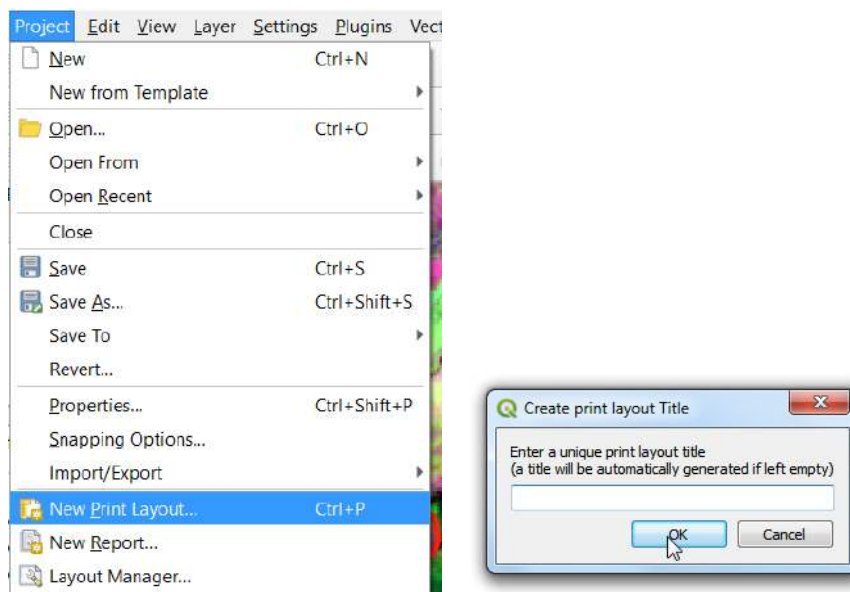
7. Add a layer with contemporary high-resolution satellite imagery to your map document. In the **Browser** panel, expand **XYZ Tiles** top-level node, select **Bing Image** (we have already added this layer to the map in one of our previous tasks, *Changes in the Upper Boundary of the Maramureş Forest*

Massif), and double-click it with the right mouse button to add to your project. You can add any layer as a common basemap, e.g. OpenStreetMap.

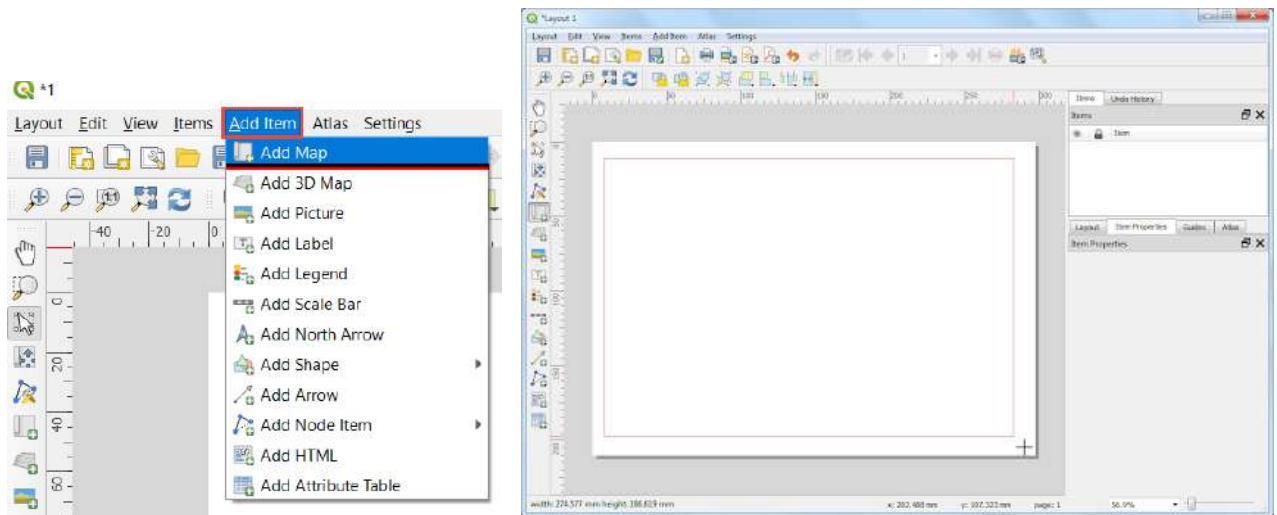


8. It is often necessary to create a map that can be printed or exported to a document. QGIS has a powerful tool called **Print Layout** that allows you to take your GIS layers and package them to create maps. We will create a layout with standard map elements like the map inset, north arrow, scale bar, and labels.

To switch to the map composition and layout display mode, open the **Project** menu and select **New Print Layout**. Enter a unique print layout title in the **Create print layout Title** dialog, or leave the field empty and click the **OK** button.



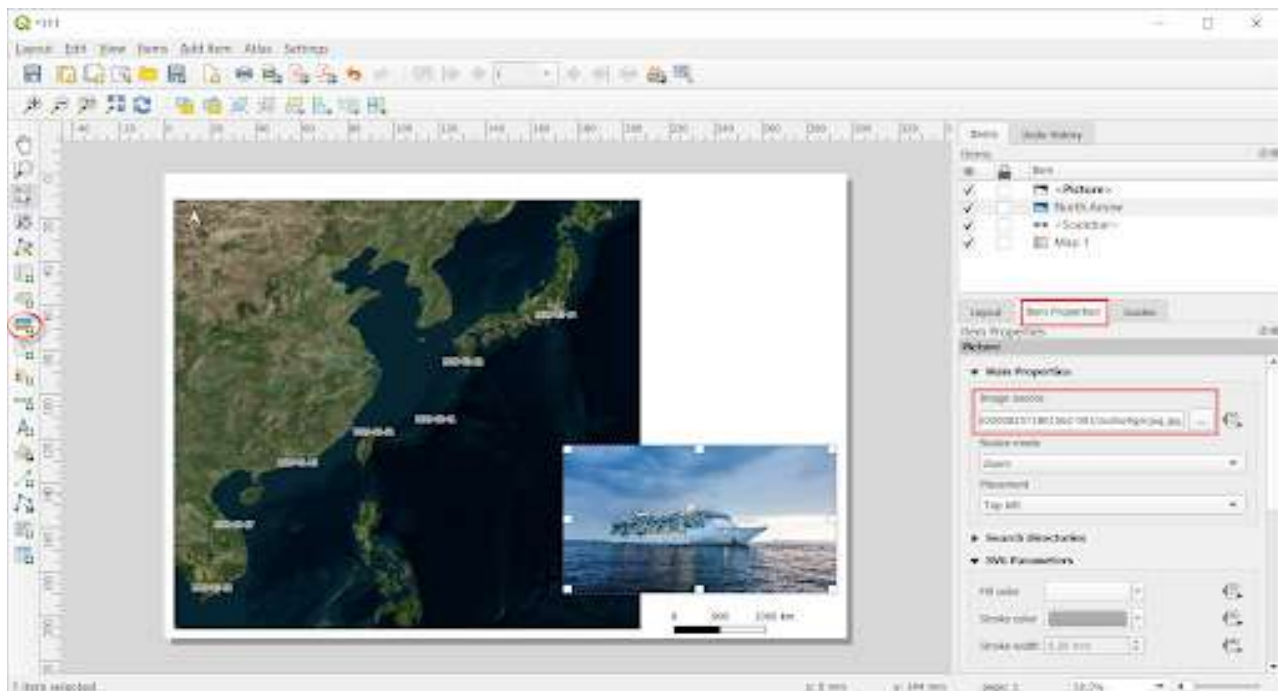
In the print layout window, click the **Add Item** button and select **Add Map** from the list. You will see that your mouse cursor has changed. Using the mouse cursor, draw a rectangle on the blank sheet page where you want to insert the map. You will see on your screen the same map as in the main QGIS canvas.



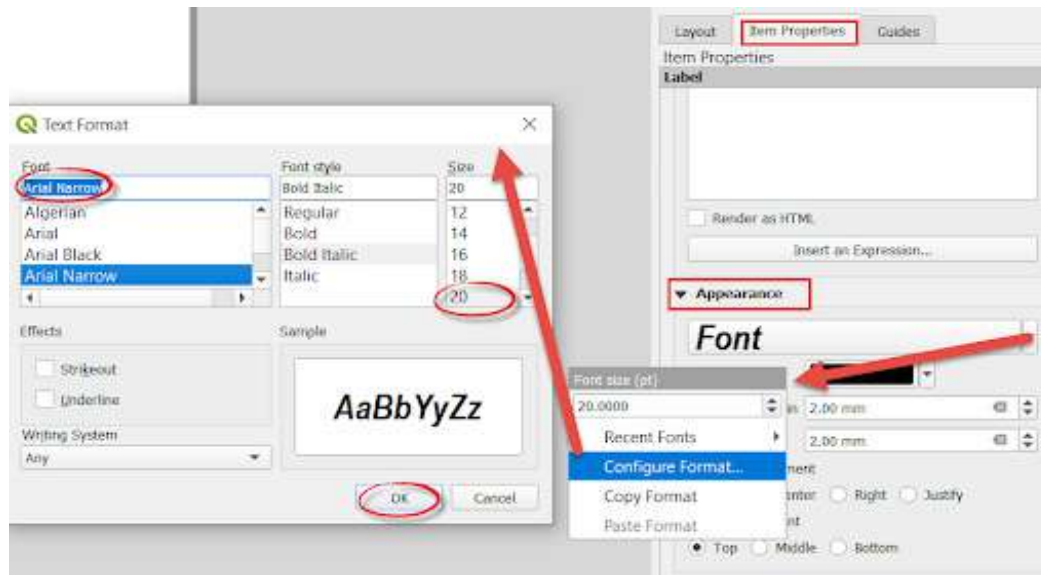
Using the **Add Item** menu, add a north arrow (select **Add North Arrow**), a scale bar (select **Add Scalebar**), and **Add Picture** to the map.

The list of elements that can be added to the layout page includes the following:

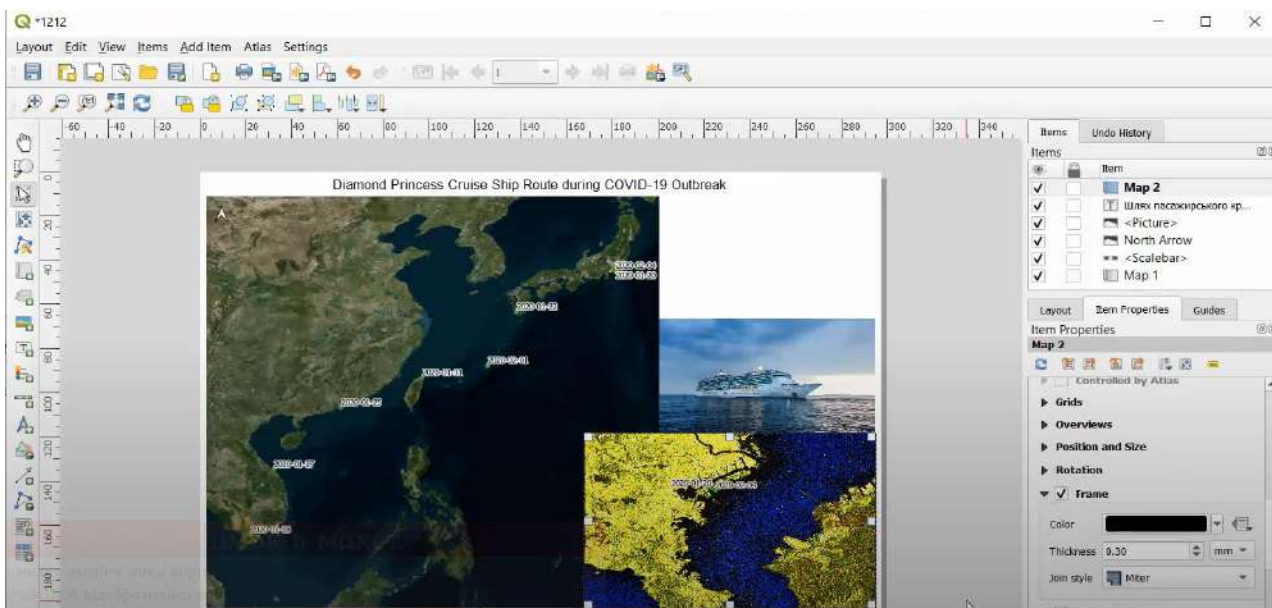
- **Legend** item allows you to adjust the appearance of symbols and their properties. When this item is activated, a corresponding dialog box shows up, in which you can specify the thematic layers to be displayed in the legend items, and set text parameters for the Legend;
- **North Arrow** ... is a tool for adding this item and adjusting its properties;
- **Scale Bar** ... allows you to add this item based on parameters selected from the **Scale Bar Selector** dialog box for the desired map frame;
- **Picture** item allows you to add raster and vector images to the map layout. For example, let's add a picture of a ship. First, search for the picture in Google and save the result. Specify the path to the picture file in the **Image source** dialog.



Now, let's add a map name: using the **Add Label** from the **Main Properties** window, enter *Diamond Princess Cruise Ship Route during COVID-19 Outbreak*. Adjust the font size and type in the **Appearance** tab.

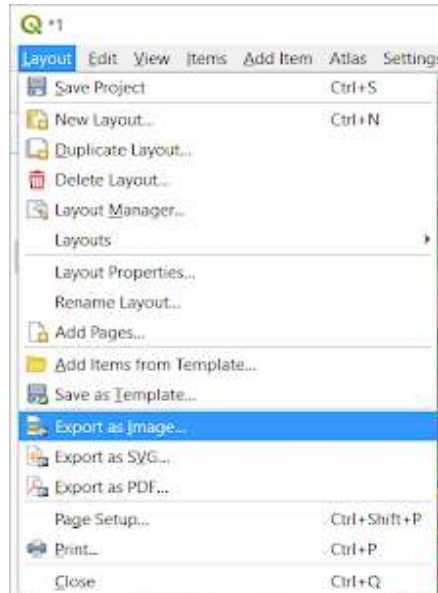


Add a Sentinel-1 radar image taken on February 27, 2020. To do this, return to QGIS and zoom closer to the image: right-click on the layer and **Zoom to Layer**. Go back to the layout, add a new map using **Add Map**, and add a label and a scale bar to your map. To display exactly the same image as you have in your map view window, select the map and check the **Frame** box.

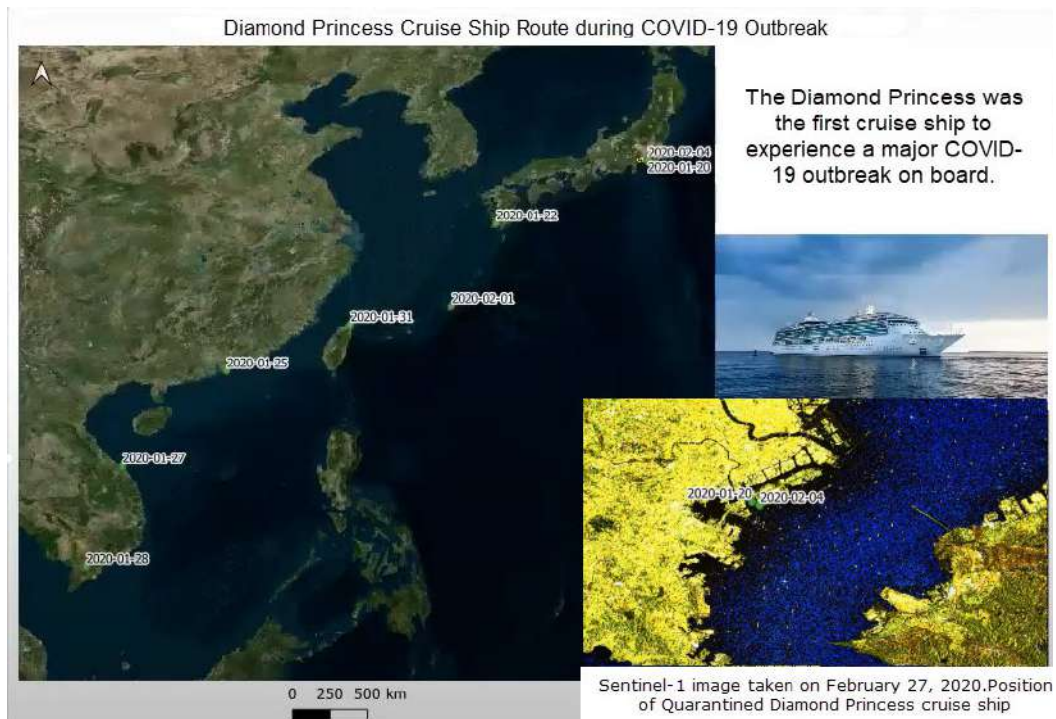


You can also add a short description to the map under **Add Label**.

After all the elements have been added to the map, save the layout as an Image or PDF file using the appropriate commands from the Project menu.



An example of a finished map layout is shown below.



9. On the <https://www.vesselfinder.com> website, you can track the movements of the world's ships sailing the ocean. For example, a suspicious vessel that is involved in illegal fishing or smuggling operations. However, it is not possible with a free version of this service to save and export the track of a ship; the free version allows you to see real-time positions of vessels and their recent port calls only.

Go to <https://www.vesselfinder.com>, and enter *Diamond Princess* cruise ship name in the search bar. Select this ship from the list by clicking on its name, and a new page with ship details will open. Here you can read more information about the vessel, see its photos, and many more. Most of the data about the ship are presented in the **Position & Voyage Data** section: vessel type, course and speed, coordinates, and the timestamp of the received data.

✔ **Important!** *Some vessels may have identical names. The Diamond Princess is a passenger cruise ship, so take this into account when searching to select the right ship from the list.*



PORT CALLS

Current AIS Destination	Estimated Time of Arrival	
SGSIN OPL	Oct 12, 00:00	
Port	Arrival (UTC)	In Port
Singapore	Oct 9, 01:02	10d 5h
Singapore	Oct 2, 05:36	6d 19h
Port Klang Anch.	Sep 13, 18:25	-
Port Klang	Sep 12, 22:52	19h 20m
Singapore Anch. 5	Aug 15, 04:28	23h 12m

Historical AIS Data



POSITION & VOYAGE DATA

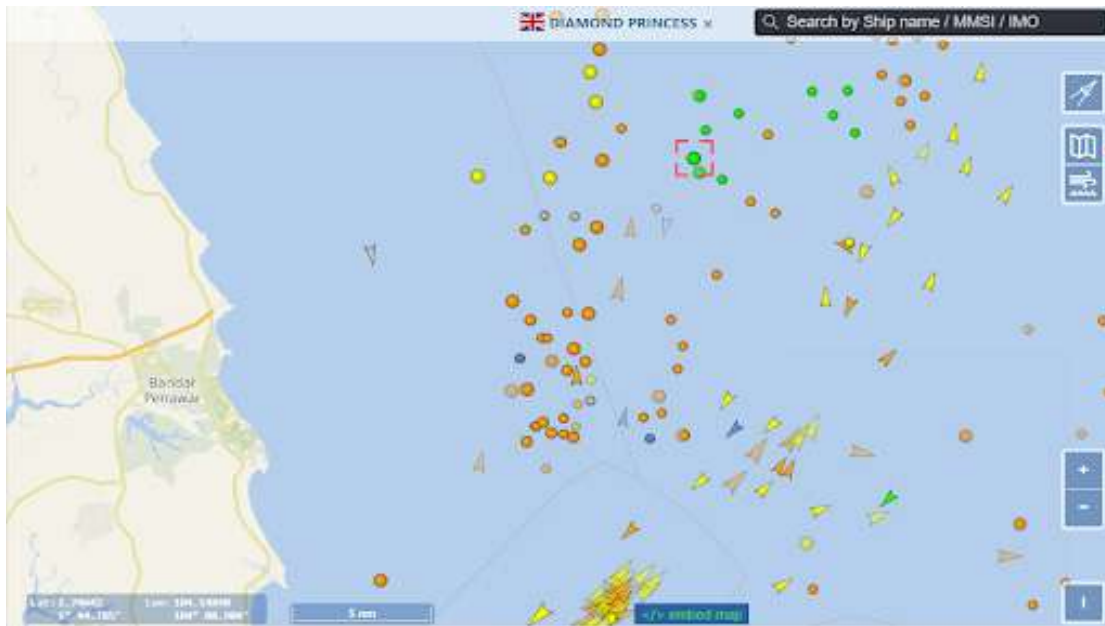
AIS Type	Passenger ship
Flag	United Kingdom
Destination	SGSIN OPL
ETA	Oct 12, 00:00
IMO / MMSI	9228198 / 235103359
Callsign	2HFZ7
Length / Beam	288 / 50 m
Current draught	8.2 m
Course / Speed	74.1° / 0.0 kn
Coordinates	1.70175 N/104.54035 E
Status	At anchor
Position received	11 hours ago

MAP POSITION & WEATHER

[embed map](#)

29 °C / 84 °F
 8.0 kn / 4.1 m/s
 N/A

By clicking the *Track on Map* button below the ship photo, or the map image under *Map Position & Weather*, you can switch to the map displaying the current position of the liner (the cruise ship will appear bright green in the map and thus may be distinguished from other vessels). Zoom to the map to see the port name and ship location, and take a screenshot using the *Print Screen* key. Crop the screenshot so that it captures the map as shown in the image below. Save a map of the vessel's location as of the date of this task. The image can also be added to your map layout.



? Check yourself

Specify the country off which coast the <i>Diamond Princess</i> cruise ship was sailing as of the day of this task?	
Specify the most recent calling port of the <i>Diamond Princess</i> .	

Scan the QR-code below to watch a video tutorial on the performance of this Task.



7.2. Detecting Oil Pollution in the Mediterranean Sea

In March 2021, the world celebrated its fifty-first Earth Day. This tradition began with a large-scale demonstration in New York in 1970. A year before, the largest oil spill in the US history occurred off the coast of Santa Barbara (California). The public response to this disaster has become a powerful stimulus for the development of the environmental movement.

The biggest losses of oil occur during its transportation from production sites. Accidents involving oil tankers, drilling rigs, or subsea pipelines account for only 25% of all oil spills at sea, while 75% result from routine transportation operations.¹ During accidents, however, with up to 40-50 thousand tons of oil released, the affected area may reach about 100 km.² Major sites of oceanic oil spills are located on the routes of tankers between the Middle East and Europe, America, and Japan. Significant marine oil pollution is also observed in the Mediterranean Sea, Caribbean Sea, South China Sea, and the Sea of Japan.³

According to the US Environmental Protection Agency, only 10 minutes after one ton of oil enters the water, a 10 mm thick slick forms on its surface. Over time, the slick gets thinner (less than 1 mm) as oil continues to spread, covering an area up to 12 sq. km. In the absence of wind, waves, and currents, 1 m³ of crude oil disperses over a radius of 50 meters in an hour and a half. Further changes take place under the combined impact of weather, wind, and waves. Elimination of such pollution can take several months or even years.

The oil film changes the composition of the spectrum and the intensity of light penetration into the water. Light transmission through thin films of crude oil ranges from 10 – 11% (280 nm) to 60 – 70% (400 nm). A 30-40 nm thick film completely absorbs infrared radiation.⁴

Case

On October 7, 2018, two merchant ships collided in the Mediterranean Sea. According to reports, a Tunisian cargo ship crashed into the hull of a Cypriot container ship north of the French island of Corsica. There were no victims but the collision caused a fuel spill.

The incident resulted from a series of human errors: the captain of a Tunisian vessel talked on the phone and ignored the radar. In addition, the Cypriot ship was anchored in the “inappropriate” area. Damage to the vessels was estimated at 13.5 million euros, plus cleanup costs estimated at 10 million euros.⁵

To watch the video of the collision provided by the *Vesseltracker*, go to: www.youtube.com/watch?v=AgXqpUCXwhU.

Task

Using the radar images, locate the fuel slick, measure its length and calculate the area covered by it. Analyze how pollution has spread in the sea.

¹ Ferraro G., Tarchi D., Fortunu Jo., Sieber A. (2004) JRC 172 Experience in the Field of Satellite Monitoring of Accidental and Deliberate Marine Oil Pollution. Joint Research Centre, Via E. Fermi, 1, I-21020 ISPRA (VA) Italy. URL: <http://serac.jrc.it/midiv/pdf/eurisy.pdf>

² Кучма Т. Л. Картографування нафтових розливів у Чорному та Азовському морях за даними дистанційного зондування Землі. Вісн. геодез. та картогр. 2006. № 2. С. 26-29.

³ Иванов А. Ю., Востоков С. В., Ермошкин И. С. Картографирование пленочных загрязнений морской поверхности по данным космической радиолокации (на примере Каспийского моря). Исследование Земли из космоса. 2004. № 4. С. 82-92.

⁴ Дембович Б. І., Яворська С. В. Забруднення океанів нафтою та нафтопродуктами. Біорізноманіття та роль тварин в екосистемах : матеріали VII Міжнар. наук. конф. Дніпропетровськ : Адверта, 2013. С. 45-48. URL:http://www.zoology.dp.ua/z13_023.html

⁵ URL: <https://safety4sea.com/human-errors-led-to-ships-collision-in-corsica/>

Task performance algorithm:

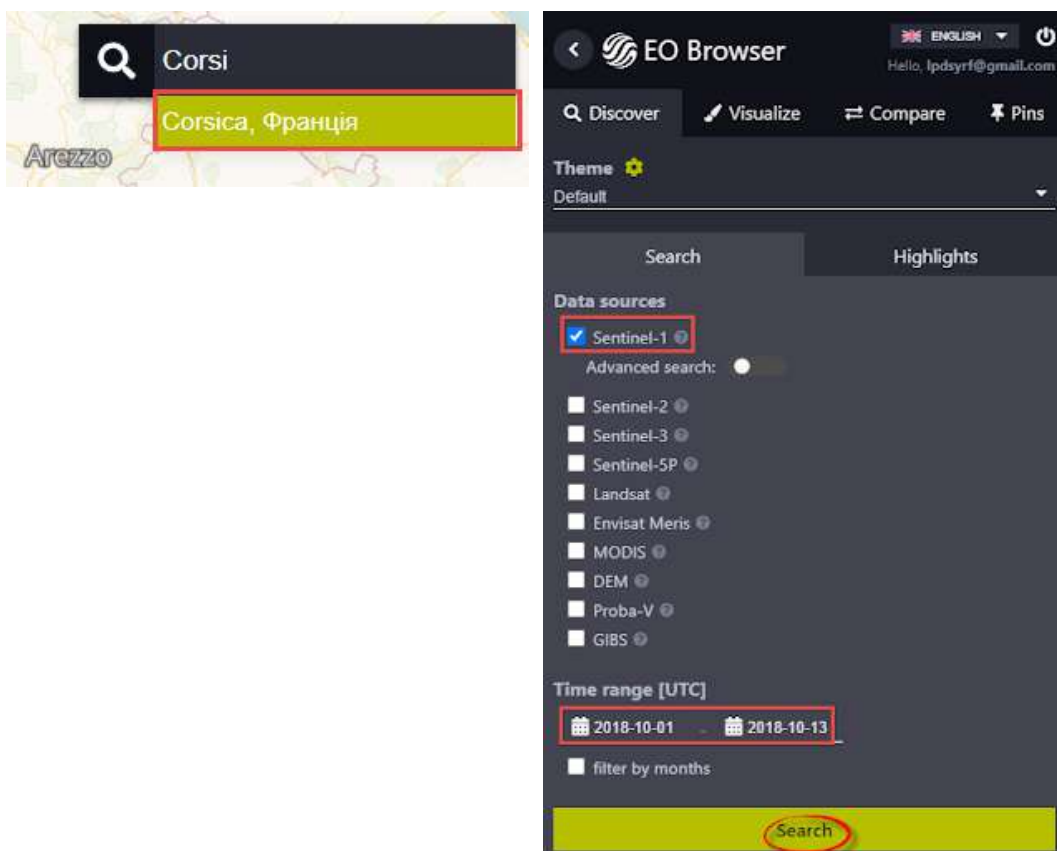
1. Download required data to your project using EO Browser.
2. Display images in QGIS.
3. Measure the length of the slick as of October 8, October 9, and October 14.
4. Digitize the area of spilled fuel on different dates.
5. Animate digitized data using the *TimeManager* plugin.

Instructions for self-guided work

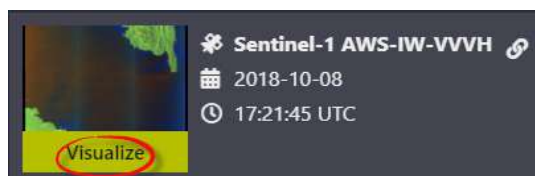
1. Go to EO Browser website, enter your login and password.
Using the search bar, find the island of Corsica in the Mediterranean Sea on the map.

In the Search tab:

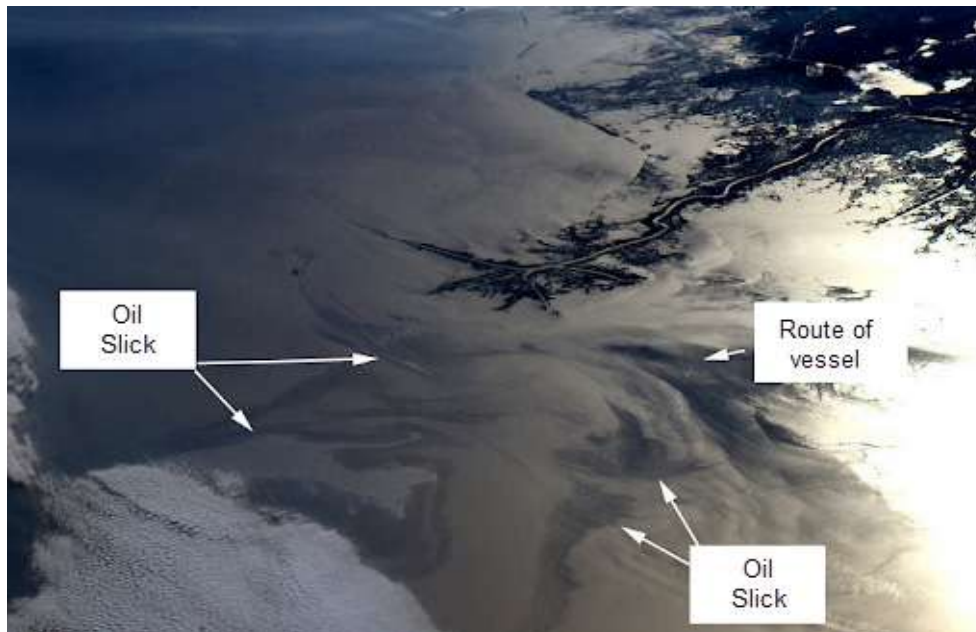
- select **Data sources** – Sentinel-1;
- select **Time range**: 01-10-2018–13-10-2018;
- Click **Search**.



Pick the image taken on 08.10.2018.



2. Satellite radar images are well suited for monitoring oil spills spread because the presence of oil on the water surface weakens the movement of waves. Radar mostly measures the texture of the surface; oil slicks are clearly visible – they appear black in a gray background. For example, the Figure below shows one of the largest oil spills in the Gulf of Mexico, which occurred in 2010.



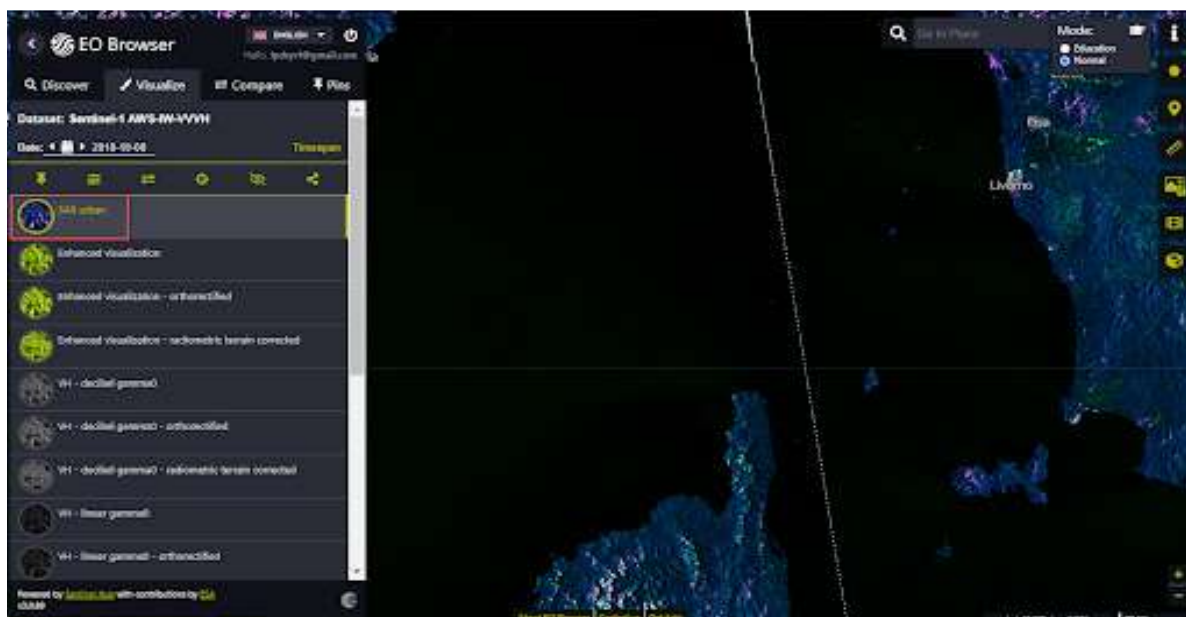
Oil slick in the Gulf of Mexico
(NASA, International Space Station, April 5, 2010)

The Mississippi Delta and the waters off the Louisiana coast appear dark in the lighter area. This phenomenon is caused by sunlight, which is reflected from the water surface.¹

However, with the SAR-urban combination (the first to open automatically in EO Browser), you won't see any oil slicks.

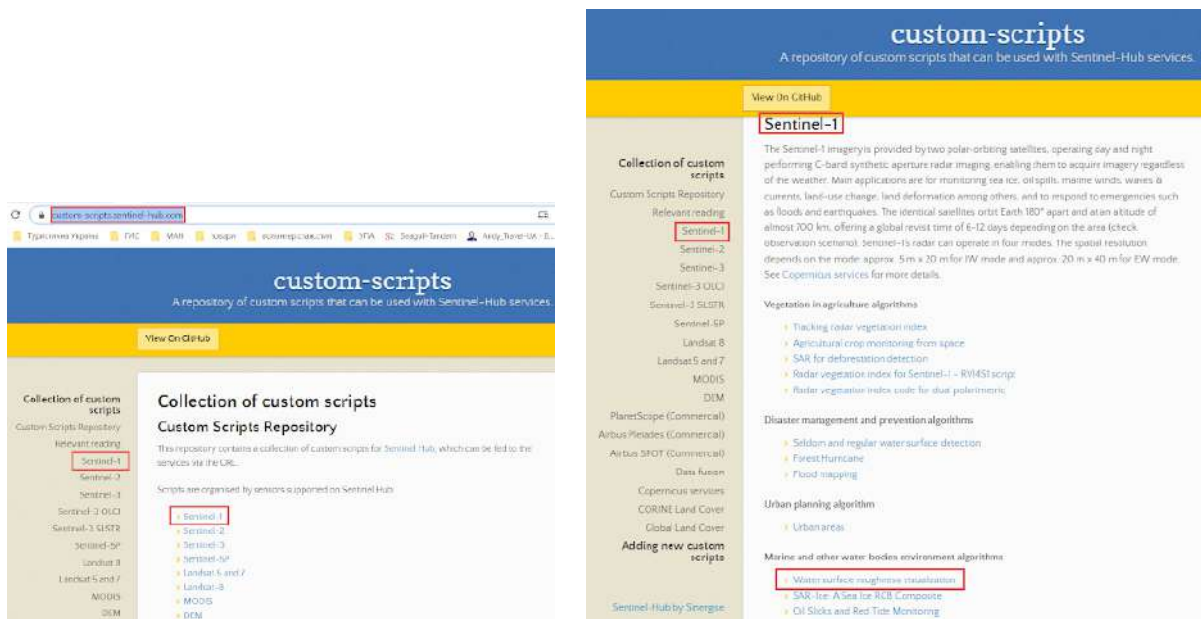
🔍 Check yourself

Why is oil pollution not visible with the SAR-urban combination?



¹ URL: <https://www.flickr.com/photos/nasamarshall/4583800305/in/photostream/>

Use the *Water surface roughness visualization* script (marine and other water bodies algorithms) to see the fuel slick north of the island of Corsica. For this, go to <https://custom-scripts.sentinel-hub.com/> and select the desired script from the Sentinel-1 collection.



Interface of custom scripts of repository for EO Browser
(source: <https://custom-scripts.sentinel-hub.com/>)

The selected script visualizes the surface roughness based on the Sentinel-1 data and is used to monitor the water surface (ships, oil pollution, sea currents, etc.).

Go to the script tab, click the **Show** button and copy the text that appears in a black background.

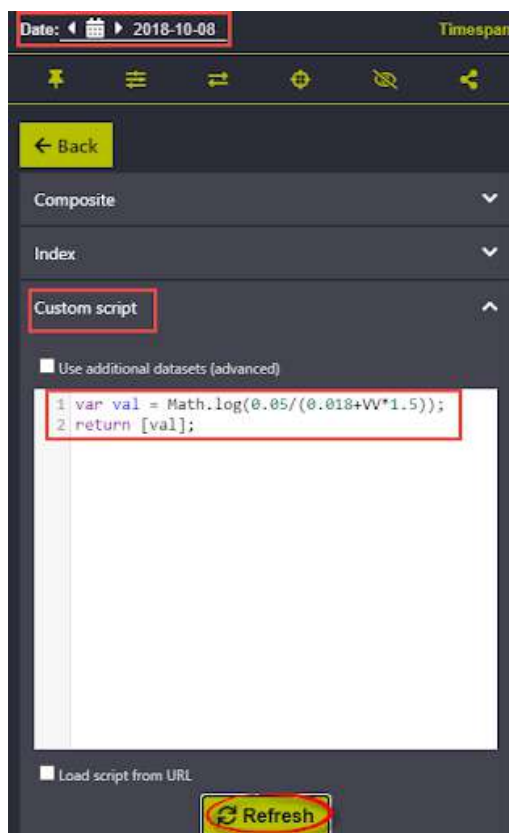
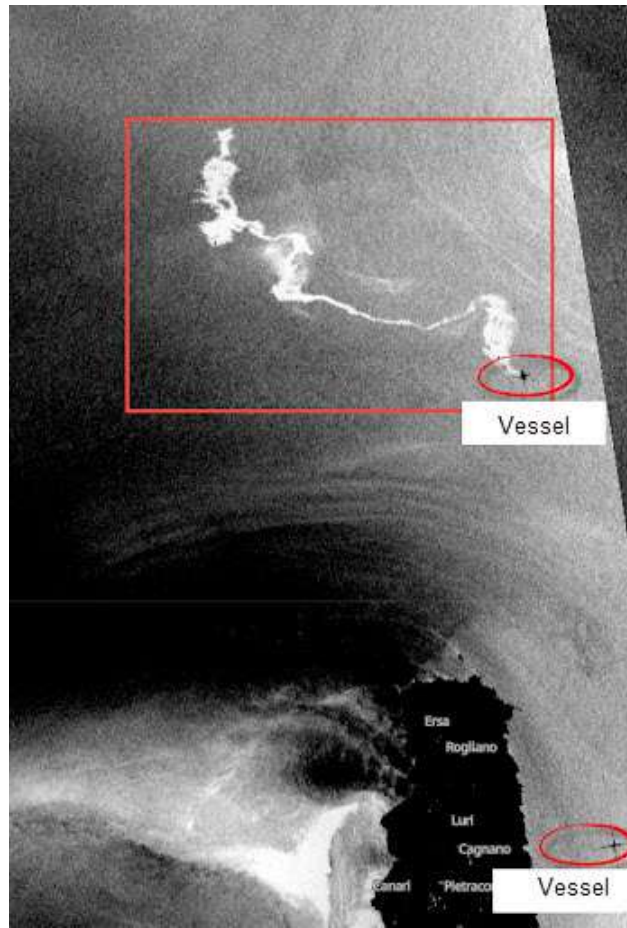
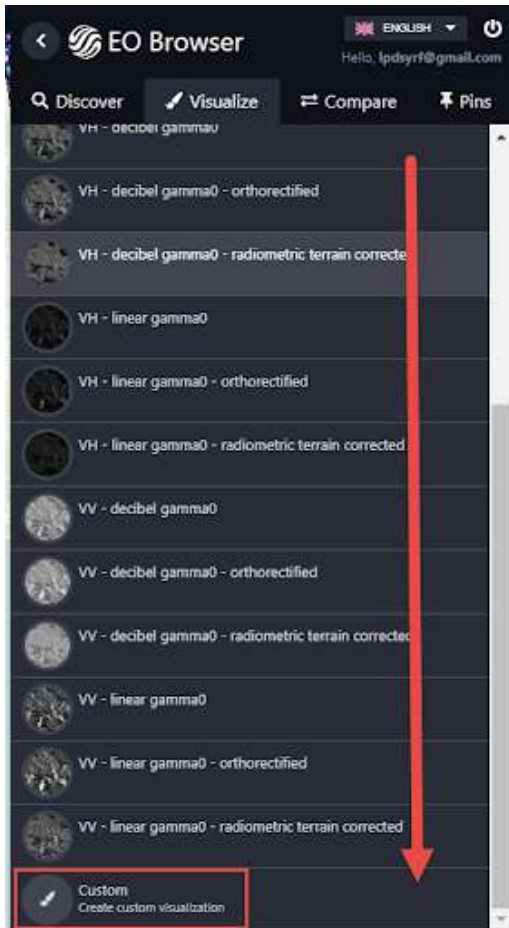


Water surface roughness visualization script download interface
(source: <https://custom-scripts.sentinel-hub.com/>)

Script text:

```
var val = Math.log(0.05/(0.018+VV*1.5));
return [val];
```


Return to EO Browser, scroll down the automatic visualizations in the left sidebar, switch to the **Custom** tab, select **Custom script** box, and paste the copied text in the box. Click **Refresh**.



The image visualization will change completely, and it will be possible to see the slick caused by the released fuel and localize the vessels (appear as black crosses at sea).

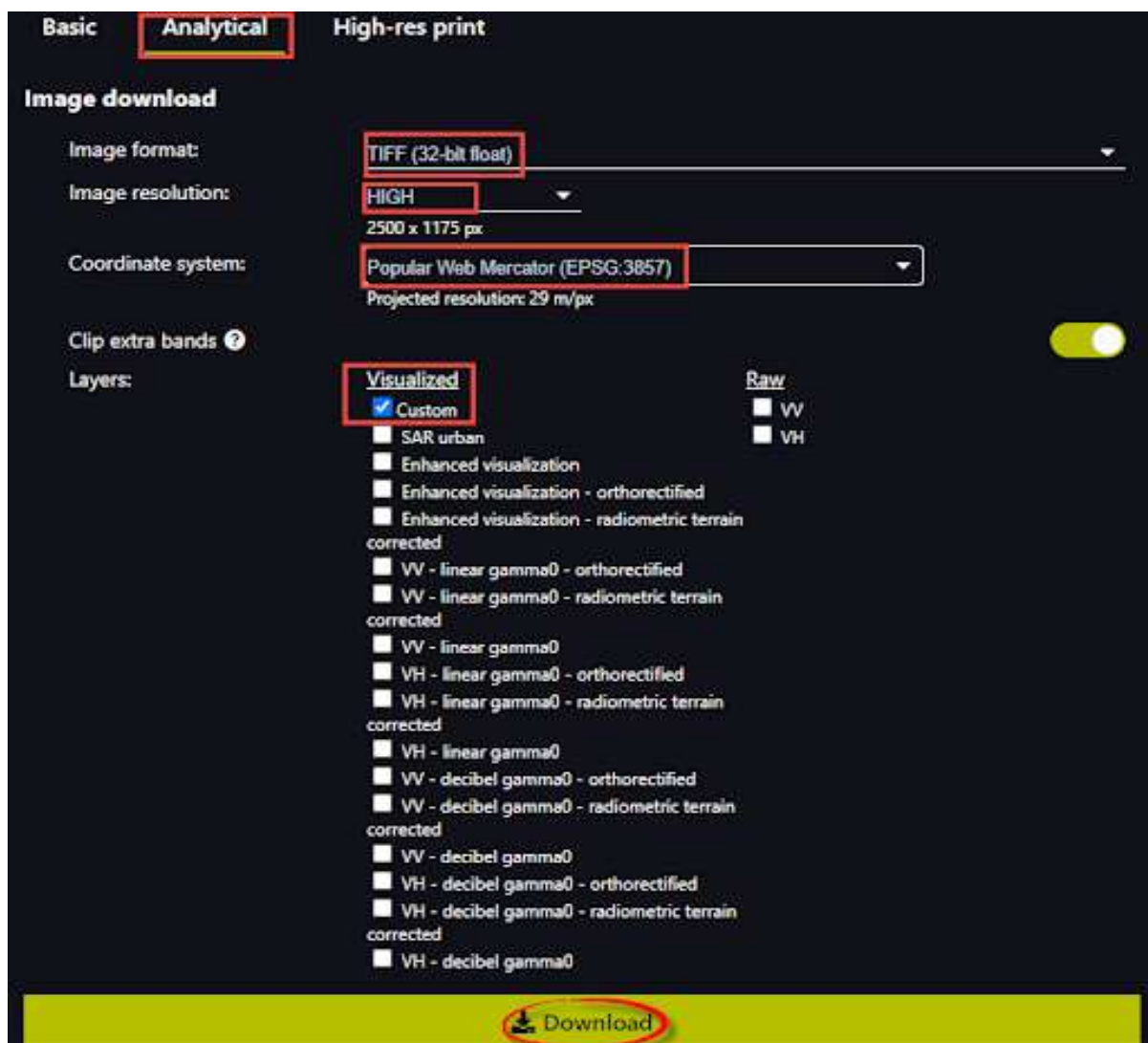
? Check yourself

Select the previous date from the calendar, and assess the fuel slick on the first day of the collision. What factors impact the direction and area of pollution spread in the sea?

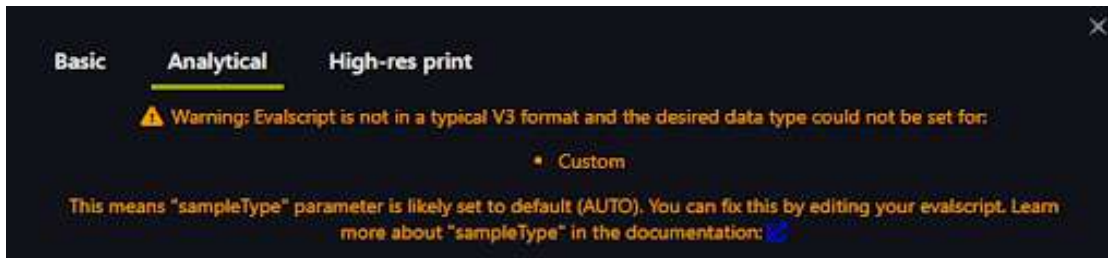
3. Download images captured on October 8, 9, and 14, 2018. Zoom to the slick on the image taken on October 8 and click  at the right sidebar. In the window that opens, select the *Analytical* tab and specify:

- *Image format* – TIFF;
- *Image resolution* – High;
- *Coordinate system* – Popular Web Mercator;
- *Layers* – Custom.

Click *Download* and specify the path to save the archive to your computer.



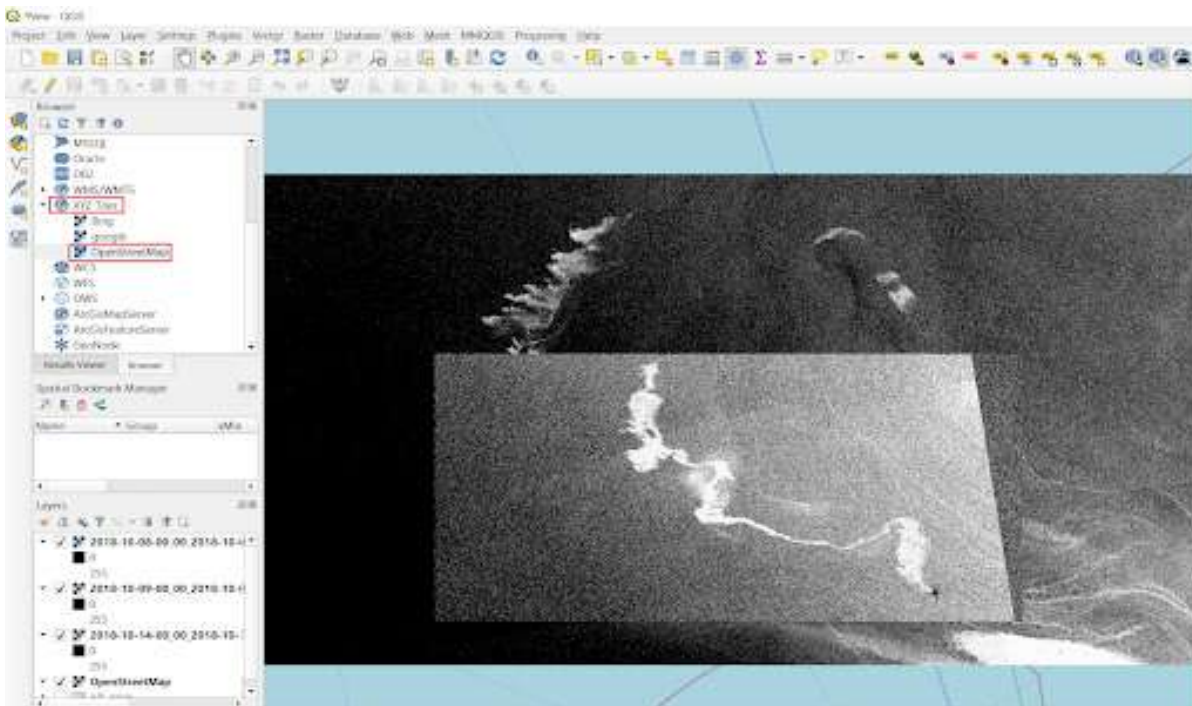
You may see a message appearing during downloading; it will not affect the download, so don't worry.



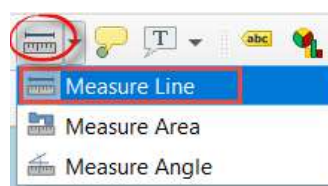
Change the date in the calendar and repeat the download procedure for the images taken on October 9 and 14.

4. Open QGIS and download the images we have earlier saved with EO Browser to your project. To open these images, simply drag them into the program window, or use the main menu: **Layer – Add layer – Add raster layer**. In the **Raster dataset(s)** field, click the three dots icon, specify the location of the file you have previously downloaded, and click **Add**.

Also, add an OpenStreetMap to your project (from the XY **Tiles** menu in the **Browser** panel) to make sure the images are displayed in the correct location.





5. Zoom to the localized slick and using the Ruler tool, measure the length of the oil slick (kilometers) as of October 8, 9, and 14.

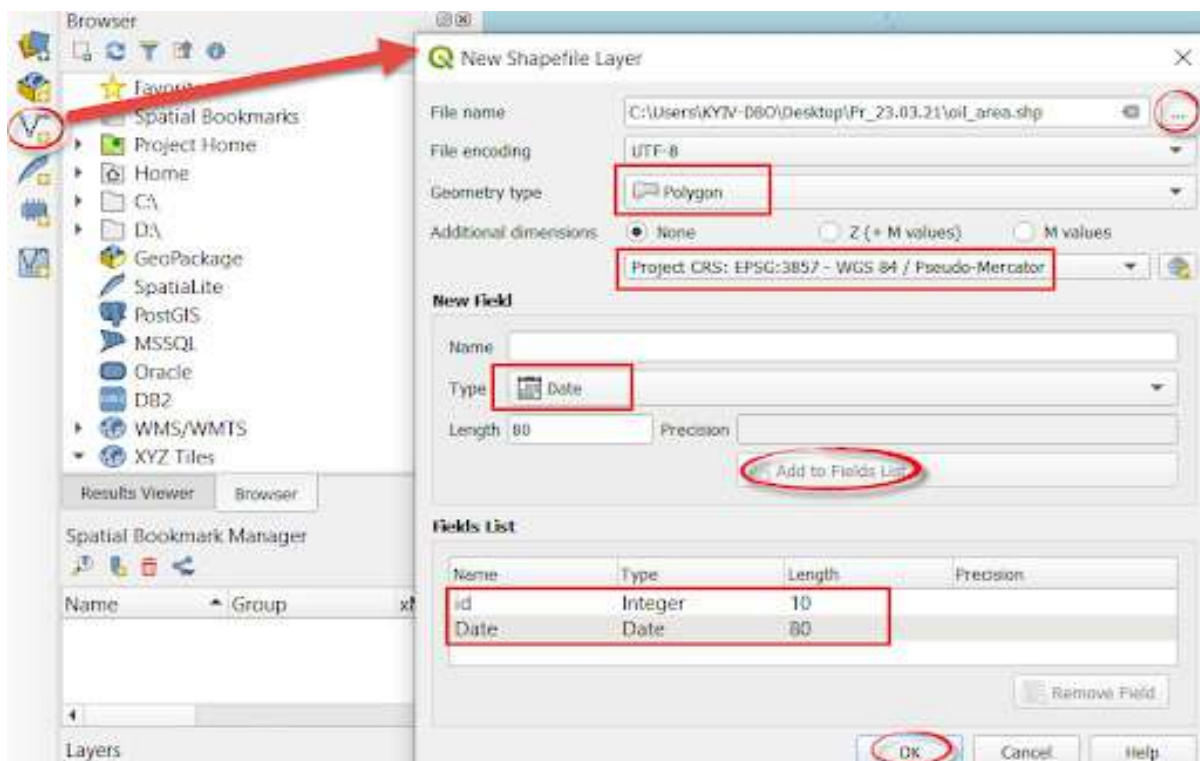




? Check yourself

Length of the fuel slick On October 8 On October 9 On October 14	
---	--

Digitize the slick as of different dates. Create a new polygonal vector layer. On the toolbar, select **New shapefile layer** . In the window that opens, click the tool  next to the **File name** field to find the desired folder for saving a new vector layer. Enter its name, e.g. “oil_area”, and click **Save**.

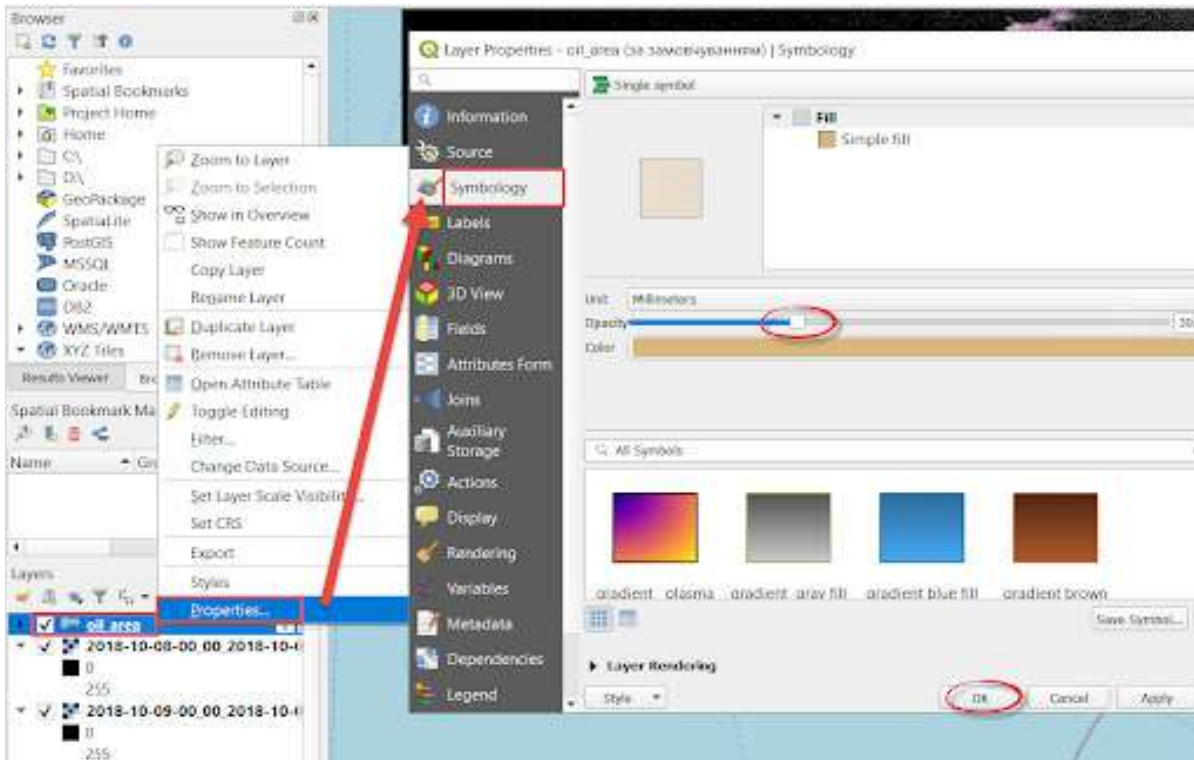
In the **Geometry type** box, select **Polygon** from the drop-down list. In the map projection box, select **WGS 84 / Pseudo-Mercator**. Add “Date” by selecting the appropriate type from the list in the **New Field** field. Click **Ok** and a new vector layer will open in your project.



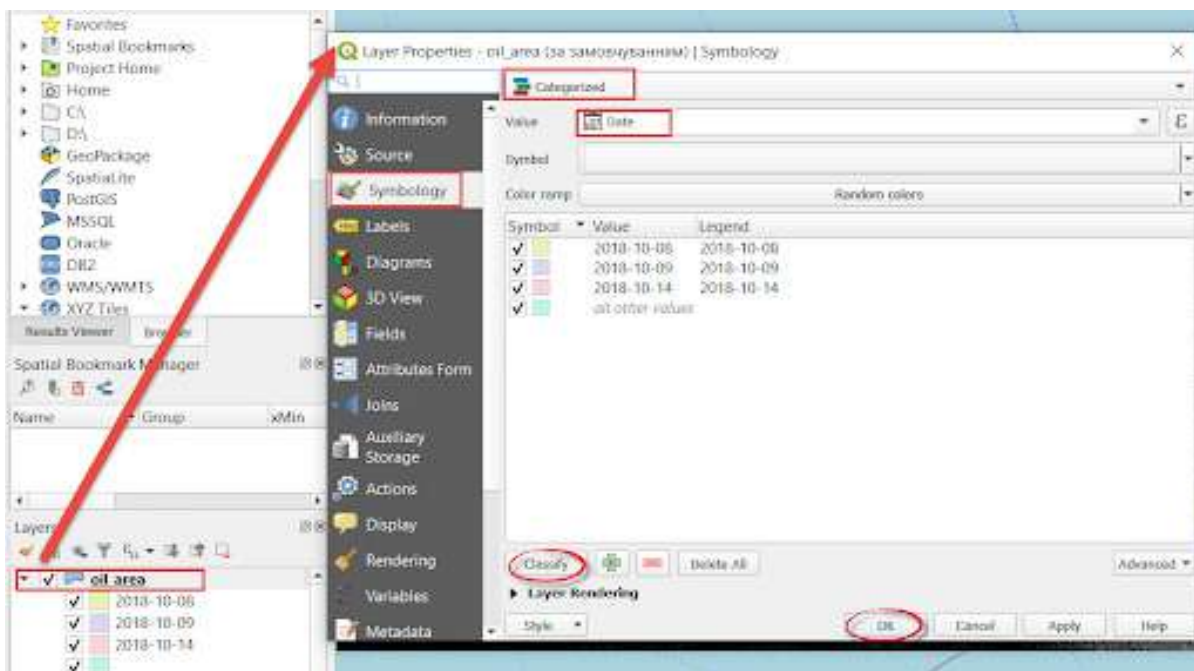
Activate vector layer editing mode: left-click the layer in the list, and click on the **Toggle Editing** tool . Upon enabling the editing mode, some tools appear with colored icons, i.e. became active. Select the **Add Polygon Feature**  digitization tool and start delineating the oil spill area boundaries from the first image taken on October 8, 2018. The entire boundary can be vectorized with a single polygon. To complete the digitization, right-click, and fill in the **Attribute Table**; be sure to specify the date of the image from which you digitize the pollution (you can quickly retrieve from the file name).



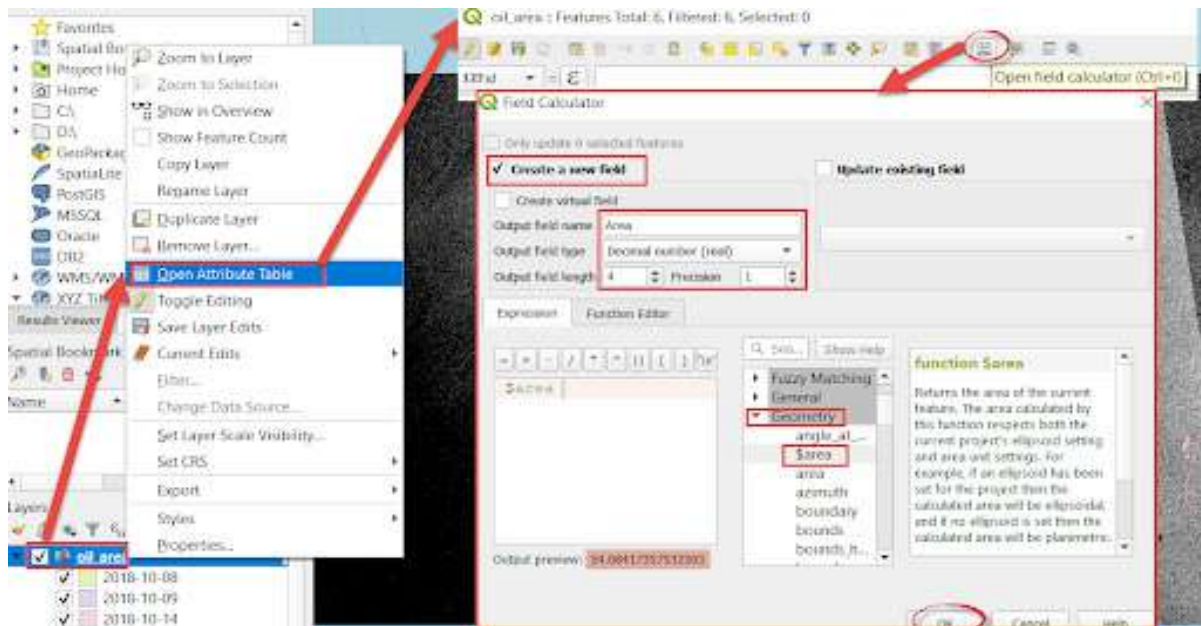
As the pollution areas on different days overlap, we suggest that you change the polygon transparency. To make the digitization of polluted areas as of October 9 and 14 more convenient, complete the editing and save all changes.



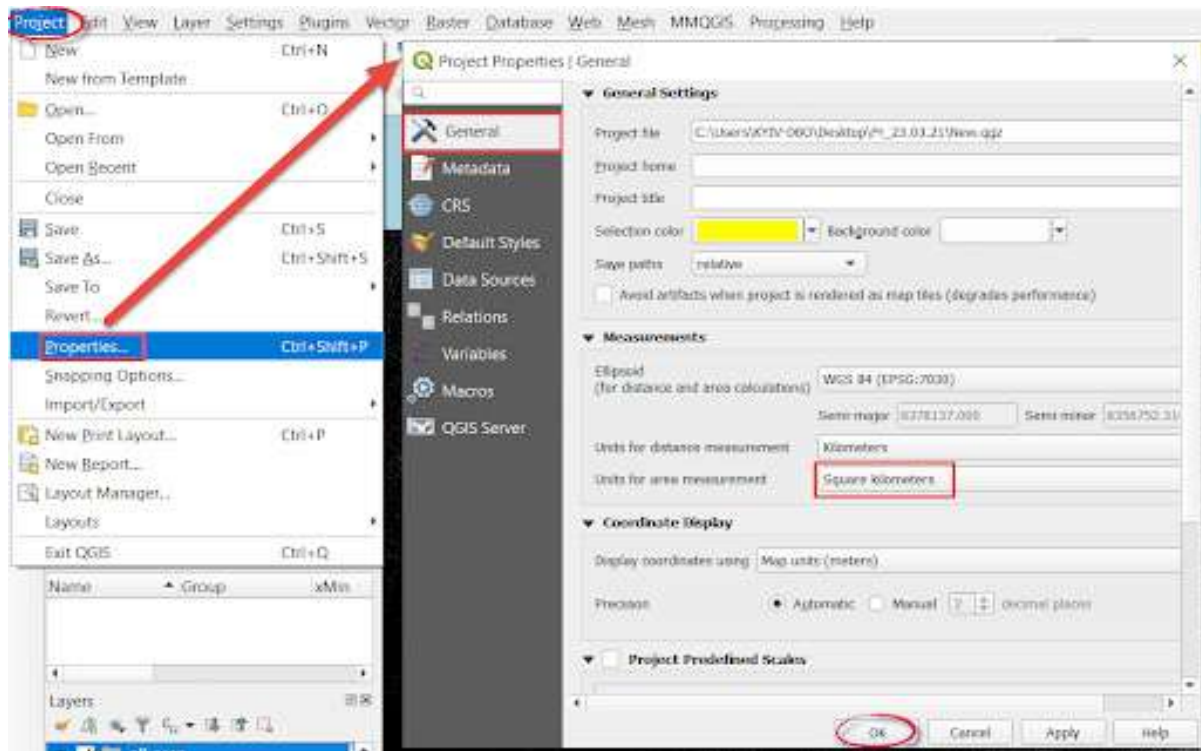
7. As a result, you should get several polygons representing oil slicks as of different dates. We suggest that you paint them in different colors. To do this, right-click the **Properties** layer, and select **Categorized** (from the first line) and **"Date"** (second line). Click the **Classify** and **Ok** buttons.



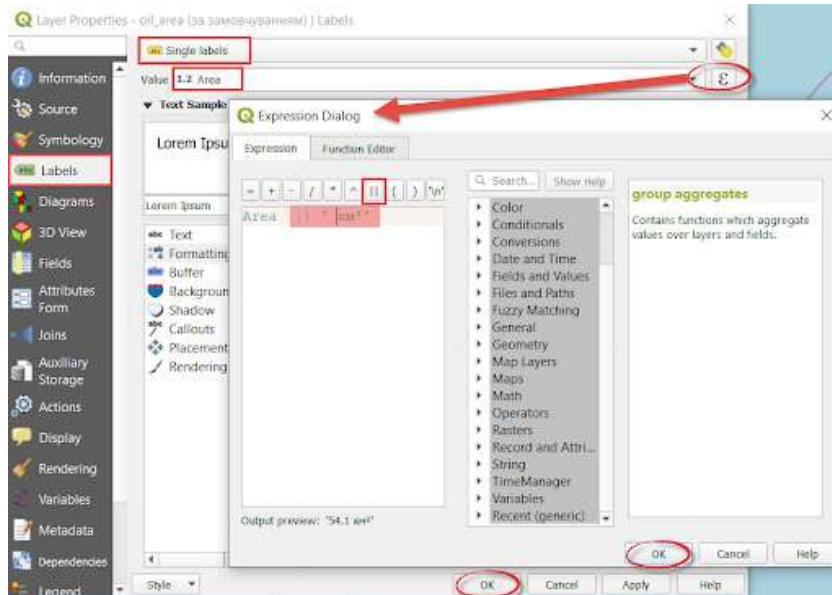
8. Calculate the area of digitized polygons. First, right-click on the layer, select **Open Attribute Table**, and pick **Open field calculator** from the toolbar. In the new window, check **Create a new field** – **"Area"** – **Decimal number (real)** – leave one decimal place – **Geometry** – **\$area** – **Ok**.



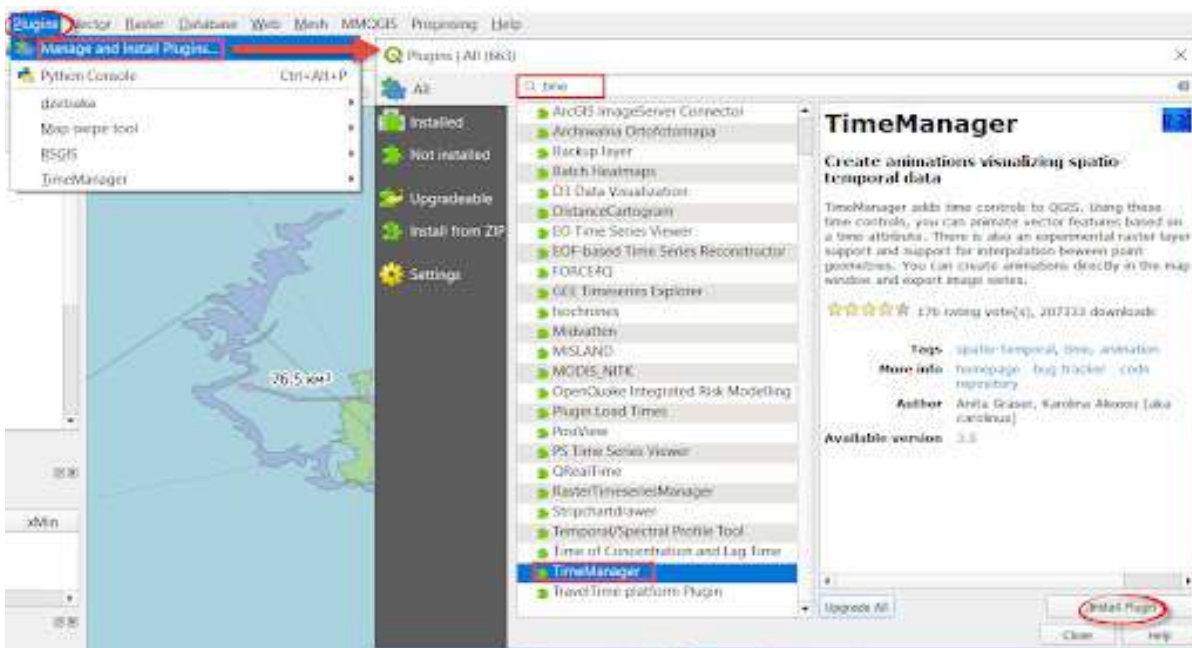
✔ **Important!** Pay attention to the numbers you get when calculating the **Output preview**. If the numbers are too large, then the unit of measurement in QGIS will be “square meters”. To change the units of measurement, go to **Project – Properties – Units for area measurement**, select “Square kilometers” and calculate the area again.



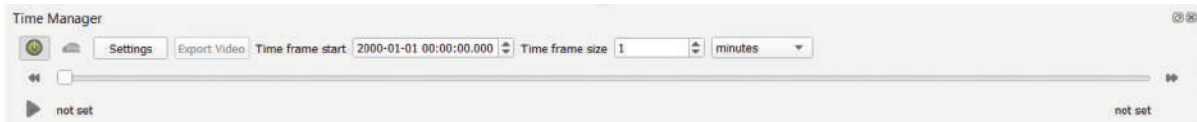
9. Label the area: right-click on the layer – **Properties – Labels – Single labels – Area – ϵ** , and add || “km” to the name of the line from which we take the name for the label, and click **Ok**.



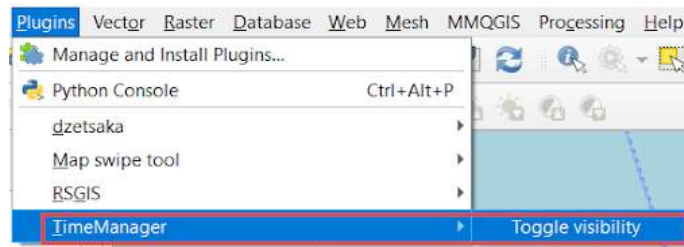
10. Download a new *TimeManager* plugin via *Plugins – Manage and Install Plugins ...*. Start typing the name of the plugin in the search bar, and it will automatically appear in the list at the bottom of the dialog. Select it from the list by left-clicking – brief information about the plugin will appear that you should read; click *Install Plugin*, and close the dialog.



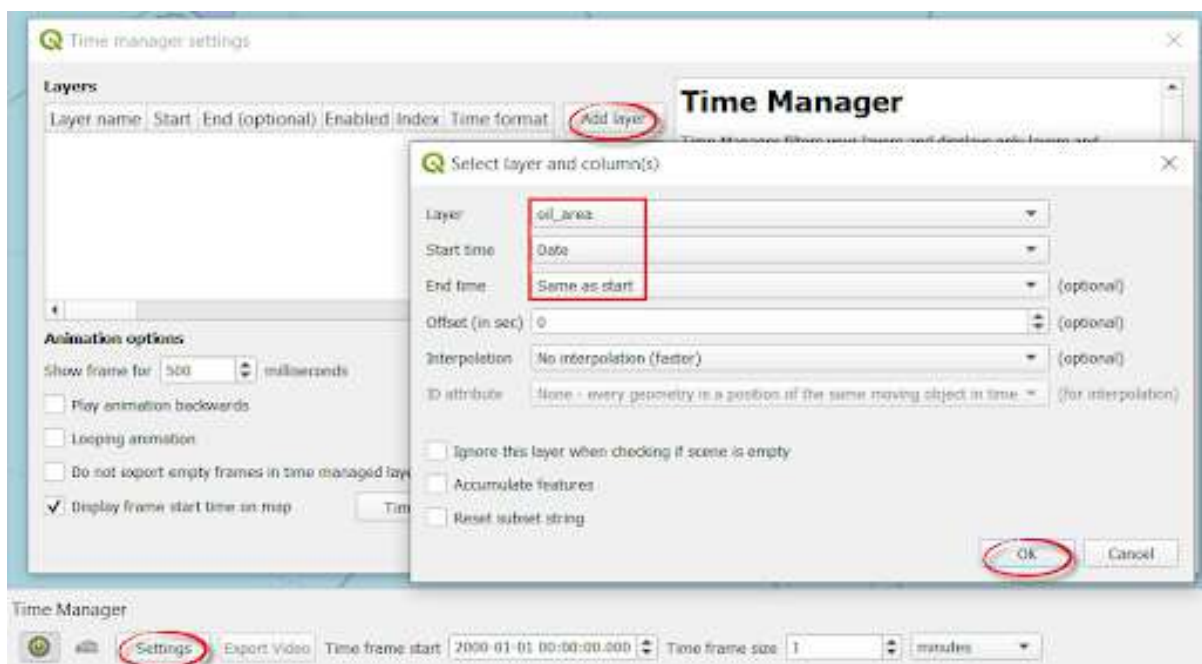
Upon successful installation, the plugin will appear as a separate panel below the map canvas window.



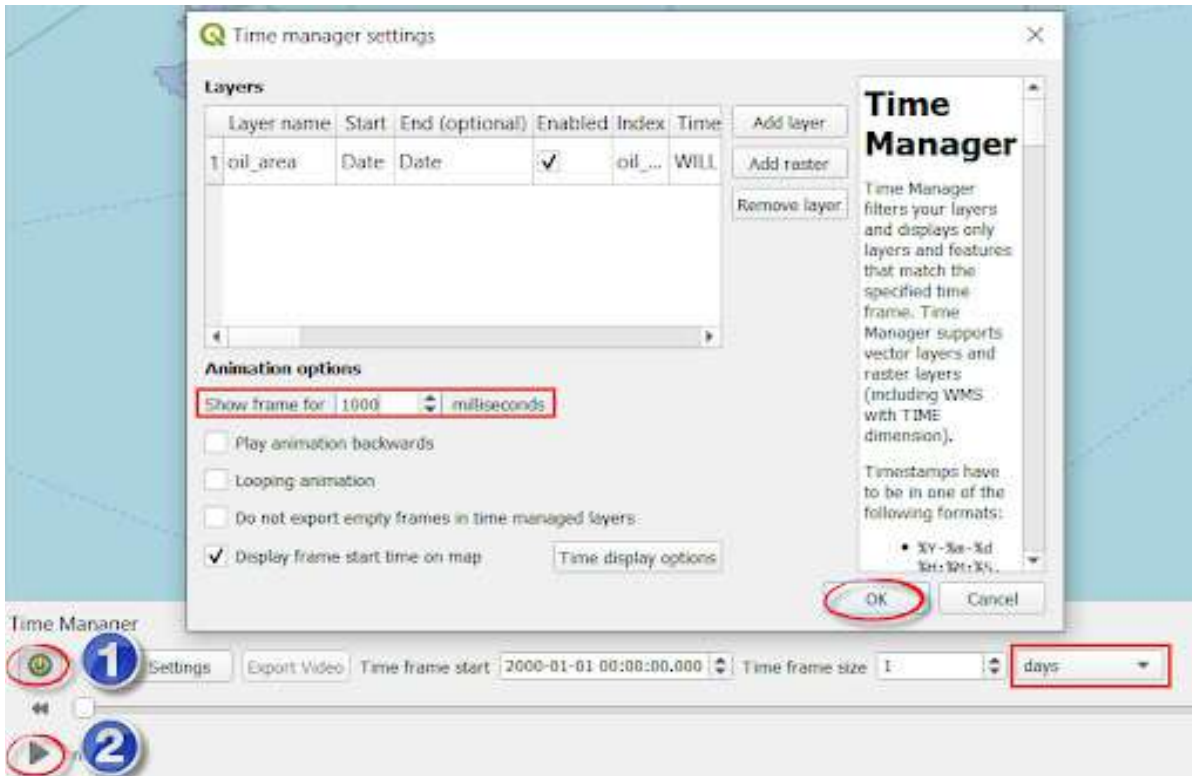
If this panel does not appear, repeat the steps specified in the Figure below.



Adjust the animation by clicking **Settings – Add Layer**. Select the created layer, specify the **Start time** and **End time**, and click **Ok**.



Increase the frame to 1000 milliseconds to slow down the animation, click **Ok**. In the **Time frame** field, select **days**. To run the animation, click **Play** and the **Play** button **▶**.



To save the animation, use the *Export video* button.

Check yourself

When (date) was the area of oil slick the largest (specify the area)?	
What in your opinion are the consequences of this oil pollution?	

Scan the QR-code below to watch a video tutorial on the performance of this Task.



8. Performing Regression Analysis Using Raster Data – Exploring the Relationships Between Features

8.1. Simple Correlation Analysis: Understanding Relationships Between Temperature and Algal Blooms in the Kamianske Reservoir

Case

According to researchers of the Institute of Hydrobiology at the National Academy of Sciences of Ukraine, the algal blooms in the Dnipro reservoirs mainly result from continuous eutrophication of their aquatic ecosystems, primarily due to over-enrichment with phosphates, decrease in precipitation, higher frequency of low water years, global climate change (especially rising temperatures), and low flow rates in circulating water reservoirs.¹

Task

Explore the relationship between remote data representing the status of the water body during an algal bloom, namely, threshold spectral indices (vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI)), and the surface temperature in the Kamianske Reservoir (until 2017, known as the Dniprodzerzhynsk Reservoir) using the Landsat 8 satellite image taken on August 12, 2017.

Task performance algorithm:

1. Download the Landsat 8 satellite image taken on August 12, 2017.
2. Using the RS&GIS plugin, obtain the following from the archive: a merged false-color satellite image, data on vegetation index, and water surface temperature (in degrees) of the territory of the Kamianske Reservoir as of August 12, 2017.
3. Download the obtained merged true- and false-color images to QGIS and visually compare them.
4. Download the obtained thermal bands, B10 and B11 (in degrees Celsius) to QGIS, select the colors, and compare the surface temperatures at different points.
5. Download and visualize the obtained vegetation index.
6. Calculate additional NDAI and NDTI indices for the clipped location.
7. Perform correlation analysis of all obtained thematic raster images (surface temperature in two bands: B10 and B11, vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI)).
8. Perform a logical analysis of your results.


Instructions for self-guided work

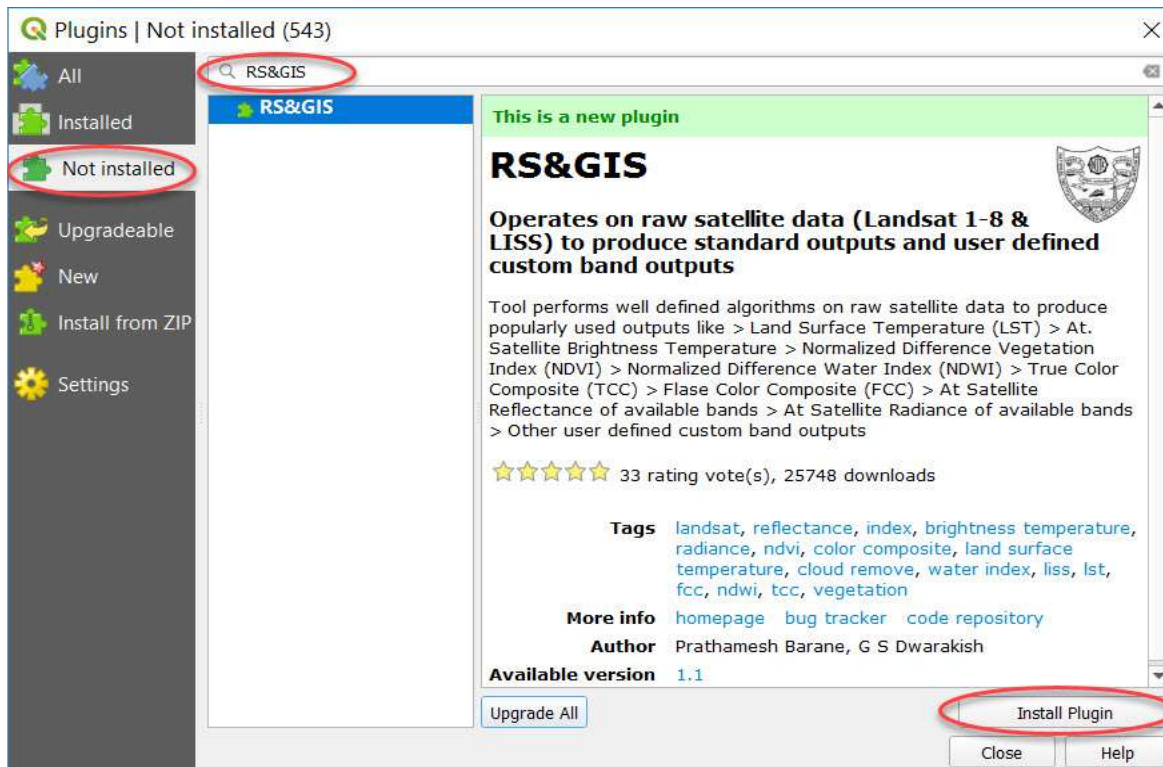
1. Download the Landsat 8 satellite image taken on August 12, 2017, that captures the territory of the Kamianske Reservoir. You can download this image from Google Drive at <https://drive.google.com/drive/folders/1z8KYPMU4LJqe1-1g3r9Gs80UPrGA4Cr>, or search for it at the USGS Explore website. Using the same Google Drive link, download the “border_Kamyanske.zip” archive including the shapefile of the Kamianske Reservoir boundaries, and unzip it to your folder.

2. Using the **RS&GIS** plugin, export the following from the archive: a merged false-color satellite image, data on vegetation index, and water surface temperature (in degrees Celsius) for the clipped territory of the Kamianske Reservoir as of August 12, 2017.

First, add the **RS&GIS** plugin: select **Manage and Install Plugins...** under **Plugins** from the top menu, and switch to **Not installed**. In the search bar, start typing the plugin name, **RS&GIS**, and it

¹ URL: <http://www.nas.gov.ua/UA/Messages/news/Pages/View.aspx?MessageID=3441> <https://texty.org.ua/d/static/wrack/>

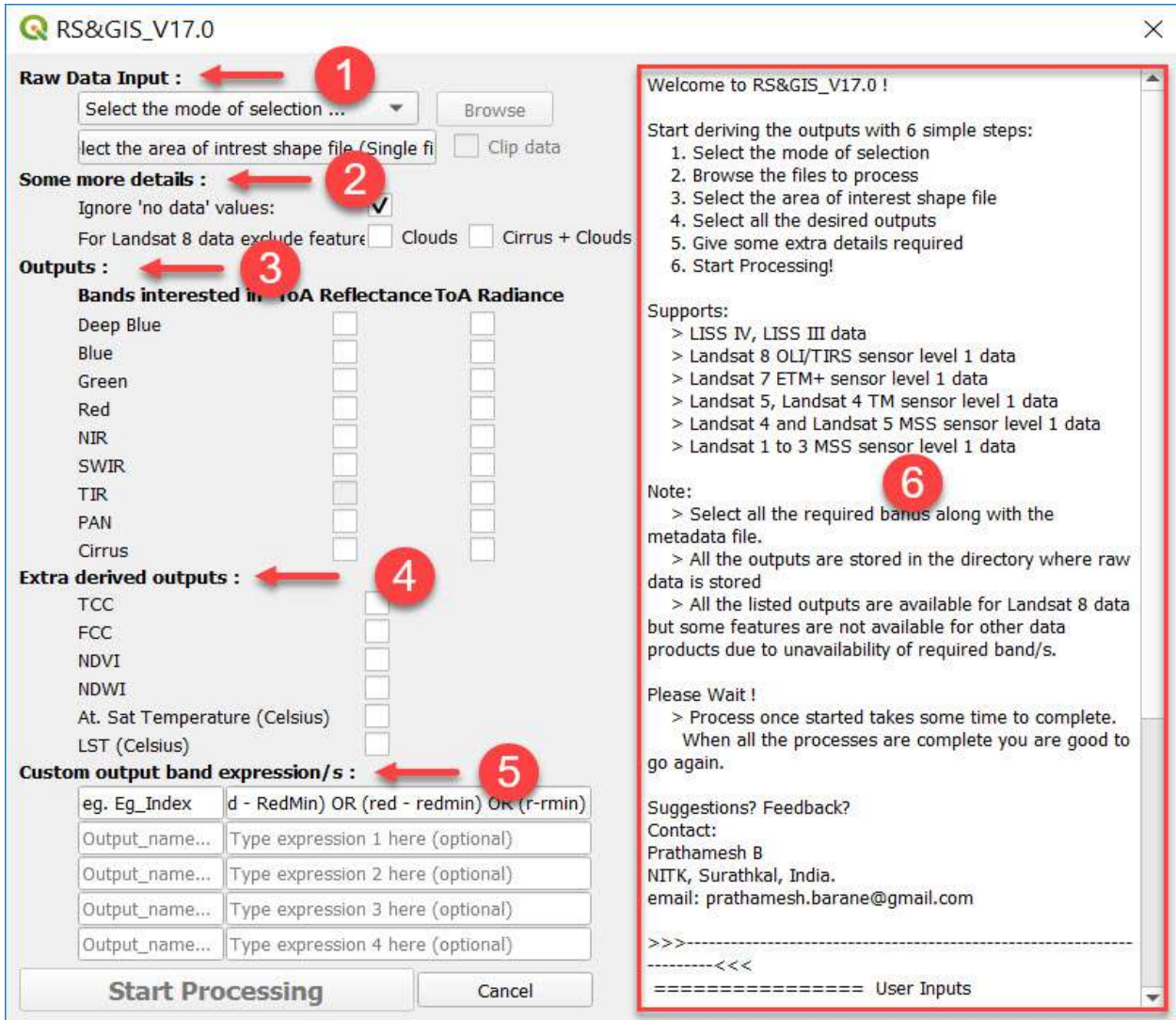
will automatically appear in the list at the bottom of the dialog box. Select it from the list by left-clicking, and brief information about this plugin will show up automatically. Read the information, click the **Install Plugin** button, and close the dialog box. Once installed, the plugin will appear on the **Installed** tab and you can see its icon  on the toolbar.



This plugin may be used with original satellite data (Landsat 1-8 and LISS), in particular archives. The unprocessed, “raw” Landsat data (first level processing) can be downloaded from the NASA and USGS Earth Explorer datasets available at <http://earthexplorer.usgs.gov/>, or from Google Drive (select image entitled *LC08_L1TP_178026_20170812_20170824_01_T1.tar.gz*.)

Below, you can see the main window of the plugin, which includes six sections:

- 1 – **Raw data input**;
- 2 – **Some more details**;
- 3 – **Outputs**;
- 4 – **Extra derived outputs** – the plugin applies clearly-defined algorithms to raw satellite data to obtain the most commonly used combinations;
- 5 – **Custom output band expression/s**;
- 6 – **Event log window** is an interactive window that provides information about the plugin at the beginning of the operation, and shows the sequence of process stages.



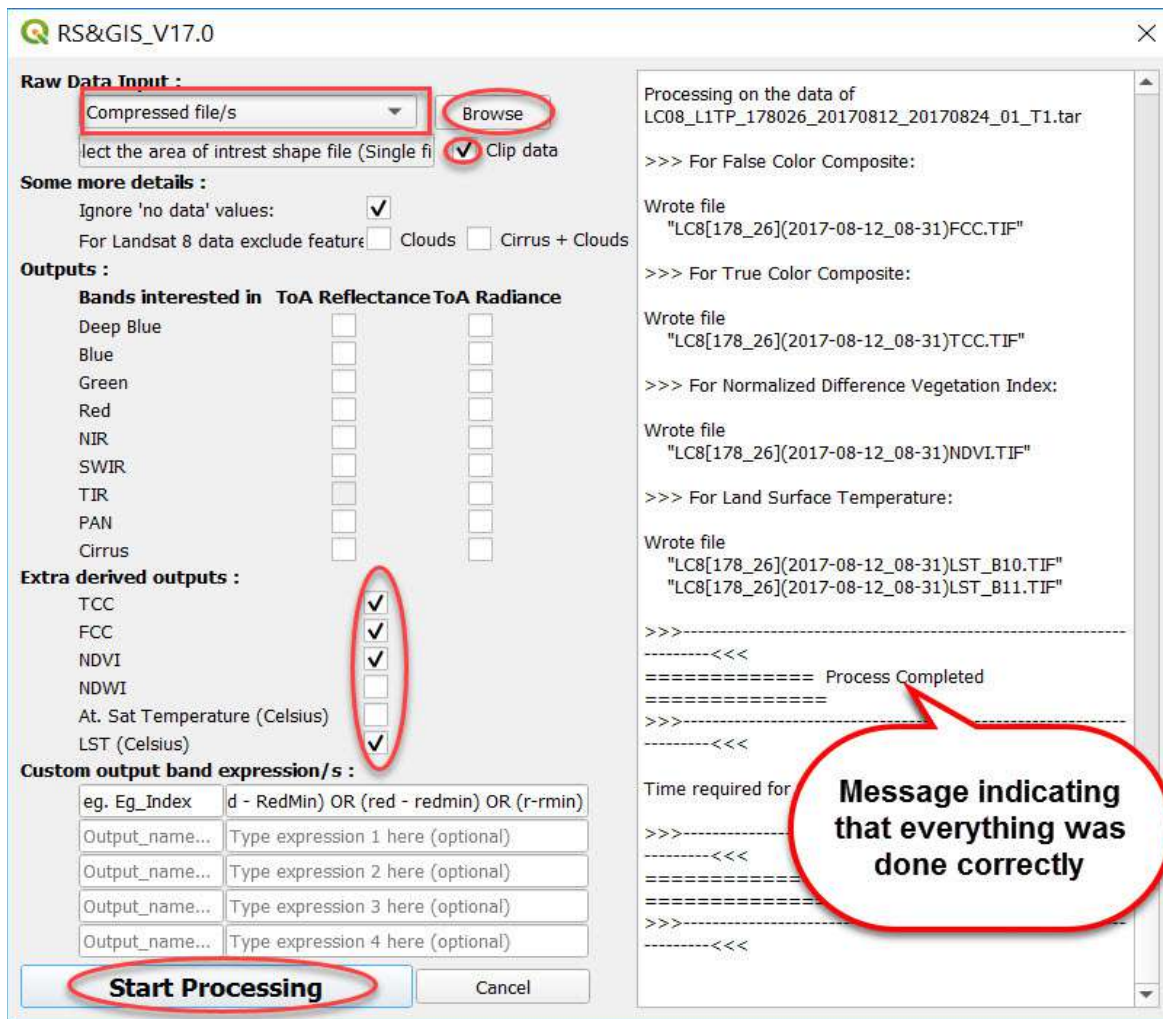
To perform this Task, first, specify the path to the image file archive (*.tar.gz) in the **Raw Data Input** 1 section: select **Compressed file/s** from the drop-down list, and in the line below, specify the path to the corresponding **Area of Interest (Aol)** shapefile of the Kamianske Reservoir borders (“border_Kamyanske.zip”) that was previously downloaded from Google Drive and unzipped.

The **Ignore “no data” values** option is set by default and does not need to be changed.

In the section 4, **Extra derived outputs**, tick the boxes next to the following desired outputs for this Task:

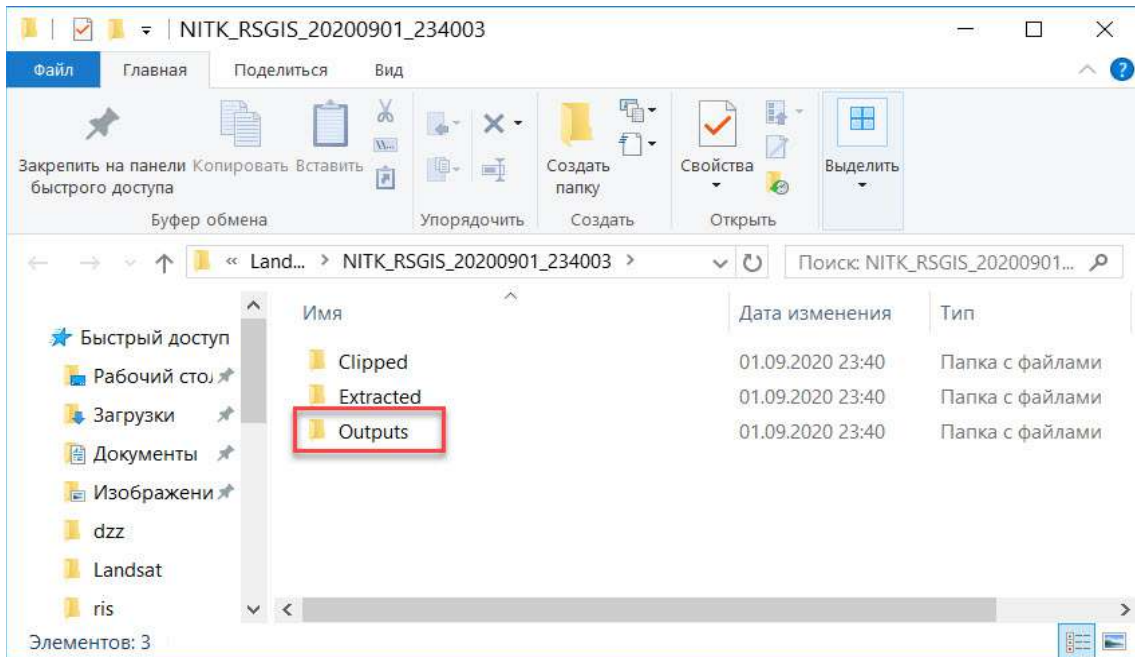
- **True Color Composite (TCC)** – a merged Landsat 8 satellite image produced with the combination of bands: B04 – Red, B03 – Green, B02 – Blue; with this combination, the features on the earth’s surface look similar to how they are perceived by the human eye: the water is dark blue, and the vegetation (phytoplankton) is green;
- **False Color Composite (FCC)** – a merged Landsat 8 satellite image produced with the combination of bands: B05 – NIR (near-infrared), B04 – Red, B03 – Green; with this combination, the vegetation appears in shades of red (in our case the intensity of red is indicative of the phytoplankton concentration, i.e. algal blooms);
- **Normalized Difference Vegetation Index (NDVI)** – a simple quantitative indicator of the amount of active photosynthetic biomass (commonly referred to as the vegetation index);
- **Land Surface Temperature (LST)** – a radiant temperature of the earth’s surface, measured by the Landsat satellite sensors, taking into account albedo, vegetation cover, and soil moisture.

To run the plugin, click the **Start Processing** button. The interactive summary of all processes performed in the background will display in the **Event log window** 6 as text messages.

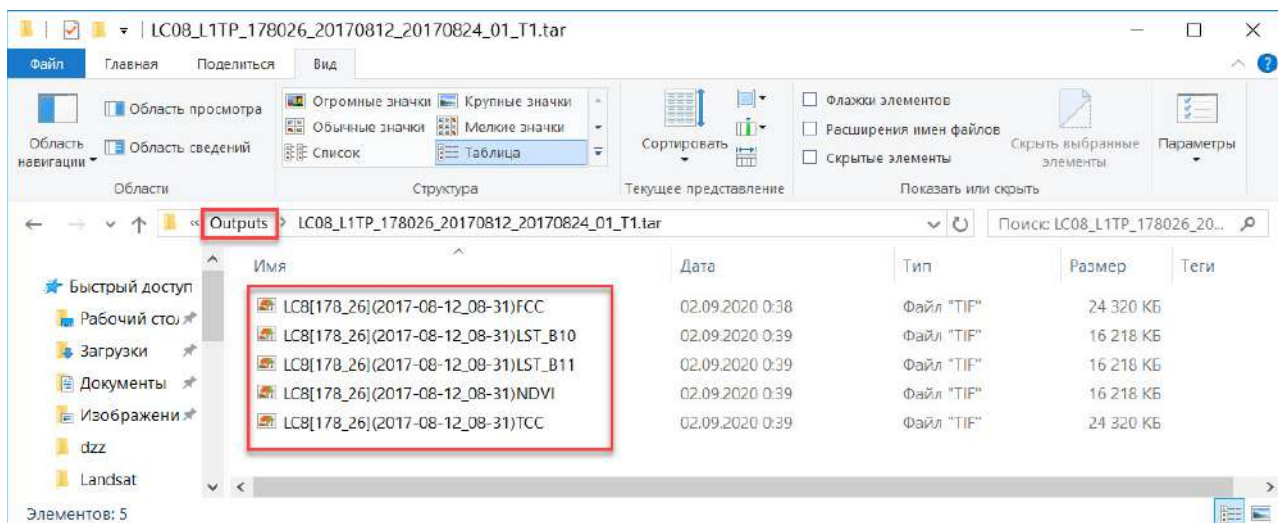


You will also see a new **Windows Explorer** window appearing on your screen and displaying a path to new data; while performing the command, the plugin automatically creates a new folder called “NITK_RSGIS_*data*_*time*”, where all extracted and unprocessed input data are stored in the “Extracted” folder, clipped bands in the “Clipped” folder, and the newly created final results in the “Outputs” folder.

Important! Please note that it will not take much time to process your image with RS&GIS plugin, and the folder appears when the operation is completed.



The contents of the *Windows Explorer* folder that was created using the plugin

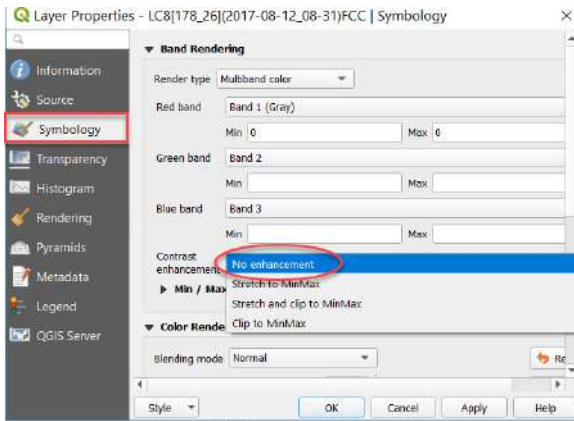


Once you have the outputs (six raster images), drag them one by one from the *Windows Explorer* window to the QGIS project window for further analysis that is described below. We will proceed now to outputs review.

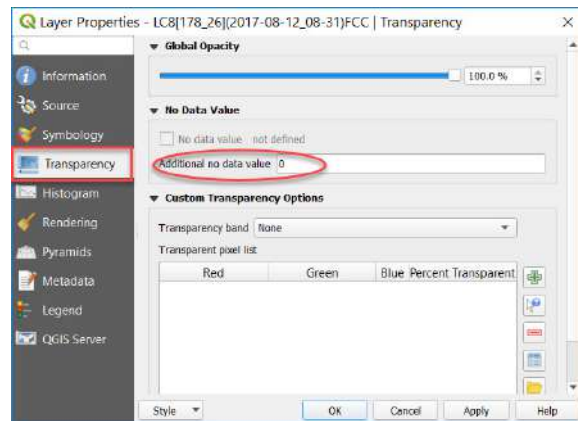
3. Download the resulting merged false- and true-color images to QGIS and visually compare them.

First, take a closer look at the merged satellite images from the "Outputs" folder, namely the files: *LC8[178_26](2017-08-12_time)FCC.TIF* and *LC8[178_26](2017-08-12_time)TCC.TIF*. To improve the visualization of these images, we shall adjust the contrast and remove the dark background.

To adjust the contrast of the merged image, double-click on its name in the *Layers* tab to open the *Layer Properties* menu. Switch to the *Symbology* tab, and select *No enhancement* from the Contrast enhancement list of options, and click *Ok*. To remove the dark background on the border of the clipped image, go to the *Transparency* tab, and enter "0" in the *Additional no data value* box, and click *Ok*. Repeat these steps for another image (*LC8[178_26](2017-08-12_time)FCC.TIF* or *LC8[178_26](2017-08-12_time)TCC.TIF*).



Adjusting the contrast

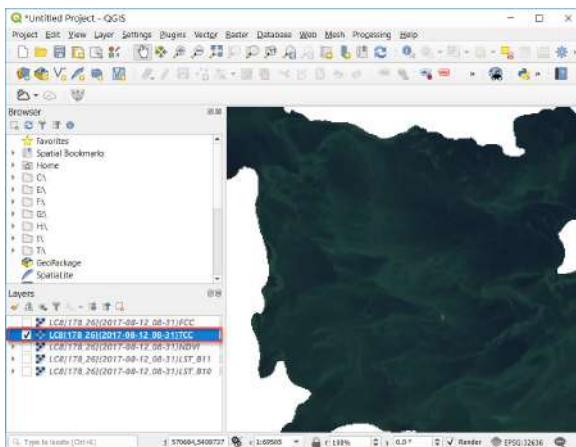


Removing dark background

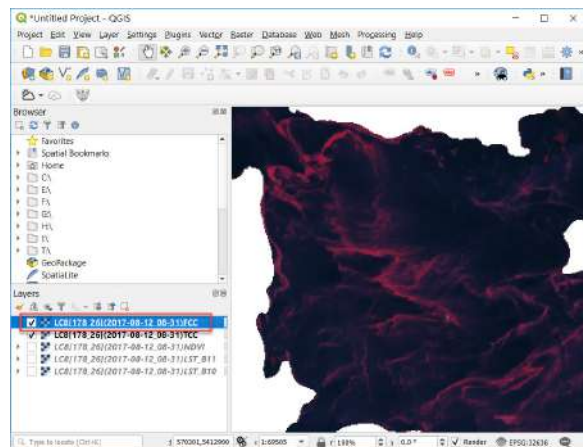
Compare these two satellite images of the Reservoir and choose the merged image (false- or true-color) that suits you best and facilitates the identification of water blooms.

How may the areas of algal blooms be identified on satellite images?

For visual identification of the areas of water blooms, it is better to focus on the image texture. The areas of intense algal blooms are often characterized by a specific filamentous texture. In particular, you can see on the satellite images the areas of intense water blooms extending along the streams and integrating into the vortex motions in the background of a uniform dark water surface. During extended periods of warm, sunny, and windless weather, cyanobacteria aggregate into colonies that float to the surface and form massive surface or subsurface mats that can be easily recognized by their bright color.



True Color Composite (TCC)



False Color Composite (FCC)

Check yourself

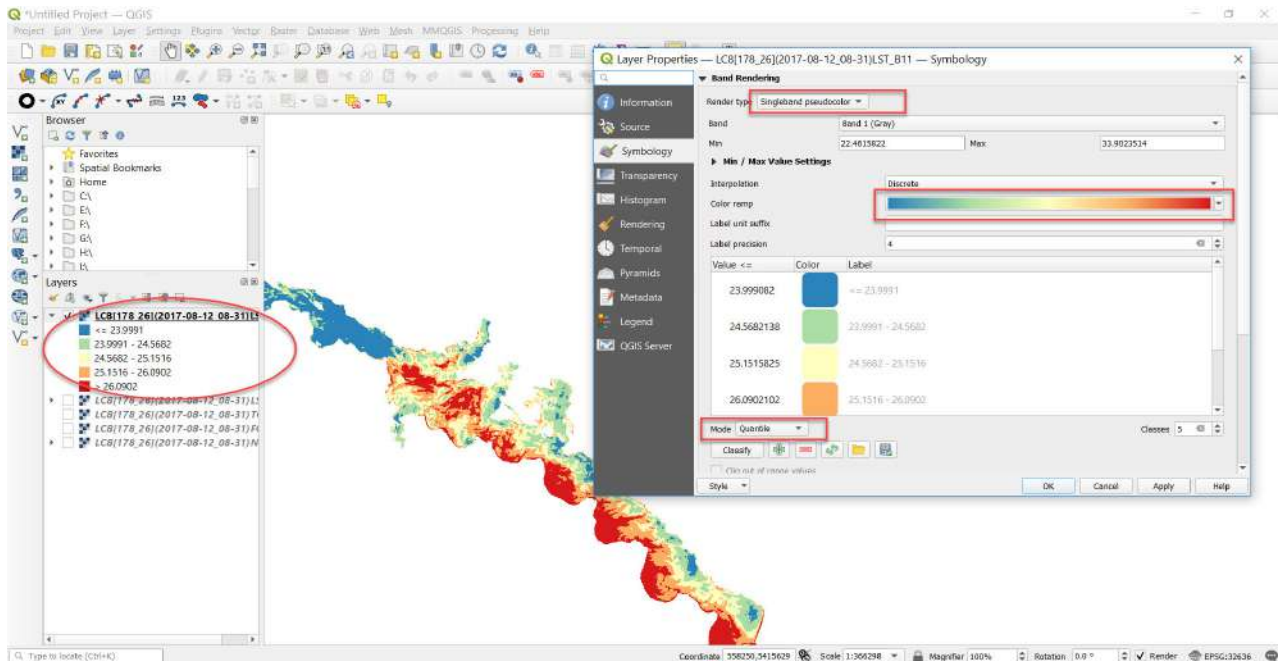
Take a closer look at the merged image of the Kamianske Reservoir and explore the distribution of water blooms. What were the directions of the current and the wind at the time the image was taken?



4. Download the thermal bands, B10 and B11, to QGIS (in degrees Celsius), select the color gamut, and compare the surface temperatures at different points.

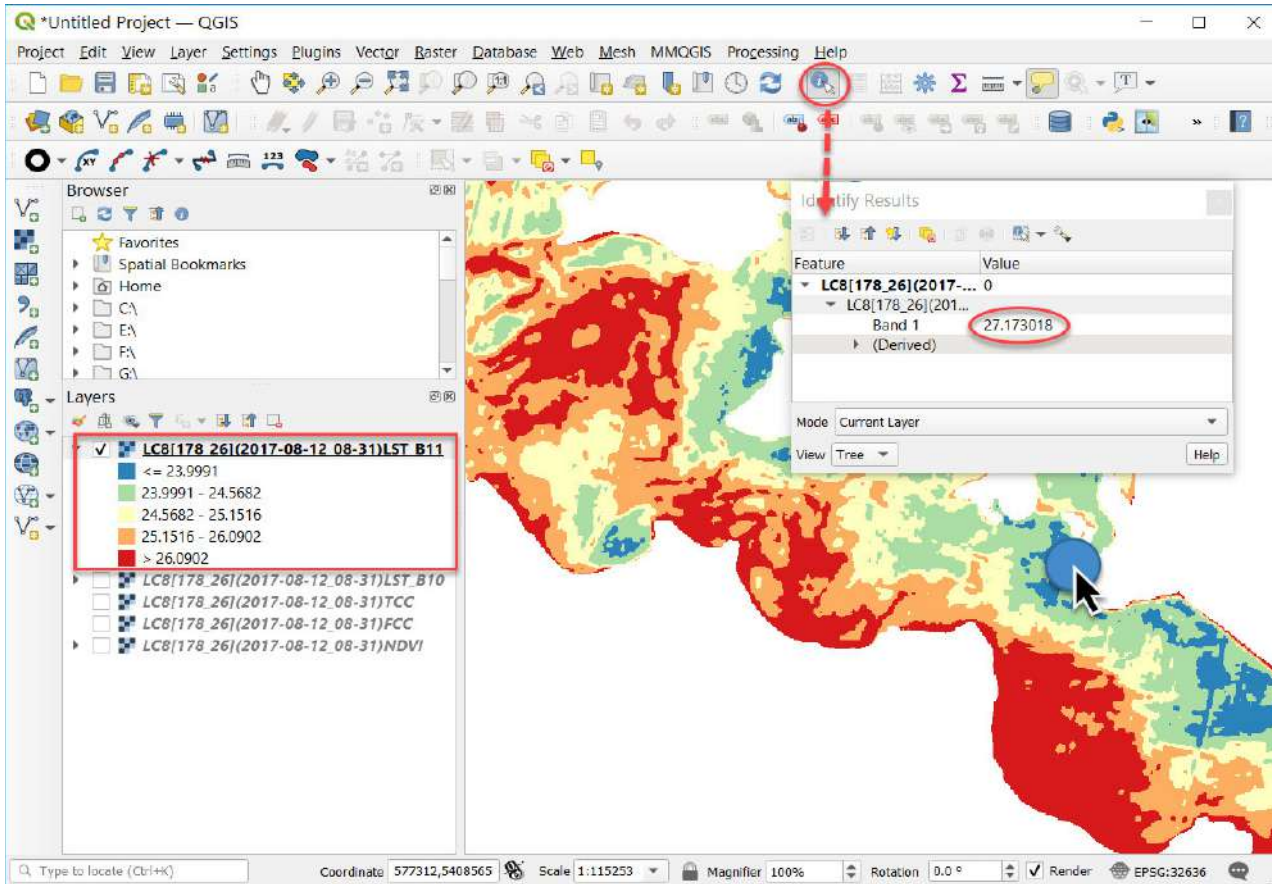
Now, we will proceed to the analysis of bands that represent the surface temperatures in the Reservoir. We will use the following files from the "Outputs" folder for the analysis: *LC8[178_26](2017-08-12_time)LST_B10.TIF* and *LC8[178_26](2017-08-12_time)LST_B11.TIF*. B10 and B11

are the far-infrared bands. Their wavelengths range from 10.30 to 11.30 μm (B10), and from 11.50 to 12.50 μm (B11), and they almost similarly reflect the surface temperatures. When analyzing the thermal band, uncheck the display of other satellite data to avoid interference.

For a better visual understanding of the temperatures distribution, you can select a color ramp for the thermal band ranging from blue to red: double-click with your left mouse button LC8[178_26](2017-08-12_time)LST_B10.TIF file name, and select the display mode, *Singleband pseudocolor*, *Interpolation* \rightarrow *Discrete* in the *Layer Properties* dialog under *Symbology*. Set the *Color ramp*, for example, blue and red (entitled Spectral), and select *Invert Color ramp* and *Quantile* mode.



Using the *Identify* tool, check the temperatures at different points within the Reservoir with one of the thermal bands, for example, B10, namely in the areas affected and unaffected by algal blooms. First, find the  icon in the toolbar (the *Attribute Toolbar*). If this icon is missing, you can switch it on: right-click within the area of the toolbar and tick the *Attribute Toolbar* box. Select the  icon, point the arrow at the area of your interest, and click it with your left mouse button. All the information about the identified pixel of the thermal band will display in the *Identify Results* sidebar. Pay attention to the *Value* in the *Band1* field – this is the surface temperature in degrees Celsius at the selected point.

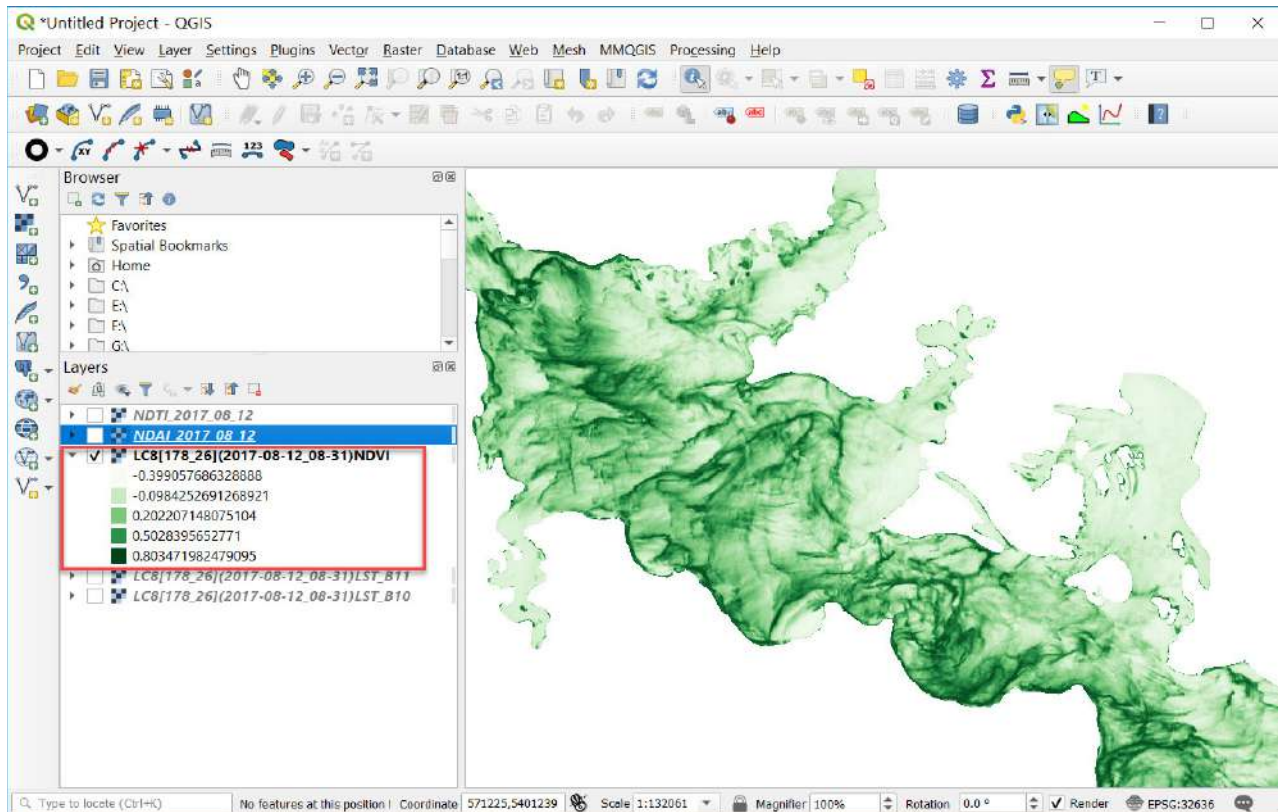


🔍 Check yourself

What is the surface temperature in the parts of the reservoir with the largest accumulation of water blooms? Is it above or below the temperature of the areas unaffected by the algal blooms?

5. Download and visualize the obtained vegetation index.

Now, we will proceed to the visual interpretation of another file, namely the vegetation index obtained with the *RS&GIS* plugin: download *LC8[178_26](2017-08-12time)NDVI.TIF* file from the “Outputs” folder to your project, and choose another color ramp for its display. To do this, right-click the NDVI raster in the project content table and select **Properties** from the drop-down menu. In the **Layer Properties** window that appears, go to the **Symbology** tab and select the **Singleband pseudocolor** display mode, and pick **Discrete** under **Color Interpolation**. You shall also change the **Color ramp** to generate a required index map display. This is not necessary, however, as our main task is to determine a correlation between different remote sensing data relating to the Reservoir.



Vegetation index

6. Calculate additional NDAI and NDTI indices using the clipped bands.

Next, we will calculate two additional indices that characterize the water blooms in the Kamianske Reservoir, namely the algae index (NDAI) and the turbidity index (NDTI).

First, download to your project the clipped bands (B2, B3, B4, B5) obtained in Section 2 of this Task with the *RSeGIS* plugin. They are stored in the “Clipped” subfolder of the same PC folder as an input image downloaded from Google Drive, *NITKTtSGIS_*data*_*time**.

The *Normalized Difference Algae Index* (NDAI) is well-suited for detecting the algae overgrowth and its stage. It has been designed in such a way as to neutralize the atmospheric interference on the one hand, and remove water background reflectance on the other hand, and also take into account the detected spectral characteristics of scattered and concentrated phytoplankton. The higher the value of the index, the more intense the water blooms, and vice versa – low values indicate water unaffected by algal blooms.

$$NDAI = (Green + 2 * NIR - Blue - Red) / (Green + 2 * NIR + Blue + Red) + 0.5$$

де: *Green* – зелений діапазон, *NIR* – ближній інфрачервоний діапазон, *Blue* – блакитний діапазон, *Red* – червоний діапазон

The *Normalized Difference Turbidity Index* (NDTI) is used to evaluate the water turbidity mainly caused by suspended particulate matter in surface layers and the activity of organisms. Uneven distribution of suspended solids is an important environmental parameter used in water quality assessment.

$$NDTI = (Red - Green) / (Red + Green)$$

where: *Red* – red range, *Green* – green range

These indices may be calculated with a raster calculator, which has been repeatedly used in previous tasks. First, switch to the *Raster* tab → *Raster Calculator* dialog in the main menu. In the appropriate field of the *Raster Calculator* box, enter the expression for calculating the required index (first, the NDAI and then, the NDTI).

NDAI formula for Landsat 8 satellite image:

$$((B3 + (2 * B5) - B2 - B4))/((B3 + (2 * B5) + B2 + B4)) + 0.5$$

NDTI formula for Landsat 8 satellite image:

$$(B4 - B3)/(B4 + B3)$$

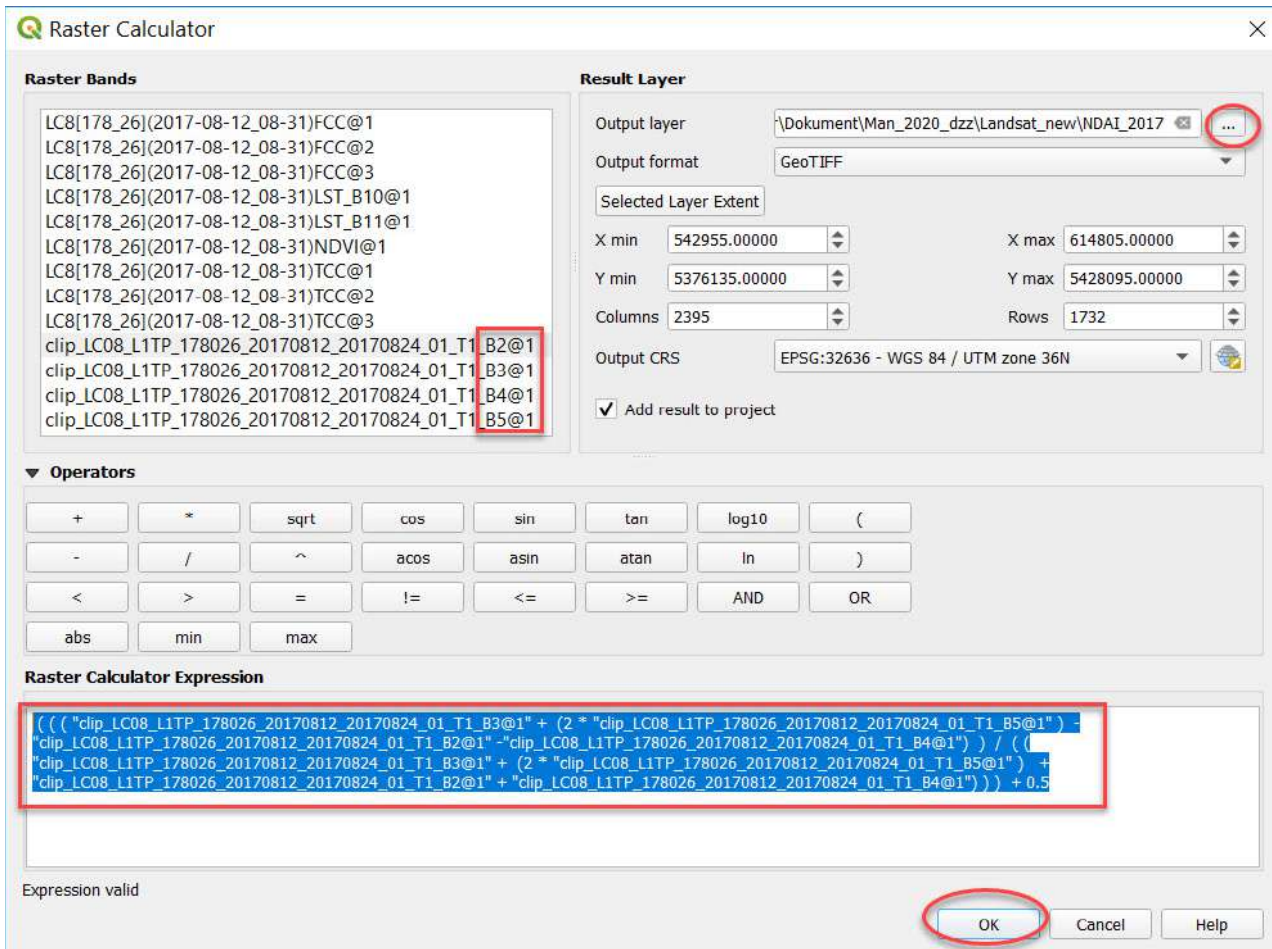
✔ **Important!** Please note that the decimal separator (point, comma) that suits best for expressing decimal numbers in **Raster Calculator** depends on your PC settings.

Select the desired bands from the **Raster Bands** list in the **Raster Calculator** dialog (at the top of the window). Use the appropriate **Operators** buttons to select the symbols (), -, +, /. To add layers to the expression dialog, double-click on the desired layer with your left mouse button.

✔ **Important!** Do not enter band names from the keyboard as the formula will not run.

Please note that the **Ok** button at the bottom of the **Raster Calculator** will activate once you specify a name and a path to the **Output layer**. Select the required folder by clicking the [...] button, and write the name of the output layer, for example, "NDAI_2017_08_12", where the numbers indicate the image date. Repeat all the above steps and you will get the turbidity index file called "NDTI_2017_08_12".

✔ **Important!** If you can't save the file, check the names of folders and files: you should not use Cyrillic and space characters in the names.



Calculating algae index in the **Raster Calculator** window

Thus, using the above procedure, you will add two more thematic raster images to your project, namely, the NDAI algae index and the NDTI turbidity index, which characterize the quality of water in the Kamianske Reservoir and will be required for further correlation analysis.

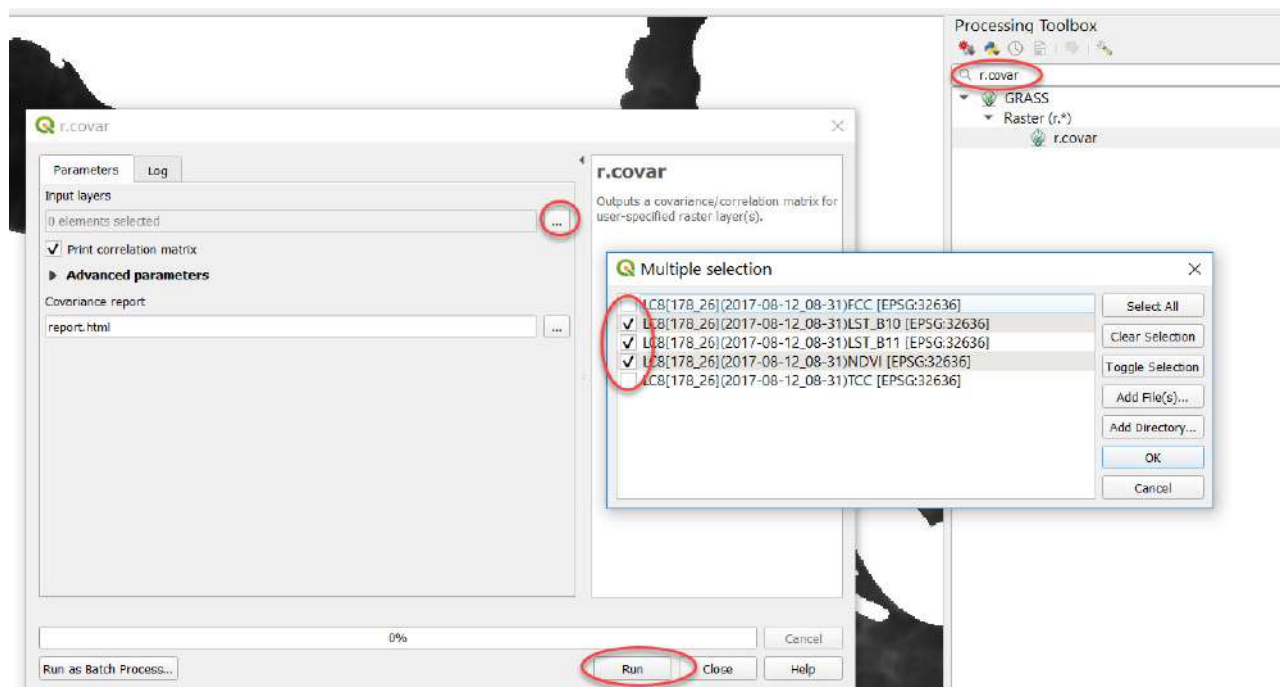
Check yourself

<p>What algae is responsible for water blooms? What processes and phenomena contribute to the water bloom?</p>	
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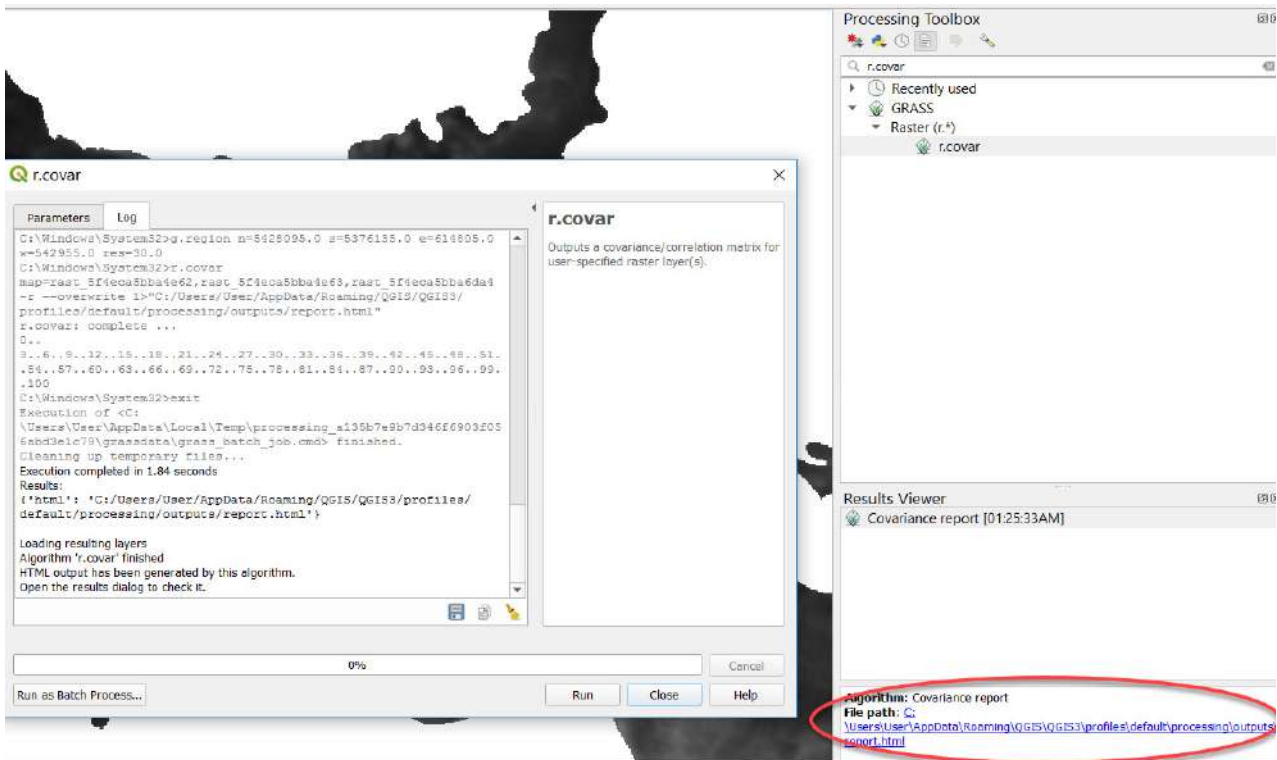
7. Perform correlation analysis for all obtained thematic raster layers (surface temperature in two bands (B10 and B11), vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI)).

To perform raster correlation, use the *r.covar* tool: select **Toolbox** from the **Processing** tab. Enter *r.covar* in the search field of the **Processing Toolbox** dialog, and select it from the drop-down list. This tool provides a covariance/correlation matrix for user-specified raster layers.

Under the **Input layers** in the *r.covar* dialog, specify all required data, namely, five thematic layers (two thermal bands (LST_B10, LST_B11) and three indices (NDVI, NDAI, NDTI)), and click the **Run** button.



As a result, you will get a **Covariance report** in HTML format. To open the report, click the link at the bottom of the window.



← → ↻ ⓘ Файл | C:/Users/User/AppData/Roaming/QGIS/QGIS3/profiles/d

```

N = 474831
1.000000 0.981305 0.708945 0.699960 -0.695062
0.981305 1.000000 0.684517 0.676162 -0.660561
0.708945 0.684517 1.000000 0.954729 -0.880499
0.699960 0.676162 0.954729 1.000000 -0.853303
-0.695062 -0.660561 -0.880499 -0.853303 1.000000
  
```

Correlation report on the water quality parameters in the Kamianske Reservoir obtained with QGIS

8. Logical analysis of results.

The symmetric covariance/correlation matrix, $N \times N$, will be the output of your analysis of water quality in the Kamianske Reservoir, where N is the number of raster layers specified in the command line, in our case:

- X 1 – corresponds to *B10* values, i.e. the surface temperature of the Reservoir in the band 10;
- X 2 – corresponds to *B11* values, i.e. the surface temperature of the Reservoir in the band 11;
- X 3 – corresponds to *NDVI* values, i.e. the vegetation index;
- X 4 – corresponds to *NDAI* values, i.e. the algae index;
- X 5 – corresponds to *NDTI* values, i.e. the turbidity index.

	<i>X1 – B10</i>	<i>X2 – B11</i>	<i>X3 – NDVI</i>	<i>X4 – NDAI</i>	<i>X5 – NDTI</i>
<i>X1 – B10</i>	1				
<i>X2 – B11</i>	0.981	1			
<i>X3 – NDVI</i>	0.708	0.685	1		
<i>X4 – NDAI</i>	0.699	0.676	0.955	1	
<i>X5 – NDTI</i>	-0.695	-0.660	-0.880	-0.853	1

Correlation analysis is a statistical method used to measure the relationship between random variables. The correlation can be positive or negative (or zero if there is no statistical relationship between independent random variables). A negative correlation is a relationship in which an increase

in one variable is associated with a decrease in another. A positive correlation is a relationship in which an increase in one variable is associated with an increase in another.

Covariance is a measure of how much two random variables vary together. Correlation is a statistical measure that expresses the extent to which two variables are related.

The analysis of obtained results shows a positive correlation between B10, B11, NDVI, NDAI and a negative correlation with NDTI

✔ **Important!** *The closer the correlation coefficient to 1, the stronger the relationship between the two variables. Each variable has the maximum similarity to itself, i.e. the correlation is equal to 1; however, it is not logical to compare the variable with itself, so when searching for the highest correlation we should not consider pairs with a correlation coefficient equal to 1.*

Table: Correlation coefficients and the extent of the relationship according to the Chaddock scale

Correlation coefficient	Extent of relationship	Results obtained for the Kamianske Reservoir
1,00	Functional relationship	1
0,90–0,99	Very strong	0.981, 0.955, -0.880, -0.853
0,70–0,89	Strong	0.708
0,50–0,69	Significant	0.685, 0.676, 0.652, -0.695, -0.660
0,30–0,49	Moderate	
0,10–0,29	Weak	
0,00	None	

According to the matrix given above, the highest correlation coefficients are observed for the relationships between the B10 and B11 thermal bands, and the turbidity and algae indices; it is not correct, however, to compare them in pairs because these variables are very similar. Our task was to determine the relationship between the temperatures and water blooms, this means to compare different thermal bands and water quality indices and select the highest value for the extent of the relationship.

❓ **Check yourself**

Which of the analyzed remotely sensed data have the strongest relationship?	
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Scan the QR-code below to watch a video tutorial on the performance of this Task.



8.2. In-Depth Regression Analysis of the Relationships between the Remotely Sensed Data of the Kamianske Reservoir

Understanding any natural phenomenon requires knowledge of its relationships with others. To capture the essence of phenomena, it is necessary to explore their relationships, determine the extent of impact exerted by certain factors. Correlation refers to an incomplete relationship between the studied phenomena. This is a sort of dependence where any value of one variable can correspond to several different values of another variable.

Regression analysis involves the identification of the relationship between one variable and one or more other variables; in contrast to correlation analysis, it focuses on a model of such relationship that is used to develop a regression equation rather than the extent of the relationship.

Task

Perform an in-depth regression analysis of remotely sensed data: water surface temperatures and threshold spectral indices of water blooms (vegetation index, NDVI, algae index, NDAI, and turbidity index, NDTI) of the Kamianske Reservoir (until November 8, 2017, known as the Dniprodzerzhynsk Reservoir) using the Landsat 8 satellite image taken on August 12, 2017.

Task performance algorithm:

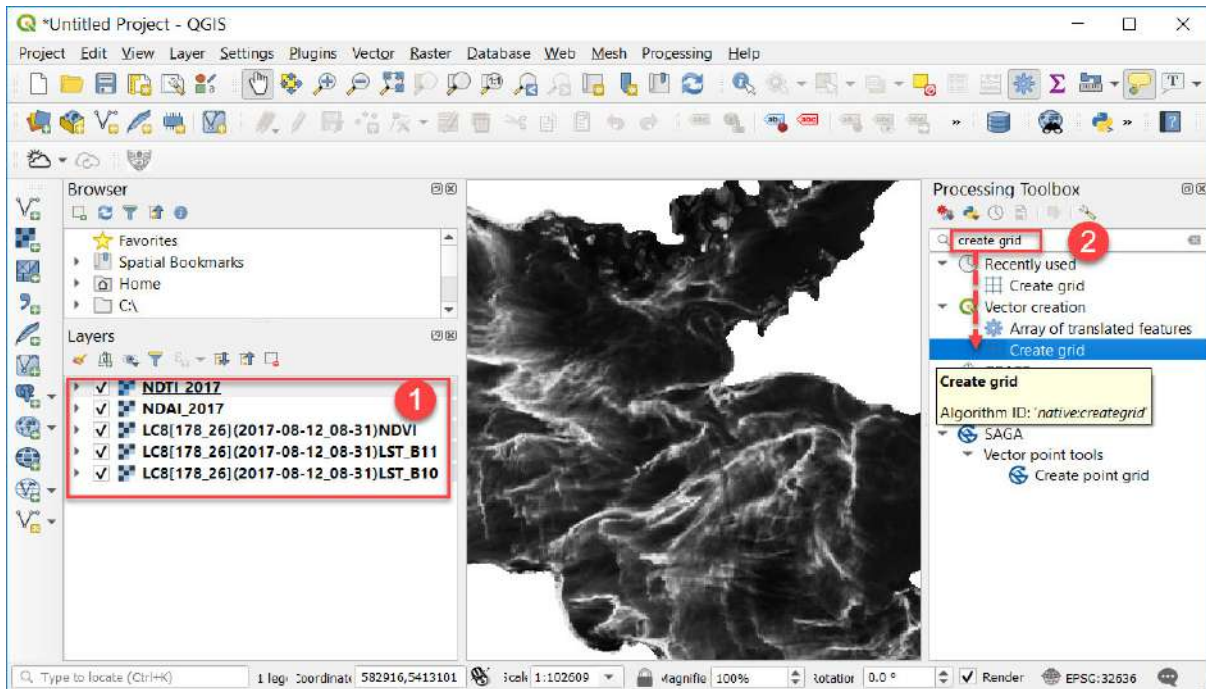
1. Create a shapefile (polygon grid) and select the area of interest within the Kamianske Reservoir.
2. Extrapolate data of thematic raster layers (surface temperatures in two bands, B10 and B11, vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI)) to the attribute table of the shp-file (grid of rectangle polygons).
3. Export the attribute table containing the thematic raster layers from the shp-file to the CSV-file.
4. Perform a regression analysis in Microsoft Excel using the correlation and regression tools.

Instructions for self-guided work

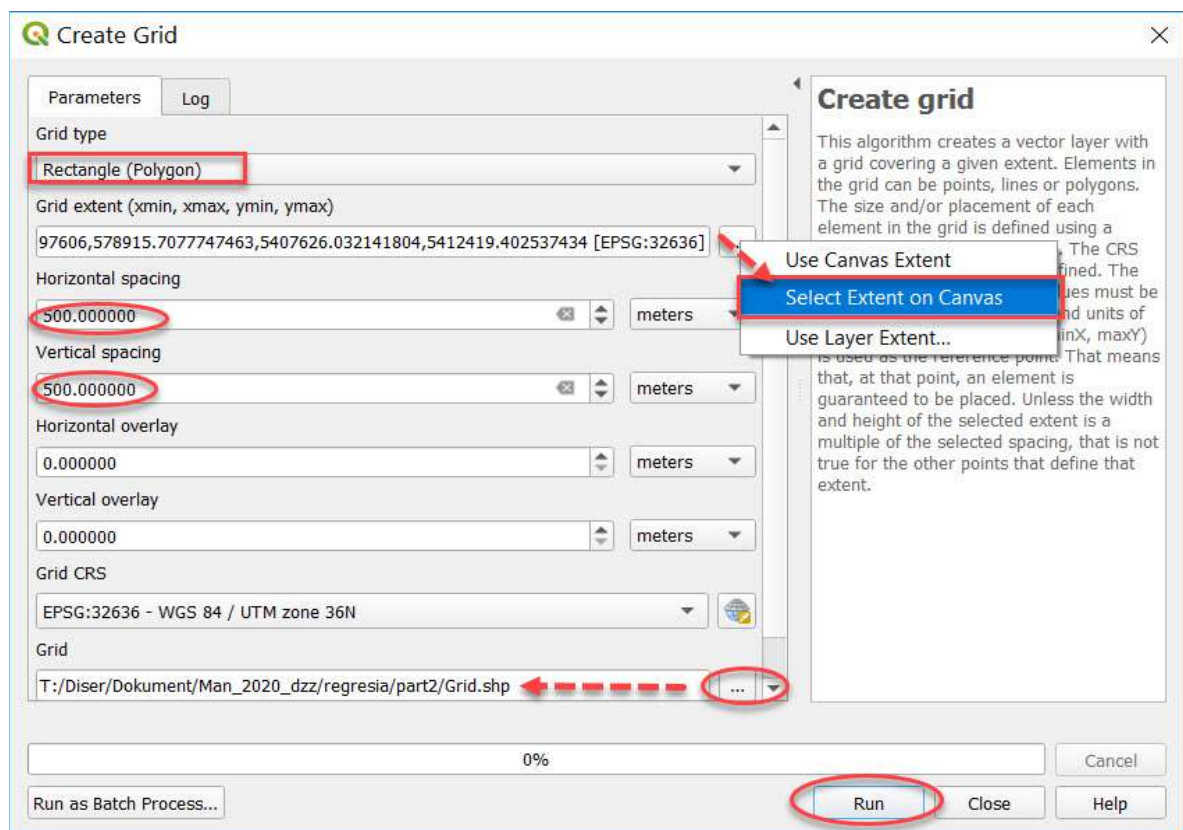
1. Create a shapefile (polygon grid) and select the area of interest within the Kamianske Reservoir.

To perform this Task, we need five basic raster images obtained in our previous Task, namely: the surface temperatures of the reservoir in two bands: B10 and B11, vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI). First, download them from the “NITK_RSGIS” folder created with the **RS&GIS** plugin to a new QGIS project.

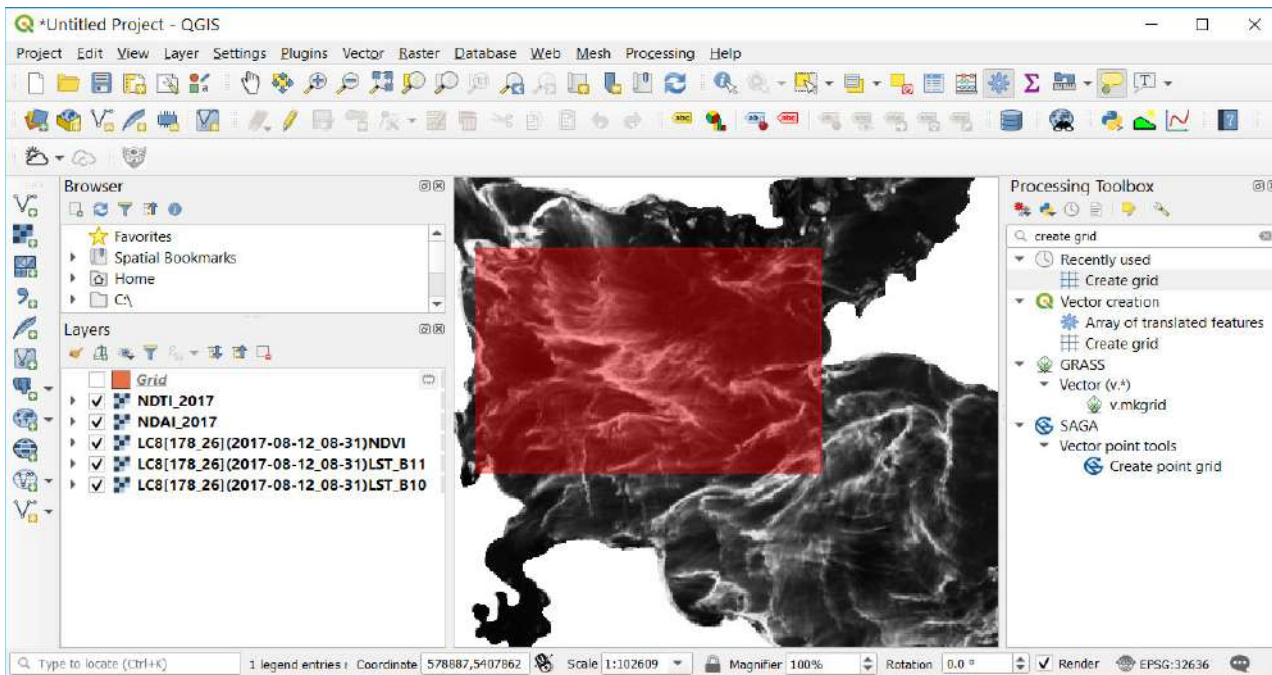
Next, create a shapefile (polygonal vector with a grid), which attribute table will be used to extrapolate the data from each cell of the polygon of five input raster images. To create a shapefile, use the **Create grid** tool. First, select the **Toolbox** service from the menu bar under **Processing**. In the **Processing Toolbox** search field, type “create grid” and select it from the drop-down list.



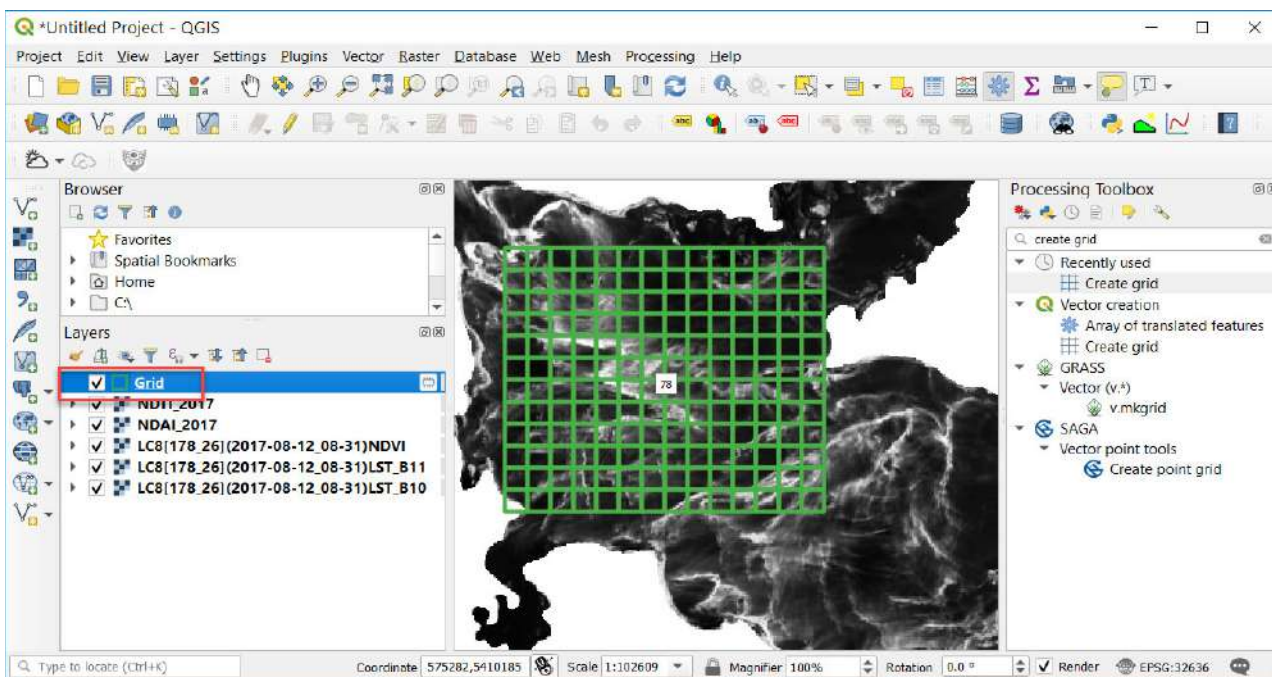
In the *Create Grid* dialog, specify *Rectangle (Polygon)* as the *Grid type*, and pick *Select Extent on Canvas* from the drop-down list in the *Grid extent (Xmin, Ymin, Xmax, Ymax)* field. You will see that the dialog box disappears, and you have to select the desired size of the area of interest on the Reservoir's map extent to be covered by the grid by pressing and holding down the left mouse button. We recommend selecting a rectangular extent at the widest part of the Reservoir to avoid any empty areas with zero values. Specify the width and height of the polygonal grid cell in the *Horizontal spacing* and *Vertical spacing* fields by entering a value of 500. In addition, configure the save options for the shapefile you want to save to your PC, name it "Grid.shp" and click the *Save to File* button.



Configuring the *Create Grid* tool



The red color indicates the area selected in the *Select Extent on Canvas* field that will be covered with a grid.

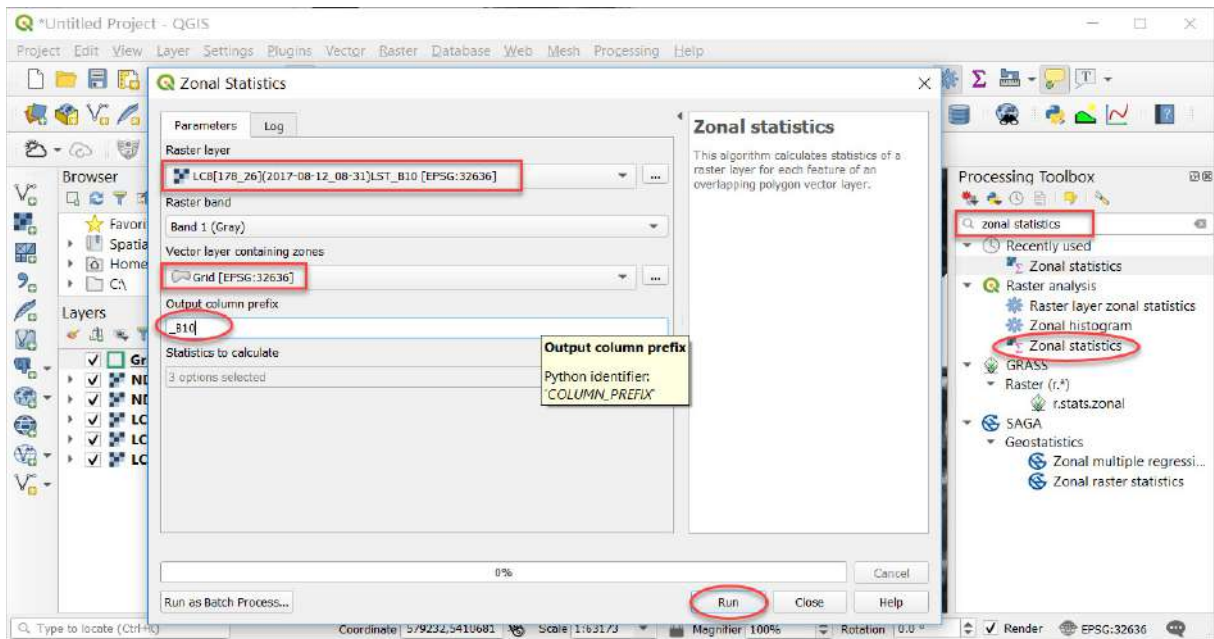


As a result, you will get a grid layer entitled “*Grid*”.

2. Extrapolate data of thematic raster layers to the attribute table of the shp-file (grid of rectangle polygons).

To extrapolate the data of all thematic raster layers (surface temperatures in two bands, B10 and B11, vegetation index (NDVI), algae index (NDAI), and turbidity index (NDTI)) to the attribute table of the created polygonal grid layer, use the *Zonal Statistics* tool. This tool calculates statistics for the pixels of an input raster within certain zones/polygons. First, go to the *Toolbox* that is located in the top menu under *Processing*. In the *Processing Toolbox* dialog, enter “zonal statistics” in the search field and select it from the drop-down list.

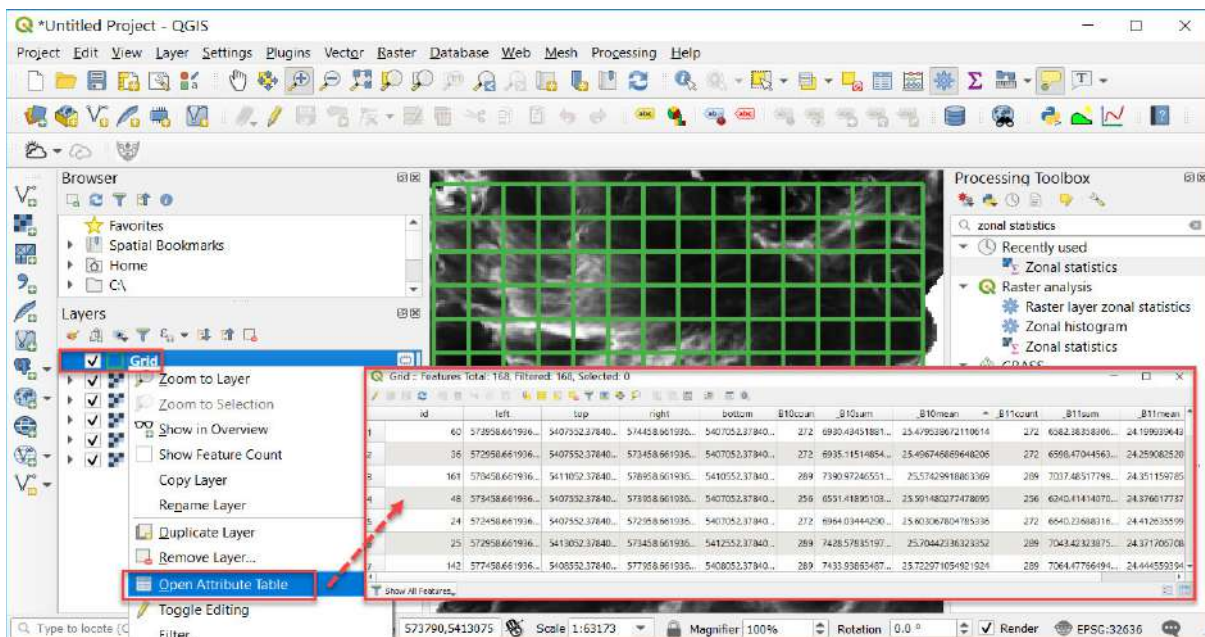
In the **Parameters** dialog, select the first thematic raster layer that is opened in your project from the list under the **Raster layer**, e.g. the thermal layer entitled *LC8[178_26](2017-08-12_08-31)LST_B10*, pick *Grid* from the drop-down list under the **Vector layer containing zone**, and indicate the name of the input thematic raster layer in the **Output column prefix** box, i.e. in this case – the thermal band B10 (type “B10”), and click the **Run** button.



You should repeat the described above procedure with the **Zonal Statistics** tool for each thematic raster layer (in our case, there are five layers). This can be done without closing the tool's dialog box: simply specify each raster in the **Raster layer** field and indicate its name in the **Output column prefix** field to create the appropriate attributes.

As a result, you will get the shapefile containing a “Grid” table of statistical attributes for each cell of all five thematic layers. To view the table, select **Open Attribute Table**. The table contains the following columns for each of our raster layers:

- **Count:** shows the number of pixels;
- **Sum:** summarizes the value of pixels;
- **Mean:** shows the average value of pixels.



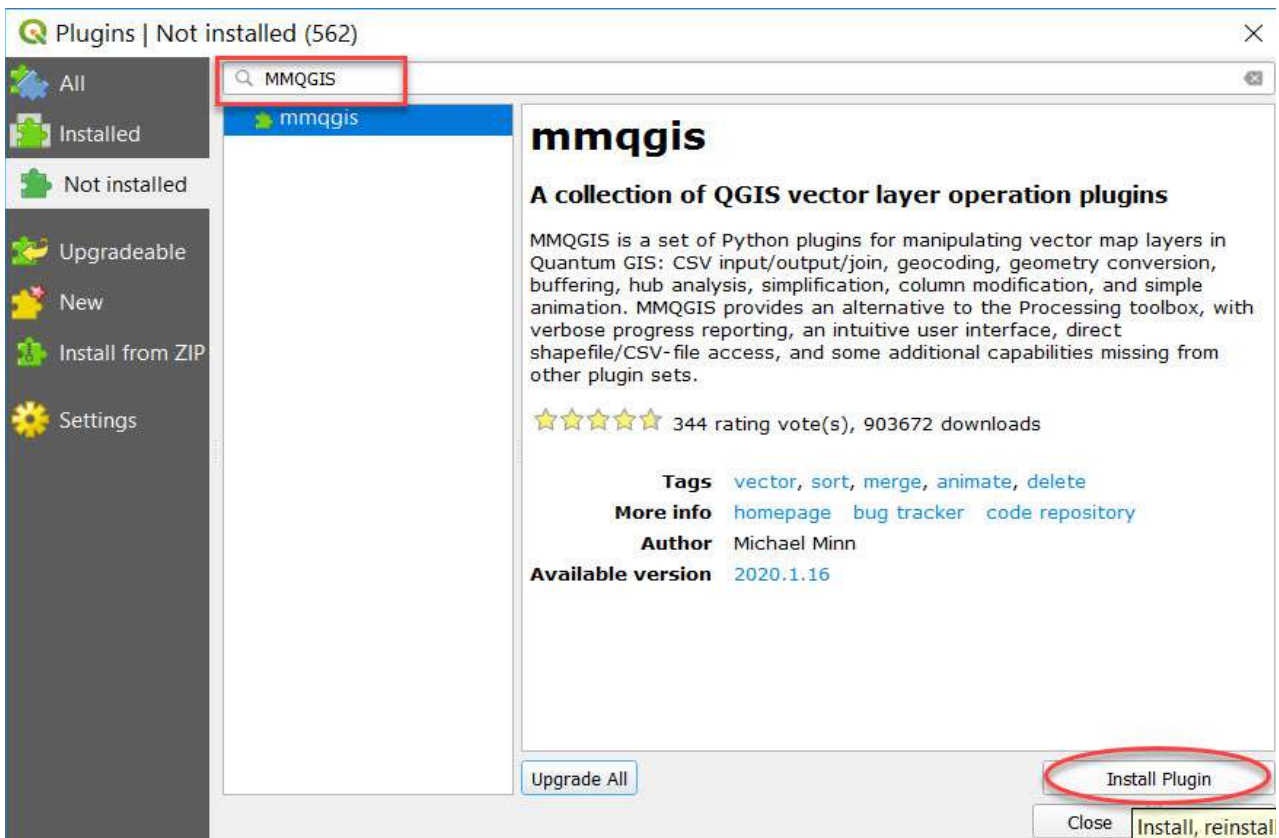
? Check yourself

Take a closer look at the resulting attribute table and try to answer the question: What is the total area of the Reservoir selected and covered by the grid if one grid cell is 500x500 meters?

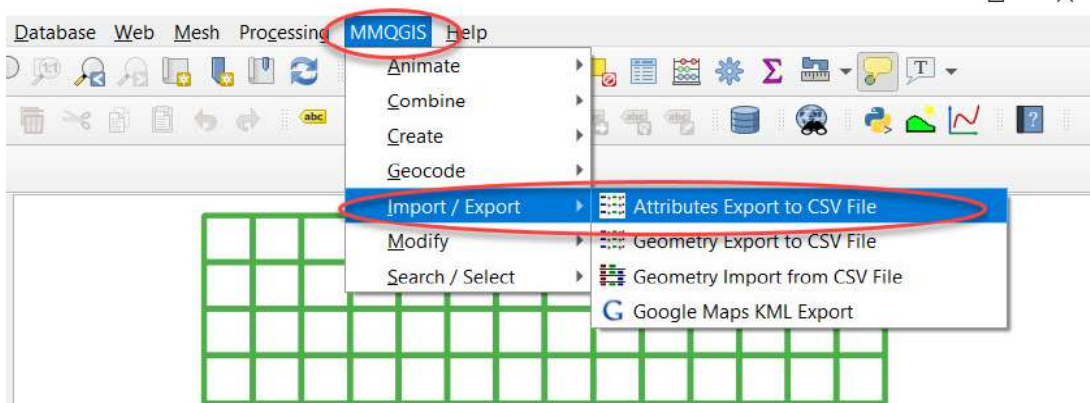
3. Export the attribute table with the values of thematic raster layers from the shp-file to the CSV-file.

The next step is to save the resulting attribute table values from the shapefile to Excel using the **MMQGIS** plugin.

To install this plugin, select **Plugins - Manage and Install Plugins ...** from the top menu and switch to the **Not installed** tab. Start typing **MMQGIS** in the search field and the plugin will automatically appear in the list at the bottom of the window. Select it from the list by left-clicking, and brief information about the plugin will pop up; read this information, and click the **Install Plugin** button, and close the dialog. Once installed, the plugin will appear in the **Installed** tab and its name will be displayed in the toolbar.



We will use the **Attributes Export to CSV File** tool of this plugin that saves the attributes from a grid layer to a CSV file, which can be later viewed or edited in Excel. Select **MMQGIS → Import / Export → Attributes Export to CSV File** from the toolbar.



In the *Export Attributes* dialog, specify the following:

Input Layer: the name of the map layer that contains the attributes for export – “Grid”;

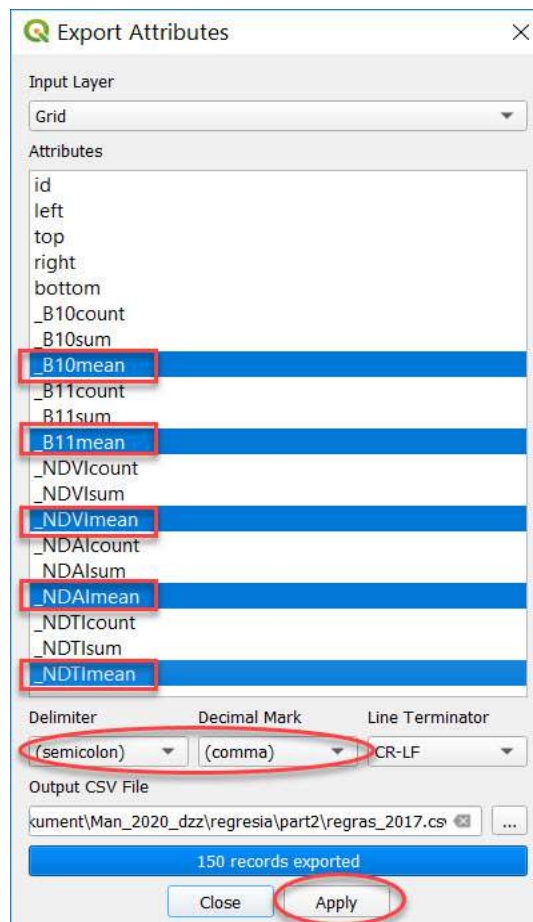
Attributes: you can pick several attributes from the multiple selection list; hold down the CTRL key and select several fields, namely: “_B10mean”, “_B11mean”, “_NDVImean”, “_NDAImean”, “_NDTImean”;

Delimiter: data delimiter for the output file field – *semicolon*;

Decimal Mark: the decimal character of the output file – *comma*;

Line Terminator: terminator symbol of the output file – *CR-LF (Windows)*;

Output CSV File: the name of the output file, for example: “regres_2017.csv”.



This was our final task in QGIS, which output is a statistical table of five different remotely sensed parameters of the Kamianske Reservoir determined based on the Landsat 8 satellite image taken on August 12, 2017.

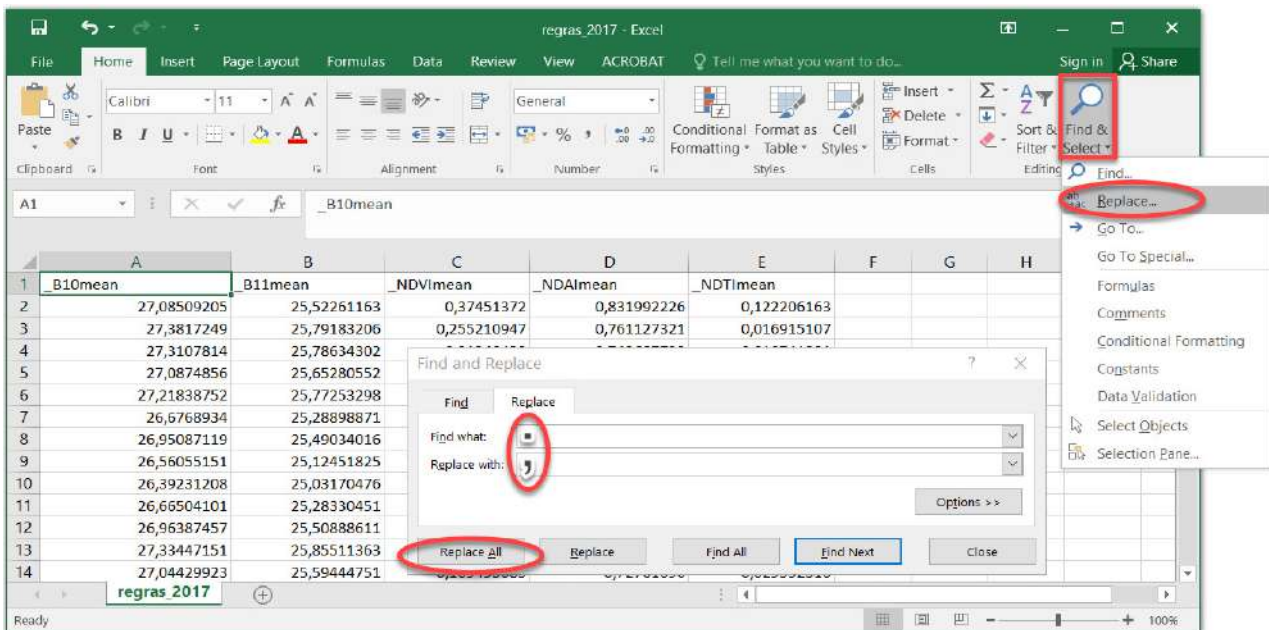
4. Perform regression analysis in Microsoft Excel.

We will proceed now to the data analysis with the Excel program.

4.1. Open the file of statistics saved in the previous step, “regres_2017.csv”.

✔ **Important!** *If the statistical information is not displayed on your device correctly (automatic breakdown into five columns (different remotely sensed variables) is missing), use the **Text to Columns** tool from the **Data** tab of the Excel menu. Select the first column and choose the tab character from the tool's dialog box (comma, point, space, semicolon, etc.) to break down the information in the table columns. However, it may be that the statistical information is displayed correctly, in which case you just need to save the resulting file.*

4.2. Replace all points in the data table with commas for correct visualization of data: switch to the **Home** tab, go to **Find & Select** and click the **Replace** tool. Indicate a point in the **Find what** box and a comma in the **Replace with** field under **Find and Replace**, and click the **Replace All** button.



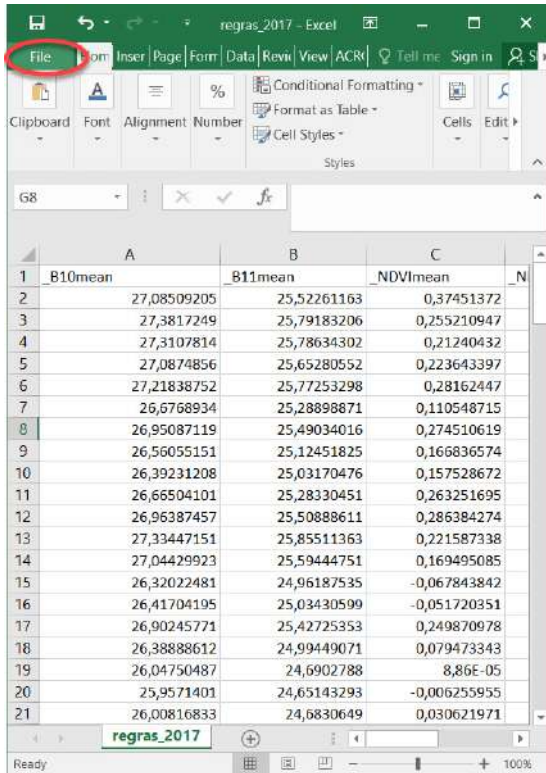
Replacing points with commas in Microsoft Excel

4.3. Activate **Data Analysis**.

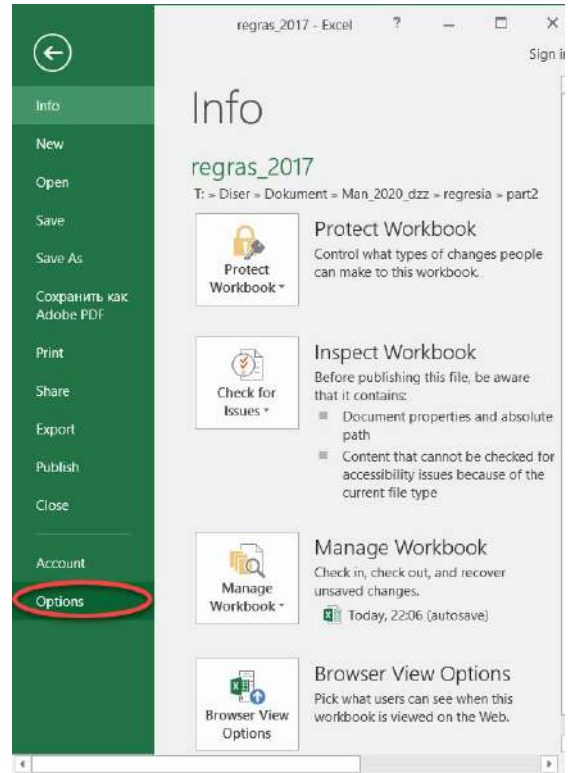
To perform the regression analysis, you must first turn on the **Data Analysis** function. The tools required for the analysis will appear in the **Excel** menu upon activation of this function.

Therefore, first, switch to the **Options** tab under **File**, and go to the **Add-Ins** tab. At the bottom of the window, select **Excel Add-ins** from the **Manage** box (in the cases where another option is specified in the **Manage** box), and click the **Go** button.

In the new Excel add-ins window, tick the box next to the **Analysis ToolPak** add-in, and click **Ok**.

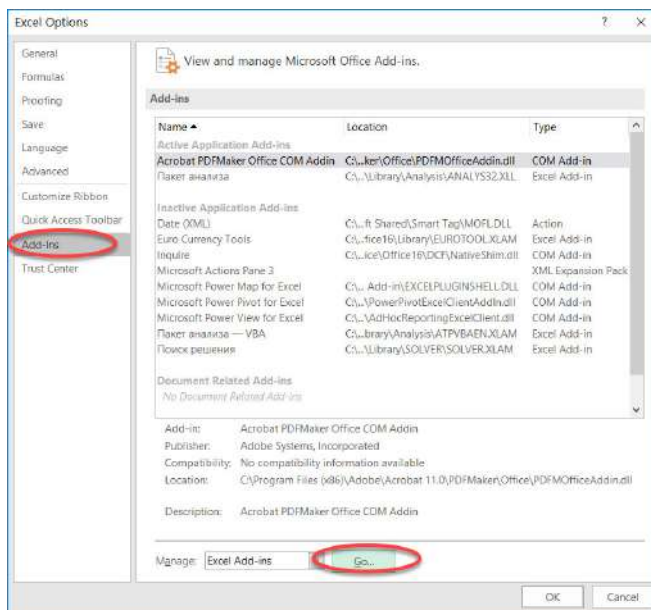


“regres_2017.csv” statistics file opened in Excel

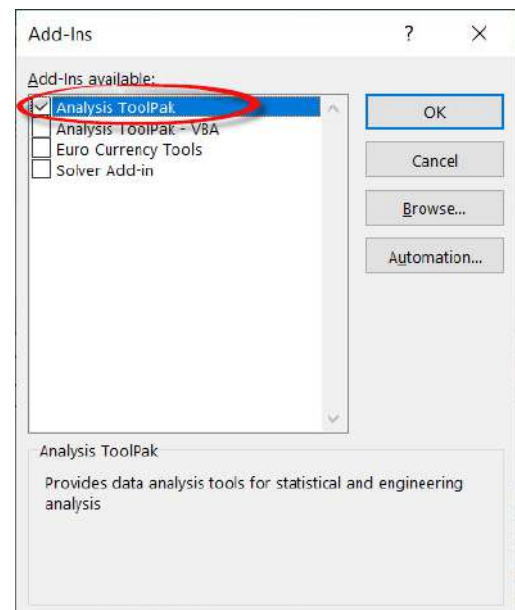


Adjustment of settings

Path for activation of the **Data Analysis** function in the Microsoft Excel program (for regression analysis)



Path to Excel add-ins



Selecting required add-in

Підключення пакета **Data Analysis** (Аналіз даних) для визначення регресійного аналізу в програмі Microsoft Excel компанії «Microsoft»

Activation of the **Data Analysis** function for the regression analysis with the Microsoft Excel program.

Once the above-mentioned steps are completed, a new button, **Data Analysis**, will appear in the **Analysis** tab under **Data**.

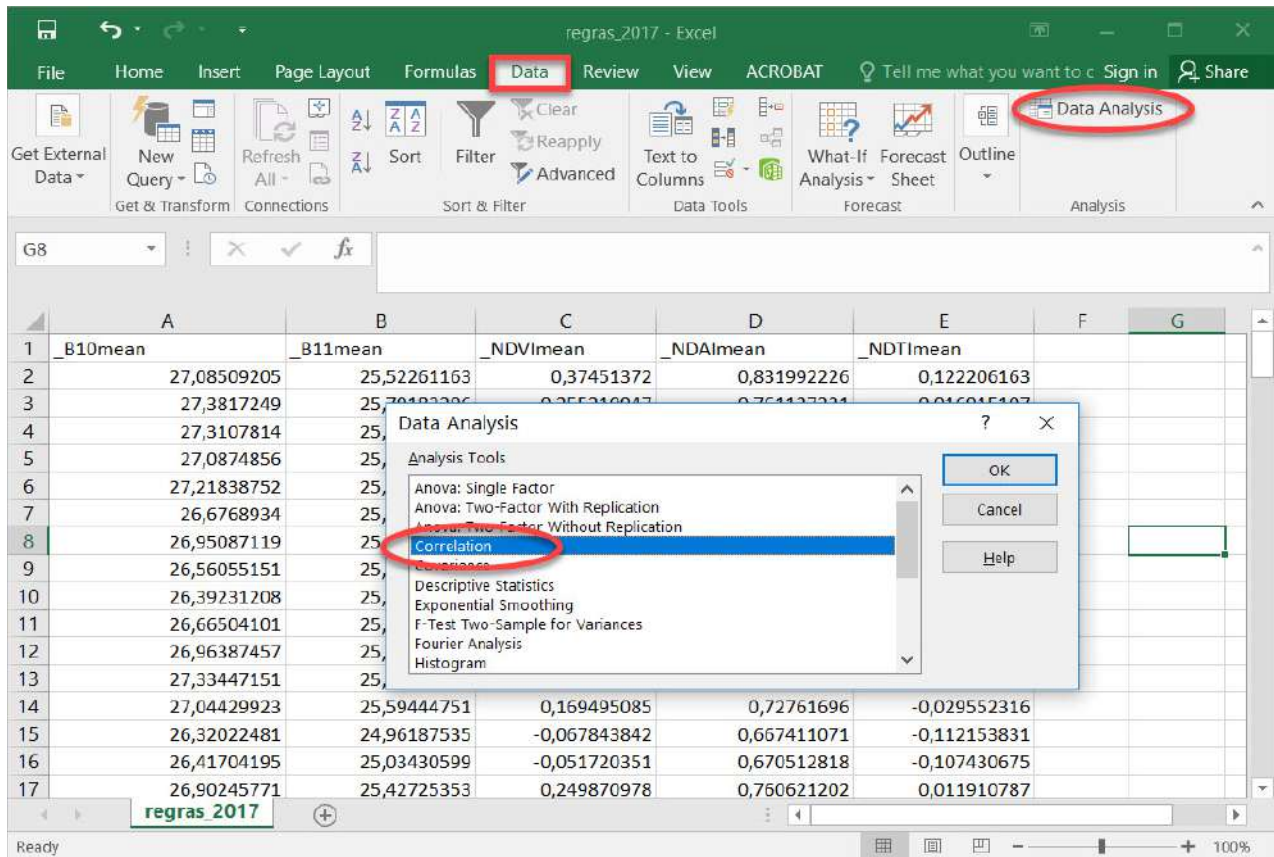
4.4. We will proceed now to the analysis of the outputs starting with correlation analysis.

Correlation analysis is a statistical method used to measure the relationship between random variables in one or two samples.

A correlation means that an increase in one variable is associated with an increase (positive correlation) or decrease (negative correlation) in another variable. Correlation analysis makes it possible to use the value of one variable to predict the value of another.

The correlation coefficient is denoted by r and represented as a value between +1 to -1.

To perform the correlation analysis, go to the **Data** tab and click the **Data Analysis** button. You will see a list of different data analysis options. Select **Correlation** from the list, and click **Ok**.

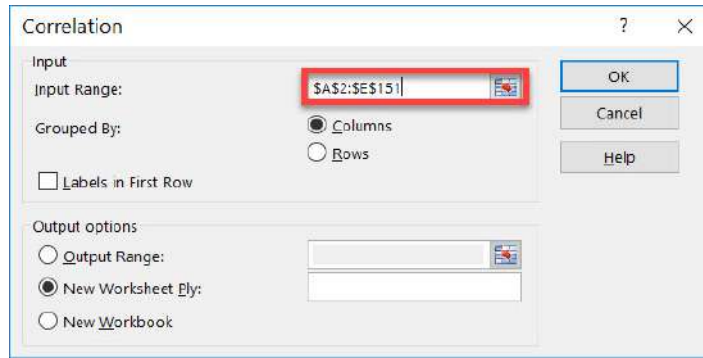


Correlation analysis with Microsoft Excel

As a result, the **Correlation** dialog will appear. Specify the interval for all columns included in the analysis (without headings) in the **Input Range** field. In our case, these are the datasets from the following columns: **_B10mean**, **_B11mean**, **_NDVImean**, **_NDAlmean**, **_NDTImean**.

The **Grouped By** default setting is **Columns** – leave it unchanged because our datasets are grouped into five columns.

The **Output options** default setting is **New Worksheet Ply**, i.e. the data will be displayed on a new worksheet. Now that you have configured **Correlation**, click the **Ok** button.



Defining data for correlation analysis with Microsoft Excel

On completion, an output matrix table will appear in a new Excel sheet, which displays the Pearson's correlation coefficients for five remotely sensed parameters of the Reservoir, namely:

Column 1 represents the values of *B10mean*, i.e. the Reservoir's surface temperatures in band 10.

Column 2 shows the values of *B11mean*, i.e. the Reservoir's surface temperatures in band 11.

Column 3 shows the values of *NDVImean*, i.e. vegetation index.

Column 4 represents the values of *NDAImean*, i.e. algae index.

Column 5 shows the values of *NDTImean*, i.e. the turbidity index.

Correlation is used to determine which parameters impact each other, while regression determines the nature of the impact. The correlation coefficient characterizes the strength of the relationship between two variables. For example, $R^2 = 0.76 = 76\%$ - coefficient of determination that shows the proportion of variance in the dependent variable that can be explained by the independent variable.

✔ **Important!** *Our main task is to determine the impact of temperature on water blooms.*

	Column 1	Column 2	Column 3	Column 4	Column 5
Column 1	1				
Column 2	0,998593	1			
Column 3	0,725505	0,72251	1		
Column 4	0,740612	0,738194	0,976651	1	
Column 5	-0,66295	-0,66205	-0,94473	-0,91759	1

The Pearson's correlation coefficients for five parameters displayed in Microsoft Excel

? Запитання для перевірки

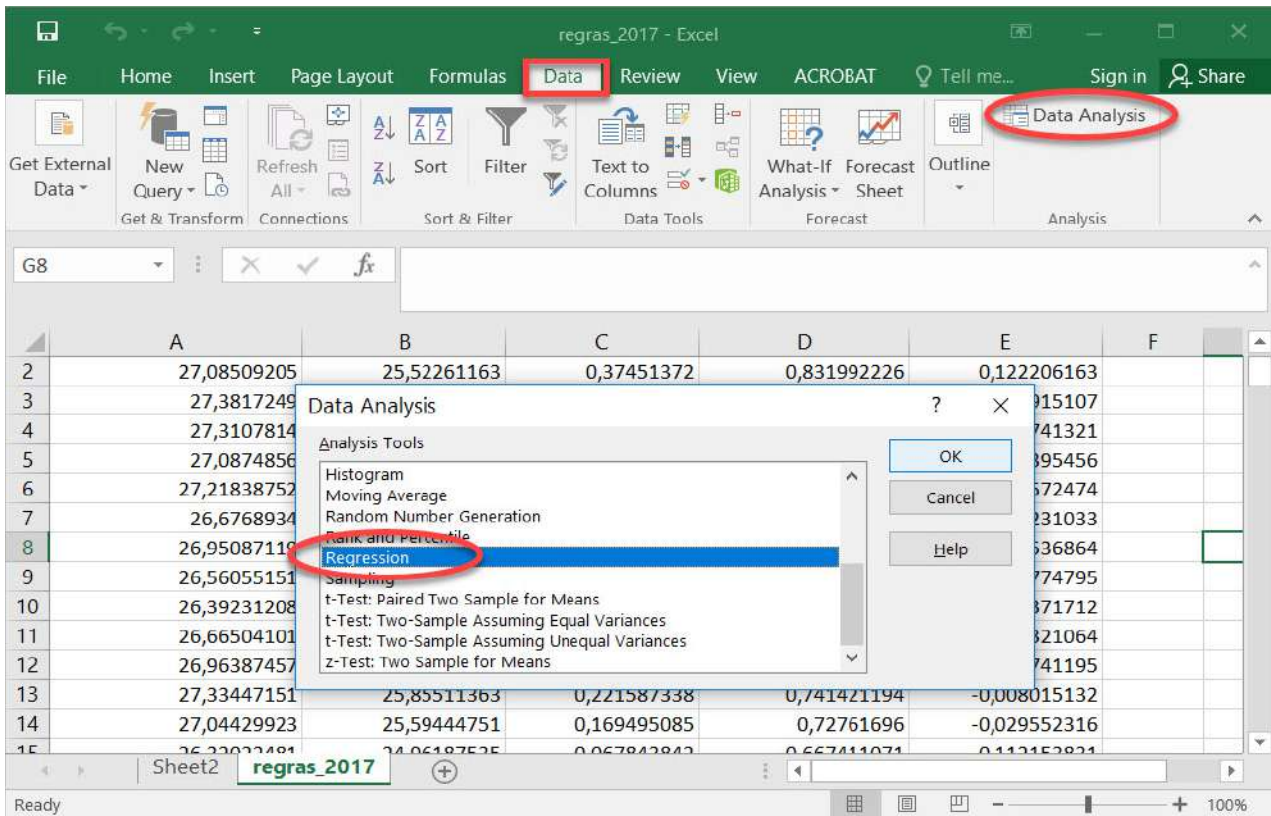
Take a closer look at the resulting correlation matrix and answer the question: What index (vegetation, algae or turbidity) has the highest correlation with the thermal band 10?

4.5. We will perform now a regression analysis of several of the most highly correlated parameters in pairs.

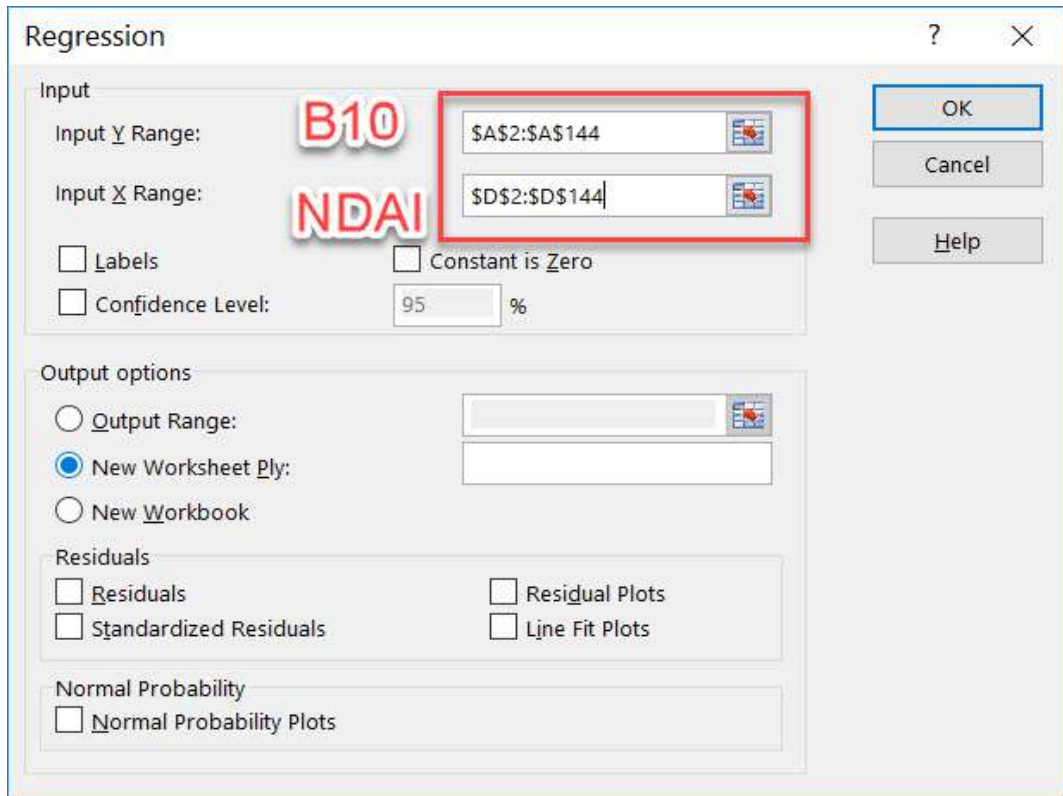
Go to the **Data Analysis** tab and select **Regression** from the drop-down list, and click **Ok**.

In the **Regression** dialog that opens, we need to set the values of **Input Y Range** and **Input X Range**. All other settings can be left unchanged (default).

In the **Input Y Range** field, indicate the address for the range of cells that contain the variables under study. In our case, these will be the cells of the column “*temperature – B10*”. In the **Input X Range** field, specify the address for the range of cells that contain data of the factor, which impact we want to determine, for example, cells of column 5, “*NDAP*” and click **Ok**.



Data analysis interface for the performance of regression analysis



Settings in the Regression dialog of the Microsoft Excel program

Please note that our main task is to determine the impact of temperatures on water blooms. The temperature datasets are provided by two bands, B10 and B11, and algal blooms can be assessed based on three indices (vegetation, algae, and turbidity). Therefore, it is not reasonable to intercompare two temperatures or three water blooms indices. We will compare one pair first: temperature “B10” and algae index “NDAI”. After that, using the **Regression** tool, we will compare one-by-one the following pairs: temperature “B10” and turbidity index “NDTI”, temperature “B10” and vegetation index.

4.6. Reviewing the results of regression analysis

The tabulated results of the regression analysis measuring the impact, for example, of the temperature on the turbidity, are displayed on a new sheet according to the settings.

One of the main variables is **R Square**. It indicates the quality of the model. In our case, this coefficient equals 0.54, or about 54%. The higher the **coefficient of determination (R²)**, the better the model fits the data. If the R² value is above 0.8 this model is considered *Good*, if the R² is below 0.5 such model is considered to have a weak predictive accuracy (the output can hardly be considered reasonable). In our example, the model has *Moderate* accuracy.

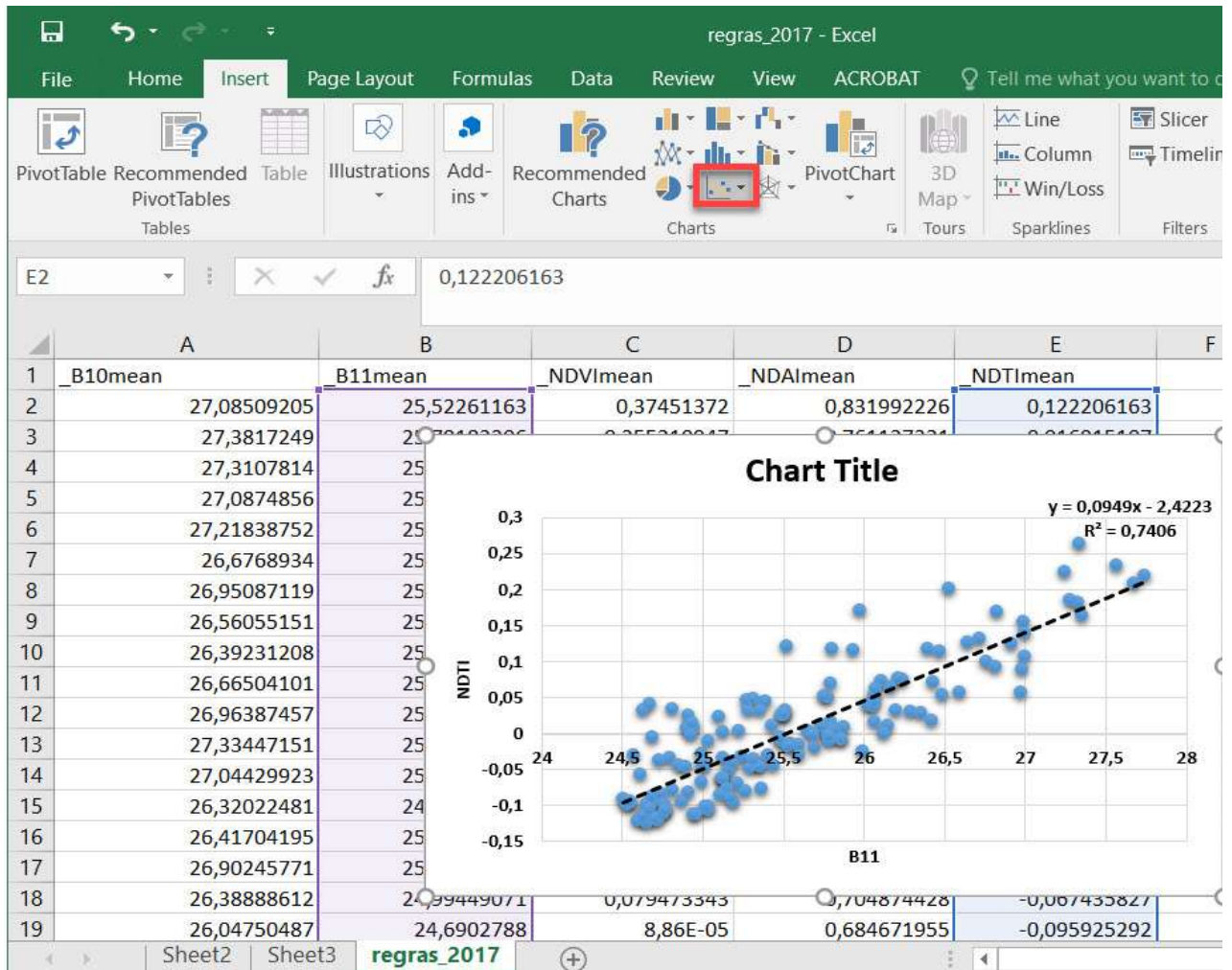
Another important variable located at the intersection of the **X Variable 1** and **Coefficients** shows the level of dependence of Y on X. In our case, this is the level of water turbidity dependence on temperature. The coefficient of 10.16 is considered to be a sufficiently high indicator of dependence.

	A	B	C	D	E	F	G	H	I	J
1	SUMMARY OUTPUT									
2										
3	<i>Regression Statistics</i>									
4	Multiple R	0,740612122								
5	R Square	0,548506315								
6	Adjusted R Squa	0,545304233								
7	Standard Error	0,671233265								
8	Observations	143								
9										
10	<i>ANOVA</i>									
11		<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>				
12	Regression	1	77,17844205	77,17844205	171,2967271	4,05E-26				
13	Residual	141	63,52812754	0,450554096						
14	Total	142	140,7065696							
15										
16		<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95,0%</i>	<i>Upper 95,0%</i>	
17	Intercept	19,24166224	0,582209189	33,04939634	2,83834E-68	18,09067	20,39265	18,09067	20,39265	
18	X Variable 1	10,16179183	0,776418297	13,08803756	4,04993E-26	8,626866	11,69672	8,626866	11,69672	

The results of regression analysis identifying the relationship between temperature and NDAI

As can be seen from the examples given above, it is quite easy to make the regression table in Microsoft Excel. Further processing and understanding outputs, however, requires an in-depth study of regression and correlation analyses concepts. Therefore, we recommend that you obtain a good knowledge of these methods that are essential for numerous scientific studies.

To complete the analysis, you can also build a chart scatter for the two most dependent features in Excel using the *Insert* → *Chart Scatter* tools, and select an express layout to display a trend line and an equation for the trend line with a coefficient of determination (R²).



Results of regression analysis represented as a chart scatter for the relationship between temperature and NDAI

Check yourself

Perform a regression analysis to measure the dependence of the vegetation index on the turbidity index and specify the coefficient of determination (R^2).

Justify the strength of the relationship. What has caused it?

Scan the QR-code below to watch a video tutorial on the performance of this Task.



List of Illustrations

Fig. 1, Fig. 46–51, Fig. 56, Fig. 57, Fig. 60–72, Fig. 75–86, Fig. 93–111, Fig. 113–115, Fig. 119–132, Fig. 134–139, Fig. 149–165, Fig. 170–180, Fig. 188–233, Fig. 243–524, Fig. 264–301 – the interface of Quantum GIS, an open source software.

The electronic resource for downloading: <https://www.qgis.org/ru/site/forusers/download.html>

Fig. 2, Fig. 3, Fig. 4, Fig. 52–55, Fig. 87–91, Fig. 166–169, Fig. 181–187, Fig. 234–238, Fig. 240–242, Fig. 255, Fig. 256, Fig. 261–263 – the interface of EO Browser, a web platform for cloud computing of remote sensing data operating under the European Space Agency’s Copernicus programme.

The electronic resource for access: <https://apps.sentinel-hub.com/eo-browser/>

Fig. 5–23, Fig. 25–45 – the interface of a web platform for cloud computing of remote sensing data operating under the NASA – Earth Science Data Systems Program.







The electronic resource for access: <https://giovanni.gsfc.nasa.gov/giovanni/>

Fig. 312–322 – Google Earth software interface.

The electronic resource for access: <https://www.google.com.ua/intl/ru/earth/>

Annex

The Appearance of Different Types of the Earth's Surface Available in Ukraine

Surface Type	Photo	Appearance on Satellite Image
<p>Deciduous Forests (change their color depending on the season)</p>		
View of the deciduous forest in the Carpathian Mountains		
<p>Coniferous Forests (stay green all winter)</p>		
View of the coniferous forest in the Carpathian Mountains		
<p>Mixed-Species Forests (in winter, it is possible to differentiate easily coniferous trees from deciduous ones)</p>		
View of the mixed forest in the Carpathian Mountains		

Thin (Sparse) Forests
(forests in which the trees do not form a closed canopy)



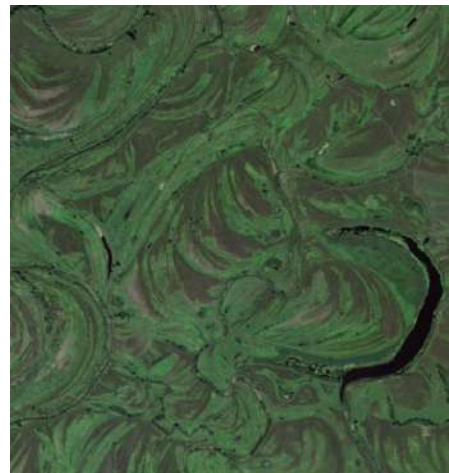
View of the sparse oak forest near Kyiv

Shrubs
(woody plants less than 2 m tall that do not provide deep shade)



View of the shrubs on the left bank of the Kaniv Reservoir

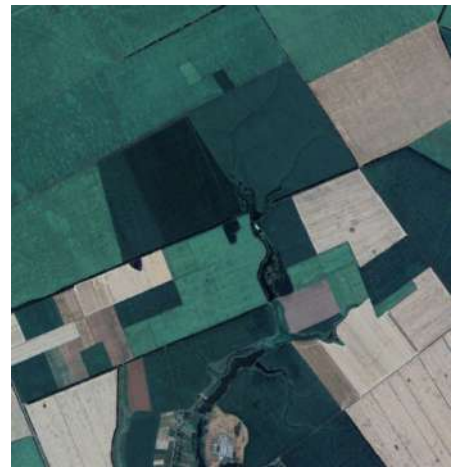
Meadows, Pastures
(are characterized by the intense green color and smooth shape)



View of the meadows in the Desna River floodplain

Fields

(are characterized by geometric rectangular shapes and varying colors depending on the season and crop rotation)



View of the fields in Boryspil District of Kyiv Oblast

Sands

(are characterized by intense, bright color against a background of vegetation)



View of the sand spits at the Desna River

Settlements

(are characterized by a uniform transport network that can be clearly seen)



View of Vyshhorod

Bodies of Water
(rivers have a tortuous shape and appear deep blue)



View of the Dniester River

Swamps
(in winter, they appear light brown with wet spots)



View of wetlands at the upper Kyiv Reservoir

List of Tools

Add Item
Add Polygon Feature
Additional no data value
Atmospheric Chemistry
Back to Data Selection
BackSpace
Datasets
Data source
Analytical
Attribute Toolbar
Categorized
Change Color
Change Opacity
Classify
Color ramp
Continuous
Contrast enhancement
Discrete
Equal interval
Event log window
Extra derived outputs
Export color map to file
False color
False Color Composite (FCC)
Frame
Geoprocessing Tools
Identify
Identify Features
Interpolation
Interpretation
Invert Color ramp
Layers
Layer Properties
Linear
Load color map to file
Manage and Instal Plugins...
Map Canvas Extent
Max. cloud coverage
Measure
Measure Area
Measure Line
Measurements
Merge
Merged
Miscellaneous
Mode
Monthly and Seasonal Averages
Multiple selection

New shapefile layer
New Spatial Bookmarks
No enhancement
Ok
Opacity
Open Attribute Table
Open Data Source Manager
Operators
Options
Output column prefix
Plot Data
Print Layout
Processing
Processing Toolbox
Project
Properties
SpatialSwipe Bookmarks
Symbology
Quantile
Raster
Raster Bands
Raster Calculator
Raster calculator expression
Rename layer
Render type
Re-Plot
Results Viewer
Run
Select Date Range (UTC)
Select Date Range
Select extent on canvas
Select Plot
Select Region (Bounding Box or Shape)
Select Seasonal Dates
Select variable
Settings
Single labels
Singleband pseudocolor
Scatter, Area Averaged (Static)
Spectral
Swipe
Time Series Area-Averaged
Time-Averaged Map
Toggle Editing
Toolbars
Toolbox
True color
True Color Composite (TCC)
Value
Vector layer containing zone
View
Zonal statistics

Навчальне видання

Бабійчук Світлана Миколаївна

Кучма Тетяна Леонідівна

Юрків Лілія Ярославівна

Томченко Ольга Володимирівна

Робочий зошит

«Аналіз космічних знімків у геоінформаційних системах»

Частина 2

Коректура *І. В. Браташук*

Верстання *О. А. Жупанська*

Дизайн обкладинки *Б. Л. Лісовський*

Формат 60×84 1/8. Папір офс. 80 г/м².

Друк цифровий. Ум. друк. арк. 24,49.

Наклад 300 прим.

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ДК № 6999 від 04.12.2019

Робочий зошит є практичним доповненням до навчально-методичного посібника «Дистанційне зондування Землі: аналіз космічних знімків у геоінформаційних системах» (С. О. Довгий, С. М. Бабійчук, Т. Л. Кучма, О. В. Томченко, Л. Я. Юрків). Практичні роботи, що містяться в робочому зошиті, укладені з метою познайомити читача з можливостями застосування відкритого програмного забезпечення – Quantum GIS у дослідженнях, зокрема кліматичних, гідрологічних, лісових, сільськогосподарських тощо. Робочий зошит може використовуватися методистами і керівниками секцій системи Малої академії наук України, вчителями й учнями шкіл, ліцеїв, гімназій в освітній та дослідницькій діяльності, а також усіма, хто прагне самостійно опанувати основи дистанційного зондування Землі.

