

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

Kyiv
2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL ACADEMY OF SCIENCES OF UKRAINE
NATIONAL CENTER “JUNIOR ACADEMY OF SCIENCES OF UKRAINE”

**S. O. Dovgyi, S. M. Babiichuk,
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Guidance Manual

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

R42

Authors:

S. O. Dovgyi – President of the Junior Academy of Sciences of Ukraine, Dr. Sci. in Physics and Mathematics, Professor, Member of the National Academy of Sciences of Ukraine, Member of the National Academy of Educational Sciences of Ukraine;

S. M. Babiichuk – Head of Geographic Information Systems and Remote Sensing Laboratory at the National Center “Junior Academy of Sciences of Ukraine”, Ph.D. in Pedagogy;

T. L. Kuchma – Senior Lecturer at the National University of Kyiv-Mohyla Academy, Research Fellow at the Institute of Agroecology and Environmental Management of the National Academy of Sciences of Ukraine, Teaching Methodology Expert at the National Center “Junior Academy of Sciences of Ukraine”, Ph.D. in Agriculture;

O. V. Tomchenko – Research Fellow at the State Institution “Scientific Centre for Aerospace Research of the Earth of the Institute of Geological Sciences of the NAS of Ukraine”, Teaching Methodology Expert at the National Center “Junior Academy of Sciences of Ukraine”, Ph.D. in Engineering;

L. Ya. Yurkiv – Coordinator of International Projects at the Geographic Information Systems and Remote Sensing Laboratory, Teaching Methodology Expert at the National Center “Junior Academy of Sciences of Ukraine”

Translation from Ukrainian:

O. L. Savychenko, O. S. Oleshko

Editors:

L. D. Hrekov – Senior Research Fellow at the Institute of Telecommunications and Global Information Space of the NAS of Ukraine, D.Sc. in Engineering;

R. Hilbert – Doctor of Natural Science, GIS Expert at the Technical University in Zvolen (Slovakia)

*Recommended by the Scientific and Methodological Council of
the National Center “Junior Academy of Sciences of Ukraine”*

(Minutes No. 2 dated June 16, 2021)

- Remote Sensing: Analysis of Satellite Images in Geographic Information Systems :**
R42 Guidance Manual / *S. O. Dovgyi, S. M. Babiichuk, T. L. Kuchma et al.* – Kyiv : National Center “Junior Academy of Sciences of Ukraine”, 2022. – 264 p.

ISBN 978-617-7945-48-1

This Guidance Manual discusses research applications of geographic information systems and remote sensing, describes the main characteristics and resources for downloading satellite images, provides examples of visualization and pre-processing of satellite imagery bands in ArcGIS and QGIS geographic information systems. The Manual also provides insight into interpretation (decoding) and analysis of satellite images in geographic information systems.

This Guidance Manual may be used by teaching methodology experts and educators at the Junior Academy of Sciences of Ukraine, teachers and students of higher educational institutions, and educators and students who get science-oriented education at specialized educational institutions, as well as by anyone seeking to master the fundamentals of remote sensing and geographic information systems.

UDC 528.8

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“Junior Academy of Sciences of Ukraine”, 2022

ISBN 978-617-7945-48-1

LIST OF ABBREVIATIONS AND EXPLANATION OF SYMBOLS

GIS	–	Geographic Information System
RS	–	Remote Sensing of the Earth
EMR	–	Electromagnetic Radiation
ESA	–	European Space Agency
IR	–	Infrared
NASA	–	National Aeronautics and Space Administration
SW	–	Software
UV	–	Ultraviolet
DEM	–	Digital Elevation Model
API	–	Application Programming Interface
ESRI	–	Environmental Systems Research Institute
GMES	–	Global Monitoring for Environment and Security
MGRS	–	Military Grid Reference System
NVDI	–	Normalized Difference Vegetation Index
OSM	–	Open Street Map
SRTM	–	Shuttle Radar Topography Mission
USGS	–	United States Geological Survey

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INTRODUCTION

This Guidance Manual continues the discussion of and expands upon an earlier publication, *Fundamentals of Remote Sensing: History and Practice*. The book provides a guide on how to download, process, visualize, interpret, and analyze satellite images.

Satellite imagery contains large datasets, which can be derived and analyzed using the specialized software (SW) tools – GIS (geographic information systems). Today’s GIS software encompasses a broad range of proprietary and open-source applications. In this Manual, we will use mostly ArcGIS (commercial) and QGIS (open source) software.

ArcGIS is a family of commercial GIS software products by an American company ESRI (founder Jack Dangermond), which started developing GIS programs in the 1970s. In January 1997, ESRI decided to upgrade its GIS software platform, creating a single integrated software architecture – ArcGIS. In late 1999, ESRI released ArcMap 8.0 which ran on the Microsoft Windows operating system. The company regularly improves and updates its ArcGIS suite. As of mid-2020, the latest updated version is ArcGIS 10.8.

Quantum GIS (short name QGIS) is one of the most popular, free (under GNU GPL license), functional cross-platform GIS application, which is dynamically developing and used internationally in the academic and professional environments. Gary Sherman created Quantum GIS in 2002, and since then many developers from around the world have been working on its improvement. QGIS is maintained by an active group of volunteers who regularly update, fix bugs, and create new modules for QGIS. Currently, QGIS may be used in more than 40 languages (including Mandarin and Esperanto).

It is hard to imagine modern research in natural sciences without the use of remote sensing data (RS), as well as without their processing in GIS. Over the last few years, it has become possible not only to visualize features studied in dynamics but also to acquire new information from data analysis.

There are plenty of Internet resources (commercial and non-commercial) available now, which allow downloading satellite images of any location on our planet. This Guidance Manual has been developed based on the experience of the GIS and Remote Sensing Laboratory of the Copernicus Academy at the National Center “Junior Academy of Sciences of Ukraine”. In its educational activities, the Laboratory uses satellite images collected by the European Space Agency within the framework of the Copernicus programme.

Copernicus is the European Union’s Earth observation programme (previously known as GMES – Global Monitoring for Environment and Security). The programme offers information services based on the Earth observation satellite system,

Sentinel, which includes five families of satellites: Sentinel 1 – designed to obtain radar data, Sentinel 2 and Sentinel 3 – provide data for land and ocean monitoring, Sentinel 4 and Sentinel 5 – designed for meteorological and climatic research.

In this Manual, we analyze the territories in Ukraine to provide examples of GIS application in scientific research. Upon mastering the research algorithm, you can do your scientific research in other locations. The methodology used by the authors for processing, visualizing, interpreting, and analyzing the satellite images contributes to the formation of numerous competencies in students that will help them adapt to the application of information technology in remote sensing surveys of natural and anthropogenic processes.

The proposed Guidance Manual may be useful for the students and experts of the Junior Academy of Sciences of Ukraine, students of higher education institutions, teachers, as well as those who want to improve their knowledge in the field of RS and GIS.

*The authoring team expresses its gratitude to
the Member of the National Academy of
Sciences of Ukraine, Vadym Ivanovych Lialko, for fruitful,
long-term collaboration with the Junior Academy
of Sciences of Ukraine*

HOW TO USE THIS MANUAL

To make the information contained in this Guidance Manual more accessible to you, we have used different color blocks:

- green color is for the “It Is Interesting” section;
- blue color is for additional information;
- all terms in the text are marked with yellow color;
- tips and warnings are written in red *Italics*.

To perform almost all tasks, we have used two main GIS applications, ArcGIS and QGIS, in this Guidance Manual. Each paragraph first identifies the **task** to be performed and briefly describes the theory required for better understanding the process, then describes the **algorithm of operations** in GIS applications, and provides **step-by-step instructions** for the usage of this algorithm in ArcGIS and QGIS (which buttons to press and which operations to perform). If you work in one of the applications (for example QGIS), you do not need to read the whole text; just read the task, the theory, and the algorithm sections and proceed to the instructions for the performance of the task in the application you use. Instructions for various software are additionally marked with color tabs located on the edges of pages: ArcGIS with blue and QGIS with green.

In addition to the main applications, ArcGIS and QGIS, some sections of the Manual comprise examples of the algorithms used in Google Earth Pro (software suitable for the youngest students), and Google Earth Engine (more complex software for those who are interested in programming). These two applications are also marked with a gray-colored tabs on the edges of pa.



ArcGIS – blue color tab
(advanced level of training, commercial GIS software)

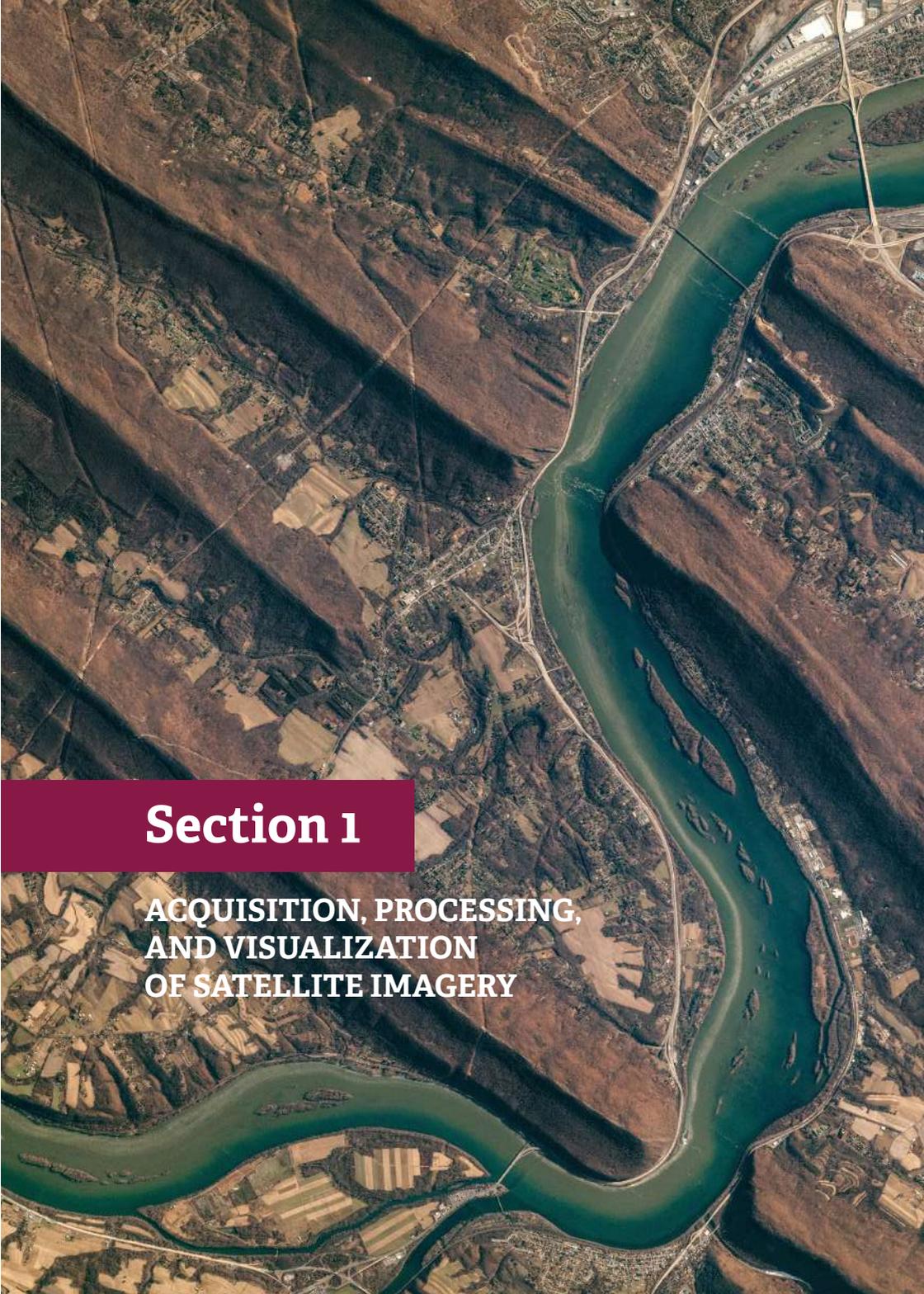


QGIS – green color tab
(advanced level of training, free GIS software)



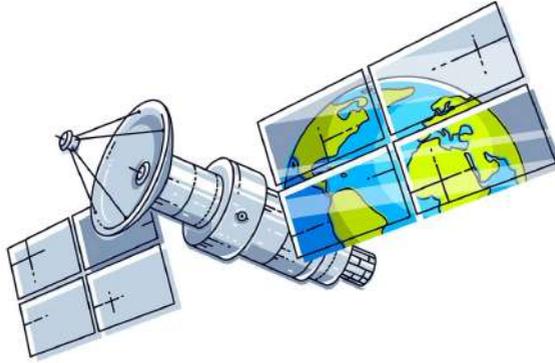
Google Earth Pro and Google Earth Engine – gray color tab
(elementary level of training or *Section for the Youngest Audience* and *For Those Interested in Programming* section)



An aerial satellite image showing a wide river winding through a valley. The river is a deep greenish-blue color. The surrounding land is a mix of brown and tan, indicating agricultural fields and some urban development. The river has several bends and a large loop in the lower right quadrant. The overall scene is a typical rural landscape with a major waterway.

Section 1

**ACQUISITION, PROCESSING,
AND VISUALIZATION
OF SATELLITE IMAGERY**



1. 1. Basic Characteristics of Satellite Imagery

Every day we come across many various images: photos, drawings, illustrations, animations, etc. In this Guidance Manual, we will discuss in detail a special type of image – satellite imagery, which is the main data source for remote sensing observation of our planet.

Production of satellite imagery is a complex process of converting the energy of solar radiation reflected from the Earth's surface into electromagnetic pulses, and their recording in a digital form, i.e. using binary codes. Such digital format images can be processed by your PC processor.

Please review the basic definitions below before we discuss the opportunities for the application of RS and GIS techniques in studying Earth's surface.

Remote Sensing (RS) refers to Earth observation using aircraft and spacecraft equipped with various types of imaging devices, which measure the energy emitted from the Earth's surface.

A satellite image is an image of our planet collected by spacecraft, which contains information about electromagnetic radiation (EMR) reflected from different types of the Earth's surface.

A digital image refers to an image represented in a digital format as bitmap files, obtained either directly via radio-frequency receivers from aircraft or spacecraft, or by digitizing analog images using a scanner, TV, or video camera.

A raster is a method of digital representation of an image in the form of a rectangular grid of image elements – pixels (Fig. 1.1).

A **pixel** (from English “picture element”) refers to the smallest element of a digital image, characterized by a square shape and size, which determines the spatial resolution of an image.

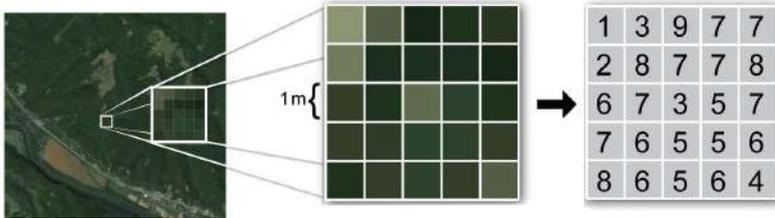


Fig. 1.1. Raster structure [1]

When selecting satellite imagery for the study, it is important to know the **basic characteristics of sensor systems**. Based on these characteristics, the decision may be made on the suitability of derived data for the particular task. There are four types of resolution:

- spectral;
- spatial;
- radiometric;
- temporal.

Spectral resolution refers to the ability of a sensor system to register electromagnetic radiation of a specific frequency range, which is determined by the number of satellite bands, i.e. the intervals in wavelengths of the electromagnetic spectrum to which the sensor is sensitive.

The range of wavelengths used in remote sensing may be roughly divided into four types – radio waves, thermal radiation, infrared (IR) radiation, and visible light. This division is due to the differences in the interaction of electromagnetic waves and the Earth’s surface, and differences in the processes that determine electromagnetic reflection and radiation. The most widely used in scientific research is the optical spectrum (also called the light portion of the electromagnetic spectrum), which embraces the visible (380 ... 720 nm), near-infrared (720 ... 1300 nm), and mid-infrared (1300 ... 3000 nm) spectral regions. In this range, the reflected solar radiation contains primarily information about the biochemical processes on the Earth’s surface. For example, the near-infrared spectral region may be effectively used to assess the condition of vegetation, determine the degree of its suppression or general health. In turn, the thermal IR radiation provides information about the surface temperature, allows to determine the temperature profiles of visible features and phenomena

(monitor forest fires, oil and gas flares dynamics), as well as investigate objects beneath the ground surface, such as subterranean rivers, underground pipelines, etc.

Depending on the spectral resolution (the number of bands corresponding to certain portions of the electromagnetic spectrum), sensor systems are divided into panchromatic, multispectral, and hyperspectral (Fig. 1.2).

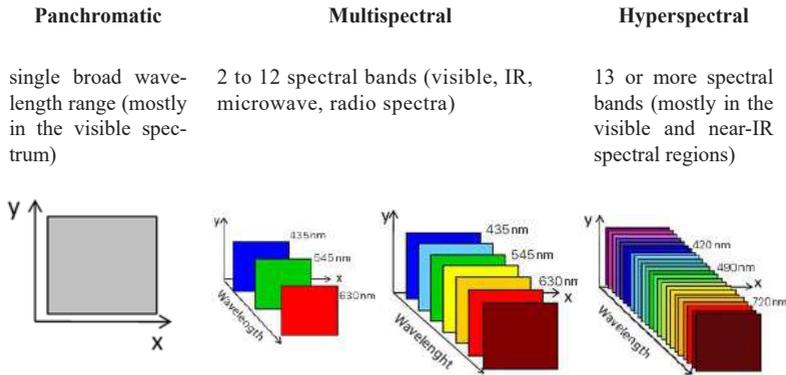


Fig. 1.2. Panchromatic, multispectral, and hyperspectral satellite imagery

Typically, optical imaging is performed either in the full spectrum of visible light (panchromatic mode) or in several narrower spectral regions (multi-zone imaging). In panchromatic imagery, information is collected from the entire visible range of the electromagnetic spectrum (0.45–0.90 μm); such images usually have a higher spatial resolution than multispectral images and are used to clarify features' boundaries, in particular in topography.

In contrast to multispectral, hyperspectral sensors divide the spectrum into many narrow bands (hundreds of channels). This helps to distinguish features more accurately according to their physicochemical composition, identify species and condition of vegetation, determine the geological structure, chemical composition of water, etc.

Spatial resolution refers to the size of the smallest identifiable features on the Earth's surface. That is the size of a pixel. Currently, the best available spatial resolution (30 cm) is provided by the commercial images collected by WorldView 3 satellite (adapted from Tvis website (Fig. 1.3, c)). This means that a 30×30 cm feature will appear in the image as a single pixel. This allows to identify a car in the image and determine its color (in case of color imagery). However, smaller details

(license plate number, design features, which help determine the make and model) will not be seen in the image.

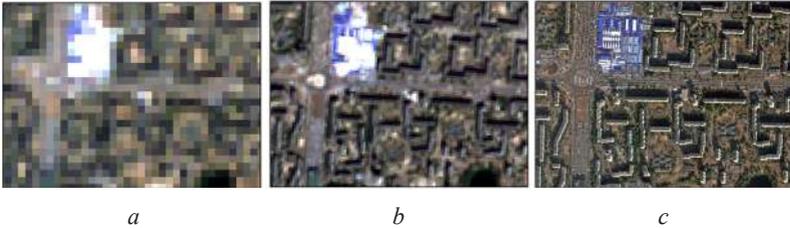


Fig. 1.3. Spatial resolution illustrated by the images of Obolon residential area in Kyiv city: 30 m – Landsat 8 (a), 10 m – Sentinel 2 (b), 1.24 m – WorldView 3 (c)

Classification of satellite images according to spatial resolution:

- very low – 10,000–1,000 m;
- low – 30–1,000 m;
- medium – 10–30 m;
- high – 1–10 m;
- very high – 0.3–1 m.

WorldView 3 satellite is owned by DigitalGlobe Company, which has been providing satellite imagery to well-known online mapping services such as Google Maps, Yandex Maps, Bing for many years.

Radiometric resolution refers to the number of possible coded values for spectral brightness in the data file for each band and is expressed in bits. It is determined by the number of gradations of color values, the corresponding transitions from the absolutely “black” to absolutely “white” brightness levels, and is expressed in the number of bits per pixel of the image (Fig. 1.4).



Fig. 1.4. Example of color gradation in the 8-bit image, where 1 byte of information contains 256 colors (e.g. shades of gray). Black represents a digital number of “0” and white represents a digital number of “255” [3]

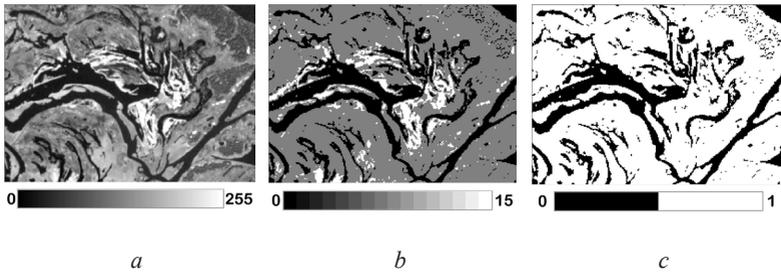


Fig. 1.5. Contrast, or the number of color shades (radiometric resolution), illustrated by the images of the Dnipro River floodplain: 8-bit (a), 4-bit (b), 1-bit (c)

This means that in the case of a radiometric resolution of 6 bits per pixel, we have only 64 color gradations ($2^6 = 64$); in the case of 8 bits per pixel – 256 gradations ($2^8 = 256$), and in the case of 16 bits per pixel – 65536 gradations ($2^{16} = 65536$). Previously, sensors mounted on remote sensing satellites had a radiometric resolution of 8 bits per pixel (Landsat 5). Currently, almost all new satellites have a radiometric resolution of at least 12 bits per pixel (for example, Landsat 8 has 12 bits/pixel, and Sentinel 2 – 16 bits/pixel), which accordingly contributes to the increase in the physical size of satellite images, measured now not in mega- but in gigabytes of information. In turn, higher radiometric resolution of modern sensors influences the accuracy of determining the coefficients of spectral reflection and reduces the noise level of satellite imagery (Fig. 1.5).



Temporal resolution is defined as the amount of time needed to revisit and acquire data for the same location. The more often a satellite appears over a certain feature, the higher is the temporal resolution.

When applied to remote sensing satellites, the temporal resolution depends on the orbital characteristics of the satellite, the number of twin satellites, and the width of the imaging swath of the spaceborne sensor. It should also be noted that operators can adjust satellites' orbits to increase the frequency of re-imaging (Table 1. 1).

Table 1. 1

Temporal Resolutions of Some Satellites

Satellite	Temporal resolution (re-visit)	Swath width, km
NOAA	30 min	2900
Aqua/MODIS	0.5 day	2300
Landsat 8	16 days	185
Sentinel 2A, 2B	5 days	290
RapidEye	5 days	77
PlanetScope	1 day	24
WorldView-3	1 day	13.1

If you want to capture the temporal dynamics of a certain process, consider such force majeure factors as weather conditions over the studied area when selecting satellite images. Since passive spacecraft register only sunlight reflected from the Earth, which does not pass through the clouds, it is difficult to find a “clear and cloudless” image in spring and autumn.

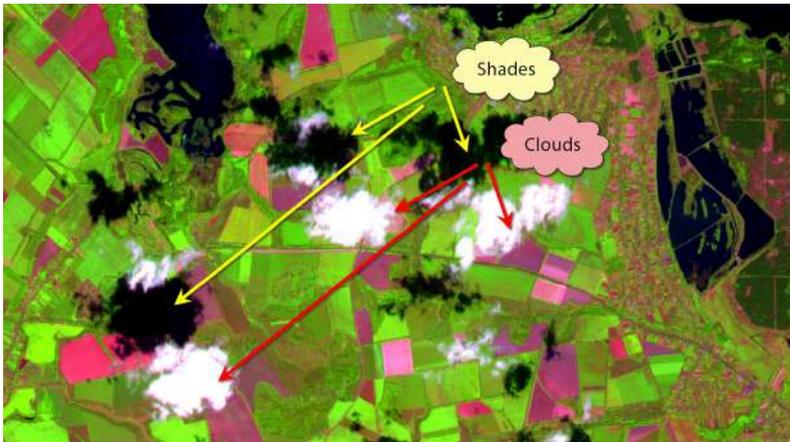


Fig. 1.6. Identification of clouds and their shadows on the satellite image captured by Sentinel 2

Tip on how to distinguish clouds from other features. If next to a white feature (cloud) you see a black (shadow) feature of exactly the same shape – be sure, it is a cloud! This principle can be used to check yourself and not confuse dark shadows with dark-colored water (Fig. 1.6).



1. 2. Sources of Remote Sensing Data

Some ten years ago, access to satellite data was limited to the world's biggest militaries, wealthiest corporations, government agencies, and some scientific institutions. Currently, terabytes of satellite data are available to everyone. Using satellite images, we can see how our planet is changing every day.

For example, this is what our planet looked like on August 2, 2019 (Fig. 1.7). We can get such images almost every day, using spacecraft. Fig. 1.7 shows data collected by NOAA-20 satellite; available at: www.nvvl.noaa.gov/view/globaldata.html#TRUE.

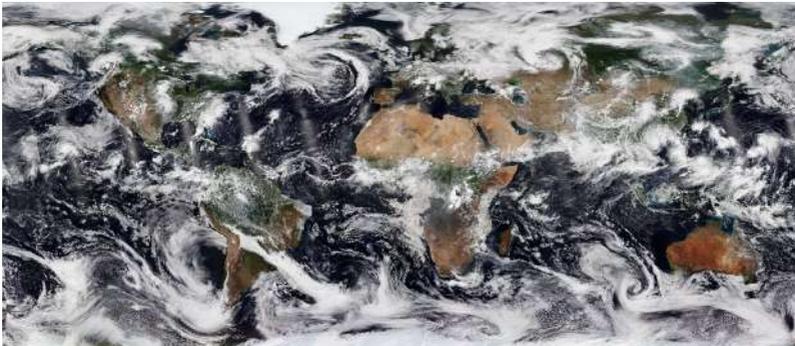


Fig. 1.7. View of the Earth from NOAA-20 satellite, August 2, 2019.

In the 21st century, there are many sources of free satellite data available. In particular, using data portals of the USGS (*United States Geological Survey*), the NASA (*National Aeronautics and Space Administration*), and the ESA (*European Space Agency*), we can download images collected by Landsat and Sentinel satellites for free and use them in GIS programs. After reading this section, you will know how to use the various websites to search for free Landsat and Sentinel imagery of the area you are interested in and will be able to download image archives to your PC for further use in the ArcGIS and QGIS applications.

Satellite images are very large files. Therefore, if you want to upload an image, first make sure there is enough disc space on your computer. The download time depends on the Internet speed and file size, so be patient and wait a few minutes.

Task

Download satellite images of the Troieshchyna residential area in Kyiv and analyze what this area looked like in 1984 and 2019.

Historic reference. In 1980, there were several housing estates on the left bank of Kyiv (Voskresenka, Rusanivka, Berezhnyaky, Sotsmisto of Darnytsia, Lisovyi, and Komsomolskyi). However, in the suburban villages of Vyhurivshchyna and Troieshchyna, locals still lived in one-story houses, took water from wells, and grazed horses on the edges of their villages. In 1981, Vygurivshchyna was demolished (dozens of streets and almost one and a half thousand houses) [4]. First residents moved into new multi-story apartment buildings in 1983. That is how the Troieshchyna neighborhood appeared on alluvial soils (Fig. 1.8).



Fig. 1.8. Troieshchyna residential area. Photo by Semen Shyrochyn [5]

If you haven't seen yet the music video for Kamikaze song by a Danish singer MØ, check it out at www.youtube.com/watch?v=eVD9j36Ke94. It was filmed in Kyiv in the Troieshchyna residential area in 2015. The main location of this music video, similar to White Mercedes by Charli XCX, was a wasteland in Troieshchyna. This area has long been appreciated by many other foreign artists who come to the Ukrainian capital to shoot music videos. Some "winter" scenes of Chernobyl series were also filmed in Troieshchyna.

Task 1. Download a Sentinel 2 image of the European Space Agency capturing the territory of Troieshchyna neighborhood, Kyiv, as of September 10, 2019.

In the following paragraphs, 1.2.1 – 1.2.5, we will discuss in more detail free resources, from which you can easily download images and perform **Task 1**.

1. 2. 1. Copernicus Open Access Hub

It is a web platform for providing users with full, open, and free access to Sentinel 1 radar images, Sentinel 2 optical multi-spectral images, and Sentinel 3 surface data.

To gain access to the archive of satellite images for downloading, first, sign up and log in at SciHub – <https://scihub.copernicus.eu/dhus/#/home>. Click the Login button in the upper-right corner of the page, and select Sign up in the drop-down list (Fig. 1.9).



Fig. 1.9. Signing up at SciHub

Following signup, return to the main page and log in.

To find satellite images on this site, zoom into the area of interest on the map using the scroll wheel of your mouse. We are looking for images of the Troieshchyna residential area in Kyiv. Click the **Switch to Area Mode** button on the right sidebar. Define the area of interest on the map (polygon) using a mouse cursor. To finish drawing the polygon, double click the last point with the left mouse button (Fig. 1.10).

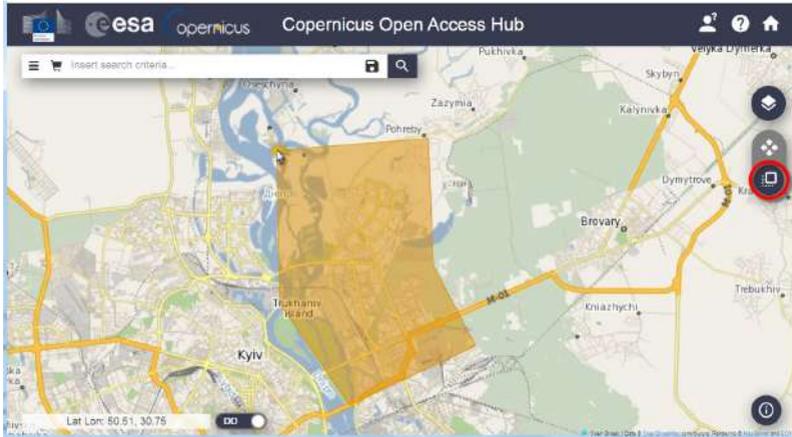


Fig. 1.10. Defining the area of interest, which will be used to search for images

Open the advanced search panel on the left sidebar by clicking the  icon (in the search bar). In this panel, you can set the time interval for images' search, select a satellite, reduce cloud coverage, etc.

In our example, check **Mission**: Sentinel 2 and click  Search icon. This website (Fig. 1.11) provides several options for images download:

- 1) click the **Download URL** link next to the image thumbnail on the left side of the screen;
- 2) click  icon next to the image thumbnail;



Fig. 1.11. Options (1) and (2) for downloading satellite images

- 3) click  icon to display the image (Fig. 1.12) on the *Footprint* map and in *Quicklook* mode.

In the popup box, click the long link at the top or  icon in the bottom-right corner of the screen. The download will start automatically.

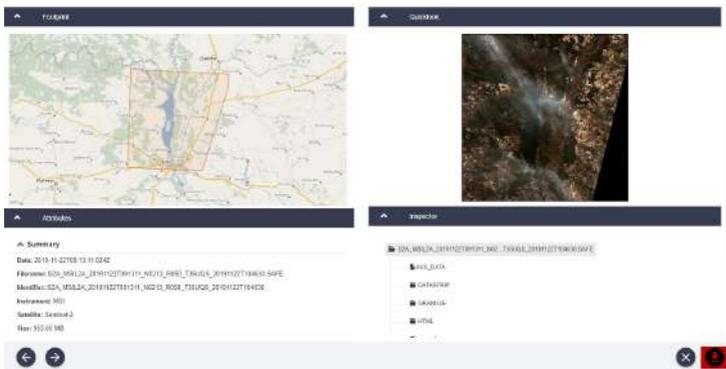


Fig. 1.12. Option (3) for downloading satellite images

1. 2. 2. EO browser

1. Open **EO browser** webpage; to do this, type “EO browser” in Google or go to <https://apps.Sentinelhub.com/eo-browser/>.

EO browser allows browsing available online medium and low-resolution images collected by the European Space Agency’s satellites: Sentinel 1, Sentinel 2, Sentinel 3, Sentinel 5P, Landsat, Envisat Meris, MODIS, Proba V, GIBS (Fig. 1.13).

Official webpage: <https://apps.sentinel-hub.com/eo-browser/>.

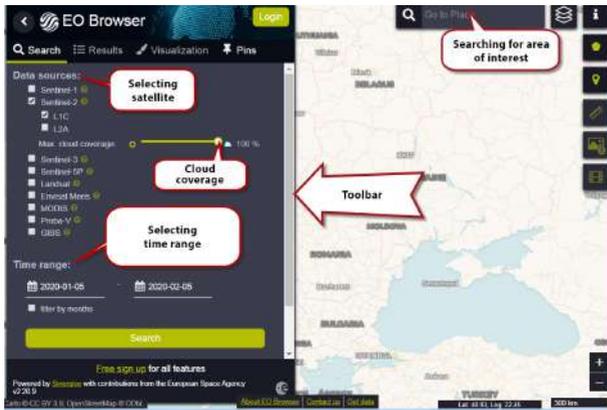


Fig. 1.13. Main screen of EO browser

2. First of all, create an account (Fig. 1.14) by clicking the *Free sign up* button on the bottom left-hand toolbar. In the popup box, enter your personal information and log in to the portal by clicking *Sign up*.

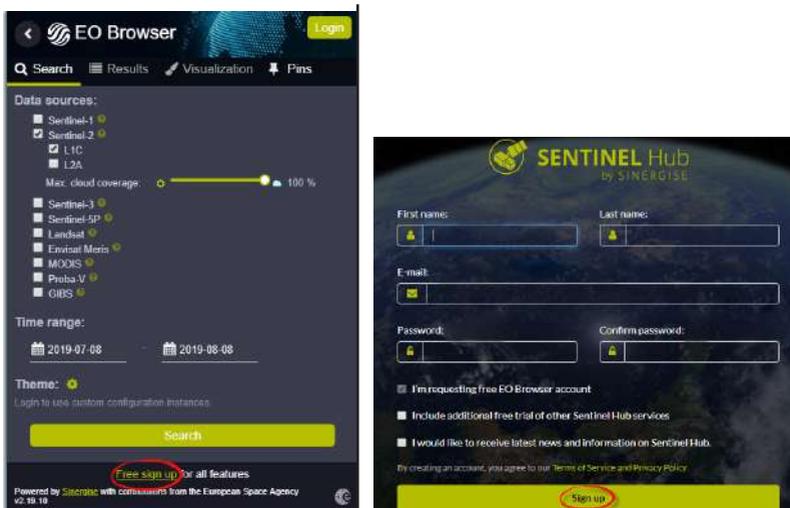


Fig. 1.14. Box for creating an account

3. You will receive an email from Sentinel Hub asking to confirm your registration on the site (Fig. 1.15). Click **Verify e-mail address** button.

Check your spam folder to make sure the verification email didn't end up there.

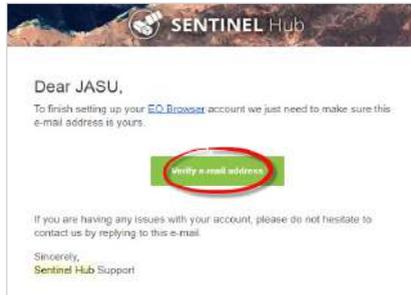


Fig. 1.15. Verification email in your inbox for finishing account setting up

4. Now log in to the site using your username and password. Click **Login** and enter your data (Fig. 1.16).

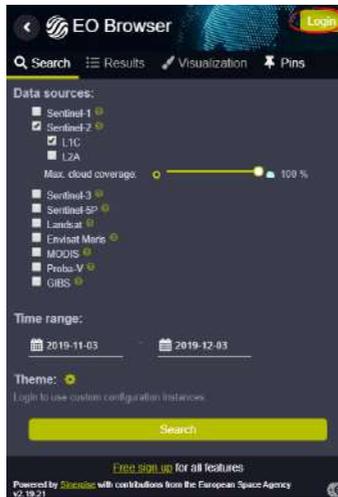


Fig. 1.16. Logging in to EO browser website

5. To find a satellite image of the area of your interest, type the name of a settlement, region, or geographical feature in the search bar in the upper-right corner of your screen, and select it from the dropdown list.

In this example, we will find a satellite image of Kyiv city, namely of the Troieshchyna residential area (Fig. 1.17).

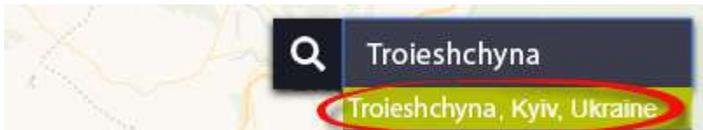


Fig. 1.17. Search for location, area of interest

6. Use the scroll wheel of your mouse or the navigation buttons in the bottom-right corner of the screen  to zoom into the feature of your interest. You can move across the map by pressing and holding the left mouse button, and in this way, you may drag the map in the desired direction.

7. In the settings toolbar on the left side of your screen, select:

- **Data source** (satellite): Sentinel 2A / LIC;
- **Max.cloud coverage**: 10%;
- **Time range**: 2019-08-01 – 2019-11-10.

To select a date, choose it from the calendar rather than type because typing does not work (Fig. 1.18).

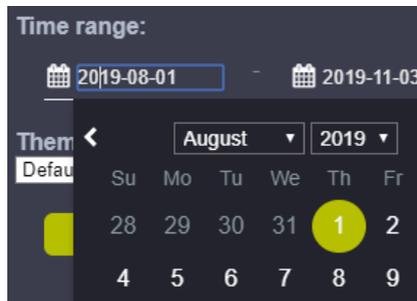


Fig. 1.18. Selecting the date from the calendar

Click the **Search** button. The search result will provide a list of all available images, which match the submitted search query.

8. View the images by scrolling through the list in the left box, find the image from September 10, 2019 (2019-09-10), and click the **Visualize** button. As a result, a visualization tab will open with different visualization options and automatic indexes based on band combinations (Fig. 1.19).

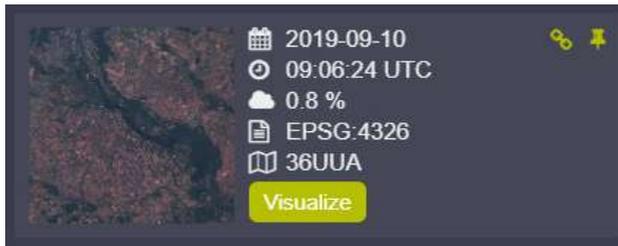


Fig. 1.19. Image from September 10, 2019, to be visualized

9. The selected image will be displayed in the cartographic window, and a **Visualization** menu will open in the left panel to adjust the image display. By default, the image is displayed in **True color**, which means that it is visible to the human eye and looks like a photo taken from above. Take a look at the image, zoom into the Troieshchyna housing estate and geographical features located next to it.

10. Save this image. Return to the search results tab and find the image you want download (in our case it is the image from September 10, 2019). Click the  icon next to the image date – a link will open for full-size images download.

11. Click the **SciHub link**. In step 1, we have created an account on this resource. Therefore, if the login was entered correctly, the download will start automatically. Otherwise, a field will appear to enter the username and password to the **SciHub** directory (Fig. 1.20).

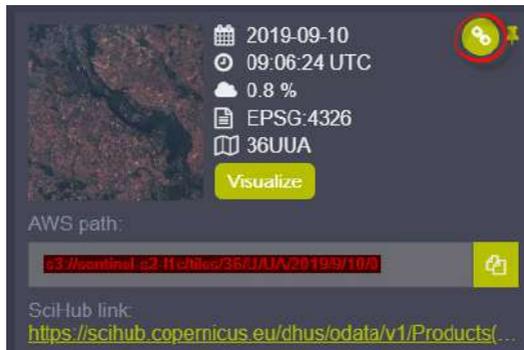


Fig. 1.20. Satellite image download

12. The downloaded archive needs to be decompressed. The images may be found in the internal archive files in the GRANULE and IMG_DATA folders. You will learn how to work with downloaded data in the following [paragraphs, 1.3 and 1.4.](#)

Task 2. Download NASA's Landsat 5 TM image of the Troieshchyna residential area of Kyiv city collected on April 7, 1984.

1. 2. 3. USGS Earth Explorer

Using this resource, you can download the following images for free: Landsat, SPOT HRV (1986-1998 images of North America), Sentinel 2 images; SIR-C/X-SAR radar images, as well as the SRTM digital elevation models (DEM). Besides, declassified archival aerial photographs of the United States and parts of the world are available for a fee, as well as images acquired by CORONA, EO-1 ALL, and Hyperion missions.

Official website: <https://earthexplorer.usgs.gov/>.

To download images, go to <https://earthexplorer.usgs.gov/> or type *Earth Explorer* in the Google search bar.

You can create an account by filling out the form in English, or you can log in to your account if you have already registered. To create an account, click the **Register** button in the upper right corner of the main window. You will automatically jump to the questionnaire. Enter your data in required fields (Fig. 1.21, 1.22).



Fig. 1.21. The main window of Earth Explorer

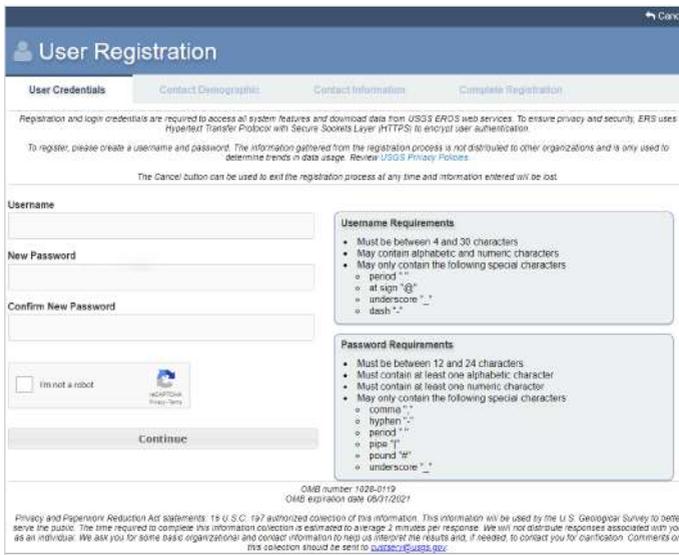


Fig. 1.22. Creating a new account in Earth Explorer

In your inbox, you will receive an email asking you to confirm your registration. Now, go to the site using your username and password. Click the **Login** button and enter your data.

You may either enclose the area for data search in a polygon with its upper points defined using the left mouse button (Fig. 1.23) or type a location or address in the search field. To perform the task, type “Troieschyna” in the search bar. Click the **Show** button to open the table of search results. Click the address in the table and a pin mark will be displayed on the map (Fig. 1.24).

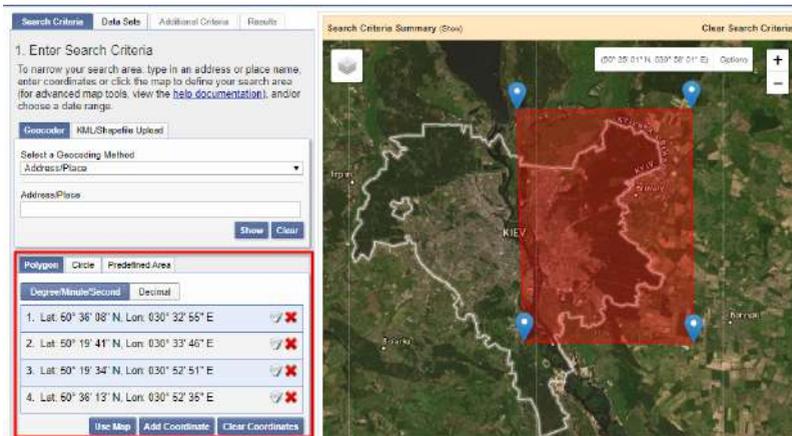


Fig. 1.23. Defining an area of interest on the map

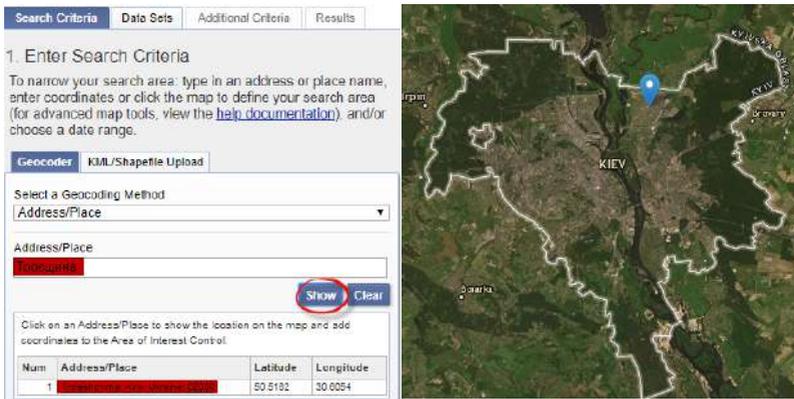


Fig. 1.24. Defining search area in the address field of the toolbar

5. When the search area has been defined, we may proceed to time range selection. Enter a date or date range in the **Date Range** field. By default, the **Search month** option includes all months of the specified time range. However, we can specify which months to search within the given date range. To do this, uncheck all other months.

Select the beginning and ending dates, 01/01/1984 and 12/31/1985, and select all search months in the checkboxes (Fig. 1.25).

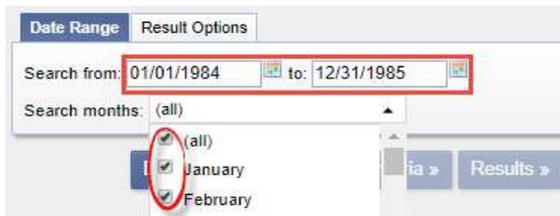


Fig. 1.25. Selecting data range for the search

6. Go to the Data Sets tab, select Landsat in the data list, and open the list. Check the box for Landsat 4, 5 TM in Landsat Collection 1 Level 1 category. By clicking on the  icon, you can find out more information about each of the satellites (Fig. 1.26).

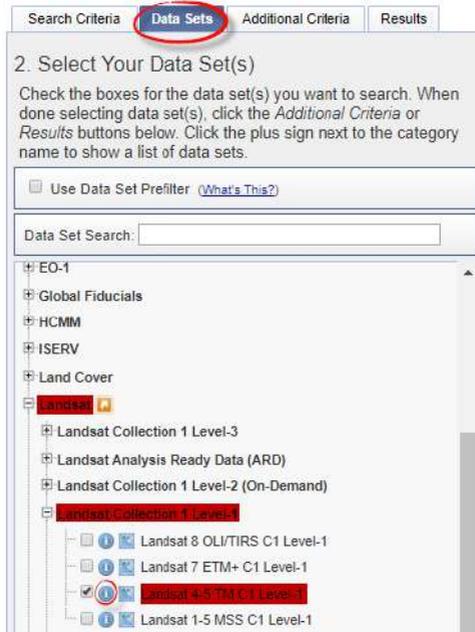


Fig. 1.26. Selecting data sets for the satellite

7. Click the **Additional Criteria** tab, which allows entering additional search criteria specific to your query, for example, the **Cloud Cover**. To perform our task, we choose a cloud cover of 20%.



Fig. 1.27. Entering additional search criteria

If you have selected more than one dataset (for example, Landsat 7 and 8, Sentinel 2), note that additional criteria will be applied separately to each dataset. You need to change the datasets and select the criteria one by one (Fig. 1.27).



Fig. 1.28. List of search result images, and method of changing *Data Set*

8. By clicking the **Results** tab a list of the data selected for your query will be displayed (see above).

If you have selected more than one dataset, you will need to change them one by one in the Data Set drop-down list (for example, Landsat 7, then Sentinel 2, etc.) because all images are filtered by type (Fig. 1.28).

Each search result includes **ID** (information on the scene), **Acquisition Date** (the date when the photo was taken), **Path** (scene column), **Row** (scene row), as well as the icon menu for scene level result controls (Fig. 1.29), where **Show Footprint displays** the area covered by the image (scene of the image), **Show Browse Overlay**  displays a preview image.



Fig. 1.29. Toolbar

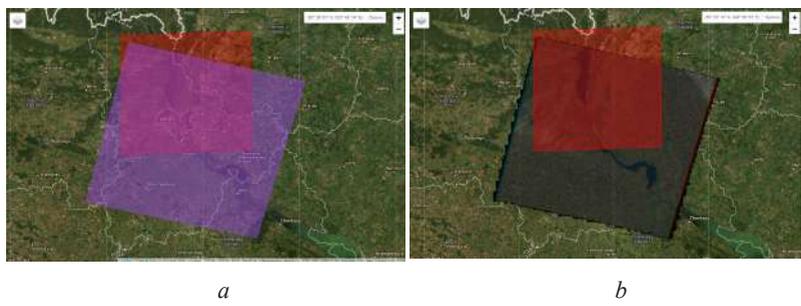


Fig. 1.30. Area covered by the image: the area of interest is displayed in red, image scene (a) or preview image (b) are displayed in purple

Using these tools, you can check if an image suits your purposes, and avoid downloading unnecessary data. If the image meets your requirements, click the  **Download options** icon to download it (Fig. 1.30).

In the list of images in the **Results** tab, find the image of April 7, 1984, and download it (Fig. 1.31).



Fig. 1.31. Image of April 7, 1984, to be downloaded

9. A window will open (Fig. 1.32) with the download options for the dataset displayed. You should select the file of the largest size and download it (in this task, it is *Level-1 GeoTIFF Data Product* file (153.2 MB)). All other files are **quick looks**, which allow you to view the image using different combinations of bands. Thus, we have downloaded an archive, which must be decompressed before image processing. We will continue working with this archive in ArcGIS 10.5 in the next Section 1.3.

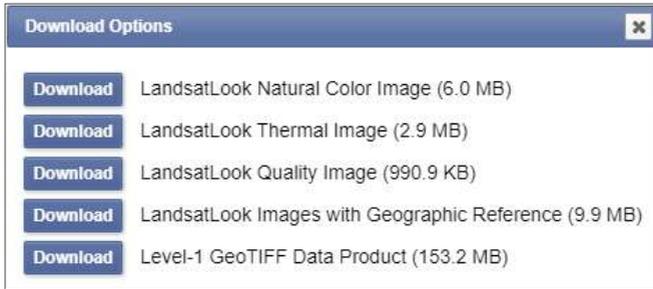


Fig. 1.32. Download options window

1. 2. 4. Earthdata Search

Earthdata Search is an open-source tool, which provides access to all Earth observation data collections from NASA, as well as from partner agencies. The resource enables users to search, visualize, compare and download Earth observation data.

Official website: <https://search.earthdata.nasa.gov/search>.



To use this tool, first, you need to register. The registration process is no different from that to the previous three resources, which we have discussed above. By scanning the following QR-code, you can open a video tutorial on how to search for datasets on this website (Fig. 1.33, 1.34).

Puc. 1.33. QR-code. Step-by-step instructions for data search on NASA Earthdata Search website

The video is in English.

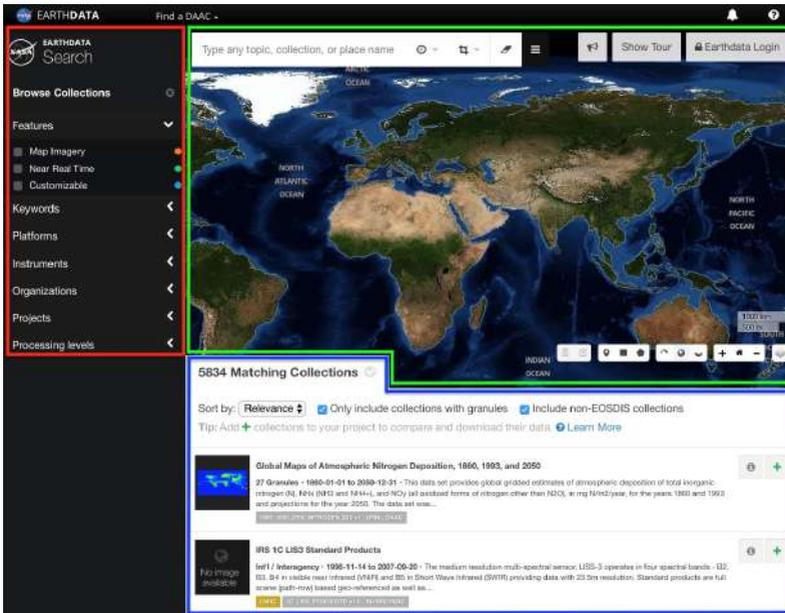


Fig. 1.34. Main fields in the working window of the Earthdata Search tool (far left side of the screen – search box, bottom of the screen – list of collections matching your search criteria, main panel – search results map)

1. 2. 5. NASA – Giovanni

Giovanni displays Earth science data from various instruments on NASA satellites in a variety of formats, including area plots, time series, meridional averages, animations, and numerical outputs, etc. This tool provides access to numerous satellite datasets, focused primarily on atmospheric composition, atmospheric dynamics, global precipitation, hydrology, and solar radiation.

Users can download data on precipitation, temperature, humidity, and gas concentration, etc. With Earthdata Search registration you can log in and gain full access to data and services within Giovanni.

Official website: <https://giovanni.gsfc.nasa.gov/giovanni/>.

By scanning the following QR code (Fig. 1.35), you can open a video tutorial on how to use Giovanni.



Fig. 1.35. QR-code to open a video on quick start guide to Giovanni interface
The video is in English.

The algorithm for working with Giovanni is very similar to that of the resources we have discussed above. First, you need to select the data you want to download, then select the date range, and the area of interest. Then, specify the variables to compare and download. More than 1,600 variables are currently available within Giovanni [6]. A keywords search feature allows you to search for the appropriate variable. The generated map will be displayed automatically, and if you do not like the result, you can change its display mode, edit the area, etc. To download the data, click the **Download** button and choose the file format that works best for your needs.

To find out about additional resources which can be used to download images, see **Annex 1**.

1. 2. 6. Commercial Vendors of Satellite Imagery

In addition to free resources, many companies provide access to images on a fee basis. Their collections include extended high spatial resolution data sets, satellite images pre-processed for specific purposes, etc. Images of high (1–10 m) and very high (1 m or less) spatial resolution are available for a fee only.

1. **DigitalGlobe** is an American company that creates images of the Earth's surface and gives access to the satellite data of NASA, Google, and Terra-Server. You can find satellite images in the **Image Library** menu – **Search Imagery** – <https://discover.digitalglobe.com/>.

Official page: www.digitalglobe.com/. DigitalGlobe's image catalog is available at https://browse.digitalglobe.com.

2. **Tvis Company** offers images from all available commercial optical and radar satellites with spatial resolutions from 200 m to 30 cm per pixel, which may be used for numerous tasks (agricultural monitoring, monitoring deforestation, detection of illegal construction sites, tracking changes in the shorelines of water bodies, monitoring of floods and fires, etc.). In addition to satellite data access, the Company services include the compilation of or-

thophotomaps, vector maps, digital elevation models (DEM), three-dimensional models, etc. Go to <http://www.tvis.com.ua/products/satellite-imagery> to review the samples of satellite images offered by the Company, and read general information about satellites and their technical characteristics. From this website, you can also learn more about additional services provided by the Company, in particular, high-resolution UAV filming services (Fig. 1.36).

The images of high and very high spatial resolution are posted on GoogleMaps and Google Earth Pro. All these resources feature many tools (see paragraph 1.3), which allow users to create their own maps using high spatial resolution images and available base maps. They cannot be applied for automated analysis and interpretation but are sufficient for the creation of the simplest maps.

It should be remembered that images provided by geo-services are subject to copyright, therefore, you must read the license agreement and define the permitted usage options before using the products.

Therefore, to select an image that suits your research the best, answer the following questions:

- What is the size of features to be identified in the image; what is the scope of research?
- What is the period and frequency of satellite images, i.e. how often should the data be updated?
- Do you plan to use spectral indices, perform mathematical operations with bands or make a classification?

The answers to these questions will reveal the four main characteristics of sensor systems (described in detail in paragraph 1.1), which determine the suitability of the selected data. Consequently, you will be able to select the proper satellite image to solve a given task.



Fig. 1.36. UAV filming services offered by Tvis Company



1. 3. Applications for Satellite Images Processing (ArcGIS, QGIS, Google Earth)

A geographic information system (GIS) is a computer system that provides the ability to use, store, edit, analyze, and display geographic data. With GIS maps it is possible to obtain the following information:

- What is located in ...? (Identify the place).
- Where is it located? (Identify the area).
- What has changed since ...? (Identify temporary changes in a certain area).
- What spatial structures do exist? (Identify overlays of features or phenomena).
- What will happen if? (See what happens if, for example, we add a new road).

To add information to a map, such information should be georeferenced (contain data about feature's longitude and latitude).

The features in GIS projects are arranged in layers. For example, the boundaries of the continents and islands are represented in one layer, administrative units are represented in another layer, roads, buildings, etc. – in other layers. A cartographic layer is a representation of the features of the same class on the map (rivers, ponds, settlements, roads). That is, each layer has a set of features of common class and geometry. During visualization, each data file is presented as a separate layer. This

is similar to a multi-layered cake, where each layer carries information about itself, and all layers superimposed make a map. This representation of data on the map allows a user to display the layers required at a particular time easily and flexibly, and adjust the legends, captions, and visibility of each layer separately, etc.

Representation of the features on the map

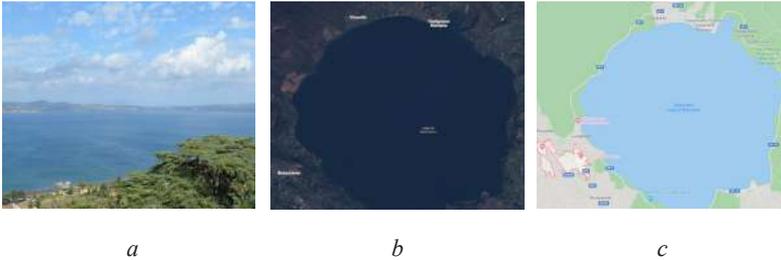


Fig. 1.37. Types of geographical features' representation: real-world (a), satellite image (raster) (b), vector (points, lines, polygons) (c)

1. Vector Data

According to the type of feature geometry, there may be the *point*, *polyline*, and *polygon* layers. Within each layer, individual legends – symbols, colors, and text – are used to visualize the information (Fig. 1.37).

Points are used to indicate geographical features for which the location rather than the shape or size is important (for example, building address, mountain top). The point has one pair of coordinates: latitude and longitude. Polylines represent linear objects that have length but have no area value (rivers, streets, state borders); polygons are features characterized by the area and perimeter (boundaries of seas, parks, states, etc.). The features on the maps are arranged in layers. For instance, one layer represents a transport infrastructure (e.g. roads), the other layer represents houses, yet another – forests or parks, etc. (Fig. 1.38).

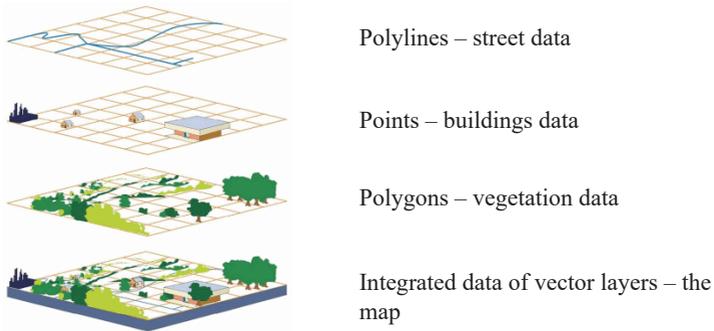
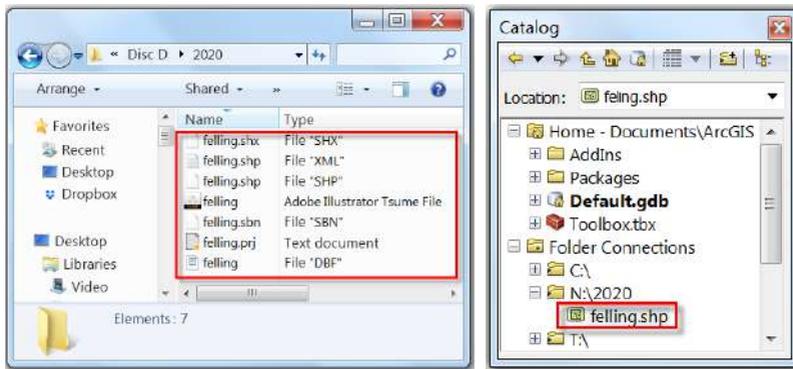


Fig. 1.38. Arrangement of vector layers on electronic map [7]

The *Shapefile* is the most popular format used to work with vector geographic data. This vector data format was first introduced in ArcView GIS in 1990 and has become very popular since then. A Shapefile file is made up of at least four related files with the same name but different extensions (*an abbreviation following a period in the file name*). Each of these files contains specific information, so when copying, you must always transfer all of the files (Fig. 1.39). The list of Shapefile files is given below:

- **.shp** – the main file that contains information about a set of features – points, lines, or polygons;
- **.dbf** – an attribute file that contains the attribute data for all the features described in the .shp file in dBase format;
- **.shx** – an index file which contains supporting information and is used to link .dbf and .shp files;
- **.prj** – a file which contains information about map projection of files [8];
- **.sbx** and **.sbn** are spatial index files that speed up operations with geometric features.

*An important feature of **Shapefile** is that one file can contain features of one type only (polygons, lines, or points).*



a

b

Fig. 1.39. A Shapefile in standard explorer window (a) and ArcCatalog (b)

2. Raster Data

A raster is a dataset consisting of pixels (cells), which provide continuous coverage of a certain area on the Earth's surface. Raster data are stored as sets of values, i.e. pixels, which have a rectangular shape and are arranged as a rectangular grid.

Each pixel of the image contains a numeric value which represents a spectral brightness of the feature located on the earth's surface at a given point. The spectral brightness depends on the spectral band covered by this image. Several images of different bands can be merged into a color satellite image (Fig. 1.40). Satellite images are examples of raster data. Each pixel of the image contains both data about the spectrum of the feature on the earth's surface and geodata about its location.

To select an application for processing satellite images, follow the algorithm described below.

1. If you want to study small features (e.g. houses, local felling areas), compare images with other data, visually interpret and digitize features with clear boundaries, choose Google Earth Pro application (<https://www.google.com/intl/en/earth/download/gep/agree.html>), which provides free access to high-resolution satellite imagery.



Fig. 1.40. Satellite image collected by Sentinel 2 on 10.09.2019. Shpola town, Cherkasy Oblast

2. If you need to work with spectral bands, to use them separately, visually interpret features with complex boundaries, create maps, perform a classification (automated designation of features with clear boundaries), choose ArcGIS or QGIS applications, which allow carrying out all these image processing operations.

3. RS data may also be processed at a professional level, which refers to a complex classification (automated designation of features with blurred boundaries), use of different algorithms, or automation of process with software code. This requires knowledge of the following software tools and libraries: GDAL, IDRISI, ENVI, R or Google Earth Engine.

In this section, we will take a closer look at the 1st and 2nd algorithms, and show you how to work with Google Earth Pro, ArcGIS 10.5, and QGIS 3.4.



This subsection discusses the use of **ArcGIS 10.5** software. It is a fee-based GIS, where you can create digital maps and work with satellite images. ArcGIS is a GIS software supplied by the American company ESRI (Environmental Systems Research Institute).

You can download the 21-day free trial version of ArcGIS Pro at: www.esri.com/en-us/arcgis/products/arcgis-for-personal-use. ArcGIS is intuitively simple to install, you just need to follow the prompts. At the link above, you can also buy a one-year subscription for the software for individual use.

ESRI Company offers various free ArcGIS versions for schools, colleges, and universities. To take advantage of this offer, contact your local ESRI representative, register your educational institution in the system and obtain free licenses for installation on PCs.

A student or teacher cannot do this independently; the management of the educational institution should be contacted, as it is important to fill in the form correctly. You can complete the training independently by creating a free ArcGIS public account at <https://learn.arcgis.com/en/>. During the training, you will learn how to work in ArcGIS Online (cloud-based version of ArcGIS) and practice various data analysis features.

ArcGIS software is used by the majority of higher educational institutions of the world, including some Ukrainian universities: Taras Shevchenko National University of Kyiv, the National Defense University of Ukraine named after Ivan Cherniakhovskyi, Ivan Franko National University of Lviv, etc.

ArcGIS has a set of applications, which can be used to solve many geoinformation tasks: mapping, data entry, data analysis, and share access to spatial information (Fig. 1.41).



Fig. 1.41. Set of applications in ArcGIS





ArcGIS for Desktop consists of several integrated applications, the primary of which are ArcMap and ArcCatalog. ArcCatalog manages the storage of spatial data, the structure of databases, and recording and viewing of metadata. ArcMap is used to create and edit maps, as well as to perform cartographic analysis. ArcMap contains ArcToolbox, which is used for data conversion and geoprocessing (Fig. 1.42).

ArcMap is the main ArcGIS application used to create and edit maps. With ArcMap, it is possible to add legends to maps, prepare maps for printing and publication. In ArcMap, the geographic information is represented as a set of layers and other map elements.

ArcMap features a *Catalog* window (Figure 1.43), where you can organize all sets of GIS data, map documents, other ArcGIS files, geoprocessing tools, and many other GIS element.

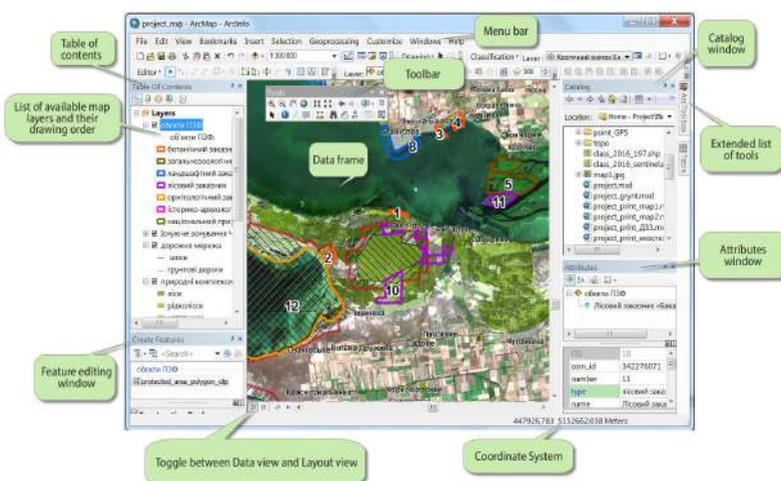


Fig. 1.42. The interface of the working window of ArcMap project

Catalog is a structure for organizing the storage of various types of GIS data. You can create personal geodatabases on your PC, or use *Catalog* tools to create or import feature classes, tables.

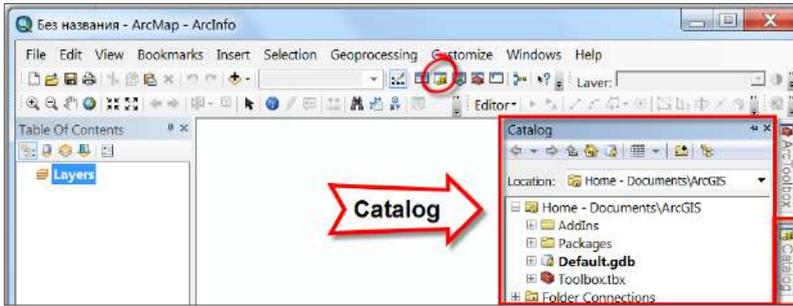


Fig. 1.43. *Catalog* window in ArcMap

ArcToolbox window contains many GIS tools for data geoprocessing. Simple tasks are performed using the tools represented in the form of dialog boxes. Each of the Toolbox sections contains certain tools that can be viewed by left-clicking the “+” icon next to the section name (Fig. 1.44).

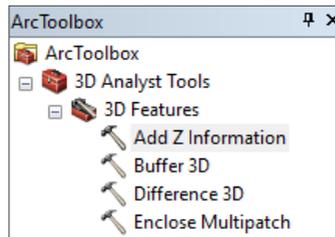


Fig. 1.44. Example of shortcut menu in *ArcToolbox*



QGIS is a free and open-source geographic information system application with a flexible system of functional modules, which is maintained and improved by a group of volunteer developers. This software allows users to visualize, edit, analyze data, prepare maps for printing, etc.

To download and install this application on your computer, go to <https://qgis.org/uk/site/> or just type **QGIS** in the Google search bar and then go to the first link in the search results. To download the installer to your computer, click the *Download Now* button. A window will appear with a list of possible downloads. You can download QGIS for Windows, Mac OS X, Linux, BSD, and Android. Different versions of



this software are available: *Long term release* – a stable version, and *Latest release* featuring the latest updates. We recommend installing *Long term release* version to avoid problems with the application functioning. In this Manual, we use **QGIS 3.4 Madeira** version (Fig. 1.45).



Fig. 1.45. Versions of QGIS software

There are two more versions of this application designed for 64- and 32-bit operating systems. You can check what type of operating system you are currently running on your computer in the Control Panel → All Control Panel Items → System section. Install the version that matches the operating system of your PC.

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

The QGIS user interface is divided into five components (Fig. 1. 46):

1. The Menu Bar provides access to all QGIS features using a standard hierarchical menu.
2. The Toolbar provides access to most of the functions in the menus, plus additional tools for interacting with the map. You can display or switch off every toolbar using the right mouse button in the context menu. Every toolbar can be moved around according to your needs.
3. The Layers panel lists all the layers in the project. The checkmark next to each layer is used to show or hide it. The order of their presentation in the legend determines the order of their display on the map. Right-click on a layer activates the shortcut menu. It differs depending on the layer type (Fig. 1.47).

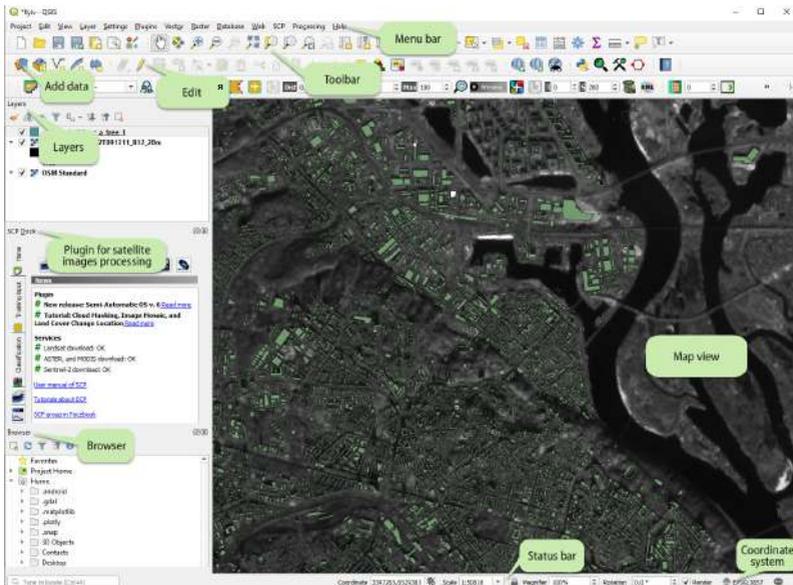
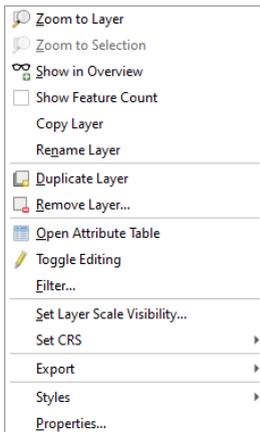
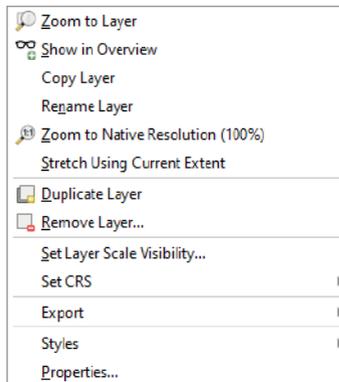


Fig. 1.46. User interface of QGIS project



a



b

Fig. 1.47. Shortcut menu of layers in QGIS: vector (a), raster (b)





4. Map View. The map displayed in this window will depend on the layers you have chosen to load in QGIS. When you add data to the Layers panel, the map display will also change.

5. Status Bar is located at the bottom of the working window and shows the current position of the mouse cursor in the units of the map (e.g. in meters or decimal degrees). It also demonstrates the scale of the map view, which can be changed using the mouse (you can zoom in/out in the status bar, or use a scale selector, which allows you to choose between predefined and custom scales in the same line). There is also a checkbox in the status bar which can be used to temporarily prevent layers from being rendered to the map view. On the right side of the status bar, you will find the  icon (the current project coordinate referencing system (CRS)). Clicking on it opens the Project Properties dialog window with the *Coordinate system* tab.

QGIS modules

Most of the functions in QGIS are implemented as Core Plugins or External Plugins:

- Core Plugins are maintained by the QGIS Development Team and automatically included in every distribution of the program;
- External Plugins are stored in external repositories and maintained by the individual authors. If a plugin is popular with users, it can be added to the set of basic QGIS plugins.

Management of plugins includes activation, installation, updating, or removal of plugins using the QGIS plugin manager. To install or activate plugins in QGIS, go to the Menu Bar: **Plugins – Manage and Install plugins**.

To install the plugin, go to the **Not installed** tab, find the appropriate plugin using the Search box, and click the **Install plugin** button. The installed plugin will appear in the **Plugins** menu. Some plugins will appear as separate toolbars, which can be disabled/activated at any time (Fig. 1.48).

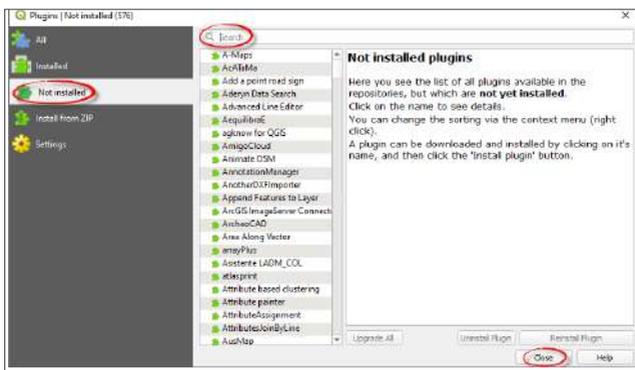


Fig. 1.48. Installing a new plugin

Task

Create a project in the GIS application, open B05 band of the downloaded Landsat 5 satellite image and B08 band of Sentinel 2 image. Calculate the increase in the area of the Troieshchyna neighborhood in Kyiv over 35 years.

Data

The territory of Kyiv in Landsat 5 satellite image collected on April 7, 1984, and Sentinel 2 satellite image collected on September 10, 2019 (we have discussed the downloading of these images in paragraph 1.2; if you don't have them, repeat the download according to the instructions).

Task Performance Algorithm

1. Unzip downloaded satellite data

In [paragraph 1.2](#), we have downloaded two satellite images, from Landsat and Sentinel. These downloaded files must be unzipped using any standard archiver, such as 7-zip (www.7-zip.org).

After complete decompression, the Landsat 5 satellite image folder will contain 9 files as black-and-white images for different bands (the number of available bands will depend on the Landsat source (for example, if you have downloaded data from Landsat 8, there will be 11 such images)) and text files with metadata. The unzipped folder of Sentinel 2 satellite image has a more complex structure and contains 14 files in the "IMG_DATA" folder for image bands. Each band is a black-and-white image, which represents the intensity of reflection of electromagnetic radiation by surface features in a given spectral range.

The file names are almost the same, except for the sequence number at the end of the name after the letter B (B refers to "band"). For example, B01 is the first

band of the satellite image. Each satellite has its own band specification, which can differ significantly in different satellites. The bands of Sentinel 2 and Landsat 5 satellites are shown in Fig.1.49.

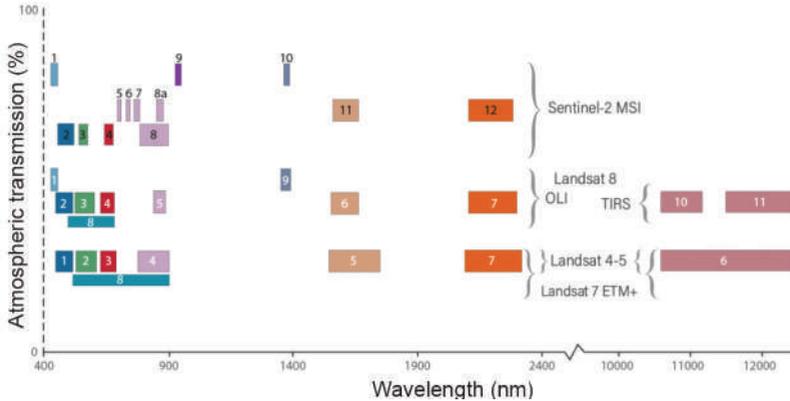


Fig. 1.49. Bands of Sentinel 2 and Landsat 5 / 7 / 8

Different image bands may have different spatial resolutions (see [paragraph 1.1](#) for more details). For example, the spatial resolution of B02 band (green – i.e. the band corresponding to the green region of the spectrum) of the Landsat 5 satellite image is 30 m, while the spatial resolution of B06 band (thermal infrared) is 120 m. The B03 band of Sentinel satellite image has a spatial resolution of 10 m, and the B01 band – 60 m. See the detailed characteristics of the different images in the Table ([Annex 2](#)).

Each band of the image can be opened in GIS applications (QGIS or ArcGIS) separately as a black-and-white image. The downloaded images have a defined geographical projection, so there is no need to refer to geographic coordinates and the images may be superimposed on other map data.

2. Open GIS application and create a project

Launch the application from the Start menu, or find the ArcMap 10.5 or QGIS 3.4 icon on your computer desktop.

Use of any GIS application starts with downloading various data (raster, vector, tabular), setting their display and order, and scaling. That is, with the creation of an operating environment or working project, where all selected settings are saved automatically.

Project is a special file, which records the current state of a working session, and therefore, this file can be further used to restore the operating environment [9].

It should be noted, however, that each GIS application creates projects in its own format, and they can be opened only in the application they were created in. Therefore, you cannot open an ArcGIS project in QGIS and vice versa.

*Creating a project is a very simple procedure. You need to find the **Save project** button on the toolbar, click it, choose a project name (it is better to use the Latin alphabet), and select a folder to save the project by clicking the **Save** button.*

Saving a project allows you to preserve all the data, the scale, the set, and placement of panels and toolbars in the GIS application until next opening of the project.

The project stores links to data, not the data itself. If you want to transfer the project to another computer, you need to move all data folders. When you save a project, a path is recorded for each layer which indicates its location on the computer. When you transfer or rename files uploaded to a project, the path changes, and the next time you open the project, you will not be able to download these data automatically.

Create a folder on your computer and name it “Kyiv_RS”. We recommend that you save all the files we will work with during tasks’ performance to this folder. Move the unzipped folder of the downloaded satellite image with all the files to this folder and save the created project.

3. Add the *OpenStreetMap* base map

We recommend that you add **OpenStreetMap (OSM)** as a base map, a source of our data. There are many types of base maps, such as that of the National Geographic, cadastral map of Ukraine, topographic maps, ocean mas, etc. You can change the type of a base map depending on the task.

OpenStreetMap is a volunteer project aimed at collecting, storing, analyzing, and free sharing geodata. The project was launched in 2004 in the UK at the initiative of Steve Coast. It is similar to Wikipedia, but instead of articles, it features maps, geographic data and layers. All data offered by this resource are distributed under the Open Database License, i.e. they can be used for any purpose, including commercial, subject to giving credit to the data source. You may join the OpenStreetMap community and review the current tasks in the blog at <https://blog.openstreetmap.org/> (you can communicate with like-minded people in Ukrainian). **Official website:** www.openstreetmap.org.

Loading maps from OpenStreetMap source may take much time and slow down all the processes in the application, so it’s better to disable OpenStreetMap map by unchecking the box when you are not using it.



Fig. 1.50. Adding a base map to the project: the map is displayed in the map window (a), the map is opened in the project but not displayed in the map window (b)

4. Zoom into Troieshchyna neighborhood

Using the toolbar navigation buttons, *Zoom In*, *Zoom Out*, and *Pan*, zoom into Troieshchyna residential area to make the map window of the GIS application look like shown in Fig. 1.51.



Fig.1.51. Map window of base OSM map of Troieshchyna residential area

5. Open the bands of downloaded satellite images in the application: B05 band for Landsat 5 and B08 band for Sentinel 2

These two bands capture NIR (Near Infrared) radiation, i.e. light within the near-infrared region of the spectrum (this is discussed in more detail in [paragraph 1.1](#)), however, there is a significant difference between them because the spatial resolution of the B05 band of Landsat 5 is 30 m, and that of the B08 band of Sentinel 2 is 10 m ([Annex 2](#)). Therefore, the level of detail will differ on these two images (Fig. 1.52).

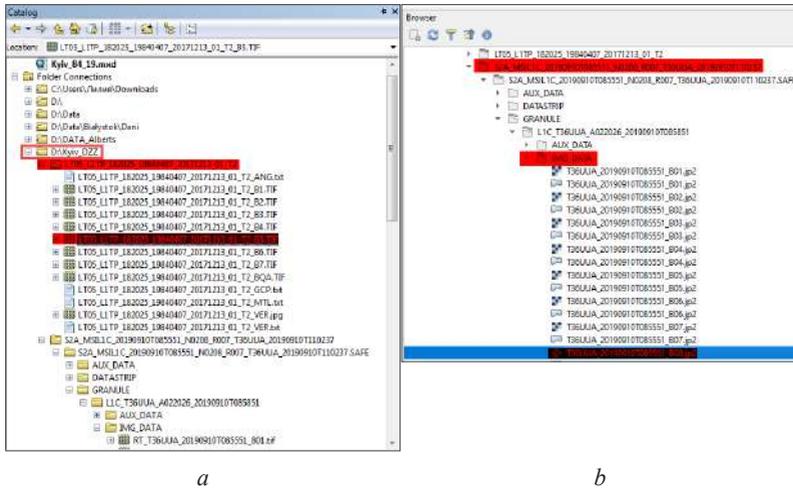


Fig. 1.52. B05 band of Landsat 5 in ArcMap *Catalog* (a) and B08 band of Sentinel 2 in QGIS *Browser* (b)

There are several ways to load the data into GIS application but the best is to use *Catalog* and *Browser* panels in ArcMap and QGIS, respectively, which allow you to activate any data folder for further work. You may add various data – raster, vector, tabular, etc. To add a file to the application layers, you need to place the cursor over it, hold down the left mouse button and drag it from *Catalog/Browser* to the map window.

If you have added data not required for your project, you may delete it by right-clicking on the layer and selecting *Remove* from the drop-down list – the layer will disappear.

6. Adjust the order of layers' visualization and rename them

The layers of your map project are stored in the *Table of Contents* (ArcMap) or *Layers* (QGIS) panels. You may change the drawing order of the layers and their visibility. You can disable and enable the layers you work with. This is especially convenient when the map has many layers. There is a mark in the box next to each layer. When this box is checked, the layer is displayed on the map.

The drawing order of the layers is important because it sets up the order of their display on the map. When you change something in the **Table of Contents** or **Layers**, the view of the map displayed in the working window changes automatically.

Sometimes it is necessary to rename the layer, especially when we deal with long names of satellite image bands, as in our case. You may both make the layer name shorter or rename the layer completely. This may be done very easily in the mentioned above **Table of Contents** or **Layers** panels in ArcMap or QGIS, respectively (Figure 1.53).

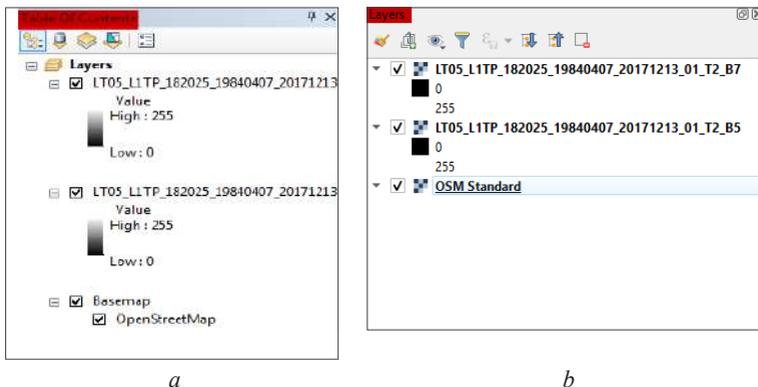


Fig. 1.53. Drawing order of layers in the **Table of Contents** in ArcMap (a) and **Layers** in QGIS (b)

7. Visually compare two images and calculate the increase in the area of the Troieshchyna neighborhood over 35 years

By adding two overlapping images you can easily see the changes in the area occupied by the neighborhood. Unchecking the box next to the layer name and using the navigation buttons allows you to view the images in detail and see different features (Fig. 1.54).

Measure the area occupied by the neighborhood using the **Measure** button on the toolbar. To do this, enclose the area of the neighborhood in a polygon in each image. Please note, to ensure matching of the units of measurement, use either square kilometers or hectares to measure the area.

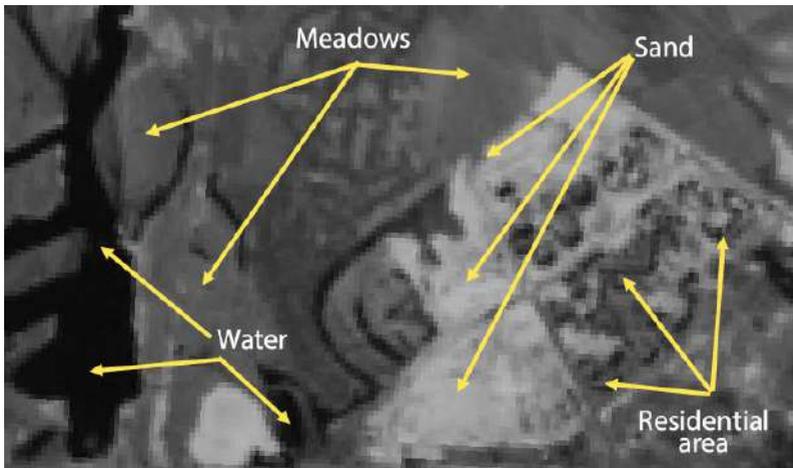


Fig. 1.54. Various features displayed in the Landsat 5 image collected on April 7, 1984 (B05 band)

8. Save the project

Since we have already created the project in step 2, to save it, click  **Save** icon on the toolbar and close the application.

We hope that the algorithm described above is clear to you. Below are the options for using this algorithm in two applications – ArcGIS and QGIS. Choose the application and let's start our work!

Performing a Task in ArcGIS



1. Unzip downloaded Landsat 5 and Sentinel 2 satellite images

We will work with two images – Landsat 5 of April 7, 1984, and Sentinel 2 of September 10, 2019. You need to decompress the files. Unzipped Landsat 5 image folder will look like shown in Fig. 1.55.

Sentinel 2 archive contains many supporting data, and the .jpg images are found in the “IMG_DATA” subfolder. Below is the path to this folder. Let's open it:

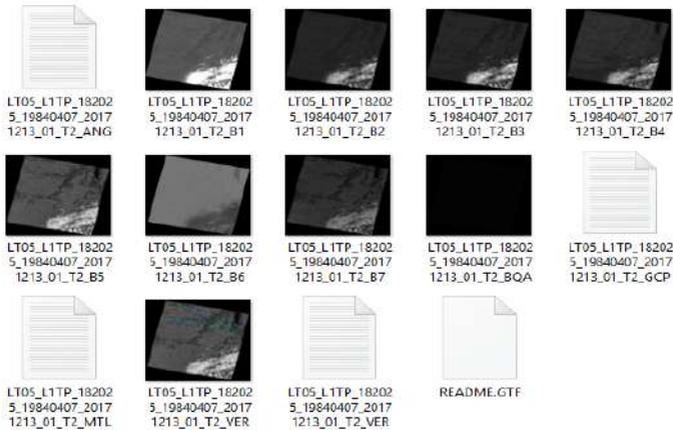


Fig. 1.55. Folder containing all spectral bands of downloaded Landsat 5 image

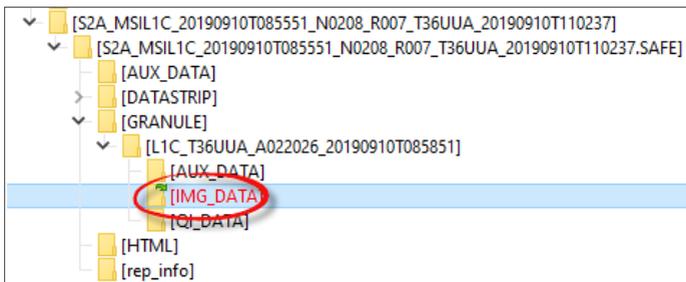


Fig. 1.56. The path to the folder with archived Sentinel 2 satellite images

2. Open ArcGIS 10.5 and create a project

To run ArcMap, click *Start* → *Programs* → *ArcGIS* → *ArcMap 10.5*, or find the program icon  on the desktop and press it. ArcMap 10.5 interface will open and the home screen will appear, where you can create *New Maps* or open the *Existing Maps* (Fig. 1.57), however, if you run the application for the first time, this list will be empty. At the bottom of the screen, there is a box to access the created map. Select *New Maps – Blank Map – Ok*. ArcMap working window will open.



A new map may be created using several other ways (Fig. 1.58):

- in the Menu bar, select **File** → **New**; select **Blank Map** in the new window → *Ok* (a);
- click the **New** button (b) on the toolbar in ArcMap and select **Blank Map** in the new window → *Ok*.

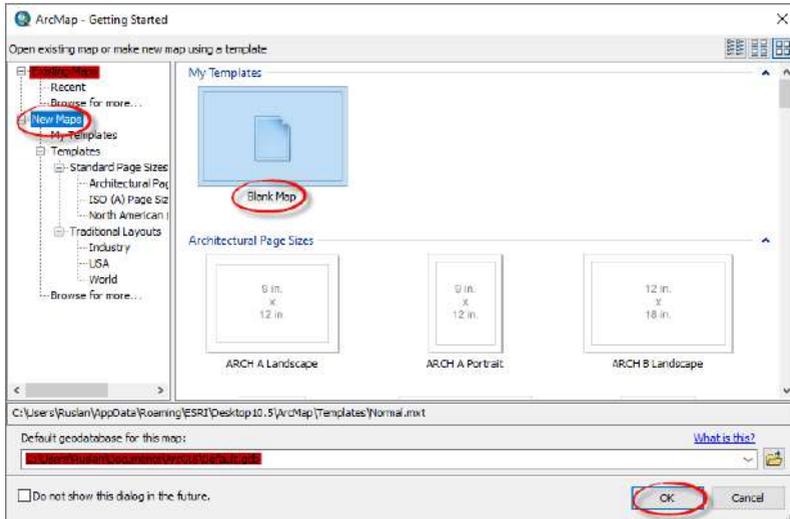


Fig. 1.57. Getting started in ArcMap

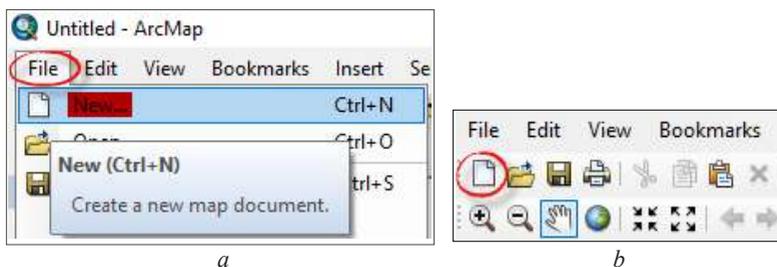


Fig. 1.58. Creating a new map document in ArcMap using the *Main menu* (a) or the *Standard toolbar* (b)



The interface of ArcMap application is discussed below. We will review the main toolbars, the buttons contained therein, their functions, and respective icons.

The **Standard** toolbar is the place to find all the buttons, which provide access to the main functions of the application (Fig. 1.59).

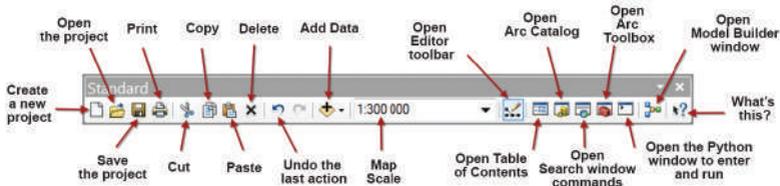


Fig. 1.59. ArcMap **Standard** toolbar buttons and their functions

Using the **Tools** toolbar, you can access the attribute table, zoom in/out, measure the distance, select features, search, etc. (Fig. 1.60).

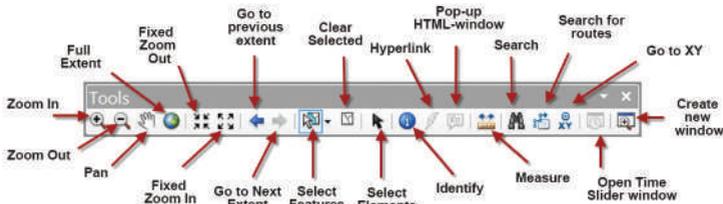


Fig. 1.60. The **Tools** toolbar

In addition to the toolbars discussed above, there are many more, which can be added to the project where needed.

To perform the task, the **Standard** and **Tools** toolbars should be checked in the boxes of the main menu, **Customize** → **Toolbars**. To do this, find these toolbars in the list and check them – any toolbar may be added to the ArcMap working window that way.

All toolbars in ArcMap are dynamic, i.e. you can change their location in the application's working window. You can move the toolbars using the cursor. Place the cursor over a far-left border of the toolbar. The cursor turns from an arrow into a crosshair. You may drag and place the toolbar whenever you feel comfortable.

Create a new project using the **File** → **Save As** buttons. Go to the “Kyiv_RS” folder in the dialog box that will appear. We have recommended that you save all project files to this folder (Fig. 1.61). In the **File name** box, type “Kyiv_84_19”. Left-click the **Save** button.

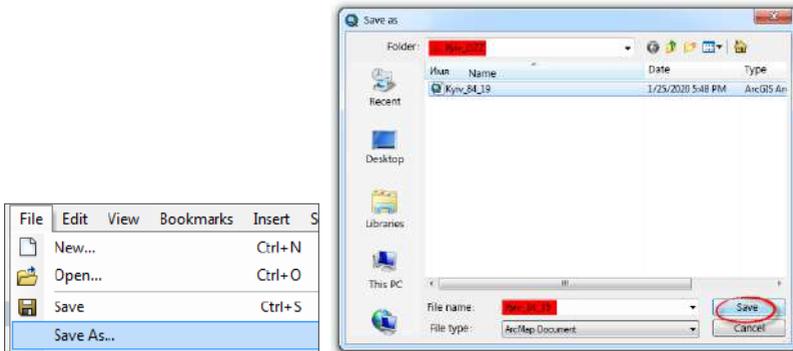


Fig. 1.61. Creating a new project in ArcMap 10.5

*In ArcMap, the project is saved as two files with *.MXD (project) and *.MXT (template) extensions. If you want to move the project to another folder, you must transfer both files.*

3. Add the *OpenStreetMap* base map

To find the boundaries of Kyiv city and determine the location of the Troieshchyna residential area, add an OpenStreetMap base map to the project. Open **Add Data** tool by clicking the arrow next to the tool icon and select **Add Basemap**. Select OpenStreetMap map in the window that opens (Fig. 1.62).

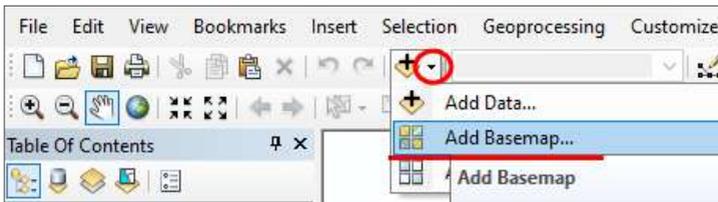


Fig. 1.62. Adding a base map to the project

As a result, the base map layer will appear in the Table of Contents.



4. Zoom into Troieshchyna neighborhood

Using the navigation tools, find Troieshchyna residential area on **OpenStreetMap** (which is located on the left bank in Kyiv city, on its northern outskirts), and zoom in to get the neighborhood completely displayed on the map as shown in Fig. 1.63.

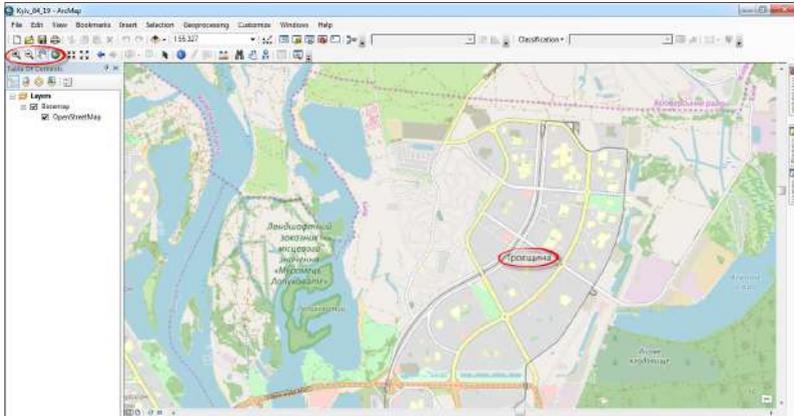


Fig 1.63. Zooming into the boundaries of Troieshchyna neighborhood in the map view

5. Open B05 band for Landsat 5 and B08 band for Sentinel 2

By selecting **Add Data**  from the menu, you can add data from different sources, as we did with OpenStreetMap. However, the **Catalog** window provides the best opportunities for searching and adding geospatial data from all available sources. It opens if you click the **Catalog** button on the right-side panel in ArcMap 10.5 application. If this button is missing in your software version, you may add it through the main menu, **Windows** → **Catalog**.

Choose **Connect to Folder** in the dialog box of the **Catalog** window and specify the path to the desired geodata folder. In this task, specify the path to the folder named “Kyiv_RS”, which you have created to store all project data (see page 51), and click **Ok** (Fig. 1.64).

The location of your folder depends on where you have saved it and is different for everyone. Try to save a folder with project data in a place where you can find it quickly.

The selected folder appears in the **Folder Connections** list of the **Catalog** window and will always be displayed there until you delete it. Open this folder (left-click the node to the left of the folder). As shown below (Fig. 1.65), this folder contains two folders with uploaded satellite images and a project file.

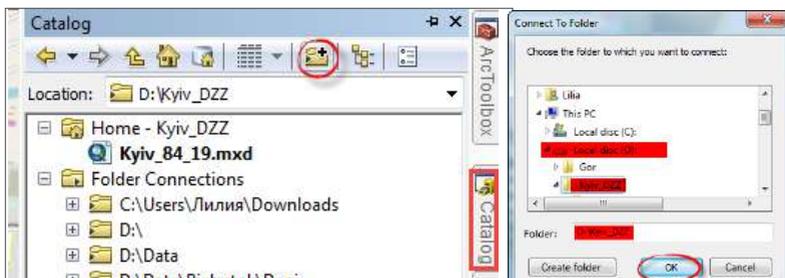


Fig. 1.64. Connecting the “Kyiv_RS” folder to the Catalog

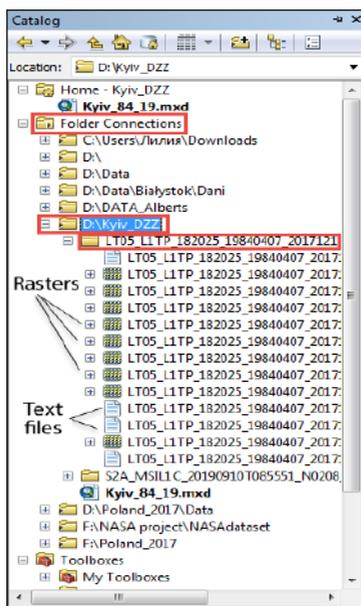


Fig. 1.65. Satellite image data in the project folder



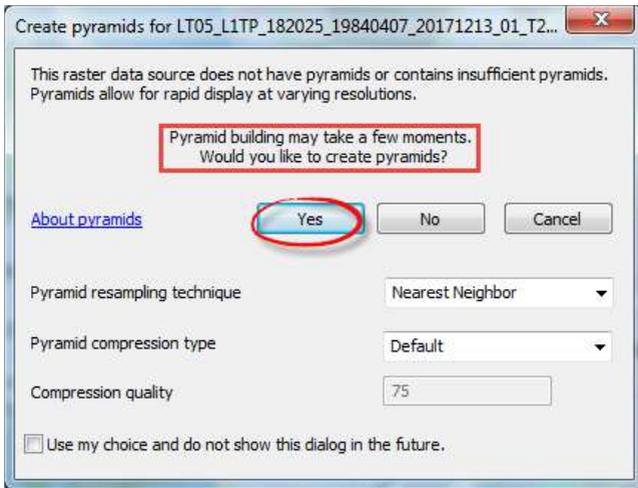


Fig. 1.67. The dialog box for creating a pyramid file for a raster image

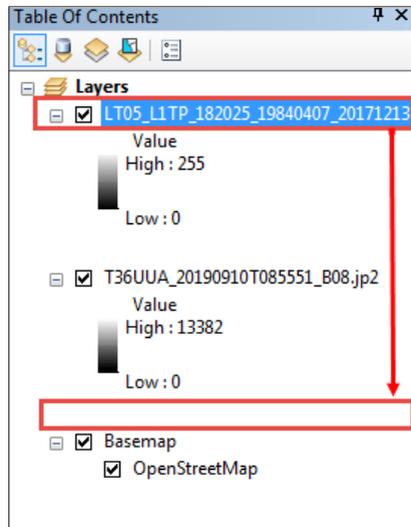


Fig. 1.68. Changing the order of layers display in ArcMap



As we see, the very first top layer in the *Table of Contents* draws on top of the layers below it. The order of layers visualization within the *Table of Contents* specifies their drawing order in the data frame. The check box next to each layer indicates that its display is currently turned on. You can turn off the layer display by unchecking the box, and then turn it on again as needed (Fig. 1.68).

Sometimes it is necessary to rename the layer, especially if it is a long name of a satellite image band, as in our case. You can do this by double right-clicking the layer name, “LT05_L1T_P_182025_19840407_20171213_01_T2_B5”. The *Properties* window will appear. Click the file name in the first *General* tab in the *Layer Name* line – it will become editable. Rename the layer to “Landsat5_B5_1984” (according to the following principle: satellite name_band name_year the image was collected) and click Ok. Similarly, rename the B08 band of Sentinel image (Fig. 1.69).

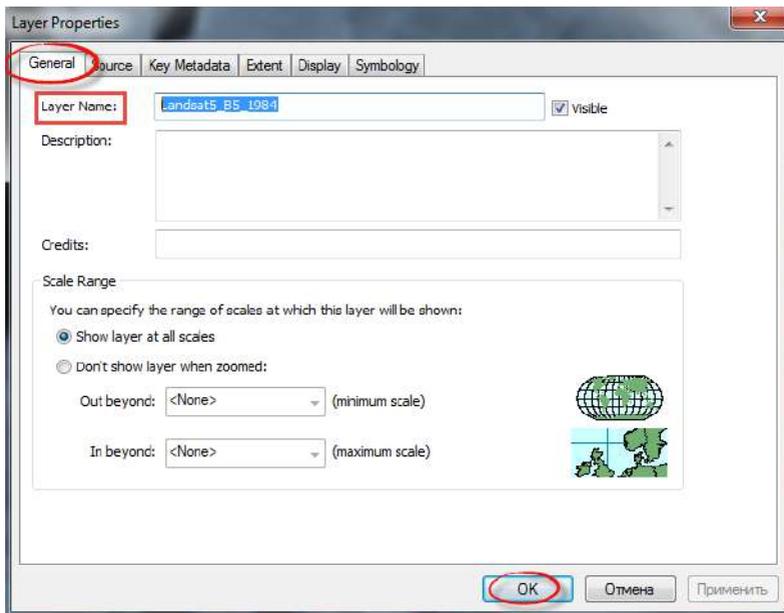


Fig. 1.69. Renaming the layer

Using the same *Properties* window, *Source* tab (Fig. 1.70), you can find out more information about the file and check whether the spatial resolution specified in the *Cell Size* line matches that stated in [Annex 2](#).



7. Visually compare two images and calculate the increase in the area of the Troieshchyna neighborhood over 35 years

By unchecking the box next to the top image in the *Table of Contents*, compare how the residential area changed in 2019 vs 1984. Note that all sandy areas, light spots in the 1984 image, are occupied with residential buildings in the contemporary image.

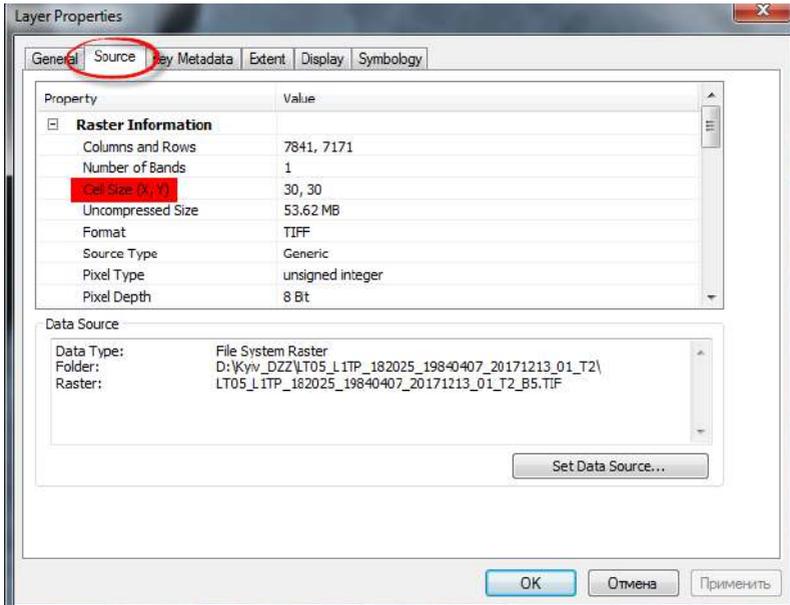


Fig. 1.70. Verifying the raster cell size

To measure the area of the neighborhood, find the *Measure*  button on the toolbar. By clicking, the mouse pointer will change to a crosshair. Make the first point at the border of the residential area. A new window will open. Select the *Area* button, then open the drop-down list next to the Σ button and select *Area* \rightarrow *Kilometers*. Enclose the area occupied by the neighborhood in 2019 into a polygon. Repeat the same procedure for the area of the neighborhood in 1984. You can complete drawing the polygon by double-clicking the last point. The area of the polygon will display in the *Measure* window, *Area* line (Fig. 1.71).

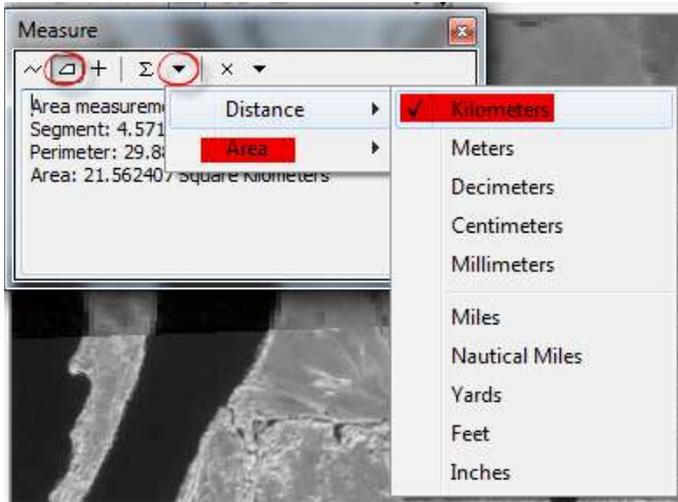


Fig. 1.71. Measuring the area in ArcMap using the *Measure* tool

Determine the changes (in square kilometers) in the area occupied by the Troieshchyna neighborhood over the period from 1984 to 2019. Write down the area of each polygon in your notebooks and calculate the difference (subtract one from another). The resulting area may differ from what is shown in Fig. 1.72, which is due to the accuracy of the polygon drawing.

8. Save the project

Since the project has already been created in step 2, now we will just save the changes by clicking the **Save**  icon on the toolbar. The application can be closed now. To reopen the project you have worked with, left-click the **Open**  icon and go to the place where you saved it, or open it via the *Catalog* (Fig. 1.73).

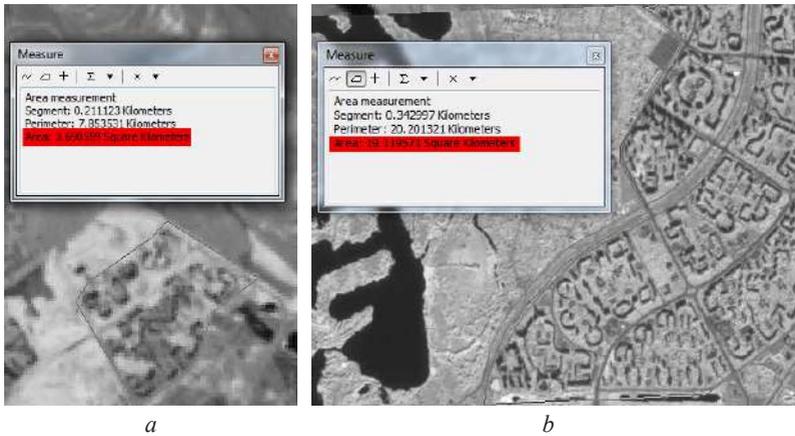


Fig. 1.72. Comparing the area of Troieshchyna neighborhood in 1984 and 2019: approximate area in 1984 according to Landsat 5 image (a), approximate area in 2019 according to Sentinel 2a image (b)

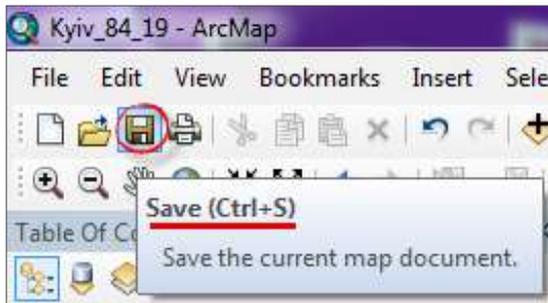


Fig. 1.73. Saving the project in ArcMap

Performing a Task in QGIS



1. Unzip downloaded satellite images

The archives of Sentinel 2 data of September 10, 2019, and of Landsat 5 data of April 7, 1984, must be decompressed using any archiver, such as 7zip (www.7-zip.org). The Sentinel 2 archive contains many supporting data, and the images are stored as .jpg files in the “IMG_DATA” subfolder. The path to this folder is shown in Fig. 1.74.

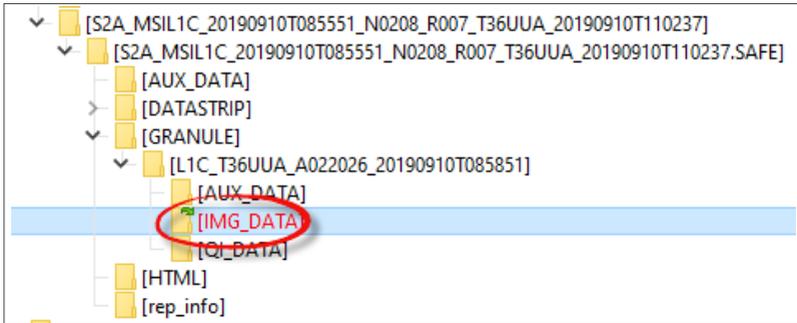


Fig 1. 74. The path to Sentinel 2 satellite imagery in the archive

A sample unzipped folder of the Landsat 5 image is shown in Fig. 1.75.

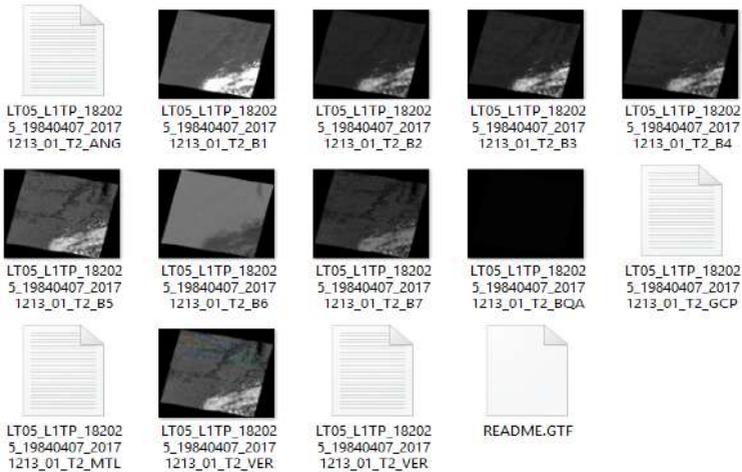


Fig. 1.75. Folder with all spectral bands of the downloaded Landsat 5 image

2. Open QGIS 3.4 and create a project

Launch QGIS 3.4 by clicking the *Start* → *Programs* → *QGIS Desktop 3.4.13 with GRASS 7.8.0* button (it is better to use this version of QGIS). You may also find the icon  on the desktop and run the program.

To install QGIS 3.4, go to official website at <https://qgis.org/uk/site/forusers/download.html> and choose the version that suits your operating system. You can read more about downloading this software in the theoretical part of this section above.

The QGIS 3.4 interface will open and the home screen will appear. It has the following options: creating a *New Project* or opening *Recent Projects*. If the program runs for the first time, however, the list of recent projects is empty. Therefore, we will create a new project by clicking the  icon (*New Project*) on the toolbar (Fig. 1.76).

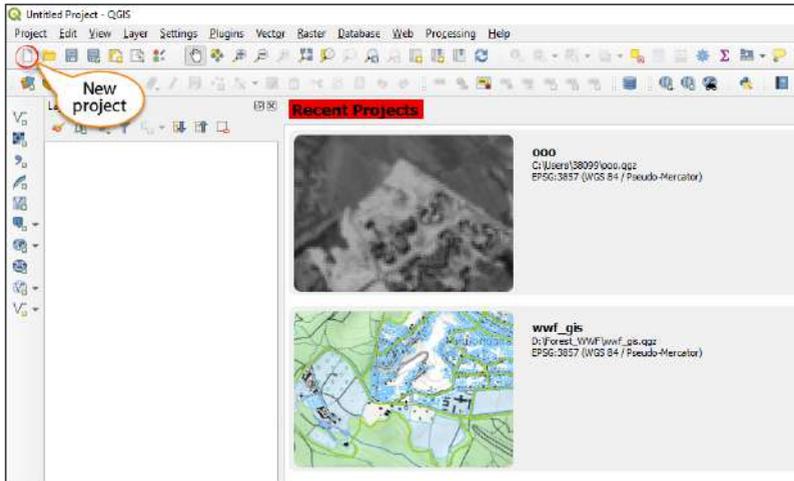


Fig. 1.76. QGIS 3.4 home screen

Make sure that the *Browser*, *Layers* and *Spatial Bookmarks* panels are open. If you do not see them, go to the top menu, *View* → *Panels*, and check the boxes near *Browser*, *Layers* and *Spatial Bookmarks* (Fig. 1.77).



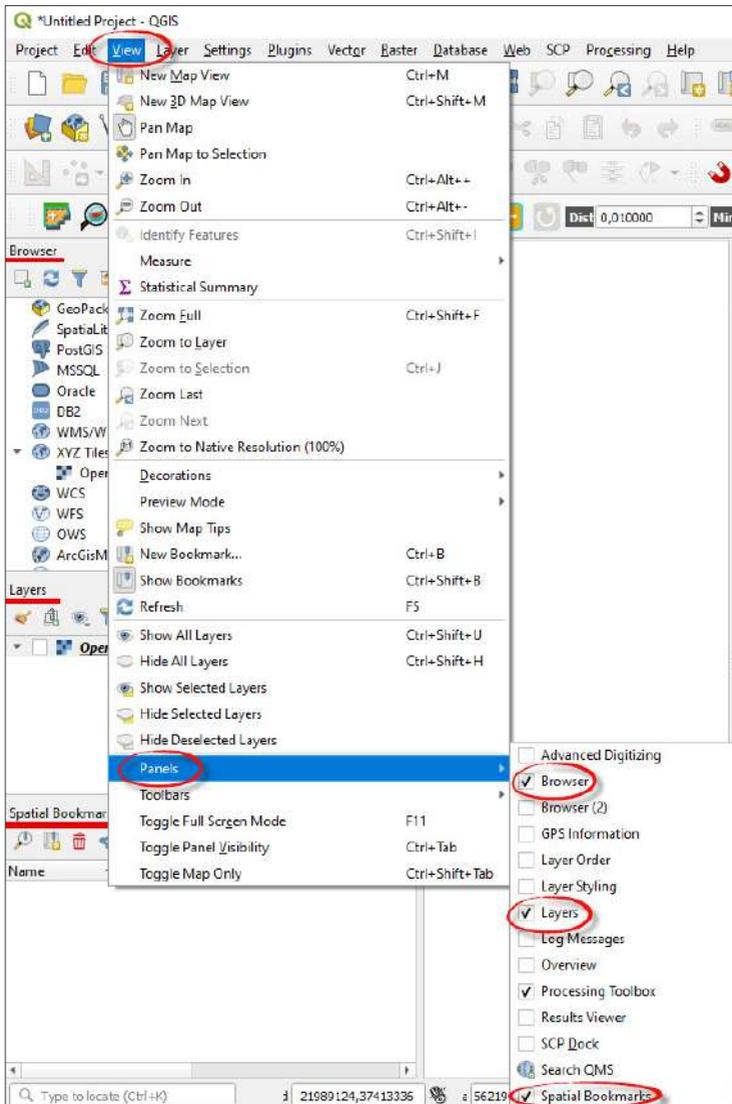


Fig. 1.77. Enabling the *Browser*, *Layers*, and *Spatial Bookmarks* panels

All toolbars in QGIS 3.4 are dynamic, i.e. you can relocate them within QGIS interface. To do this, place the cursor at the far-left border of the toolbar (the cursor will turn from an arrow into a crosshair), and move the panel wherever you feel comfortable.

Create a new project using the **Project** → **Save As** buttons. Go to “Kyiv_RS” folder in the dialog box. We have recommended saving all project files to this folder (Fig. 1.78). Type “Kyiv_84_19” in the **File name** line. Left-click the **Save** button.

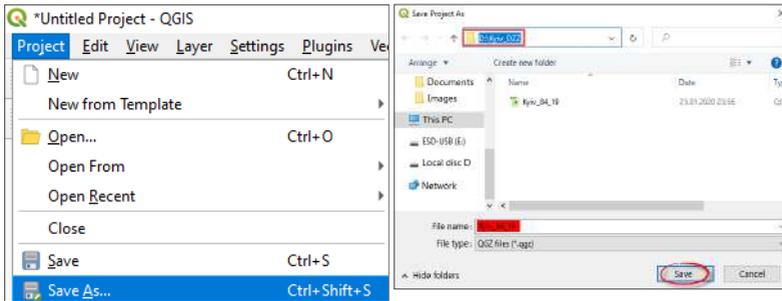


Fig. 1.78. Creating a new project in QGIS 3.4

3. Add the *OpenStreetMap* base map

To find the boundaries of the Troieshchyna residential area, add an OpenStreetMap map to the project. To do this, open **XYZ Tiles** on the **Browser** panel, and double-click the OpenStreetMap layer to open it in the Layers list and in the map view window (Fig. 1.79).

4. Zoom into Troieshchyna neighborhood

Using the navigation tools listed in [Table 1.2](#), find the Troieshchyna residential area on OpenStreetMap (it is located on the left bank in Kyiv city, on its northern outskirts), and zoom in to get the neighborhood completely displayed on the map as shown in Fig. 1.80.



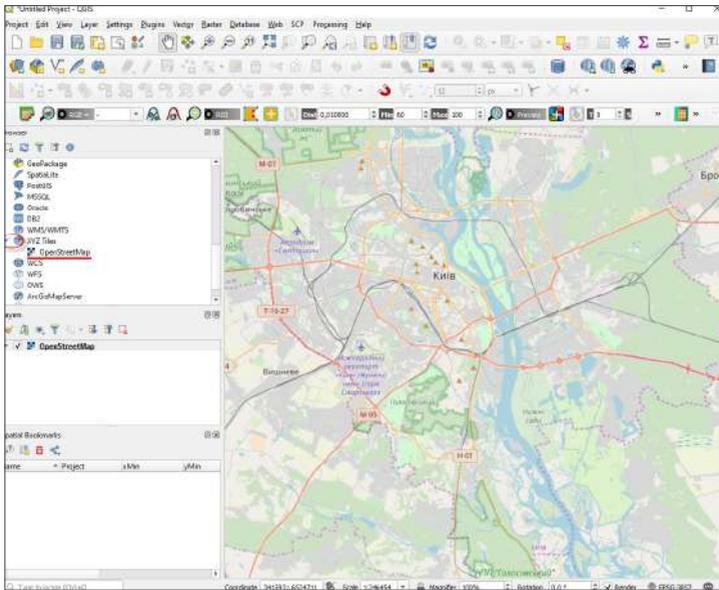


Fig. 1.79. Adding the OpenStreetMap base map to the project

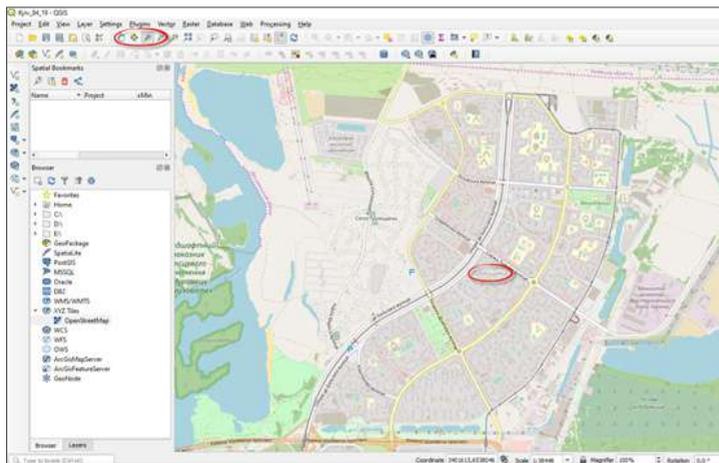


Fig. 1.80. Zooming into the boundaries of the Troishchyna neighborhood in the map view window

Table 1.2

QGIS Navigation Tools

Menu Button	Functions
	Pan map
	Pan map to selection
	Zoom in
	Zoom out
	Zoom full
	Zoom to selection
	Zoom to layer

5. Open B05 band of Landsat 5 and B08 band of Sentinel 2

The **Browser** function provides the greatest opportunities for searching and adding geospatial data from all available sources. The **Browser** window opens if you click the **Catalog** button on the left-side panel of QGIS 3.4 (Figure 1.81).

In the **Browser** dialog box, expand the path to the required geodata folder (namely, “Kyiv_RS”), which you have created before to store all project data, and click **Ok** (Fig. 1.82).

The location of your folder depends on where you have saved it and is different for everyone. Try to save a folder with project data in a place where you can find it quickly.



Open this folder (left-click on the triangle to the left of the folder). As you can see, the folder contains two more folders with downloaded satellite images and a project file. If you open, for example, the Landsat 5 image folder, you will see thumbnails next to the file names, which are visual representations of the type of spatial features contained in the file. In our case, the thumbnails show that the folder contains bitmap files and several text files.

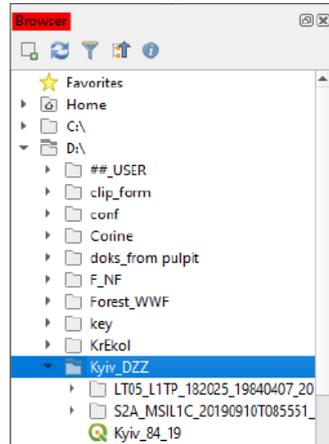


Fig. 1.81. “Kyiv_RS” folder in the *Browser* panel

Find the B05 band in the Landsat folder (LT05_L1TP_18...) and the B08 band in the Sentinel folder (S2A_MSIL1C_2019...), and relocate them to the map view window. To do this, just hold down the band with the left mouse button and drag it from the *Browser* to the QGIS map view window (Fig. 1.83).

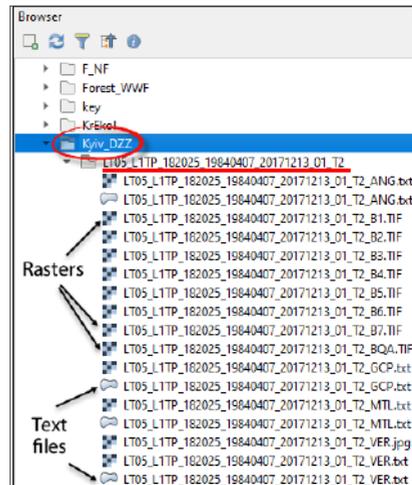


Fig. 1.82. Satellite image data in the project file

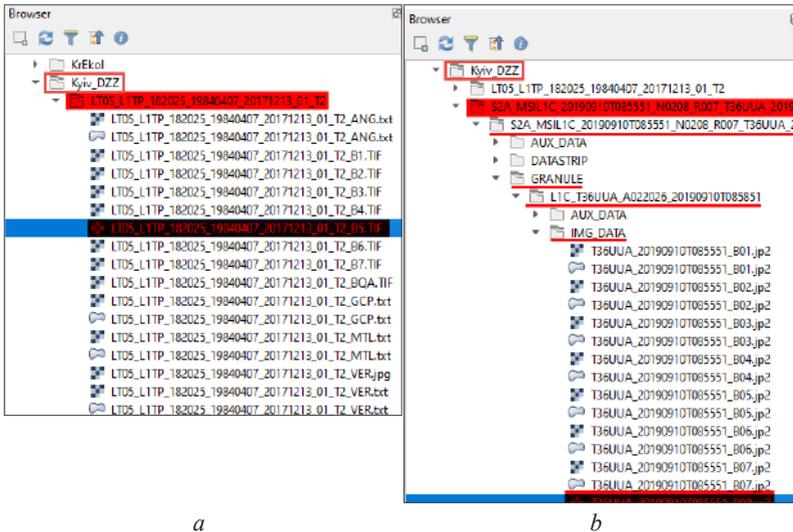


Fig. 1.83. Location of bands to be downloaded to QGIS: B05 band of Landsat 5 (a), B08 band of Sentinel 2 (b)

If you have added an unnecessary layer, you can remove it (Fig. 1.84). Just right-click such layer, and select **Remove Layer** in the drop-down box.

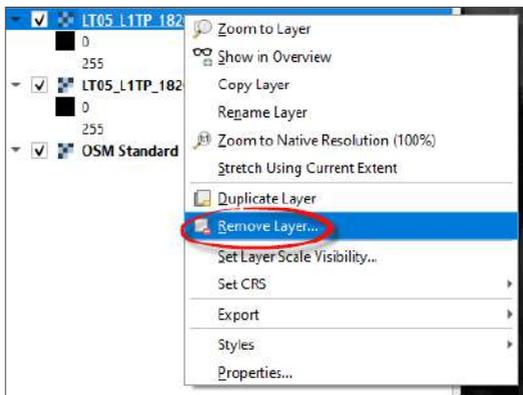


Fig. 1.84. Removing a layer in QGIS



6. Adjust the order of layers' visualization and rename them

Select the name of the B5 Landsat 5 layer, and drag it to the bottom of the *Layers* panel while holding down the mouse button, and place it below the B8 Sentinel 2 layer.

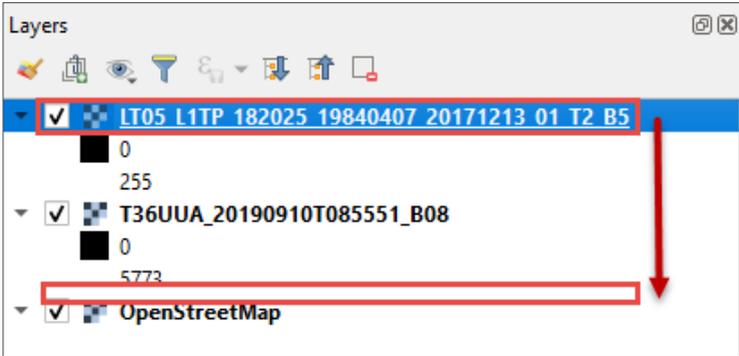


Fig. 1.85. Changing the order of layer visualization in QGIS

As we can see, the very first layer in the Layers panel draws on top of the layers below it. The check box next to each layer indicates that its display is currently turned on. You can turn off the layer display by unchecking the box, and then turn it on again as needed (Fig. 1.85).

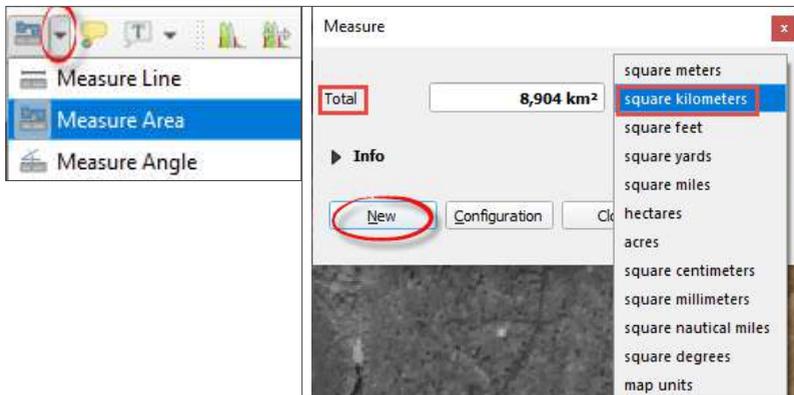
Sometimes it is necessary to rename the layer, especially when working with a long name of a satellite image band, as in our case (Fig. 1.86). You can do this by double right-clicking the layer name, “LT05_L1TP_182025_19840407_20171213_01_T2_B5”. The *Layer Properties* window will appear. Click the file name in the *Source* tab in the *Layer Name* line – it will become editable. Rename the layer to “*Landsat_B5_1984*” (according to the following principle: satellite name_band name_year the image was collected) and click Ok. Similarly, rename the B08 band of Sentinel image.

In the same Layer Properties window, particularly in the Information tab, you can find more information about the file and verify whether the spatial resolution (Fig. 1.87) specified in the Pixel Size line matches that stated in the [Table \(Annex 2\)](#).

7. Visually compare two images and calculate the increase in the area of the Troieshchyna neighborhood over 35 years

By unchecking the box next to the top image in the *Layers* module, determine how the area changed in 2019 vs 1984. Note that all sandy areas (light spots in the 1984 image) are occupied with residential buildings in the recent image.

To measure the area of the neighborhood, find the *Measure* button on the toolbar. By clicking the triangle next to it, a drop-down menu will appear. Select *Measure Area* in this menu.



a

b

Fig. 1.88. Measuring area in QGIS using the *Measure Area* tool (a) and adjusting units of measurement (b)

The mouse pointer will turn into a crosshair, and a dialog box will appear where you need to select the units of measurement – square kilometers (Fig. 1.89). Put the first point at the border of the neighborhood. Enclose the area occupied by the neighborhood in 2019 into a polygon. Repeat this operation for the area of the neighborhood in 1984. You can complete drawing the polygon by right-clicking the last point. To start enclosing a new area into a polygon, click the *New* button in the *Measure* window. The area of your polygon will be displayed in the *Total* bar expressed in square kilometers.

Determine the changes (in square kilometers) in the area occupied by the Troieshchyna neighborhood over the period from 1984 to 2019 (Fig. 1.89). Write down the area of each polygon in your notebooks and calculate the difference (sub-

tract one from another). The resulting area may differ from what is shown in Fig. 1.89, which is due to the accuracy of polygon drawing.

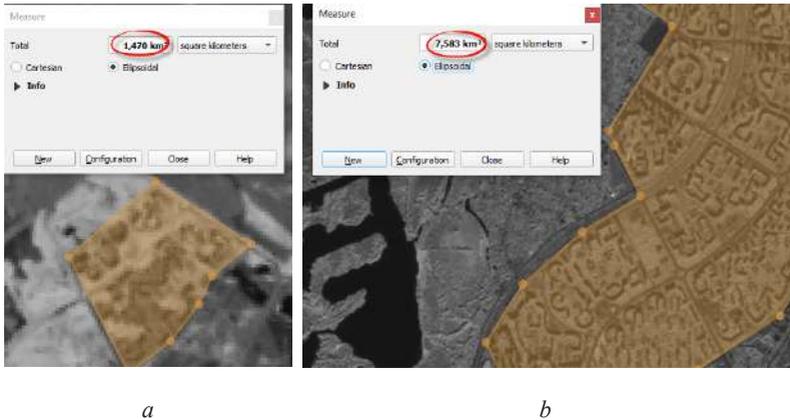


Fig. 1.89. Comparing the area of Troieshchyna neighborhood in 1984 and 2019: approximate area in 1984 according to Landsat 5 image (a), approximate area in 2019 according to Sentinel 2a (b) image

8. Save the project

Since the project has already been created in step 2, now we will just save the changes by clicking the **Save Project**  icon on the toolbar (Fig. 1.90). Close the application now. To reopen the project you have worked with, left-click the **Open**  icon and go to the place where you saved it, or open it via the **Browser** panel.

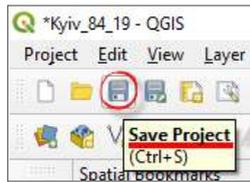


Fig. 1.90. Saving the project in QGIS



Section for the Youngest Audience



Google Earth is a free program, a “*virtual globe*” from Google that allows users to view 3D-models of Earth, Mars, and Moon with superimposed high-resolution aerial photography and satellite images, and various data layers, including detailed celestial maps.

Currently, there are two simplified versions of Google Earth: a web version for exploring 3D locations in the browser, and a version for mobile devices, which enables browsing the globe with a swipe of your finger on your phone or tablet (Fig. 1.91).

However, the most convenient for the users who need advanced features is an extended desktop version of Google Earth Pro, which allows you to import and export GIS data, and go back in time with historical imagery.

To download and install Google Earth on your computer (Fig. 1.92), go to the official website <https://www.google.com.ua/earth/> and click the *Earth Versions* tab on the homepage to select the required version of the application, namely – *Google Earth Pro on desktop* (Download Earth Pro on desktop).

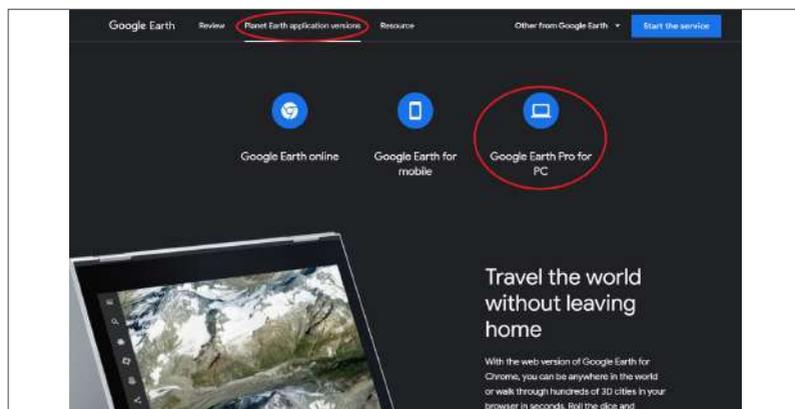


Fig. 1.91. Official Google Earth website; selecting an application version [10]

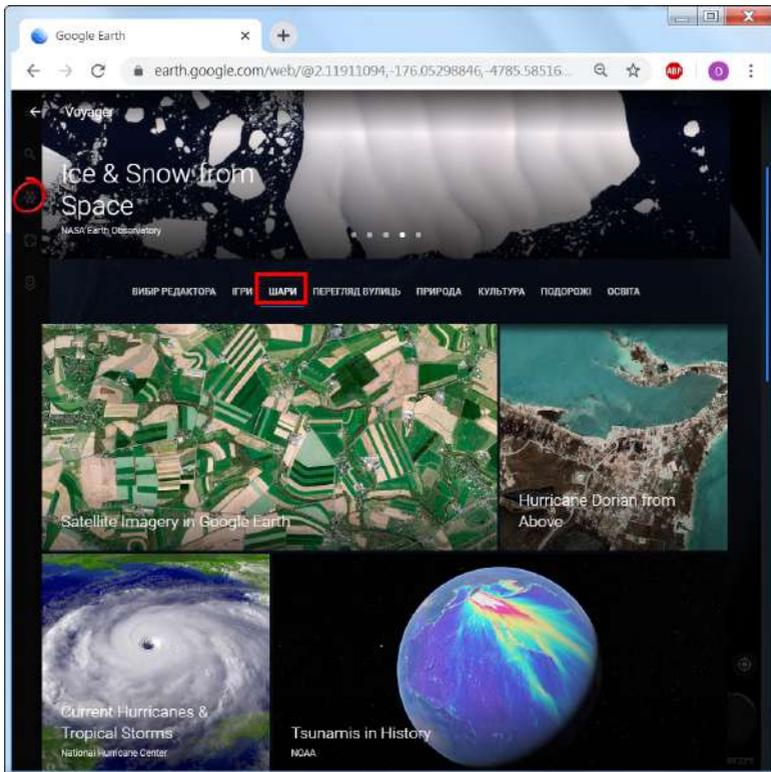


Fig. 1.92. Google Earth for Chrome; available layers

Below is a detailed description of Google Earth Pro functions. When you launch the application, the Earth appears in the 3D viewer within the user interface. It is possible to change the position of the view through the navigation controls (Fig. 1.93). In Fig. 1.94, we have zoomed into Mount Hoverla – the highest mountain in Ukraine (Fig. 1.94). The mouse navigation provides wide capabilities:

- with the left mouse button held down, you can pan the map relative to the point where the cursor is fixed;
- with the right mouse button held down, you can zoom in by moving the mouse down, and zoom out by moving it up;





- with the right button or mouse wheel held down, you can rotate the map by dragging the mouse to the left or to the right;
- with the mouse wheel held down, you can change the tilt by dragging the mouse up and down.

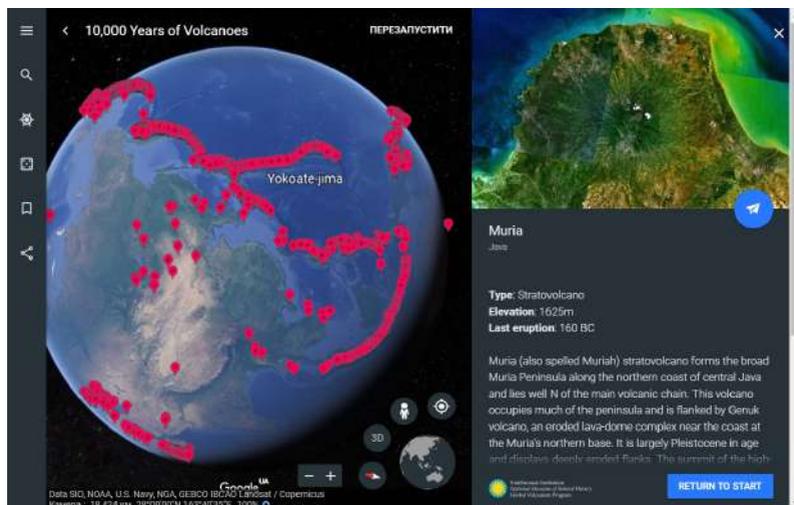


Fig. 1.93. The web version of Google Earth for Chrome; *1,000,000 years of Volcanoes* layer

The panel on the left-hand side of the screen allows you to search for locations by their names (*Search* module), manually digitize the areas of your interest, and export them to GIS (*Places* module), or view available layers (*Layers* module). The most interesting reference information is contained in the application's thematic layers. In particular, the *Gallery* layer has the information about the features available from the Internet, or other data such as: "360 cities", Discovery channel, YouTube, Everytrail, National Geographic Magazine, and many more. With the *Photos* layer, it is possible to explore our planet based on the photos taken by different users in remote parts of the world and upload your own photos of a specific location.

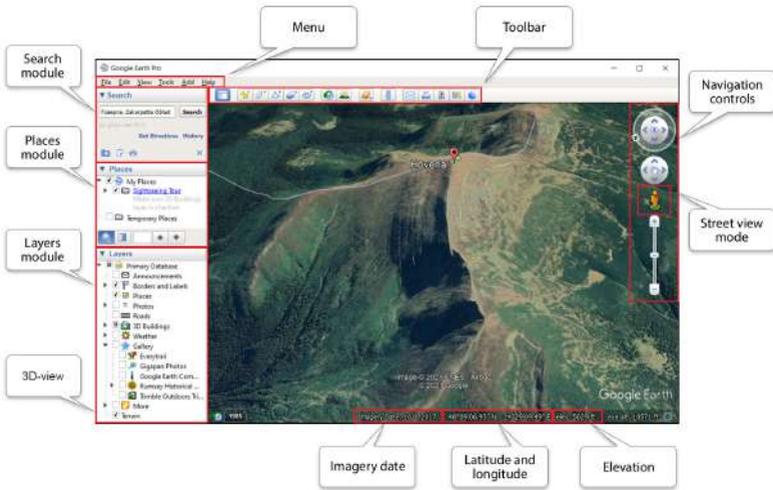


Fig. 1.94. Google Earth Pro user interface

The Menu and Toolbar at the top of the Google Earth screen give access to a variety of program settings and features (Fig. 1.95). Some tools allow you to create your own placemarks, routes, make virtual trips, record and save them for playback. Using other tools, you can create animations, visually illustrate changing seasons, the revolution of the Earth around the Sun, and the day and night cycle. There are also tools that allow you to measure the exact distance between geographical features, view celestial bodies in a virtual planetarium, and save and share other screen images via email, and print, view specific features using Google Maps service.

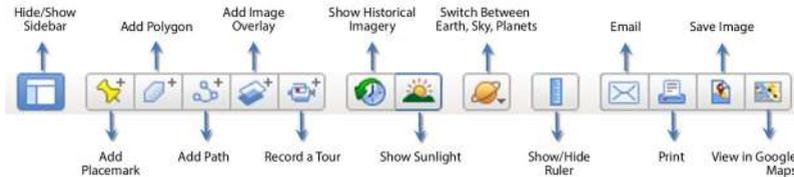


Fig. 1.95. Google Earth Pro Toolbar

The use of Google Earth Pro application for studying the development of one of the residential areas of Kyiv (Troieshchyna) is discussed below.

Task

Calculate the increase in the area of the Troieshchyna neighborhood in Kyiv over 35 years.

1. Zoom into the Troieshchyna neighborhood

In Google Earth Pro, you can search for a specific location by entering geographical coordinates or simply using the map navigation. The easiest way, however, to find the Troieshchyna residential area is to type the name in the search bar (Fig. 1.96).

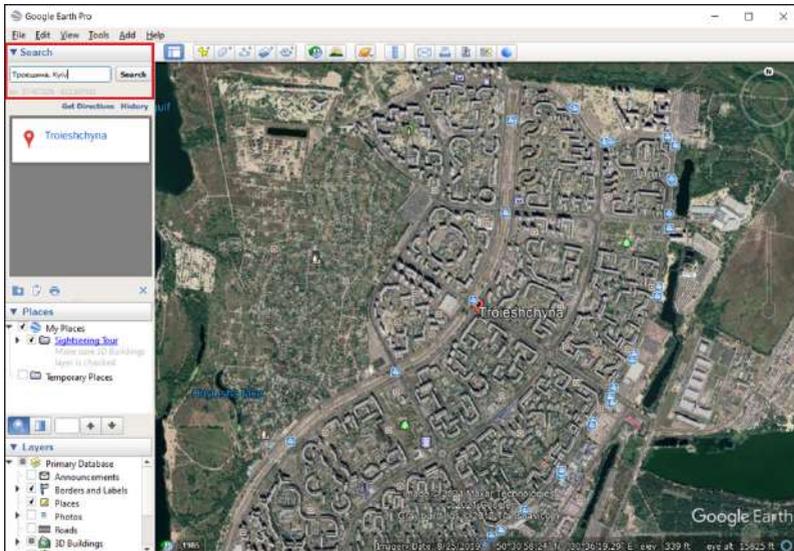


Fig. 1.96. Searching for the Troieshchyna neighborhood by entering the name in the Search bar

2. Find the oldest and most recent images

To see how the residential area looked like in the past, use the historic imagery function of the application, namely select the tool *Show Historical Imagery*. Use the time slider to move between acquisition dates. This tool can also be called a *Chronograph*. It allows you to see how much the land has changed using the satellite images.

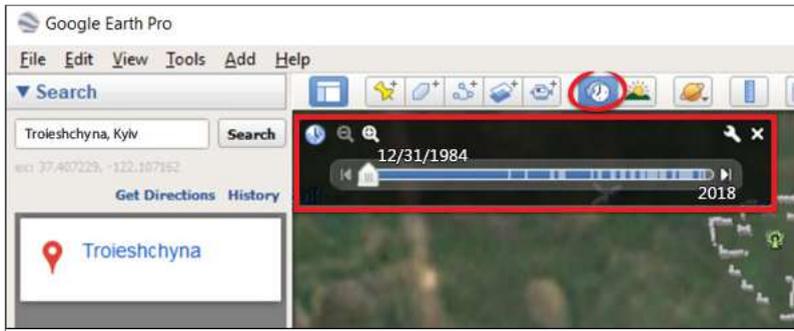


Fig. 1.97. Searching for images from 1984 using *Show historical imagery* tool

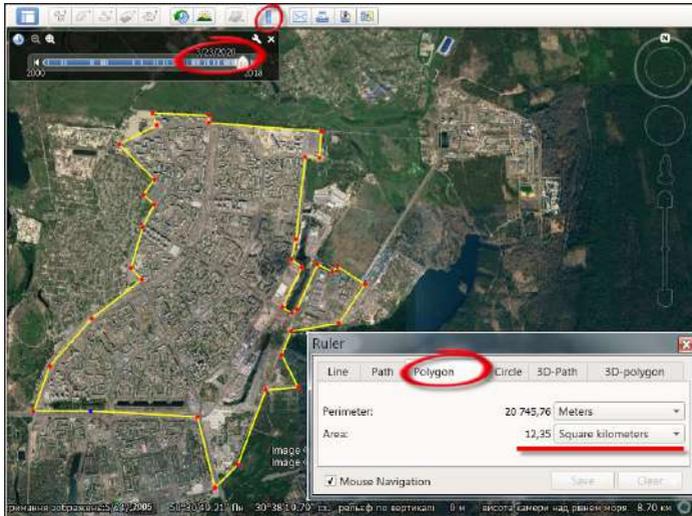
3. Visually compare two images and calculate the increase in the area of the Troieshchyna neighborhood over 35 years

Use a *time slider* to scroll through imagery collected at different dates and see how much the neighborhood has changed. In particular, Fig. 1.97 shows the Troieshchyna residential area in 1984, when it was covered with floodplain meadows. White areas in the satellite image represent areas of hydraulic fill intended for construction. To measure the area of the neighborhood, click the *Show ruler*  button on the toolbar. The mouse pointer will turn into a crosshair, and a dialog box will appear where you should select a shape – *Polygon*, and units of measurement – *Area, Square kilometers* (Fig. 1.98). Add a starting point on the edge of the neighborhood and smoothly outline the neighborhood’s boundaries by holding down the left mouse button. Draw polygons for the areas of 2019 and 1984. To save your polygons, click *Save*.

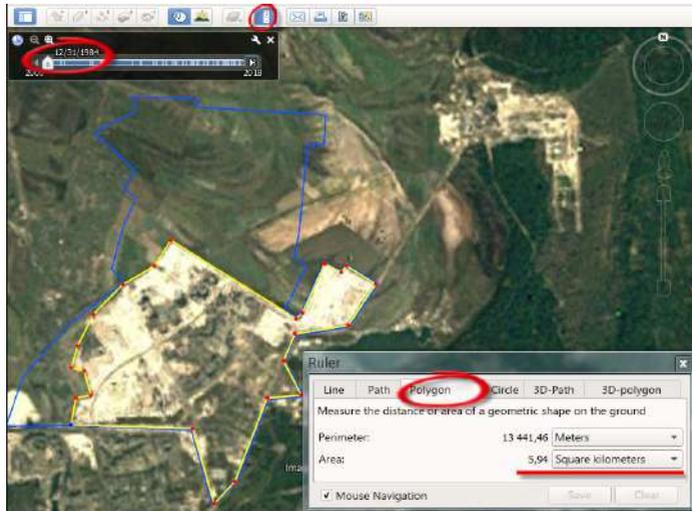
Calculate the changes (in square kilometers) in the area of the Troieshchyna neighborhood over the period from 1984 to 2019. Write down the results obtained for two polygons and calculate the difference.

This application has many other interesting functions, which will be further discussed in [Section 2.1](#). One more Google service, Google Timelapse, is described in [Annex 3](#).



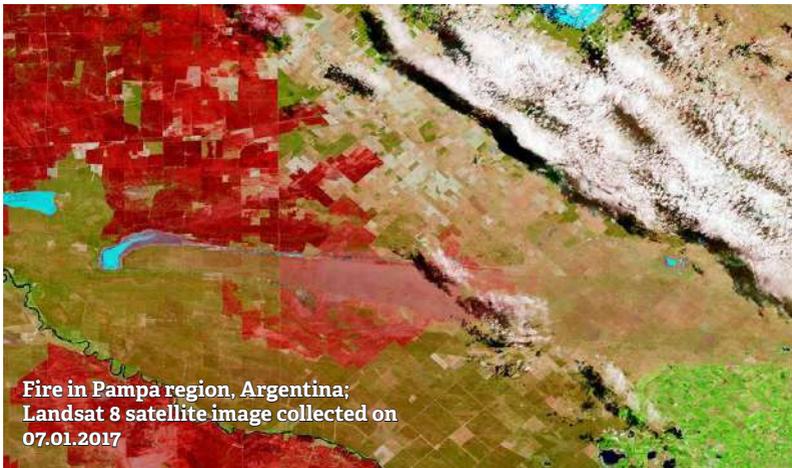


a



b

Fig. 1.97. Measuring the area of the Troichshchyna neighborhood in 2019 (a) and 1984 (b)



1. 4. Pre-Processing and Visualization of RS Data

As you already know from the previous Section, “raw” satellite images may provide little information when you first see them. However, using appropriate visualization and processing tools, we can retrieve enormous amount of information from satellite imagery.

Task

In this task, we will create a color satellite image of Kyiv city and identify a fire seat in Darnytsia forest using the images collected by the satellite (Sentinel 2) on October 4, 2015.

Data

Two Sentinel 2 images of the territory of Kyiv dated October 4, 2015; tile numbers: 36UUB and 36UUA.

Task Performance Algorithm

1. Selecting and downloading images

If we look at the scheme of scenes (tiles) on the Sentinel 2 satellite imagery, which depends on the satellite’s orbit, we will notice that to create a comprehensive satellite image of Kyiv city it is necessary to combine two satellite images: tile numbers 36UUB and 36UUA or 35UQS and 35UQR (Fig. 1.99).

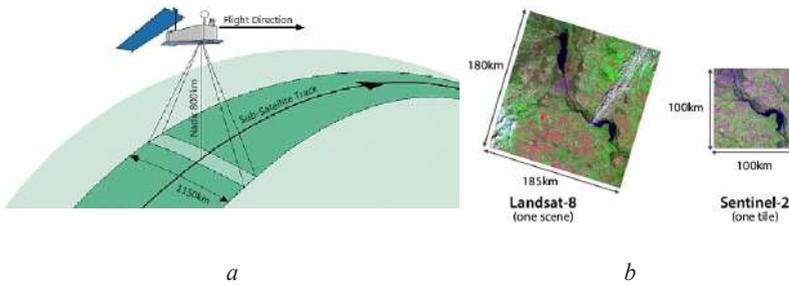


Fig. 1.101. Satellite sensor swath (a) and comparison of image sizes (b)

We will find and download two images of Kyiv city collected by Sentinel 2 on 04.10.2015 (tile numbers 36UUB and 36UUA) using downloading instructions of Copernicus Open Access Hub catalog described in paragraph 1.2 (Fig. 1.102).

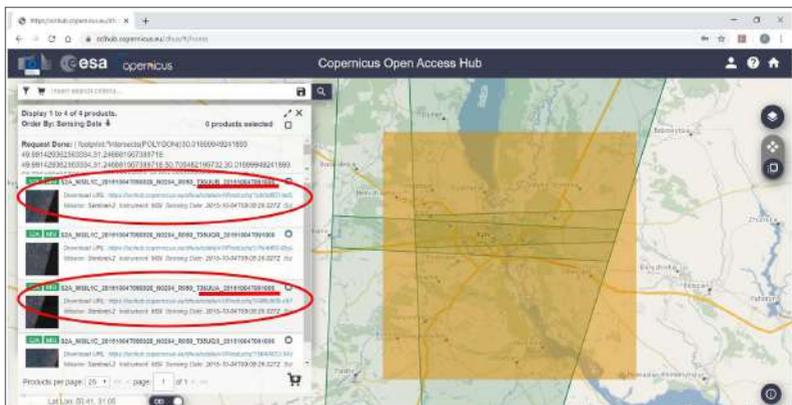


Fig. 1.102. Selecting images for the task using Copernicus Open Access Hub catalog

As a result, we will have two files, which must be unzipped using any standard archiver, such as 7zip (<https://www.7-zip.org>).

2. Band combination and synthesis for identification of fires

Band synthesis refers to the merge of satellite image bands into one color image.

Different terrestrial objects (e.g. forests and water) reflect different wavelengths of light (within different spectral ranges) (see Fig. 1.103).

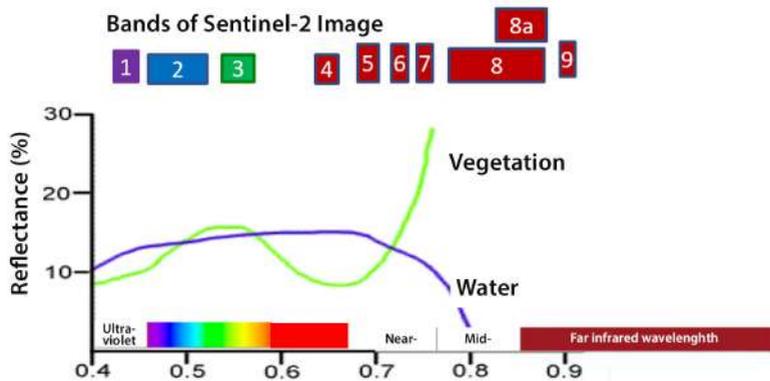


Fig. 1.103. Bands of Sentinel 2 with spectral curves of water and vegetation

For example, the forestland on the Sentinel 2 image collected in the band B04 (red) will have low values and appear as a dark area (color gradation is usually displayed from black to white), while the road will be displayed in a lighter color. (Fig. 1.104). At the same time, the forestland will appear as a light area in the band B08 (infrared) image and the road – as a dark area, since vegetation high reflectance in this band. Using the combination of bands of different sections of the electromagnetic spectrum allows identifying the phenomena or properties of terrestrial objects invisible to the naked eye.

As you can see, the forest cover appears differently in the two images.

Find areas in the forest which differ in the two images collected in different bands – these areas may be indicative of different species, ages, and condition of trees.

To create a color image, you need to perform **band synthesis** using ArcGIS or QGIS tools. Any color image is composed of three bands: **Red**, **Green**, and **Blue**. Such images are also called RGB images – this principle is shown in Fig. 1.105.



Fig. 1.104. The appearance of forestland in red (a) and infrared (b) bands

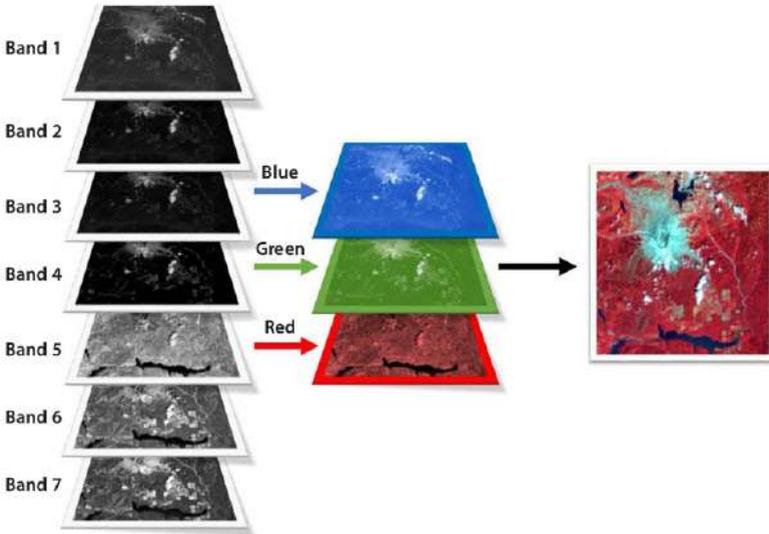


Fig. 1.105. Synthesis of satellite bands: of the available black-and-white images (various bands), we can select any three and represent them in blue, green, and red colors; these colors produce the whole range of colors when combined



Fig. 1.106. Place of fire in the satellite image collected by Sentinel 2: a combination of B04, B03, B02 bands (a), a combination of B12, B08, B02 bands (b)

To make natural-color image (such as seen by the human eye), it is necessary to select three satellite bands that register EMR in the red, green, and blue ranges, respectively, for bands synthesis (a portion of the spectrum visible to the human eye). According to Table in [Annex 2](#), these bands for the Sentinel 2 satellite are, namely: B04, B03, B02.

Using the combination of bands in natural colors (Fig. 1.106, a) we can clearly notice the clouds of smoke at the site of a forest fire. However, it is quite difficult to determine the area covered by the fire. You can detect the fire area using a thermal (infrared) band. For example, with the combination of bands, B12 (Mid-IR), B08 (Near IR), and B02 (Blue), the forest area damaged by fire becomes visible (Fig. 1.106, b).

To learn more about the combination of bands of Landsat 8 and Sentinel 2 satellite images, see [Annexes 4 and 5](#).

3. Clipping images

Clipping an image refers to the extraction of a required area from a satellite image for further study. This is important both for a better visual representation of the area of interest and for accelerating data processing by the computer. Large image files can use too much CPU; therefore, you should work with the area of study only, not the entire satellite image scene.

There are many ways to specify the area for clipping:

- using the contours of the rectangle defined by specific x and y minimum and maximum coordinates (i.e. the coordinates of the top left and bottom right corners of a rectangle that defines the area of interest;

- using the extent of the current work window (map extent);
- using the contours of another raster or vector layer.

Since Kyiv city is located at the junction of two Sentinel 2 images, and each of the images covers a much larger area than required to create an image of the city (Fig. 1.99), it is worth clipping the images to limit the display to the studied area only rather than displaying the whole scene (covered area). It is also important to clip the image to make its processing faster.

4. Mosaicking

A mosaic is a combination or stitching two or more images to create a single raster dataset. This tool allows getting an integral image of the area under study.

5. Image enhancement

Sometimes the image may appear too dark or too light. To enhance the image, you may use image brightness and contrast adjustment tools, or histogram stretching in the layer properties window. Histogram stretch function analyzes the pixel values of the entire image and enhances its display, for example, in the range from the minimum to the maximum pixel values. Another common type of the histogram stretch is percent clip, which allows you to display the image within a specified percentage of values, such as 95% of the pixel values of the image, ignoring 5% of the highest and lowest pixel values, which may be erroneous, unimportant or caused by sensor failure (Fig. 1.107, 1.108).

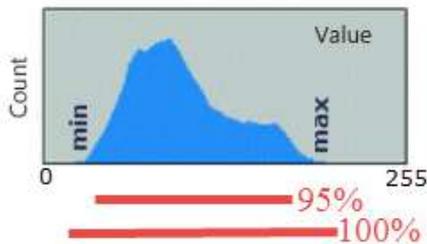


Fig. 1.107. Histogram of image pixel values

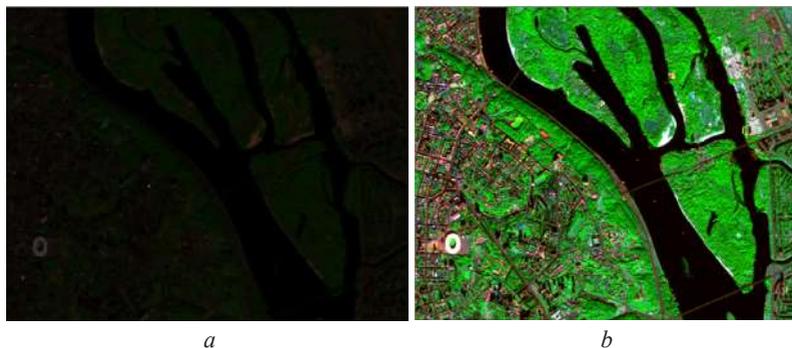


Fig. 1.108. Example of histogram stretching: not adjusted image (a), image following *Percent Clip* histogram stretching (b)



ArcGIS

Performing a Task in ArcGIS

To begin with, run ArcMap application, create a new project and open the OpenStreetMap layer following the instructions in [paragraph 1.3](#).

Using the navigation tools, find Kyiv city on the OpenStreetMap map and zoom into the map so that the whole city is fully displayed on the map as shown in Fig. 1.109.

In our example, we will perform image clipping. To use the same map area in different image processing procedures, such an area may be saved to bookmarks, and you will be able to return to it easily after moving across the map. To do this, click the **Bookmarks** tool in the top menu and select **Create Bookmark**. If necessary, invent a name for the bookmark and click *Ok* (Fig. 1.110).

By reopening the **Bookmarks** menu, you can select the desired bookmark for the saved map area, and the desired location will be automatically displayed in the map window. The *OpenStreetMap* layer can be disabled in the project to prevent the slow running of the application.

Open *ArcToolbox* in the top menu. The ArcToolbox toolbar will appear to the right of the map view window. Select **Data Management Tools** tab, **Raster** tab, and **Raster Processing**. Double-click **Composite Bands** tool.

You will see a window for band synthesis. Specify the bands you want to merge in the **Input Rasters** line. To do this, click the folder icon in the **Input Rasters** line, find the folder that contains the image bands and select the required bands.

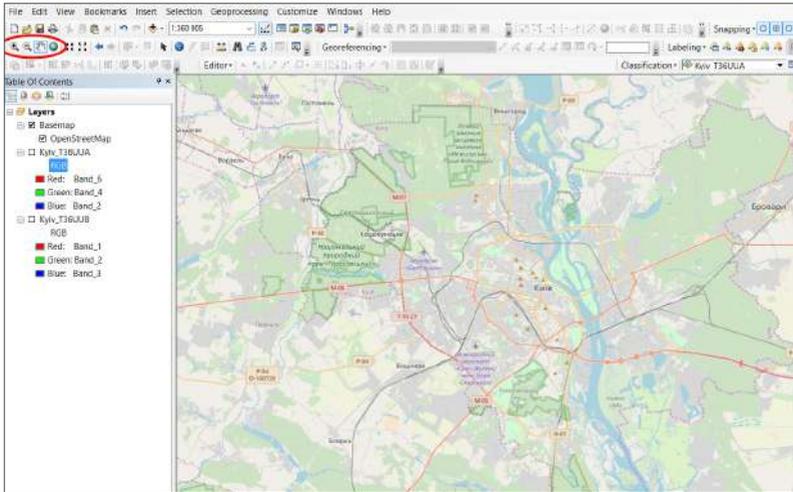


Fig. 1.109. Zooming into Kyiv boundaries in the map view window

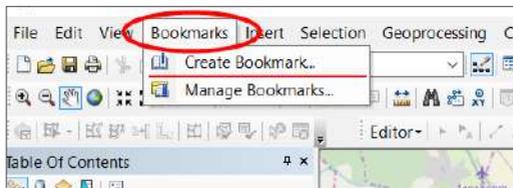


Fig. 1.110. Creating a bookmark for a certain map area

First off, create an image in natural colors, i.e. familiar and visible to the human eye (Fig. 1.106, *a*), using B04, B03, B02 bands (see [Annex 2](#)). It is important to select the bands in the following sequence: red (B04), green (B03), and blue (B02). You can select three bands at once by holding down the *Shift* or *Ctrl* key on the keyboard. Then, click the **Add** button and the selected images will be displayed in the input window. Next, specify the **Output Raster** by opening the folder again using the icon and saving the image under a new name (for example, Kyiv_36UUA for the image with the tile number T36UUA).

It is better to name files using Latin letters since Cyrillic is not always read correctly by the applications.





Next, clip the output image along the borders of the map view window (if necessary, first return to your previously saved map area in the bookmarks). To clip the output image, click the **Environments** button, and open the **Processing Extent** tab in the *Environment Settings* window, expand the drop-down menu, select **Same as Display**, and click **Ok**. Fig. 1.111).

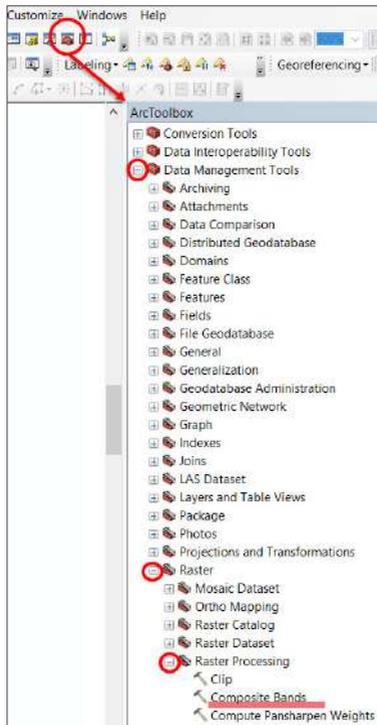


Fig. 1.111. Composite Bands tools

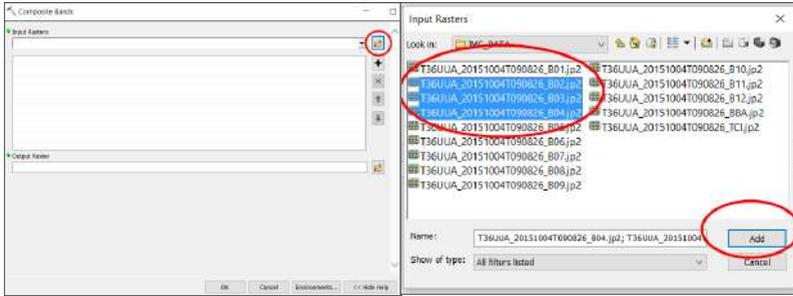


Fig. 1.112. Composite Bands tools: selecting bands

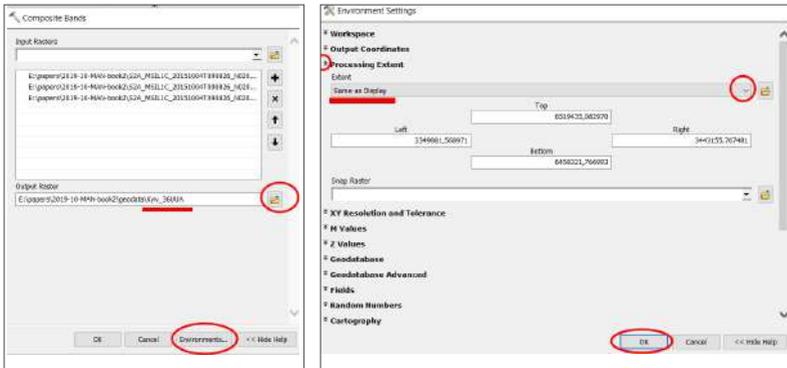


Fig. 1.113. Environment settings

Then click *Ok* in the *Composite Bands* window. It may take some time to create the synthesized image. When the process is completed, a new color raster layer will open in the cartographic window of the project (Fig. 1.112, 1.113).

The boundaries of the city may be easily distinguished in the image by the building density. Kyiv is located on both banks of the Dnipro River (clearly seen in the center of the image) and is partially surrounded by forests (dark green areas). Within the forestland in the north-eastern part of the image, you can see a strip of smoke caused by the fire (Fig. 1.114). Get closer to this place using the navigation tools. As you can see now, the fire broke out in the forest near the buildings and the road. Apart from determining the size of smoke clouds, it

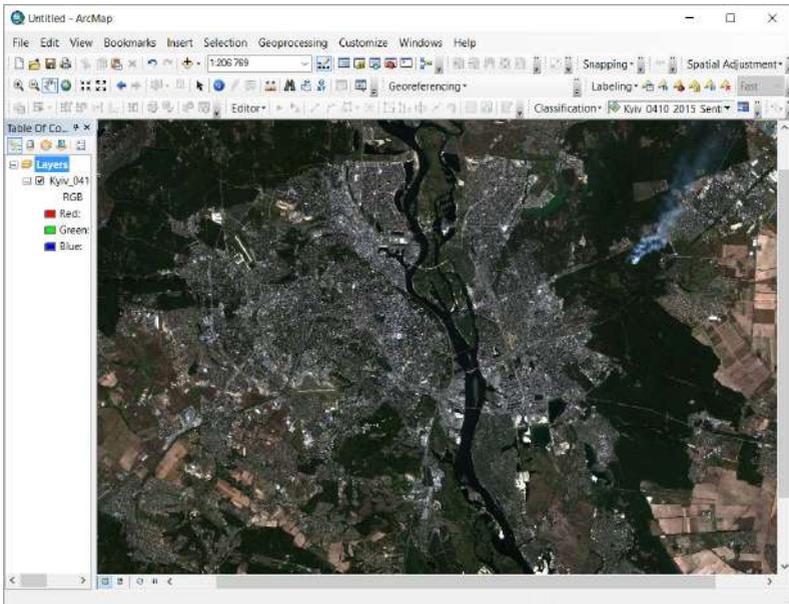


Fig. 1.114. Combination of bands to display the image in natural color

is important to identify the area covered by the fire. This may be done with the function of composite bands, using the infrared (thermal) range (Fig. 1.106).

*Go back to the saved area of the map (Bookmarks menu) and open the Composite Bands tool. Select B02, B08, and B12 bands and perform settings of the Environments as described in this section above to clip the image, and click **Ok**. Note, the B12 band has a spatial resolution of 20 m, and the B02 and B08 bands – 10 m (Annex 2). The resulting image will have a spatial resolution of the first input layer, so you should select the bands in the following sequence: B02, B08, B12. Upon bands synthesis, change the bands display to B12, B08, B02.*

To rearrange the bands of the synthesized image, right-click the image layer in the **Layers** panel to open the context menu (Fig. 1.115), and select **Properties**. A layer properties window will open, in which you need to expand the **Symbology** tab.

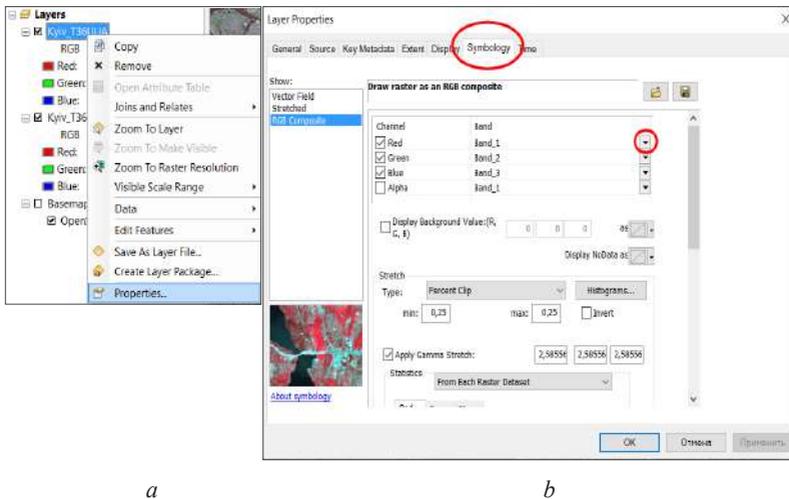


Fig. 1.115. Layers menu (a) and band combination window (b)

Expand the tab next to **Red**, **Green**, **Blue**, and change the combination of bands. Select from the drop-down menu Band_3 for **Red**, and Band_1 for **Blue**, and click *Ok*.

As a result, a false-color image will open in the project with the following combination of bands: B12, B08, B02. Zoom into the area of fire on the map. It is much easier to identify the area covered by the fire now.

Create the same synthesized image with a combination of bands B12, B08, B02 for the second downloaded image archive (tile number 36UUB). This image should complement the image of the northern part of the city. Don't forget to open first the map area saved in the *Bookmarks*, and then perform the above operations. As a result, two images will be created and opened in the project: *Kyiv_36UUA* and *Kyiv_336UUB*.

Mosaicking

In the top menu, select *Windows* → *Image Analysis* to open an image analysis panel. The *Image Analysis* panel allows performing multiple image processing tasks. Using this tool, you can interactively adjust the histogram stretch, brightness and contrast, turn off the black background around the image, clip part of the image of any shape, calculate spectral indices, such as NDVI, and even calculate the height of trees by their shadows and many more. Some of these operations will be discussed in the following sections. Now, we will use this panel for images' mosaicking.



When the *Image Analysis* panel is activated, both images appear in the list at the top of the window. Select them and click the *Blend* tool at the bottom of the window as shown in Fig. 1.116.

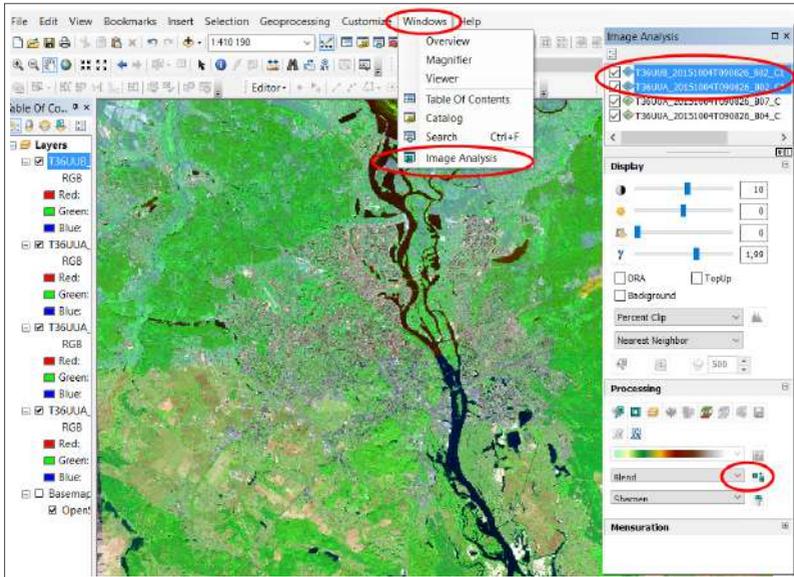


Fig. 1.116. Creating a mosaicked image using *Image Analysis* tools

The resulting mosaicked image will open in the project. Now open the *Layer Properties* tab and swap the *Band_1* and *Band_3*. Do not close the *Layer Properties* window – we will use it to adjust the image contrast.

Image enhancement

Adjust image brightness and contrast using the *Layer Properties* tools. Usually, the *Percent Clip* is set by default in the *Symbology* tab as an image enhancement method. In general, this method provides the best adjustment of the image display. Another effective way to enhance the image view is to use the *Standard Deviations* function. Open the drop-down menu next to the *Stretch Type*, select *Standard Deviations*, and press *Ok*.

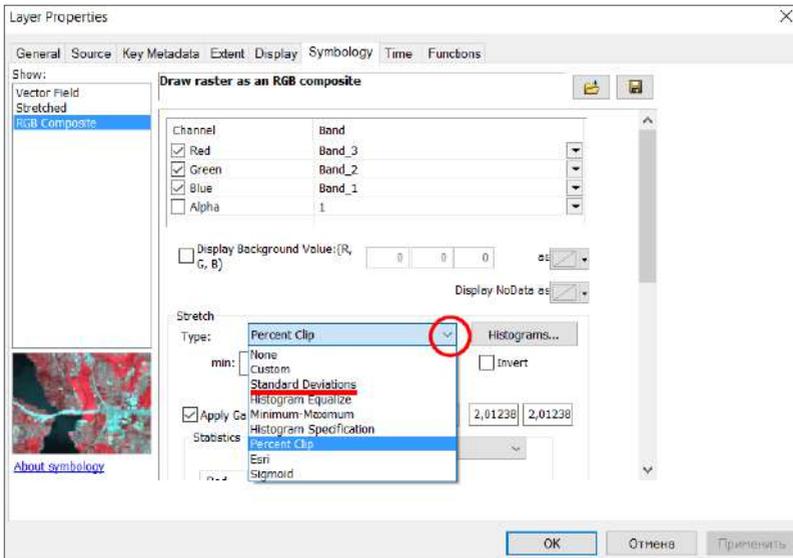


Fig. 1.117. Selecting image enhancement method

Which version of the image display (Fig. 1.117) do you like more: the first one, where the **Percent Clip** function was used, or the second one, where the **Standard Deviations** function was employed? Use the **Percent Clip** enhancement method again.

*You can quickly open the **Layer Properties** window by double-clicking on the desired layer in the table of contents using the left mouse button.*

You can also manually change the image contrast and brightness. Open the **Layer Properties** window and select the **Display** tab. Increase or decrease the **Contrast** or **Brightness** values. You can enter negative numbers as well. For example, if the image is too light, you should decrease its brightness by entering a negative value such as “-5” in the **Brightness** field. You can also adjust the layer transparency in this window using the **Transparency** function. Click the **Ok** button if you have entered all desired values (Fig. 1.118).

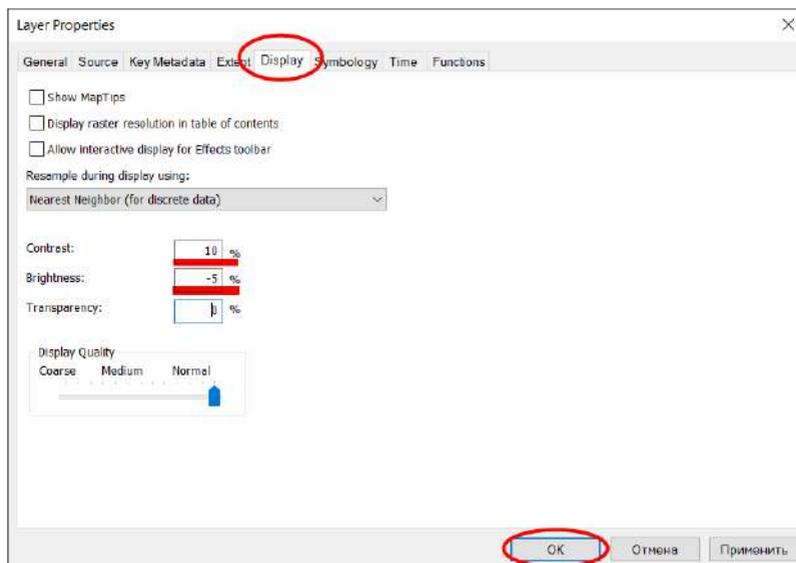


Fig. 1.118. Adjusting image brightness and contrast

In the end, you should save the resulting synthesized image to your folder because the mosaicked image of the territory of Kyiv city, created using *Image Analysis* tools, is stored in temporary files of the ArcGIS system. To do this, left-click the “Mosaic” layer in the *Layers* panel and select *Data* → *Export Data* in the context menu. In the data export window, specify the folder for saving the image in the *Location* field, and the name of the output image in the *Name* field (Fig. 1.119).

*You can also use the export tool to clip an image within a map view window. In our task, we clipped the image during band synthesis by setting up the environment. In other cases, you can use the export tool to quickly clip the image. To do this, select **Data Frame** in the **Extent** module at the top of the window.*

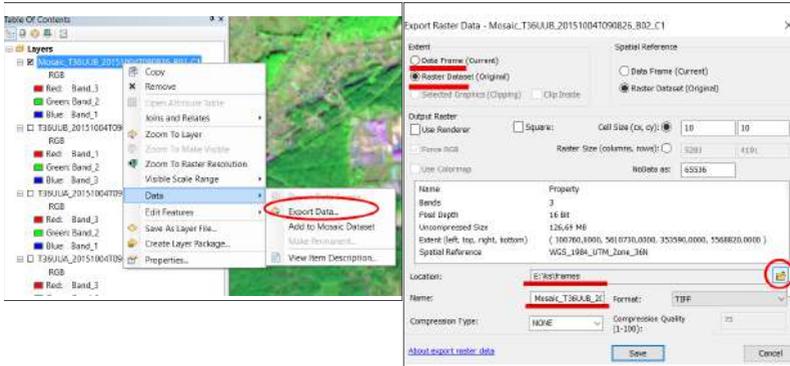


Fig. 1.119. Exporting the image

We have performed image clipping in the previous step. Therefore, in this task, we need to select the **Raster Dataset** function in the **Extent** module. This means that the coverage area will be the same as that of the input image. Then click **Ok** to save the created image in the working folder; it can also be added to the project.



Performing a Task in QGIS

First, open QGIS Desktop 3.4.13 application with GRASS 7.8.0 (it is better to use this version of QGIS) and create a new project following the instructions described in [paragraph 1.3](#). Make sure that the **Browser**, **Layers**, and **Spatial Bookmarks** panels are open in the project. If these panels are missing, add them and the OpenStreetMap base map as described in [paragraph 1.3](#).

Using the navigation tools, find Kyiv city on the map and zoom into it. The city should be fully displayed on the map as shown in the figure below.

In this example, we will clip the image along the map area (Fig. 1.120). You can save the map area in the bookmarks and use this area in different image processing operations later (Fig. 1.121). To do this, select the **Add bookmark** tool in the **Spatial Bookmarks** panel, and a **New bookmark** option will appear in the bookmarks bar.



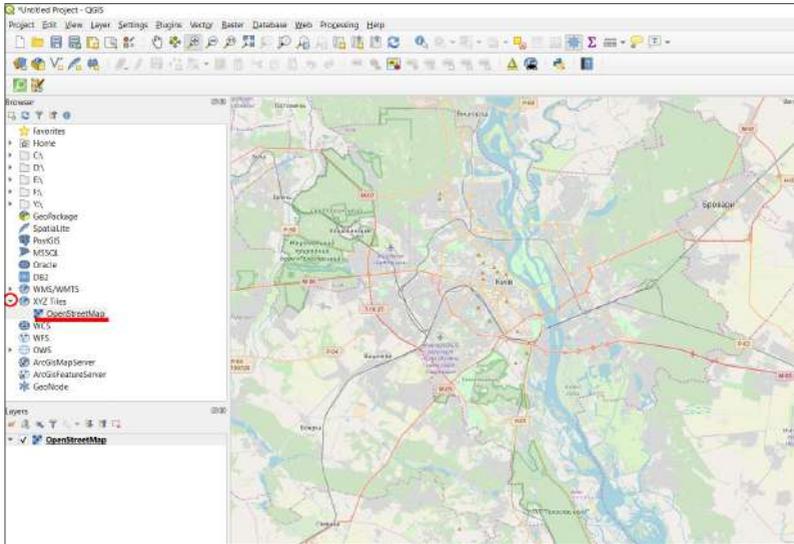


Fig. 1.120. Adding the OpenStreetMap base map to the project

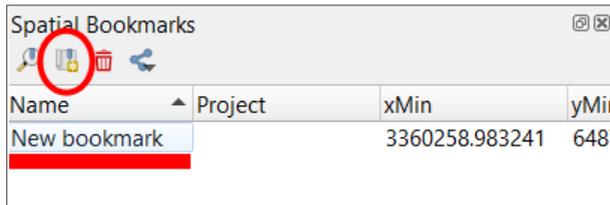


Fig. 1.121. Saving a spatial bookmark

You can change the name of a bookmark, for example to Kyiv, by double-clicking it with the left mouse button. Now zoom into any Kyiv district using the navigation tools, and double-click the bookmark. The map will automatically be positioned on the saved area.

To blend black-and-white bands of a satellite image (Fig. 1.122) into one color image (i.e. to perform band synthesis) in QGIS, select **Raster** in the top menu, expand the **Miscellaneous** tab, and select **Merge**.

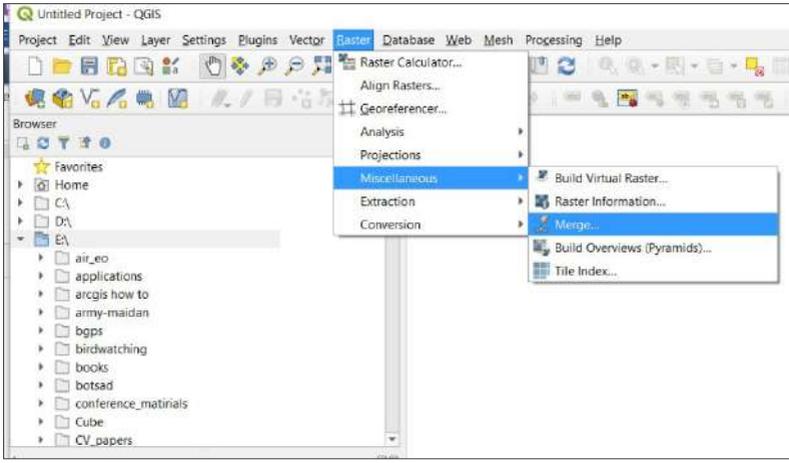


Fig. 1.122. Selecting a tool for satellite bands merging

A window for band synthesis will open. In this window, specify the bands you want to merge in the Input Layers line. To do this, click on the [...] icon next to the **Input Layers** line. In the **Multiple selection** window, click **Add files** and find the folder where the image bands are saved and select the desired bands (Fig. 1.123).

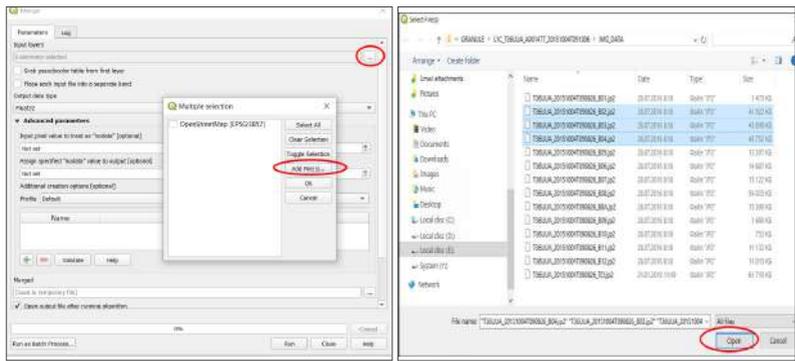


Fig. 1.123. Band merge tools: selecting bands

First, create an image in natural colors (Fig. 1.106, a) using B04, B03, B02 bands (see Annex 2). You can select three bands at once by holding down the *Shift*

or *Ctrl* key. Click **Open**, and the selected images will be uploaded 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, drag the bands so that the order of their display is as follows: B4, B3, B2, and click **Ok** (Fig. 1. 124).

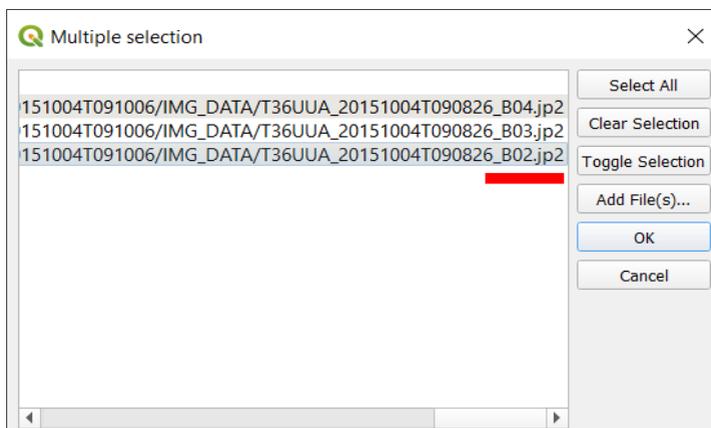


Fig. 1.124. The sequence of bands combination

The number of selected bands (3) will be displayed in the **Input layers** line of the **Merge** window (Fig. 1.125). Now, check the box next to the **Place each input file into a separate band**, and click the icon next to the **Merged** line. Select **Save to file**, find the path to the folder and give a name to your file (for example, *Kyiv_T36UUA* for the image with T36UUA tile number), and click **Run**.

It is better to use the Latin alphabet to name the files since Cyrillic is not always read correctly by the applications.

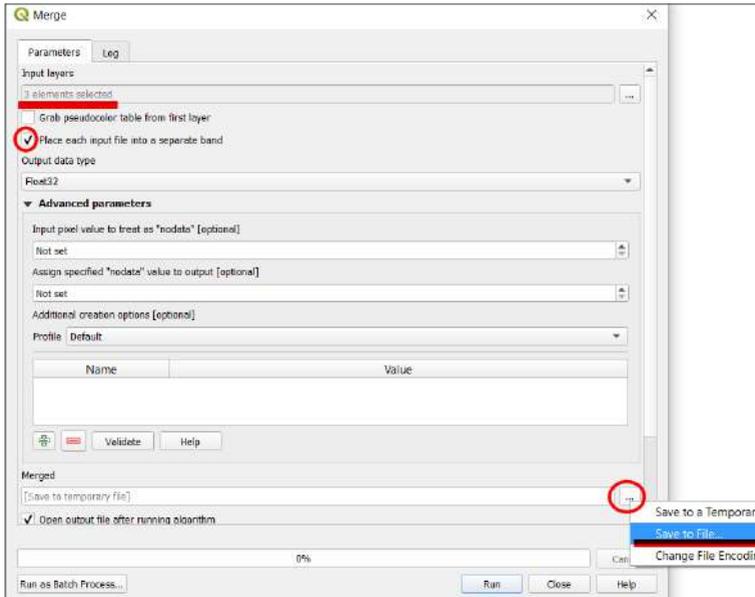


Fig. 1.125. Creating merged image

It may take some time to create a merged image. Upon completion of the process, a new color raster layer should open in the project map window.

Now you need to clip the merged image (Fig. 1.126) along the map canvas to prevent the application from processing unnecessary areas of the image (if required, first return to the area of the map saved in the bookmarks). To do this, right-click the merged image in the project and select **Export** → **Save As** in the context menu.



Fig. 1.126. Image clipping along map area

In the **Save Raster Layer** window, click [...] icon next to the **File Name** line and specify the path to the folder for image storing, as well as its name.

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

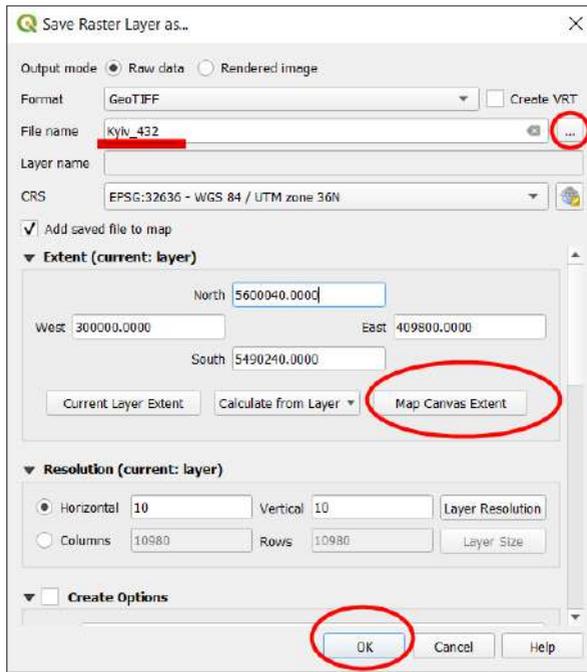


Fig. 1.127. Clipping according to map canvas extent

A new merged image will open in the map view window. It consists of true colors combination and was clipped according to map canvas extent (Fig. 1.127).

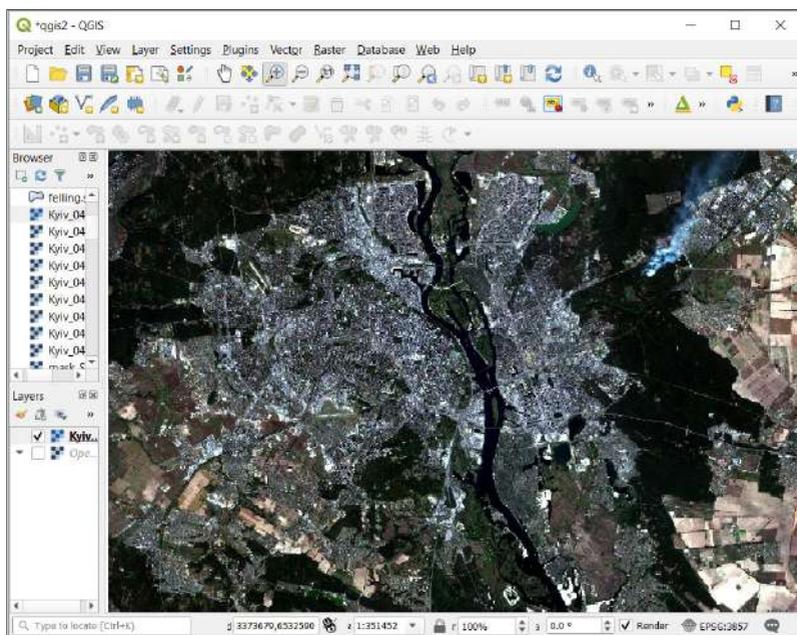


Fig. 1.128. Combination of bands in natural colors

The boundaries of the city may be easily distinguished in the image by the building density. Kyiv is located on both banks of the Dnipro River (clearly seen in the center of the image) and is partially surrounded by forests (appear as dark green areas). Within the forestland in the north-eastern part of the image, you can see a strip of smoke caused by the fire (Fig. 1.128). Get closer to this place using the navigation tools. As you can see now, the fire broke out in the forest near the buildings and the road. Apart from determining the size of smoke clouds, it is important to identify the area covered by the fire. This may be done with the merge bands function, using the infrared (thermal) range (Fig. 1.106).

Go back to the area of the map saved in the bookmarks (the **Bookmarks** menu) and open the **Merge** tool. Select B02, B08, and B12 bands and press **Ok**.

Clip the image according to map canvas extent as described above. Note, the B12 band has a spatial resolution of 20 m, and the B02 and B08 bands – 10 m (Annex 2). The resulting image will have a spatial resolution of the first input layer, therefore, you should select the bands in the following sequence: B02, B08, B12. When the merge process is completed, change the order of bands display to B12, B08, B02. To swap the bands of the merged image, right-click the image layer in the table of contents. The context menu will open, from which



you should select **Properties**. A **Layer Properties** window will open (Fig. 1.129). Expand the **Symbology** tab here.

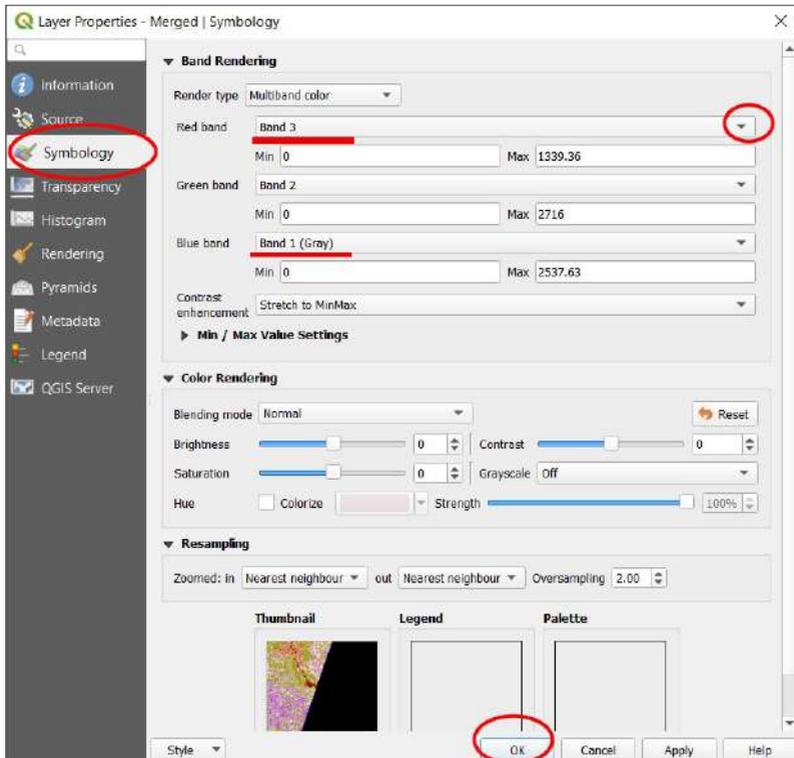


Fig. 1.129. Adjusting layer symbology

On the map, zoom into the place of the fire. As you can see, it is much easier to distinguish the area covered by the fire now.

Create the same merged image with a combination of bands B12, B08, B02 for the second downloaded image archive (tile number 36UUB). This image should complement the image of the northern part of the city. Don't forget to open first the map area saved in the **Bookmarks**, and then perform the above operations. As a result, two images will be created and opened in the project: Kyiv_36UUA and Kyiv_336UUB.



Mosaicking

Now we need to stitch two pictures of the northern and southern parts of Kyiv to get a whole image of the city. We will use again the *Merge* tool. Open this tool from the menu: *Raster* → *Miscellaneous* → *Merge* (as described in this section above) and specify as *Input Layers* two images, which were obtained, merged, and clipped along the map canvas window (Fig. 1.130).

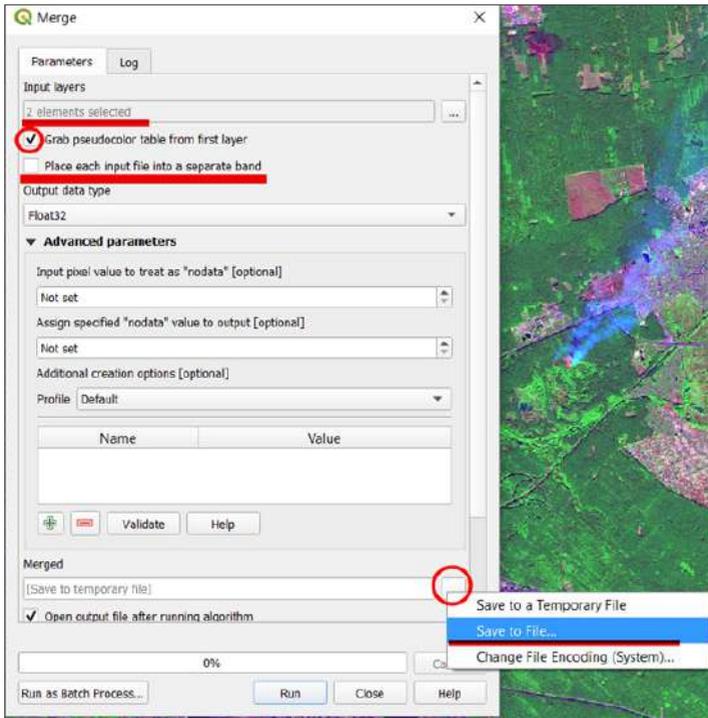


Fig. 1.130. Creating a mosaicked image using *Image Analysis* tools

The resulting mosaicked image will open in the project. Now open the *Layer Properties* tab and swap the *Band_1* and *Band_3*. Do not close the *Layer Properties* window – we will use it to adjust the image contrast.

Image enhancement

Adjust image brightness and contrast using the *Layer Properties* tools. In the *Symbology* tab, select *Stretch to Min/Max* in the *Contrast enhancement* field. Open the drop-down menu in the *Min/Max Value Settings* field, check the box next to *Mean +/- standard deviation* as shown in the figure below, click *Apply* and *Ok* (Fig. 1.131).

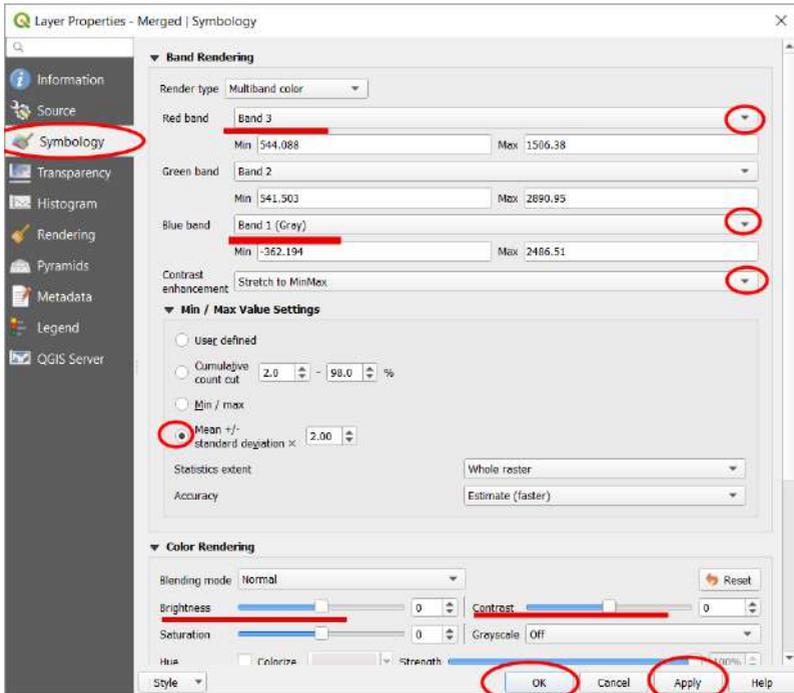


Fig. 1.131. Choosing image enhancement method

To open the *Layer Properties* window quickly, double-click the desired layer in the table of contents with the left mouse button.

You can also manually change the image contrast and brightness by increasing or decreasing the *Contrast* or *Brightness* values in the *Symbology* box. You can enter negative numbers as well. For example, if the image is too light, you should decrease its brightness by entering a value such as “-5” in the *Brightness* field.

Have a look at the image on the map. What else objects are better interpreted in a false-color image than in an image in the visible spectrum? For example, if you look at the forestland to the north of the fireplace, you can identify yet another place of a recent fire, already extinguished. Damaged trees appear here in dark red-purple colors, which allows to determine the area of fire and calculate the losses (Fig. 1.132).



Fig. 1.132. Extinguished fire on Sentinel 2 satellite image

This extinguished fire, whose consequences are shown in Fig. 1.132 above, occurred a month before the image was collected by the satellite. The rescue team shot a video at the scene of the fire using a drone. To watch the video, go to Youtube at <https://youtu.be/fzhE2m-vbeb4>. Try to compare the area displayed in the image and the video, and determine the place the rescue team launched the drone from.





Google Earth Engine

For Those Interested in Programming

The images may also be processed in JavaScript using a web-based Google Earth Engine Code Editor. The Code Editor is a part of Google Earth Engine's cloud-based platform for the analysis of satellite data, which allows processing large arrays of images without uploading them to the computer.

Task

The task is to perform **band synthesis, image clipping, and mosaicking** as described in pp. 88–92 (namely, to create a color satellite image of Kyiv city and identify a fire seat in Darnytsia forest from the images collected by the satellite (Sentinel 2) on October 4, 2015) using software code.

It is not necessary to install specialized software to use the cloud-based platform. All you need to run the Code Editor is an internet connection. To access Google Earth Engine, you should have a Google account (sign in to Gmail) and sign up for Google Earth Engine at <https://signup.earthengine.google.com>.

Within a few hours or days after the registration, you will receive a confirmation letter to the e-mail address provided during signup. Now you can access the code editor at <https://code.earthengine.google.com>.

To get started, open the data directory at <https://developers.google.com/earth-engine/datasets>, select the Sentinel tab, Sentinel 2, and **Top-of-Atmosphere Reflectance** (*at-sensor reflectance values*). A page will open with a description of Sentinel 2 images. Expanding the **Bands** tab, you will see a complete list of satellite bands and their spatial and spectral resolution values. This information is available for all satellites contained in the Google Earth Engine catalog.

At the bottom is a code for Sentinel data display, and we will start editing it now. Find the **Open in Code Editor** button at the bottom of the screen and click it. The Code Editor interface will open with the downloaded code in the editing panel.

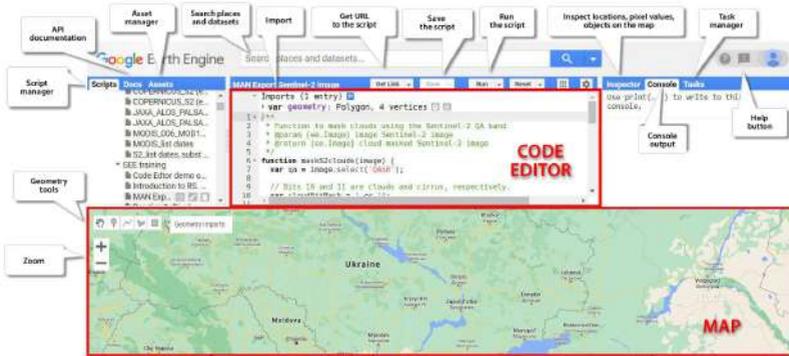


Fig. 1.133. The user interface of the Google Earth Engine Code Editor

Press the **Run** button to execute the script. As a result, a color satellite image with a combination of true color bands will be displayed on the map canvas. You can move across the map, zoom in or out using the navigation tools and the mouse (Fig. 1.133).

Let's return now to line 23 of the code editor (for convenience, each line of the code is numbered), where we can select images available in the dataset by date. You can see the date of image collection – it is the period from 2018-01-01 to 2018-06-30 (note, the date is displayed in “year-month-day” format). Change these dates to the date of the fire, namely October 4-5, 2015. Line 23 should read:

23	<code>.filterDate('2015-10-04', '2015-10-05')</code>
----	--

Below, in lines 29-33, is specified a combination of bands used for producing a color image. Namely, these are true color bands, B4, B3, and B2. Change this combination to the following: B12, B8, B2 – this will make it easier to determine the area of the fire. Line 32 should read:

32	<code>bands: ['B12', 'B8', 'B2']</code>
----	---

Find Kyiv on the map and determine its coordinates (Fig. 1.134). To do this, you can use the **Search places and datasets** box. Open the **Inspector** tab and click on Kyiv location on the map. The **Inspector** tab shows information about the cursor location (coordinates). Copy this information.

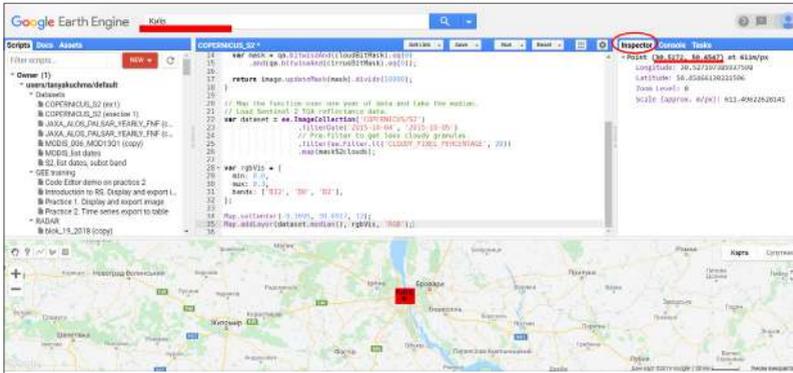


Fig. 1.134. Searching for a place on the map and determining the coordinates

Find line 34 of the code, which positions the map according to the specified coordinates, and replace the first two numbers in parentheses (coordinates of the city in Portugal) with the copied coordinates of Kyiv. Line 34 should look like this (decimal values of coordinates may vary depending on which part of the city you put the cursor):

34	Map.setCenter(30.5272, 50.4547, 12)
----	-------------------------------------

Press the **Run** button and view the result. A color image of Kyiv as of October 4, 2015, should display on the map canvas.

As you can see, the image displayed in the map window covers a large area, much larger than that of the Kyiv city. Therefore, we need to limit the selection to the territory of Kyiv and clip the image (Fig. 1.135).

To select the area for image clipping, use  tool (*Draw a rectangle*) from the left corner of the map canvas, and draw a rectangle so that Kyiv is completely inserted inside it (Fig. 1.136).

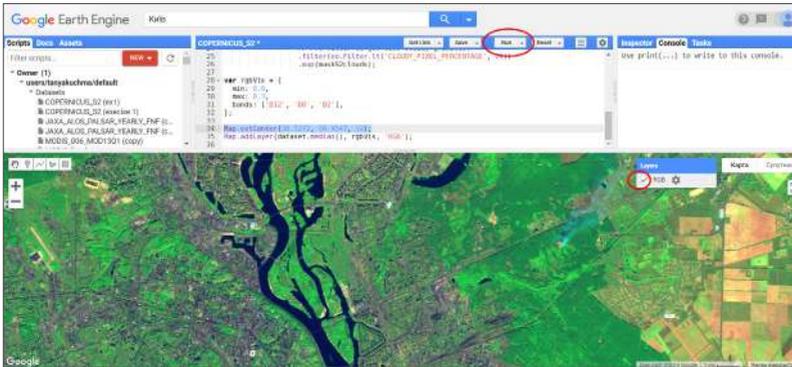


Fig. 1.135. Uploading image collected by Sentinel 2 to the map canvas in Code Editor Google Earth Engine

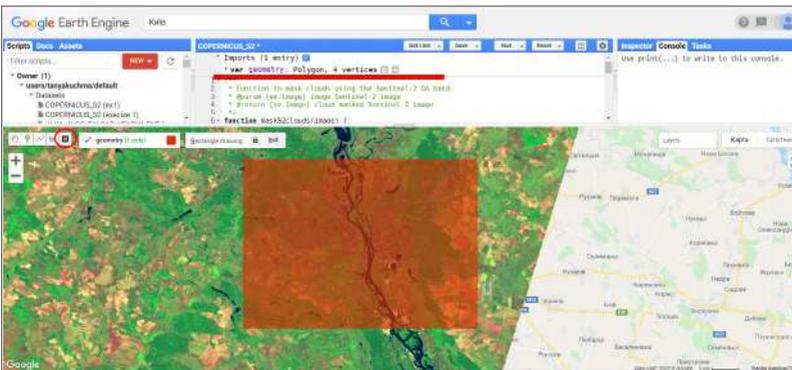


Fig. 1.136. Selecting the area of interest

If you look at the code again, you may notice a new line that automatically appeared at the top, which indicates a new variable (*geometry*) and is called “*geometry*”. Now add the task for image clipping outside the polygon, namely *clip(geometry)* to the last code line (35) (this line choose and compute median value of previous collection, *dataset.median()*). Line 35 should read:

35	Map.addLayer(dataset.median().clip(geometry),	rgbVis,
	'RGB')	



To find the required task, use the *Docs* tab from the top left menu. Now we need to export the image to disk. Our code can upload the image to the map canvas only. However, you may need to use the resulting image later in ArcGIS or QGIS applications, for example, to compare it with other data or prepare a map layout. Therefore, open the *Docs* tab and type “*export*” in the toolbar search box (Fig. 1.137).

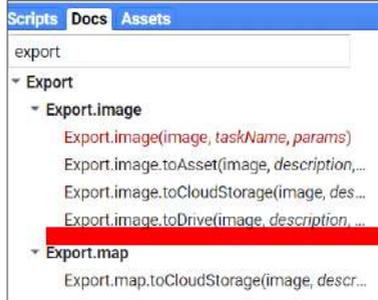


Fig. 1.137. Searching for the *Export image to Drive* task

In the search results, click *Export.image.toDrive*. This function allows you to save the image in GoogleDrive (data repository linked with your Google account), from which you can download the processed image to your computer. The information about the task will be displayed. Copy the text written on a blue background in the window title – this is the exact name of the task (function) and additional parameters, which may be specified in the code (Fig. 1.138).

Not all the parameters mentioned in the parentheses need to be specified in the code; we will leave the essential ones only.

The first important parameter is the *image*. You need to specify a variable, i.e. an image you want to export. In our case, it is a *dataset* (Sentinel 2 images filtered by date, cloud coverage, and territory, lines 22–27). However, it would be incorrect to mention the *dataset* since the territory of Kyiv is covered by two images as discussed in paragraph 1.4. Therefore, it is necessary to make a stitched image from the available ones. Thus, instead of *dataset*, specify *dataset.median* (averaged image from a set of images). In addition, we want the color image to be created from the bands B12, B8, B2, so we specify not just a mosaic, but - *dataset.median.select(['B12', 'B8', 'B2'])*. Finally, clip the image by the shape drawn on the map. The resulting image parameter should read: *dataset.median.select(['B12', 'B8', 'B2']).clip(geometry)*.

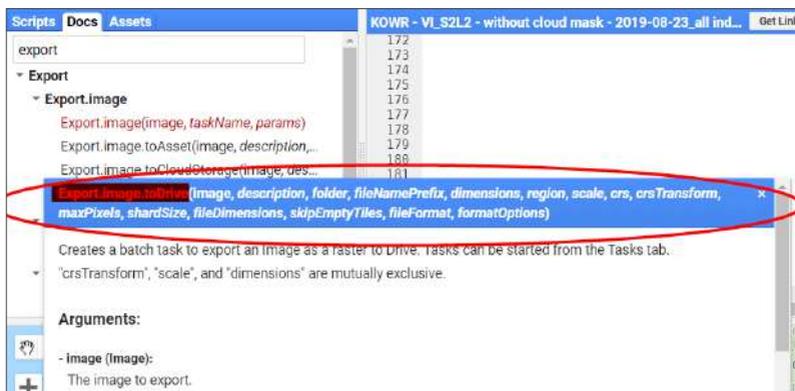


Fig. 1.138. Parameters of the *Export image to Drive* task

The next essential parameter is the *description* – the name of the output file, for example, ‘Kyiv_0410_2015_Sentinel2’.

Then, it is important to specify the *scale*; in our case, it is the spatial resolution of the output image in meters, i.e. 10 m for Sentinel 2 imagery.

Specify the *region* too: *geometry* (i.e. the area inside the polygon).

The last parameter to be specified is *crs* (*coordinate system*). It is convenient to use for Kyiv a projected coordinate system, WGS 84 / UTM zone 36N, or its code name, EPSG:32636.

Therefore, to export an image to a disk, you need to add the following text to the code, starting from line 37:

```
37     Export.image.toDrive({
38         image: dataset.mean().select(['B12', 'B8', 'B2']).clip(geometry),
39         description: 'Kyiv_0410_2015_Sentinel2',
40         scale: 30,
41         region: geometry,
42         crs: 'EPSG:32636'
43     }).
```

The code is ready now. You can save it by clicking the *Save* button at the top of the code editor, and run it by pressing the *Run* button.



Note that you need to confirm again image saving to disk in the **Tasks** menu. To do this, after running the code, go to the **Tasks** tab and click the **Run** button next to the name of the output file (Fig. 1.139).

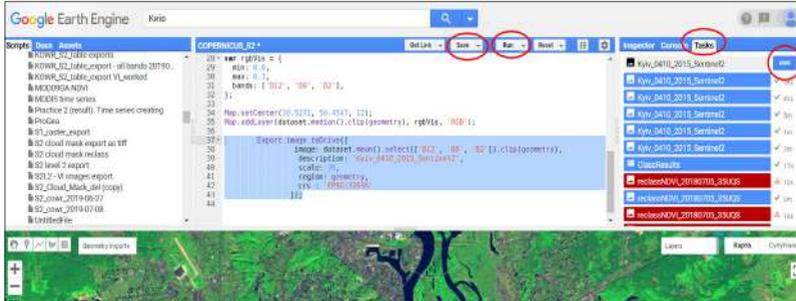


Fig. 1.139. Exporting an image to Google Drive

Following image uploading, the line of the image name in the **Tasks** menu will highlight in blue. Point the mouse cursor over it and a question mark will appear. Click on it. In the window that opens, select **Open in Drive** (Fig. 1.140).



Fig. 1.140. Opening a file saved to Google Drive

The Google Drive and saved image will open. Right-click on the image and select **Download** and save the image to a folder on your computer (Fig. 1.141).

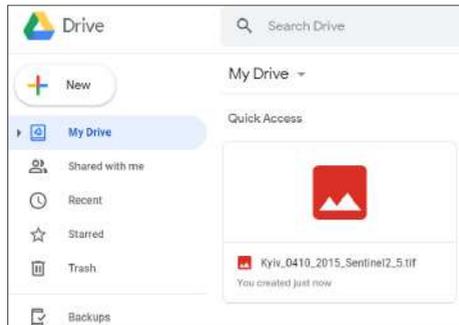


Fig. 1.141. An image of Kyiv saved to Google Drive

As a result, you will get a color image of Kyiv, which can be used later in various applications (Fig. 1.142).

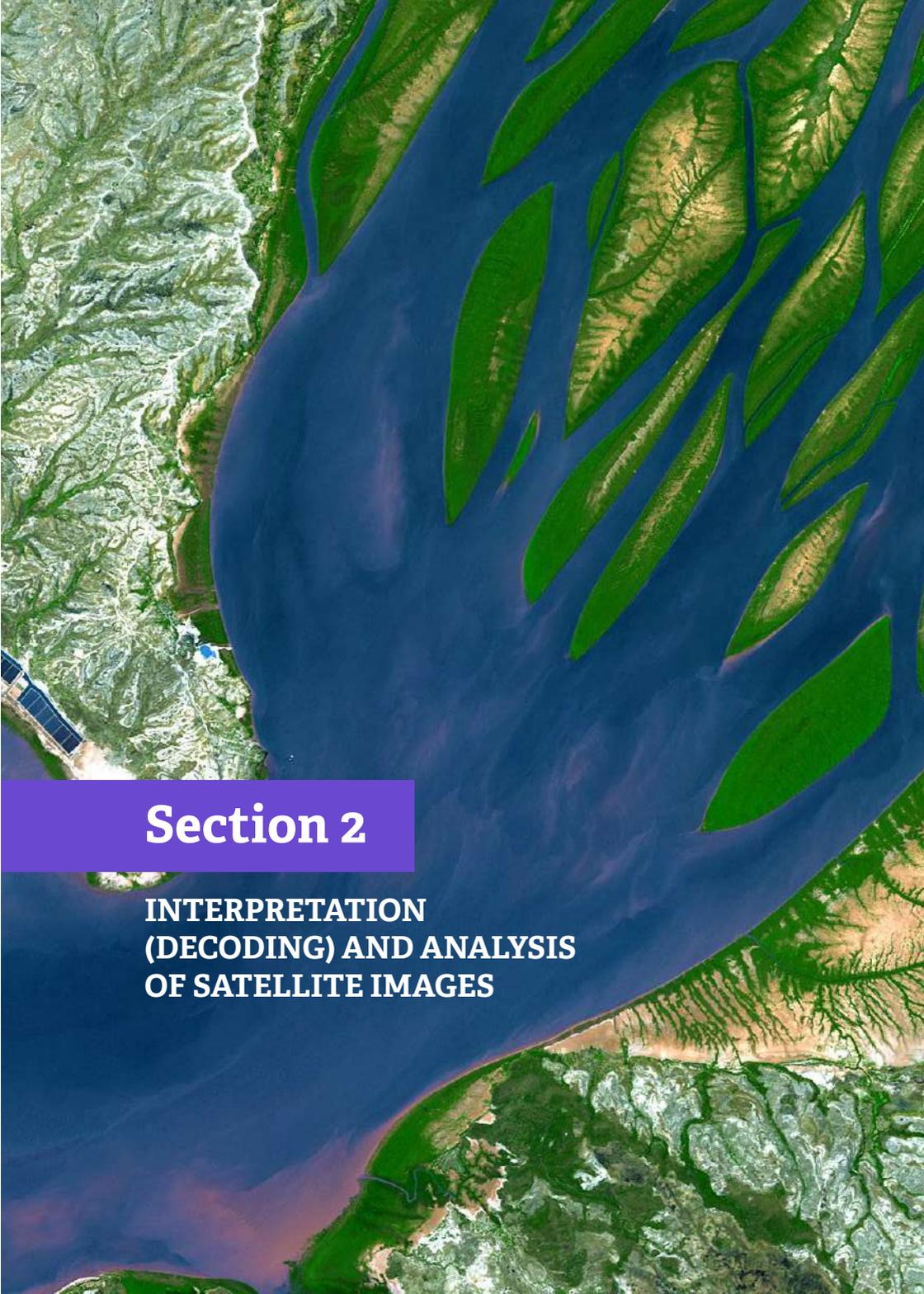


Fig. 1.142. The resulting color image of Kyiv (combination of bands: B12, B8, B2)

To open the ready code, go to: <https://code.earthengine.google.com/c5b1c1e11fd3cb476f-b5a7fd765a06a8>.

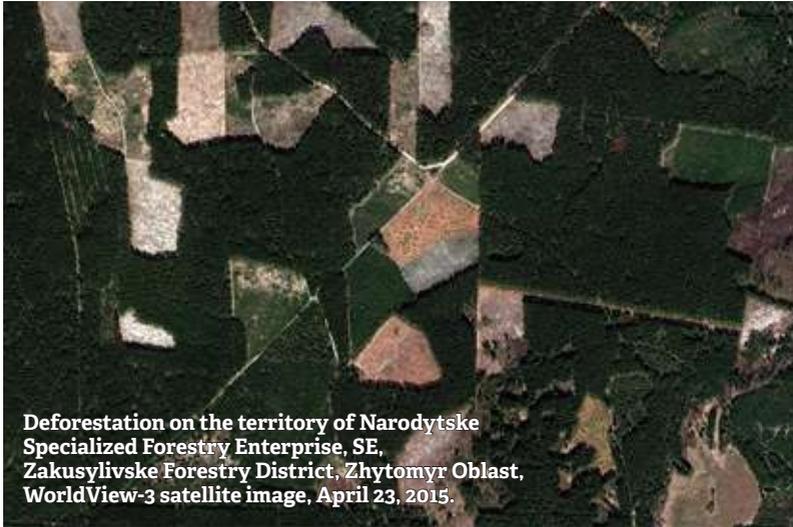
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9. Прикладні аспекти використання геоінформаційної системи QGIS для вирішення завдань геоаналітики / Путренко В. В. та ін. Київ : ННК «Світовий центр даних з геоінформатики та сталого розвитку», 2019. 130 с.
10. Версії додатка Планета Земля. URL: https://www.google.com/intl/uk_ALL/earth/versions/#earth-pro.
11. Level-1C product tiling. URL: <https://sentinel.esa.int/web/sentinel/user-guides/Sentinel-2-msi/product-types>.

An aerial satellite image of a river delta, showing a large body of water (blue) branching into numerous smaller channels (green and brown) that flow into a landmass. The landmass is characterized by a complex network of rivers and a dense forest (green). A small structure, possibly a dam or bridge, is visible on the left side of the landmass. A purple rectangular box is overlaid on the bottom left of the image, containing the text 'Section 2'.

Section 2

**INTERPRETATION
(DECODING) AND ANALYSIS
OF SATELLITE IMAGES**



2. 1. Manual Interpretation

Processing RS data involves the use of a large number of different methods, their only goal, however, is to generate a map based on satellite images. The resulting map should reflect the information about certain features and phenomena important for the researcher. This process is called *image interpretation*. Depending on the task and available data, automatic, semi-automatic, and manual interpretation of images may be used.

To recognize the features, you need to know the basic characteristics of their display on the images. It is best if the analysis of satellite images is supported by ground surveys that can be used to verify remote data. Any reference information may also come in useful, such as open data of OpenStreetMap and thematic geoportals, photos of the site, etc.

Interpretation of high- and medium-resolution satellite images is somewhat different because it directly depends on the size of the smallest features, which can be seen and detected from the images. In particular, high-resolution images are more suitable for the elementary level of GIS technology use since they can be easily “read” without training. Such images are freely available on Google Earth Pro, the main properties of which have been discussed [in paragraph 1.3](#). The advantage of such data usage is the opportunity to detect the slightest changes in landscapes, accumulation of landfills, landslides, forest diseases, coastal development, etc.

However, there are some disadvantages of using Google Earth Pro – such detailed images do not cover the entire territory of Ukraine and are often insufficient to track the dynamics of the process over time. Besides, these images visualize the Earth’s surface in the visible range of the spectrum only, in a single combination of “true colors”. Therefore, more thorough research studies are carried out based on multi-band medium resolution images, and more complex GIS applications such as ArcGIS and QGIS.

Below we will discuss some examples of image interpreting at the elementary and advanced levels of GIS knowledge. We will use the medium resolution images to detect deforestation areas in the Kyiv Oblast using the ArcGIS and QGIS programs, and high-resolution images to digitize the sand wash in the Dnipro River floodplain near Kyiv in Google Earth Pro.

Thematic Mapping of Deforestation

Deforestation is cutting, felling, or chipping trees and shrubs to obtain wood, as well as to rehabilitate, restore forests and increase their productivity.

Before starting work, let’s get acquainted with an interesting resource that will allow you to review the global dynamics of deforestation and the consequences of forest fires.

*The **Global Forest Watch (GFW)** is an online forest monitoring system that allows everybody interested to access real-time information about the state of forests around the world. This project was launched in 2014 by Google together with the World Resources Institute based on Landsat satellite images with a resolution of 30x30 cm per pixel. The interactive map of this portal shows forest cover, its changes over time, land use, and forest protection activities around the world, but does not reveal the causes of forest loss. The **Tree cover loss** thematic layer shows the annual loss of forest cover, which is defined as the change in the level of vegetation over 5 m within the selected area (displayed in pink). The layer in blue color – **Tree cover gain** – reflects the growth of forest cover (reforestation).*

According to the Global Forest Watch portal [1] data on deforestation over 2011-2018, forests occupied 11.3 million hectares of the territory of Ukraine (more than 19% of the total country's area) in 2010, and by 2018, our state lost 74.2 hectares of forests.

The four top regions of Ukraine with the largest “forest losses” are Zhytomyr, Rivne, Kyiv, and Volyn Oblasts.

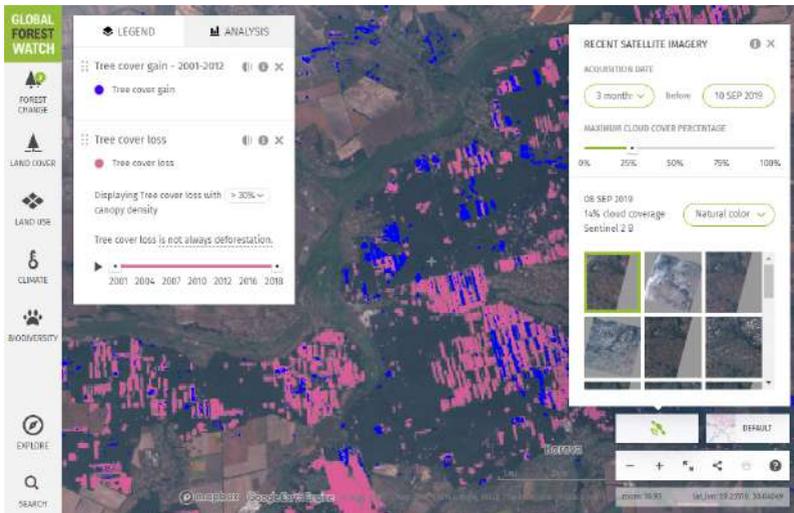


Fig. 2.1. www.globalforestwatch.org/map interface.
Displayed: Fastivskiy District of Kyiv Oblast

According to Global Forest Watch, most of the “forest losses” in Ukraine result from continuous fellings in the framework of forest management programs by state and municipal forestry enterprises. Almost all of these areas are reforested either by planting (“development of forest crops”) or by facilitating a natural regeneration if natural conditions allow (Fig. 2.1).

For more details about the prospects of deforestation of Ukraine, use the online map of the “Forest in a Smartphone” pilot project launched by the State Forest Resources Agency. Go to the website <https://lk.ukrforest.com/map/general> to review the information on the issuance of permits for logging. You can also check the legality of felling on the map (Fig. 2.2).

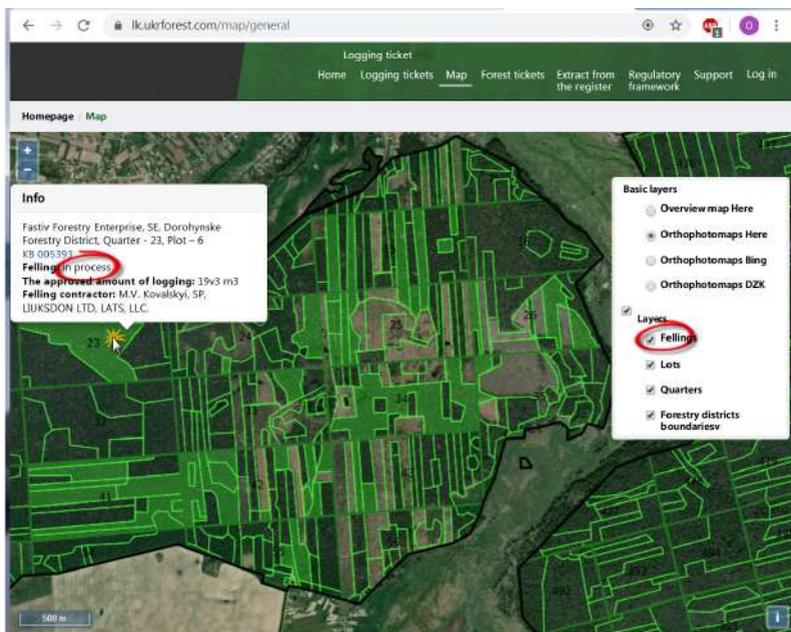


Fig. 2.2. Planned felling on the territory of Dorohynske Forestry District. Source: website <https://lk.ukrforest.com/map/general>

The Task to be performed in ArcGIS and QGIS

Digitize and display on the map the dynamics of deforestation over the period from 2015 to 2019 in the Dorohynske Forestry District of Fastivske Forestry Enterprise based on the Sentinel 2 satellite images.

Data

Sentinel 2 satellite images collected on October 4, 2015, and September 10, 2019, of the territory of Fastivske Forestry Enterprise (we have downloaded these images in [paragraph 1.2](#). If you do not have them, repeat downloading according to the instructions).

Task Performance Algorithm

1. Creating thematic layers

You know that cartographic information in digital format is displayed as thematic layers. Each layer is a set of features that share a common attribute and data

type (points, polygons, or lines), e.g. a landfill layer, a logging layer, a lake layer, a park layer, etc. Such presentation of data on the map allows users to easily and flexibly display those thematic layers that are required at a certain point of time – to adjust symbols, captions, and visibility for each layer separately, etc.

As you already know, according to the features' geometry, there may be vector layers: point (*Point*), linear (*Polyline*), and polygonal (*Polygon*), as well as raster layers. A satellite image is a raster layer, and the features selected based on image interpretation are mostly vector layers. To obtain a visual representation of each layer, we should use individual map keys: symbols, colors, and text. One of the most common formats for saving vector layers in GIS applications is the Shapefile format.

Note that every Shapefile consists of six separate files, although in fact, it is one thematic layer. Therefore, all six files must be transferred when copying. For more details, see paragraph 1.3.

2. Working with vector layers

Following the creation of a vector layer, we can proceed to digitization (drawing, contouring, outlining) of the studied features. In our case, it is the manual delineation of the felling area. To identify and digitize correctly the area of felling, it is necessary to recognize it in a satellite image. A satellite image is like an encrypted drawing, and you need to learn to read it like a book using certain attributes for interpretation. Note that the interpretation is based on such characteristics as color, shape, size, texture, shadows and terrain features, etc. Let's discuss the recognition of felling areas based on these signs. The foremost characteristic feature is the color – areas of felling always appear as contrasting light spots on a dark background of mature forest. The example of the view of felling area on a synthesized Sentinel 2 satellite image in a combination of colors (*SWIR*, *NIR*, *Red*) is shown in Fig. 2.3. The felling area can be easily recognized by the pink color on the background of a green forest. By color, you can also identify the segments of felling that differ in habitat conditions or undergo different stages of reforestation (by age and prevailing species). In particular, forest areas that have recently been cut down and replanted with young trees appear as light green spots, and we may determine how long ago the reforestation was carried out, by the color intensity.

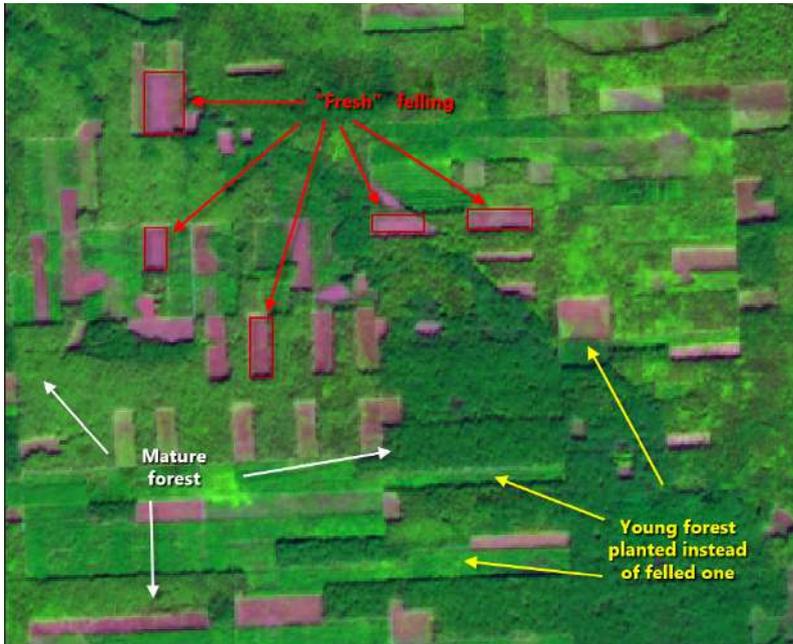


Fig. 2.3 View of felling areas in Sentinel 2 satellite image

The next feature is the shape of felling area, which is rectangular and homogeneous. In general, most man-made artificial features (reservoirs, fields, roads, forest belts, buildings, etc.) have a rectilinear geometric shape, while natural objects, in contrast, have smooth, tortuous, and inhomogeneous shapes (rivers, swamps, floodplains, etc.)

The scale of felling directly depends on the type of felling technique employed. There are four main types of felling methods according to the intended purpose: main use, maintenance felling, sanitary and complex. Let's discuss in more detail large-scale main use logging operations, which are carried out for timber procurement, as well as their appearance on satellite images in Google Earth Pro. Depending on forest characteristics, this type of felling may be:

- *Selective* – recurrent felling of individual trees or groups of trees;
- *Gradual* – felling of forest stand in several steps;
- *Clear cut* – felling of entire forest stand in a cutting area at once.

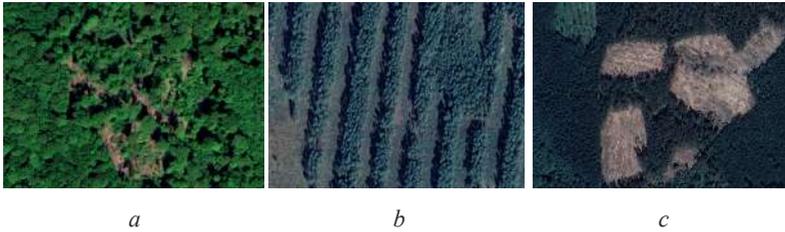


Fig. 2.4. Shapes of felling areas on Google Earth Pro satellite images. The following types of felling are presented: selective (a), gradual (b), clear cut (c)

The age of a mature forest may also be determined by the shadows. The taller the trees, the more shadows they produce on the felling border (Fig. 2.4).

3. Working with attribute data

Along with geometric (spatial) information about environmental objects, vector layers contain attribute information, i.e. accompanying tabular information, which is the basis for identifying their properties. This information allows to visualize, build queries and analyze thematic vector data. In general, Attribute Tables consist of columns (fields) that describe a particular attribute or characteristic of features of a certain type (for example, text, number, date, or sequence number) and lines that contain the values of these characteristics for each feature of a vector layer, respectively. It means that the number of lines in the Attribute Table corresponds to the number of thematic layer features. Note: when a Shapefile is created, it is automatically assigned a table with special fields that contain information about the geometry of thematic features. Such fields are the *Shape* and *ObjectID* or *FID* (*Unique Identifier of a Feature*). Users can create other fields of the Attribute Table independently, for example, a field with the name of each feature or its physico-chemical properties, date of observation, or information about its status.

4. Designing map layout

A map design (layout) is a set of map elements arranged in a certain way to enable map printing. As a rule, these elements include a scale bar, a north arrow, a coordinate system, a map title, a text description, and a legend. You can also add a coordinate grid to display a geographic spatial reference (Fig. 2.5).

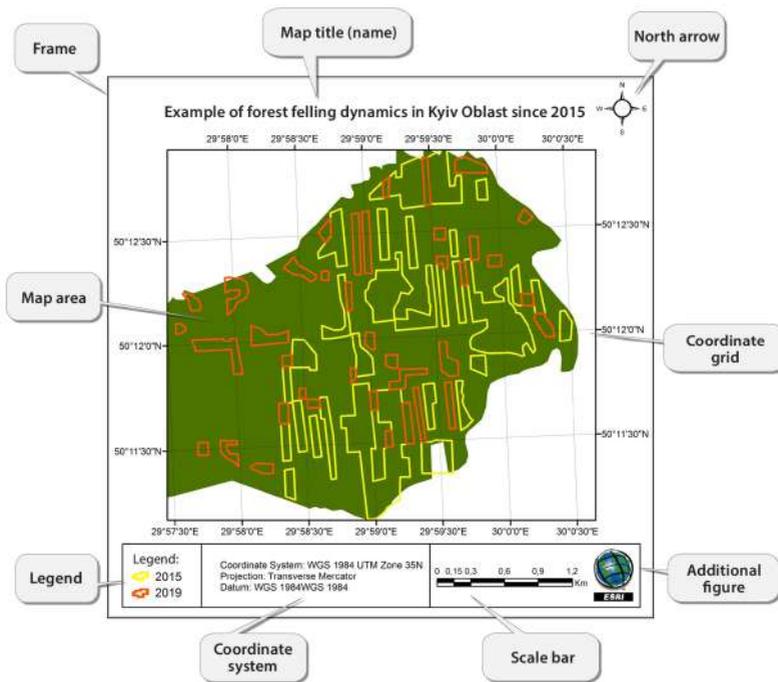


Fig. 2.5. Main elements of map layout

An appropriately designed (mounted) map can be exported to a raster file and used electronically to illustrate the research result in an essay or a presentation. However, the main purpose of layout settings is printing the map, in particular when designing a poster. The page layout can be landscape (extended in length) or portrait (extended in height) [3].



Performing a task in ArcGIS

1. Let's discuss the creation of thematic layers in *.shp format

To begin with, run ArcMap application, open a new project, and upload two Sentinel 2 images collected in 2015 and 2019. Adjust the combination of bands 7, 4, 3 for these images in the project



(this procedure was described in more detail in [Section 1.4](#)). Using the navigation tools, find the forest area in Fastivskiy District (OSM map will help you find the right place; [Section 1.3](#) describes how to add it to the project).

Next, use the *ArcCatalog* module. First, select the folder for storing the thematic layer of felling (Fig. 2.6).

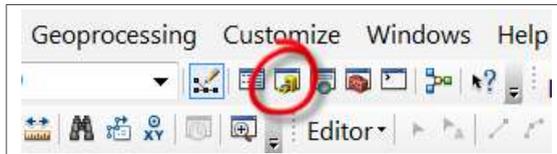


Fig. 2.6. *Arc Catalog* module

Upon selecting a folder, right-click it and select the *New* → *Shapefile* from drop-down menu. A dialogue box will appear (Fig. 2.7) for creating a new shapefile – *Create New Shapefile*.

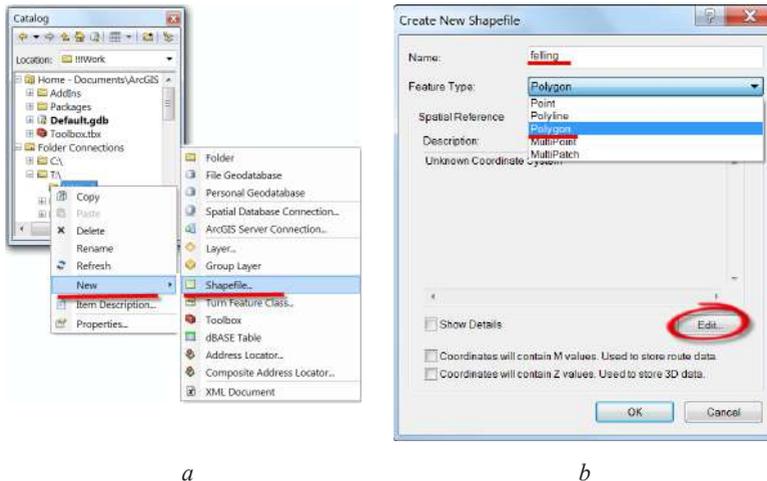


Fig. 2.7. Creating a new shapefile using the drop-down menu in the Catalog window (a); *Create New Shapefile* dialogue box (b)

In this window, you must specify the following information:

- name of a thematic layer (*Name*) – write the word “*felling*” in English;



The name of the thematic layer should be specified in Latin without additional characters due to the potential of errors with the use of some tools if the name is in Cyrillic (this also applies to the names of folders where you save your files).

- type of geometry of thematic features – **Feature type**. In our case, the polygonal type suits the best as we plan to calculate the felling areas;
- **XY Coordinate System**. To determine the required spatial reference, click the **Edit** button; select the appropriate coordinate system and projection in the **Spatial Reference Property** window. The easiest way to assign it from the image opened in the project is to click the **Import** button. Then, find the image in the **Browse for Dataset** window, select it, and click **Add**. A description of the assigned map projection will appear in the **Spatial Reference** module. Click **Ok** to finish creating the Shapefile. A new Shapefile will be automatically displayed in your project (Fig. 2.8).

Now we need to select a **convenient mode of a Shapefile display**.

To access the tools adjusting the display of Shapefiles, right-click on the felling layer and select **Properties** from the drop-down menu. Go to the **Symbology** tab in the **Layer Properties** window. You can choose the mode of displaying Shapefile features in the left part (**Show**) of this window. The **Single Symbol** option displays all the features contained in the selected Shapefile equally. This method is useful when the features in the same layer have no attributes to represent them by different symbology. Therefore, this method of display is suitable for a start because we have not drawn any polygon yet. Click on the square icon below **Symbol** and choose a convenient Shapefile display mode from the **Symbol Selector** window, selecting the colors for contours and fills, and contours width (Fig. 2.9).

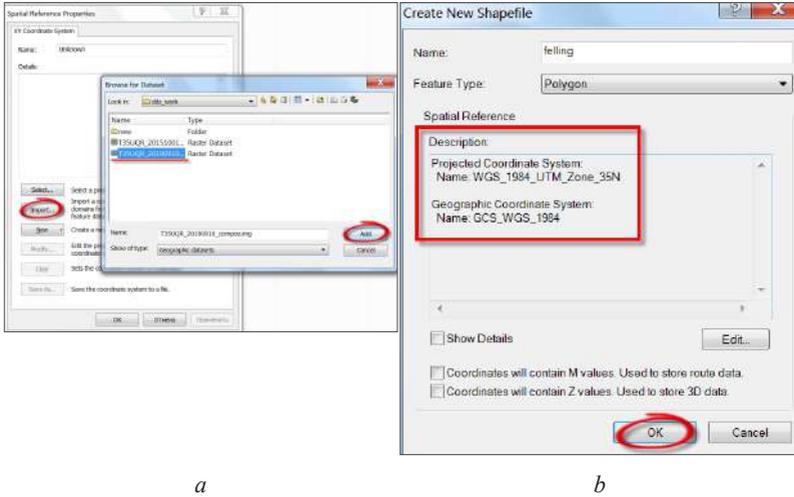


Fig. 2.8. Assigning spatial reference to vector layer from the satellite image (a) and description of the coordinate system (b)

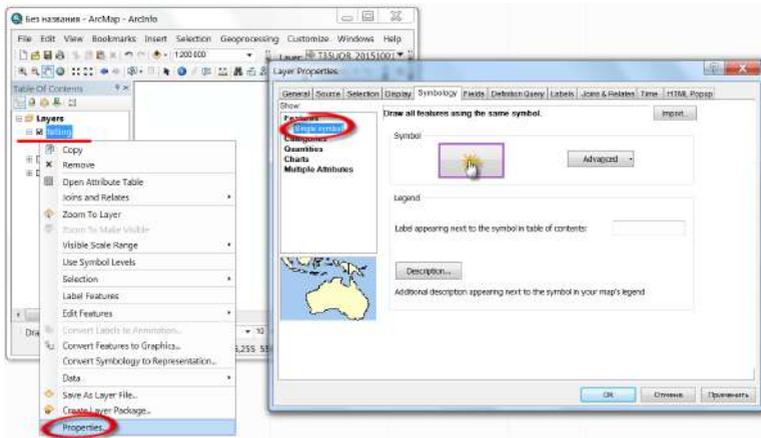


Fig. 2.9. View of the *Symbology* tab in the *Layer Properties* window



Another display option, *Categories*, allows you to display the layer features according to their properties, namely: *Unique value* – in this case, features will be displayed based on different values of a particular attribute, such as the «year» field (year of felling). We will describe this mode below when all felling areas are digitized and require display in different colors based on a unique sign – the year of felling (2015 or 2019).

*Note! To quickly change the color, you can open the **Symbol Selector** window by hovering over the square of the conditional color of the Shapefile in the **Layers** window and double-clicking with the left mouse button (Fig. 2.10).*

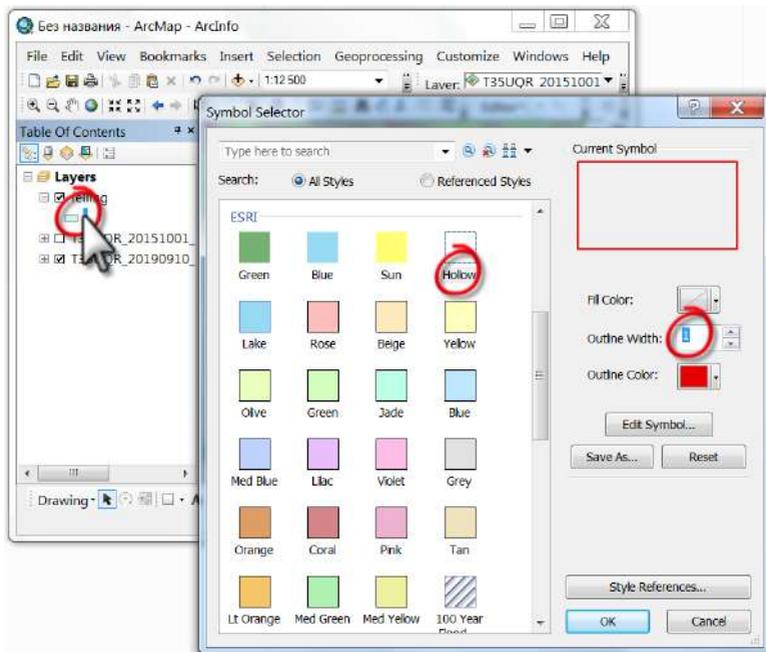


Fig. 2.10. The window for selecting the symbol for the polygonal layer

2. Starting editing the vector layer

Editing vector data in ArcMap of ArsGIS is done through the *Editor* toolbar. To use this toolbar, you first need to know how to start and finish drawing a polygon (Fig. 2.11).

*The first left button on this toolbar is **Editor**, which has a drop-down menu that provides access to advanced functions. The first in the menu is the **Start Editing** function. When ac-*



tivated, this function initiates editing the felling Shapefile, which we have created. To finish editing the felling vector, you will first need to click the **Save Edits** and then **Stop Editing** buttons. If you click **Stop Editing** first, a window will automatically appear asking you to save the edited data.

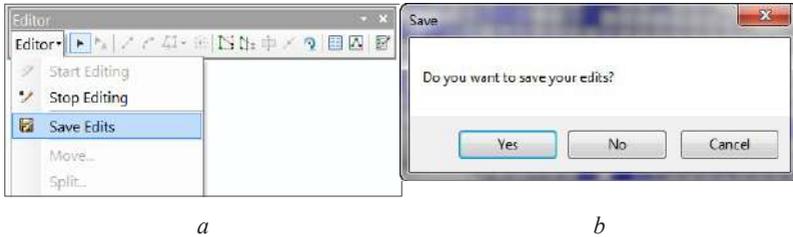


Fig. 2.11. Editor toolbar (a) and dialog box to confirm data saving after editing (b)

Therefore, when you click **Start Editing**, a new **Create Features** dialogue window opens (Fig. 2.12). This window displays a list of editable Shapefiles (at the top) and the types of features geometry, **Construction Tools** (at the bottom).



Fig. 2.12. The window for creating features in thematic layers

To digitize the felling, we shall use a **Polygon** tool, which is designed to create planar features of complex configuration and further calculate the area. Finally, we may start performing our task. First, it is necessary to digitize all the felling in the 2015 satellite image.

Basics of digitization: for step-by-step manual digitization of felling, place a **vertex** by vertex, each time left-clicking, or digitize in the **Streaming** mode by hold-



ing down the left mouse button and gently moving the cursor along the contours of the feature. In the streaming digitization mode, when you move the mouse cursor over the map, Arc Map adds vertices automatically at a specified interval. To start digitizing in a streaming mode, specify the first vertex from which the digitization will begin, and press the function key “F8”.

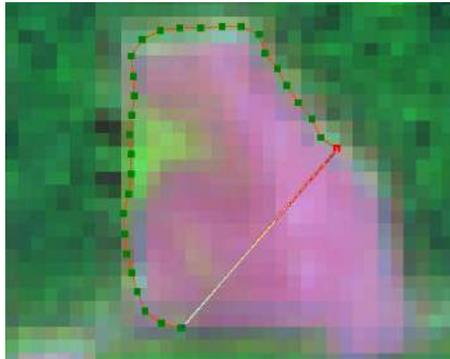


Fig. 2.13. Digitization of the polygon in streaming mode

You will see a series of green dots and one red dot indicating the last point where you stopped, and thus showing the direction of digitization (Fig. 2.13).

The polygon may be not continuous; for example, part of the trees inside the compartment felling area may remain uncut. In such a case, you need to cut out part of the polygon using the **Cut Polygons Tool** in the **Editor** toolbar. Note: pre-selection of the feature for cutting is required (Fig. 2. 4, Fig. 2.15).

Having digitized all the “fresh” felling areas captured in the 2015 satellite image (the vector of felling is shown in yellow on Fig. 2.16), we obtained a map of felling for 2015.



Fig. 2.14. **Editor** window – a tool for cutting polygons

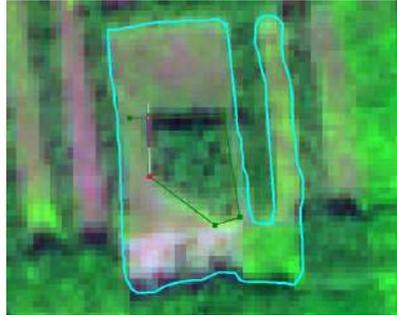


Fig. 2.15. Using the *Cut Polygons Tool*

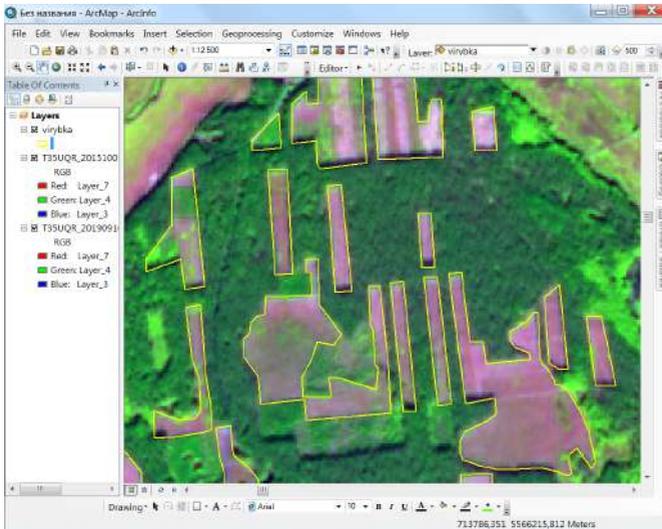


Fig. 2.16. Digitized felling on the 2015 satellite image

3. Working with attribute data

To assess the scale of felling over four years, you must first select all felling areas in the image as of 2015 and assign it a code “2015” in the attribute data, and then digitize the felling areas in the image as of 2019 and assign a code “2019” to new features. Therefore, the first stage – digitizing the felling areas of 2015 – has

been completed. Now we need to create a special column in the Attribute Table, assigning it appropriate code.

To access the Attribute Table, right-click the desired thematic layer or table (Fig. 2.17) and select the *Open Attribute Table* command in the shortcut menu.

Note! You can create new columns only when the Shapefile is not being edited, i.e. in the Stop Editing mode.

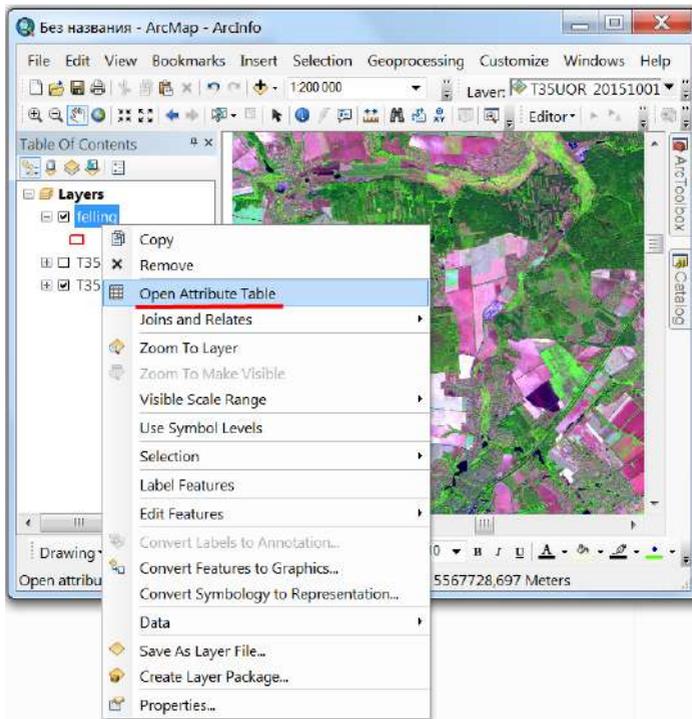


Fig. 2.17. *Open Attribute Table* drop-down window

The *Add Field ...* command allows adding new fields to the existing table to fill in the attribute data of the appropriate type (Fig. 2.18).



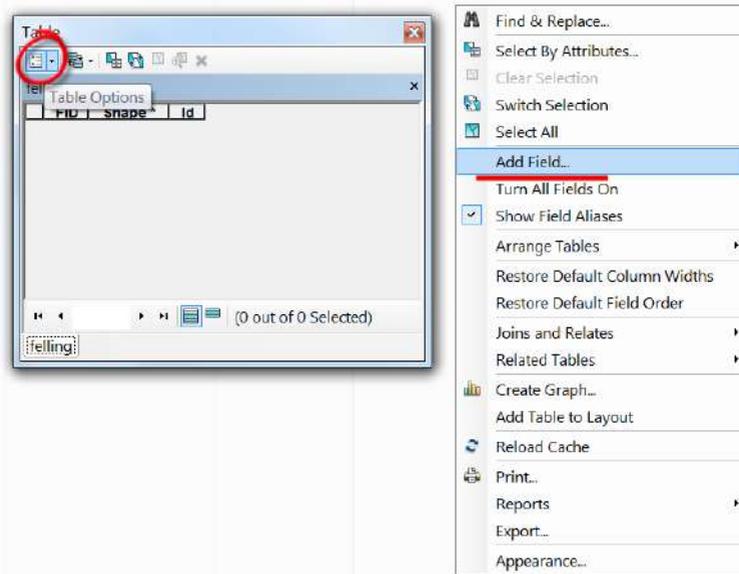


Fig. 2.18. *Add Field...* drop-down menu

When this command is activated, a corresponding dialogue box appears, allowing you to specify the name, type, and properties of the field being created. Among the field types in *ArcGIS* for the *.SHP format, it is possible to enter values in **Short Integer** and **Long Integer**, decimal values with a fixed **Double** and **Float** decimal point, **Text**, and **Date** information. The **Field Properties** module allows you to specify the number of characters (including spaces and other valid characters) a field can contain, the number of decimal values, and the default values.

When creating a new column with the code of the year of felling, write the title of the column, for example, “year”, and choose **Type** (data type) – Text with a default length of 50 characters in the **Add Field** window. Add another column (Fig. 2.19), which we will need later to calculate the felling area. The name of the column “area” and **Type** (the type of data) – **Float** (digital values with a comma).

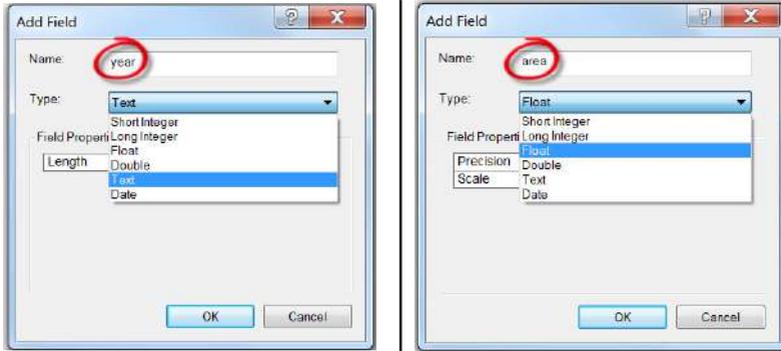


Fig. 2.19. Parameters for creating new columns in the *Add Field* window

Calculating the area. To calculate the basic cartometric parameters, such as area, the *Calculate geometry* command is used. To activate this function, right-click on the title of the “area” column. A dialogue box appears. Select the type of cartometric parameter (area, perimeter or length, coordinates of central points, etc.), coordinate system, and units of measurement. Each type of geometry of spatial features has its own set of cartometric parameters to choose from. In our case, we need to select the “area” as a parameter and “hectare” as a unit of measurement and click *Ok* (Fig. 2.20).

FID	Shape	Id	year	area
0	Polygon	0	0	0
1	Polygon	0	0	0
2	Polygon	0	0	0
3	Polygon	0	0	0
4	Polygon	0	0	0
5	Polygon	0	0	0
6	Polygon	0	0	0
7	Polygon	0	0	0
8	Polygon	0	0	0
9	Polygon	0	0	0
10	Polygon	0	0	0
11	Polygon	0	0	0
12	Polygon	0	0	0
13	Polygon	0	0	0
14	Polygon	0	0	0

Fig. 2.20. View of the Attribute Table after creating two new columns



We have chosen the *Text* data type for the “year” field, although we will enter numbers (2015 or 2019) here. This value is a code and we do not plan to use it for mathematical calculations, so it is advisable to use the *Text* data type instead of numerical. The *area* field, on the contrary, will be used to sum the area of all polygons or perform other mathematical operations, so it is important to keep the values as accurate as possible, therefore we have chosen the *Float* data type for this field.

Now select all digitized features and assign them a code “2015”. For this purpose, click *Table options* in the Attribute Table and use the *Select All* command to select all the features within the felling vector. The next step is to assign the code “2015” to the selected features. To do this, use the *Attributes* table in the *Editor* toolbar. In this table (Fig. 2.21), click the “year” field and assign code “2015” to the selected features.

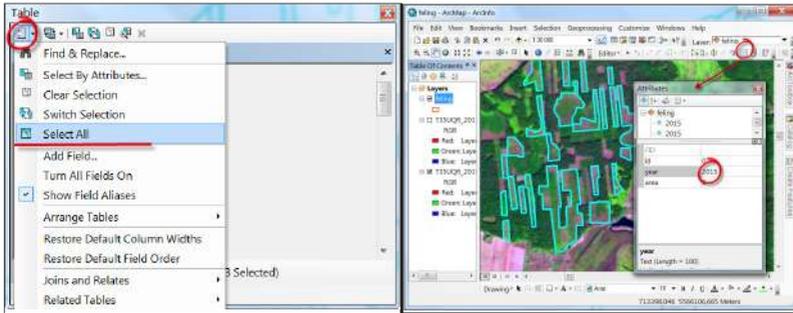


Fig. 2.21. Table options drop-down menu (a) and a short *Attributes* table (assigning a new code “2015” to the selected features) (b)

Then, digitize the new felling in the 2019 image and assign the code “2019” to new features (Fig. 2.22). To do this, first select the newly created features using the *Select by Attributes ...* tool.

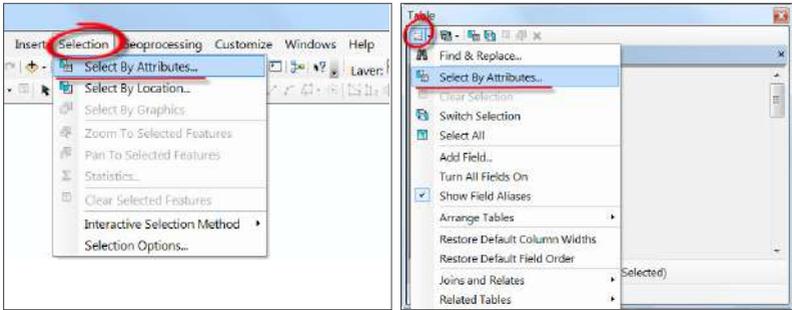


Fig. 2.22. Alternative ways to access the *Select by Attributes...* command using the *Selection* menu and the *Table options* tab in the Attribute Table window

The command allows selecting vector features based on attribute data. This command is also available in the corresponding Selection menu. In the working window of the *Select by Attributes* tool, specify “year” = “0”, i.e. selecting features without a code (Fig. 2.23).

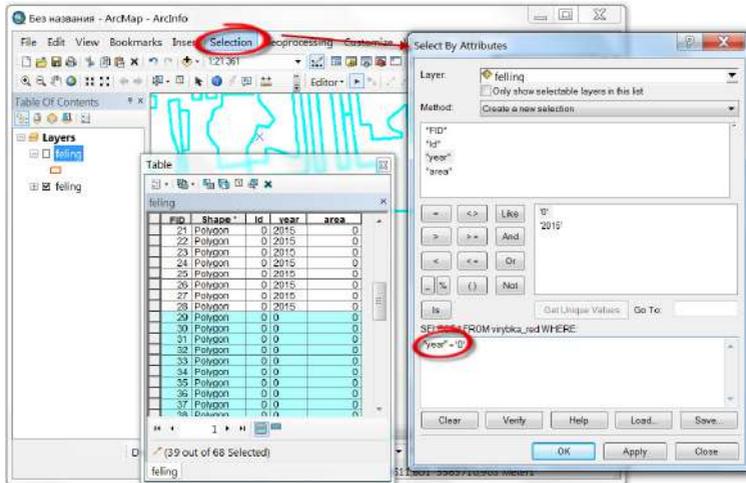


Fig. 2.23. The window for selecting features by defined attributes, *Select by Attributes...*



Upon assigning the codes, paint the created polygons of felling using different colors, such as yellow for 2015 and red for 2019. You can do this through the *Categories* menu, the *Symbology* tab in the *Layer Properties* window, as was described above at the end of the first paragraph of this Task (Fig. 2.24, Fig. 2.25).

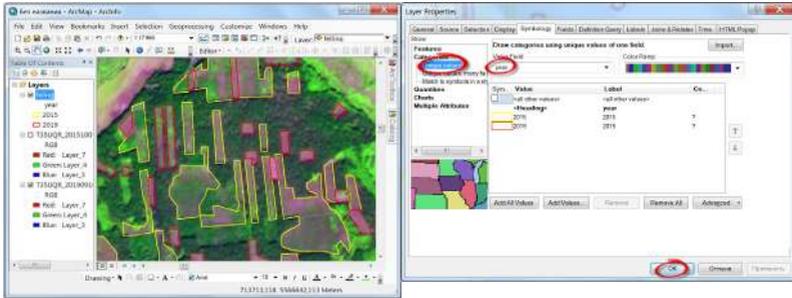


Fig. 2.24. Selecting display styles for the felling vector by category and the code of felling year, respectively

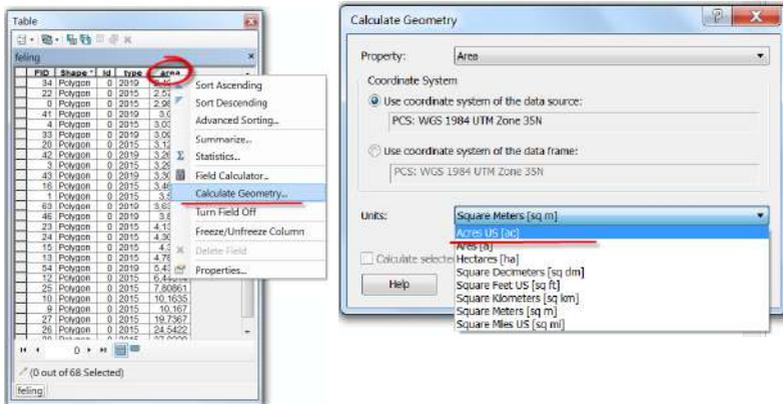


Fig. 2.25. The *Calculate geometry* dialogue box



The *Statistics* command will also be useful. It enables you to quickly retrieve information about the main statistics and the frequency of distribution of the selected field values. Upon selecting it, a dialogue box appears containing information on the main statistical indicators in the right part, and the distribution of values in the left part (Fig. 2.26). Thus, you can calculate the total felling areas for 2015 and 2019.

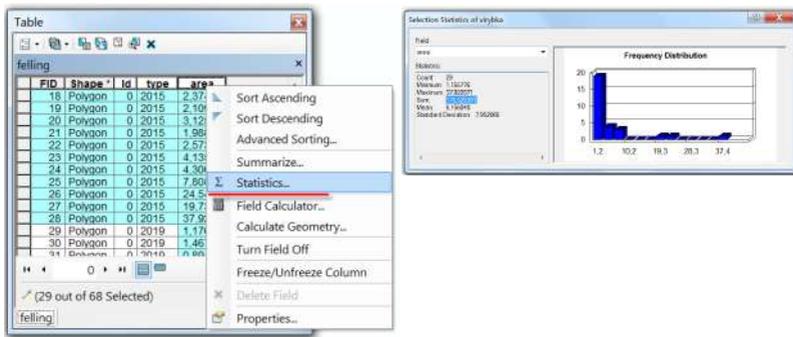


Fig. 2.26. The Dialogue box for displaying the main statistical indicators

4. Designing map layout

To switch to the layout view mode, click the *Layout View* icon at the bottom of the screen (Fig. 2.27). The layout size and orientation are selected using the *File* menu and the *Page and Print Setup* command.

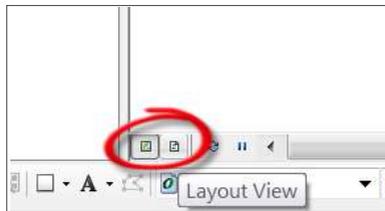


Fig. 2.27. Switching between map display modes

Setting up the map layout items using the *Insert* menu commands. The elements that can be inserted in the layout of the map (Fig. 2.28) include:

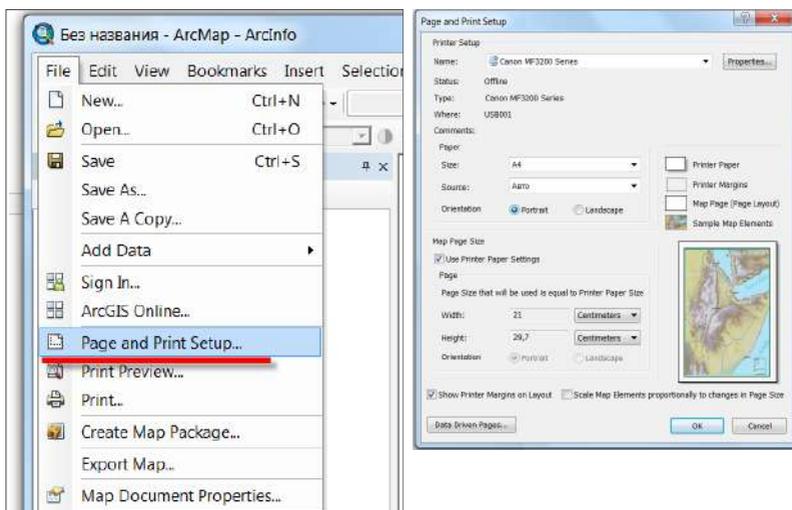


Fig. 2.28. Page and print setup

- **Legend** – this command enables to adjust the view of the symbols and their parameters. Upon selecting this command, the corresponding dialogue box appears, in which a list of thematic layers is sequentially set. These thematic layers will be displayed in the symbols and parameters of the Legend inscription;
- **North Arrow...** – this command enables to display a symbol on the map in the form of an arrow pointing to the north to determine the cardinal directions;
- **Scale Bar...** – displays the scale of the created map in the form of a dimensional ruler;
- **Scale text...** – displays the scale of the created map in the form of text inscription;
- **Picture** command enables adding the imagery to the layout in raster and vector formats that are supported by ArcGIS Desktop;
- **Object** command enables to add an item from other software.

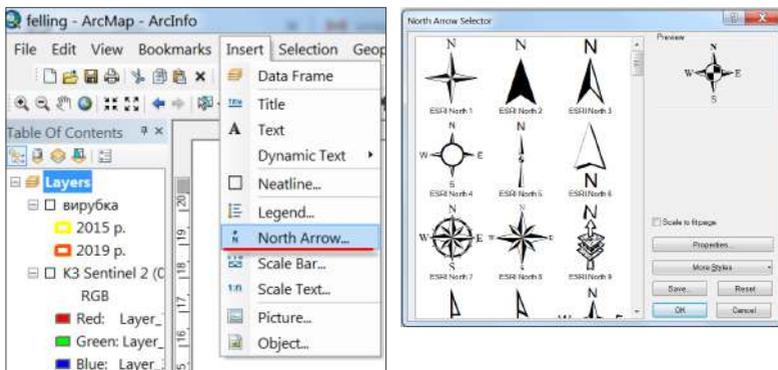


Fig. 2.29. Access to the *Insert* menu command with the *North Arrow* tool and its properties

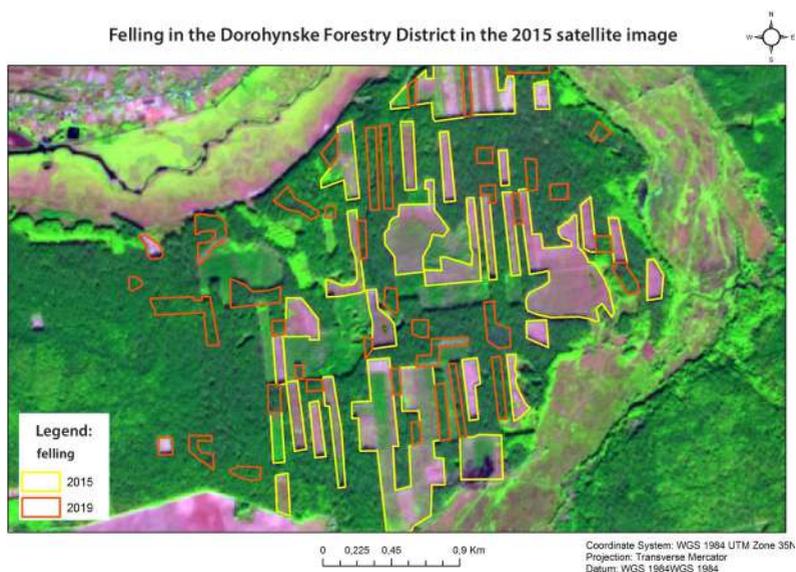


Fig. 2.30. The completed map of felling in Dorohynske Forestry District for four years



In addition to the mentioned elements, you can also add to a map layout a coordinate grid (geographical and rectangular), an index grid, a fragment of the Attribute Table, graphs and charts, reports created using the appropriate tools in the ArcGIS Desktop environment (Fig. 2.29).

Dorohynske Forestry District's felling map is an example of the completed layout (Fig. 2.30)



Performing a Task in QGIS

1. Create thematic layers in *.shp format

To get started, run QGIS Desktop. Open a new project and add two Sentinel 2 images as of 2015 and 2019. Adjust the combination of bands 7, 4, 3 for these images in the project (it was described in detail in Section 1.4). Using the navigation tools, find the forest area in Fastivskiy District (OSM map will help to find the right place (Section 1.3 describes how to add it to the project)).

On the toolbar, select **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 a new vector layer with selected felling areas. Enter its name, for example, “*felling*”, and click **Save**.

The name of the thematic layer should be specified in Latin without additional characters due to the potential of errors with the use of some tools if the name is in Cyrillic (this also applies to the names of folders where you save your files).

Select **Polygon** from the drop-down list in the dialogue box for creating a shapefile in the **Geometry type** field. In our case, the polygonal type suits the best, as we plan to calculate the felling area after digitization thereof (Fig. 2.31).

Below the geometry field, there is another drop-down list with the names of the projected coordinate systems. Open it and select the **WGS 84 / UTM zone 36N** projection. This drop-down menu displays the most often used projected coordinate systems (Fig. 2.32). If you haven't specified the projected coordinate system yet, it may not be available in the list. In this case, click on  icon and write “**WGS 84 / UTM zone 36N**”, in the top bar **Filter** in the window that opens. As a result, this projection will be displayed in the **Coordinate Reference System** window. Select it and press **Ok**.

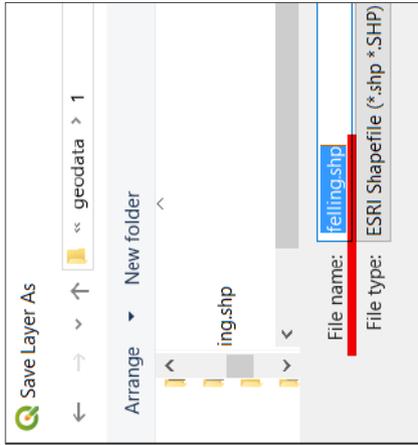
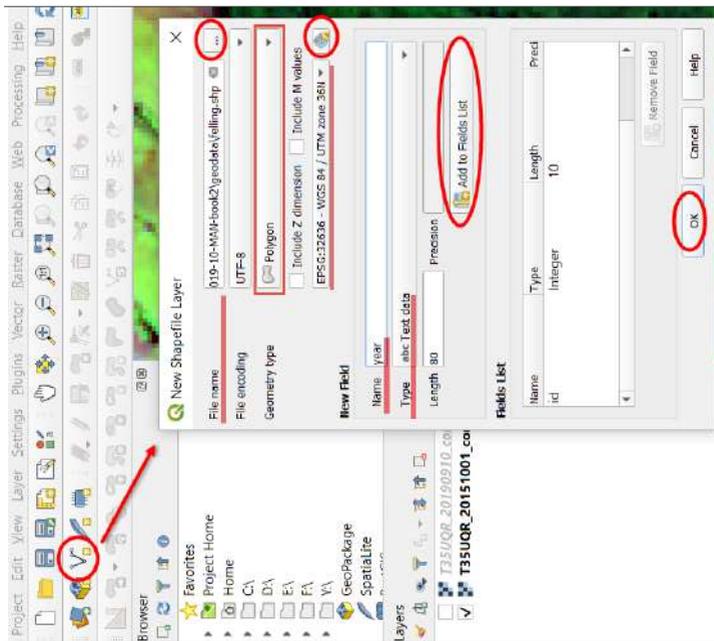


Fig. 2.37. New Shapefile dialog box

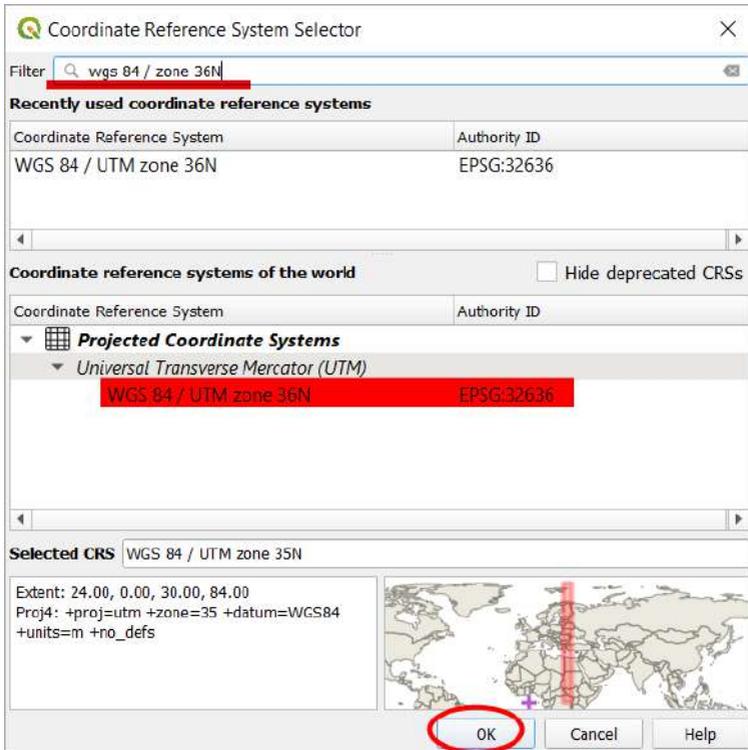


Fig. 2.32. The window for selecting projected coordinate system

Create a new field with the attribute “year”, i.e. the field in which we will enter the year of felling for each vector feature (digitized polygon of felling). To do this, specify *Name* – “year”, *Type* – *Text data* (Text Code) and click on *Add to Fields List* in the *New field* window. A new field, “year”, will be added to the *Fields List* window.

You can also create new fields with attributes for existing vector layers, i.e. not only when creating a new vector layer. We will discuss this method in the section below.

Finally, click *Ok* and a new layer, “*felling*”, will automatically open in the project layers.

Now we need to find a convenient **style for displaying the Shapefile**.

To access the shapefiles settings toolbar, right-click on the felling layer and select **Properties** from the drop-down menu. Then go to the **Symbology** tab in the **Layer Properties** window.

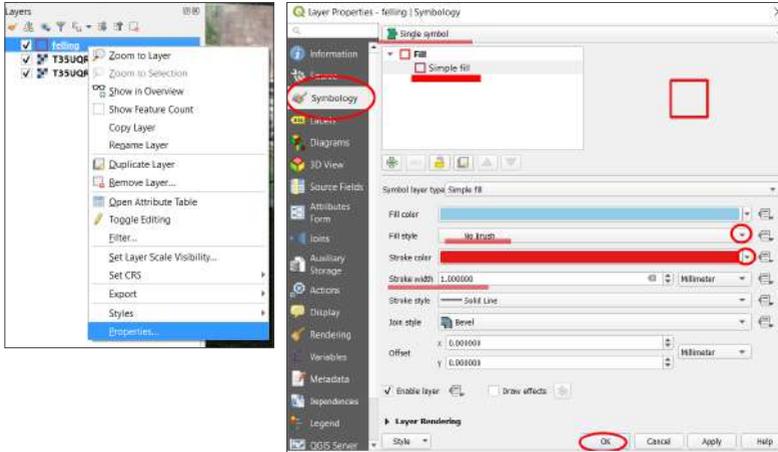


Fig. 2.33. View of the Symbology tab in the **Layer Properties** window

At the top of this window, you can select the option for displaying the shapefile features. The **Single Symbol** option displays all the features in the selected layer in the same way. This method is useful when the features in one layer have no classification attributes. We can use this method at the start of the project since we have not drawn yet any polygon (Fig. 2.33).

Another common way to display a layer is the **Categorized** one, which enables to display layer features based on their properties. In this case, the features will be displayed according to different values of a certain attribute, such as the “year” field (year of felling). We will describe the usage of this method below when we digitize all fellings. You will have to display them in different colors based on a unique feature – the year of felling (2015 or 2019).

At this stage, we will leave the **Single Symbol** display type. You can select below in the **Fill** field the style of polygon fill. In our case, select the **Simple fill** type – the fields for setting up the polygon stroke and fill style will open. Polygons which are displayed only by a stroke without fill are more convenient for digitization, therefore, select **No Brush** in the **Fill style** field, and for example color red from the



drop-down menu in the *Stroke color* field, and enter number 1 (i.e. the width of a contour will be equal to 1 mm) in the *Stroke width* field, and press **Ok**.

2. Start editing the vector layer

Editing vector layers in QGIS is done using the standard tools, as well as the advanced toolbar. By default, this panel is not displayed in the top toolbar, so you need to open it first (Fig. 2.34). To do this, click on the *View* → *Toolbars* menu and check the box next to *Advanced Digitizing Toolbar*.

As a result, the digitization tools appear in the upper toolbar (Fig. 2.35).

Tool icons are displayed in gray because they are not active. This panel includes many useful tools, but first and foremost, you need to know how to start and complete the polygon drawing.

To begin with, activate the vector layer editing mode: select the layer you want to edit in the Layers menu (in our case, the “*falling*”) by left clicking on it, and then click on the  *Toggle Editing tool*. You can see that after enabling the editing mode, some tool icons gained on color, i.e. became active. One of them is a tool for digitizing polygons . Select it and start outlining the fellings in the image (Fig. 2.36).

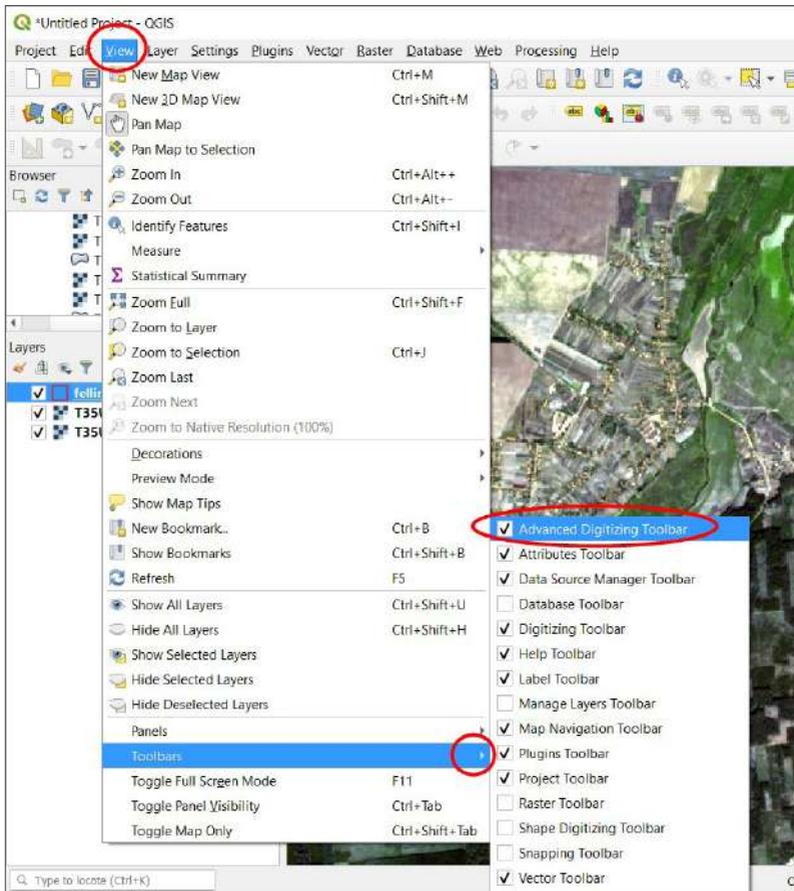


Fig. 2.34. Adding advanced toolbar for digitization





Fig. 2.35. Advanced toolbar for digitization



Fig. 2.36. Activating the editing mode

For stepwise manual digitization, place a vertex by vertex, each time left clicking. When you complete drawing the polygon, right-click to finish the job. A window for entering attribute data will appear. The “*id*” (feature ID) field can be left unchanged, it will be filled in automatically, and enter 2015 in the “*year*” field, click **Ok** or press the **Enter** key (Fig. 2.37).

You can also leave the “*year*” field blank while continuing digitizing other polygons. We will enter this value for all polygons at once later, when working with the Attribute Table, as all polygons will be created according to the 2015 image.

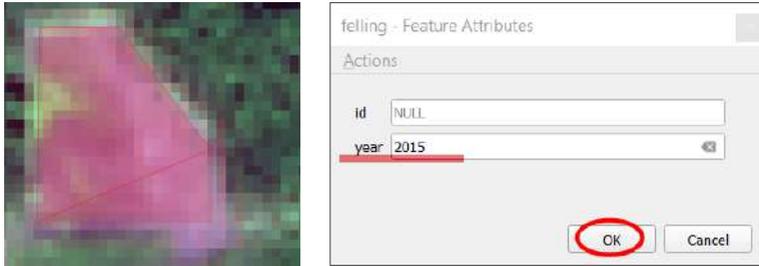


Fig. 2.37. Manual digitization and attribute data input when creating vector features

To complete digitizing the entire vector feature layer, click the Save tool again, and then click **Toggle Editing**. If no edit changes have been saved before selecting this feature, a window will appear asking whether to save the edited data. Click **Save** if you want to save all changes (Fig. 2.38).

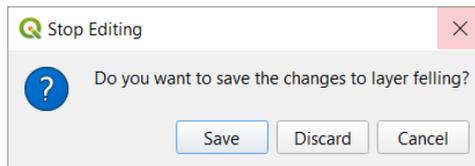


Fig. 2.38. A dialog box for confirmation of saving data after editing

Now everything is ready to start the task performance. First, you need to digitize all the felling in the 2015 satellite image (check the map window; it should display the image as of 2015. For more information on changing the order of layers' display in the Layers panel, see [Section 1.3](#)).

The polygon may be interrupted, for example, part of the trees inside the compartment felling area may remain uncut. In such a case, you need to use the  **Add Ring** tool, which is located on the **Advanced Digitizing Toolbar**, by selecting it and delineating the hole inside the existing polygon (Fig. 2.39).



Fig. 2.39. **Add Ring** tool on the **Advanced Digitizing Toolbar**

Thus, having digitized all the “fresh” fellings in the 2015 satellite image, we obtained a map of fellings for 2015 (Fig. 2.40).



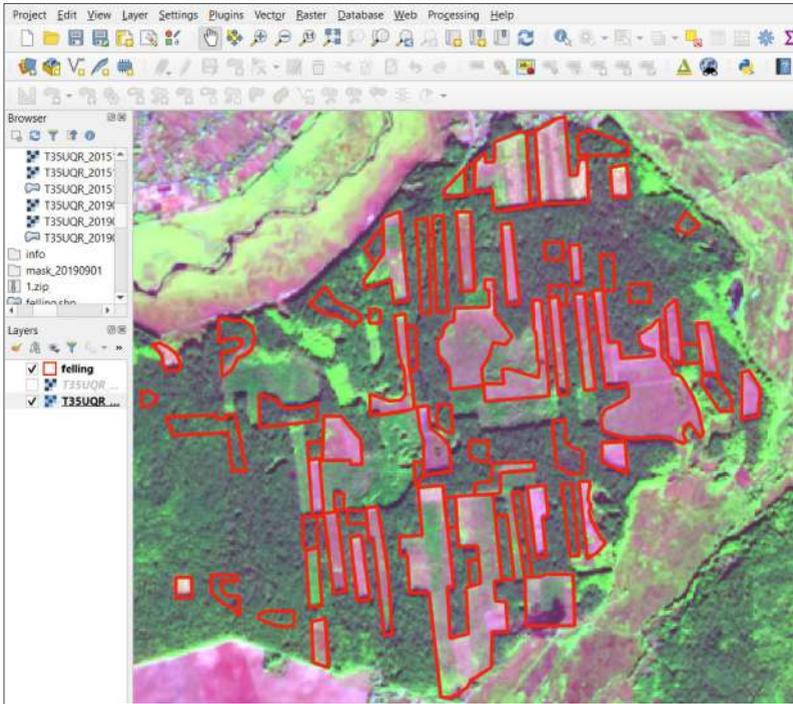


Fig. 2.40. Digitized felling in the 2015 satellite image

5. Working with attribute data

To assess the scale of felling over four years, first, select the whole area of felling in the 2015 image and assign it "2015" code in the attribute data, then, digitize the felling in the 2019 image and assign "2019" code to new facilities. Therefore, the first stage is completed: we have digitized the felling data for 2015, and now we have to assign appropriate code to them.

To open the Attribute Table (Fig. 2.41), right-click on the desired thematic *layer* or table in the Layers panel and select the *Open Attribute Table* command.

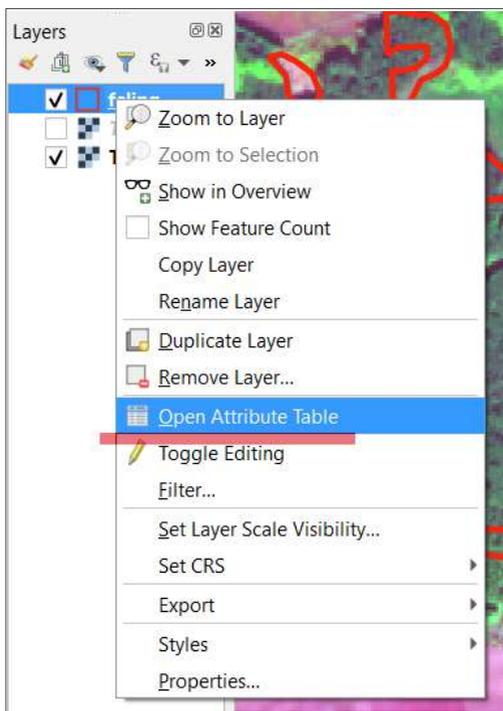


Fig. 2.41. **Open Attribute Table** drop-down window

In the Attribute Table that opens, enable the editing mode by clicking on the **Toggle Editing** tool , select the “*year*” field from the drop-down list, enter “2015” in the line for values, and click **Update All**.

Note! You can enter data into a table or create new columns only after enabling layer editing mode.

Since the objective of our Task is to calculate the areas of felling, we need to create another field in the Attribute Table – the “*area*” field, in which we will calculate the area of each polygon (Fig. 2.42).



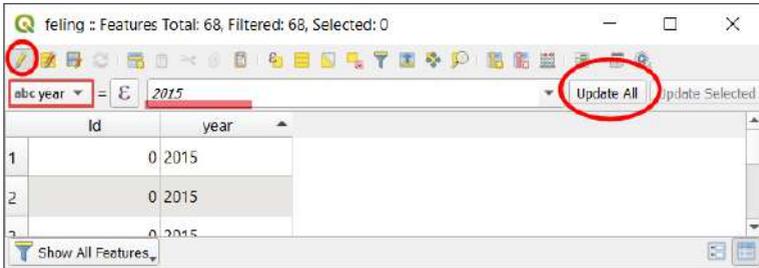


Fig. 2.42. Assigning a code in the *Attribute Table*

To add a new field in the Attribute Table, click on the *New field* tool , and in the window that opens, specify the name of the new field in the *Name* box, select the *Decimal number* from the *Type* box, and click *Ok* (Fig. 2.43).

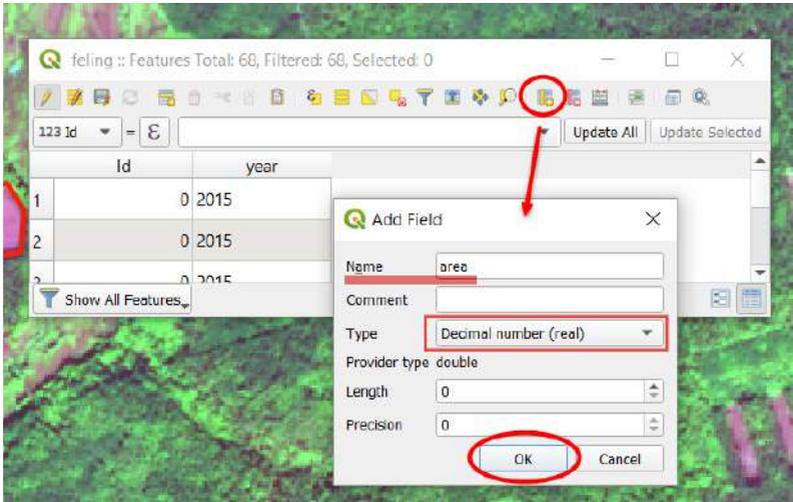


Fig. 2.43. *New field* drop-down window

Among the types of fields (Fig. 2.44) in QGIS for the format *.SHP, it is possible to enter values in integers (*Whole number/integer* and *integer 64 bit*), decimal numbers (*Decimal number*), text value (*text/string*), as well as in the form of date (*Date*) and date and time (*Date & time*). The properties of the value field enable us to determine the number of characters (including spaces (*length*)).

Whole number (integer)
Whole number (integer 64 bit)
Decimal number (real)
Text (string)
Date
Date & Time

Fig. 2.44. Selecting field type in the *Attribute Table*

When creating the vector layer ([see paragraph 1](#)), we have selected a text data type for the “*year*” field. Although we have entered the numerical value (2015) in this field, this value is a code, and we are not going to use it for mathematical calculations, so it is advisable to use the text data type rather than numerical. The “*area*” field, on the contrary, will be used to sum the area of all polygons or perform other mathematical operations, so it is important to keep the values as accurate as possible, therefore we have chosen the **Decimal number** data type for this field.

Now we need to digitize the felling in the 2019 image. When digitizing new features, do not enter a year for each polygon separately – we will select all new features and assign them a common code, “2019”. For this purpose, when you complete digitizing all polygons, reopen the Attribute Table and you will see that the new polygons for which we did not enter a year, have the “*Null*” value in the column “*year*”. This means that the data is missing. We will select these features and assign them the code “2019” using the tool **Select features using expression**. The command allows you to select vector features based on a certain attribute (Fig. 2.45).

In the middle of feature selection window, select the **Fields and Values** tab to open a list of all layer attributes. Double-click on “*year*” to display the field name in the box with the expression to the left. Then click on the **All Unique** button in the right part of the window – a list of all unique values in the “*year*” field, in our case it is “2015” and “*NULL*”, will appear below. Double-click on “*NULL*”, and the expression “*year*” *NULL* will appear in the window on the left. At the bottom of the window for the expression, you can see the inscription in red letters, **Expression is invalid**. Now type the word “is” on the keyboard so that the expression looks like “*year*” is *NULL*. Now you can see that the red inscription at the bottom has disappeared, which means that the expression is correct. Therefore, the system understands this expression as our intention to select all the features from the Attribute Table with *NULL* value in the “*year*” field. Since the “*year*” field is a text one, we use the operator “is” for the sample. In this case, you need to use the operator “=” for the numeric field. This is how the commands are created in the SQL program-



ming language. To select the desired features, click *Select features* at the bottom of the window (Fig. 2.46). As a result, information that 39 features were chosen out of the total number of features (68) will appear at the top of the Attribute Table.

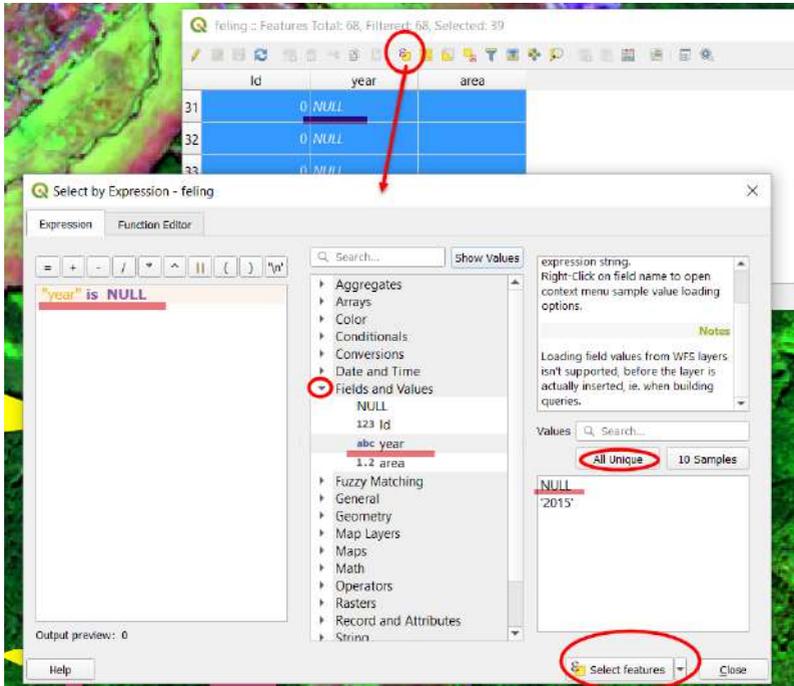


Fig. 2.45. Selecting features by expression

QGIS felling :: Features Total: 68, Filtered: 68, Selected: 39

Fig. 2.46. Information about the number of selected features from the Attribute Table

Then check whether the layer editing mode is enabled, and select the field “year” for editing (Fig. 2.47), enter the value “2019” and click *Update Selected*.

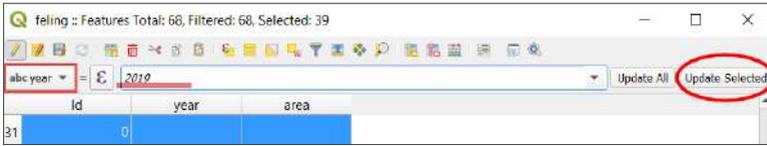


Fig. 2.47. Assigning a common field value to selected features

Upon completing the code assignment, paint the features in different colors. For instance, we will use yellow stroke line for 2015 and red for 2019. Open **Layer Properties** as described above at the end of the first paragraph of this Task, then – the **Symbology** tab and select the display type **Categorized**. Below you need to specify which categories of the field you want to display (Fig. 2.48). That is, in the **Column** line, select the “year” field from the drop-down list and click **Classify**. Then adjust the desired color and shape for each year by double-clicking on the polygon symbol next to the year, and click **Ok**.

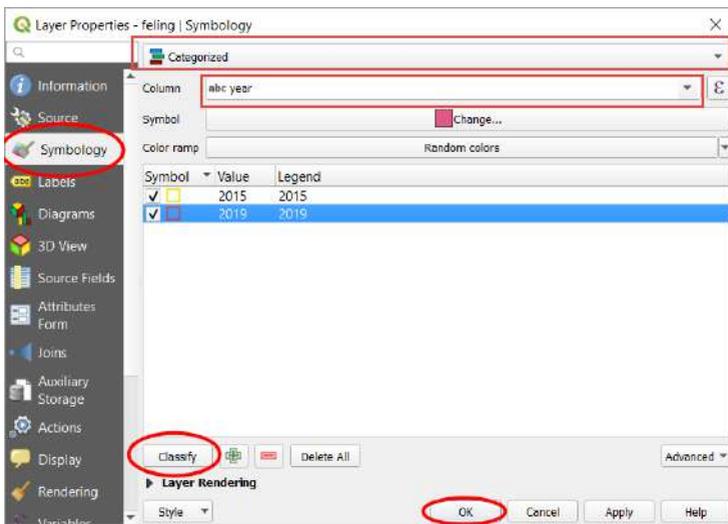


Fig. 2.48. View of the **Symbology** tab in the **Layer Properties** window with activated **Categorized** type of display



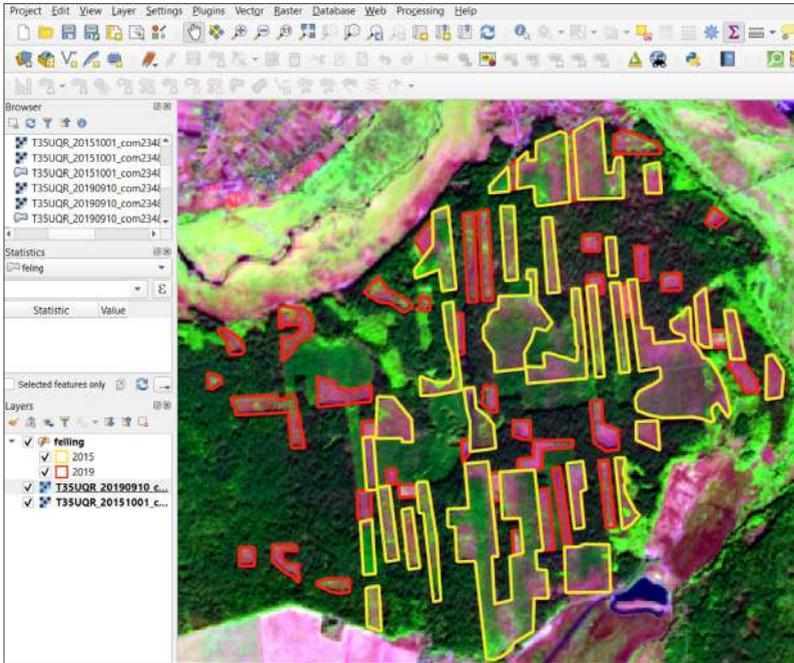


Fig. 2.49. View of digitized felling in the 2019 satellite image

Area calculation. Let's compare the felling areas in 2015 and 2019 (Fig. 2.49). To do this, open the Attribute Table again and calculate the area of each polygon (feature). Above, we have created the field “area” to calculate the area of each polygon. So, make sure that the editing mode is enabled, select the “area” field in the operations box, and click on the **Expression** tool. In the new dialogue box, open the **Geometry** tab, double-click the operator “\$area” to display it on the left side of the window, and click **Ok**. Then click **Update all** in the Attribute Table, and the area of polygons will be automatically calculated in the field “area” (Fig. 2.50).

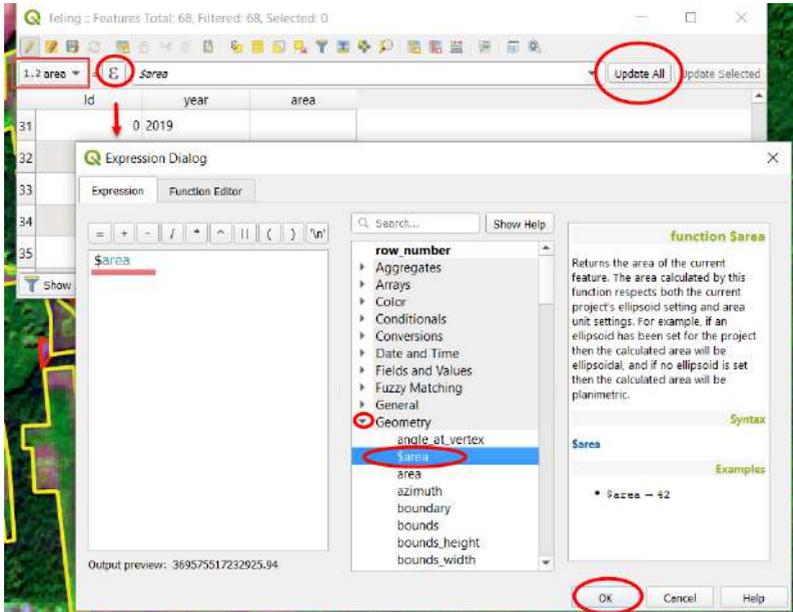


Fig. 2.50. Calculating the area of polygons

Note that the area of polygons was calculated in m² (Fig. 2.51). If we want to get it calculated in km², divide the expression “\$area” by “10,000”.

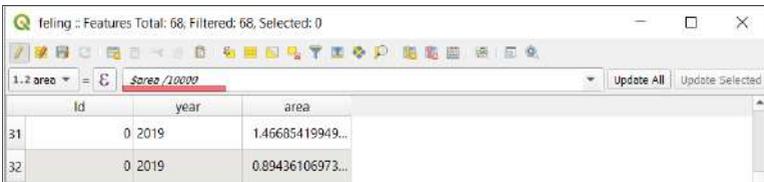


Fig. 2.51. Calculating the area in km²

Show Statistical Summary tool  on the toolbar is also useful (if the tool is not displayed on the toolbar, you need to enable it via the **View** menu → **Statistical Summary**, and this toolbar will appear in the left part of the window). Select the layer (**felling**) and the field (**area**) for which you want to calculate statistics. The statistical indicators will be automatically displayed in the statistics window (Fig. 2.52).

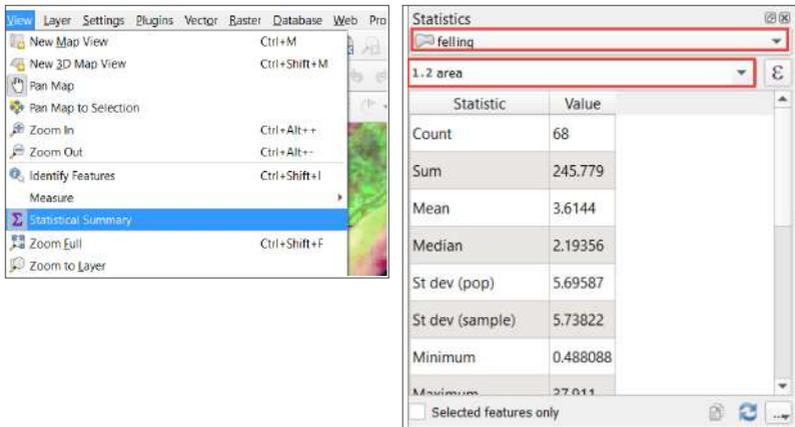


Fig. 2.52. Using the *Show Statistical Summary* tool

Alternatively, you may first select the features by a certain parameter (for example, 2019) and check the box next to the *Selected features only* box at the bottom of the statistics window. The statistics will be displayed for selected features only. Therefore, we can see that the area of felling was 67.3 km² in 2019 and 178.5 km² in 2015 (values may be different depending on what part of the images you have digitized – smaller or larger).

6. Designing the map layout

To switch to layout and map layout mode, open the *Project* menu and select → *New Print Layout*. A window may appear asking you to name the layout, in which case add an arbitrary name or leave the box blank and click *Ok* (Fig. 2.53).

In the window for creating a map layout, open the *Add item* menu and select *Add map* from the list. You will see that your mouse cursor has changed; outline the area on the white sheet of the map layout where you want to place it (Fig. 2.54).

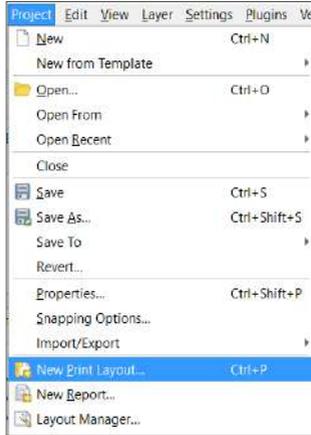


Fig. 2.53. Creating a new print layout

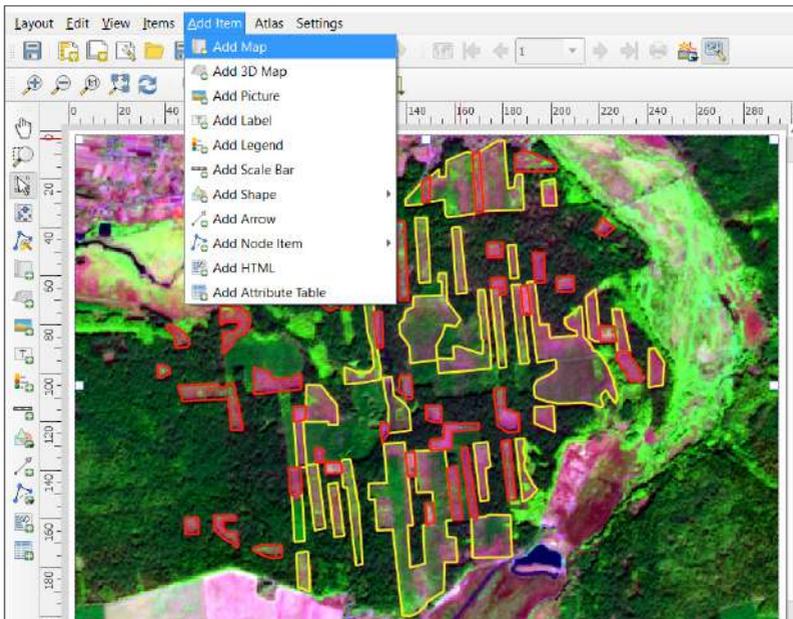


Fig. 2.54. Designing the map layout



Using the *Add item* menu, add a legend to the map – the *Add legend* tool, the north arrow – *Add Arrow* or *Add Shape*, the scale bar – *Add Scale Bar*.

Then you can save the layout (Fig. 2.55) as Image or PDF using the appropriate commands from the *Project* menu.

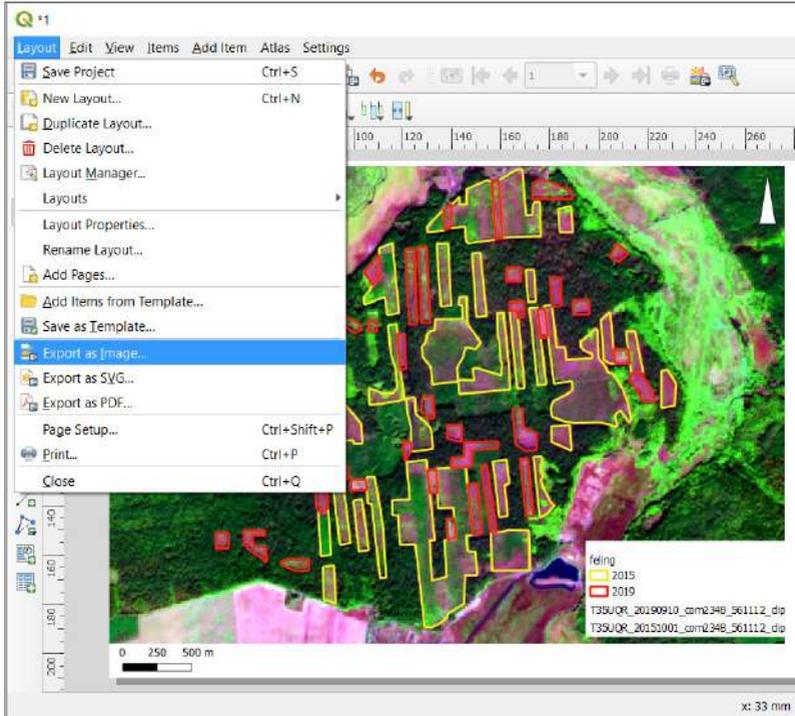


Fig. 2.55. Saving the map layout

Here is an example of a completed layout – the map of felling in Dorohynske Forestry District (Fig. 2.56).

Felling in the territory of Dorohynske Forestry District in the 2015 satellite image



Fig. 2.56. The completed map of felling in Dorohynske Forestry District for four years

Section for the Youngest Audience



Interpreting sand washing in the Dnipro River floodplain

Kyiv is the capital of our state. It is a city with an official population of about three million and, according to unofficial statistics, more than five million. The number of metropolitan residents increases every year, and, respectively, the city is growing rapidly. However, as the areas for construction in the central part of the city are almost exhausted, the urban planning vector is gradually shifting to the suburbs. In particular, the new mass elite buildings are erected on the floodplains of the Dnipro River.

Now, we will discuss the development of the southern edge of Kyiv, on the right bank of the Dnipro River, near Kozyn urban-type settlement and Pliuty village. Originally, there was a series of shallow, well-heated, overgrown with aquatic vegetation ponds, which were valuable spawning and feeding grounds in this area along the banks of the Dnipro River. Currently, the intensified construction in aquatic buffer, which is the territory with a limited regime of land use, causes irreparable



harm to the natural environment. Sand for building new residential areas is extracted from the Dnipro riverbed using hydraulic installations, which leads to a radical transformation of the river floodplain (Fig. 2.57).



Fig. 2.57. Sand washing near Kozryn urban-type settlement [4]

We will use Google Earth Pro to perform this Task. The program's mapping tools allow us to draw our own routes, polygons, features, overlay various images, links, etc. We can also add color, size, style, inscription to our choice for each added element. This allows us to easily create maps of different areas of study. Also, the advantage of this resource is a large number of satellite images with a high spatial resolution of up to 1 m, using which you can trace the smallest changes in any area, such as coastline construction and, accordingly, sand wash, which will be discussed in more detail below.

Performing Task in Google Earth Pro

To digitize the areas of sand wash for construction in the floodplain of the Dnipro River from the contemporary and archival satellite images available in Google Earth Pro and display the dynamics of their changes in the form of a map.

Data

Satellite images collected on May 23, 2005, and May 24, 2018, for the territory of the Dnipro River floodplain near the Kozyn urban-type settlement, Pliuty village.

Task Performance Algorithm

1. Search for the area of interest on the Virtual Globe of Google Earth Pro.
2. Create thematic layers.

The main format of geospatial data in the Google Earth Pro program is *.kml/kmz – Keyhole markup format. By default, all thematic layers you create will be displayed in the Places section. If you want to share them with friends or open them in other GIS programs, you need to save them to your computer (Fig. 2.58) as *.kml or *.kmz files.

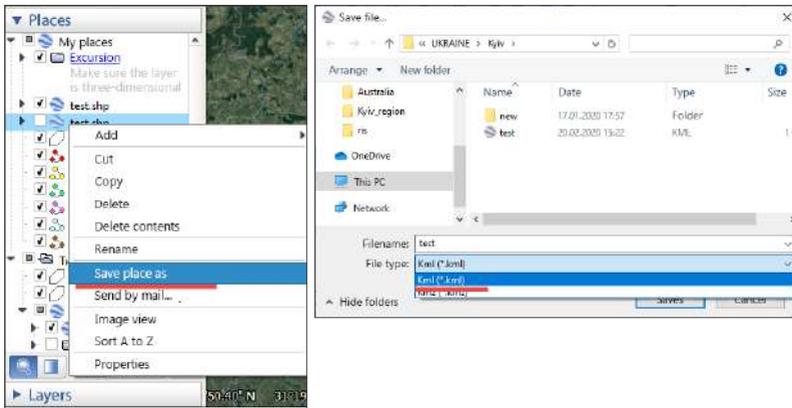


Fig. 2.58. Saving the created thematic layer in the *.kml format

3. Work with thematic layers (editing).
4. Design the map layout.

Performing a Task

1. Search for the area of interest on the virtual globe of Google Earth Pro

First, find the area of interest by typing its name in the search bar, in our case – “Kozyn”, and review the historical view of the Dnipro River floodplain using the *Show historical imagery* tool. The sand massifs are clearly distinguished in satellite



images by their bright white color, so you can easily recognize (identify) them by this characteristic (Fig. 2.59).

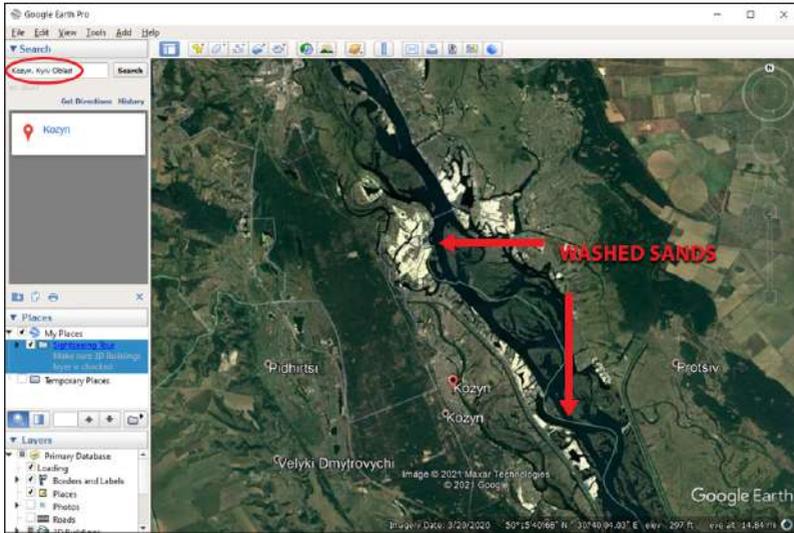


Fig. 2.59. Search for Kozyn urban-type settlement by name in the Google Earth Pro search bar and identification of newly created sand massifs

2. Create thematic layers

To create a vector map of the reclaimed artificial islands, it is necessary to digitize the shore line data of the Dnipro River near Kozyn urban-type settlement, Pliuty village, for two periods: the oldest (the 2005 image is available in the program) and modern (the 2018 image), as well as to compare in more detail the changes in the shape of natural and newly formed artificial islands and calculate their area.

First, create a working folder (Fig. 2.60). To do this, go to the **Places** section and right-click on the **My Places** thematic layer. From the drop-down menu, **Add**, select **Folder**, and name the new folder "Reclaimed Islands".

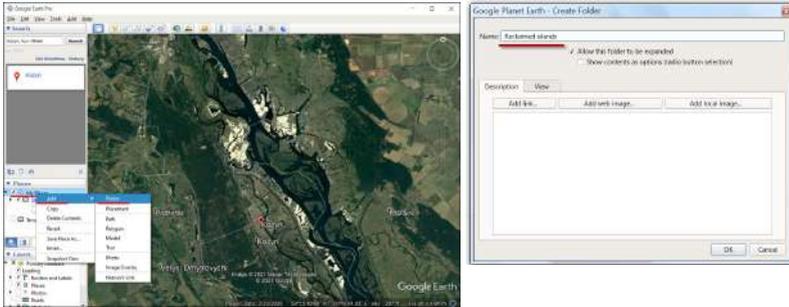


Fig. 2.60. Creating a working folder

The next step is to create a new polygonal feature (Fig. 2.61). To select the outline of the feature (in our case – the reclaimed islands as of 2018), use the **Add Polygon** tool.

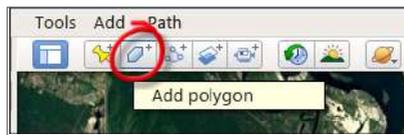


Fig. 2.61. The **Add Polygon** tool

To do this, click **Add Polygon** on the toolbar. The **New Polygon** window will open automatically. Type the **Name** of the feature you are creating (in our case “2018”), and change the color and width of the line in the **Style** tab (optional), for example, select the red color, the line thickness “2”. For the convenience of digitization, change the type of fill from **Filled** to **Outlined**.

3. Work with thematic layers (editing)

Now you can go to the map window and start manual digitization. Left-click on the map to delineate the boundaries of the feature without closing the **New Polygon** window. Save the changes by clicking **Ok**. To continue editing the same feature, right-click on the created polygon “2018” → **Properties**, and the **Edit Polygon** window will open again, and you can continue digitizing (Fig. 2.62).



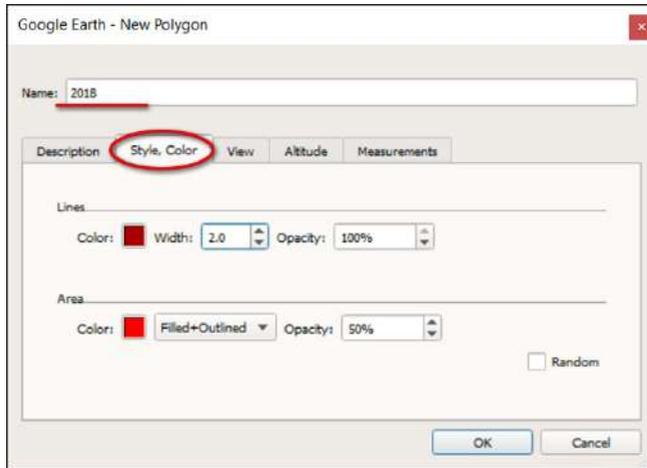


Fig. 2.62. View of the *New Polygon* working window

Digitization particulars: for step-by-step digitization, put a vertex, each time left-clicking, or digitize in the Trace mode holding down the left mouse button and gently moving the cursor across the screen. You will see a series of red vertices and one blue vertex, which indicates the last vertex you stopped on and, thus, shows the direction of drawing. If you have drawn an incorrect segment or made the wrong move in the Trace mode, you can cancel it by clicking the appropriate vertex with the left mouse button (it will change color to green) and right-clicking on it to delete (Fig. 2.63).

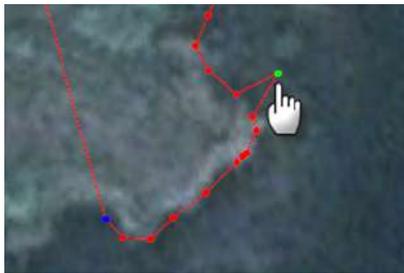


Fig. 2.63. Editing a polygon's vertices

Try to draw the polygon as accurately as possible to get the correct area values.



When you have completely outlined (digitized) one island, go to the **Measurements** tab and see what area it occupies in the **Area** menu, selecting the usual units of measurement, such as **Square Kilometers**, and write down the result (Fig. 2.64). Save the changes by clicking **Ok**. To enclose the next island into a polygon, you need to create a new polygon again, using the **New Polygon** tool.

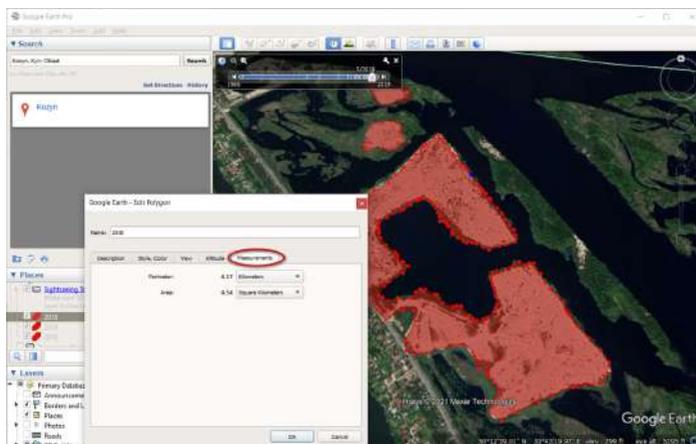


Fig. 2.64. View of the outlined reclaimed sandy massif with an open window of the area

Next, create a general map displaying changes of the islands, which will consist of the contours of the Dnipro River shoreline near Kozyn urban-type settlement, Pluity village, for two periods (the oldest and modern). To do this, use the **Add Path** tool (Fig. 2.65).

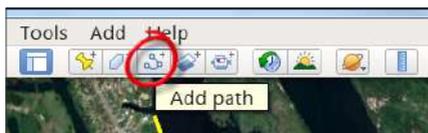


Fig. 2.65. Add Path tool

First, outline the shoreline of the Dnipro River from Pluity to Kozyn using the contemporary image, which is displayed by default on the program screen. The date of the image is displayed in the central bottom part of the window, “*The date of image acquisition*” (in our case it is 24.05.2018). When you have finished editing the path, save the changes by clicking **Ok** in the **New Path** window. Next, using the **Show historical imagery** tool, move the slider bar to the first available archival

image and see what this area looked like in the past, namely on 23.05.2005, and create a corresponding contour of the shoreline by analogy with 2018 (Fig. 2.66).



Fig. 2.66. Comparing the views of the islands using the Show historical imagery tool. The red color of the shoreline for 2018 and the yellow for 2005 are superimposed on the image: 2005 (a), 2018 (b)

4. Designing the map layout

At the final stages of this task, you need to choose the colors to display each year, create a legend and save a map of the Dnipro River coastline.

You can change the color of the shoreline for each year in the *Edit Path* window → *Style* tab.

To save the created map, use the *Save image* tool. Write the name of the map, for example, “*Map of artificial islands of the Dnipro River floodplain*”, and a description in the  field. Select a convenient legend scale and style for displaying the background from satellite images in the *Map options* window (Fig. 2.67).

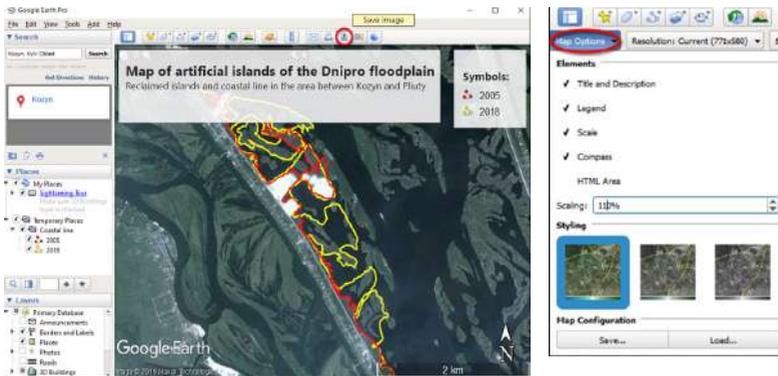


Fig. 2.67. Saving the created map using the *Save image* tool

Finally, save the map to your computer in a good (high) resolution by selecting 4800×3678 from the drop-down menu (Fig. 2.68).



Fig. 2.68. Selecting the resolution in the *Save image* tool

Important to know – in the symbols on the map, only the captions in English are displayed correctly, i.e. if you gave polygons or paths the names in Ukrainian, replace them with numbers and decipher their meaning separately from the figures in the sub-text captions.





Water "blooming" in the water area of the Kyiv Cistern opposite Hlibivka village, WorldView-2 satellite image from 07.09.2014

2. 2. Semi-Automatic Interpretation: Calculation of Spectral Indices and Threshold Classification

Spectral indices are indicators, which characterize the ratio of EMR reflection in different bands of satellite imagery. Initially, they were used in remote sensing to assess the state of vegetation, therefore they are called *vegetation indices*. A list of the most common spectral indices can be found in [Annex 6](#). Spectral band transformation is used to obtain a normalized range of values that provides the most suitable information for studying a particular feature, in other words, to select the necessary and remove the redundant data. This method allows improving the results of both visual interpretation and simple automated classification techniques.

Index Data Base (IDB) refers to a database that organizes information about all existing spectral indices. It contains data on 519 indices, 167 satellite sensors, and 43 types of indices application.

IDB page contains four lists: a list of indices, a list of satellite sensors, a list of possible applications of the indices, and a list of references. However, there is confusion on the website between the names of satellites and the names of sensors. In some cases, a satellite name is used instead of a sensor name [5], so it is worth checking the information.

Official website: www.indexdatabase.de.

The **Normalized Difference Vegetation Index (NDVI)** is the most popular vegetation index. Based on biomass activity data, this index is used to assess the condition of crops at a particular time or in dynamics. During photosynthesis, the green plants absorb the majority of wavelengths of light within the visible light spectrum and reflect near-infrared waves (Fig. 2.69). The NDVI index is calculated by the following formula:

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

where **RED** is the red part of the spectrum with wavelengths in the range of 0.62 – 0.75 μm (which accounts for the maximum absorption of solar radiation by chlorophyll);

NIR is the area of the near-infrared part of the spectrum with wavelengths in the range of 0.75 – 1.3 μm (the spectral region with the maximum reflection of energy by the cellular structure of the leaf).

Thus, NDVI calculation is based on the two most stable (independent of other factors) sections of the plants' reflectivity curve (see Fig. 1.49 in Section 1).

NDVI is directly associated with the presence of chlorophyll in biomass, and by this logic, forests have the highest NDVI values, shrubs have lower values, and grassy vegetation has the lowest NDVI values. In practice, however, this correlation is very rare. The agricultural lands, fires, pest activity, wetland vegetation – all this violates the regular distribution of biomass and, consequently, deciduous forests have the same NDVI value as some crops, and the NDVI value of a forest affected by pests is equivalent to that of dry grass.

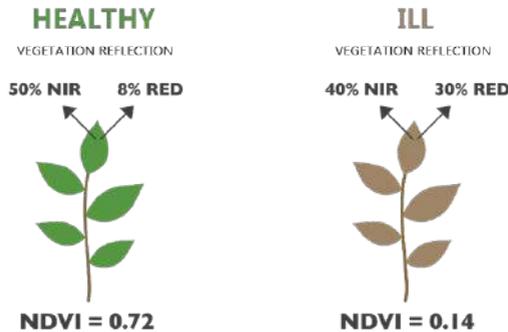


Fig. 2.69. Determination of vegetation status based on NDVI values

It should be noted that in addition to vegetation, this spectral index is used to study water bodies, soils, snow, separation of land boundaries from water, etc. In this Task, we will learn to use the NDVI index to detect clusters of planktonic algae (water “blooming”) in the Kyiv Cistern.

You will also learn how to combine data into classes, in other words, to carry out the threshold classification, as this enables to reveal data trends.

The purpose of the threshold classification is to divide features into classes according to the value of a certain indicator or property (attribute value).

When classifying, similar features are grouped into classes by assigning the same character to each class unit. Defining a class range outlines the features that belong to that class and how they will be displayed on the map. By changing the boundaries between classes, you can change the display of a particular phenomenon on the map. The number of classes may be determined manually or using a standard classification scheme, for example, there are selected scales for vegetation indices in certain colors.

You can create classes manually so that the features meet certain criteria or can be compared with certain valid values. To do this, specify the upper and lower limits for each class. Data can also be classified manually to select a specific range of values, for example, located above or below the threshold. For example, you can select an area below a certain elevation, which is prone to flooding.

That is, a threshold is set, and if the value of the attribute is below this threshold, the features are assigned to one class, and if such value is above this threshold, to another one. It is also possible to set several thresholds and make a scale of corresponding ranges of values.

Therefore, single-band raster layers may be displayed either in the shades of gray (low values = black, high values = white) or using different colors, when individual colors are assigned to the same values. In addition, single-band rasters can be displayed using a color palette.

You will learn how to change the display of a gradient thematic image to make a gray raster colored. GIS programs feature three modes for displaying the distribution of values:

- **interpolated** (linear): the final color is the result of linear color interpolation;
- **discrete**: a color used corresponds to or is larger than the color of the respective value of the color map;
- **exact**: no interpolation, only pixels are displayed according to the values available in the color map.

Task

Analyze the water “blooming” phenomenon in the Kyiv Cistern in August 2016 using satellite images.

Water is one of the most valuable resources on our planet. Therefore, the deterioration of its quality causes a number of hazards for the health of the population, the environment, and the state in general. The problem of water “blooming” is very acute for various water areas. Intense “blooming” is characteristic of reservoirs with weak flows, in particular, such as the Dnipro reservoirs cascade. Residents of settlements located near these artificial reservoirs suffer the most because they use the Dnipro water for domestic and industrial needs.

Water “blooming” is a phenomenon that is manifested in the change of water color due to the mass growth of microscopic blue-green algae (cyanobacteria), which is accompanied by a significant deterioration in water quality. These algae are very small and are freely transported by water masses to any part of the reservoir; their distribution directly depends on the directions of flows and wind. The increase in the manifestations of this process is caused by a set of factors, the main of which are shown in Fig. 2.70. It should be noted that no less important factor that affects the dynamics of the intensity of water “blooming” is the annual rainfall and, above all, the amount of precipitation and rainy days at the “blooming” peaks.



Fig. 2.70. Key causes for reservoirs blooming [6]

Over the last 10 years, the level of phosphates in wastewater coming from Kyiv to the Bortnytska Aeration Station (the station responsible for water supply and water treatment in Kyiv) has increased from 8 to 30%. None of the treatment plants in Ukraine is able to completely clean water off that large amounts of phosphates. Many EU countries have legal restrictions on the phosphate content in commercially available detergents. There are no such laws in Ukraine yet.

What is the effect of detergents on water “blooming”?

It is correct to say the effect of phosphates! They are usually found in detergents. The main negative impact of phosphates on the environment is that they contribute to the mass growth of algae in water bodies. As a result, such water becomes unsuitable for domestic use. These algae differently color the water, and this process is called the “blooming” of reservoirs. Rotting processes during the death of algae produce an unpleasant odor. The reservoirs begin to lack oxygen causing the oxygen starvation and death of fish and other fauna.

When we use a 400 g package of washing powder with 15% phosphate content, 60g of phosphates are released in the wastewater. Therefore, the next time you buy a detergent, pay attention to its composition.

Another process that affects the condition of water bodies is “weediness” – a natural process of higher aquatic plants’ growth in water bodies. These plants are much larger than microscopic algae causing the water “blooming” phenomenon. Aquatic plants grow and spread in shallow water only, up to 2.5 m deep (i.e. along riverbanks or on sand bars only). Usually, intensive growth of aquatic weeds leads to bogging of water bodies, i.e. lakes gradually turn into swamps.

Obtaining data on the phytoplankton condition, particularly relevant data – a rather time-consuming and costly process. That is why there was a need to develop an algorithm for operational remote monitoring of large-scale clusters of planktonic algae and methods for quantifying their density using satellite imagery data. Methods of processing satellite images to identify water “blooming” areas usually are based on the analysis of the difference in the spectral characteristics of a water body with the clean surface and subsurface layers and the same covered with aquatic plants.

How to find “blooming” areas in satellite images? Water blooming areas may be easily identified using the **vegetation index (NDVI)**. In addition, **the image structure** can serve as an additional decoding feature in the visual identification of water “blooming”. Areas of intense “blooming” are often characterized by a specific **filamentous texture**. In particular, satellite images show that areas of intense water “blooming” run along the flows and enter the **vortex motions**. During the periods of prolonged warm, sunny and windless weather, cyanobacteria combine into **aggregates** that come to the surface, forming **surface or subsurface clusters** (Fig. 2.71).

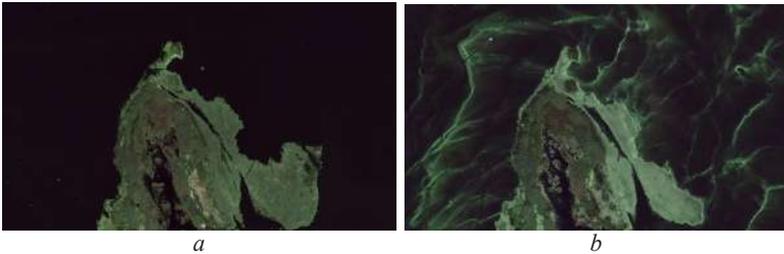


Fig. 2.71. An example of the difference between the water “blooming” and weeding in the south of Kyiv in the Google Earth images: the view of an island overgrown with higher aquatic plants (a), water “blooming” (b)

Task

Identify the areas of water blooming in the Kyiv Cistern based on the threshold classification of the vegetation index.

Data

Sentinel 2 satellite images dated August 6 and 9, 2016 of the territory of the Kyiv Cistern (we have discussed downloading [in paragraph 1.2.](#), please repeat download according to the instructions).

Task Performance Algorithm

1. Downloading images and opening them in a new project

Download images from the *USGS Earth Explorer* website (official site – <https://earthexplorer.usgs.gov/>). We have described in paragraph 1.2 the procedure of using the website and downloading an image from this resource. If you have not signed up to this resource, go to paragraph 1.2.3 and download two Sentinel 2 images of the Kyiv Cistern collected on August 6 and 9, 2016 (Fig. 2.72).

Open a new project and images in the GIS program. Adjust the combination of bands 11, 8, 4 (SWIR, NIR, Red) for these images in the project ([it was described in more detail in paragraph 1.4](#)). With this combination, clear deep water will appear very dark, shallow water or water containing sediments will be displayed in the shades of light blue, healthy vegetation will appear bright green, and soils – purple. The combination of B11, B08, B04 bands is useful for studying vegetation and is widely used to identify water “blooming” areas.

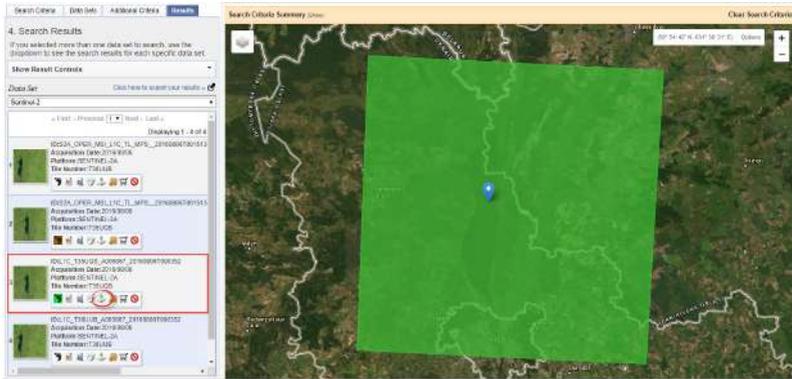


Fig. 2.72. Downloading the Sentinel 2 image dated August 6, 2016

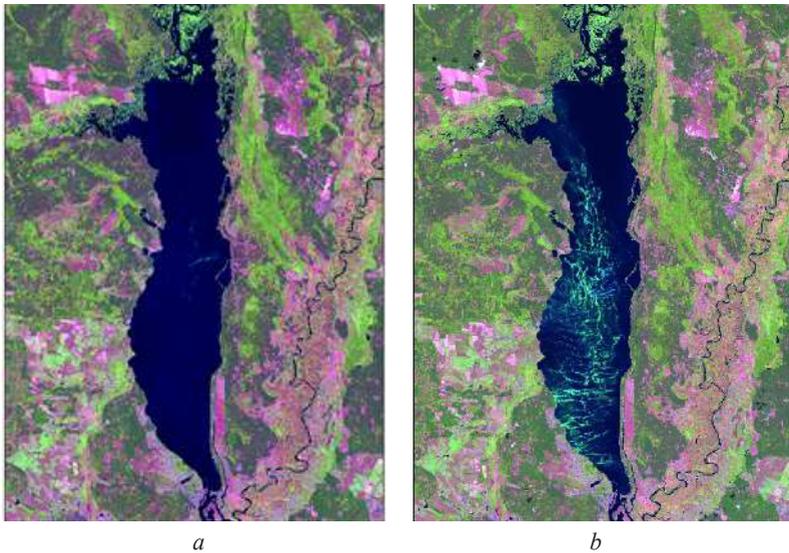


Fig. 2.73. Sentinel 2 satellite images of the Kyiv Cistern: August 6, 2016 (a), August 9, 2016 (b)

By the way, where do you think the water stagnates more: upstream of the Kyiv Hydropower Plant (HPP) dam or at the source of the reservoir? In what way does the direction and speed of flow affect the distribution of the most heated water mass?

Using the navigation tools, find the Kyiv Cistern – the largest water body in the image (the OSM map will help you to identify the right place ([see section 1.3 for instructions on adding this map to the project](#))). Take a closer look at the satellite images of the Kyiv Cistern. As you know, the clear water surface in this combination of bands appears as dark blue. This is how the entire Cistern looked like on August 6. However, in three days, bright green spots appeared – the water “blooming” areas carried by the wind, which have a wavy shape. Thus, you have performed the visual analysis of the satellite image and identified water “blooming” areas. Now you can analyze in which part of the Cistern and near which bank they were spread at the time of image acquisition (Fig. 2.73).

2. Determining Sentinel 2 bands for calculation of NDVI vegetation index

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

where **RED** is the red part of the spectrum with wavelengths ranging 0.62 – 0.75 μm (which accounts for the maximum absorption of solar radiation by chlorophyll); **NIR** is the near infrared part of the spectrum with wavelengths ranging 0.75 - 1.3 μm (the spectral part with the maximum reflection of energy by the cellular structure of a leaf).

NDVI values vary from -1 to 1, vegetation is displayed in the shades of green (a shade depends on the intensity of vegetation development – dark green color denotes healthy and most developed vegetation, and it has a value from 0.2 to 1).

Depending on the satellite, the NDVI formula will vary. Do you remember why? If you don't know the answer to this question, take a closer look at the Table, *Correspondence of Landsat 5, 8 and Sentinel 2 satellite bands*, in [Annex 2](#). Therefore, the formula is:

- For Landsat 8: $\text{NDVI} = (\text{B5} - \text{B4}) / (\text{B5} + \text{B4})$;
- Landsat 4-7: $\text{NDVI} = (\text{B4} - \text{B3}) / (\text{B4} + \text{B3})$;
- Sentinel 2: $\text{NDVI} = (\text{B8} - \text{B4}) / (\text{B8} + \text{B4})$.

To calculate the NDVI in this Task, we will use the last formula in the list.

3. Calculating vegetation indices for both images

Float is the format of floating point numbers (Fig. 2.74). Conversion to fractional format is necessary, because when calculating NDVI, the distribution will give a fractional result in the range $[-1 \dots +1]$. If we convert the *uint8* format, the output will be a file consisting of three values only: “0”, “-1” and “1”.

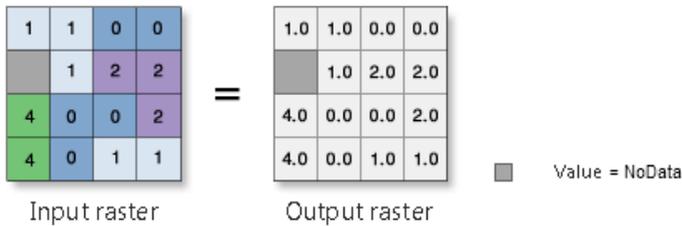


Fig. 2.74. Algorithm for operation of the Float tool, which converts each value of a raster pixel into a floating point number [7]

4. Selecting NDVI threshold values and creating water “blooming” distribution maps

The resulting NDVI rasters are now displayed in the shades of gray. Our goal at this point is to change the display style of the raster, i.e. to make our gray raster color.

In order to show a color map of the water “blooming” distribution within the reservoir, it is necessary to change the display method to one that allows grouping pixels into a given number of classes with an option to change the threshold values of each class.

We can set any number of classes and the range, and change them. In this case, our task will be to select the number of classes and the range that reflect the “blooming” classes we study the best.

Please note that the NDVI index is very sensitive to the atmosphere, so you must first perform an atmospheric correction of the output image. Without this correction, it may be difficult to compare the obtained NDVI values with the data of other studies, and the index values will be affected by atmospheric conditions, such as smoke content or temperature inversion, observed on the day of the image acquisition. However, if you are not going to compare the data with other results, such as values for other days, you can proceed without correction.

*As a rule, satellite data with the second level of processing (Level-2 data) already have atmospheric correction. That is, in fact, the data for which the EMR values recorded by the sensors at the top of the atmosphere (**Top-Of Atmosphere Reflectance, TOA**) were convert-*



ed into the EMR values of the features on the Earth's surface considering the atmospheric conditions at the time of survey. In particular, Landsat images with atmospheric correction may be obtained from the website earthexplorer.usgs.gov, category **Landsat Collection 1 Level-2 (On-Demand)** → **Landsat 8 OLI / TIRS C1 Level-2**.

Sentinel 2 images are available with L1C processing level and **Top-Of Atmosphere Reflectance (TOA)** albedo data and radiometric and geometric correction for the entire period of satellite operation. L2A data with atmospheric correction (**Surface reflection, SR**) are also available for the majority of images.

MODIS imagery is characterized by a high level of processing, including correction for atmospheric effects, and therefore does not require additional processing.

In general, the issue of atmospheric correction is rather complicated, so we will discuss it briefly and will not include it in the algorithm. Please, remember, however, that it may cause slight differences between the values of our indices and real values.



Performing a Task in ArcGIS

1. Downloading images and opening them in a new project

Download Sentinel 2 images dated August 6 and 9, 2016 of the Kyiv Cistern from the USGS Earth Explorer.

Use *ArcToolBox* → *Data Management Tools* → *Raster* → *Raster Processing* tools and double-click the **Composite Bands** tool (see [paragraph 1.4](#) for details) to unzip both images and make a synthesized image in a combination of bands 11, 8, 4 (SWIR, NIR, Red) for each of them.

If you have done everything correctly in the previous steps, a new project will display two color images. To quickly find the objects of your interest, you can add an OSM base map by clicking the button  **Add Data** → **Add Basemap** → **OpenStreetMap** (see [paragraph 1.3](#) for details).

2. Determining Sentinel 2 bands for calculation of NDVI vegetation index

Compare the vegetation index formula, $NDVI = (NIR - RED) / (NIR + RED)$, with the Table of Sentinel 2 bands and determine the bands to be used in the formula. For Sentinel 2, the NDVI formula will look like this: $(B8 - B4) / (B8 + B4)$. We have already used bands B8 and B4 to make a synthesized image in the previous paragraph.



3. Calculating vegetation indices for the both images

Open the *ArcToolbox* window (Fig. 2.75), find *Spatial Analyst Tools* and click (Fig. 2.76) *Raster Calculator*.



Fig. 2.75. Opening the *Arc Toolbox* window

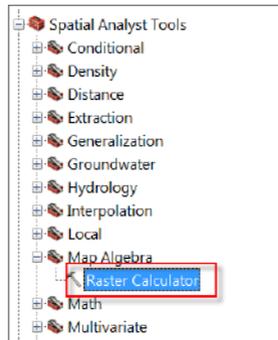


Fig. 2.76. *Raster Calculator* Tool

In the *Raster Calculator* it is necessary to enter the formula for calculating the vegetation index $(NIR - RED) / (NIR + RED)$, in our case it is:

$$(Band8 - Band4) / (Band + Band4).$$

Prior to this, you need to convert certain bands to the “float” format using the following operations: *ArcToolbox* → *Spatial Analyst Tools* → *Math* → *Float* for each band separately, or you may simply include the float conversion directly in the formula for calculating NDVI in *Raster Calculator*:

$$Float(Band8 - Band4) / Float(Band8 + Band4).$$

To begin with, select appropriate bands from the *Layers and variables* menu in the *Raster Calculator* dialog box (Fig. 2.77), and insert formula symbols $-$, $+$, $/$ using the *Float* tool in the right panel of the calculator and the appropriate *Operator buttons*. Note that the result is stored in a temporary file, which is added to the list



of layer as “Calculation”. If you want to save it to your computer, select the desired folder by clicking the icon , type the name of the output layer, for example "NDVI_201686", and specify the data format, for example *.tif.

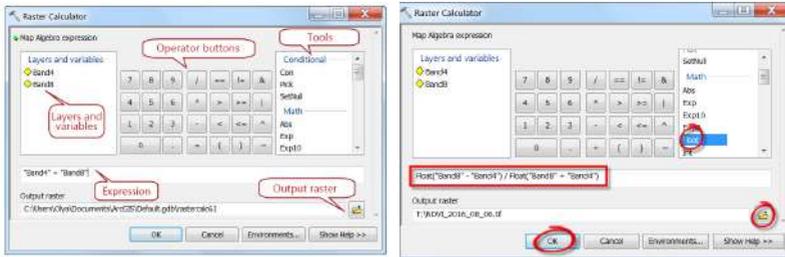


Fig. 2.77. NDVI calculation in a raster calculator

Thus, you will obtain two vegetation indices for the Cistern – as of August 6 and 9, 2016, which will automatically upload to your project as black and white rasters with the values ranging from 1 to -1.

4. Selecting NDVI threshold values and creating maps of water “blooming” distribution

To obtain a color map of water “blooming” distribution within the Cistern, you should perform several steps. As you see, the intensity of water “blooming” in different parts of the Cistern is irregular. Using the threshold classification of the NDVI raster layer, we can distinguish five classes: clear water and four “blooming” zones from low to high concentrations of blue-green algae. To access the raster display configuration tools, right-click on the NDVI raster in the **Layers** module and select **Properties** from the drop-down menu, then go to the **Symbology** tab in the **Layer Properties** window and select the **Classified** display method. This method allows grouping pixels into a given number of classes with the ability to change the threshold for each class.

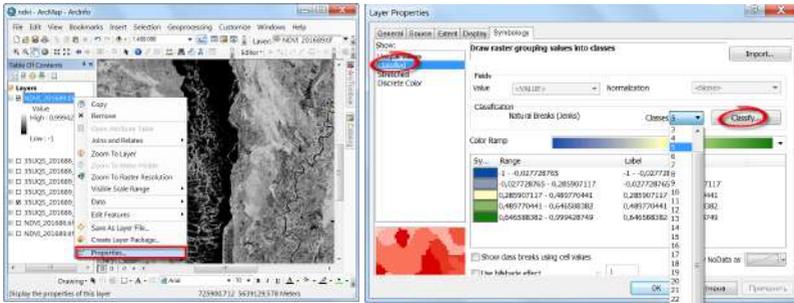


Fig. 2.78. Setting raster display using the *Classified* method

Then, using the *Classify* button, go to the additional menu to set the number of classes and the range they cover; in our case it is five classes (Fig. 2.78).

By default, we have obtained the classification thresholds using the *Natural Breaks* method. By moving the sliders or directly changing the values in the *Break Values* field, we can change the values obtained automatically. By clicking Ok in the *Classification* window and in the display settings grouping window, we can check the classification result, i.e. whether we have a raster layer divided into five color classes of the same type. If not, open the *Classification* window again and manually edit the thresholds for each class (Fig. 2.79).

In our case, the threshold classification of the vegetation index was performed using the threshold values for clear water from -1 to -0.027 (first class); the remaining four classes belong to the group of water “blooming” areas of different intensity, from the slightest change in water color (threshold -0.027 – 0.285, or second class) to the largest accumulation of phytoplankton (threshold 0.646 – 0.999, or fifth class). Thus, we have adjusted the threshold values for five thematic classes, which can be later converted into a vector and, accordingly, used for calculating the areas of water “blooming” in the Cistern (Fig. 2.80).

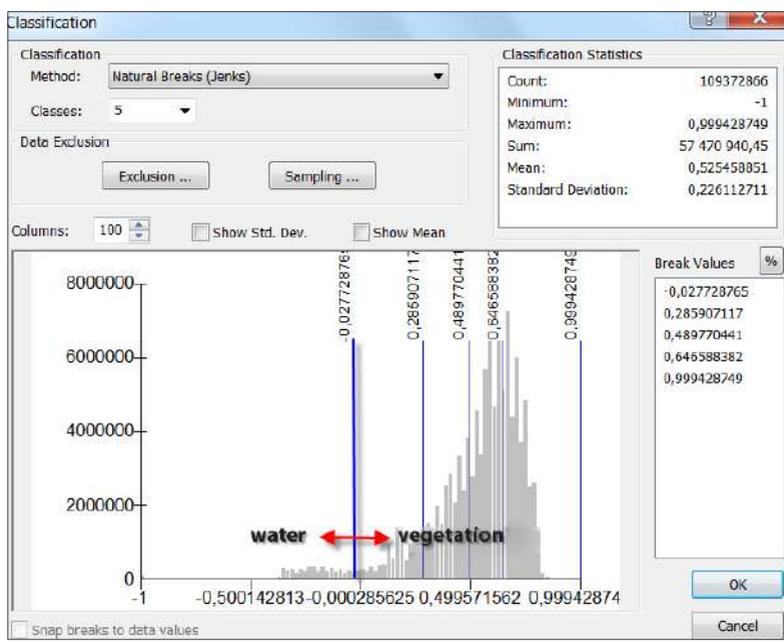
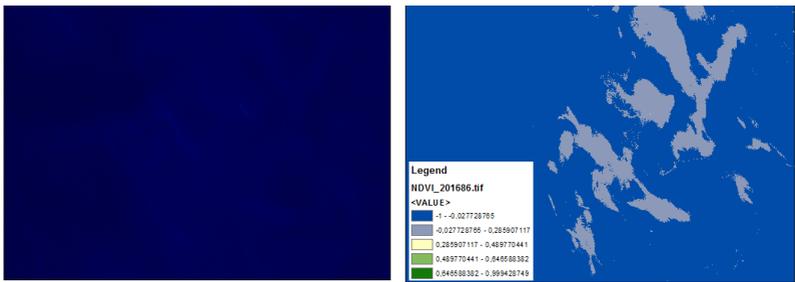


Fig. 2.79. Adjusting the NDVI thresholds in the *Classification* window



a

b

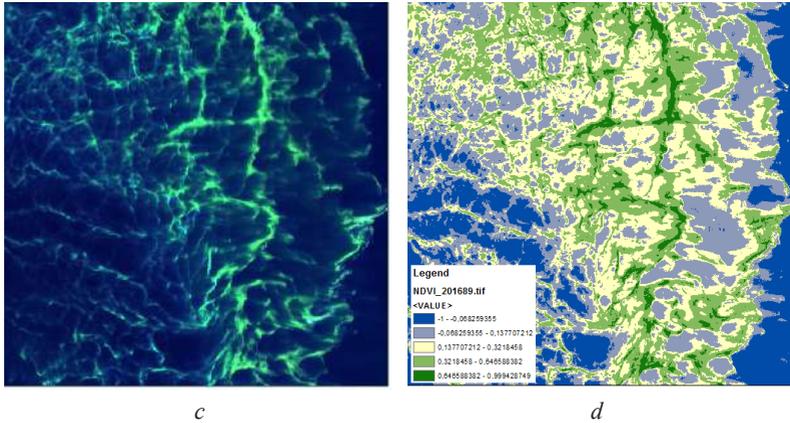


Fig. 2.80. Dynamics of water “blooming” distribution in the Kyiv Cistern in satellite images (a – 6.08.2016 and c – 9.08.2016) and thematic maps of blue-green algae distribution obtained on the basis of the vegetation index values (b – 6.08.2016 and d – 9.08.2016))



Performing a Task in QGIS

1. Downloading images and opening them in a new project

Download Sentinel 2 images dated August 6 and 9, 2016 of the Kyiv Cistern from the *USGS Earth Explorer*.

Unzip the images, run QGIS and create a new project in which you can upload an OSM map *via Browser* → *XYZ Tiles* → *OpenStreetMap* for better map orientation (see paragraph 1.3 for more details).

Download the synthesized image in a combination of bands 11, 8, 4 (SWIR, NIR, Red) *via Raster* → *Miscellaneous* → *Merge* to a new project: first for one image (you can select any image for calculation, since the order is not important) (see paragraph 1.4 for more details).

To calculate NDVI, it is important to convert the values for the bands used in the formula into “float” format. Therefore, when creating a synthesized image in *Output data type*, specify “float32” data type (Fig. 2.81).

Pay attention to the order of the bands when creating a synthesized image. If the bands are displayed in a different order, swap them by dragging the mouse as shown in Fig. 2.81.

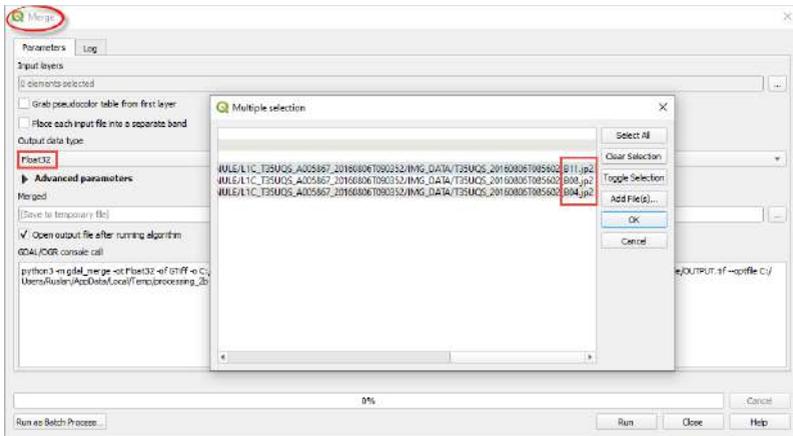


Fig. 2.81. The order of bands combination and the selection of output data type “float32”

Upon completion of the *Merge* operation, the synthesized image in the combination of bands 11-8-4 is added to the project as a new layer called “Merged”. To avoid confusion in the names, we recommend renaming this layer by adding the date of the photo.

Add the next image to the project following the same procedure.

2. Determining Sentinel 2 bands for calculation of NDVI vegetation index

Compare the formula of the vegetation index, $NDVI = (NIR - RED) / (NIR + RED)$, with the Table of Sentinel 2 bands and determine the bands to be used in the formula. For Sentinel 2, the NDVI formula will look like: $(B8 - B4) / (B8 + B4)$. We have already used bands B8 and B4 to make a synthesized image in the previous paragraph.

3. Calculating vegetation indices for the both images

In the main menu, open the *Raster* tab → *Raster Calculator*.



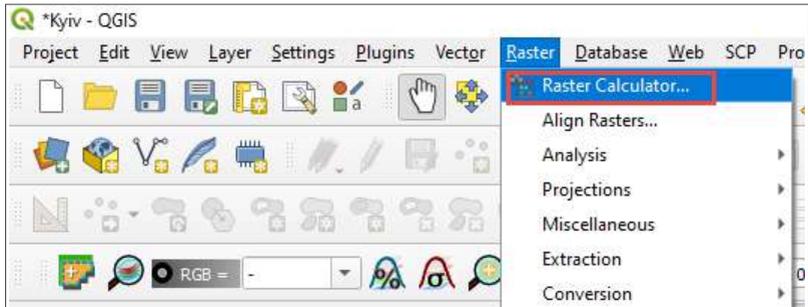


Fig. 2.82. Activating the *Raster Calculator*

In the appropriate field of the *Raster Calculator* window, enter the formula $(\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$, where NIR and RED are the bands selected from the menu at the top of the calculator window (Fig. 2.82).

The band values have been already converted into the “float” format in the first paragraph, so now we can simply enter the NDVI calculation formula in the *Raster Calculator* substituting the band values:

$$(\text{Band8} - \text{Band4}) / (\text{Band8} + \text{Band4}).$$

First, select appropriate bands from the *Raster Bands* menu in the open *Raster Calculator* dialog box (Fig. 2.83) at the top of the window using the *Operators* to select the symbols for the formula: -, +, /. To add layers, double-click on the desired layer with the left mouse button.

Do not enter the band names from the keyboard – the formula will not work.

Note that the *Ok* button at the bottom of the calculator will not be active until you specify a name and location – the *Output layer*. Select the desired folder by clicking icon and write the name of the output layer, for example: “ndvi_06_08_16”, where the numbers indicate the date of the image.

Do not use Cyrillic characters and spaces in paths and file names, since it may disable file saving.

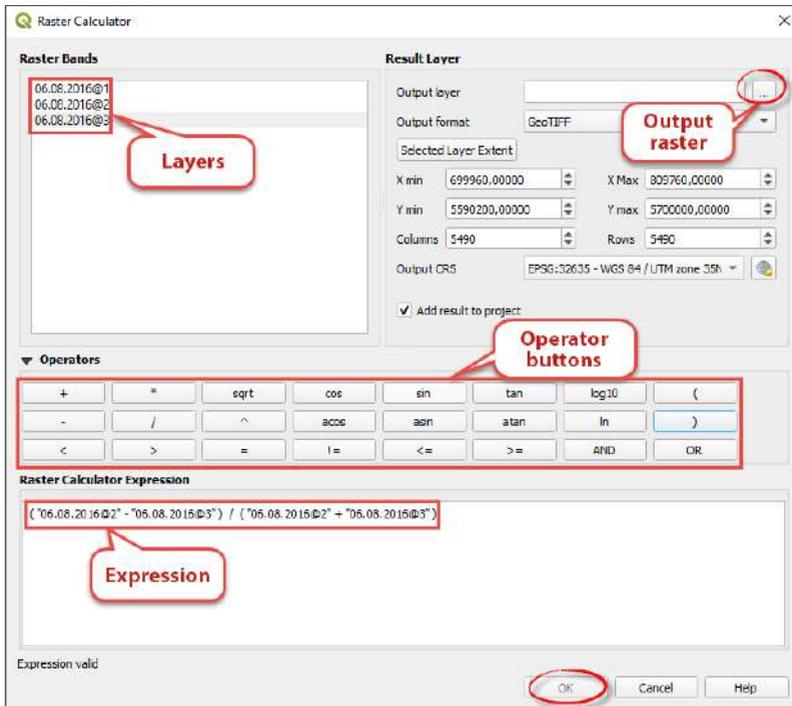


Fig. 2.83. Calculating NDVI in *Raster Calculator*

In our case the band names in the *Raster Calculator* were changed since we made a synthesized image. However, they correspond to the combination B11, B8, B4. Accordingly, the band ending in @1 is the first band in the combination, i.e. B11, @2 = B8, @3 = B4. Therefore, the expression to be entered in the *Raster Calculator* will be as follows: (.... @2-.... @3) / (.... @2 + @3), where the name of your file will replace the omission points in the formula.

After making calculations in the *Raster Calculator*, you should obtain two vegetation indices for the Cistern as of August 6 and 9, 2016, which will automatically open in your project as black and white rasters with values ranging from 1 to -1.

To verify the correctness of our calculation of the index, open the *Properties* module of the created NDVI 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 values in the calculated histogram are from -1 to 1, your calculation was correct (Fig. 2.84).



Fig. 2.84. Calculating the histogram for the created NDVI raster

4. Selecting NDVI threshold values and creating water “blooming” distribution maps

To obtain a color map of water “blooming” distribution within the Cistern, you should perform several steps. As you see, the intensity of water “blooming” in different parts of the Cistern is uneven. Using the threshold classification of the NDVI raster layer, we can distinguish several classes of water surface ranging from clear water to areas with high concentrations of blue-green algae. To access the raster display configuration tools, right-click on the NDVI raster in the *Layers* module and select *Properties* from the drop-down menu, then go to the *Symbology* tab in the *Layer Properties* window and select the *Singleband pseudocolor* display method. This method allows grouping pixels into a given number of classes with the option to change the threshold values of each class. Next, select *Color Interpolation – Discrete* (for an exact discrete scale) or *Linear* (for a continuous color scale), and change the *Color ramp* to make the index map look the way we need. We recommend choosing shades of green.



The Table shown below has three columns:

Value – the upper limit of the range;

Color – color of the range, which can be selected manually;

Label – a text line, where you can set digital limits for a range or make a short text description.

Using the **Classify** button, run the classification for the raster. Here you can also change the number of **Classes** and the range they cover by selecting the **Value**, which best reflects the “blooming” classes that we highlight (Fig. 2.85).

*If the number next to **Classes** cannot be edited, change the **Mode** from **Continuous** to **Equal Interval**, or **Quantile**.*

If you do not want to manually select value ranges, it will be easier to apply the NDVI scale, which is already divided into colors and values. For this purpose, find **Style** → **Load Style** at the bottom left part of the window and select the style file previously downloaded to your computer (Fig. 2.86). Download it by scanning the QR code (Fig. 2.87), unzip the folder, and you will see two files there – *ndvi_discrete* and *ndvi_linear* (it has been discussed above that *discrete* and *linear* represent the type of data interpolation). Try displaying one style file first and then the other to see the difference between them. To apply the downloaded style to the selected raster, click **Apply** or **Ok**.

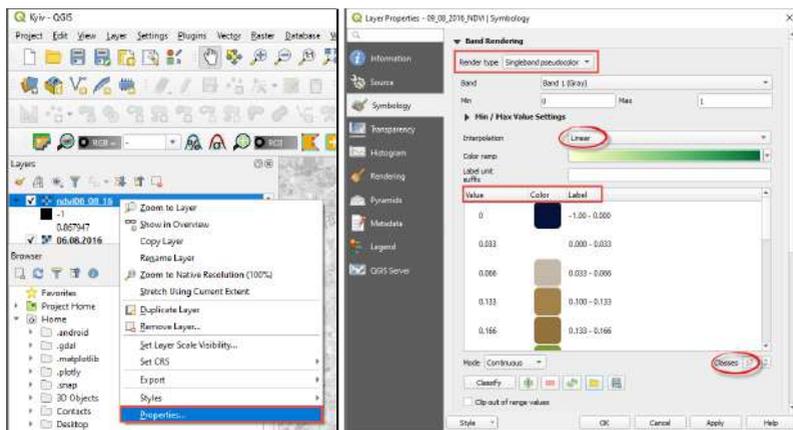


Fig. 2.85. Setting raster display mode using **Classified** method

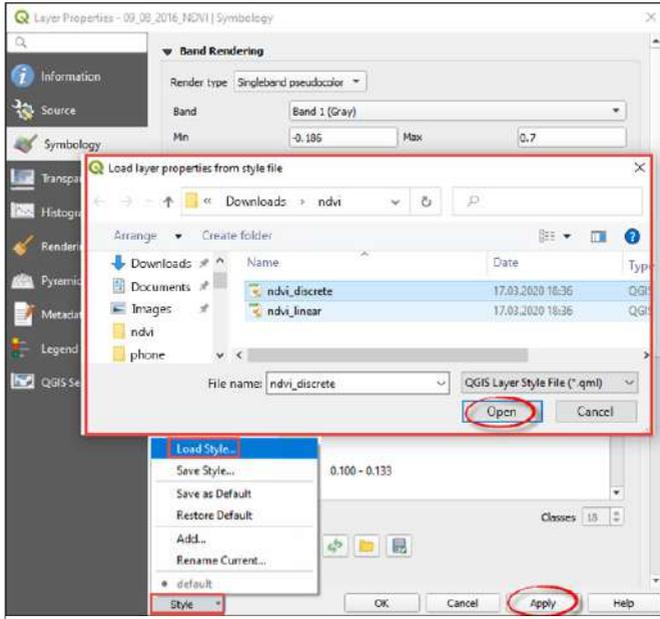


Fig. 2.86. Load *Style* tool

In our case, the uploaded *ndvi_linear* style template is used for two rasters. Detailed analysis of the ranges of NDVI values in the scale showed that the classification of the vegetation index was performed using the threshold for aquatic vegetation from 1 to -0.033; all other values were assigned to the water class. As a result of all transformations, thematic rasters were obtained, which can be further converted into a vector, and used to calculate water “blooming” areas in a reservoir (Fig. 2.88).



Fig. 2.87. QR code with NDVI style template

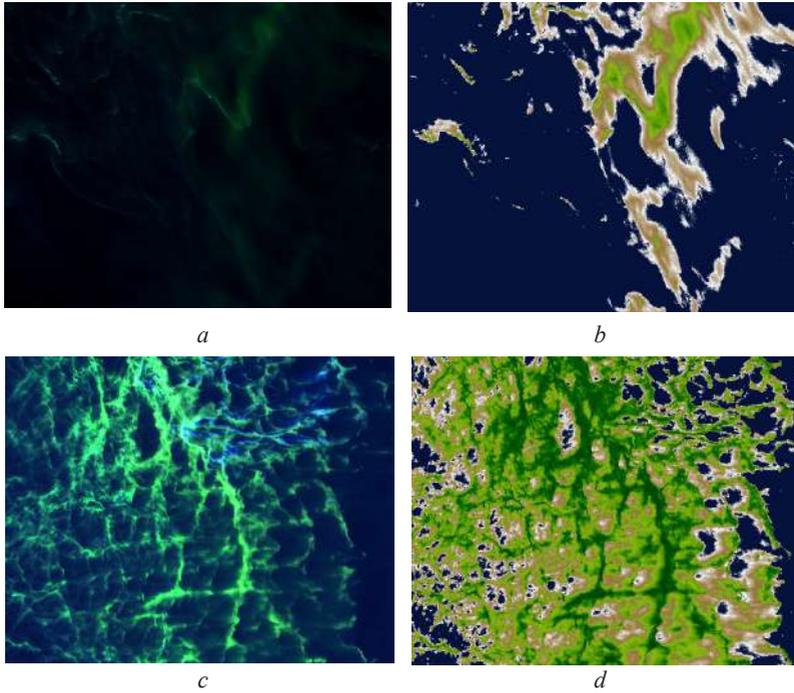


Fig. 2.88. Dynamics of water “blooming” distribution in the Kyiv Cistern in satellite images (*a* – 6.08.2016 and *c* – 9.08.2016) and on thematic maps of blue-green algae distribution compiled according to vegetation index value (*b* - 6.08.2016 and *d* - 9.08.2016)





2. 3. Automatic Classification (Unsupervised)

Satellite imagery is an important source of thematic information about land use and surface cover at various scales. The process of obtaining thematic information based on remote sensing data using automatic (computerized) image processing methods is called *automatic thematic classification*.

The classification involves analyzing the location of a pixel in the space of spectral features by comparing it with a certain class of terrestrial features, and is sometimes called spectral image recognition. From this point of view, it is important to distinguish between:

- *spectral classes* – groups of pixels that are uniform with respect to their location in the space of spectral features and characterized by near-similar values of spectral reflection;
- *thematic classes* – types of terrestrial features, which should be recognized in the image (for example, coniferous and deciduous vegetation, water, open ground, etc.) [8].

Thus, the main task of classification is to establish the links between the spectral classes and thematic ones.

Task

In Kyiv Oblast, the territories affected by various exogenic geological processes, such as landslides, karst formations, flooding, and loess subsidence, are constantly growing. Loess soils prone to subsidence are spread over an area of 12.47 thousand km², and their prevalence is 43.13%.

The soil water regime in the fields with micro-depressions resulting from loess subsidence has a significant effect on the yield of winter wheat starting from the very period of snowmelt (Fig. 2.89). Substantial deterioration of crops, until their complete rotting, is undoubtedly caused by the thaw water that fills the depressions and stays there for a long period (this period of time depends on the water reserves from snow, the rate of temperature rise, precipitation intensity, etc.).



Fig. 2.89. Manifestations of loess subsidence in Baryshivskiy District in the Google Earth Pro satellite image (a) and example of wheat yield reduction and intensification of weed overgrowth on aerial photo (b)

Let's discuss the peculiarities of classification of such depressed soils and the processes of plants suppression and crops weeding caused thereby that leads to the reduction of winter wheat yield.

Task

To assess the extent of loess subsidence and its impact on the crops' conditions based on Sentinel 2 satellite images on the example of the area between Gostroluchchia and Paryshkiv urban type settlements, Baryshivskiy District of Kyiv Oblast.

Data

Sentinel 2 satellite images dated April 18, 2018 and May 23, 2018 of the territory of Baryshivskiy District of Kyiv Oblast.

Task Performance Algorithm

1. Downloading images and opening them in a new project

To begin with, run ArcMap, open a new project, upload two Sentinel 2 images dated April and May 2018 (see details in Section 1.3) and visualize them in a combination of bands (11, 8, 4). By comparing these two images, you will see numerous rounded features that cover the fields in spring. These features are filled with water and are the areas of subsidence we need to classify (Fig. 2.90).

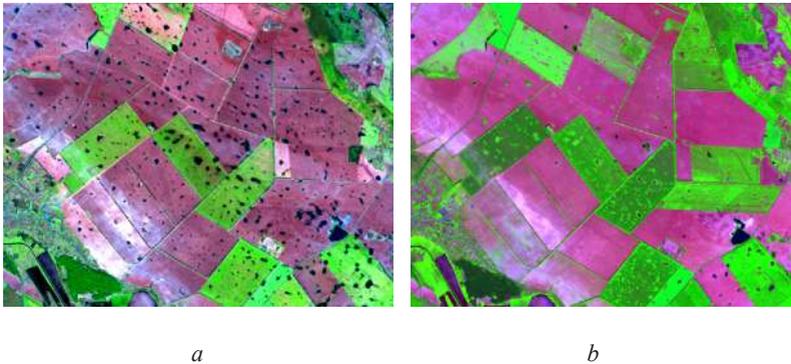


Fig. 2.90. Loess subsidence detected in Sentinel 2 satellite images synthesized in a combination of bands (11, 8, 4): April 18, 2018 (a), May 23, 2018 (b)

2. Unsupervised classification

Automatic classification is one of the automated interpretation methods. With this method, the user has no need in manual delineation of the features' boundaries – it is made by a computer program. According to the degree of user participation in the automated interpretation, classification algorithms are divided into two groups: classification without training (autonomous classification, uncontrolled or unsupervised classification, clustering) and classification with training (controlled or supervised classification).

If you don't know before starting the classification how many and which objects are in the image, you should use the classification without training (unsupervised classification) [8].

Unsupervised classification, also referred to as classification without training, involves the distribution of all image pixels into relatively homogeneous classes based on the proximity of their spectral characteristics only. Unsupervised classification is used when the reference data on terrestrial features are missing, i.e. when

their spectral properties are a priori unknown due to the lack of terrestrial information or well-defined landscape attributes in the image itself. In this case, the main task of the analyst is to justify the optimal number of classes and determine their correspondence to the classes of terrestrial features [8].

Supervised classification, also referred to as classification with training, involves assigning each pixel in an image to a known class of terrestrial features, which corresponds to a predetermined spectral image. To obtain this spectral image, **signatures** are used – reference areas of the image, which represent well certain thematic classes. Signature pixel values are used as training samples to configure (teach) the recognition algorithm. During recognition, each pixel of the image is consistently compared with the standards and assigned to a particular class.

3. Reclassification of unsupervised classification result

Reclassification or merger of classes enables converting any gradient image (vegetation index value) or image with any number of different surface classes (previous result of unsupervised image classification) into a thematic map featuring selected classes. To do this, reclassification tools are used, which include the following options: manual, equal interval, defined interval, quantile, natural breakdown and standard deviation (Fig. 2.91).

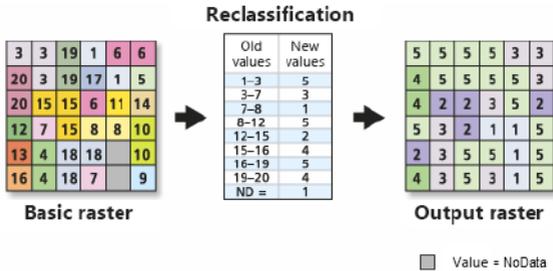


Fig. 2.91. Example of reclassification by value ranges [9]

4. Converting a raster into a vector

Raster data can be automatically converted into vector; this process is called **vectorization**. You can convert raster data to both polygonal vector layers and linear ones. In such case, the corresponding value of the output class or each raster pixel is recorded in the Attribute Table for each polygon of the created vector. (Fig. 2.92).

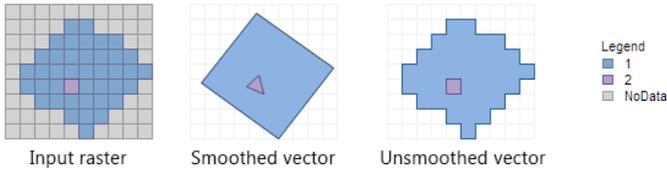


Fig. 2.92. Converting a raster into a vector using various simplified settings [10]



Performing a Task in ArcGIS

2. Unsupervised classification

To interpret the satellite image dated April 18, 2018 and make a thematic map of subsidence, use the ***Iso Cluster Unsupervised Classification*** tool. With classification without training, the spectral classes (or clusters) are identified automatically in a multi-band image (Fig. 2.93). To perform a classification without training, select the ***Classification*** → ***Iso Cluster Unsupervised Classification*** command in the ***Image Classification*** toolbar.

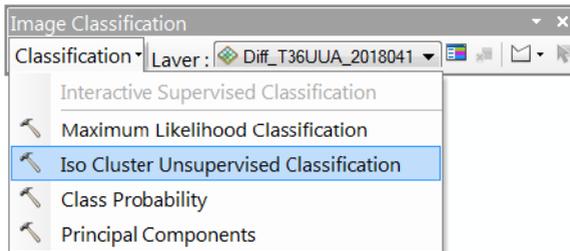


Fig. 2.93. ***Iso Cluster Unsupervised Classification*** tool

In the tool dialog box, specify the following: ***Input raster bands***, ***Number of classes*** and ***Output classified raster***. In this case, select the input data in the appropriate line – the image from April 2018, then specify the number of classes – 25 and select the path for saving the result. For other parameters, the default values may be used. Click Ok to run the tool (Fig. 2.94).

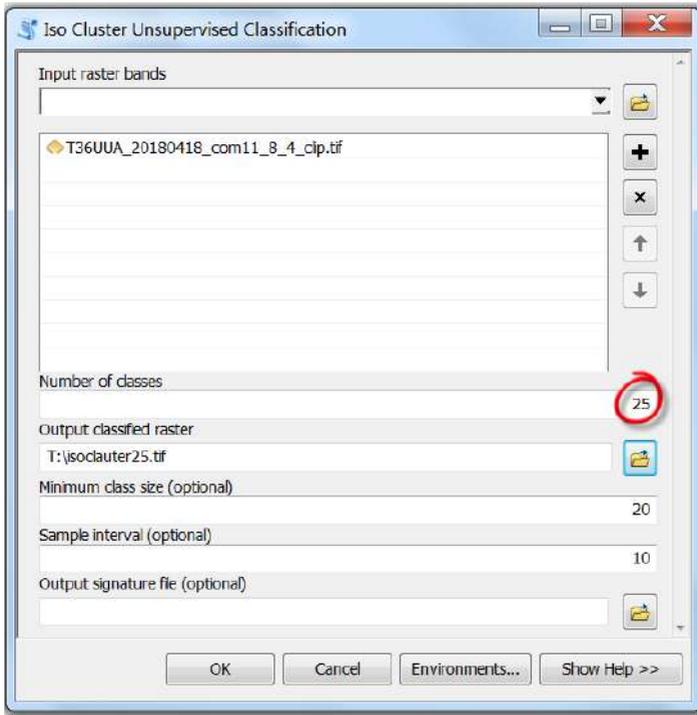


Fig. 2.94. *Iso Cluster Unsupervised Classification* tool

Upon completing the unsupervised classification, you will receive a thematic raster divided into 25 conditional classes of spectral characteristics of the surface (Fig. 2.95).

Therefore, we have 25 different classes of the surface displayed in different colors. Now your task is to review each class and make the transparent fill for unnecessary classes, and select one color, e.g. red, for the classes indicating subsidence areas. The analysis of the resulting thematic map shows that the subsidence areas are denoted by three codes (1, 2, 3) only, i.e. the first three spectral classes indicate the depressed areas in the fields (Fig. 2.96).

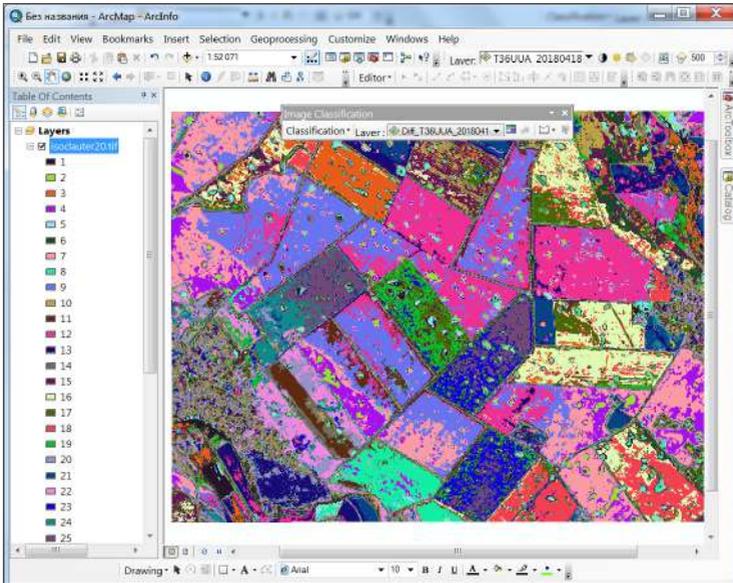


Fig. 2.95. The result of the unsupervised classification with a random color scheme

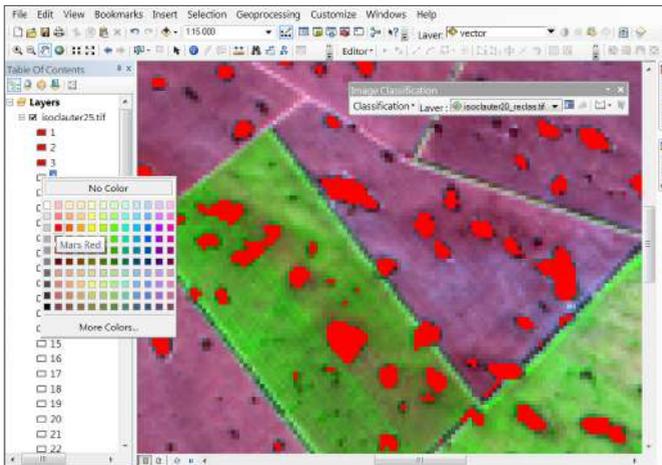


Fig. 2.96. The result of the classification with selected symbols



3. Reclassification of unsupervised classification result

The next step is to reduce 25 classes to two, and assign to depressions code 1 (value with red fill color) and all the rest – code 0 (classes with transparent colors). To do this, use the **Reclassify** tool, which reclassifies (or changes) the raster value (Fig. 2.97).

ArcToolbox → *Spatial Analyst Tools* → *Reclass* → *Reclassify*.

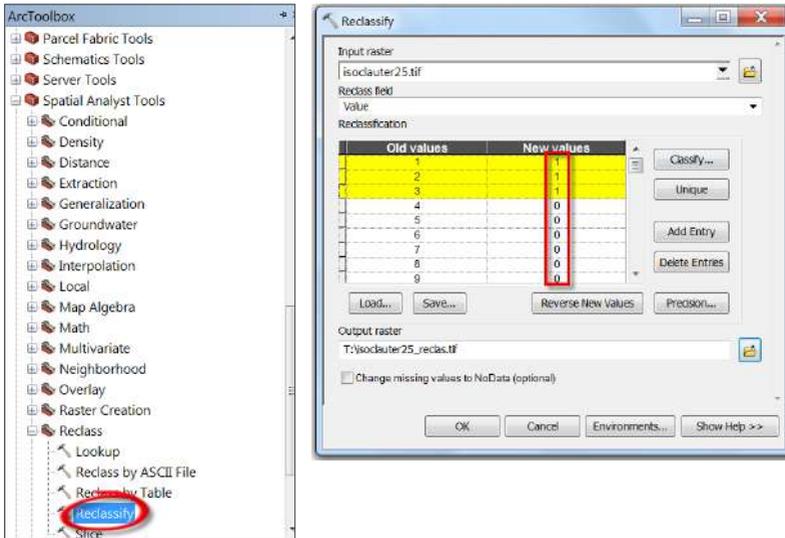


Fig. 2.97 The **Reclassify** tool

We have created a new thematic raster with two classes (Fig. 2.98).

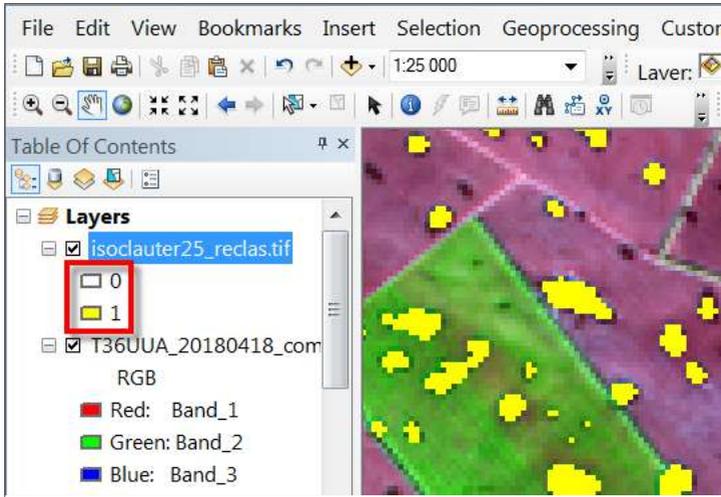


Fig. 2.98. New *Iso Cluster* reclassification raster

4. Converting a raster into a vector

The final operation is the translation of the completed thematic raster into a vector layer to obtain the area of loess subsidence. To do this, use the *Raster to Polygon* tool, which converts a set of raster data into polygonal spatial features (Fig. 2.99).

ArcToolbox → *Conversion Tools* → *From Raster* → *Raster to Polygon*.

In the window for converting a raster into vector, specify the reclassified raster in the *Input raster* line, and the name of the resulting layer in the *Output polygon features* line. All other parameters could be left unchanged. For example, the *Field* parameter allows you to select the attribute field of the input raster as an attribute in the output vector. Be sure to uncheck the *Simplify* parameter (disable default settings) so that the view of the final vector is not simplified.

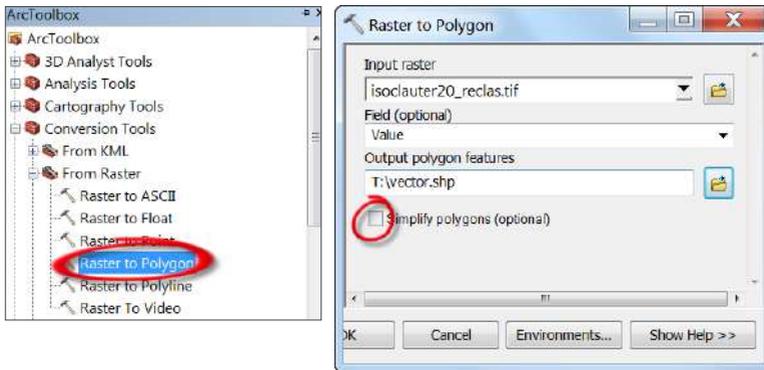


Fig. 2.99. Raster to Polygon tool window

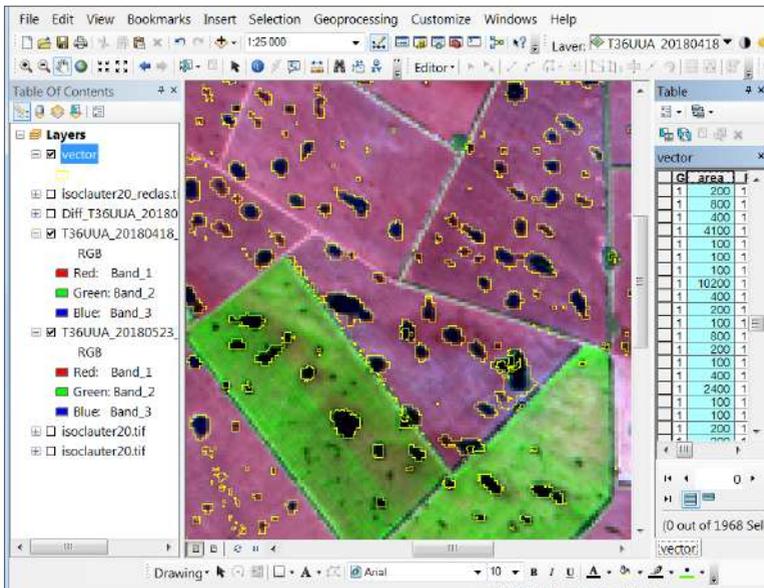


Fig. 2.100. Thematic vector layer of depressions superimposed on the Sentinel 2 satellite image dated April 18, 2018

In the previous sections, we have discussed adding a new field with an area value to the Attribute Table. Let us calculate now the loess areas, i.e. plots from the vector layer, which were assigned code 1. Thus, we have obtained a vector map of loess subsidence and accordingly calculated the areas of agricultural land that suffer from wetting and weeding (Fig. 2.100).



Performing a Task in QGIS

To perform unsupervised classification in QGIS, you must first install the **Orfeo ToolBox (OTB)** plugin featuring the appropriate tools. For QGIS Desktop 3.4 version described in this Guidance Manual, the **OTB** plugin can not be installed using a standard installation through the plugin manager. This is a separate module, you can download it at www.orfeo-toolbox.org/download/ or from the git repository at: <https://gitlab.orfeo-toolbox.org/orfeotoolbox/otb>.

2. Reclassification of unsupervised classification result.
3. Converting a raster into a vector.

Installing the Orfeo ToolBox (OTB) plugin

To begin with, open QGIS Desktop 3.4.13 with GRASS 7.8.0 (it is better to use this version of QGIS) and create a new project according to the instructions described in [paragraph 1.3](#). Next, open the QGIS plugin manager by selecting **Plugins** from the menu bar → **Manage and Install Plugins**. The plugin we need is available in the **OTB** repository at: orfeo-toolbox.org/qgis/. Select **Settings** in the left panel and click the **Add** button to add this plugin repository (Fig 2.101).

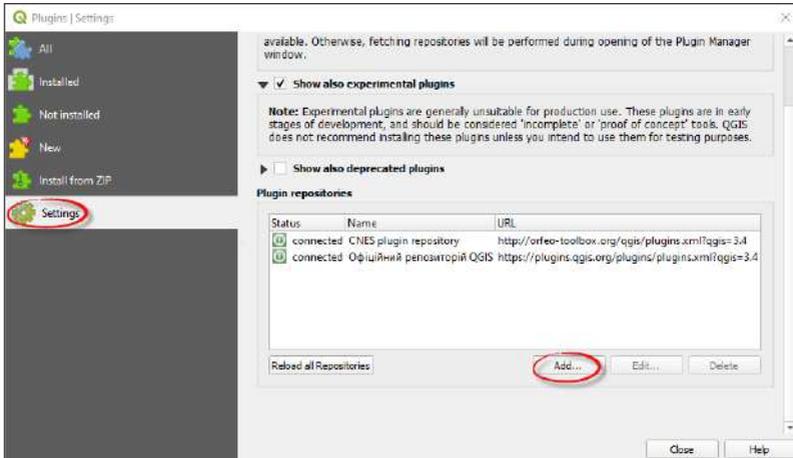


Fig. 2.101. Adding a new plugin repository to QGIS

Write in the **Name** bar “CNES plugin repository” for our new repository. In the **URL** bar, specify the address: <http://orfeo-toolbox.org/qgis/plugins.xml>. Click Ok to add a new plugin library to QGIS (Fig. 2.102).

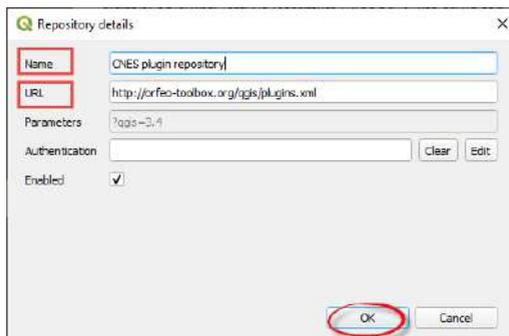


Fig. 2.102. Adding OTV plugin to QGIS

Once the plugin is obtained from the specified repository, it will be automatically added to the list of plugins (Fig. 2.103).

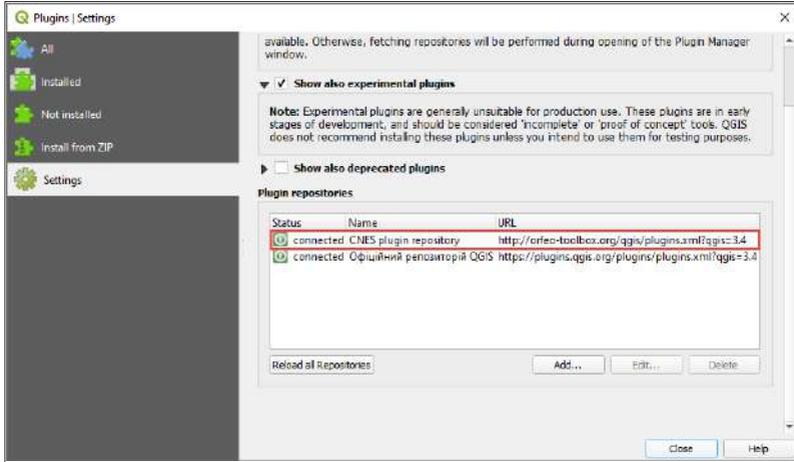


Fig. 2.103. New plugin library added to QGIS

Select *Not installed* in the left panel and type “*Processing OTB Provider*” in the search bar at the top of the screen – the plugin will appear in the list below. Select it by clicking on the name and on the *Install plugin* to download and install the *otb* processing (Fig. 2.104).

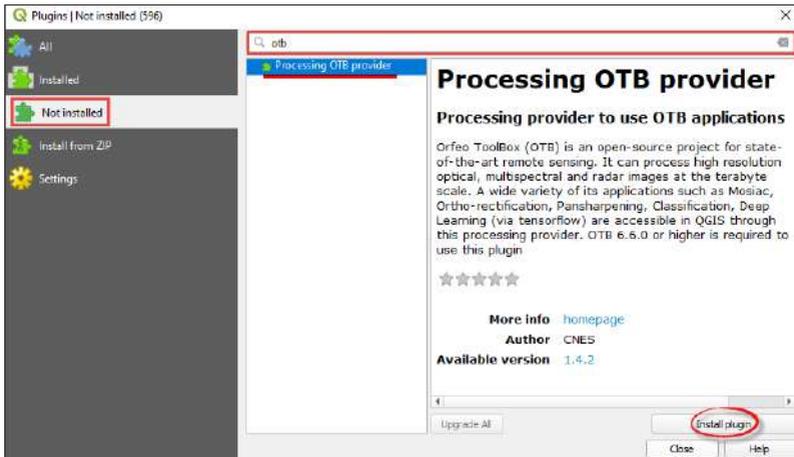


Fig. 2.104 Installing OTV plugin

Upon completion of the installation, QGIS (Fig. 2.105) will display the message *Plugin installed Successfully*.

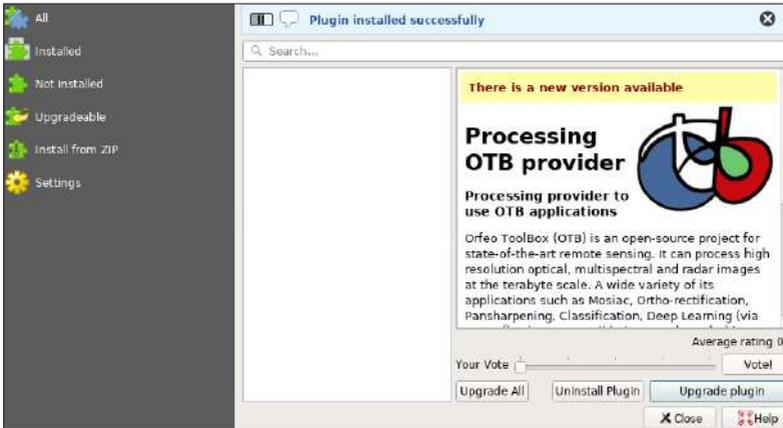


Fig. 2.105. *Plugin installed successfully* message

Go to the *Installed* tab on the left side of the window and make sure the check box next to *Processing OTB provider* is selected (Fig. 2.106).

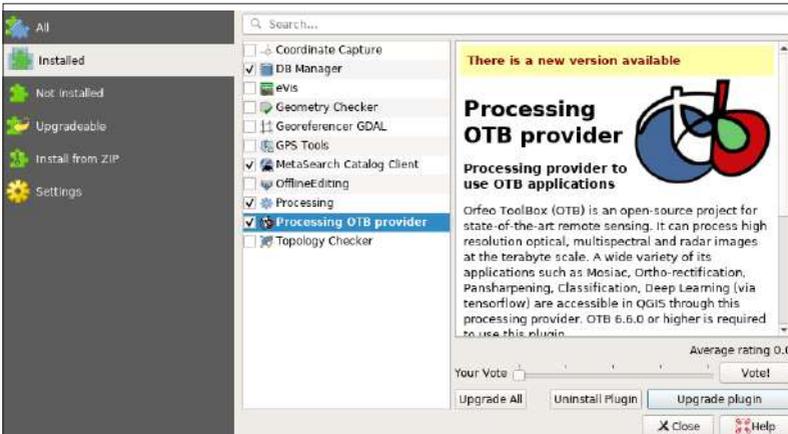


Fig. 2.106. Checking the installation of the OTB plugin



Go to **Settings** → **Options** → **Processing** in the left panel. OTB can be found in the **Providers** tab.

Open the OTB tab and check the **Activate** bar. Navigate to the **OTB application folder** below and specify the path to the “application” folder in the downloaded OTB installation folder. In the bar below the **OTB folder**, specify the path to the OTB installation folder and click **Ok** (Fig. 2.107).

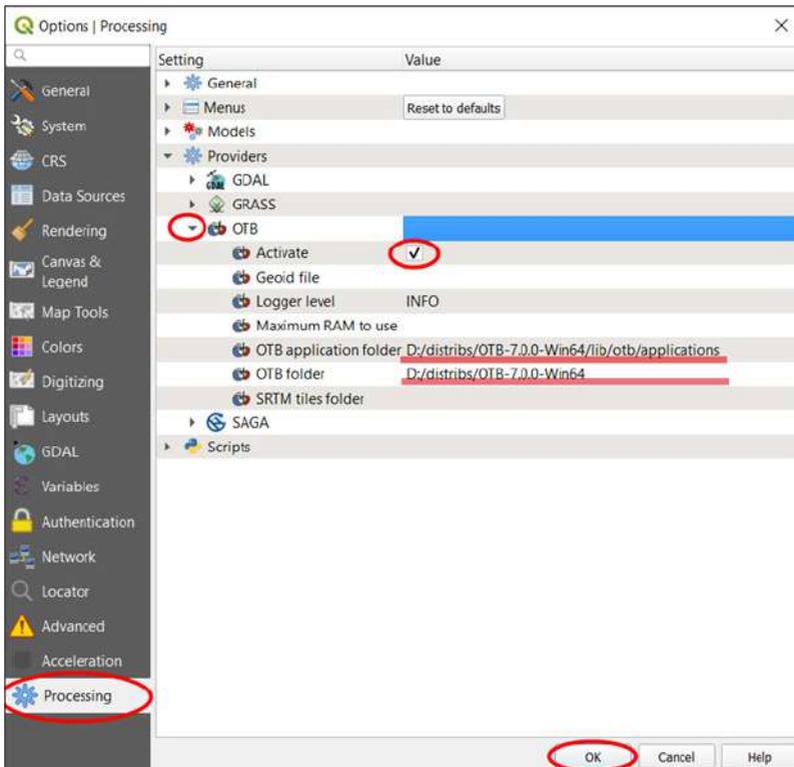


Fig. 2.107. Activation of the OTB plugin

As a result, the OTV module will display in the **Processing Toolbox** (Fig. 2.108). If the **Processing Toolbox** is not displayed in the application window, go to **Processing** → **Toolbox** menu to open it.

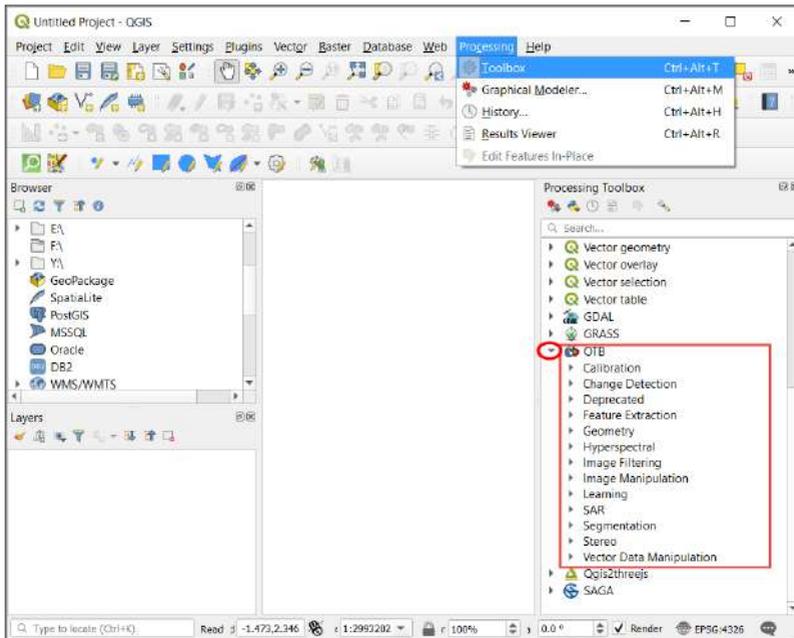


Fig. 2.108. The OTV module in the *Processing Toolbox* panel

2. Performing Unsupervised Classification

To interpret the satellite image dated April 18, 2018 and make a thematic map of subsidences, we will use the unsupervised classification tool, *KMeanClassification*. With classification without training, the spectral classes (or clusters) are identified automatically in a multi-band image without analyst's intervention. To perform the classification without training, open the OTB tools tab on the *Processing Toolbox* toolbar (Fig. 2.109) and select *KMeanClassification*.

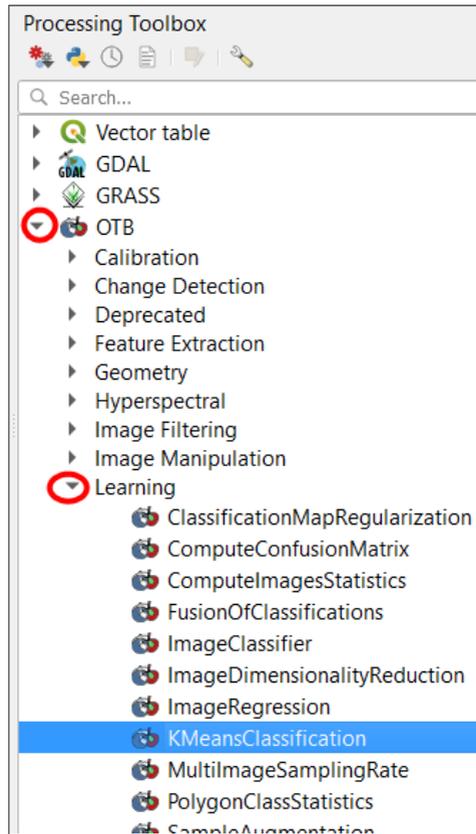


Fig. 2.109. Opening the *KMeanClassification* tool

In the tool dialog box, specify the values of the options: **Input Image**, **Number of classes** and **Output Image**. In this case, select the image as of April 2018 as input data, then specify the number of classes – 25 and select the path where to save the result. You may assign values to other parameters by default. Click **Run** to start the tool (Fig. 2.110).

As a result, you get a thematic raster divided into 25 conditional classes of the spectral characteristics of surface (Fig. 2.111).

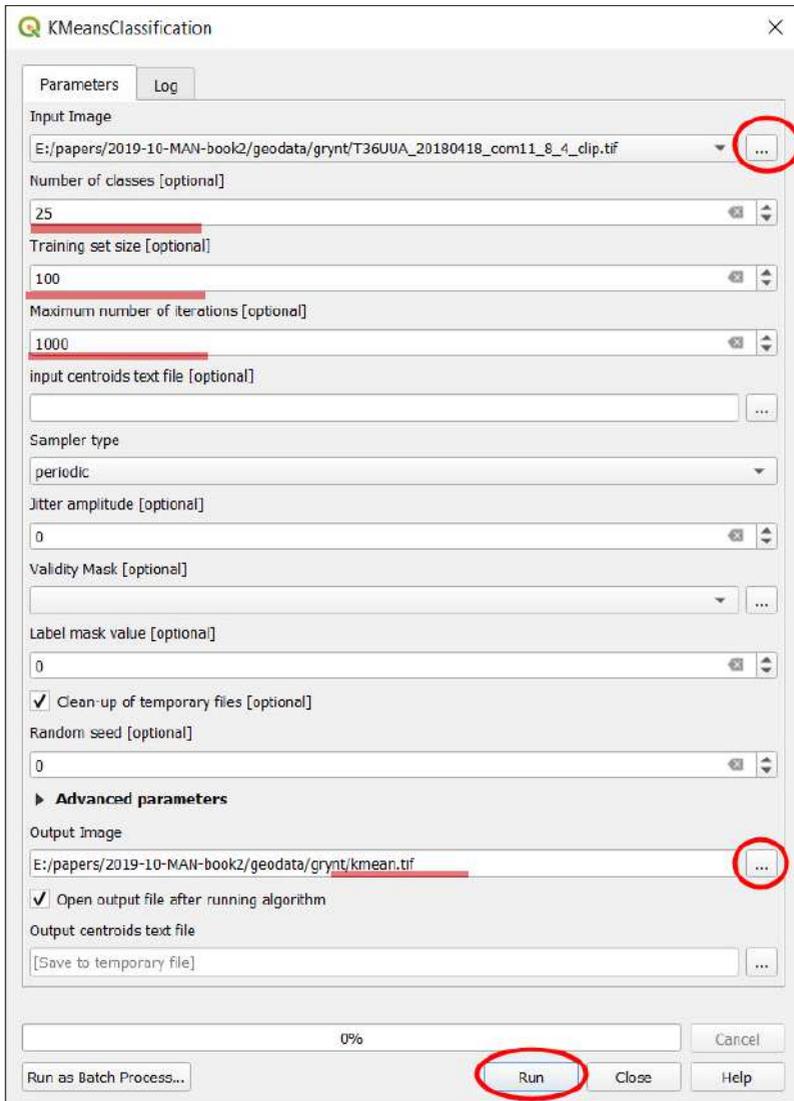


Fig. 2.110. Parameters of the *KMeanClassification* tool



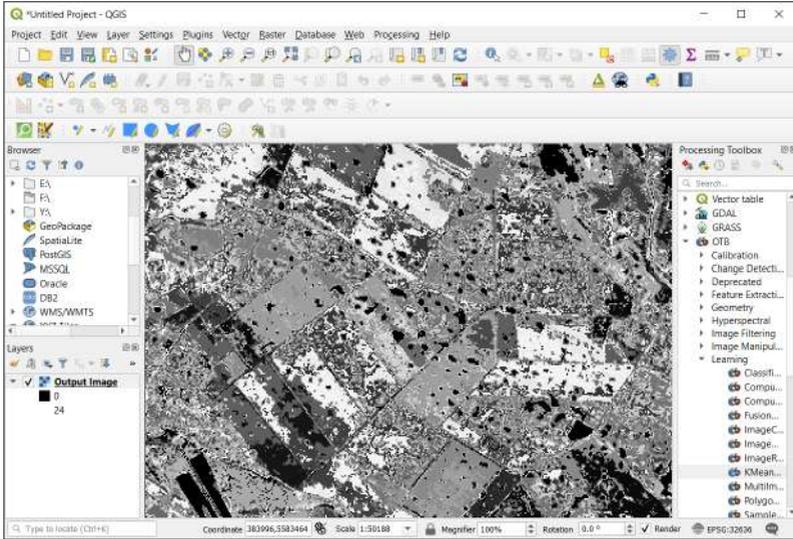


Fig. 2.111. The result of unsupervised classification

Therefore, we have 25 different classes of surface, which is represented in gray shades. To facilitate the identification of spectral class, which indicates the areas of subsidence, we will change the image in such a way that the classes are displayed with a gradation of different colors. To do this, open the image properties (double-click the raster layer in the table of contents). In the **Symbology** tab, select the **Paletted/Unique values** type from the drop-down menu in the **Render type** bar. In the **Color ramp** bar, select, for example, red-green-blue color gamut. Then click **Classify** – as a result, all classes with the respective color should load into the appropriate window with class values. Finally, click Ok (Fig. 2.112).

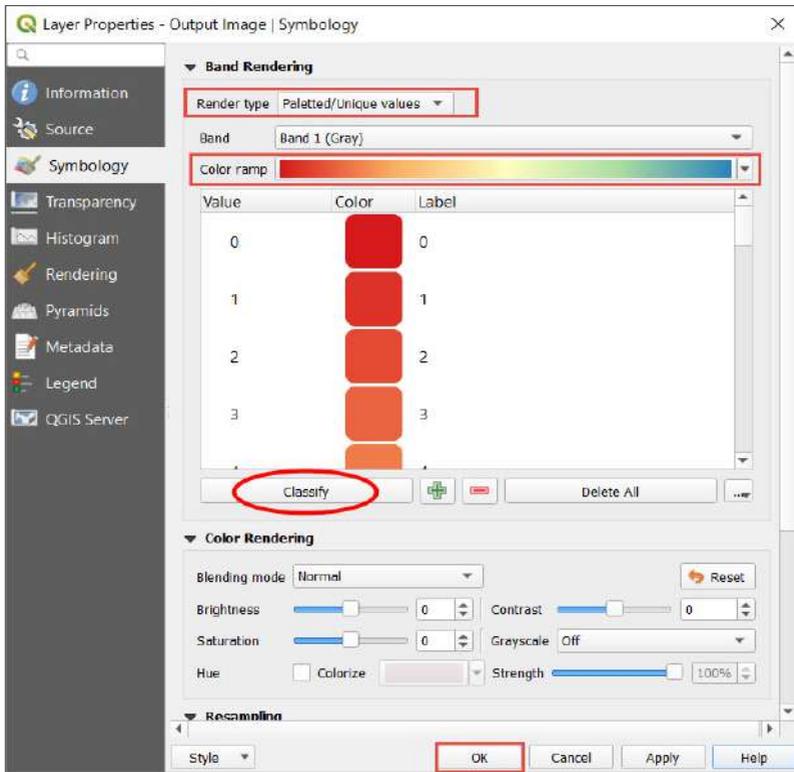


Fig. 2.112. Adjusting the display of raster image classes by color gamut

Now, to see which spectral class indicates the subsidence areas, zoom into several fields in the center of the image in the map window, and open the tab next to the image name in the table of contents as shown in Fig. 2.113.

In this example, we see that the subsidence areas are displayed in red, i.e. have codes 0 and 1.



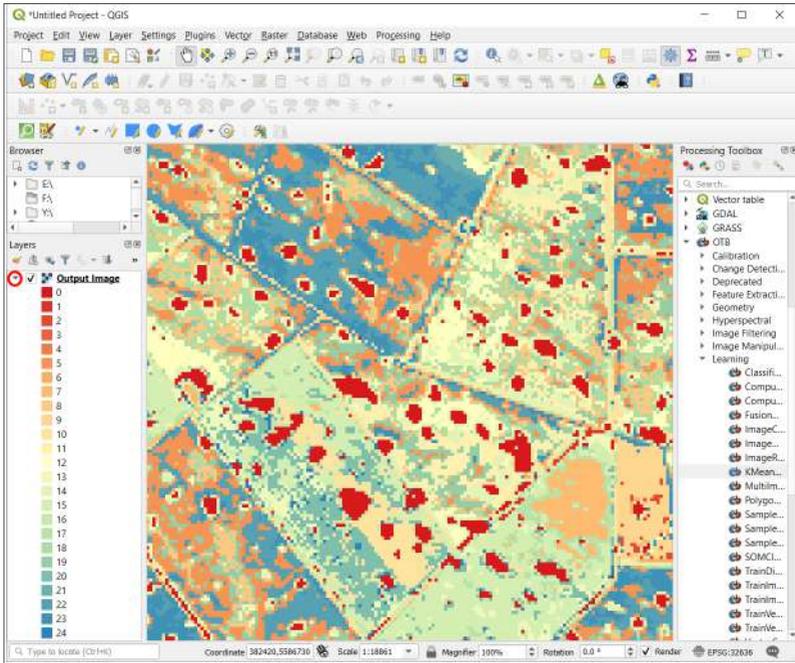


Fig. 2.113. Display of raster image classes by color gamut

3. Reclassification of unsupervised classification result

The next step is to reduce 25 classes to two, i.e. the areas of subsidence should be assigned code 1 (in the present raster image they have codes 0 and 1), and all other values (from 2 to 24) must be assigned code 0, which will indicate the entire area without depressions. As a result, it will be easier to further convert the raster image into a vector layer and calculate the area of depression.

To reclassify the image (Fig. 2.114), i.e. to change the values (codes) of the raster, use the **Reclass** tool of the GRASS module from the **Processing Toolbox** toolbar. To quickly open this tool, you can enter “reclass” in the search bar in the **Processing Toolbox**; as a result, all tools that contain this word in the title would be filtered out. Select the **R.reclass** tool from this list.

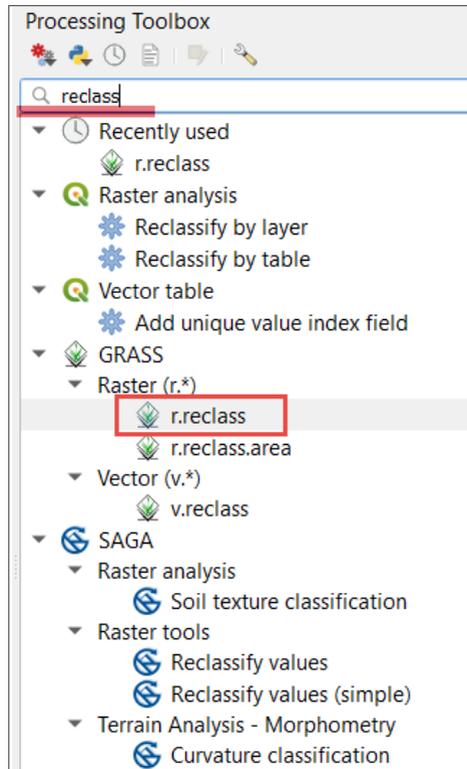


Fig. 2.114. Search and selection of a tool for reclassification of raster codes

Specify the raster image to be reclassified in the ***Input raster layer*** bar and type the following expression in the ***Reclass rules text*** bar:

$0 \text{ thru } 1 = 1$

$2 \text{ thru } 24 = 0,$

which means that classes with code 0 and 1 will be assigned value 1, and all other classes from 2 to 24 will be assigned value 0.

Next, specify the name and path for saving the resulting layer (Fig. 2.115) in the ***Reclassified*** bar and click ***Run***.

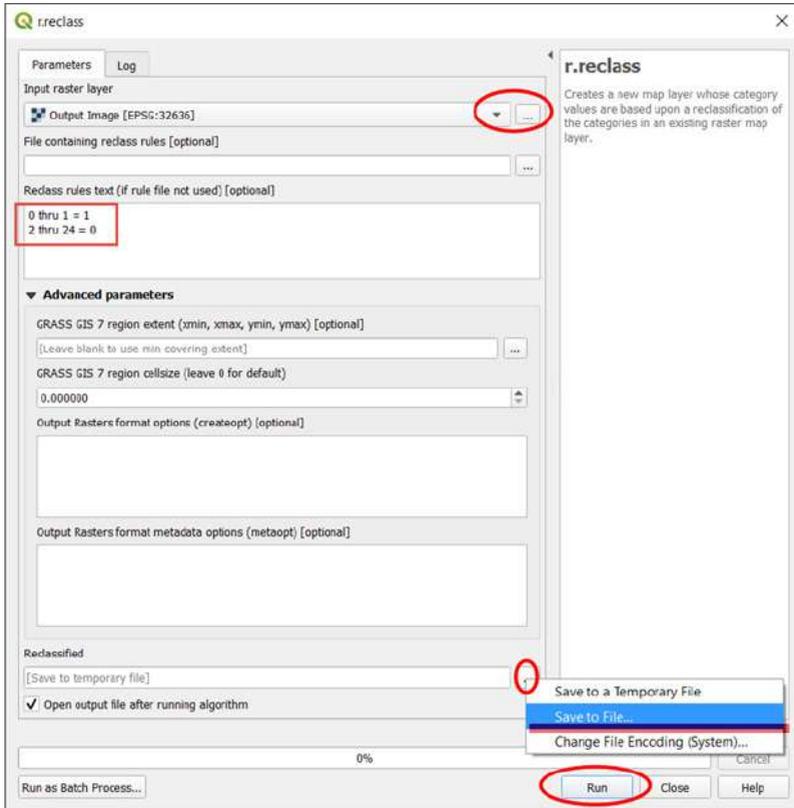


Fig. 2.115. Tool for raster reclassification

Thus, we have obtained a new thematic raster with two classes (Fig. 2.116).

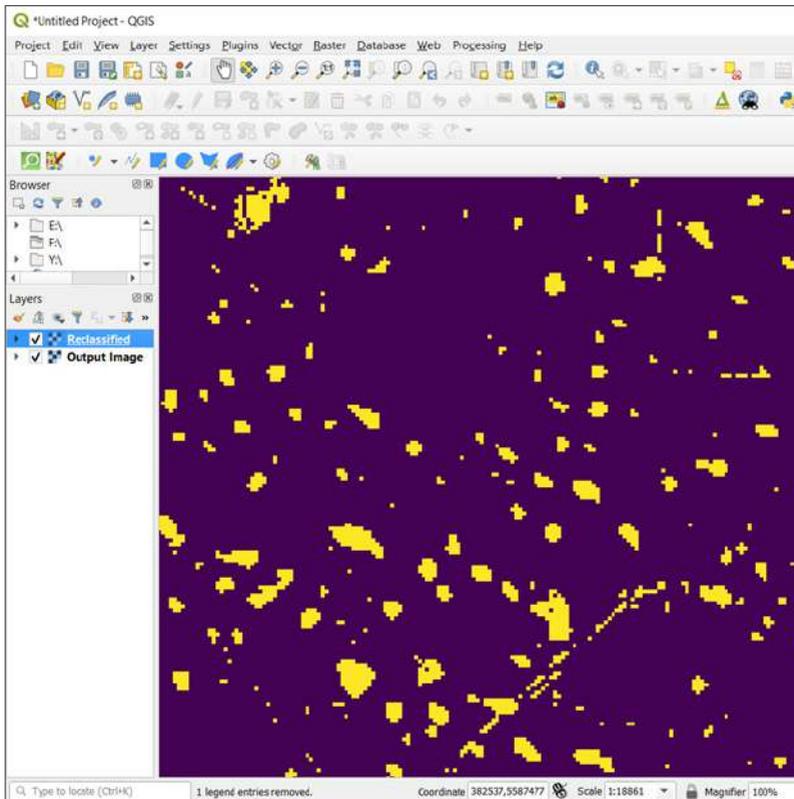


Fig. 2.116. New reclassified raster

4. Converting a raster into a vector

The final operation is the transformation of the completed thematic raster into a vector layer to obtain the loess subsidence area. For this purpose, use the *Polygonize* tool, which converts a set of raster data into polygonal spatial features (Fig. 2.117). To open the tool, go to the *Raster* menu → *Conversion* → *Polygonize*.



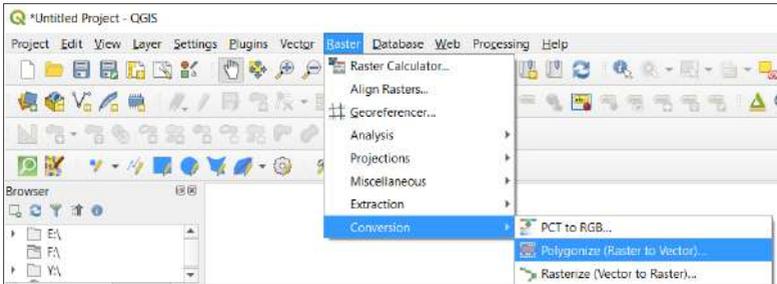


Fig. 2.117. Selecting a tool for converting a raster into a vector

To convert a raster into a vector, specify the reclassified raster in the **Input layer** bar, and the name of the resulting layer in the **Vectorized** bar; all other parameters can remain unchanged (Fig. 2.118). For example, the **Name of the field to create** parameter allows you to specify a name for the attribute field in the output vector layer that will contain the corresponding class value from the raster layer (by default, this field is named DN, it may be left unchanged).

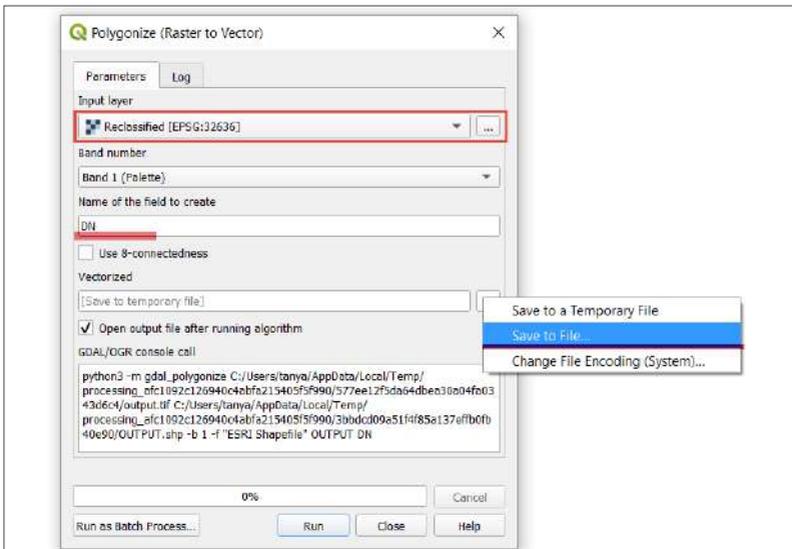


Fig. 2.118. *Polygonize* tool window

In the previous sections, we have discussed adding a new field with an area value to the Attribute Table. Let us calculate now the loess areas, i.e. plots from the vector layer with assigned code 1. Thus, we have obtained a vector map of loess subsidence areas and accordingly calculated the agricultural areas that suffer from wetting and weeding (Fig. 2.119).

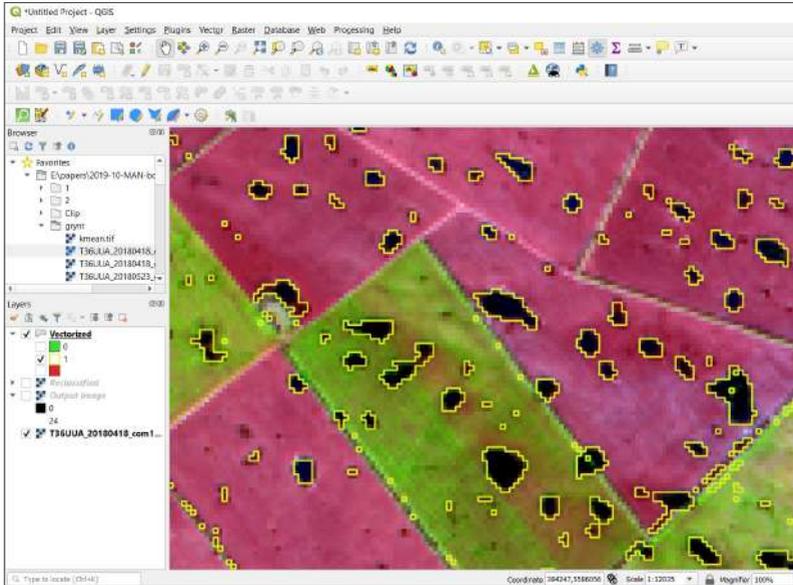
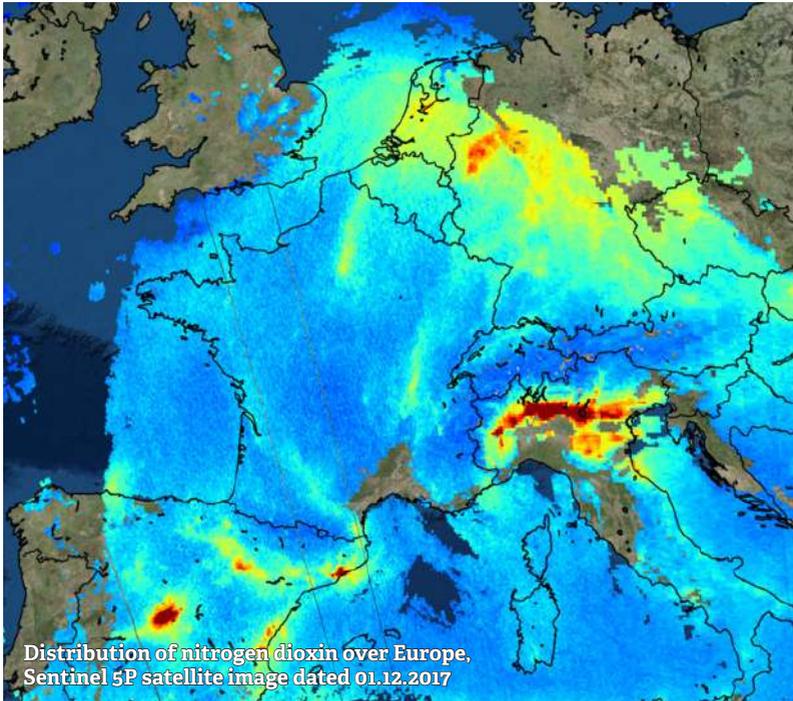


Fig. 2.119. Thematic vector layer of depressions superimposed on the Sentinel 2 satellite image dated April 18, 2018





2. 4. Analysis of Geophysical Data from Satellite Images

Satellite imagery allows not only to obtain images of the ground and water surface and calculate different spectral indices, but also generate maps of geophysical data on a planetary scale using various climatic, hydrological, chemical and other models in combination with ground surveillance data from monitoring stations. These are, for example, temperature charts of the ground and water surfaces, the content of organic compounds in water, the amount of precipitation, the moisture content of the soil, the concentration of atmospheric gases in the air, the content of aerosols and much more. In particular, at the website of the National Aeronautics and Space Administration (USA), <https://giovanni.gsfc.nasa.gov>, you can find and download more than a thousand data sets with different geophysical indicators obtained by different satellites. For example, the portal contains more than 400 different data sets related to atmospheric processes and more than 650 different hydrological indicators (Fig. 2.120).

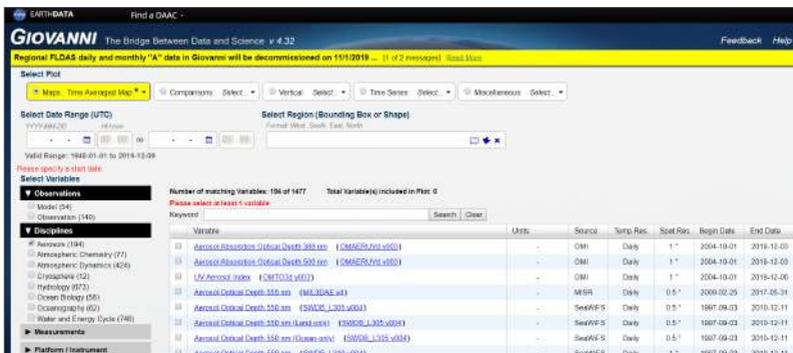


Fig. 2.120. Selecting data to download from the Giovanni website

However, given the complexity of modeling such data and their significant dependence on a network of ground-based surveillance units, these data have a low spatial resolution – from one to tens of kilometers. At the same time, their temporal resolution, i.e. the frequency of surveying, is usually quite high – once a day, which allows the monitoring services to effectively use these data and warn of emergencies such as floods, droughts or the spread of volcanic dust.

In October 2017, the European Space Agency successfully put into orbit the Sentinel 5P satellite, specifically designed for atmospheric monitoring. It features a Tropomi sensor (TROPOspheric Monitoring Instrument) capable of registering the content of ozone, methane, formaldehyde, aerosol, carbon monoxide, NO₂ and SO₂ in the atmosphere with a spatial resolution of 7 x 3.5 km.

Task

In September 2019, similarly to the same period in recent years, Kyiv was dragged by smog and fog. The stated reasons for smokiness included the temperature inversion phenomenon, burning of peatlands near Kyiv, vehicle emissions or a fire at a landfill. In this Task, we will analyze the Sentinel 5P satellite images for the first week of September 2019 and see what was the content of NO₂ and SO₂ in Kyiv and Ukraine in general. It is believed that the main sources of NO₂ and SO₂ in the atmosphere are vehicles and thermal power plants (Fig. 2.121).

Data

Seven Sentinel 5P images of the territory of Ukraine covering the period from 1 to 7 September, 2019 and containing data on NO₂ and SO₂ concentrations.

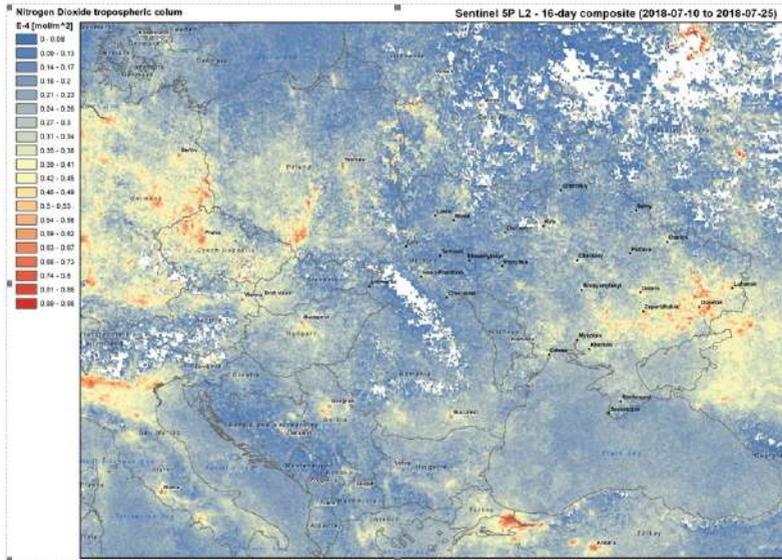


Fig. 2.121. Map of NO₂ concentration in the air over Ukraine and Eastern Europe according to Sentinel 5P (July 2018)

Task Performance Algorithm

1. Data downloading and preparation

We will find and download all available Sentinel 5P images capturing the territory of Ukraine for the period from 1 to 7 September 2019 using EO Browser. Detailed description of EO Browser interface and images downloading is given in [paragraph 1.2](#) of this Guidance Manual. Please refer to it if you have difficulty with completing this task.

In this task, you need to log in to the portal and find Kyiv on the map (using the search bar), specify the period, select the data type (Sentinel 5P/NO₂), as shown in Fig. 2.122, and click Search.

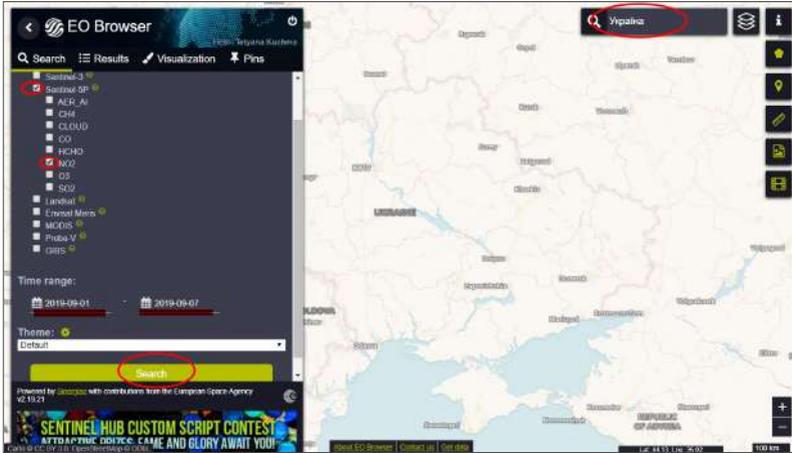


Fig. 2.122. Search for Sentinel 5P data in EO Browser

As a result, the list of images available for the specified period should be downloaded. Upload them in turn. To do this, click on the **Visualize** button displayed in the image results and adjust the download settings by clicking on the button .



Fig. 2.123. Image download settings

From the download options, select:

- download type: **Analytical**;
- **image format**: tiff-32 bit;
- **layers**: **RAW** (raw data) / **NO₂** and click **Download**.

Then click on the “back” arrow next to the calendar icon in the upper left corner of the window to open the previous image, and save it, making sure to use the same save settings as shown in the figure above (Fig. 2.124).

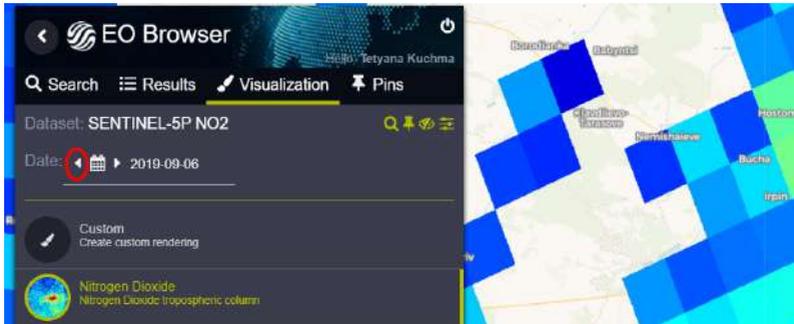


Fig. 2.124. Opening the image for the previous date

Save all seven images dated September 1-7, 2019. Note that the boundaries of the saved image are the areas of the map window coverage in the EO Browser. Make sure that Ukraine is fully displayed in the map window.

Now download images with data on atmospheric content of SO₂ for the same period (September 1–7, 2019).

2. Creating a cloud mask

When scrolling the images in the EO Browser, you may have noticed that the they were not solid and often contained areas with missing values. These areas in the images were covered with clouds, which prevented the sensor from detecting concentrations of the substances in the atmosphere. When we open the downloaded images, we will see that these areas are marked in the digital image with a certain code that indicates the clouds. The code usually has a numerical value (in this case “1”), and to correctly calculate the average weekly concentrations of substances, we need to exclude this value from the raster. Therefore, replace the code value of the clouds with *NoData*, i.e. cut them from the image. The easiest way to do this is to create a cloud mask by selecting from the digital image only the pixels with appropriate code and clipping the downloaded input image according to the cloud mask line (Fig. 2.125).

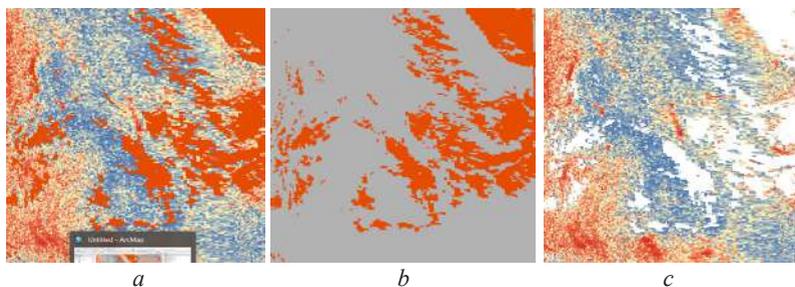


Fig. 2.125. Clipping the image along the cloud mask: the output image (a), the cloud mask (b), clipped image along the cloud mask (c)

3. Calculating average weekly concentrations of air pollutants

Depending on the wind speed and direction, atmospheric pollutants can spread rather quickly along great distances away from the source of pollution. In such cases, it may be difficult to identify a permanent source of pollution, so it is advisable to determine the average concentration of substances in the atmosphere for a certain period. Continuous emissions will be visible on each image from the entire time series and, accordingly, will contribute to the increase in average concentrations. The easiest way to create an averaged image over a period is to use a raster calculator: to sum up all the images of a particular time series and divide them by their number.

Then we will open the images in ArcGIS or QGIS, cut out the clouds, calculate the average weekly concentration of pollutants in the atmosphere and create a map of its distribution in Ukraine.



ArcGIS

Performing a Task in ArcGIS

Analysis of NO₂ concentration in the atmosphere

Using ArcMap application, we will create a map of the average weekly values of NO₂ concentration in the atmosphere.

Open ArcMap and create a new project called NO2 (according to the instructions specified in [paragraph 1.3](#)).

Open the first uploaded image dated September 1, 2019 and the **Layers Properties** window by double-clicking on the image. Go to the **Symbology** tab and select the display type: **Show** → **Unique Values**. It is important for us to check the range of values and see what values indicate the clouds. Change also the **color scheme** to a color mode for displaying values in ascending order from blue to red and click **Ok** (Fig. 2.126).



This visualization enables to notice that the maximum value within the studied area – 1, which differs significantly from the range of other values, therefore, it denotes the clouds (Fig. 2.27).

To calculate the average weekly pollution, this value 1 should not be taken into account, otherwise we will get erroneous data. To do this, replace the value 1 for each image with *NoData*, i.e. you actually need to create a cloud mask and cut it out of the image (Fig. 2.128).

Use again the **Raster Calculator** tool from *ArcToolbox* → **Spatial Analyst** → **Map algebra** → **Map algebra** toolbar. Open it and in the raster calculator window, drag the Sentinel 5P_NO2_2019-09-01.tiff image from the top of the window to the calculation field below the list of layers and type <1. Specify the name of the output layer, e.g. *mask_2019-09-01*, and the path to the folder for saving the files.

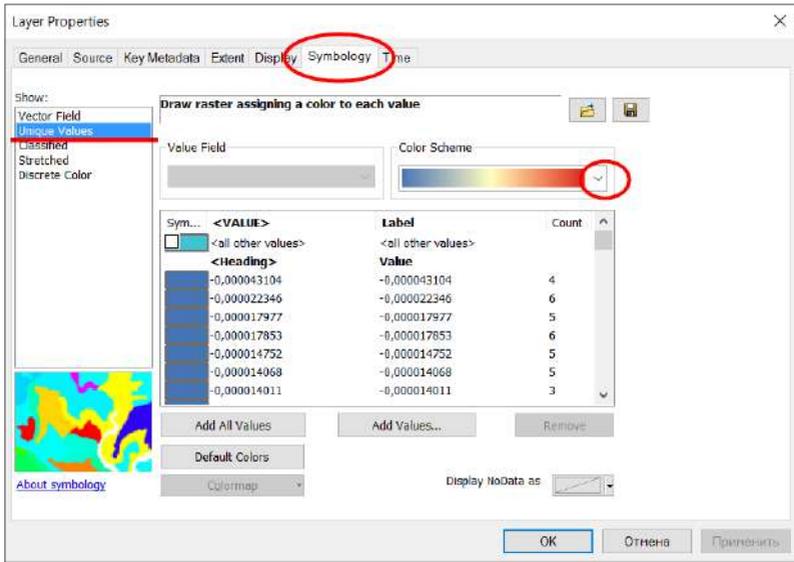


Fig. 2.126. Image visualization settings

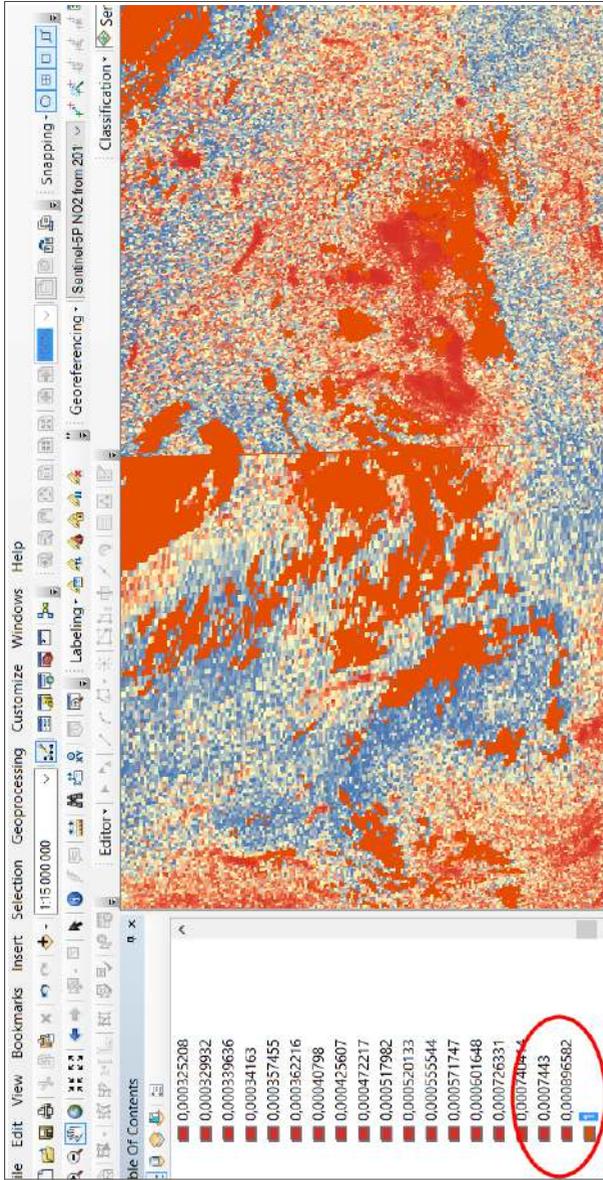


Fig. 2.127. Analysis of the range of the image values



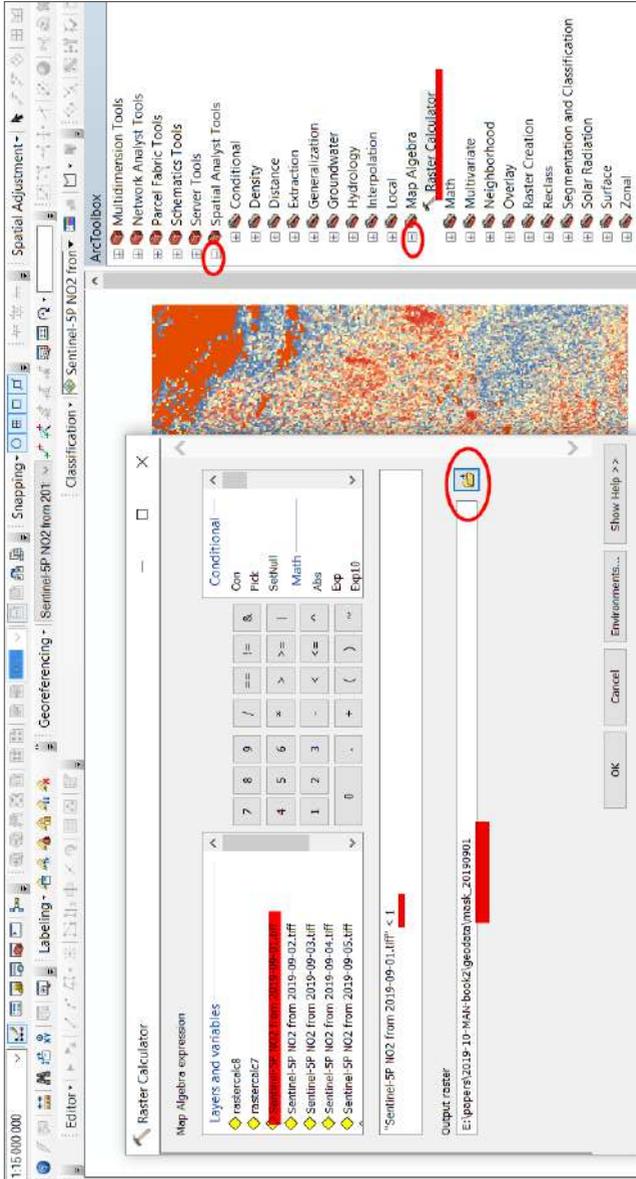


Fig. 2.128. Creating a cloud mask

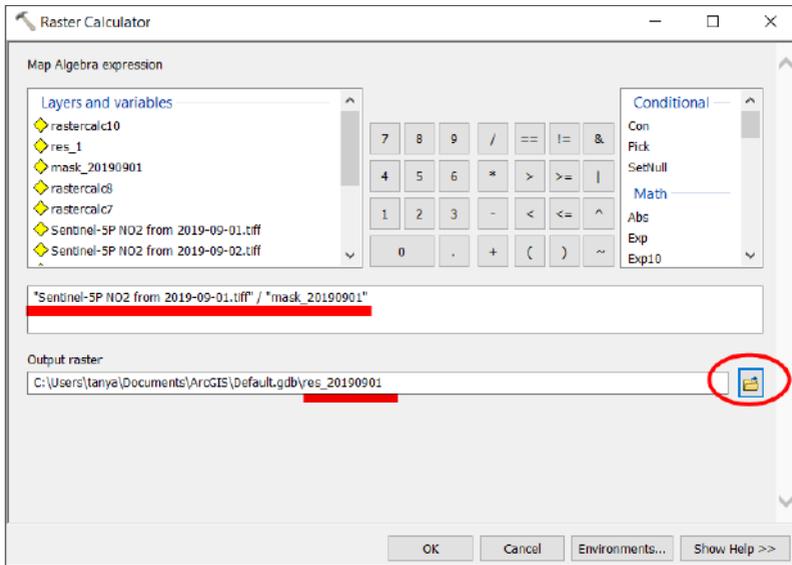


Fig. 2.129. Clipping the image along the cloud mask

Hence, you will create a new layer, in which all Sentinel 5P_NO2_2019-09-01.tiff image pixels with value 1 have value 0, and all other pixels have value 1.

Now again, using raster calculator, you need to divide the Sentinel 5P_NO2_2019-09-01.tiff image into a cloud mask (*mask_2019-09-01*). As a result, we will get a new raster in which the values that were equal to 1 on the cloud mask will remain unchanged, and where the cloud mask was equal to 0, there will be NoData.

However, we have cut clouds for one of the seven images only so far (Fig. 2.129). Perform the same operations for each uploaded image.

The last step will be performed using the tools from the *Image Analyst* window, which we have already used to stitch the images (paragraph 1.4). To open the *Image Analyst* window, go to *Windows* in the top menu and click *Image Analyst*. Select with your mouse seven resulting rasters with cut cloud masks at the top of the *Image Analyst* window. Then, open the drop-down menu and select the calculation method *mean* in the *Processing* window next to the tool  (Mosaic).

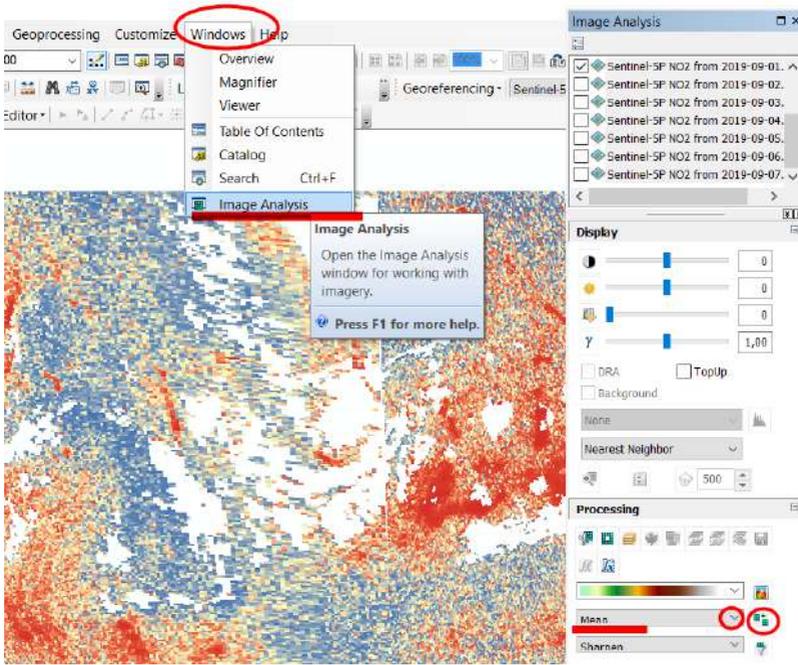


Fig. 2.130. Averaging the values of NO_2 concentration in the atmosphere for a week

Based on the week-averaged data, you can create a map of pollutants distribution over the entire area under study (Fig. 2.130). Instructions for creating a map layout can be found in [paragraph 2.2](#).



Performing a task in QGIS

Analysis of SO_2 concentration in the atmosphere

We will create a map of weekly average values of SO_2 concentration in the atmosphere using QGIS application.

Open QGIS Desktop 3.4.13 with GRASS and create a new project called SO_2 (according to the instructions in [section 1.3](#)).

Open the first uploaded image dated September 1, 2019 and the **Layers Properties** window by double-clicking on the image. It is important for us to check the range of values and see what values the clouds are marked by. To do this, adjust

the display of the image (Fig. 2.131). Click the **Symbology** tab, and select **Render type** → **Singleband pseudocolor**. In the same window, open the **Min/Max value settings** tab and check the box next to **min/max**; make sure that the **whole raster** is selected next to the **Statistics extent** menu. Change also the **color ramp** to a color scheme for displaying ascending values, for example, from red to blue, click **Classify** → **Ok**.

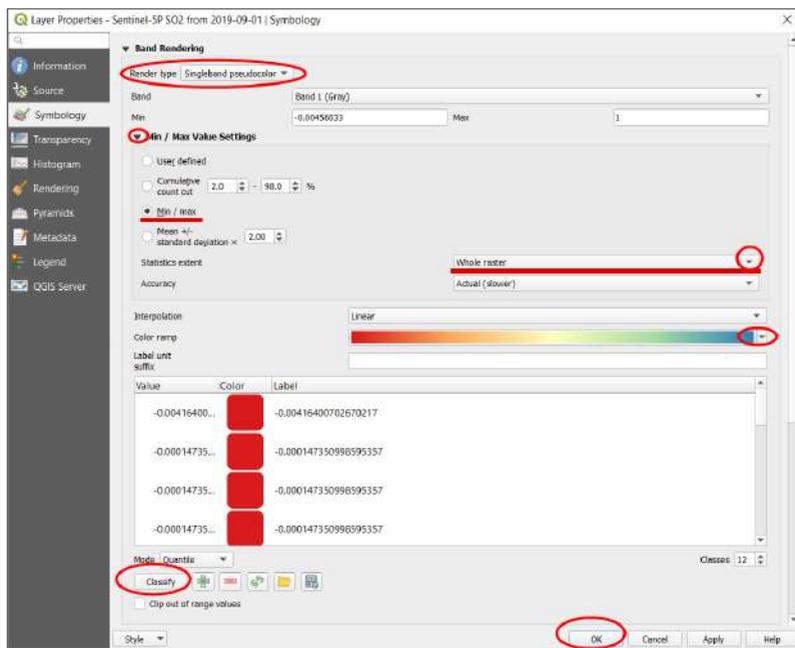


Fig. 2.131. Image visualization settings

As a result, the image will be displayed in the appropriate color gradation, and the class gradation values will appear in the table of contents. If the gradations of classes are not opened by default in the table of contents, open the drop-down menu next to the name of the raster (Fig. 2.132).



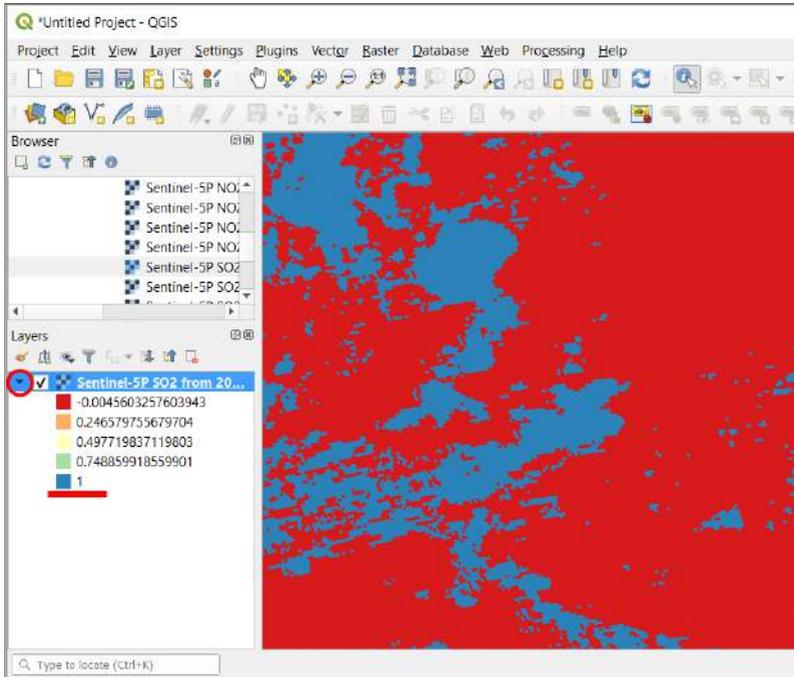


Fig. 2.132. Display of class gradations in pseudo-color image

This visualization demonstrates that the maximum value within the studied area is 1, which significantly differs from the range of other values, therefore, it represents clouds.

To calculate the average weekly concentration of pollutants, this value 1 should be ignored in calculations, otherwise we will get erroneous data. To do this, replace the value 1 for each image with *NoData*, i.e. create a cloud mask and cut it out of the image.

Again, the *Raster Calculator* tool will come in useful. To open it, click on the *Raster* menu in the top of the screen and select the *Raster Calculator* tool.

At the top of the *Raster bands* window, double-click the Sentinel 5P_NO2_2019-09-01.tiff image – it will automatically appear at the bottom of the *Raster Calculator Expression* window. Type <1. Specify the name of the output layer, e.g. mask_2019-09-01, and the path to the folder for saving the files and click *Ok* (Fig. 2.133).

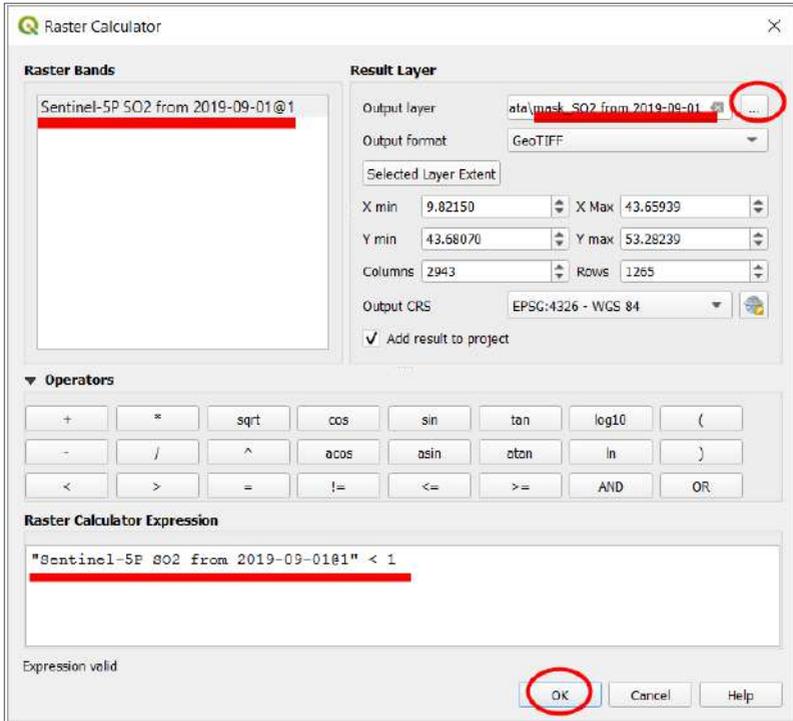


Fig. 2.133. Creating a mask of clouds

As a result, we will obtain a new layer in which all Sentinel 5P_NO2_2019-09-01.tiff image pixels that had value 1 will be assigned value 0, and all other pixels will have value 1.

Now repeat the operation of dividing the Sentinel 5P_NO2_2019-09-01.tiff image on the cloud mask (mask_2019-09-01) using raster calculator, and you will get a new raster in which the values equaling to 1 on the mask of clouds remain unchanged, and values equaling to 0 on the mask of clouds have *NoData* (Fig. 2.134).



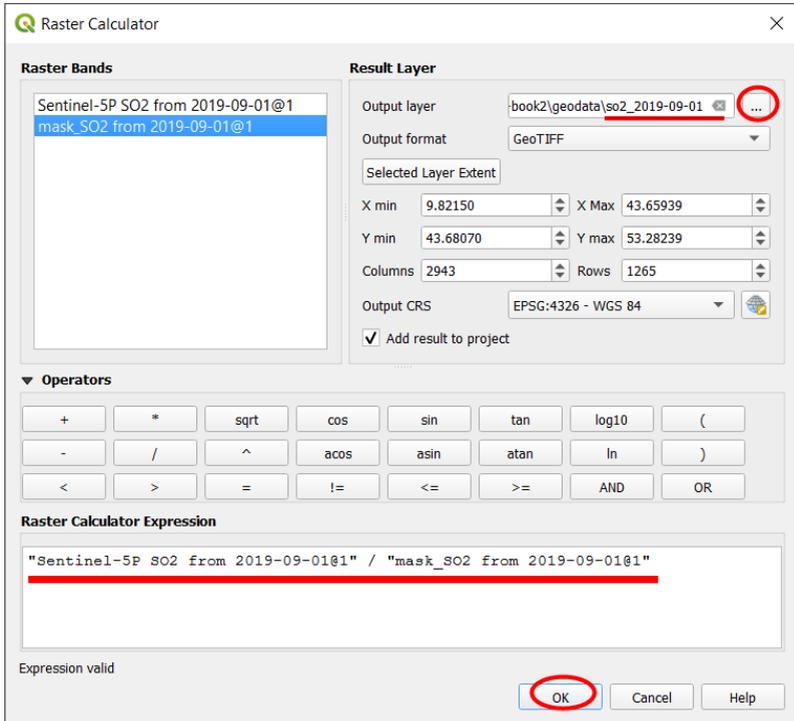


Fig. 2.134. Clipping the image along the mask of clouds

However, we have cut the clouds for one of seven images only so far. Perform the same operations for each uploaded image.

Then create a raster with average weekly values for SO₂ air concentration. To do this, open the **Raster** → **Miscellaneous** menu and select the **Merge** tool.

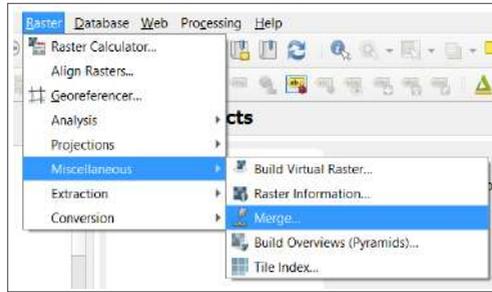


Fig. 2.135. Choosing a tool for images merging (mosaicking)

In the window for merging images (Fig. 2.135), check the box next to **Grab pseudocolor table from the first layer**, specify the path to save the file and click **Run**.

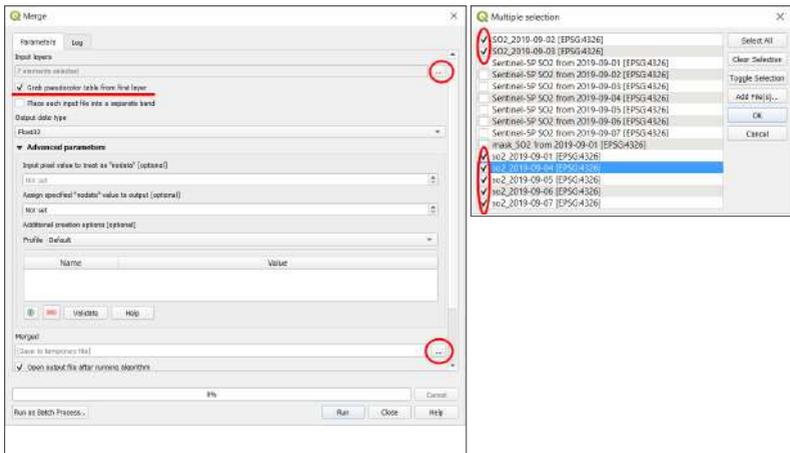


Fig. 2.136. Averaging the values of SO2 concentration in the atmosphere for a week

Based on the average weekly data you can create a map of pollutants distribution over the entire area of the study (Fig. 2.136). You may find instructions for creating a map layout in [paragraph 2.2](#).

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Conclusions

The era of the Fourth Industrial Revolution demands from the humanity not only to reconsider its attitude to the role of information technologies in all spheres of life of a modern man, but also to prepare today's children for life in the second half of the 21st century through new approaches to learning.

Today, in the age of big data, development and improvement of artificial intelligence, nanorobots and quantum computers, when devices have become an integral part of our life and we use them almost from the cradle (even if a child is imposed with use restrictions, the main factor of adaptation is that a child sees his/her parents using phones, computers, tablets, etc. and this is perceived as the norm), education cannot remain uninvolved.

One of the tenets of education in the early 2000's was to lay emphasis on the development of students' ability to acquire new information rather than focus on memorizing already existing one. This approach is driven by the comprehensive influence of the Internet, where any information can be found if you know where and how to search for it.

Given these two conditions as of 2020 – the total computerization and big data that can and should be used – a new tenet has been set up in education: to teach to verify information and identify true, reliable data.

We were governed by these factors when writing this Guidance Manual. The application of information technology in the natural sciences allows not only to verify information, but also to form (based on the concept of science education) a new, own system of knowledge and ideas about how our Earth functions and how we influence it. Currently, anyone can access satellite observation data. After completing the tasks contained in this Guidance Manual, you will be able to see how the Troieshchyna housing estate was built in Kyiv, determine the fire seat in the Darnytskyi forest, find areas of inwashed sand for construction in the Dnipro River floodplain, analyze the dynamics of felling in Fastivske Forestry Enterprise, determine the water “blooming” areas in the Kyiv Cistern, estimate the amount of loess subsidence in Baryshivskiyi District of Kyiv Oblast, and determine the NO₂ and SO₂ concentrations in Kyiv and Ukraine during the 2019 autumn smog period.

One may reasonably ask: why RS and GIS technologies have not been properly applied yet in school education? Perhaps the most correct answer is the need to adapt and test the pedagogical methods of the RS and GIS to be used for different age categories of schoolchildren, and to introduce the potential of these technologies to teachers. This Guidance Manual was preceded by the publication, “Fundamentals of Remote Sensing: History and Practice”, which allows to form a general idea of the mechanism and possibilities of remote sensing use in the natural sciences, and shows in practice how the GIS and RS are interrelated and what results can be achieved in the research process.

Given the total computerization that already exists and is rapidly developing, the use of information technology in science education will not lose its relevance.

Glossary of GIS Terms

(adapted from the Manual, "Fundamentals of Creating Electronic Maps based on Arcgis 10.1 Software / S. M. Brevus et al, Kyiv: CITIPRINT LLC, 2013, p. 142)

Address data feature refers to the data which contains information used for geocoding. Address data may consist of one individual address or a table comprising many addresses.

Attribute refers to nonspatial information about a geographic feature, which is usually stored in a table and linked to the feature by a unique identifier. For example, attributes of a river might include its name, length, and sediment load at a gauging station.

Attribute data is defined as GIS data that contains information about the coordinates or location of features and data that describe the quantitative and qualitative characteristics of spatial features.

Attribute Table is a database or tabular file that contains information about a set of geographic features, usually organized so that each row represents one spatial feature, and each column represents an attribute. In raster data sets, each row of the Attribute Table corresponds to a specific area of cells with the same values.

Attribute query refers to a request for selection of spatial features or geodatabase records based on their attribute values.

CAD refers to a system of automatic design for the development, drawing and display of graphic information. Such systems are often used in construction and planning.

Catalog tree refers to a hierarchical display of folders providing access to GIS data stored on local disks and in the network, which allows users to manage connections to databases and GIS servers.

Cell refers to the smallest unit of information in an image, raster, or grid. On the map, each cell represents an area of the earth's surface, for example square meter or square mile, and usually has a related attribute value, such as soil type or vegetation.

Column refers to an element of the Attribute Table. Each column contains attribute values of the same type, such as numbers, text, or dates only.

Computer-aided design refers to a computer information processing system used for computer-aided design, development and manufacture of a final product, as well as for preparation of design and technological documentation.

Coordinate system refers to a system that determined the location in space and relationship between positions. Coordinate system allows individual determination of the data of each point. Defining a coordinate system is one of the main steps in

creating a new class of features or raster data. ArcGIS typically uses three coordinate systems: geographic, projection, and vertical.

Database refers to an arranged set of logically interrelated data that is shared and designed to meet the users' information needs. Storage of data in the database ensures the centralized management, compliance with standards, security and integrity of data, reduces redundancy and eliminates data inconsistencies.

Degrees/minutes/seconds denote units of measurement of latitude and longitude. Degree means 1/360 of a circle. One degree contains 60 minutes, and one minute – 60 seconds.

Desktop GIS refers to a mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations.

Digital map (numerical map) refers to a digital model of the surface, formed taking into account the laws of cartographic generalization using the projections, layout, coordinate system and heights adopted for the maps. In fact, the term “digital map” means a digital model, digital cartographic data. A digital map is created with full observance of norms and rules for mapping, maps accuracy, generalization, and system of symbols. The digital map is the basis for the production of ordinary paper, computer, and electronic maps. It is included in the cartographic database. The digital map is one of the most important elements of GIS information support and at the same time may be the result of the GIS operation.

E-map refers to an image formed on the display screen based on raster and vector digital maps, databases, symbols, legends and other elements of cartographic design of a given standard and scale.

Extent refers to pairs of coordinates that define the minimum rectangle that limits the data source on the map. All coordinates of the data source fall within these boundaries.

Feature class refers to a set of geographic features with similar geometry type (points, lines, or polygons), attributes, and spatial reference. Classes of spatial object can be stored in a geodatabase or included in shapefiles, covers, and other spatial data formats.

Feature layer refers to a layer referencing to a set of feature data. Spatial data represent the following geographical elements: points, lines and polygons.

File geodatabase refers to a geodatabase that is stored in the form of file folders. Multiple users can use the file geodatabase at the same time, but only one of them can edit it.

Folder connection refers to ArcCatalog, an element of the top level of the Catalog tree that provides quick access to geographic data stored on local disks (including CD-ROM) or shared on the network.

Geo-feature refers to a digital representation of a real-world feature (digital terrain model) that contains information about its location and a set of properties,

characteristics, attributes, or the feature itself. There are four main types of spatial facilities: point, linear, planar (polygonal), contour and surface.

Geographic data refers to the information about real-world objects including their shape, location, and descriptions.

Geographic information system refers to an integrated set of hardware, software and information tools that provide input, storage, processing, manipulation, analysis and display (presentation) of spatially coordinated data.

Geoinformatics refers to the science, technology, and applied activities related to the collection, storage, processing, analysis, and display of spatial data, as well as the design, creation, and use of geographic information systems. In a narrower sense (as a science), the geoinformatics is an interdisciplinary science about the means, methods and ways of collecting, storing, exchanging, processing, analyzing and displaying spatial (or spatially coordinated) information.

Geoinformation technologies refers to a set of tools, methods and techniques for automated collection, storage, manipulation, analysis and display (presentation) of spatial information.

Georeferencing refers to adjusting geographic data with a known coordinate system to enable viewing, querying, and analyzing along with other geographic data. Georeferencing may include shifting, rotating, scaling.

Geo-spatial analysis refers to an approach, which involves the application of statistical analysis methods and various information technologies to geographic or geospatial data (geodata). Such analysis involves the use of specialized software for geospatial processing and presentation, the application of analytical methods to terrestrial or geographic data, including geographic information systems (GIS) and geoinformatics.

Layer refers to a set of uniform (of same dimension) spatial objects that relates to a single theme (class of objects) within a territory and in a coordinate system common to a set of layers.

Layout refers to the organization of the elements of a digital or printed map display, including headings, legend, north arrows, scale and geographic data.

Legend is defined as a list of feature types displayed on a map; they are usually present in a map layout. Legends often contain symbols or map feature samples along with description of the meaning of each symbol.

Line refers to a shape on a map that connects a series of points, one after another, representing the x- and y-coordinates. The line can be straight or curved.

Map refers to a flat, mathematically defined, reduced, generalized symbol of the Earth's surface, other celestial body or outer space, showing the location, properties and relationships of natural and socio-economic phenomena. The map is considered a figurative-symbolic model with high information content, spatio-temporal similarity in relation to the

original, metricity, special visibility and clarity, which makes it the most important knowledge acquisition tool in the area of Earth sciences and socio-economic sciences.

Map document refers to a file in ArcMap that contains a single map, its layout, and associated layers, tables, and charts. Map documents can be printed or inserted in other documents. Map document file has *.mxd extension.

Map template refers to a map document that allows quick creation of a new map. Templates can contain data, user interface and predefined layout, in which such elements of a map as north arrows, scale bar and logos are already organized on the virtual page.

Metadata – information about the content, quality, status and other characteristics of data. Metadata may contain information about what geographic data represent, how and by whom it was collected, what is the projection, scale, resolution, accuracy, and compliance with certain standards.

Overlay analysis refers to operations of overlapping two or more layers, which results in either a graphic composition (graphic overlay) of the output layers, or one derived layer, which topological and semantic attributes are derived from the values of the output layers attributes.

Personal geodatabase refers to a geodatabase that stores data in a single-user relational Microsoft Access database management system. Multiple users can view the personal geodatabase at the same time, but only one of them can edit it.

Pixel refers to the smallest unit of information in an image or raster map, usually square or rectangular. The term “pixel” is often used synonymously with cell.

Point feature refers to a cartographic object that has neither length nor area on an accepted scale, such as a city on a world map or a house on a map of Ukraine.

Polygon refers to a closed shape on a map formed by sequentially connected points with X- and Y-coordinate pairs, where the first and last pairs coincide, and all other pairs are unique.

Polygon feature refers to a cartographic feature that delimits an area on a given scale, such as a country on a world map or a county on a city map.

Projection refers to a method of depicting the spherical surface of the Earth on a plane. Mathematically, this is a certain transformation of the angular values of longitude and latitude on a plane.

Raster refers to a model of spatial data, which defines space as a set of equal cells, arranged in rows and columns. Each cell contains an attribute value and location coordinates.

Reference scale refers to the scale at which symbols appear on a map at their true size, specified in page units. As the extent is changed, the size of text and symbols

will change along with the display. Without a reference scale, symbols will appear the same at all map scales.

Scale refers to the ratio of a distance on the map to the corresponding distance on the ground, which is usually expressed as a fraction or the ratio of one number to another. A 1: 100,000 scale means that one unit on the map corresponds to 100,000 same units on the ground.

Scale bar refers to an element of a map that graphically displays a scale.

Selectable layers refer to layers whose spatial objects can be selected in ArcMap using interactive sampling tools.

Shapefile refers to a vector format for storing the features (points, lines, polygons, etc.) The format was introduced for ArcView GIS version 2 in the early 90's

Spatial database refers to a structured set of spatial data and related attributes organized for efficient storage and retrieval.

Symbol refers to a graphic representation of a geographical feature or a class of features that helps to identify and distinguish them from other features on the map. For example, linear symbols represent spatial objects – arcs; marker symbols – point features; fill characters – polygonal features; text symbols – annotations. The meaning of the symbols is usually explained in the map legend.

Table of Contents refers to a list of data frames and layers (or tables) of the map, which shows the symbols of the data, the data source and availability of the layers for sampling.

Triangulated irregular network refers to a description of the map surface with triangular faces, according to which each data point in space corresponds to a triangle of the reference grid.

Vector refers to a coordinate-based data model, which represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as arranged lists of vertices.

Visualization is defined as design and generation of geoimages and other graphics on display devices (mainly on the display screen) based on the original digital data, rules, and algorithms for their conversion.

Workspace is defined as a repository for geographic data. The workspace can be a folder that contains Shapefiles, a geographic database, a set of feature classes, or an ArcMap workspace.

x, y coordinates – a pair of values that represents the distance from the starting point (0.0) along two axes: the horizontal axis (x), which represents East – West direction, the vertical axis (y), which represents North – South direction.

Annexes

Additional Resources Where You Can Search for Images:

LandLook (US Geological Survey, USGS) – <https://landlook.usgs.gov/viewer.html>.

Here you can search for available medium-resolution images collected by Landsat and Sentinel satellites. Using this resource, you can create features, and design maps for printing.

GeoVisual Search – <https://www.descarteslabs.com/search.html>.

This is a search engine that allows users to search for images for similar geographic features. The Descartes Labs platform is based on satellite images provided by Landsat, the National Agricultural Imagery Program (NAIP) and PlanetScope.

OpenAerialMap – <https://openaerialmap.org/>.

The Open Imagery Network (OIN) collects data with open licenses. OIN providers allow using images and related metadata under a general license. The Open Imagery Network brings together satellite and aerial imagery providers, governmental and non-governmental organizations, mapping companies and anyone involved in the production, distribution and use of aerial imagery. OpenAerialMap, based on the Open Imagery Network (OIN), is an open service that provides search and access to these images.

EarthTime – <https://earthtime.org/>.

A free platform developed by the CREATE Lab at the Carnegie Mellon University's in the United States, which “allows users to interact with Earth transformation visualization over time” and create animations.

Spectator – <https://spectator.earth/>.

This free web application simplifies the acquisition of images through verbal search, such as “cloudless images of New York for the last month”. A free account enables you to create your own repository to track changes in the area you are interested in.

Worldview – <https://worldview.earthdata.nasa.gov/>.

A browser provided by the NASA, which offers many options to visualize different layers of environmental information.

Annex 1 (continued)

Earthnet On Line Interactive Stand Alone client (EOLI – SA) – <http://eoli.esa.int/>.

A program to search for the images distributed under the auspices of the European Space Agency, for a fee and free of charge – ENVISAT ASAR, SPOT HRV (IR), ERS SAR, JERS SAR, Proba CHRIS, HRC, KOMPSAT.

Earth from Space – NASA Space Shuttle Earth Observations Photography database of images – <http://earth.jsc.nasa.gov/sseop/efs/>.

Free – selected Shuttle images.

Global Change Master Directory – <http://gcmd.gsfc.nasa.gov/>.

Data for studying global changes. Free data, maps and images collected under the auspices of the Global Change Program.

Earth Science Data Interface (ESDI) at the Global Land Cover Facility – <http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp>.

Free - selected Landsat and Terra ASTER images, as well as SRTM digital terrain models.

Geostationary Satellite Server – www.goes.noaa.gov/.

Catalog of geostationary satellites images. Free – GOES images and images from other geostationary satellites.

Meteosat Image Services –

<http://www.eumetsat.int/Home/Main/DataAccess/EUMETSATDataCentre/index.htm?l=en>.

Free Meteosat satellites images.

Correspondence of Landsat 5, 8 and Sentinel 2 Satellite Bands

Landsat 8			Landsat 5			Sentinel 2		
Spectral bands	Wave length (µm)	Spatial resolution, m	Spectral bands	Wave length (µm)	Spatial resolution, m	Spectral bands	Wave length (µm)	Spatial resolution, m
Band 1 (Ultra Blue)	0.433–0.453	30	–	–	30	Band 1 (Ultra Blue)	0.433–0.453	60
Band 2 (Blue)	0.45–0.515	30	Band 1 (Blue)	0.45–0.52	30	Band 2 (Blue)	0.458–0.522	10
Band 3 (Green)	0.433–0.453	60	Band 2 (Green)	0.52–0.6	30	Band 3 (Green)	0.543–0.577	10
Band 4 (Red)	0.63–0.68	30	Band 3 (Red)	0.63–0.69	30	Band 4 (Red)	0.650–0.680	10
–	–	–	–	–	–	Band 5 (Vegetation Red Edge)	0.698–0.712	20
–	–	–	–	–	–	Band 6 (Vegetation Red Edge)	0.733–0.747	20
–	–	–	–	–	–	Band 7 (Vegetation Red Edge)	0.773–0.793	20
Band 5 (NIR)	0.845–0.885	30	Band 4 (NIR)	0.76–0.9	30	Band 8 (NIR) Band 8a (Vegetation Red Edge)	0.784–0.899 0.855–0.875	10 20
–	–	–	–	–	–	Band 9 (Water vapour)	0.935–0.955	60
Band 6 (SWIR1)	1.56–1.66	30	Band 5 (NIR2)	1.55–1.75	30	Band 11 (SWIR1)	1.565–1.655	20
Band 7 (SWIR2)	2.1–2.3	30	Band 7 (SWIR)	2.08–2.35	30	Band 12 (SWIR2)	2.100–2.280	20
Band 8 (PAN)	0.50–0.68	15	–	–	–	–	–	–

End of Annex 2

Band 9 (<i>SWIR</i> , <i>Cirrus</i>)	1.36– 1.39	30	–	–	–	Band 10 (<i>SWIR</i> , <i>Cirrus</i>)	1.360– 1.390	60
Band 10 (<i>TIR1</i>)	10.6– 11.2	100 *(30)	Band 6 (<i>TIR</i>)	10.40– 12.50	120 *(30)	–	–	–
Band 11 (<i>TIR2</i>)	11.5– 12.50	100 *(30)	–	–	120 *(30)	–	–	–

Ultra Blue (Coastal / Aerosol) – ultraviolet (coast and aerosol);

NIR – Near Infrared;

SWIR – Short Wavelength Infrared;

TIR – Thermal Infrared;

Cirrus – cirrus clouds;

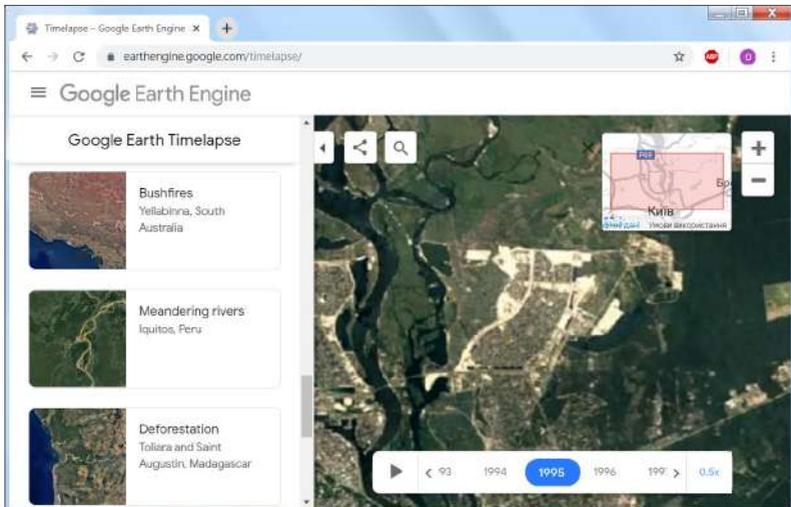
PAN – Panchromatic.

Google Timelapse

Official webpage: <https://earthengine.google.com/timelapse/>

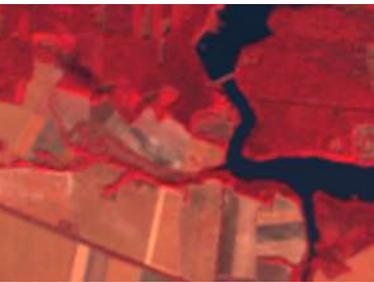
Timelapse is used to accelerate the reproduction of relatively slow processes, in our case – time series of the Earth satellite images.

Back in 2013, the Google Earth mapping service created the Timelapse function, in which chronologically arranged satellite images give a full picture of the changes of our planet over a few decades. The animated map contains more than five million images: the oldest of them are from the Landsat 5 archive, and the latest – from the Landsat 8 and Sentinel 2 satellites. Thus, more than 25 million spectacular videos showing the Earth's surface for the period 1984-2018 have been created.



Animation of the construction of the Troieshchyna residential area in the Google Timelapse window

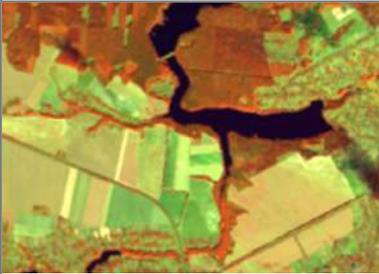
The most common Band combinations for Landsat 5, 7, 8

Combination for Landsat 5, 7	Combination for Landsat 8	Information
B03, B02, B01	B04, B03, B02	<p>A combination of “true colors”. In this combination, the features on the earth's surface are similar to how they are perceived by the human eye. Healthy vegetation looks green, cleared fields – light, unhealthy vegetation – brown and yellow, roads – gray, coastlines – white. This combination of bands enables us to analyze the condition of water bodies, to estimate the depths. It is also used to study anthropogenic objects. Cuttings and sparse vegetation are poorly differentiated; it is difficult to distinguish one type of vegetation from another.</p>
<i>Red, Green, Blue</i>		
		
B04, B03, B02	B05, B04, B03	<p>The standard combination of “artificial colors”. Vegetation is represented in shades of red, urban development – green and blue, and soil colors vary from dark to light brown. Saturated shades of red are indicators of healthy and/or deciduous vegetation, while lighter shades characterize grassy or sparse / shrubby vegetation. This combination is very popular and is used to study the condition of vegetation, soil monitoring, as well as to study crops.</p>
<i>NIR, Red, Green</i>		
		

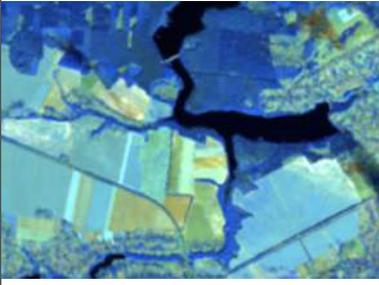
Annex 4 (continued)

B07, B04, B02	B07, B05, B03	<p>This combination produces an image close to true colors, but at the same time enables us to analyze the atmosphere condition and smoke. Healthy vegetation looks bright green, grass – green, bright pink areas indicate open ground, brown and orange tones are characteristic of sparse vegetation. Dry vegetation looks orange, the water – blue. This combination gives an excellent result in the analysis of deserts and desert areas. In addition, it can be used to study agricultural lands and wetlands. This combination is used to study the dynamics of fires and post-fire analysis of the territory. The burned areas will look bright red.</p>
<p><i>SWIR-2, NIR, Green</i></p>		
		<p>Healthy vegetation appears in the shades of red, brown, orange and green. Soils can look green or brown, urban areas – whitish, gray and green-blue, recently cut areas may appear bright blue, and restoration of vegetation or sparse vegetation may look reddish. Adding a middle infrared band enables to distinguish well the age of vegetation.</p>
B04, B05, B01	B05, B06, B02	
<p><i>NIR, SWIR-1, Blue</i></p>		
		

Annex 4 (continued)

B04, B05, B03	B05, B06, B04	<p>This combination of the near, middle infrared bands and the red visible band enables us to clearly distinguish the boundary between water and land. Vegetation is depicted in different shades and tones of brown, green and orange. This combination allows us to analyze the moisture in the study of soils and vegetation. In general, the higher the soil moisture, the darker it will look, due to the absorption of water by IR radiation.</p>
<i>NIR, SWIR-1, Red</i>		
		
B07, B05, B03	B07, B06, B04	<p>This combination produces an image close to natural colors, however at the same time allows us to analyze the atmosphere condition and smoke. Vegetation is depicted in shades of dark and light green, urban areas look white, green-blue and crimson; soil, sand and minerals can be depicted in very different colors. Almost complete absorption in the middle IR range by water, snow and ice allows us to distinguish very clearly the shoreline and very clearly highlight bodies in the image. Hot spots (such as volcanic craters and fires) look red or yellow. One of the possible applications of this combination of bands is fire monitoring.</p>
<i>SWIR-2, SWIR-1, Red</i>		
		

End of Annex 4

B05, B04, B03	B06, B05, B04	<p>Similar to combination 4-5-1, this combination provides a lot of information and color contrasts. Healthy vegetation looks bright green, and the soil is pinkish-purple. Unlike 7-4-2, which includes 7 bands and allows us to study geological processes, this combination enables us to analyze agricultural lands. It is very convenient for studying vegetation and is widely used to analyze the condition of forest communities.</p>
<i>SWIR-1, NIR, Red</i>		
		
B07, B05, B04	B07, B06, B05	<p>This combination does not include any band in the visible range and provides optimal analysis of the atmosphere. The coastlines are clearly visible. It can be used to analyze the texture and moisture of soils. Vegetation looks blue</p>
<i>SWIR-2, SWIR-1, NIR</i>		
		

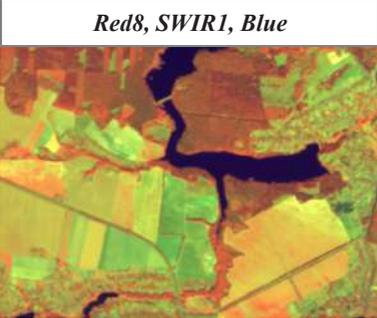
The most common Band combinations for Sentinel 2a

Sentinel 2a combination	Information
Natural colors B04, B03, B02	<p>A combination of “true colors”. Since this combination uses visible bands, terrestrial objects are displayed in colors which are customary for a human eye: healthy vegetation is green, freshly cleared fields are light, unhealthy vegetation is brown and yellow, roads are gray, and the shoreline is white. However, water bodies here will be too dark due to insufficient passage of blue color through the atmosphere, and you can analyze their condition and assess their depth based on color intensity. This combination is also used to study anthropogenic objects.</p>
<i>Red, Green, Blue</i>	
	
Artificial colors (vegetation) B08, B04, B03	<p>A combination of “artificial colors”. Vegetation is depicted in shades of red, urban development – blue, and the soil varies from dark to light brown. Ice, snow and clouds are white or light blue. This is a very popular combination of bands, which is useful for studying vegetation, monitoring soils and different stages of crop growth. Typically, deep shades of red indicate deciduous and healthier vegetation, while lighter shades of red indicate meadows or areas with sparse vegetation. This combination gives results similar to those obtained through the infrared aerial survey.</p>
<i>NIR, Red, Green</i>	
	

Annex 5 (continued)

<p>Agro B11, B8A, B02</p>	<p>This combination is useful for crop monitoring. Bright green color represents energetic, healthy vegetation. Coniferous forests look dark green, and deciduous – bright green. Areas with sparse vegetation and bare areas are displayed in brown and purple.</p>
<p><i>SWIR1, Red8, Blue</i></p>	
	<p>This combination also provides a “natural” image. Vegetation is reflected in shades of dark and light green during the growing season, urban development – white, gray, blue or purple. Virtually complete absorption of medium infrared bands in water, ice and snow provides well-defined shorelines. Snow and ice are blue, and waters are black or dark blue. Hot surfaces, such as forest fires and volcanic craters, saturate the mid-infrared bands and appear in shades of red or yellow. This combination is, among others, used for forest fires monitoring.</p>
<p>Artificial colors (urbo) B12, B11, B04</p>	
<p><i>SWIR2, SWIR1, Red</i></p>	<p>This combination is, among others, used for forest fires monitoring.</p>
	

Annex 5 (continued)

Land/water: B8A, B11, B04	<p>This combination of bands is suitable for displaying lands and waters. The ground is depicted in shades of orange and green, ice – in bright purple, and water – in shades of blue.</p>
<p><i>Red8, SWIR1, Red</i></p>	
	<p>Healthy vegetation is depicted in shades of red, brown, orange and yellow. Soils can be green and brown, urban developments – white, blue and gray, reddish areas represent new vegetation, probably sparse meadows. Pure deep water in this combination will be very dark. If the waters are shallow or contain sediments, they will look like shades of light blue. This is not a good combination for studying man-made features, such as roads or runways.</p>
<p>Healthy vegetation: B8A, B11, B02</p>	
<p><i>Red8, SWIR1, Blue</i></p>	
	

Annex 5 (continued)

<p>Vegetation analysis B11, B8A, B04</p>	<p>This combination provides a user with big volumes of information and color contrasts. Healthy vegetation is bright green, and soils are purple. It is useful for studying vegetation and is widely used in forestry to identify areas of insect-infested trees.</p>
<p><i>SWIR1, Red8, Red</i></p> 	
<p>Shortwave infrared B12, B8A, B04</p>	<p>This combination of bands is very useful for vegetation research, because here the reflectivity in SWIR depends on the moisture content in leaves or soil. Thus, healthy vegetation with high moisture content, as well as coastal areas are reflected in bright green, while arid areas in dark green. The coniferous forest is deep green, and the deciduous forest is bright green. The soil looks brown and purple. This combination of bands is suitable for studying the vegetation condition, detecting soil disturbances, soil type, etc.</p>
<p><i>SWIR2, Red8, Red</i></p> 	

Annex 5 (continued)

<p>Elimination of atmospheric influences B12, B8A, B03</p>	
<p><i>SWIR2, Red8, Green</i></p>	
	<p>This combination provides a “true colors” reproduction. Healthy vegetation will be bright green, its color intensity may be changed during different growing seasons. Meadows are green, barren soils are depicted as pink areas. Dry vegetation will be orange and water will be blue. This combination of bands provides vivid images of desert areas. The combination is useful for geological, agricultural and wetland research. The fire looks red in the images, and this combination is used to control fires and analyze burned forest areas. Urban buildings are displayed in different shades of purple. Meadows look light green. Light green spots in the city indicate the grassy vegetation of parks, cemeteries, and golf courses. Olive-green or bright green shades usually indicate areas covered with coniferous forest, and dark green mas-sifs – deciduous forest.</p>

End of Annex 5

Snow / Clouds B02, B11, B12	<p>This combination is good for detecting snow and ice because they are reflected in the visible part of the spectrum and highly absorbed in the shortwave infrared range. Snow and ice look bright red. The more ice, the stronger the absorption in SWIR and the more saturated the red color. Thick ice and snow are depicted in bright red (or red-orange). The vegetation will look greenish in this combination. Bare soil will look bright blue. The water will be very dark as it absorbs red and SWIR, but small drops of sparse water in the clouds scatter light equally in both the visible and SWIR ranges and will therefore appear white.</p>
<i>Blue, SWIR1, SWIR2</i>	
	

The most common spectral indices

<p>NDVI Sentinel 2 (B8A-B04) / (B8A+B04)</p> <p>NDVI Landsat 8 (B5-B4)/(B5+B4)</p>	<p>The normalized differential vegetation index is often used for drought monitoring, agricultural production, etc. NDVI is a standardized vegetation index that allows us to generate images showing relative biomass. The absorption of chlorophyll in the red band and the relatively high reflectivity of vegetation in the near infrared band (NIR) are used to calculate NDVI.</p>
<p>ARVI Sentinel 2 (B08-(B04-1*(B02-B04))) / (B08+(B04-1*(B02-B04)))</p> <p>ARVI Landsat 8 (B5-(B4-1*(B2-B4))) / (B5+(B4-1*(B2-B4)))</p>	<p>The vegetation index is resistant to atmospheric influences. This is an improved NDVI, which is used to correct the atmospheric influences. It is mostly useful in regions with a high content of atmospheric aerosol, including in tropical areas contaminated with soot. Users apply it with NDVI.</p>
<p>EVI Sentinel 2 2.5*((B8A-B04) / ((B8A+6*B04-7.5*B02)+1))</p> <p>EVI Landsat 8 2.5*((B5-B4) / ((B5+6*B4-7.5*B2)+1))</p>	<p>The Extended Vegetation Index EVI is an “optimized” vegetation index designed to enhance the signal of vegetation with improved sensitivity in regions with high biomass and improved vegetation monitoring by reducing atmospheric exposure.</p>
<p>SIPI Sentinel 2 (B08-B02) / (B08-B04)</p> <p>SIPI Landsat 8 (B5-B2) / (B5-B4)</p>	<p>SIPI enables us to determine the initial stage of plant disease. It is analyzed together with NDVI. SIPI is a good indicator for use in areas with high variability in vegetation structure.</p>
<p>NBR Sentinel 2 (B8A-B12) / (B8A+B12)</p> <p>NBR Landsat 8 (B5-B7) / (B5+B7)</p>	<p>The standardized NBR combustion index uses NIR and SWIR bands to highlight burnt areas, attenuating differences in lighting and weather conditions. Before using this index, your images must be adjusted for reflection values.</p>

<p>NDWI Sentinel 2 (B03-B08) / (B03+B08) NDWI Landsat 8 (B3-B5) / (B3+B5)</p>	<p>The NDWI Normalized Difference Water Index uses reflected near-infrared radiation and visible green light to enhance the presence of such elements, excluding the presence of soil and terrestrial vegetation elements. NDWI allows researchers to estimate the turbidity of water bodies with the help of satellite images.</p>
<p>Index Stack Sentinel 2 (B03-B11) / (B03+B11), (B8A-B04) / (B8A+B04), (B03-B08) / (B03+B08) INDEX STACK Landsat 8 (B3-B6) / (B3+B6), (B5-B4) / (B5+B4), (B3-B5) / (B3+B5)</p>	<p>In this index, the images are changing, and certain colors can be equated to different elements of the landscape. For example, the vegetation here turns green, the water turns purple, the snow/ice turns purple, and the soil, rocks, and barren land turn blue.</p>
<p>NDSI Sentinel 2 (B03-B11) / (B03+B11) NDSI Landsat 8 (B3-B6) / (B3+B6)</p>	<p>The Normalized Difference Snow Index (NDSI) is a spectral band ratio that uses the spectral differences of snow in the shortwave infrared and visible spectral ranges to identify snow compared to other features in the scene. At visible wavelengths, the snow cover is as bright as clouds, and therefore difficult to be distinguish from the cloud cover. However, at a wavelength of 1.6 microns, the snow cover absorbs sunlight, and therefore has a much darker view than clouds. This allows us to effectively distinguish between snow cover and clouds. Values of NDSI “> 0.4” usually indicate the presence of snow.</p>

**List of Satellite Images Used for Tasks Performance
in this Guidance Manual****Section I**

Landsat 5 satellite images capturing the territory of Kyiv as of April 7, 1984 and Sentinel 2 as of September 10, 2019.

Sentinel 2 satellite images capturing the territory of Kyiv as of October 4, 2015 with tile numbers 36UUB and 36UUA.

Section II

Sentinel 2 satellite images capturing the Fastivske Forestry Enterprise territory as of October 4, 2015 and September 10, 2019.

Sentinel 2 satellite images capturing the Kyiv Cistern territory as of August 6 and 9, 2016.

Sentinel 2 satellite images capturing the the Baryshivskiyi District of Kyiv Oblast territory as of April 18, 2018 and May 23, 2018 of.

Seven Sentinel 5P images capturing the territory of Ukraine for the period from September 1 to September 7, 2019 showing NO₂ and SO₂ concentration.



You can use this QR code to download all the satellite images used by us for Tasks performance in this Guidance Manual.

Навчальне видання

Довгий Станіслав Олексійович
Бабійчук Світлана Миколаївна
Кучма Тетяна Леонідівна
Томченко Ольга Володимирівна
Юрків Лілія Ярославівна

**ДИСТАНЦІЙНЕ ЗОНДУВАННЯ ЗЕМЛІ:
АНАЛІЗ КОСМІЧНИХ ЗНІМКІВ
У ГЕОІНФОРМАЦІЙНИХ СИСТЕМАХ**

Навчально-методичний посібник

Редагування: *І. В. Браташук*
Дизайн і верстання: *О. А. Жупанська*

Формат 60x84 1/16. Папір офс. 80 г/м².
Друк цифровий. Ум. друк. арк. 15,34.
Наклад 300 прим.

Видавництво: Національний центр «Мала академія наук України»,
Кловський узвіз, буд. 8, м. Київ, 01021

Свідоцтво суб'єкта видавничої справи:
ДК № 6999 від 04.12.2019

Навчально-методичний посібник містить відомості про можливості застосування геоінформаційних систем та дистанційного зондування Землі у процесі дослідження; описує основні характеристики і ресурси для завантаження супутникових знімків; наводить приклади візуалізації та попереднього опрацювання каналів супутникового знімка в геоінформаційних системах ArcGIS та QGIS. Також у посібнику представлено інформацію про процес інтерпретації (дешифрування) та аналізу супутникових знімків у геоінформаційних системах.

Посібник може використовуватися методистами і педагогами Малої академії наук України, викладачами і студентами закладів вищої освіти, вчителями й учнями, які здобувають освіту наукового спрямування в закладах спеціалізованої освіти наукового профілю, а також усіма, хто прагне самостійно опанувати основи дистанційного зондування Землі та геоінформаційних систем.

