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# GIS in Mineral Resource Management

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In two parts
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The electronic educational and methodological complex (EEMC) part 2 is intended for undergraduates studying in the specialty 1-31 80 02 “Geography” and it could be useful as well for the specialty 7-06 0532 01 “Geography”. The content of the EEMC involves increasing the efficiency of managing the educational process and independent work of undergraduates in mastering the academic discipline “GIS in Mineral Resource Management” through the introduction of innovative educational technologies into the educational process, ensuring high-quality training of highly qualified geographers.

ОГЛАВЛЕНИЕ

EXPLANATORY NOTE ........................................................................ 4
1. THEORETICAL SECTION ........................................................................ 6
1.1. Introduction ........................................................................ 6
1.2. Structure and content of the “GIS in Mineral Resource Management” ................ 7
1.3. QGIS Introduction and Definitions ........................................................................ 8
1.7.1. Main characteristics of QGIS ........................................................................ 9
1.7.2. Brief comparison between QGIS and ArcGIS ................................................ 17
2. PRACTICAL SECTION ........................................................................ 18
2.1. Laboratory work 1. QGIS basic techniques ........................................................ 18
2.1. Laboratory work 2. Geographical linking of raster in QGIS .............................. 38
2.3. Laboratory work 3. Creating a point layer from text data in QGIS. Heat maps 49
2.4. Laboratory work 4. Creating a tourist map in QGIS ........................................... 60
2.5. Laboratory work 5. Receiving basic spatial characteristics of objects in QGIS . 81
2.6. Laboratory work 6. Joining tables in QGIS ........................................................ 93
2.7. Laboratory work 7. Search the shortest route with road graph for QGIS.......... 110
2.8. Laboratory work 8. Construction and analysis of a digital relief model ........... 117
2.9. Laboratory work 9. Getting started in GRASS GIS via QGIS GUI .................. 130
3. KNOWLEDGE CONTROL SECTION ............................................................ 146
3.1. Questions for the discipline exam ...................................................................... 146
3.2. Abstract topics ........................................................................ 148
3.3. Organization of independent work ..................................................................... 149
4. AUXILIARY SECTION ........................................................................ 151
4.1. Educational and methodological map for the academic discipline.................... 151
4.2. Recommended reading ........................................................................ 153
4.3. Electronic Resources ........................................................................ 156

## EXPLANATORY NOTE

The electronic educational and methodological complex (EEMC) "GIS in Mineral Resource Management" is designed to implement the requirements of educational programs, educational standards and training in the specialty 7-06 0532 01 "Geography". It could be useful also for the specialty 1-31 80 02 "Geography". Its presence provides the stability of the quality of the educational process and is a methodological basis for ensuring effective independent work of undergraduates. The total course consists of 126 hours, which includes 52 classroom hours; lectures – 8 hours, laboratory classes – 12 hours, curricular control of managed independent work – 32 hours, tests at the end of the course with an exam – 3 hours.

The EEMC compiled in two parts. Part1 includes a description of the following software packages: GMT [ ], Oasis montaj, Surfer, Introduction to ArcGIS, and Strater. The part 2 includes mainly the description of laboratory works (tests) proposed to students and compiled for the QGIS-3 release.

The EEMC for the discipline "GIS in Mineral Resource Management" was created at the scientific-methodological and software-technical levels corresponding to modern information and communication technologies and is designed to ensure the implementation of educational goals and objectives at all stages of the educational process in this discipline.

Its purpose is to implement requirements of the educational standard and curriculum, ensuring the continuity and completeness of the learning process, systematization and control of knowledge in the discipline "GIS in Mineral Resource Management".

The goal of the EEMC is to increase the efficiency of managing the educational process and the independent work of undergraduates in mastering the academic discipline "GIS in Mineral Resource Management" by introducing innovative educational technologies into the educational process, ensuring high-quality training of highly qualified specialists.

Scope of application is for distance learning, conducting classes on the subject "GIS in Mineral Resource Management", during independent preparation for classroom lessons, current and final control of knowledge in sections of the discipline, orientation in performing controlled independent work.

The functionality of the EEMC are the means of orientation in the content of the discipline "GIS in Mineral Resource Management" and the order of studying educational material, mastering theoretical and practical material, preparing for knowledge control. All EEMC material is structured into parts in such a way that a master's student can master knowledge on the specified subject independently. EEMC on "GIS in Mineral Resource Management" includes four main sections: theoretical, practical, knowledge control and auxiliary ones. The part 2 includes 9 laboratory works using the QGIS-3 release.

The theoretical section of the EEMC contains lecture notes for the theoretical study of the academic discipline (part 1), based on lecture notes for the course “GIS in Mineral Resource Management” [electronic resource] / BSU The Electronic Library of BSU.

The knowledge control section of the EEMC contains materials for knowledge control and certification, which make it possible to determine the compliance of the results of students’ educational activities with the requirements of the educational standard and educational program documentation for the specialty. This section includes options for test tasks, questions for the exam, a list of tasks and measures for controlled independent work.

The auxiliary section of the EEMC contains training programs on “GIS in Mineral Resource Management”, a list of information and analytical materials [electronic resource] / BSU Electronic Library. – Access mode: https://elib.bsu.by/handle/123456789/213996 – Access date: 09.09.2024.

The EEMC on “GIS in Mineral Resource Management” is intended for teachers, students, graduate students, undergraduates studying geological and geographical sciences.

The EEMC "GIS in Mineral Resource Management" reveals the methodological foundations for organizing geological exploration for minerals, obtaining source materials and their theoretical processing.

The subject “GIS in Mineral Resource Management” reveals research methods and the general theory of the occurrence of geological and geodynamic processes in the study area. The methodological foundations of regional geology and geodynamics, applied and fundamental problems of the placement and use of mineral resources are considered.

All laboratory works, considered below were tested with the QGIS release 3.34.6. The package QGIS is freely available to download in Internet. It was released under the terms of the GNU General Public License (GPL). It means that the software is free and freely adaptable. Several times a year new releases of it become available. Most releases were developed to install under several platforms including Windows.

The algorithm and source data (shape files, Excel data, test maps, etc. were used from [11] with minor modification or some additions.

# 1. THEORETICAL SECTION

*LECTURE NOTES*

## 1.1. Introduction

Geological exploration of various types of mineral raw materials requires sufficient knowledge about the geological evolution of regions, the causes and features of geological processes, the conditions for the formation of various minerals in the bowels of the Earth in all its shells in the context of the development of our planet over time. This science actually studies both random and systemic geological processes and their manifestations.

Minerals provide the material used to make most of the things of industrial-based society, for instance, roads, cars, computers, fertilizers, etc. [1 – 9]. Demand for minerals is increasing worldwide as the population increases and the consumption demands of individual people. The mining of Earth's natural resources is, therefore accelerating, and it has accompanying environmental consequences. The development of industrial production steadily requires the expansion of the mineral resource base in all regions of the world.

A mineral is a pure inorganic substance that occurs naturally in the Earth's crust. All of the Earth's crust, except the rather small proportion of it that contains organic material, is made up of minerals; they originate in the process of geologic evolution and transformations of rocks. Main types of them are igneous, sedimentary and metamorphic rocks. Some minerals consist of a single element such as gold, silver, diamond (carbon), and Sulphur.

More than two-thousand minerals have been identified and most of these contain inorganic compounds formed by various combinations of the eight elements (O, Si, Al, Fe, Ca, Na, K, and Mg) that make up 98.5% of the Earth's crust. The industry depends on about 80 of the known minerals. Sometimes hydrocarbons and water ice also are considered as minerals.

A mineral deposit is a concentration of naturally occurring solid, liquid, or gaseous material, in or on the Earth's crust in such form and amount that its extraction and its conversion into useful materials or items are profitable now or may be so in the future. Mineral resources in most cases are non-renewable and include metals (e.g. iron, copper, and aluminum), and non-metals (e.g. salt, gypsum, clay, sand, phosphates).

Minerals are valuable natural resources being finite and non-renewable. They constitute the vital raw materials for many basic industries and are a major resource for development. Management of mineral resources has, therefore, to be closely integrated with the overall strategy of development; and exploitation of minerals to be guided by long-term national goals and perspectives.

There are three main groups of minerals: metallic, non-metallic and energy ones. In turn, metallic minerals are divided into ferrous (iron ores, manganese, nickel, cobalt, etc.), non-ferrous (copper, lead, tin, bauxite, etc.), precious (gold, silver, platinum, etc.). Mica, salt, potash, Sulphur, granite, limestone, marble, sandstone, etc. comprise the non-metallic group. Coal, petroleum, natural gas belong to energy minerals. Some minerals, like gold and diamond, are rare and precious, while others, like quartz, are more ordinary.

Minerals grouped also by their chemical composition. Silicates, oxides, sulfates, sulfides, carbonates, native elements, and halides are all major mineral groups. Many minerals play important role for industry.

Different types of mineral resources require using of different methodological techniques for conducting geological exploration, as well as different methods for their development and obtaining the final mineral. For example, excavators and large trucks are necessary to extract coal after stripping operations in quarries. In contrast, seismic surveys are required to identify potential traps for hydrocarbon accumulations, and deep wells are required to extract such minerals. Special dredges usually used to extract gold from placers in alluvial deposits of river valleys, etc.

In each specific case, a lot of specialized software has been developed for computer processing and analysis of the received data. For instance, for oil exploration and recovery they are “Petrel”, “FieldPro” and others”. The “NETPROMine“ mining and geological software, covering a number of modules: Geology, Open Pit Mining and Underground Mining are used to model processes estimate of resources and creating of quarries for extraction of solid mineral resources, etc. However, the geographic information systems (GIS software) along with this, other software resources are widely used in the practice for prospecting and exploration of mineral deposits for mapping, statistical data processing, constructing maps, profiles and sections. It depends on the kind of mineral resource, on their occurrence and the extraction technology, on assessing recoverable mineral reserves, etc.

This guide “GIS in Mineral Resource Management” is based on processing the latest data on practical and theoretical components of research methods (discussed in both parts), general and specific issues of an application of the GIS software. In particular spatial systems that creates, manages, analyzes, and map all types of data for the sphere of mineral resources, their geological exploration, mapping resource deposits, methods of their development and relater tasks.

## 1.2. Structure and content of the “GIS in Mineral Resource Management”

There are several program packages frequently used in practice: ArcGIS, QGIS, Oasis Montaj [16], MapInfo, Adobe Illustrator, Generic Mapping Tools

(GMT), Surfer [17, 18], Corel Draw, Grapher, NETPROMine, etc. The packages GMT and QGIS are freely available in Internet. They are the fast-growing open source geographic information systems and released under terms of the GNU General Public License (GPL). It means that they are free to download and freely adaptable. Several times a year new releases of them become available. Some of them can be installed under several platforms. For instance, QGIS [11] and GMT [10] are available free for installation under Windows, macOS, Linux, FreeBSD, and Cygwin (a Unix-formatted operating system). The Cygwin can coexist with Windows on a personal computer or laptop. Other software products are commercial ones.

The course “GIS in Mineral Resource Management” consists of sections covering the following issues:

1. Mineral Resources: Definition, Types, Use and Exploitation (part 1)
2. Main GIS software used for development and analysis in Mineral Resource Management (parts 1)
3. Generic Mapping Tools (GMT) Introduction and Definitions (part 1)
4. Golden Surfer [19, 20] (part 1)
5. Oasis montaj (part 1)
6. Laboratory tests based on GMT (part 1)
7. QGIS Introduction and Definitions (part 2)
8. Laboratory tests based on QGIS (part 2)

### 1.3. QGIS Introduction and Definitions

QGIS is a powerful, full-featured GIS widely used in the scientific field [12, 13]. It allows you to create professional-quality graphics. QGIS is one of the fastest growing open source geographic information systems. QGIS is released under the terms of the GNU General Public License (GPL). It means that it is free to download and freely adaptable. Several times a year new releases of QGIS become available.

This tutorial provides the information on the QGIS software package and instructions for performing basic operations in QGIS. Developers periodically upload to their server new versions with enlarged capabilities. The latest basic release (as for January 2024) is QGIS 3.36 (e.g., its setup file for QGIS-OSGeo4W-3.36.3 has 1.2 GBytes). We will consider it capabilities using one of its simpler stable releases QGIS 3.34 Prizren as an example. Its distribution is available free at the URL: http://www.qgis.org/ru/site/forusers/download.html (file QGIS-OSGeo4W-3.34.6.msi -Setup-x86 which is only 1 240 260 MBytes) or from any nearest site, e.g. https://qgis.org/ru/site/forusers/download.html. It is less sophisticated and provides the familiarization with main elements of the QGIS interface when working with shape files, loading vector data into the project, visualization and study of spatial data in the QGIS. The installation runs smoothly and no additional alignments are necessary.

Laboratory works [11] aimed at studying the interface and basic capabilities of the QGIS [12], performing georeferencing of raster images, creating and editing vector objects and their attributes, building surfaces, conducting vector and raster GIS analysis, and creating map layouts using GIS tools will be considered in the practical section below.

### 1.7.1. Main characteristics of QGIS

QGIS uses spatial data to compile maps. Each piece of data will also contain non-spatial data known as attribute data. Attribute data is generally defined as additional information about a spatial feature, for example, a government building. The actual location of the government building is the spatial data. The attribute data includes the building name, the number of floors in the building, the government departments that use the building, when it was built, etc. QGIS includes a number of layers having different information, fig. 1.

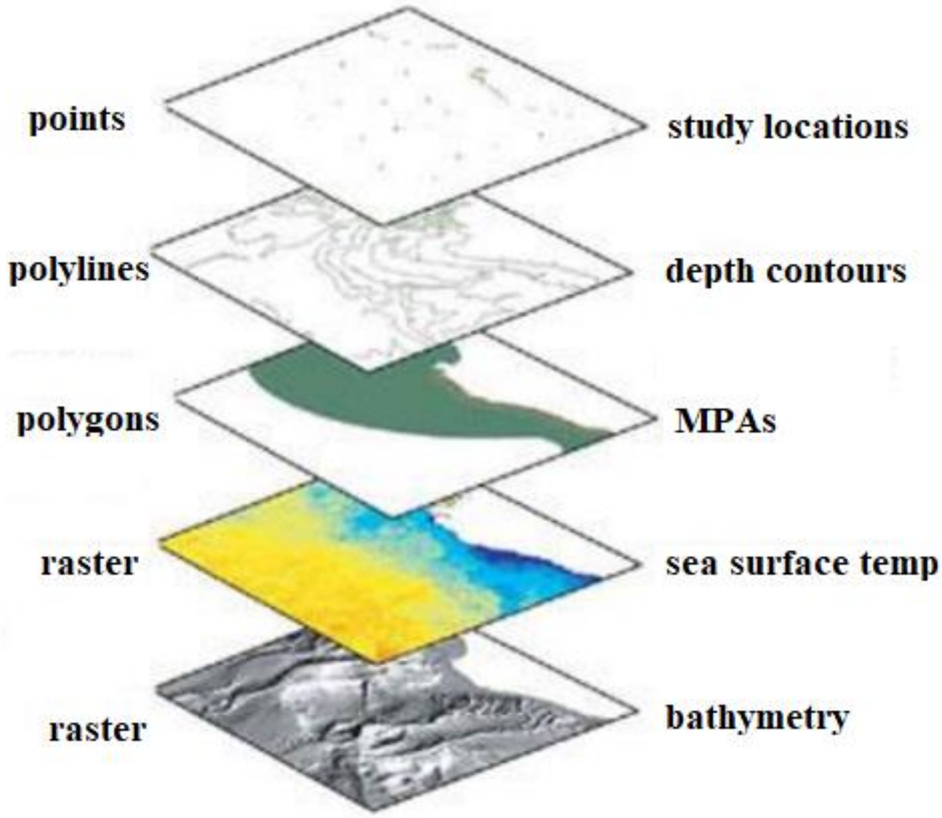



Figure 1. – Different layers of the same area [13, modified]

***A Vector layer***. A representation of the world using points, lines, and polygons. Vector layers are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets, fig. 2.

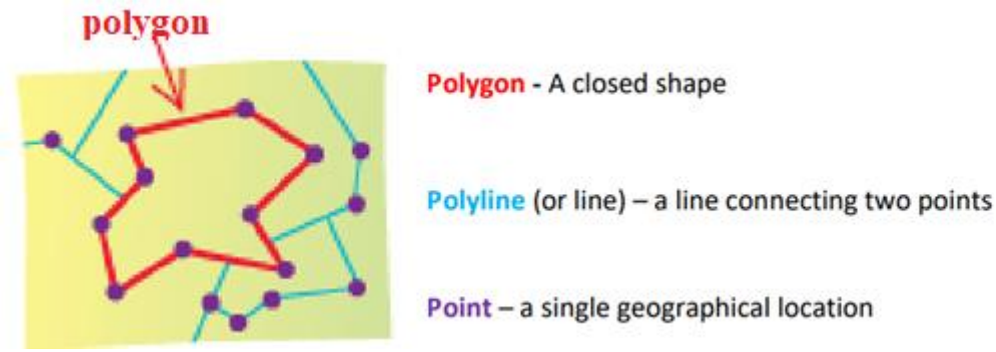



Figure 2 – Points, lines and polygons [13]

**Raster layers**. A spatial data layer that is in the form of an image with pixels. The image is made up of equally sized pixels (or cells) arranged in rows and columns, fig. 3. Each pixel contains an attribute value and location coordinates. Groups of cells that share the same value represent the same type of geographic feature, fig. 4.

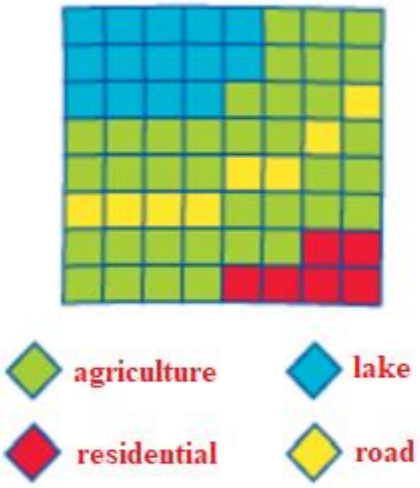



Figure 3 – A raster grid [13, modified

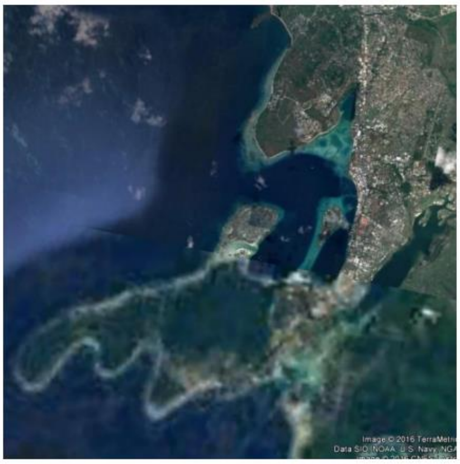


Figure 4. – Areal image (raster), Port Vila, Vanuatu [13]

Main terminology used [13]:

*Attribute*. An information about a spatial feature. For example, attributes about a school may include the name, level of education, and number of students.

*Coordinate system*. A coordinate system is a reference system used to represent the locations of geographic features, imagery, and observations such as GPS locations within a common geographic framework.

*Scale.* A level of resolution or zoom. The relationship between the size of the map and the corresponding size of the real world.

*Shape file* (*.shp). A type of vector data storage format for storing the location, shape, and attributes of geographic features. Each shape file relates to a specific feature class i.e. the Roads shape file only contains information on roads.

*Symbology*. Conventions or rules that define how geographic features are represented by symbols on a map.

*Query*. In GIS, a request to select features or records from an attributes table based on user-selected criteria to display only those features or records that meet the criteria.

Quantum GIS project started in 2002. Now QGIS is free and open source Geographic Information System (GIS) application that allows users to create spatial datasets, manage, analyze and display them on a map or another plot. It comes with the right to download, run, copy, alter, and redistribute the software. It is multi-platform and can run in Windows, OSX, UNIX and UNIX-compatible operational systems, such as Linux, Cygwin and others. It is extendable, many of its functionalities are provided by plugins and scripts.

It permits:

• Adding Vector and Raster layers
• Adding tabular information as a Delimited text Layer
• Symbolizing vector data
• Symbolizing raster data
• Installing plugins
• Querying data
• Joining tables
• Introduction to the Processing toolbox
• Map Layouts

The QGIS interface shown in fig. 5.

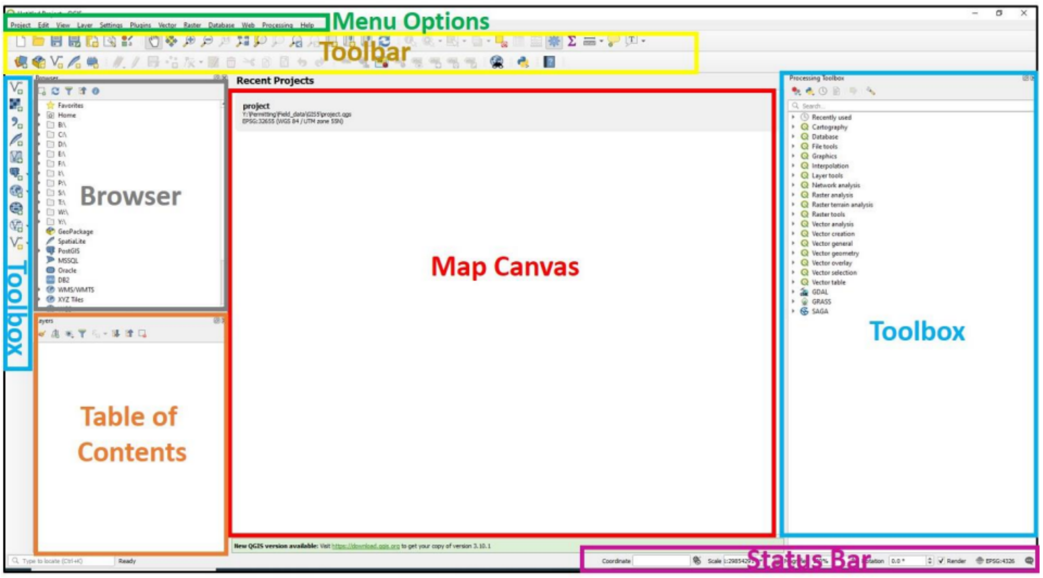



Figure 5. – The QGIS interface [13]

Some panels could be rearranged to better suite you need. For example, the QGIS interface for the release 2.18 could look like this, fig. 6:

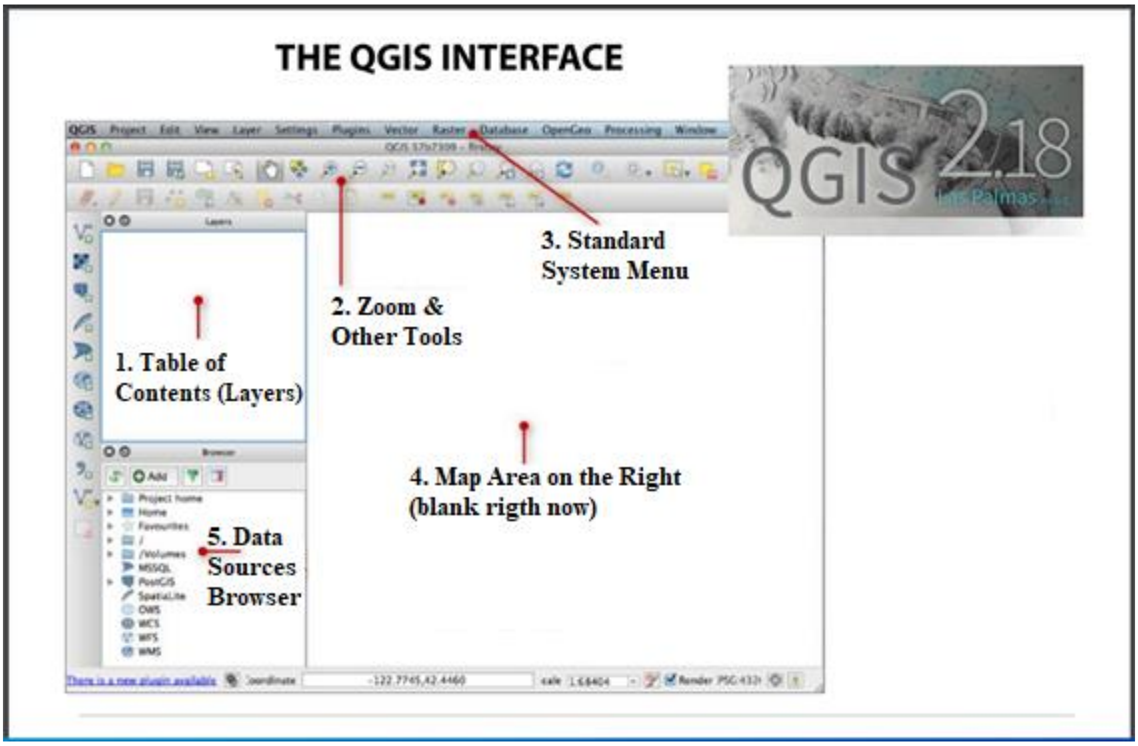



Figure 6. – The QGIS interface [12]

Typically, the QGIS work area has seven parts;

- Menu Options
- Toolbar

• Map Canvas
• Browser
• Table of Contents
• Tool Box
• Status Bar

***Menu Options,*** fig. 1.7


Figure 7. – Menu Options [13]

The Menu Options bar provides access to various QGIS features using a standard hierarchical menu (drop down menu). Most menu options have a corresponding tool in the Toolbar, fig 8 and Tool Box; however, the menus are not organized exactly like the toolbars and may contain additional tools.

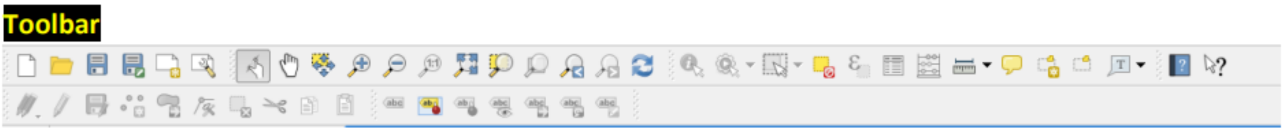



Figure 8. – Toolbar

The ***Toolbar*** provides an access to most of the functions found in the menu options bar, plus additional tools for interacting with the map canvas. Each Toolbar item has pop-up help available. Hold your mouse over an item and a short description of the tool's purpose will be displayed.

Below is a view of the Managing Layers Toolbar, fig. 9.

Figure 9. – Managing Layers toolbar [13]

The Managing Layers Toolbar contains frequently used tools relating to GIS layers. The two symbols circled in red represent the 'add vector layer' tool and the 'add raster layer' tool, which will be most commonly used to bring data into the QGIS document.

Parts of the Toolbar can be moved around according to your needs. Additionally, parts of the Toolbar can be switched on/off. Hold the mouse over a blank spot on the Toolbar and click the right mouse button to see the context menu, which allows you to turn on/off tools.

If you have accidentally hidden all your Toolbars, you can get them back by choosing Menu Options – View – Toolbars

***Map Canvas.*** The Map Canvas is the main part of QGIS – this is where the maps are displayed. The map displayed in the window will depend on the vector and raster layers you have chosen to load. The Map Canvas can be panned, shifting the focus of the display to another part of the map. The map can also be zoomed in and out. Various other operations can be performed on the map using the Toolbar. The Map Canvas and the Table of Contents are tightly bound to each other – the maps in Map Canvas reflect changes you make in the Table of Contents area.

Zooming the Map with the Mouse Wheel. You can use the mouse wheel to zoom in and out on the map. Place the mouse cursor inside the map area and roll the wheel forward (away from you) to zoom in and backwards (towards you) to zoom out. The zoom is centered on the mouse cursor position.

***Table of Contents***. The Table of Contents area lists all the layers in your map project. Click on a check box to turn a layer on or off. Double click on a layer in the legend to customize its appearance and set other properties (e.g. appearance of symbols, labels). A layer can be selected and dragged up or down in the Table of Contents to change the Z-ordering, which means that layers listed nearer the top of the Table of Contents are drawn over layers, listed lower down in the Table of Contents.

***Tool Box***, fig. 10.

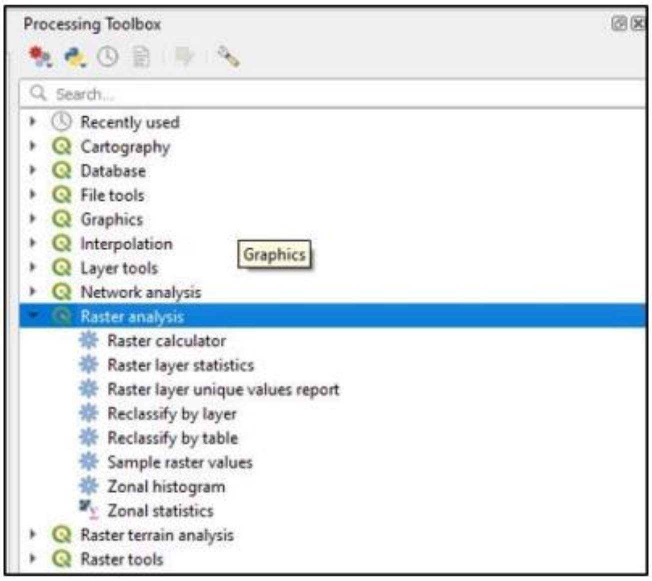



Figure 10. – Processing Toolbox [13]

The Processing Toolbox, which contains geoprocessing tools, used for creation and analysis of both vector and raster data. As mentioned before, some of these tools will also be available in the Menu Options as well.

***Status Bar.*** The Status Bar shows you the current position of the mouse pointer in map 

coordinates (expressed as decimal degrees or meters) as well as the map scale and coordinate system. As you move the mouse pointer across the map view, the coordinates will change. As you zoom in and out of the map, the scale will change.

**Adding Vector Datasets in QGIS**. To start working with a map, we need load source data. Vector data is arguably the most common kind of GIS data. It describes geographic data in terms of points, which may be connected into lines and polygons. Every object in a vector dataset is called a ***feature***, and is associated with data that describes that feature. The raster data are also used when constructing QGIS maps.

QGIS can support a number of different vector data formats. These include ESRI Shape files and MapInfo TAB files, all of which can be used in QGIS in their current formats. We will mostly be using ESRI Shape files in QGIS tests below.

**Map projections**

*Geographic Coordinate Systems* [11]

• Defines locations on spherical model of the Earth

*Projected Coordinate System*

• Defines locations on flat model of the earth, fig. 11.

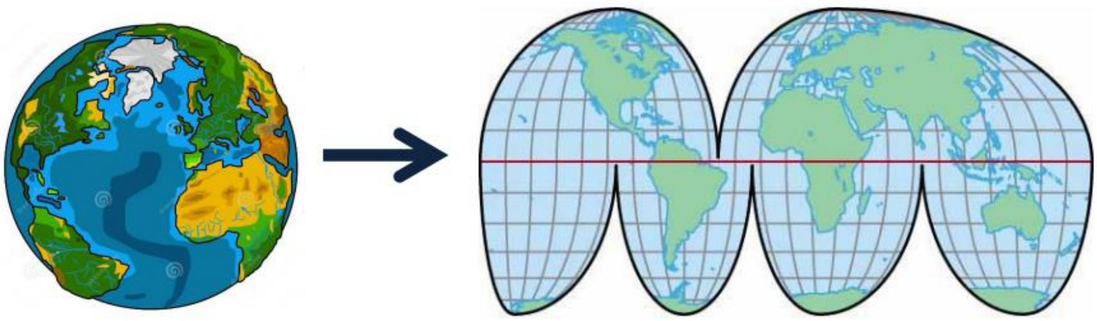


Figure 11. – Geographic and projected coordinate systems in QGIS [12]

Projected Coordinate System is shown below and can be easily changed, figs. 12 – 14 [12].

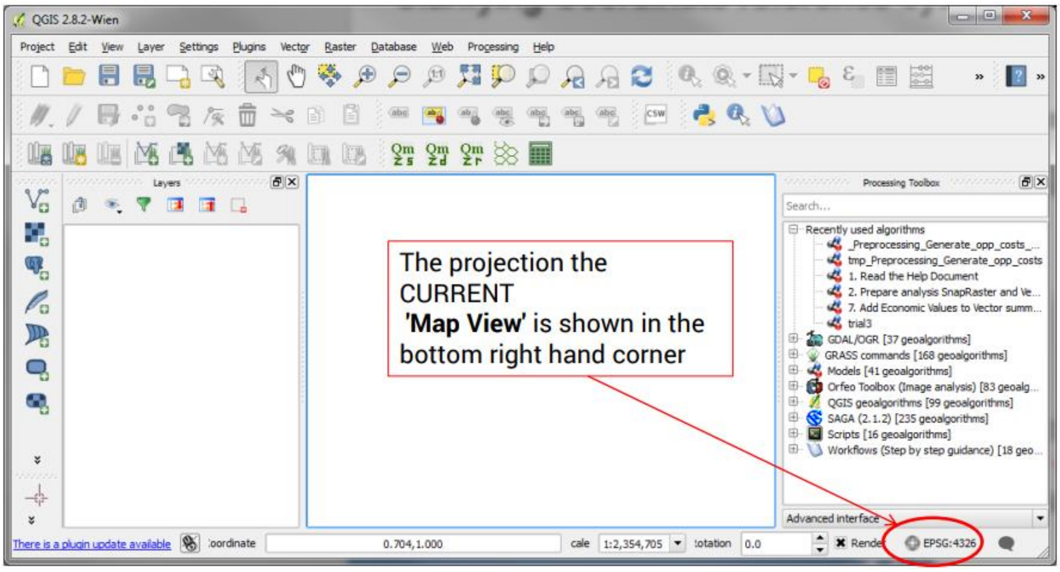



Figure 12. – Changing the projection of the QGIS Map View (step 1)

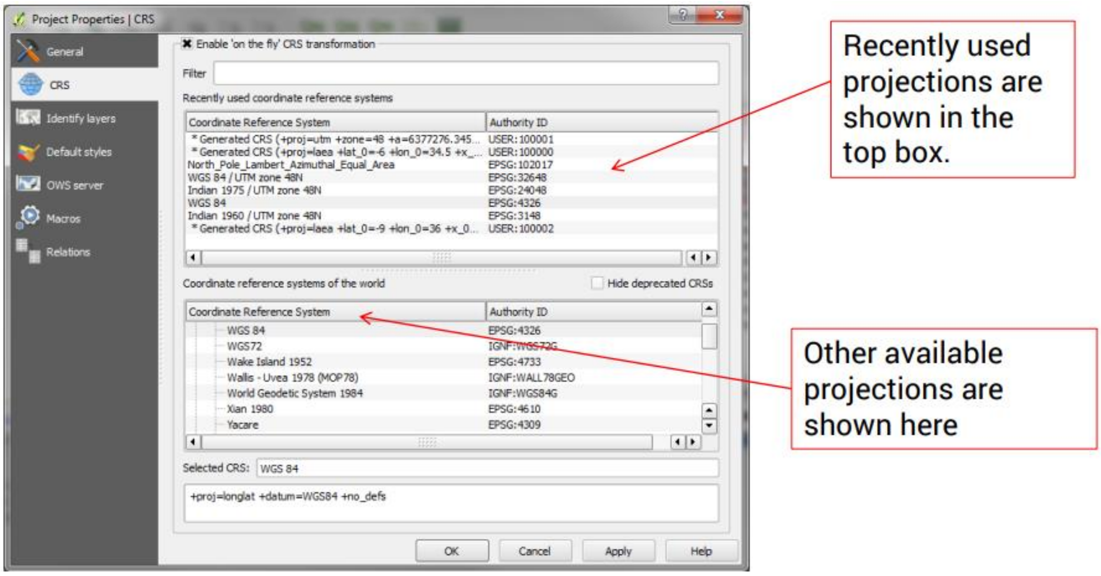



Figure 13. – Changing the projection of the QGIS Map View (step 2)

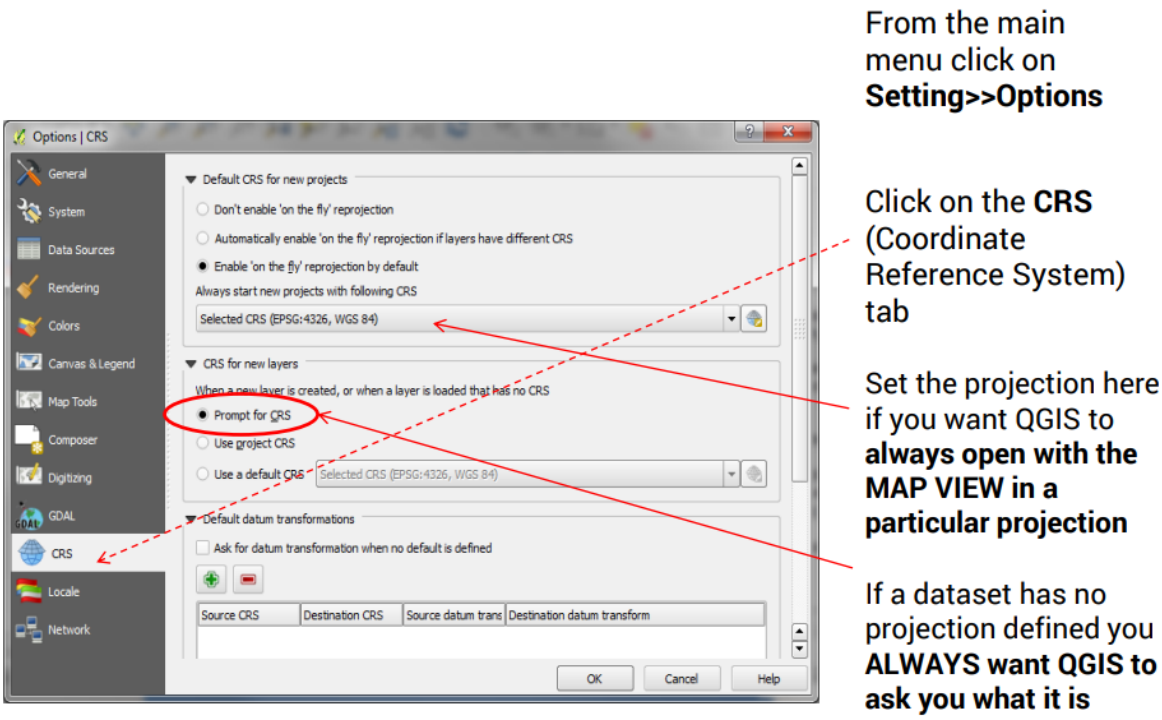



Figure 14. – Changing the projection of the QGIS Map View (step 3)

### 1.7.2. Brief comparison between QGIS and ArcGIS

**QGIS** *is free. Open-source, source codes are open for everyone to modify to particular needs. Huge support on forums like stack exchange. Many supported data formats thanks to GDAL/OGR library. High functionality for vector and raster operations through plugins. Easy integration with other open source software such as GRASS or SAGA.*

**ArcGIS** *Commercial – Not freely available.*

*License is restricted.*

*Source codes not available for users.*

*Huge support on ESRI forums.*

*More restricted data formats, preference for ESRI created data formats such as shape files and grids.*

*Higher functionality, especially spatial analysis, and more reliable results than QGIS for some of them.*

*Designed as a single, stand-alone platform.*

The ArcGIS [14] is a powerful software and usually is delivered to students as a separate course, therefore very scarce information is given below on this software package and we do not plan laboratory tests for this section.

Maps provide a powerful mean to define and standardize how people use and interact with their geographic/geologic datasets. Interactive maps [21] provide the main user interface for most GIS applications. Modern ArcGIS software aimed to perform numerous tasks, including advanced data compilation, cartography, analysis, query, and field data collection.

GIS users pan and zoom interactive maps, where map layers apply symbols based on a set of attributes and perform query and analysis of operations through the map layers. Parcels can be filled with colors based on their zoning types, or the size of point symbols for oil or gas wells can be specified based for instance on their production levels. GIS user can point to a geographic object in an interactive map to get information about the object. ArcGIS users can edit data and feature representations through interactive maps.

Geographic datasets can represent raw measurements (for example, satellite imagery), information interpreted and compiled by analysts (for example, roads, buildings, and soil types), or information derived from other data sources using analysis and modeling algorithms.

The GIS includes a rich set of tools to work with and process geographic information. This collection of tools is used to operate on the GIS information objects, such as the datasets, attribute fields, and cartographic elements for printed maps. Together, these comprehensive tools and the data objects on which they operate form the basis of a rich geoprocessing framework [15].

Geoprocessing is used to model how data flows from one structure to another to perform many common GIS tasks – for example, to import data from numerous formats, integrate that data into the GIS, and perform a number of standard-quality validation checks against the imported data, as well as perform powerful analysis and modeling. The ability to automate and repeat such workflows is a key capability in a GIS. It is widely applied in numerous GIS applications and scenarios.

# 2. PRACTICAL SECTION

*QGIS examples of laboratory works* [11]

## 2.1. Laboratory work 1. QGIS basic techniques

**The purpose of the laboratory work:** familiarization with the main elements of the QGIS interface, loading vector data into the project, visualization and study of spatial data in QGIS.

**Initial data:**

● shapefile containing the border of the Minsk region (*Minsk_region. shp*);

● shapefile containing the boundaries of the administrative districts of the Minsk region (*district_Minsk_reg.shp*);

● shapefiles containing the river network (*rivers_Minsk_reg.shp*) and lakes of the Minsk region (*lakes_Minsk_reg.shp*);

● shapefile of cities in Minsk region (*town_Minsk_reg.shp*).

**Laboratory progress**

***Step 1.*** Launch GIS QGIS basic techniques via *Start Menu → All Programs → QGIS 3.34.6 → QGIS Desktop3.34.3 with GRASS GIS 8.3.2*. Familiarize yourself with the basic elements of the QGIS interface. The working window of the program (fig. 1) consists of five main areas:

*1. Main Menu* - Provides access to all QGIS features in a standard hierarchical menu.

2. *Toolbars* provide access to most of the same functions as the menus, and also contain additional tools for working with the map. Toolbars are floating. In addition, each toolbar can be added/hidden using the context menu, fig.15.

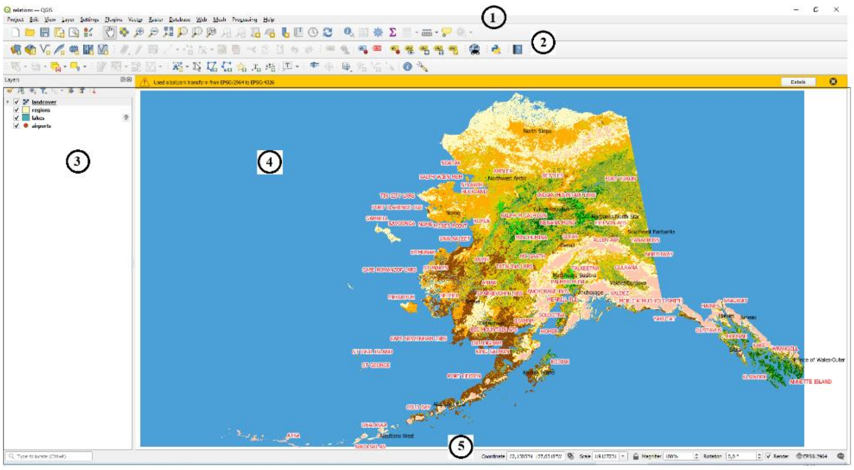



Figure 15. – Basic elements of the QGIS interface

3. *The legend* contains a list of all project layers. Each layer displays its name, geometry type, and legend. The check box next to each legend item is used to set visibility. The order of the layers in the legend determines the order in which layers are displayed on the map. Layers at the top of the list will appear on top of layers at the end of it.

The toolbar located at the top of the legend contains the following controls: *Add group (of layers)*, *Manage map themes*, Filter the legend by map content; Expand All; Collaps All; Remove Layer/Group.

4. *Map area*. The most important part of QGIS is where the cartographic image is given. The latter is determined by the layers loaded into QGIS. The data in the map window can be panned (scrolled, shifted the map focus to another area) and scaled.

5. *The status bar* displays the cursor position on the map in current coordinates or coordinates of the map display boundaries when zooming and panning, the map scale. The scale can be selected from a list of preset values from 1: 500 to 1: 1,000,000.

There is a small checkbox on the right side of the status bar, that allows you to stop drawing layers in the map window. Last on the right side of the status bar is the EPSG code of the current coordinate system and the *Coordinate Transformation* icon.

One of the advantages of QGIS is a flexible, easily customizable interface. You can configure the settings using the Interface settings dialog box (*Settings → Interface Customization…*), fig. 16.

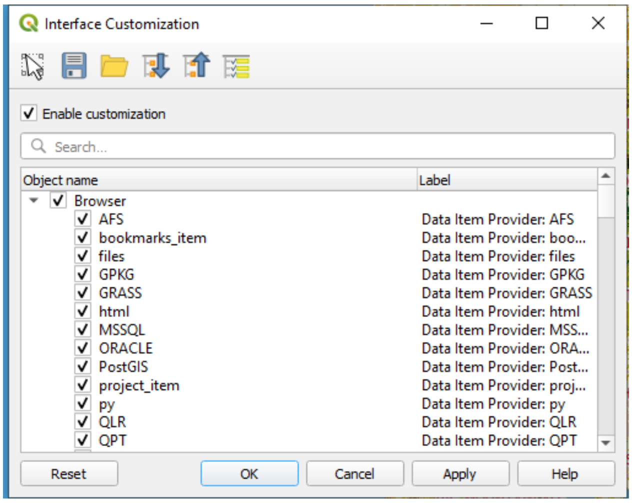



Figure 16. – Customization the Interface

The session state in QGIS is called a project. You can only work on one project at a time. You can save the state of your session in a project file using the menu item *Projects → Save* (or *Save as*...). Information stored in a project file includes added layers, layer properties including symbology, project coordinate system, last map coverage, etc. The project does not contain the data itself; it only stores references to them. The project file is saved in XML format with a *.qgs extension.

***Step 2.*** Loading vector data. Using the Layer → Add Lauer → *Add vector layer tool*, fig. 17, add the following vector layers to the project from the source data folder: "Minsk_region.shp", "district_Minsk_reg.shp", "lakes_Minsk_reg.shp", "rivers_Minsk_reg.shp", "town_Minsk_reg.shp".

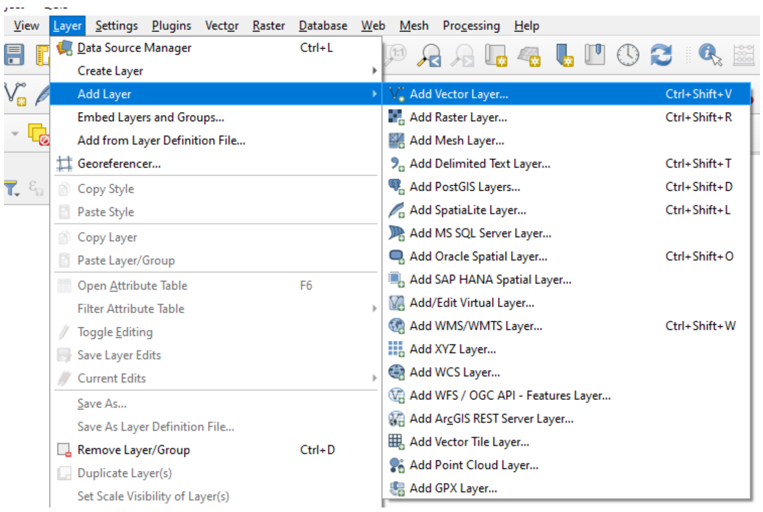



Figure 17. –Add Vector Layer steps

When uploading, select UTF-8 from the *encoding* drop-down list on the panel “Data Source Manager”. By default, it can be *Automatic*. If you open the file in the wrong encoding, then for instance, Cyrillic (Russian) letters (CP1251) will be unreadable there. In this case, you need click on *Automatic* to open the list of encodings and set the UTF8 in the layer properties, fig. 18. The *Add vector layer* dialog box can be called also by the key combination Ctrl + Shift + V, or click the  button.

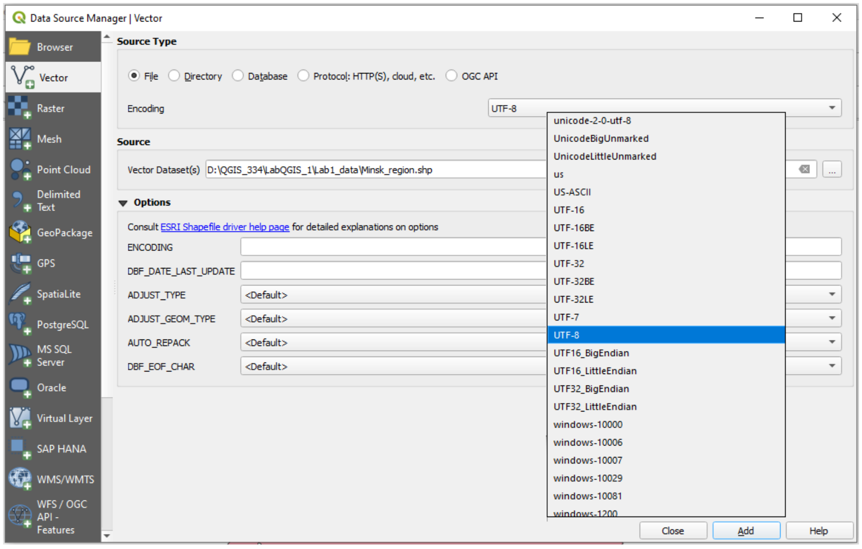



Figure 18. – Panel Data Source Manager | Vector

Data can also be added to a project directly from the Browser. Browser is a floating panel in QGIS that allows you to navigate through catalogs and manage geodata. To activate the Browser, you call the context menu in an empty place on the toolbar and turn on the corresponding checkbox, fig. 19.

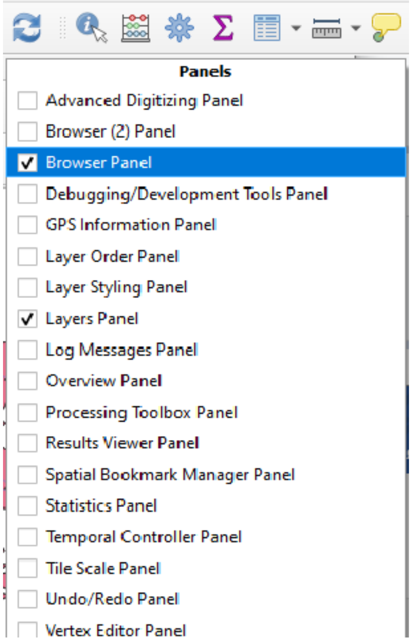



Figure 19. – Activating the Browser

In the Browser window, navigate to the source data folder and select the "town_Minsk_reg.shp" layer. Add a layer to the project by clicking the *Add Selected Layers* icon. You can also load data by dragging the selected layer to the map area or legend, fig. 20.

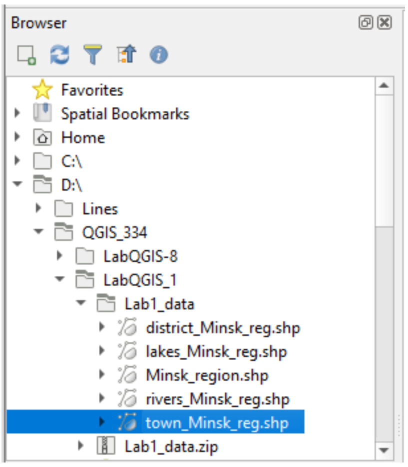



Figure 20. – The Browser window

***Step 3.*** Create a group of layers. Layers can be combined into groups, including nested ones, creating a complex hierarchy and building your own data organization logic. In the Layers window, click on the *Add group* icon. Right-click on the group added to the list of layers and in the context menu that opens, select *Rename Group*, type *Hydrography*. Drag the "lakes_Minsk_reg" and "rivers_Minsk_reg" layers into the created group.

***Step 4.*** Change the project coordinate system. In QGIS, the project's coordinate system is determined by the coordinate system of the first layer you add. Define the coordinate system of the current project. To do this, in the *Projects* menu, select *Properties* and go to the CRS (*Coordinate Reference System*)  tab. The project coordinate system is set to WGS 84. Click *Hide deprecated CRSs*. In the list of coordinate systems, select *Rectangular coordinate systems* - WGS 84 / UTM zone 35N, fig. 21. Click *Apply* and OK.

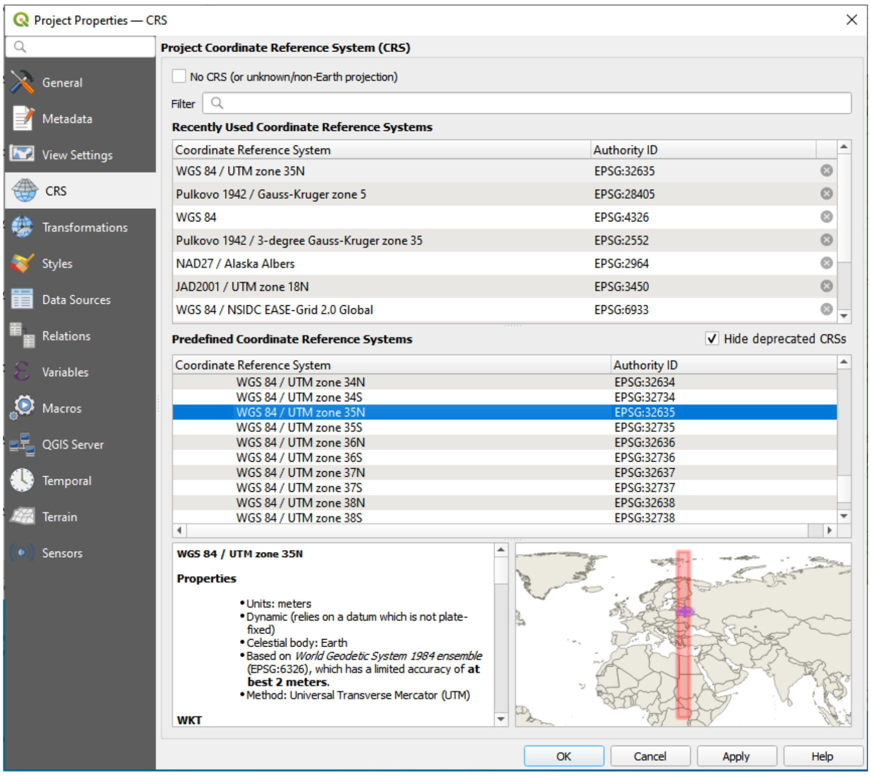



Figure 21. – Project properties | Coordinate Reference System selecting

Thus, you have changed the project coordinate system, but the layers continue to be stored in the original shape, different from the project coordinate system. QGIS supports on-the-fly reprojection or automatic transformation of data from a known but different coordinate system from the project to the project coordinate system. On-the-fly reprojection does not change the CRS of the layer itself, but transforms it into the specified one only on the basis of known parameters.

***Step 5*** Change the names of the layers. The name of the added layer inherits the name of the data source. You can give the layer a more meaningful name without changing the name of the source. To do this, right-click on the layer name in the Layers. From the context menu that appears, select *Properties*. On the *Layer Properties* dialog box, in the *Layer name* field, *Rename Layer* of the vector layer "Minsk_region" to "Border", "district_Minsk_reg" to "Districts", "rivers_Minsk_reg" to "Rivers", "lakes_Minsk_reg" to "Lakes" , "town_Minsk_reg" - to "Towns", fig. 22. Click OK.

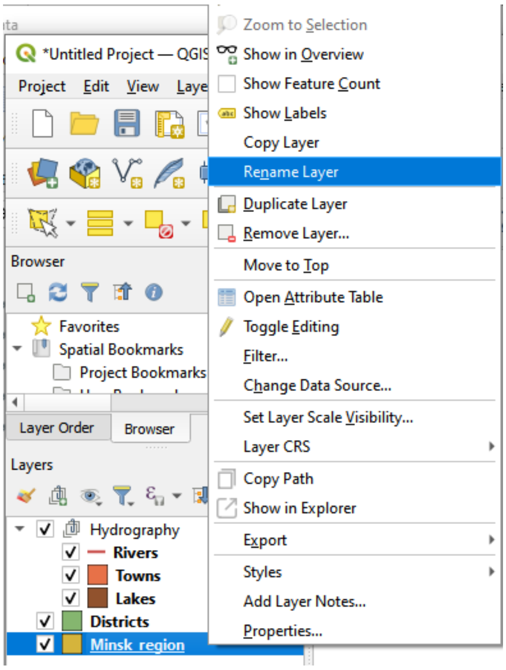



Figure 22. – Layer properties selecting "Rename Layer"

***Step 6.*** Symbolize the layers. Click the layer name "Border" with the right mouse button. In the Layer *Properties* window that opens, select the *Symbology* tab. The rendering type is set to *Single Symbol* (icon). The *Single symbol* drawing is used to display all features in a layer with a single user-specified symbol. In the preview window of the current state of the symbol, select the second level of the symbol (*Simple fill*). Set the following parameters: *Fill color* – no fill, *Stroke style* – Dash Line, *Stroke width* – 0.86 millimeters. Select e.g. a dark *gray stroke color*. Click *Apply* and OK.

Symbolize the "Towns" layer with a *Simple Fill*, the fill color is brown. Display the "Rivers" layer in blue with a width of 0.3 mm. Lakes are a *Single Symbol* (icon), the fill and stroke colors are blue, fig. 23.

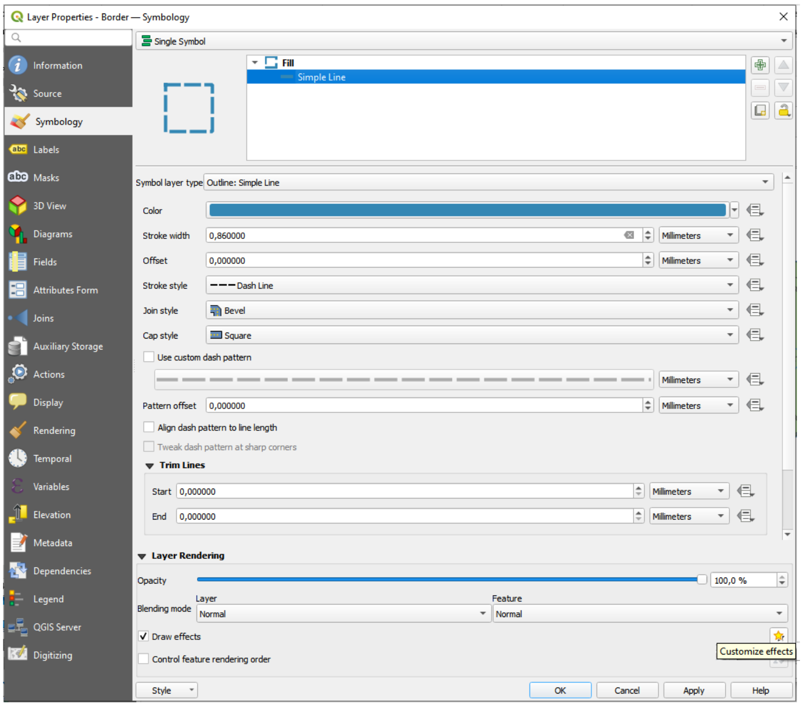



Figure 23. – Layer properties – symbology panel

In the *Symbology* section, check the box next to the *Draw effects* option and click the icon *Customize Effects* (fig. 24). The Effect Properties panel pops up after you click the icon . Perform the setup as shown in fig. 25.

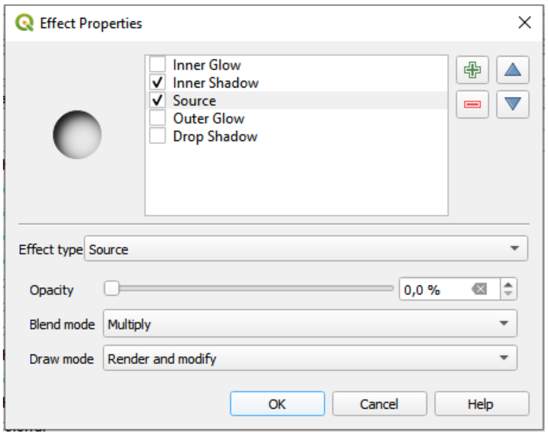



Figure 24. – Rendering – effect properties

For the "Districts" layer in the Layer *Properties* window, on the *Symbology* tab as rendering type, specify *Categorized* ( icon). This type is used to symbolize all objects of the layer with a single symbol, the color of which reflects the value of the element's selected attribute. Click on *Down* arrow in the *Value* row and select *abc NAME*. For the *Color ramp* set option select *Random Colors* and click the *Classify* button. Switch off an extra item (*all other values*) of symbols. Click *Apply* and *OK* (fig. 25).

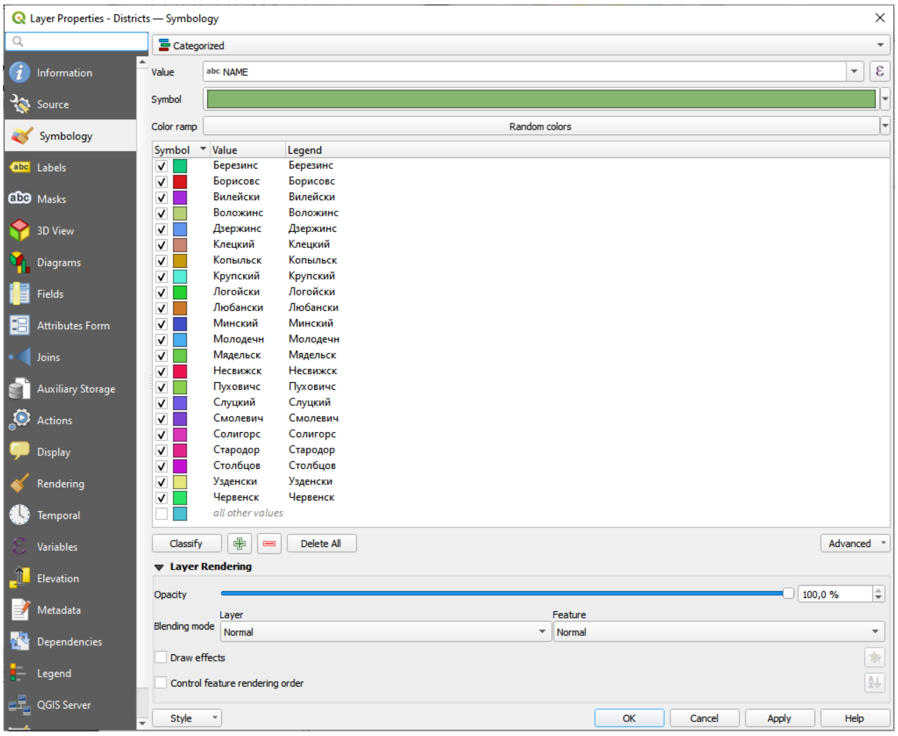



Figure 25. – Layer properties – Districts – Symbology

***Step 7*** Arrange the added layers as shown in fig. 26. To do this, in the table of contents, select and drag the layer up or down.

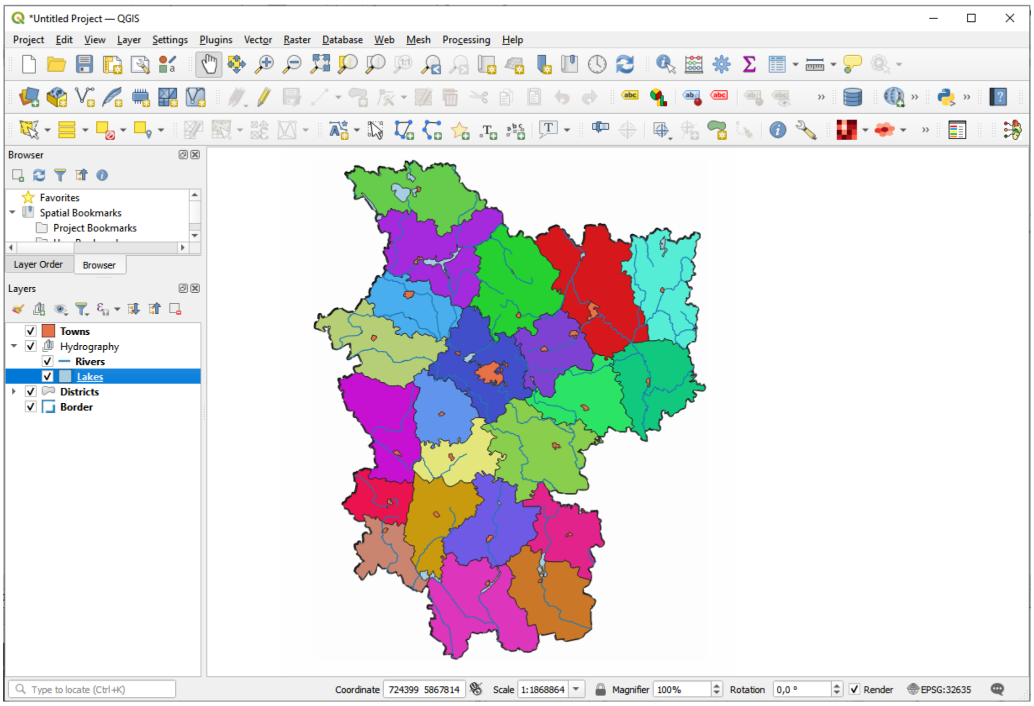



Figure 26. – General view of the Minsk region with classified districts

***Step 8.*** Navigation in the map area is carried out using the tools of the *Tools panel for moving around the map*. When you place the mouse cursor over any button, a small pop-up window will appear with a prompt for the purpose of this key, for example “Zoom In” as shown in fig. 27.


Figure 27. – Tools panel for moving around the map

If a definite toolbar is not in the toolbar area, then enable it using the command *View → Toolbars → Tools*. Tools allow you to reduce or enlarge the scale of spatial data loaded into the project; move the image; create bookmarks and manage them. You may experiment to move and scale tools.

***Step 9.*** Creating a bookmark. Spatial bookmarks allow you to create unique geographic location markers and return to them later.

Pan and zoom the map to get closer to the Myadel (Мядель) district. Right click the *Show Spatial Bookmarks* button or press *Ctrl* + *Shift* + *B*. Select the Spatial Bookmark Manager Panel. In the window of the spatial bookmark panel that appears, click the *Add Bookmark* button to add/change the name of the bookmark to "Myadel" (Мядель), fig. 28. The Spatial Bookmarks panel allows you to view or delete bookmarks.

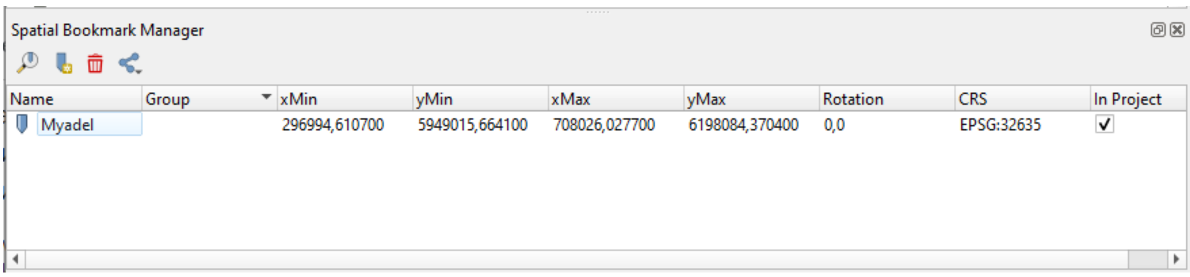
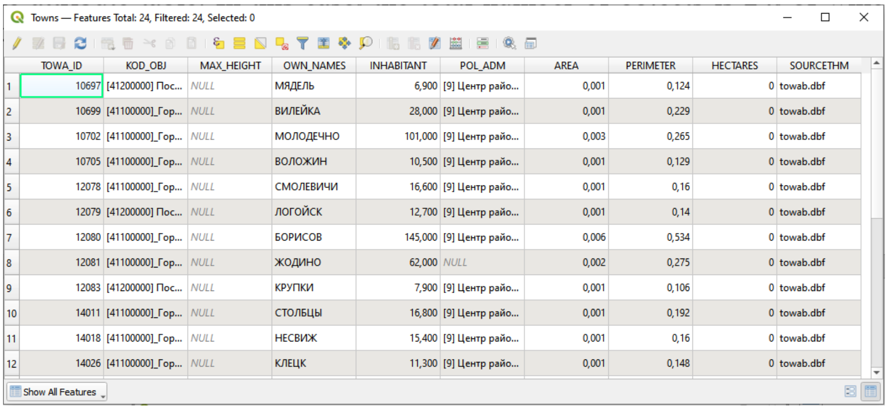



Figure 28. – A panel of the Spatial Bookmark Manager

Navigate to the full extent of the map by clicking *Zoom Full*. To return to a bookmark in the Spatial Bookmarks panel, with the entry selected, click the *Zoom To Bookmark* icon. You can also view a bookmark by double-clicking on it.

***Step 10.*** Each feature on the map is associated with a specific row in the attribute table. Explore the attribute table of the "Towns" layer. To do this, right-click on the layer name in the legend and select *Open Attribute Table*. After that, the features table of this layer will appear, fig. 29. The number of features is indicated in the header of the attribute table. In this case, the total number of objects is 24, of which ‘0’ are selected.



Towns — Features Total: 24, Filtered: 24, Selected: 0

| | TOWA_ID | KOD_OBJ | MAX_HEIGHT | OWN_NAMES | INHABITANT | POL_ADM | AREA | PERIMETER | HECTARES | SOURCETHM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10697 | [41200000] Пос... | NULL | МЯДЕЛЬ | 6,900 | [9] Центр райо... | 0,001 | 0,124 | 0 | towab.dbf |
| 2 | 10699 | [41100000]_Гор... | NULL | ВИЛЕЙКА | 28,000 | [9] Центр райо... | 0,001 | 0,229 | 0 | towab.dbf |
| 3 | 10702 | [41100000]_Гор... | NULL | МОЛОДЕЧНО | 101,000 | [9] Центр райо... | 0,003 | 0,265 | 0 | towab.dbf |
| 4 | 10705 | [41100000]_Гор... | NULL | ВОЛОЖИН | 10,500 | [9] Центр райо... | 0,001 | 0,129 | 0 | towab.dbf |
| 5 | 12078 | [41100000]_Гор... | NULL | СМОЛЕВИЧИ | 16,600 | [9] Центр райо... | 0,001 | 0,16 | 0 | towab.dbf |
| 6 | 12079 | [41200000] Пос... | NULL | ЛОГОЙСК | 12,700 | [9] Центр райо... | 0,001 | 0,14 | 0 | towab.dbf |
| 7 | 12080 | [41100000]_Гор... | NULL | БОРИСОВ | 145,000 | [9] Центр райо... | 0,006 | 0,534 | 0 | towab.dbf |
| 8 | 12081 | [41100000]_Гор... | NULL | ЖОДИНО | 62,000 | NULL | 0,002 | 0,275 | 0 | towab.dbf |
| 9 | 12083 | [41200000] Пос... | NULL | КРУПКИ | 7,900 | [9] Центр райо... | 0,001 | 0,106 | 0 | towab.dbf |
| 10 | 14011 | [41100000]_Гор... | NULL | СТОЛБЦЫ | 16,800 | [9] Центр райо... | 0,001 | 0,192 | 0 | towab.dbf |
| 11 | 14018 | [41100000]_Гор... | NULL | НЕСВИЖ | 15,400 | [9] Центр райо... | 0,001 | 0,16 | 0 | towab.dbf |
| 12 | 14026 | [41100000]_Гор... | NULL | КЛЕЦК | 11,300 | [9] Центр райо... | 0,001 | 0,148 | 0 | towab.dbf |

Show All Features

Figure 29. – Panel of towns and their features

The panel at the top of the features table window includes tools that allow you to add (remove) an object or field, perform sorting, filtering, form a selection of objects, calculate the field value based on existing attribute values or specified functions, etc.

Click the (*Select Features Using an Expression*) button on the toolbar in the attribute table window. In the *Select by expression* dialog box that appears, you compile an expression to sample your data. In the middle section of it, select the *Fields and Values* section to open a list of available attributes. Double-click the attribute "INHABITANT" in the list to add it to the *Expression* field. Expand the *Operators* list and double-click on the ">" (greater than) symbol. A logical operator is added to the query text block. In the same place, type 40. Click *Select Feature* and *Close* in succession, fig. 30.

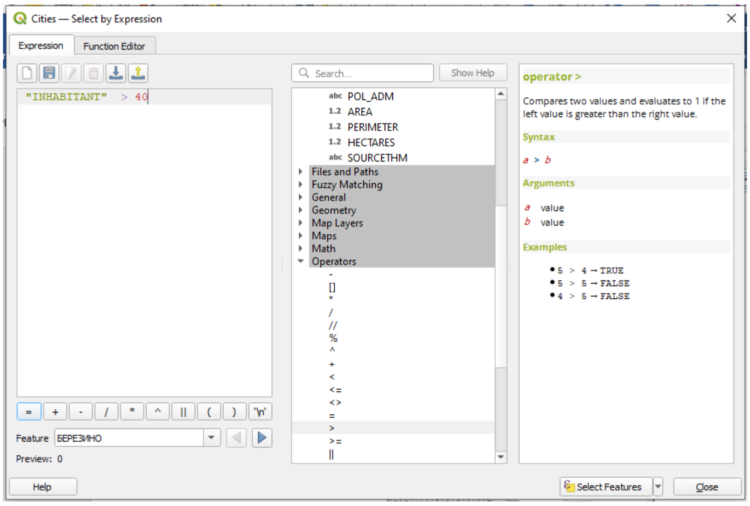



Figure 30. – Panel of Cities – Select by expression – towns

In accordance with the condition of the expression you compiled, there will be selected cities with a population of more than 40,000. In the drop-down list at the bottom left of the attribute table window, select "*Select Features*". Only selected objects will be displayed in the attribute table *Cities – Features*. Click *Close* the attribute table window. You'll see selected cities, some of them are shown in fig. 31.

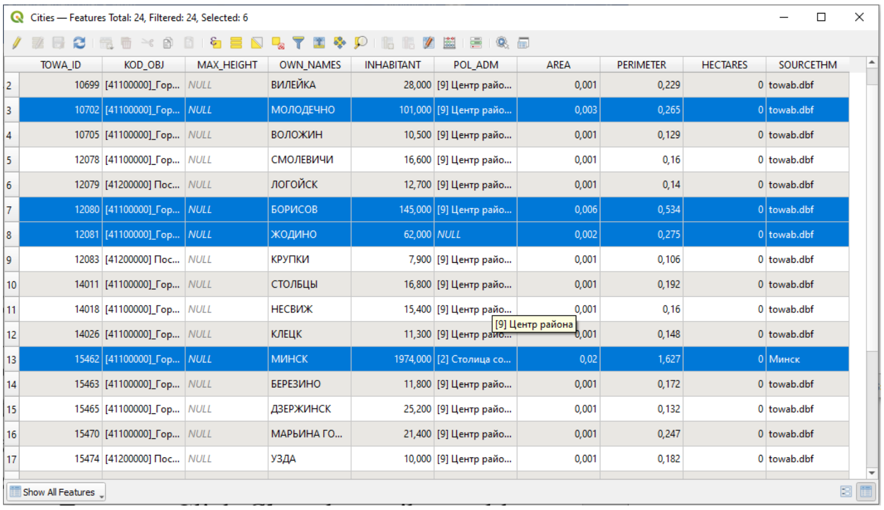


Figure 31. – An example of highlighted selected cities

***Step 11***. Let's save the selected objects in a separate layer. For this in the *Layers* panel, right-click on the layer name "Cities". From the menu that appears, select *Export → Save Features As...* Save to your working folder under the name "city.shp", fig. 32. Enable Options *Save only selected features* and *Add saved file to map*. Rename Layer "Towns" (see Step 5) to "Large Cities" (*Layer Properties → Source*).

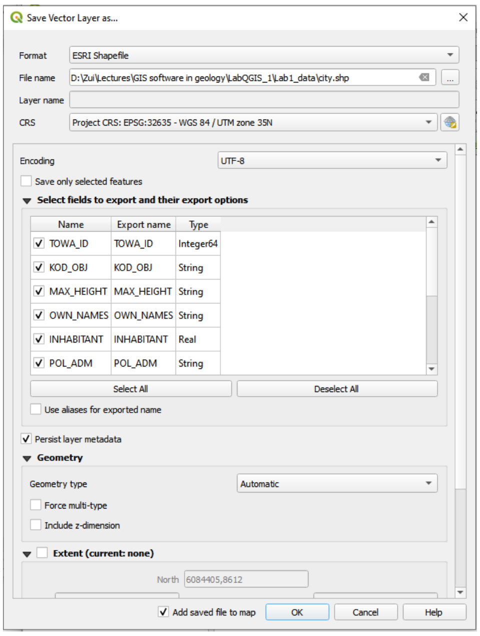


Figure 32. – Save Vector Layer As… panel

***Step 12.*** Classify the cities (large cities layer), once divided into three classes by population 40–100, 101–1500, 1501 and higher. On the *Symbology* tab of the *Layer Properties* – Large Cities dialog box, set drawing style – *Graduated* symbol ( icon), Value – INHABITANT, click an arrow in the line *Color Ramp*, then *All Color Ramps* and select *Color map* – OrRd, as shown in fig. 33. Select *Classes* – 3, *Mode* – Equal intervals.

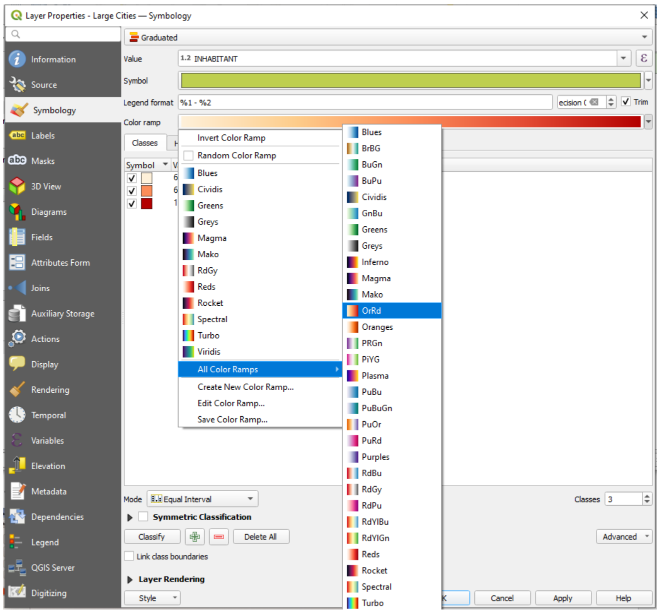



Figure 33. – Selecting OrRd color option panel

Double click on the class borders (click sequentially *Values*, then *Legend* tabs) and manually change values of the ranges. Adjust the legend as shown in fig. 34. Click *Apply* and *OK*.

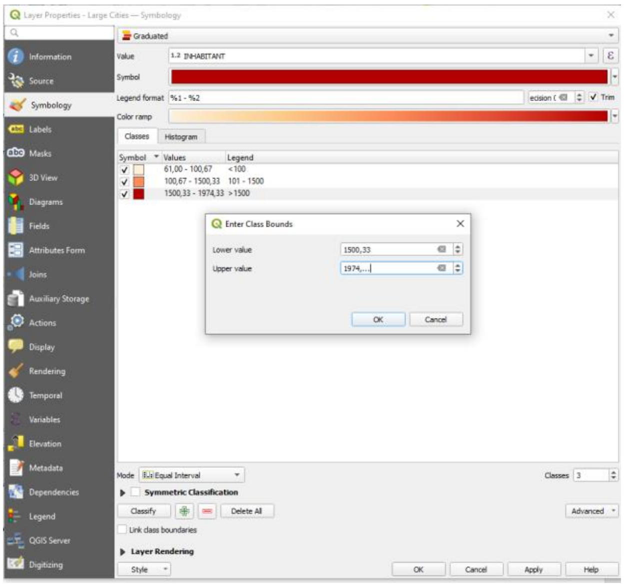



Figure 34. – Layer properties – Large cities divided into 3 subclasses

***Step 13***. Place the "Cities" layer below the "Large Cities" layer and set the Scale Dependent *Visibility* (*Layer properties* → *Rendering*) so that at full extent the objects in the "Cities" layer are not visible, and when the map is enlarged to several times – appeared; the “Large Cities” layer disappeared at the same magnification, fig. 35.

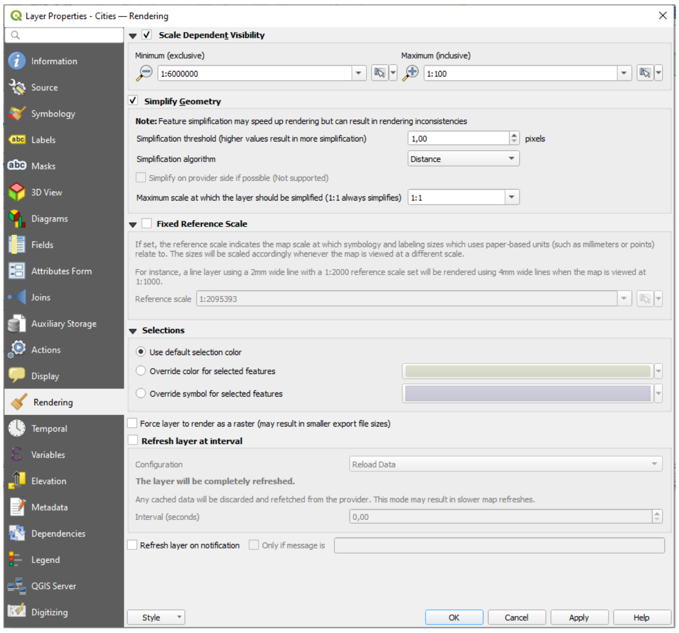



Figure 35. – Layer properties / Cities – Rendering | Scale Dependent Visibility

After you set the range of visible scales, the layer does not will be displayed if the map scale is out of range. The legend will show an unselectable checkbox.

***Step 14***. In the "Rivers" layer, we will display only permanent watercourses. To do this, select *Filter…* from the context menu of the layer. In the *Query Builder* dialog box that appears, you build an expression to fetch your data. The simplest form of an expression should consist of a field name (selected from the *Fields* block on the left side of the window), a logical operator (selected using the buttons in the center of the window), and a value. In order for the values to appear, it is necessary to press the *Sample* button with the selected field and double click “Постоянная” (Permanent).

In the field list, double-click TYPE_RIVER to add that field to the query text block. Click the tab "=" (equal to) in the *Operators* group. Click the *Sample* button and double-click *Constant* item in the *Values* list, fig. 36.

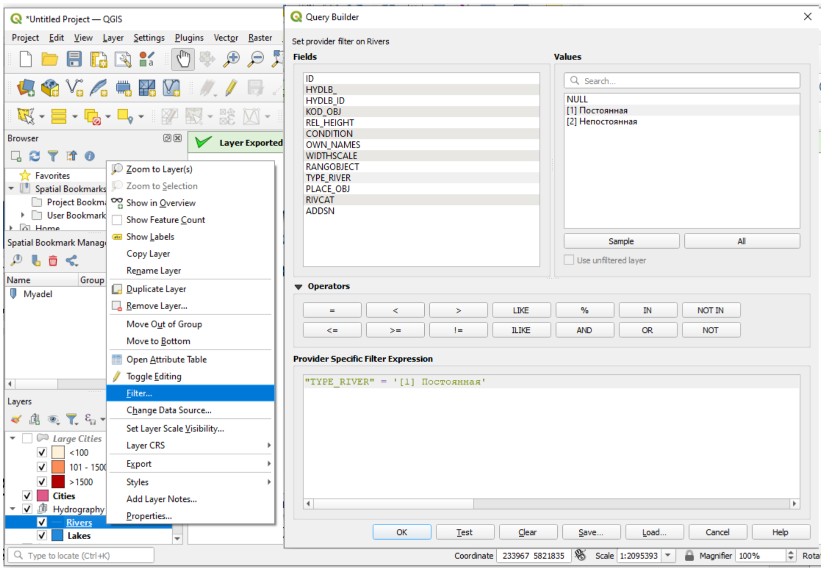



Figure 36. – Rivers and their types

Click OK. In accordance with the terms of your expression all non-permanent streams will no longer be displayed in the map window.

***Step 15***. Label the objects of the "Cities" layer. On the *Labels* tab in the *Layer Properties* dialog box, select *Single Labels*. Set the field OWN_NAMES in the *Value* list. Go to the *Text* group and specify the *Font* field – Times New Roman, *Size* 10. Then in the *Placement* group, select *Left* sector, fig. 37.

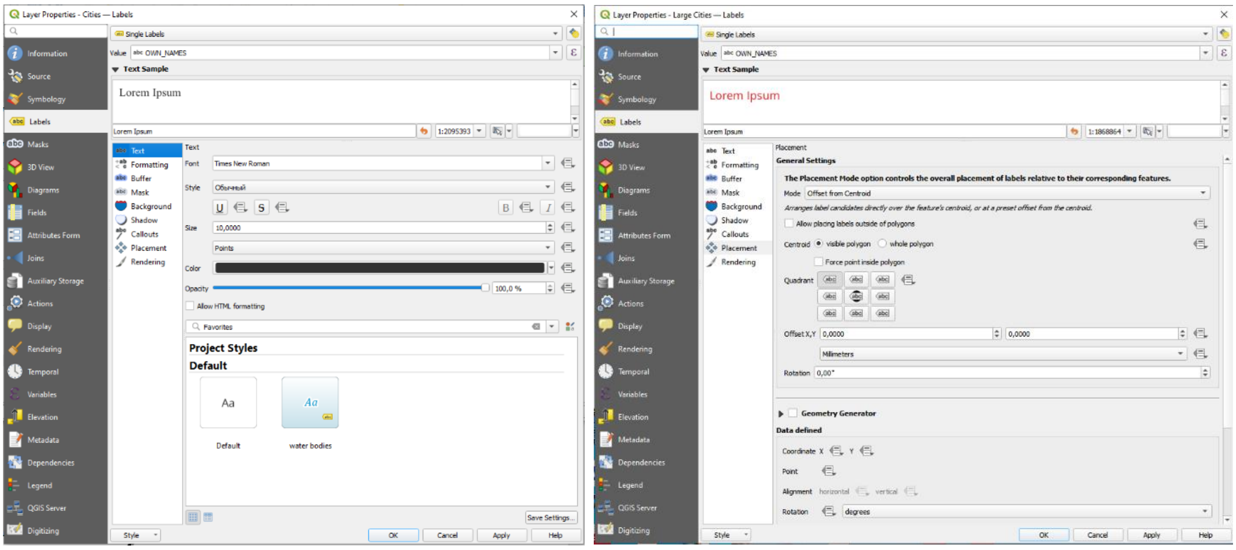



Figure 37. – Layer Properties – Towns – Labels

Label the objects of the "Large Cities" layer in red, in Times New Roman font, size – 12. Placing *Mode* for labels ode –at the top right of the center of the polygon. In result the map looks like in fig. 38.

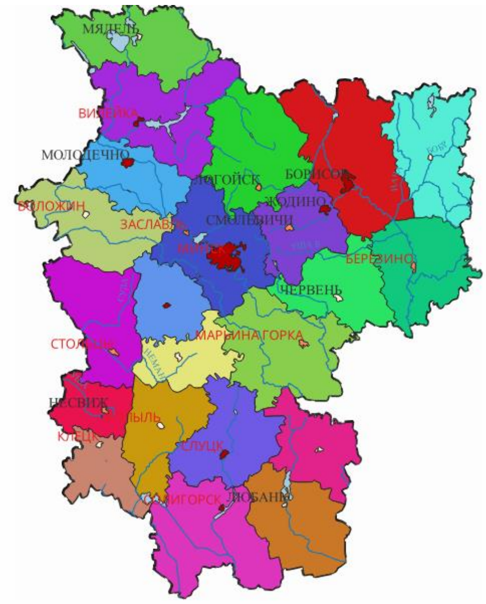



Figure 38. –Labels of towns and cities

***Step 16.*** Create labels for the objects of the "Lakes" layer. On the *Labels* tab of the *Layer Properties* dialog box, select *Single Labels*. Set the *Value* field to OWN_NAMES. The color of the labels is blue, *the font* is Times New Roman, and the *size* is 8. Placing labels Mode – *Offset of Centroid*. In the *Rendering* group, select the *Visible to scale* check box. Specify the scale for the appearance of inscriptions the same as for the "Cities" layer, fig. 39.

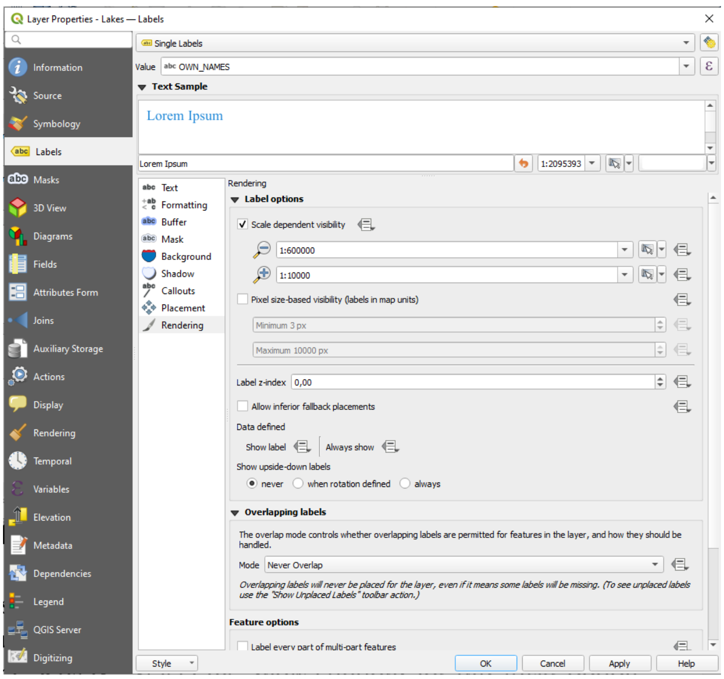



Figure 39. – Layer properties Lakes – Labels panel

***Step 17.*** Create labels for the objects of the "Rivers" layer, for this, select *Labels* from the *Layer Properties* menu. In the *menu* select the *Single Labels* option. Set the label field to *OWN_NAMES* and symbolize the labels: *Font* – Times New Roman, style – *Italic* (курсив), size – 7, color – *Blue*. In the *Placement* group – Mode – select *Curved*. In the *Rendering* group, check elect *Scale Dependent visibility* and Mode – *Never Overlap* (fig. 40). Click *Apply*.

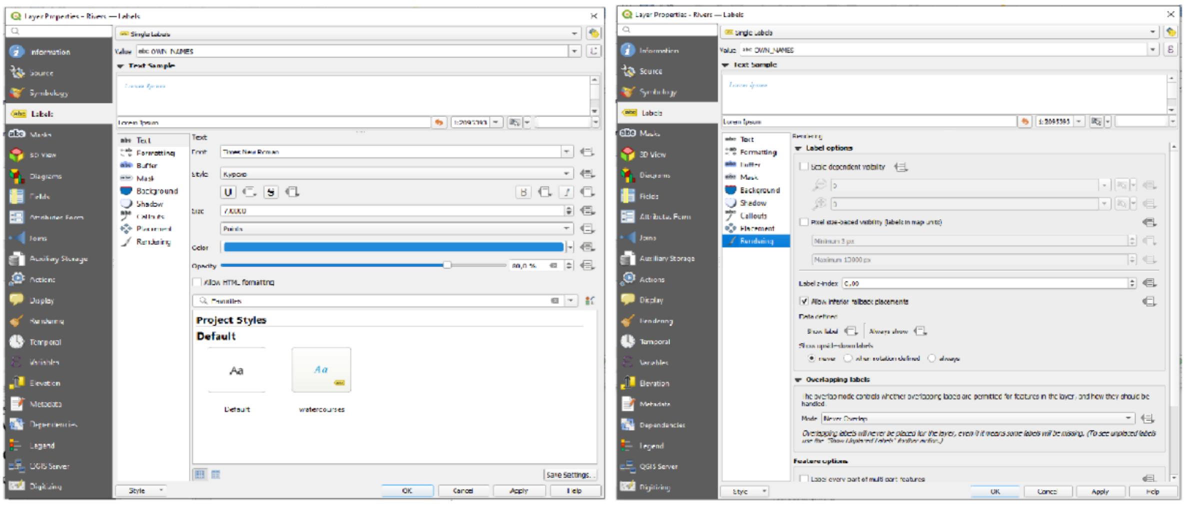


Figure 40. – Layer Properties – Rivers – Label styling

***Step 18***. Open the attribute table of the "Districts" layer (right-click on the layer name in the legend *Open attribute table*). Click the *Edit mode* icon at the top of the attribute table window. Create a new field in the table by selecting the *New Field* tool. In the *Add Field*, specify *Name* – Density, *Type* – decimal number (real), *Length* – 5, *Precision* – 2, fig. 41. A field size of 5 with a precision of 2 means that a three-digit number, a decimal point, and 2 decimal places specifying the precision can be entered in the field.

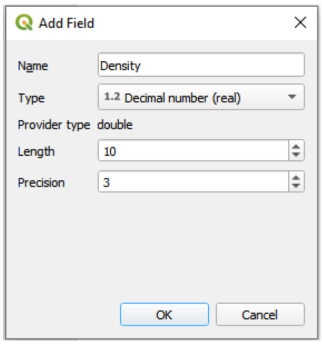



Figure 41. – Add field panel

Calculate the values of the *Density* field using the field calculator, which can be called up by clicking on the icon (*Open Field Calculator*) of the corresponding tool. The field calculator allows you to perform calculations based on existing attribute values or given functions. In the tool's dialog box, activate the *Update existing field* option. Select the *Density* field from the drop-down list of the section. In the middle section of the window, expand the *Fields and Values* section and double-click on the *POPUL* field name. Then type * 1000 / and double click on *AREA* (fig. 42).

Click *OK*. The calculated values are added to the *Density* field. Save changes and ( icon), exit the edit mode by pressing the *Toggle Editing* icon. Close the window attribute tables.

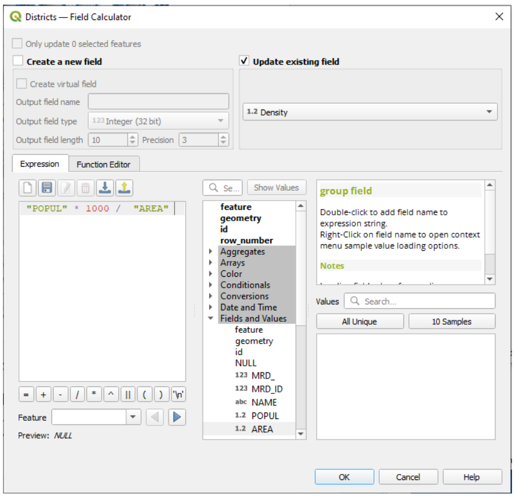



Figure 42. – Calculator of fields panel

***Step 19.*** Symbolize the Districts layer with a Graduated ( ) icon over the *Density* field. *Gradient* - YlOrBr, *Number of classes* - 3, *Mode* - natural intervals. Customize the display of data values in the legend by setting the number of decimal places *(Precision 1*). In the *Rendering* group, set the transparency using the slider or by typing 25 in the box, as shown in figs. 43, 44. Click *Apply* and OK.

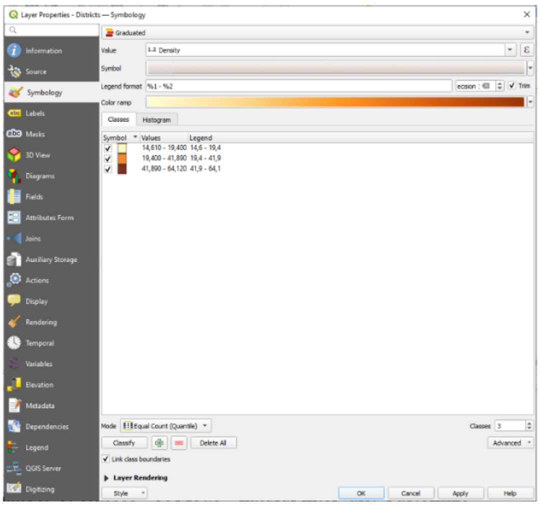



Figure 43. – Layer Properties – Districts | Symbology panel

***Step 20:*** Adding a base map (called an underlay) to the QGIS project. To add a map, we will use the QuickMapServices module. QGIS has a modular architecture, which makes it easy to add missing functionality to an application. Most of the functions in QGIS are implemented as core or external modules. Modules are managed using the *Plugins Manager* and involve downloading, updating or deleting them. QuickMapServices is an external plugin and is not included in the basic QGIS package. Check if this module is installed. To install (if not installed earlier) the module, open the *Plugins* menu and switch to the *Not installed* tab, where, either by sorting by name or by entering part of the module name in the search bar, find the module of interest. Select *QuickMapServices* from the list of modules and click *Install Plugin* (fig. 45).

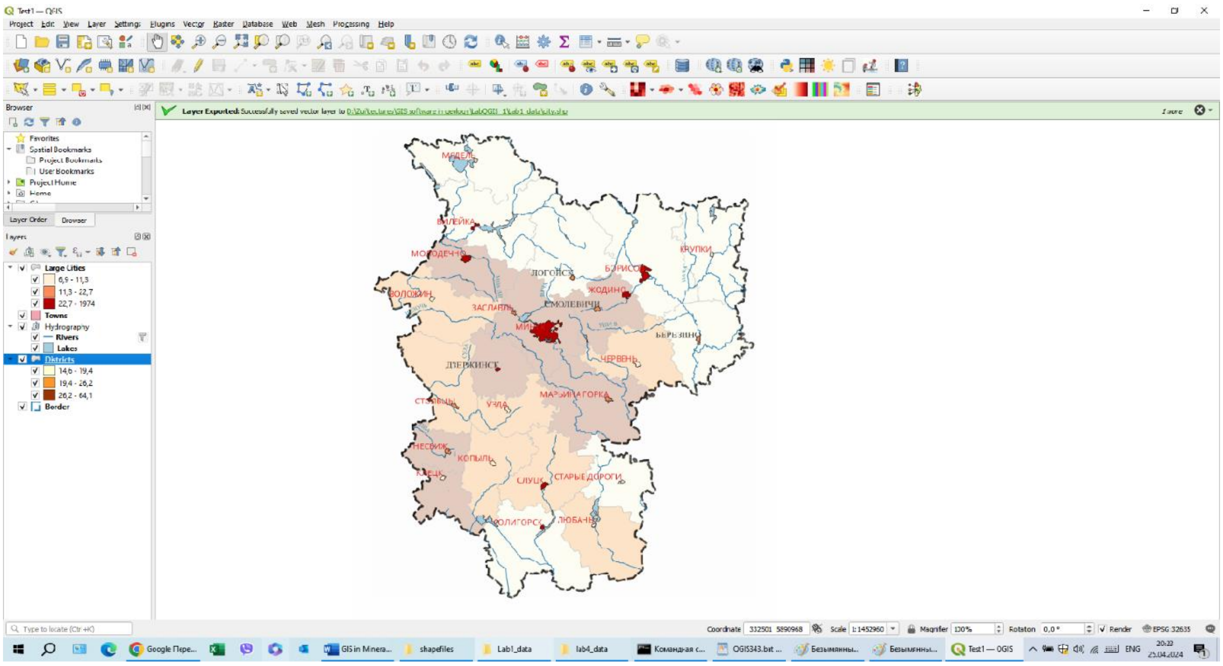


Figure 44. – Minsk region map view

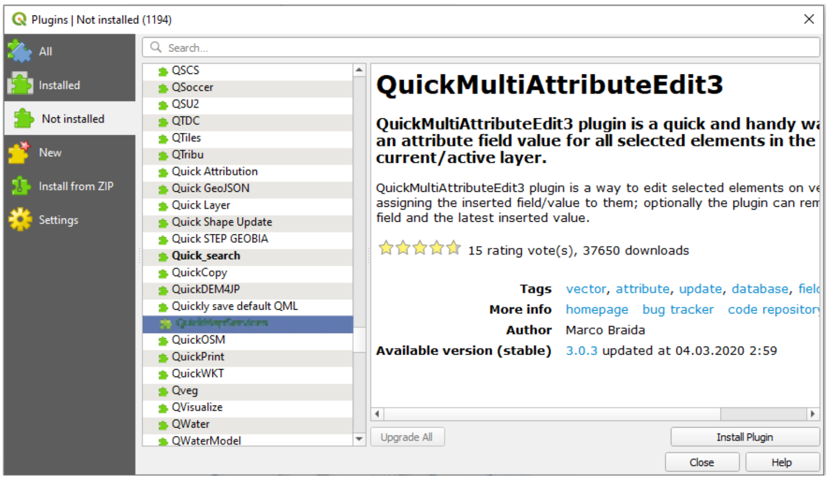



Figure 45. – List of modules not installed

After installing the plugin, the QuickMapServices group will appear in the *Web* menu. Also, extension buttons will be added to the web toolbar, fig. 46.

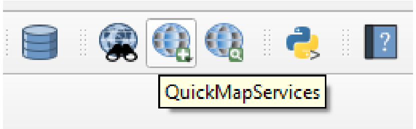



Figure 46. – QuickMapServices Toolbar

Click the  QuickMapServices icon and select *OSM* → *OSM Standard* from the menu that opens. The map will automatically be included in the project as a layer, fig. 47. In the legend, the layer is at the end of the list.

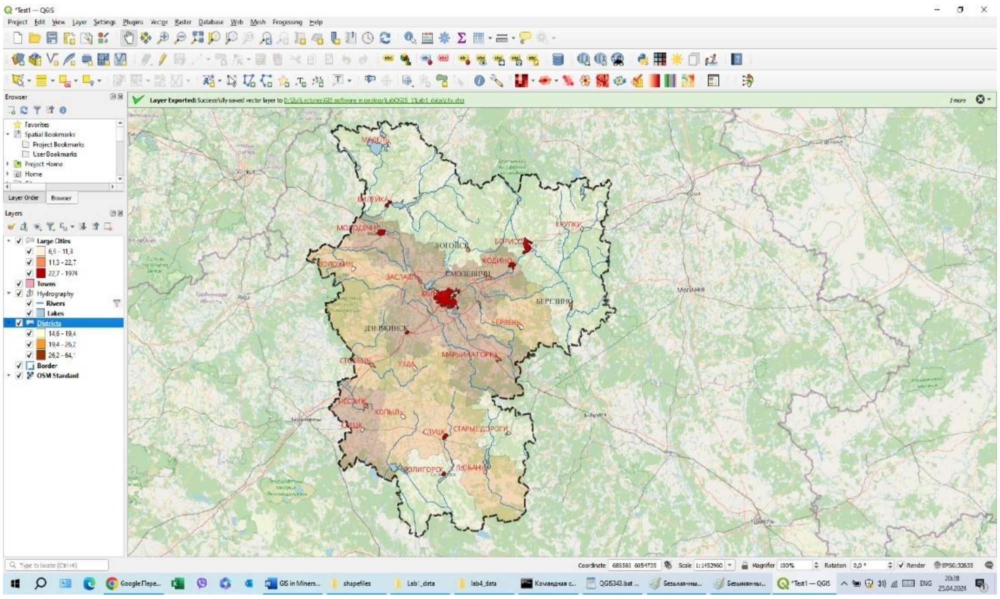


Figure 47. – Minsk region modified

A base map added through QuickMapServices is a special kind of layer whose display can be configured through the *Layer Properties* dialog box. The settings allow you to enable/disable smoothing, convert the background to grayscale, adjust brightness, contrast, and transparency.

Today, there are several QGIS extension modules for working with underlays, including the OpenLayers plugin, which is automatically installed with QGIS and allows you to display data from OSM, GoogleMaps, Yahoo Maps, and other services in a QGIS project.

Delete the "OSM Standard" layer from the project (right-click on the layer name in the legend → *Delete)*.

**Step 21** Save the project using the *Save As...* option on the *Project* menu. Save it in your folder under the name "Minsk_obl". Close QGIS.

## 2.1. Laboratory work 2. Geographical linking of raster in QGIS

**The purpose of the laboratory work:** to master the basic algorithms for performing georeferencing of raster images in QGIS.

**Initial data:**

- shapefile containing administrative borders of European countries (*country.shp*);
- **bitmap** (raster) *linguistic_map.jpg*;
- scanned topographic maps of Belarus at a scale of 1: 100,000.

**Laboratory progress**

**I. Geolinking of the topographic maps on the coordinate grid**

The linking of raster information is its transformation from the coordinate system in which it exists to the coordinate system associated with the reference surface or the coordinate system of the projection that can be used to solve real spatial problems. Geolinking data in QGIS is done using a special module called *Raster Anchor (GDAL)*.

***Step 1.*** Open *QGIS Desktop 3.34.6*. Start working with a new empty project (*Projects* → *New*). Run the Layer menu – *Georeferencer* as shown in fig. 48.

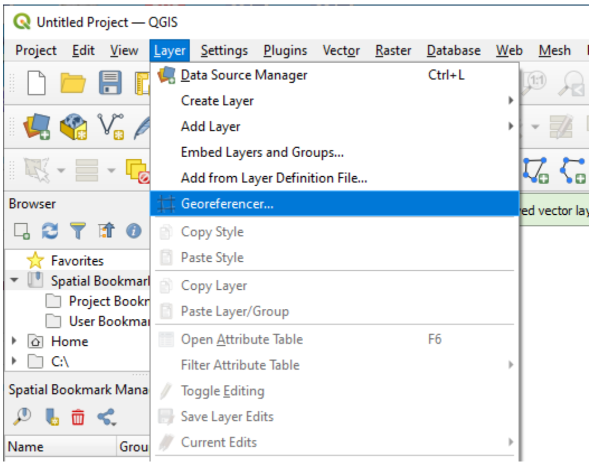



Figure 48. – Georeferencer location

Georeferencer panel with an explanation of the toolbar icons shown in fig. 49.

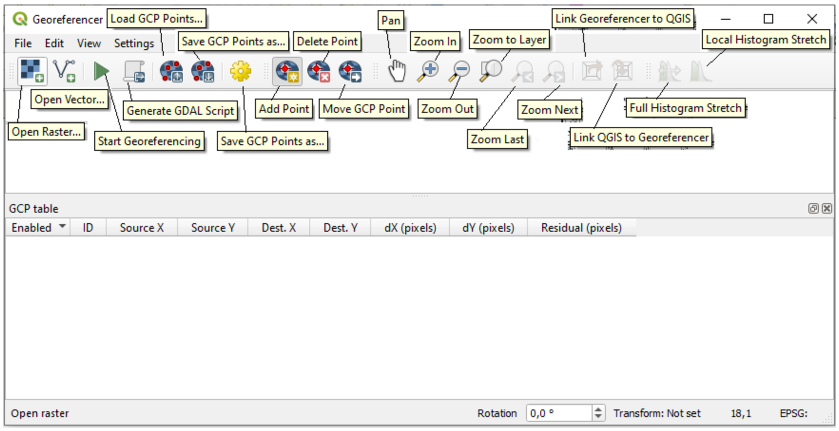



Figure 49. – Georeferencer panel with the toolbar icons explanation

**Step 2.** Load the linked raster file into the data view (the task is performed by variants – the variant number corresponds to the number of the computer you occupy, the rasters are located in the source data folder).

*1st option - n35-081.jpg (Cherven)*
*2nd option - n35-122.jpg (Bereza)*
*3rd option - n35-019.jpg (Braslav)*
*4th option - n35-066.jpg (Molodechno)*
*5th option n35-082.jpg (Berezino)*
*6th option - n35-054.jpg (Vileika)*
*7th option - n35-143.jpg (Mozyr)*
*8th option - n35-116.jpg (Salihorsk)*
*9th option - n35-085.jpg (Skidel)*
*10th option - n35-048.jpg (Senno)*

After launching the *Georeferencer*, a dialog box of the tool will open, divided into two parts: a data part and a part of the table GCP of anchor points, fig. 50.

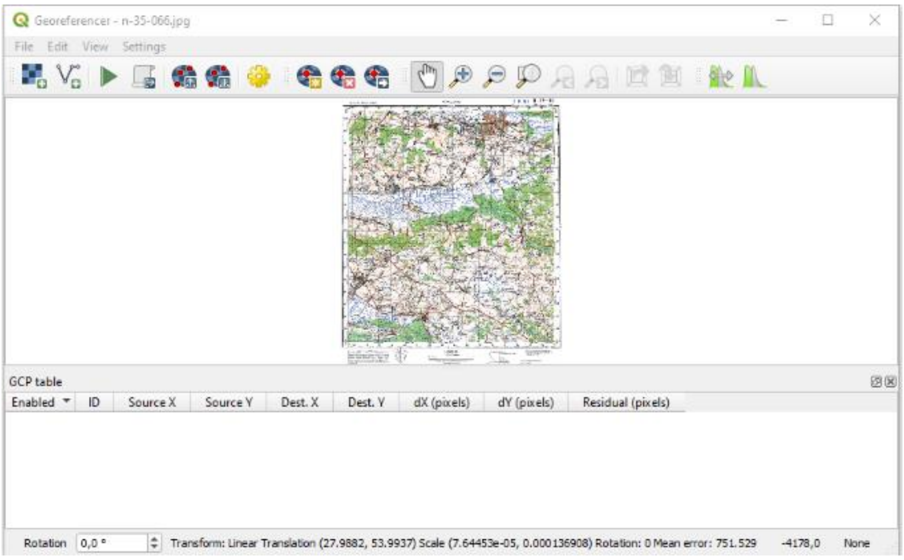



Figure 50. – Loaded a raster map

To add a raster, choose on the panel *File* → *Open raster* or use the *Open raster* icon on its toolbar and load one of raster maps, for instance *n-35-066.jpg*.

Click the *Start Georeferencing* icon, a small pop up panel reminds you 'Please set output file name', click OK, fig. 51. On the panel of Trasformation Settings, that appears, select Resampling method –*Nearest Neughbour* and check ☑ 'Save GCP points' and 'Load in Project when done'. Click the Start CRS icon, and click OK, fig. 52.

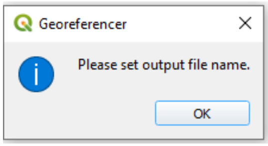



Figure 51. – Georeferencer reminder

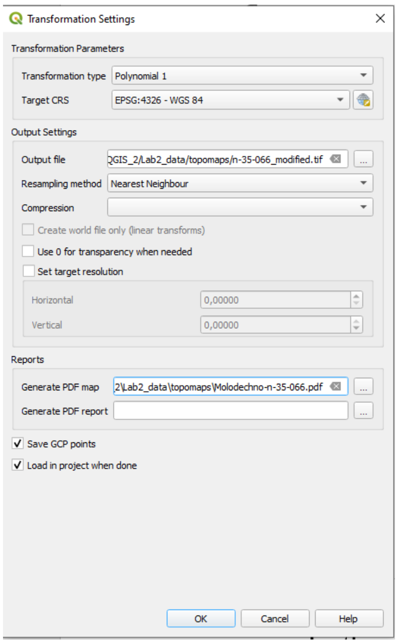



Figure 52. – Transformation Settings panel

In the panel Coordinate Reference System (CRS) Selector, that appears, set the following coordinate system: Rectangular coordinate systems Transverse Mercator - *Pulkovo 1942/GaussKruger zone 5* (linking maps are compiled in this coordinate system) and click OK button, fig. 53.

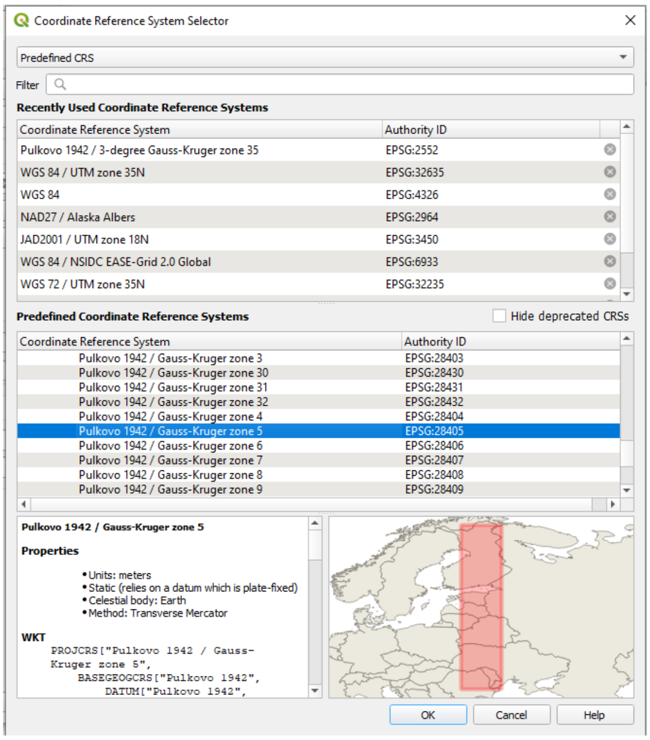



Figure 53. – The panel of Coordinate Reference System Selector

We will use the intersection nodes of the kilometer grid as reference points. The kilometer grid is formed by a system of lines parallel to the image of the axial meridian of the zone (vertical grid lines) and perpendicular to it (horizontal grid lines). The distance between adjacent grid lines on maps at a scale of 1:100,000 is 1 cm (1 km). The ends (outputs) of the coordinate grid lines near the frame of the map sheet are signed with the values of their rectangular coordinates in kilometers. The extreme lines on the sheet are signed with the full values of zonal coordinates in kilometers. The rest of the grid lines are the last two digits of the coordinate values (abbreviated coordinates).

The labels of the vertical lines indicate the zone number (first digit) and the distance in kilometers (three digits) from the origin of coordinates, conditionally moved to the west of the middle meridian by 500 km. For example, the signature 5596 in the upper left corner means: 5 is the zone number, 596 is the distance from the conditional origin in kilometers.

Labels of horizontal lines mean the number of kilometers, on which a particular line is offset from the equator. Thus, the point, located at the intersection of the kilometer grid lines (5596 and 6170), will have the following coordinates (in meters): $x$ = 5,596,000 and $y$ = 6,170,000, fig. 54.

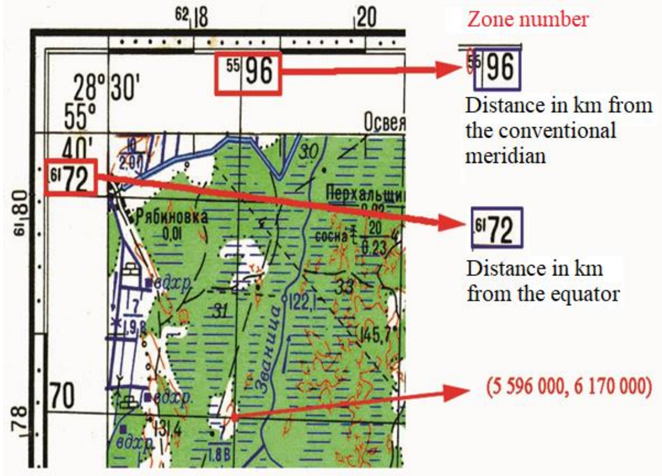



Figure 54. – Fragment of a map

***Step 3.*** Increase the extent of the raster using the *Zoom* and *Pan* tools near the top left corner of the topographic map.

Select the *Add point* tool, click the cursor at the intersection of the kilometer grid lines on the map. In the window that appears, enter the coordinates of the corresponding intersection node, fig. 55, they will be added to the GCP table.

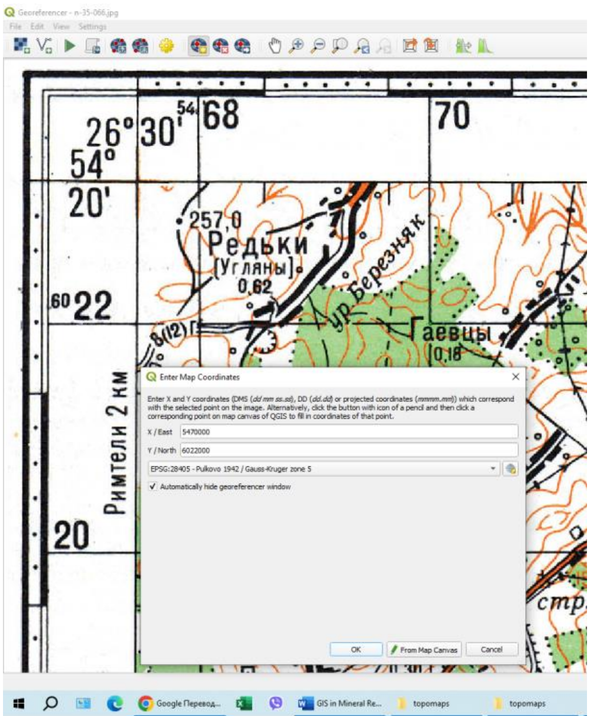



Figure 55. – Fixing coordinates of control points

Using button *Move GCP point* button you can move created points, if they are not located where you want. Digitize at least four reference points (preferably six to eight), which are evenly spaced on the map sheet.

After placing the required number of points, the points collection window should look like in fig. 56.

GCP table

| Enabled | ID | Source X | Source Y | Dest. X | Dest. Y | dX (pixels) | dY (pixels) | Residual (pixels) |
|---|---|---|---|---|---|---|---|---|
| ✓ | 0 | 437.828226 | -405.740323 | 5470000.00 | 6022000.00 | -0.341532 | -0.683065 | 0.763689 |
| ✓ | 1 | 3773.9153 | -394.128226 | 5498000.00 | 6022000.00 | 0.341532 | 0.683065 | 0.763689 |
| ✓ | 2 | 3790.3089 | -4416.0121 | 5498000.00 | 5988000.00 | -0.341532 | -0.683065 | 0.763689 |
| ✓ | 3 | 452.855645 | -4424.8919 | 5470000.00 | 5988000.00 | 0.341532 | 0.683065 | 0.763689 |

Figure 56. – GCP table with parameters of control points

To save the collected points, in the *File* menu of the Georeferencer panel, select *Save GCP points as*... or use the icon . They will be saved to an additional file with the *.points extension, which has same name as the raster map being linked. The content of the file is easy to edit in any text editor. If for some reason the process of arranging points had to be interrupted, then the next time the raster is loaded, the placed points will be loaded along with it. To load another point file, select *File* → *Load GCP Points*... at the same panel. A view example of another raster map with 5 points selected and the GCP table is shown in fig. 57.

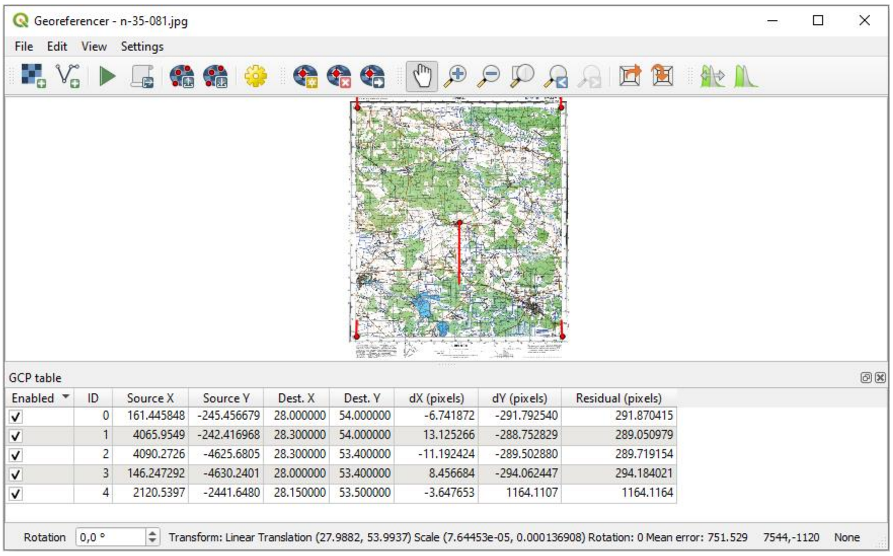



Figure 57. – A map view with GCP table of 5 control points in degrees-minutes (Dest. X – Dest. Y columns)

***Step 4*** Define the transformation options for the binding. Click *Settings* → *Transformation Settings*... ( icon) and set the following settings: *Transformation type* – Polynomial 1 or Polynomial 2 (it is recommended to use a polynomial model corresponding to the number of created control points); The *Interpolation method* is Nearest Neighbor as it was selected above, if not indicated earlier (see figs. 52, 53).

Save the target raster to your folder with a new name (for example, n-35-066_modified.tif). Target coordinate system – Rectangular coordinate systems Transverse Mercator – *Pulkovo 1942/GaussKruger zone 5*. Activate *Load in project when done* (see fig. 52). Once the transformation is complete, the output raster will automatically be loaded into QGIS, fig 58.

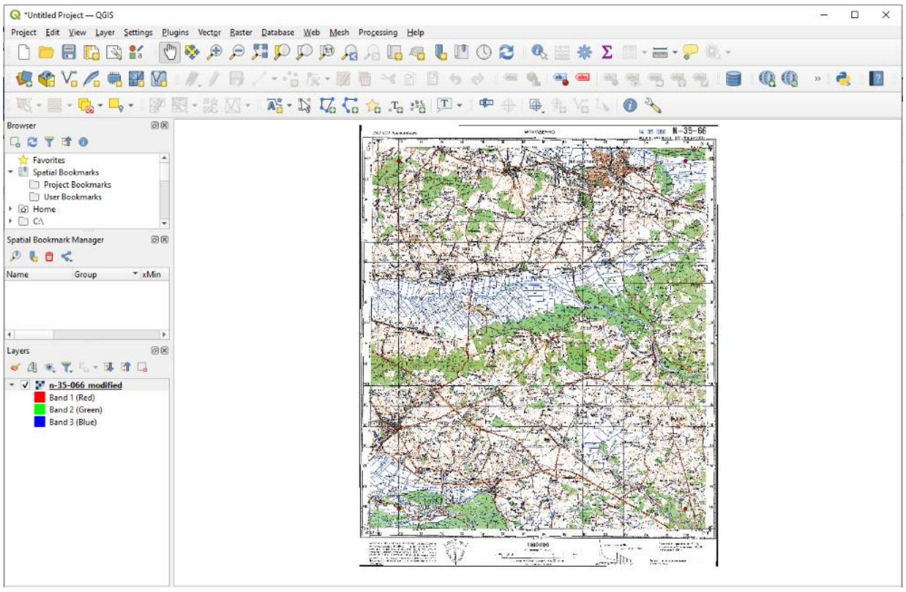



Figure 58. – Map view

***Step 6.*** Using the *Add vector layer* tool, load the kilometer grid shapefile located in the source data folder (z5gk.shp) into the project to check the alignment accuracy, fig. 59. First make sure that in the project properties (*Project → Properties…*) the Pulkovo 1942/GaussKruger zona 5 coordinate system is set.

| | |
|---|---|
|  |  |
| An example of a "good" anchor - the anchored map matches the computational grid (red lines) | An example of inaccurate referencing – the referenced map does not match well with the computational grid (red lines) |

Figure 59. – Checking the alignment accuracy

Close the *Georeferencing* tool window.

## II. Georeferencing a raster image by a vector layer

**Step 1.** In the QGIS Desktop 3.34.6, create a new project (*Project* → *New*). Using the *Add Vector Layer* tool, load the *country.shp* shapefile (located in the source data folder) into the map area. Specify the coordinate system of the project, to do this, in the *Projects* menu, select *Properties* and go to the Project Properties – CRS. *Selected system*: WGS 84.

***Step 2*** Change the symbology of the "country" layer. Right-click on the layer name in the legend and in the menu that opens, select *Symbology*. In the *Symbology* window, select *Simple fill*. Set: *Fill style* – No Brush, *Stroke color* – red, *Stroke thickness* – 0.6 mm, fig. 60.

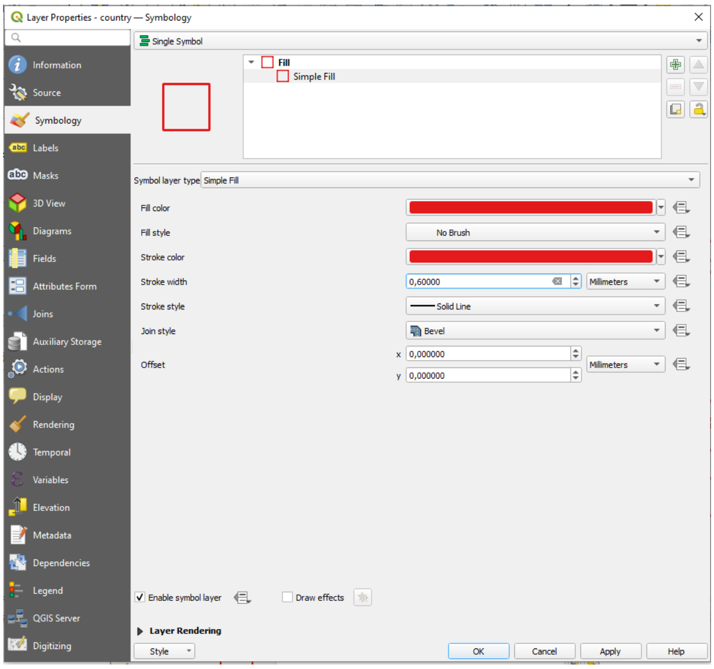



Figure 60. – Layer Properties country – Symbology

Click OK and close the *Properties* dialog box.

***Step 3***. Use the *Zoom In* and *Pan* tools to enlarge the map extent so that it includes Latvia, Belarus, and Ukraine, fig. 61.

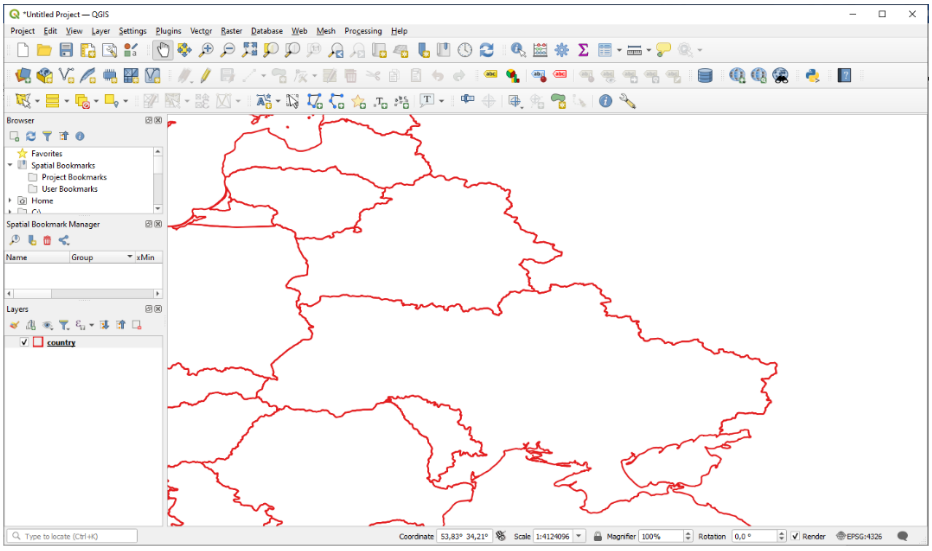


Figure 61. – Borders of Belarus and neighbor countries

***Step 4***. Launch the Georeferencer (*Layer → Georeferencer*). Load a raster layer "linguistic map.jpg" into the module data view from the source data folder (*File → Open raster* or click *Open raster*). Set the coordinate system of the vector layer (*Source – Assigned Coordinate Reference System (CRS) – Set CRS*) by which set to be bound and will be performed (Geographic coordinate systems – WGS 84). To quickly find the required coordinate system, you can use the EPSG (European Petroleum Survey Group) code, fig. 62.

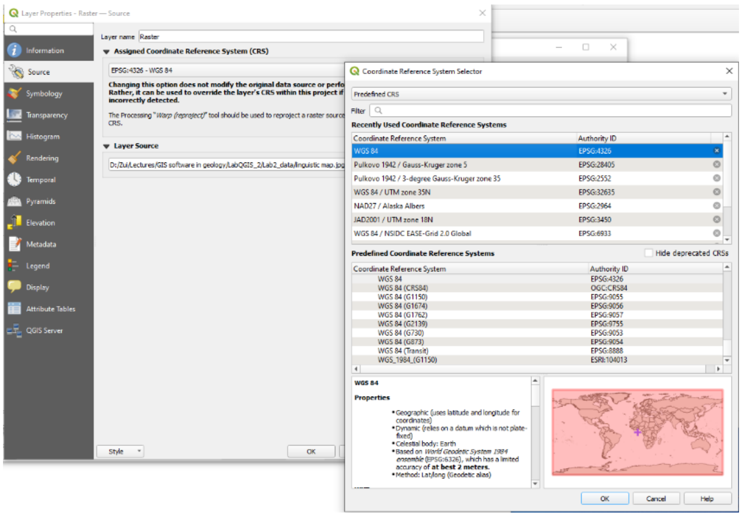


Figure 62. – Selecting of the coordinate system

EPSG codes, which are a register of definitions of various coordinate systems and transition parameters between them, are stored in a database and can be used to describe a projection.

***Step 5*** Use the *Zoom in* tool to zoom in on the northwestern tip of Belarus. Click the *Add Point* icon of Georeferencer, the cursor will turn into a crosshair and place it at the junction of the borders of Belarus, Poland and Ukraine and click the left mouse button. In the *Enter map coordinates* window that appears, select *From map canvas*, fig. 63. In the QGIS map area (with the "country", that appears), specify left-clicking by your mouse the corresponding intersection of Belarus, Poland and Lithuania borders. The X, Y coordinates of the reference point will be added to the GCP table. Click OK.

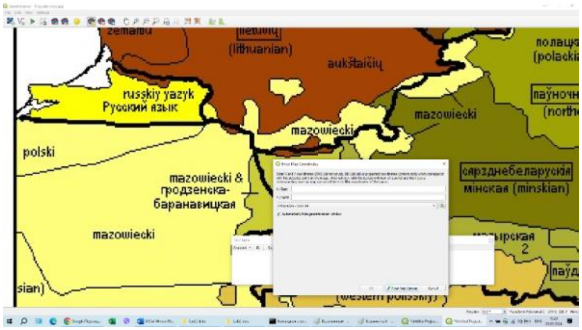



Figure 63. – Selecting of the coordinate system

Continue entering control points. Use the administrative boundary crossing points, characteristic bends of the border lines as reference points. The points must be evenly spaced. Set at least 10 control points (required for 3rd degree polynomial conversion). Save the checkpoints (*File* → *Save GCP Points As*...).

***Step 6***. Set the following transformation parameters in Georeferencer (*Settings* → *Transformation Settings*). The dialogue panel will appear: set there the *Transformation type* – polynomial 2, Transformation type – *Cubic* (*4×4 Kernel*). Define the *Output file*. The Target CRS (target coordinate system) should be set automatically (WGS 84). Activate *Save GCP points* and *Load in project when done*, fig. 64. Click OK.

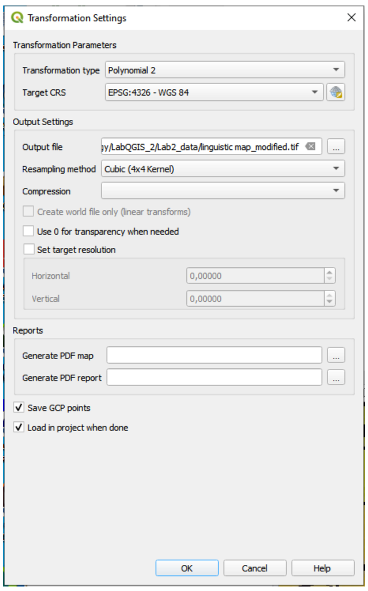



Figure 64. – Transformation settings panel

On the Georeferencer toolbar, click the ▶ *Start Georeferencing* icon.

Rebind using a 3rd degree polynomial transform type (*Settings* → *Transformation settings*, then in *Transformation Settings* panel change the polynomial transform type in *Transformation Type* window). Increase the number of anchor points if necessary.

The alignment accuracy of all control points can be measured mathematically by comparing the known location of the point in map coordinates and its position on the transformed raster. The distance between locations of these two points is called residual error (RMS). In the *Control Points* window of the *Raster Binding* module (*Residual* column) you can estimate the error value for each point. The error is measured in units of the original coordinate system, i.e. if you refer to a newly scanned map, then the transformation error will be expressed in pixels.

The total root-mean-square (RMS) conversion error is calculated by taking the square root of the sum of the squared errors of all links and dividing by the number of links. This value shows how different the result of the transformation is from the ideal combination of all control points (links).

To reduce the magnitude of the error, it is generally recommended to eliminate the control point with the largest deviation (or replace it). A point should not be deleted if its position is confidently determined or if its deletion violates the condition of uniform distribution of control points over the entire geoimage.

Transform the map using the *Thin Plate Spline* and *Projective* methods. Create and complete the table 1.

Table 1. – Raster transformation

| Transformation Method | Total RMS Error | Print Screen Map |
|---|---|---|
| 2nd order polynomial | | |
| 3rd order polynomial | | |
| Thin-walled spline | | |
| Projective method | | |

Figure 65 shows a raster image bound by the 3rd order polynomial transformation. As you can see, the map quite accurately coincided with the contours of the administrative-territorial division, which, given the initial quality of the materials, can be considered a satisfactory solution.

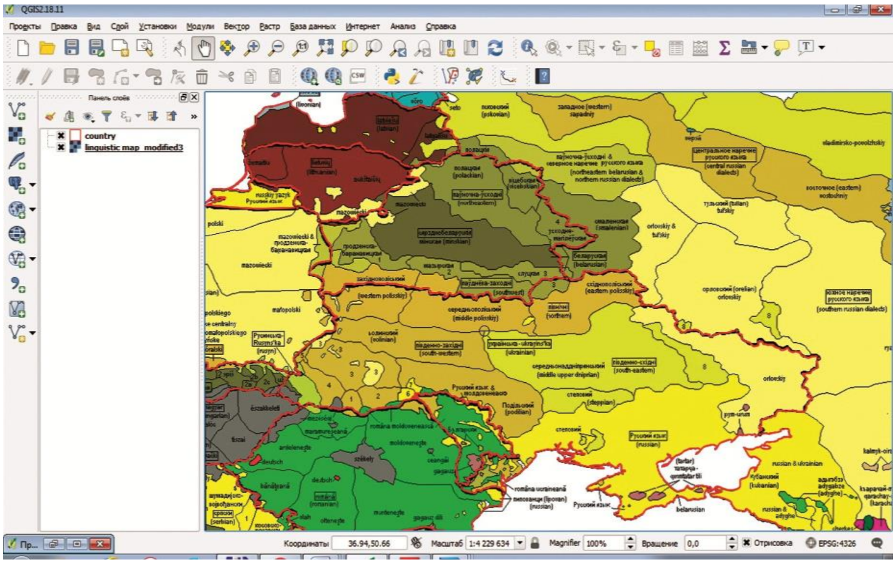


Figure 65. – Study region

## 2.3. Laboratory work 3. Creating a point layer from text data in QGIS. Heat maps

**The purpose of the laboratory work**: to become familiar with the algorithm for converting sets of coordinates from various kinds of tables into vector layers of a point type and creating ‘heat’ maps in QGIS**.**

**Initial data:**

● data on the coordinates of tourism objects in the Brest region in MS Excel format;

● shape file containing the boundary of the Brest region (*Grodno_boundary.shp*).

### Laboratory progress

### I. Creating a point shapefile from text data

Let us analyze the problem of creating a shapefile from text data using the example of creating a vector layer of tourist objects in the Grodno region.

***Step 1***. Preparing data for import. The initial data contain information about the coordinates of tourist sites in the Grodno region and are presented in the Excel format. Open the *attraction.xlsx* file located in the source data folder in Microsoft Excel. Add a *numb* field and number the objects from 1 to 49. Save as a *.csv* (comma delimited – разделители запятые) text file, fig. 66. CSV is a text format for storing tabular data.

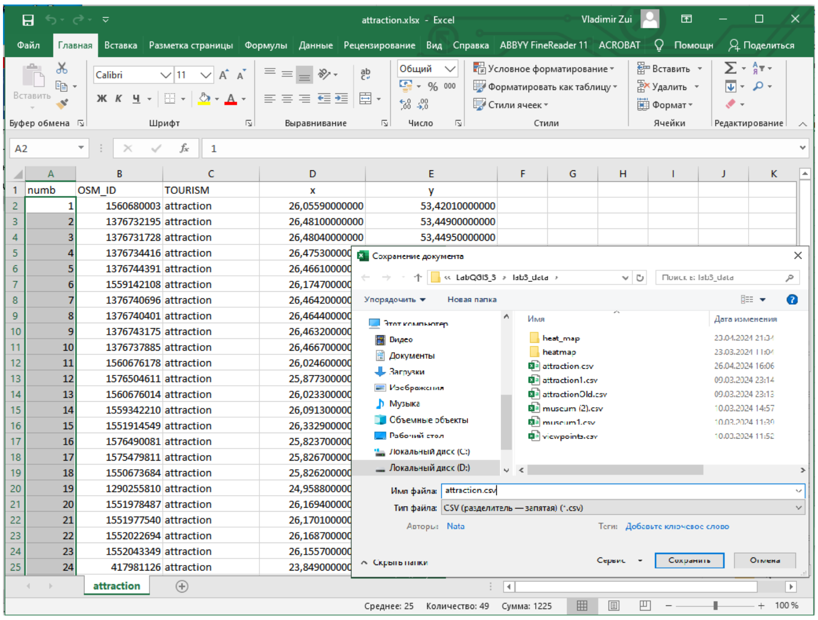



Figure 66. – Reformating a *xlsx* Excel file into *csv* Excel file

.1

***Step 2***: Open QGIS Desktop 3.34.6. Start working with a new empty project. Activate the *Add Delimited Text Layer…* tool in the *Layer– Add Layer* panel. In the *Data Source Manager | Delimited text* dialog box that opens, specify the *attraction.csv* file to be added by clicking the *Browse* button (or drag-n-drop it from the source folder). Check the *Custom Delimiters* option and select *Semicolon*. If the separators are selected correctly, the data is displayed correctly in the preview area. Check that the *Xcoordinate* field is set to *x*, and the *Ycoordinate* field is set to *y*. Leave the rest of the settings as default. Click Select CRS icon. In the Coordinate Reference System Selector, which opens, specify WGS 84. The "attraction" layer will appear in data view, fig. 67. Click Add, then – Close.

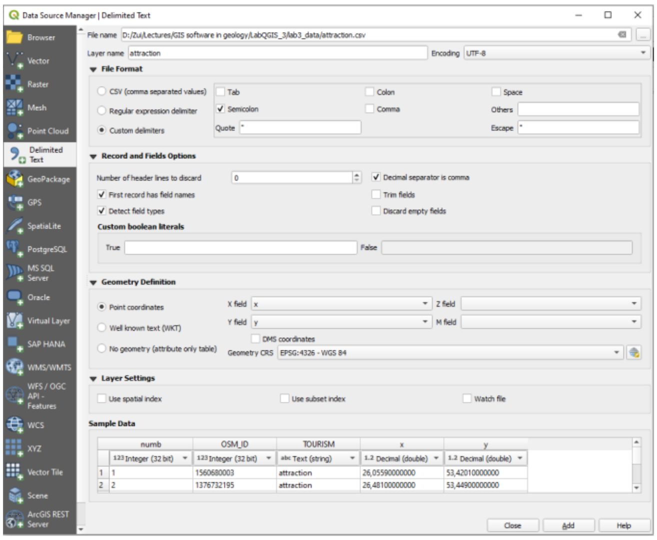



Figure 67. – Creating a shape file progress

***Step 3*** Open the attribute table of the "attraction" layer. The full set of values from the source database for each point is stored. At the same time, the resulting layer is virtual: it is not written to disk and is not available for editing. Save the virtual layer as a shapefile. Right-click on the name of the vector layer in the legend, select *Save as*..., fill in the window: using the *Browse* button, specify the location and name of the new file (for example, *attraction1.shp*), set the project coordinate system to WGS 84. Click OK. A new layer will appear, written to disk, available for editing. Delete or uncheck the "attraction" virtual layer (right-click on the layer name in the legend → *Delete*)**.**

***Step 4.*** In the same way, convert the files located in the source data folder *museum.xlsx* and *viewpoint.xlsx* into point shape files.

***Step 5.*** Add the "Grodno_boundary" layer to the project (located in the source data folder). Move it down in the legend. Symbolize the layer with a *Single Symbol* ( icon). Set the *Stroke* – red, *Stroke widths* – 0.6 mm, fig. 68.

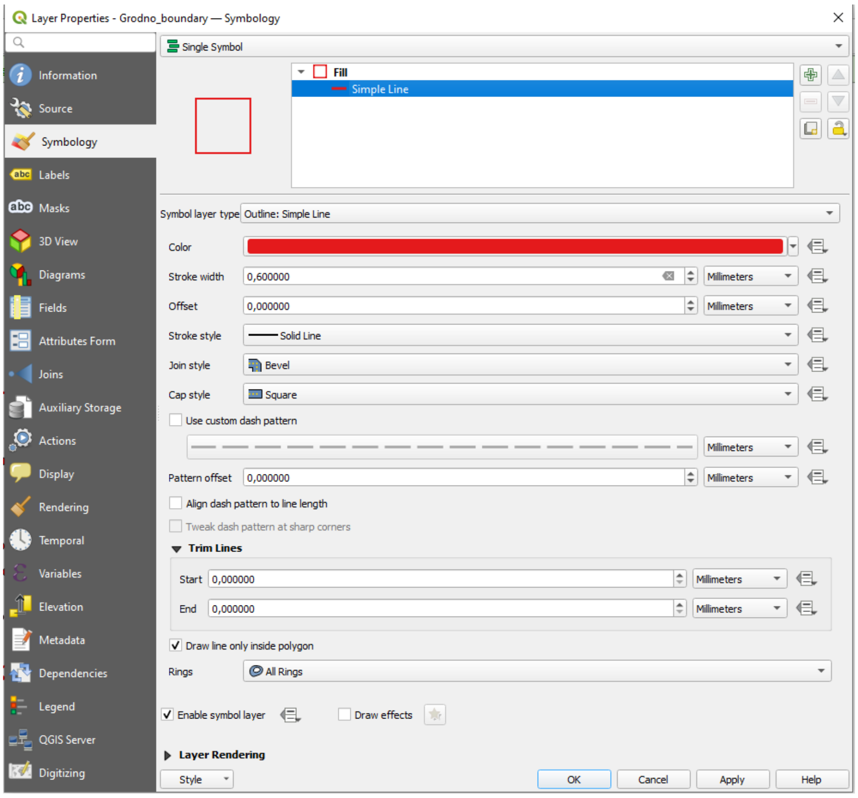



Figure 68. – Layer properties – Grodno_boundary Symbology panel

***Step 6.*** Merge shapefiles. From the *Vector* menu, select *Data Management Tools* → *Merge Vector Layers*, fig. 69.

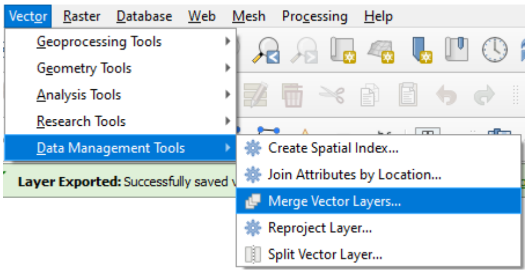



Figure 69. – Merging vector Layers option

In the *Merge vector layers* window on the *Parameters* tab, click the button *Select All* at the Input Layers line and in the window that opens, select three created shapefiles simultaneously (*attraction1.shp, museum1.shp and viewpoint1.shp*). Click OK, fig. 70.

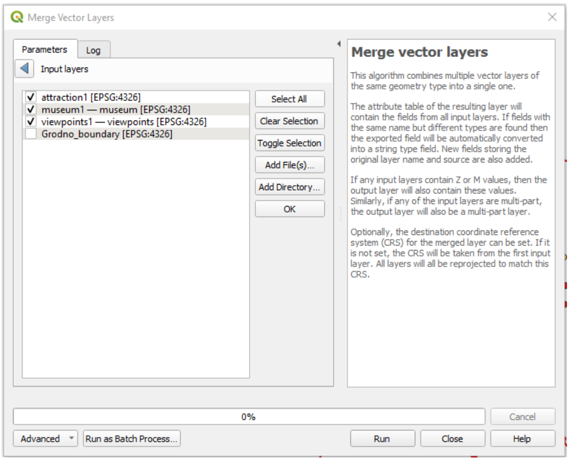



Figure 70. – Merging vector Layers option – selecting three files

Save the result of the merging to your folder under the name "poi-point.shp". Check the *Open output file after algorithm execution* option. Press the *Run* button, fig. 71.

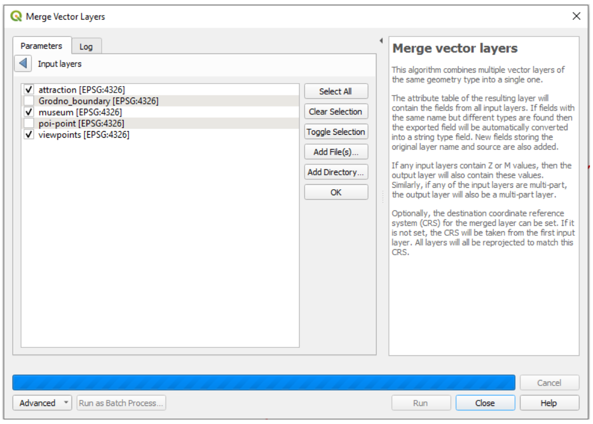



Figure 71. – Progress of merging vector layers

A layer called "Merged" will be added to the project, containing features from the three source shapefiles, fig. 72.

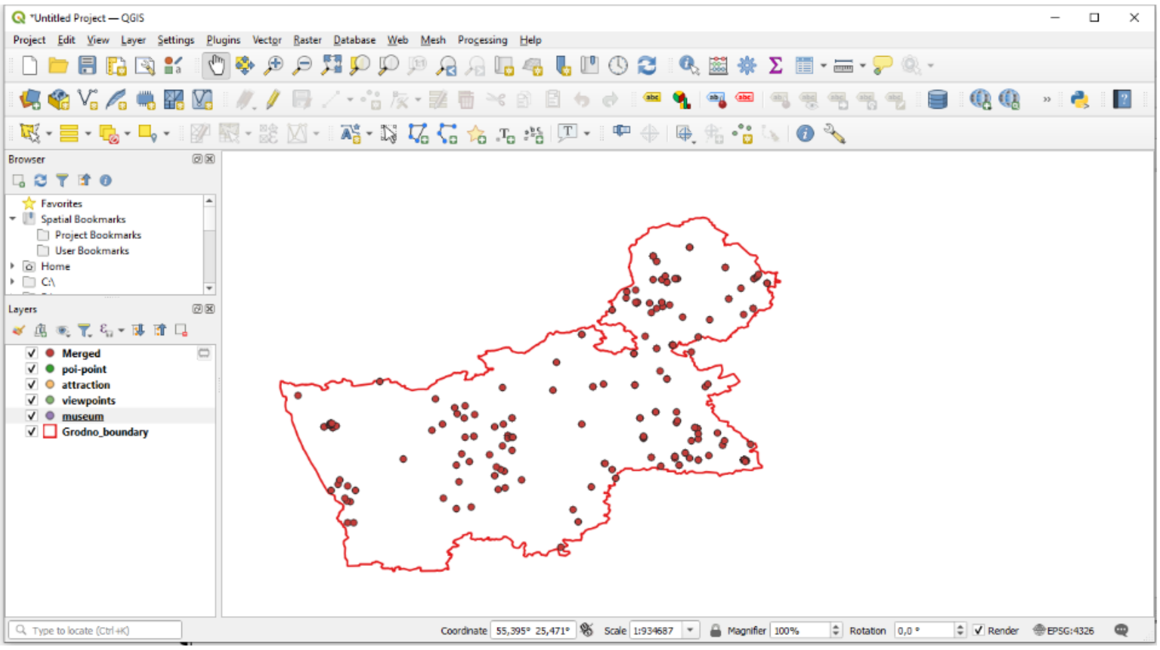



Figure 72. – Map with points within Grodno region

**II. Creating a Raster Density Map (Heat map)**

**A heat map** is a raster map that shows the density of point data. Density is calculated from the number of points in a certain area, more points gives a higher density value. Heat maps make it easy to identify clusters of points and identify "hot" areas. Density maps in QGIS are created using several individual modules to create "heat maps", for instance: *D3 Data Visualization*; *heatmapplugin*; *densityanalysis-2024.1.23.* The *Density Analysis* plugin included in the used QGIS release.

This plugin automates the creation of density heatmaps in QGIS with a heatmap explorer to examine the areas of greatest concentrations. It includes H3, geohash, and polygon density map algorithms along with several styling algorithms. It can paste a style onto all selected layers. Two options are described below: Option 1 and Option 2, you may choose one (or both) of them.

**Option 1.**

***Step 1.*** Activate the plugin by selecting *Manage and Install Plugins…* from the *Plugins* menu. On the *Installed* tab, check Density. If it is not installed, then open *Not Installed*, find and install it, fig. 73. After successful installation, several icons will be added to the toolbar).

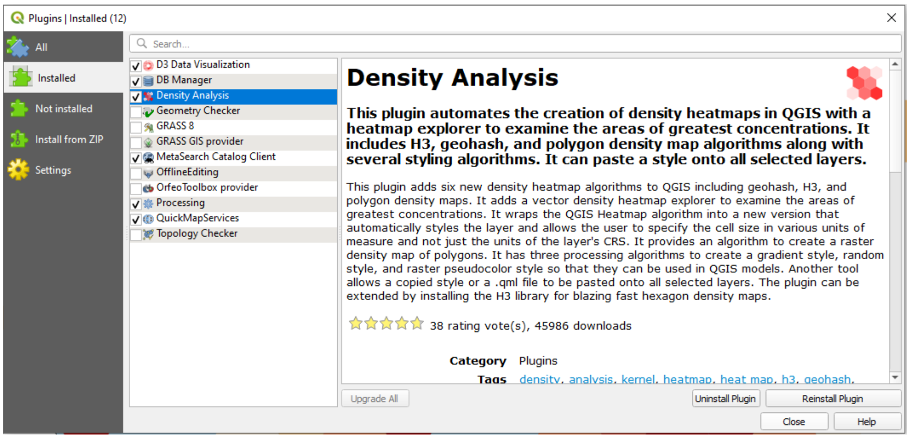



Figure 73. – Density Analysis plugin

This plugin adds additional density heatmap algorithms to QGIS including geohash, H3, styled heatmap, and polygon density maps. It adds a vector density heatmap explorer to examine hotspot areas of greatest concentrations. It wraps the QGIS Heatmap (Kernel Density Estimation) algorithm into a new version that automatically styles the layer and allows the user to specify the cell size in various units of measure and not just the units of the layer's CRS. It provides an algorithm to create a raster density of polygons. It has processing algorithms to create a gradient style, random style, and raster pseudocolor style so that they can be used in QGIS models. Another tool allows a copied style or a *.qml* file to be pasted onto all selected layers. Once installed, the plugin is located under *Plugins* → *Density analysis* in the QGIS menu, on the toolbar, fig. 74, and can be found in the *Processing Toolbox* under *Density analysis*, fig. 75. This shows plugin from the main menu with Geohash density algorithms expanded.

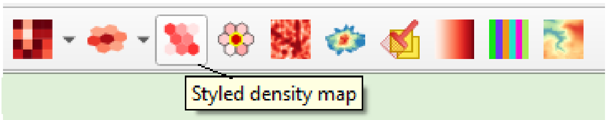



Figure 74. – Ten icons created after installation the Density analysis plugin

Details with multi-page description for each of its options can be fined at: https://github.com/NationalSecurityAgency/qgis-densityanalysis-plugin?tab=readme-ov-file.

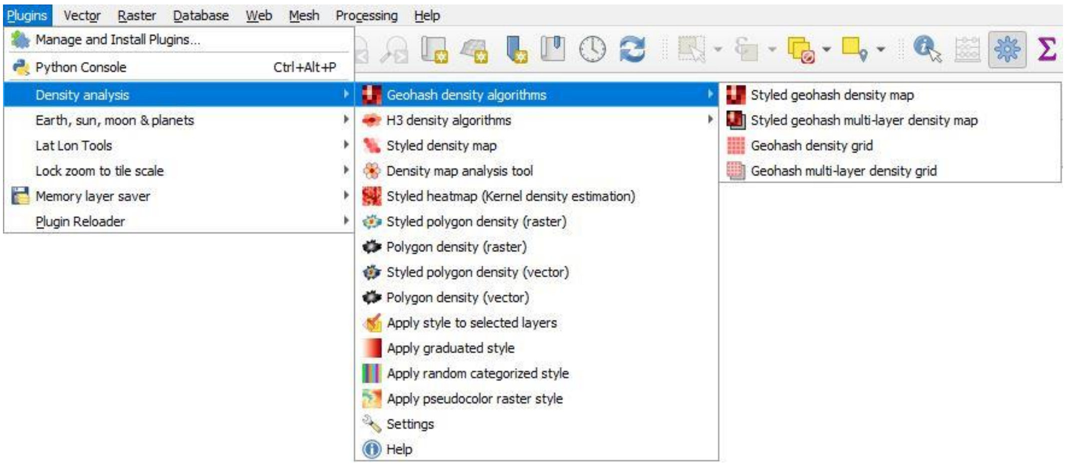



Figure 75. – Main options of the Density analysis plugin

***Step 2.*** Click the Styled density map  icon to open this plugin. The Styled Density Map panel will be open, fig. 76.

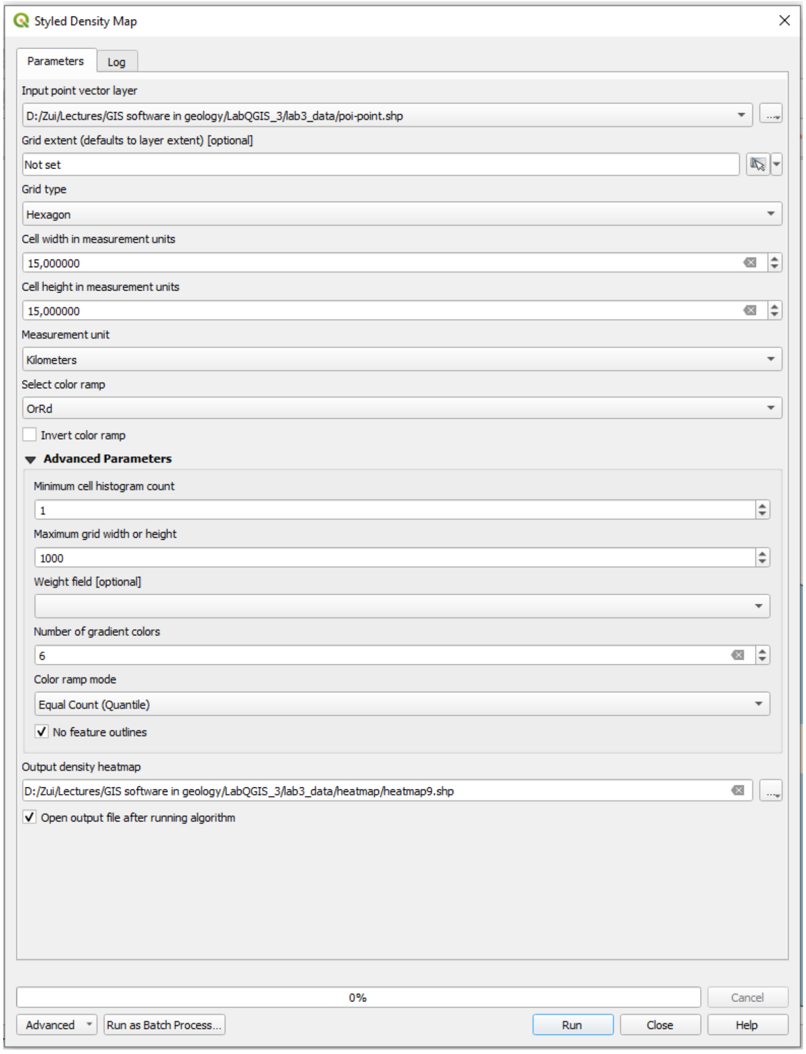



Figure 76. – The Styled Density Map panel

At this panel you'll configure your input and output parameters. Please use the created poi-points.shp as the input file, grid type, windows cell width in measurement units, cell height in measurement units, select color ramp, and maximum grid width on heights and number of gradient colors could be adjustable according your request. An example is shown in fig. 76.

Finally, you'll select the output density heatmap, for instance as file poi-heatmap.shp, and click Run. You'll see the image like shown in fig. 77.

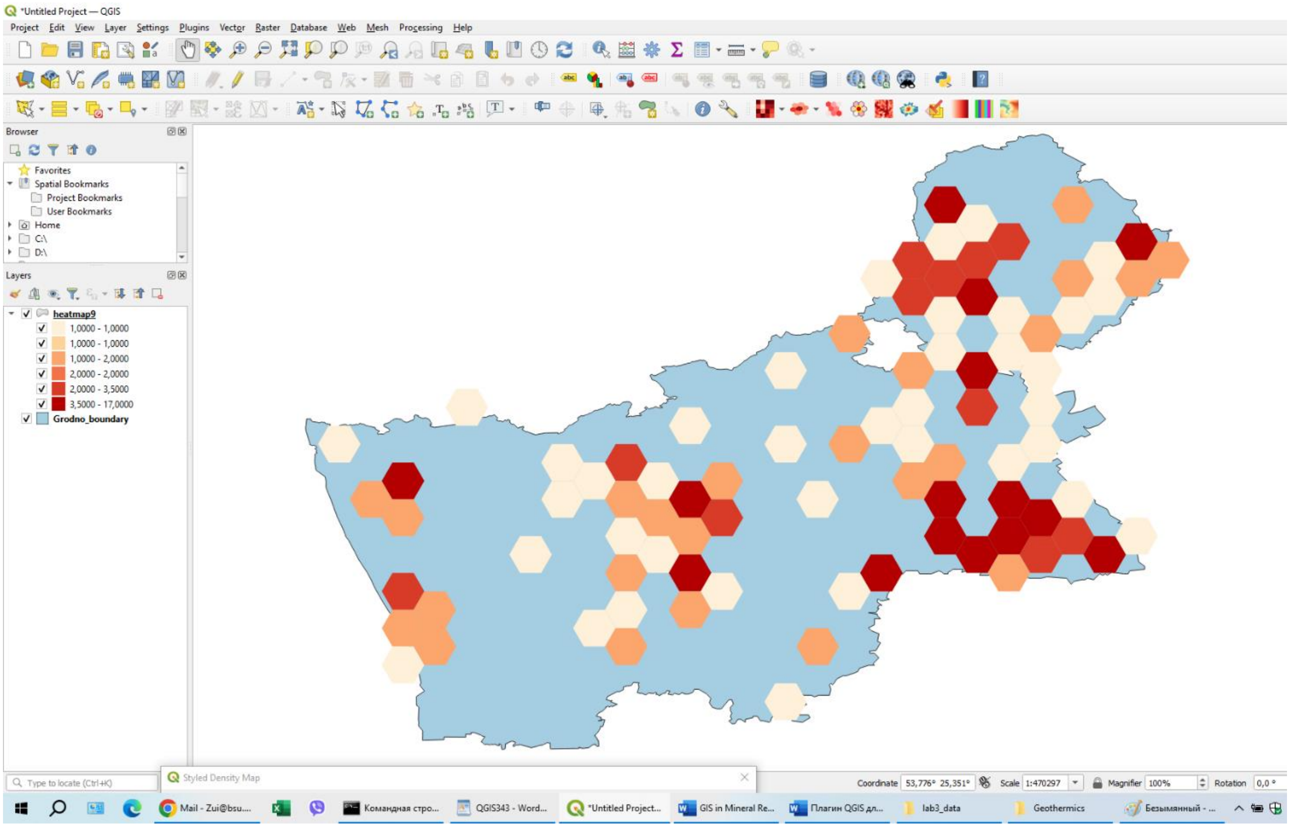


Figure 77. – An example of the heat map according to parameters set above

You can play with options in the Style Density map panel, see fig. 76 and heatmaps with individual colors and shapes. The variety of options of the Density Analysis plugin was shown in fig. 75 above. If you like, you can also experience with other options besides already considered one (Styled density map) of the Density Analysis plugin yourselves (they are: *Geohash density algorithms*, *H3 density algorithms*, *Density map analysis tool*, *Styled heatmap (Kernel density estimation)*, *Styled polygon density (raster)*, *Polygon density (raster)*, *Styled polygon density (vector)*, *Polygon density (vector)*, *Apply style to selected layers*, *Apply graduated style*, *Apply random categorized style*, *Apply pseudocolor raster style*). Details with multi-page description for each of its options can be fined at: https://github.com/NationalSecurityAgency/qgis-densityanalysis-plugin?tab=readme-ov-file.

**Option 2.**

***Step 1***. There is another frequently used heatmap module (Kernel Density Estimation) available in the third QGIS releases, in particular in QGIS 3.34.6.

To open it click *Processing* → *Interpolation* → *Heatmap* (Kernel Density Estimation), fig. 78 and the dialogue panel pops up, fig. 79.

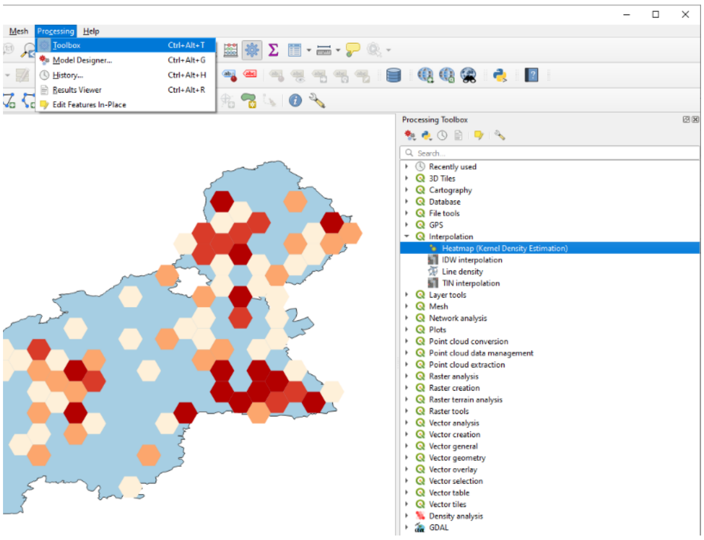



Figure 78. – Calling up the heatmap module

***Step 2.*** Set the source layer to "poi-point.shp" (the extension is not obligatory) from the work folder. Indicate the heat_map.tif in the "Heatmap" window, set "Radius" to be 0.30 degrees (you can play with this parameter, as well as with Rows and Columns).

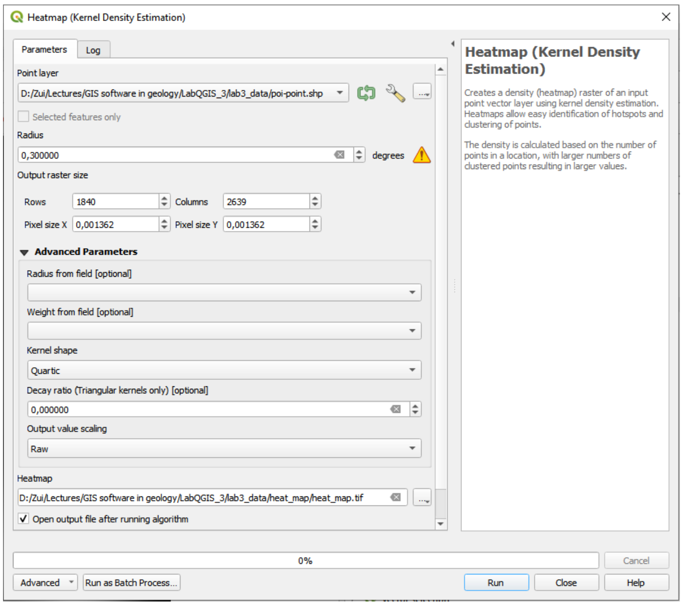



Figure 79. – Heatmap (Kernel Density Estimation) dialogue panel

Check the "Open output file after running algorithm". Radius determines the zone of influence of each point. Leave other options as shown in fig. 78. Click Run to create and load the heatmap in QGIS. Close the Heatmap dialogue panel.

Once loaded, the heatmap is displayed in grayscale settings, with low raster values representing dark shades and high raster values representing light shades, fig. 80.

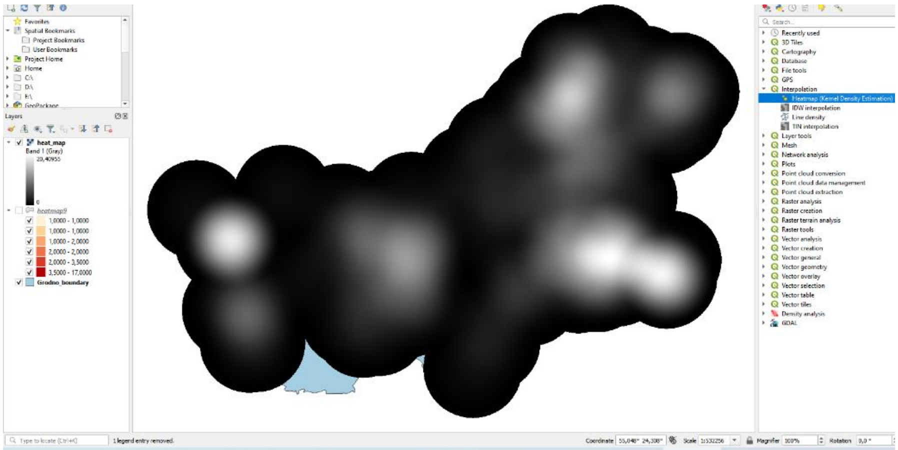


Figure 80. – Heatmap raster in dark shades

***Step 3***. Cut out the resulting raster along the border of the Grodno region. To do this, in the *Raster* menu, select *Extraction → Clip Raster by Mask Layer*. In the dialogue Clip Raster by Mask Layer in the *Input layer* window select "*heat_map*" (raster) in the drop-down list. In the *Mask layer* group, select *Grodno_boundary.shp*, other options are shown fig. 81. Click "Run" and "Close". The clipped map looks like in fig. 82.

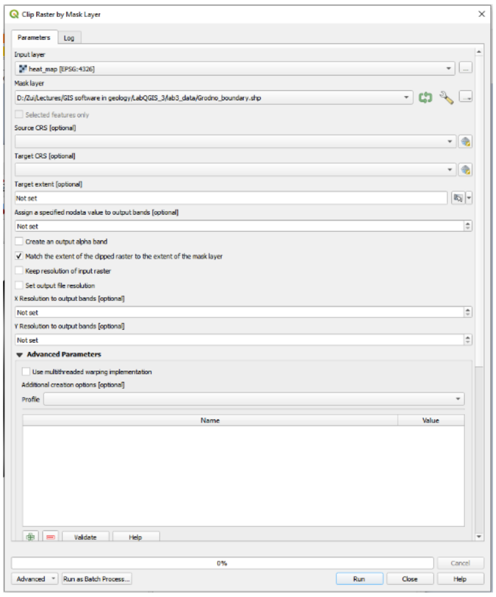


Figure 81. – Heatmap with raster in dark shades

In the Layers panel the *Clipped (mask)* raster layer (in the GeoTIFF format) will be added. Rename it to "POI_heat_map". Now you may deactivate or delete the *heat_map* layer from the project.

Figure 82. – Clipped heat map raster in dark shades

***Step 4***. Change the symbolization of the layer "POI_heat_map". To do this, select the layer in the list of project layers, call the context menu with the right mouse button and select *Properties*. Go to the *Symbology* tab. Change the rendering style in the *Band Rendering* field from "Singleband gray" to "Singleband pseudocolor." Select a suitable color map in the *Color ramp* field, for example OrRed. Mode – *Continuous* (fig. 83). Click the "Classify" button and adjust the classes of colors, e.g. – 5, then close the window and apply the raster display settings, fig. 84.

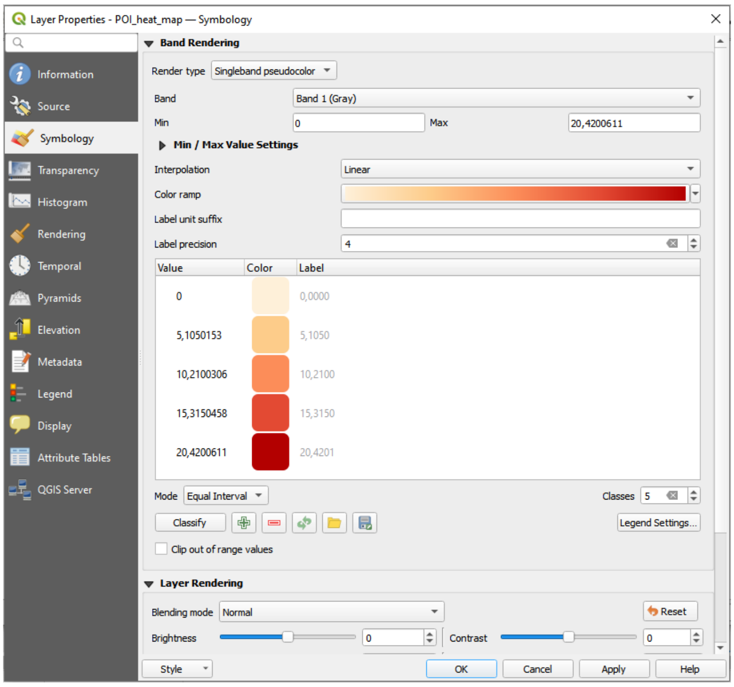



Figure 83. – Change the band (grey) for pseudocolor dialog

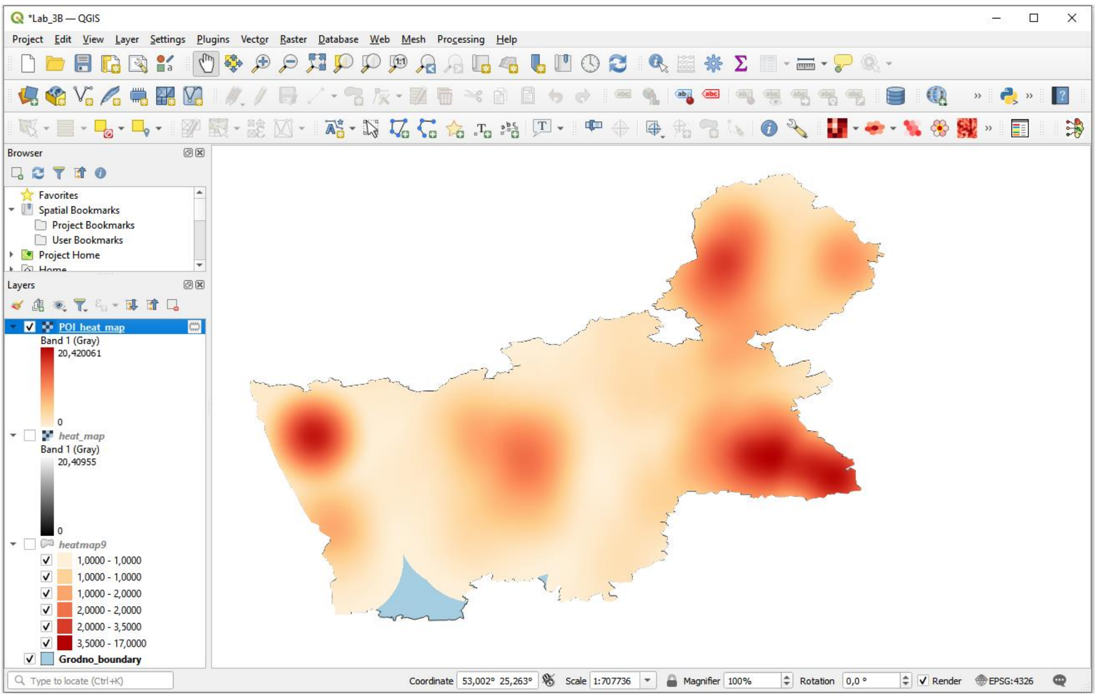


Figure 84. – Raster map in pseudocolor

***Step*** *5*. Create your own density maps using a *viewpoint* shapefile. When creating, select the optimal radius parameter. For *viewpoint* objects, create two heat maps using the kernel functions: Triweight one and Epaneshnikov (the kernel function can be selected in the corresponding drop-down menu of the *Advanced* group of the Create Heat Map tool). The kernel function specifies an algorithm that calculates the decrease in the influence of a point as the distance from it increases. Different functions have different reduction factors. Thus, the Triweight function gives more weight at small distances from a point compared to the Epaekshnikov function. And as a result, the Triweight function makes the "hot" spots clearer, and the Epaneshnikov function makes them smoother.

## 2.4. Laboratory work 4. Creating a tourist map in QGIS

**Lab Objective:** To learn how to create and edit vector polygonal, line and point objects and their attributes, actions and map layouts in QGIS.

**Initial data:**

● scanned and georeferenced map of Zaslavl – georeferenced *zaslavl.bmp* (which is successfully loaded as a raster layer under old QGIS releases, e.g. QGIS 2.18, but is loaded not correctly under, QGIS-3 releases). Its converting into *tif*, *jpg*, or *png* formats doesn't solve the problem. Therefore, we'll use the *Zaslawl_region.qgs* instead (created using QGIS 2.18) the single of which incorporates the raster file *zaslavl.bmp*.

● shapefile containing the railroad of the Minsk region (railway_Mo.shp);

● shapefile of buildings in Zaslavl (*building.shp*);

● shapefile of points of interest (POI) of the Minsk region (*entertainment_Mo.shp*).

## Laboratory progress

## I. Creating point, line and polygon features in QGIS

***Step 1.*** Open QGIS Desktop 3.34.6. Load the *Zaslawl_region.qgs* project with a single layer, fig. 85.

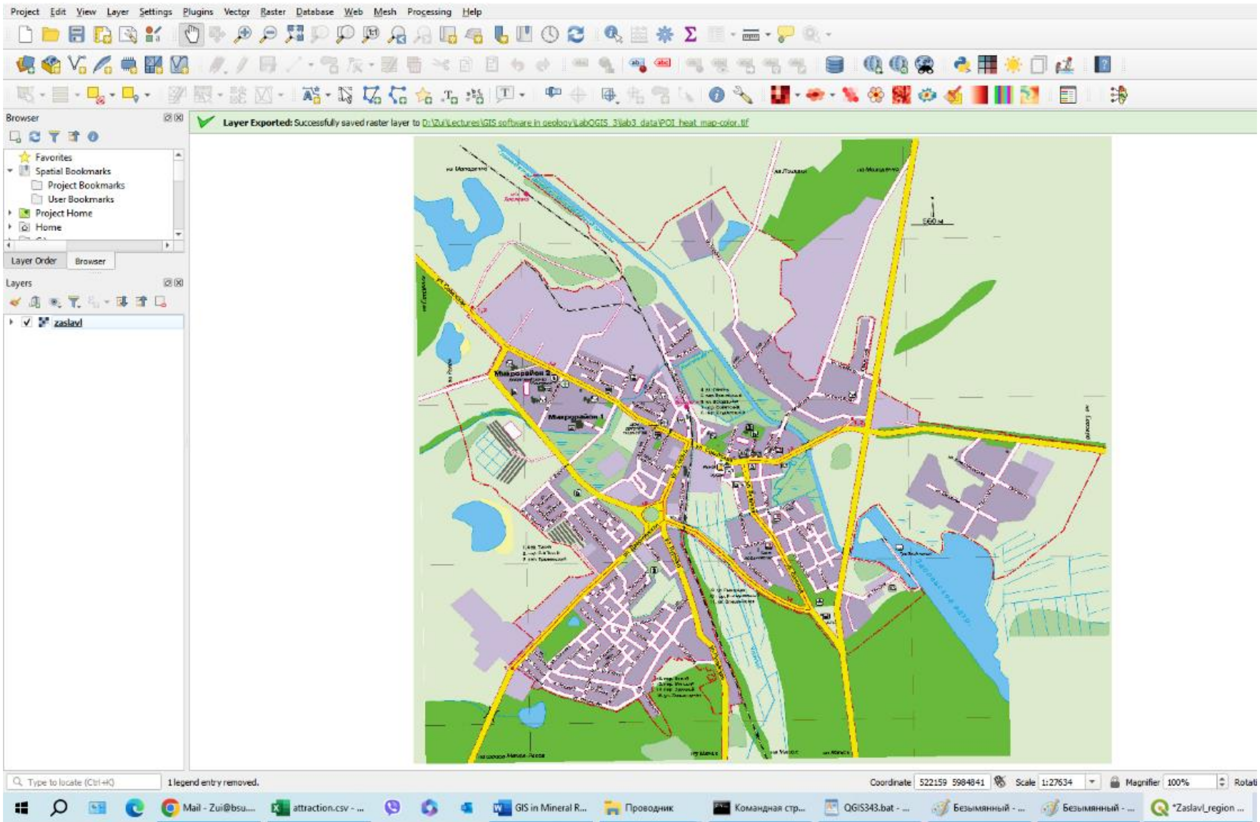



Figure 85. – Zaslavl town and adjoining area

Check the coordinate system for loaded image (*zaslavl layer* → *Properties* → *Source* → *Assign Coordinate Reference System* (*CRS*), it must be: *Rectangular coordinate systems* – WGS 84 / UTM zone 35N – EPSG: 32635, fig. 86. Otherwise, correct it.

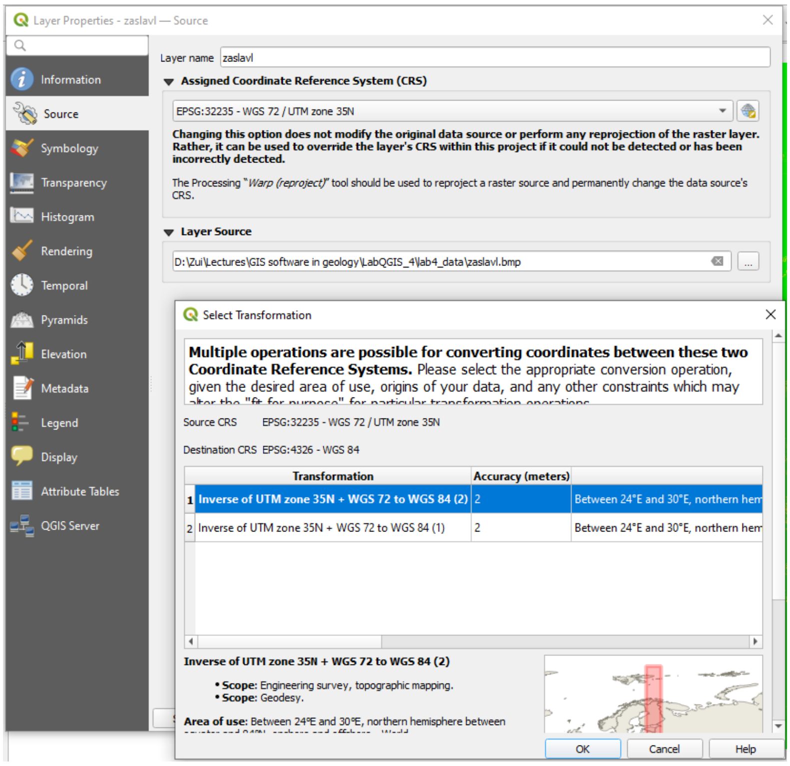



Figure 86. – Checking the coordinate system

***Step 2:*** Create a New Polygon Shapefile for the town boundary (ZaslavlBorder). From the *Layer* → *Create Layer* → *New Shapefile layer*… and click it to open the dialog panel, fig. 87. You also may use the icon, by default on the layers panel.

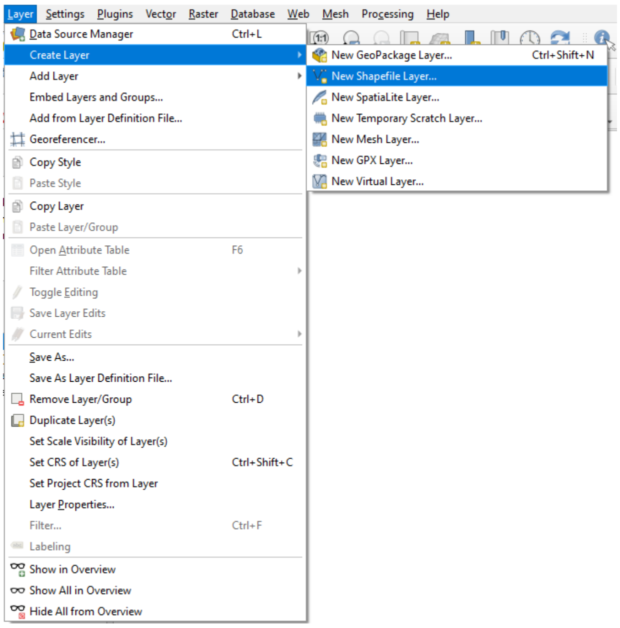



Figure 87. – Creating new shape file layer

In the dialog box set the required parameters. Firstly, set the geometry type of layer being created – polygonal ( Polygon), encoding: UTF-8, additional dimensions

– M values. Define the coordinate of the layer: WGS84 / UTM zone 35N. You can also define tab fields of the table of attributes. In the *Name* field, enter its name, in the *Type* field, select integer, decimal, text. To add and remove fields can be changed using the *Add to Field List* and *Delete field* buttons. By default, only the required attribute is included in the field list, but "id" (type – Integer, size – 10). This is a unique identifier.

Create a Name text field with a size of 50. Note that the name attribute must be written in Latin letters and contain no more than 12 characters. Most field properties after table creation, in particular, the field type and size cannot be changed.

The last step in creating a shapefile is assigning name and select the folder where the file will be stored. It is better to assign short and understandable names, such as "border", "river", etc. Name with stored shapefile "*ZaslavlBorder*" and click *Save* (fig. 88).

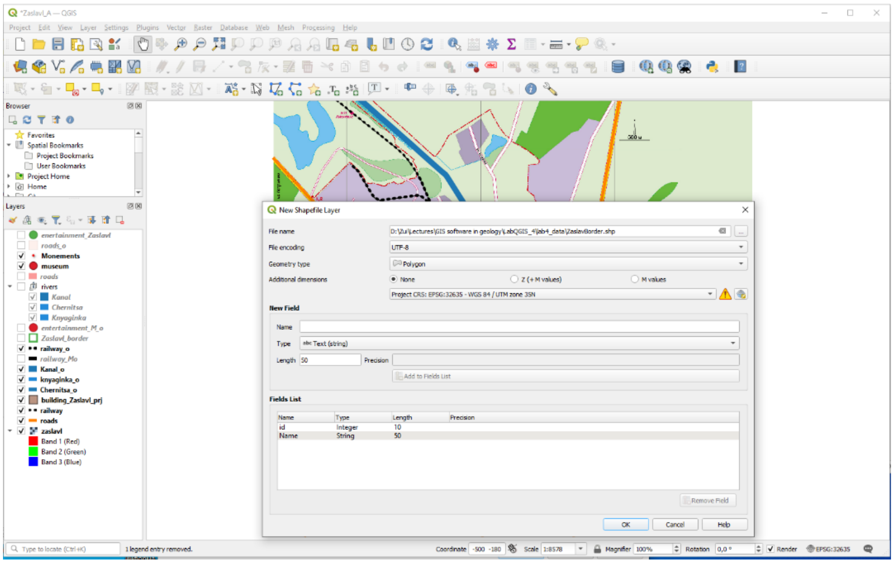


Figure 88. – Creating a new shape file polygon layer

After all the necessary parameters have been set, click OK button.

The newly created layer will appear in the legend of the QGIS project. The layer is edited in the appropriate mode using the editing panel tools, fig. 89.

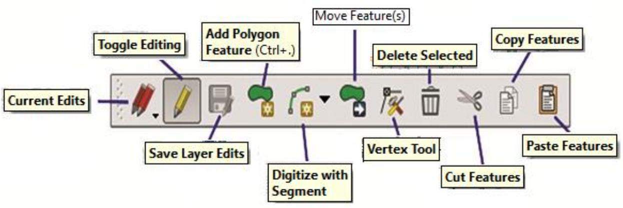



Figure 89. – Editing tools panel

***Step 3.*** Zoom in the Zaslavl raster map to desired extent to clearly distinguish small details along the border line. Now we'll set the vector layer editing parameters. For settings editing options select the *Layer properties – ZaslavlBorder* settings menu and go to the *Digitizing* tab. In the dialog box that opens, fill some of digitizing parameters. An example is shown in fig.90. Click Apply and OK.

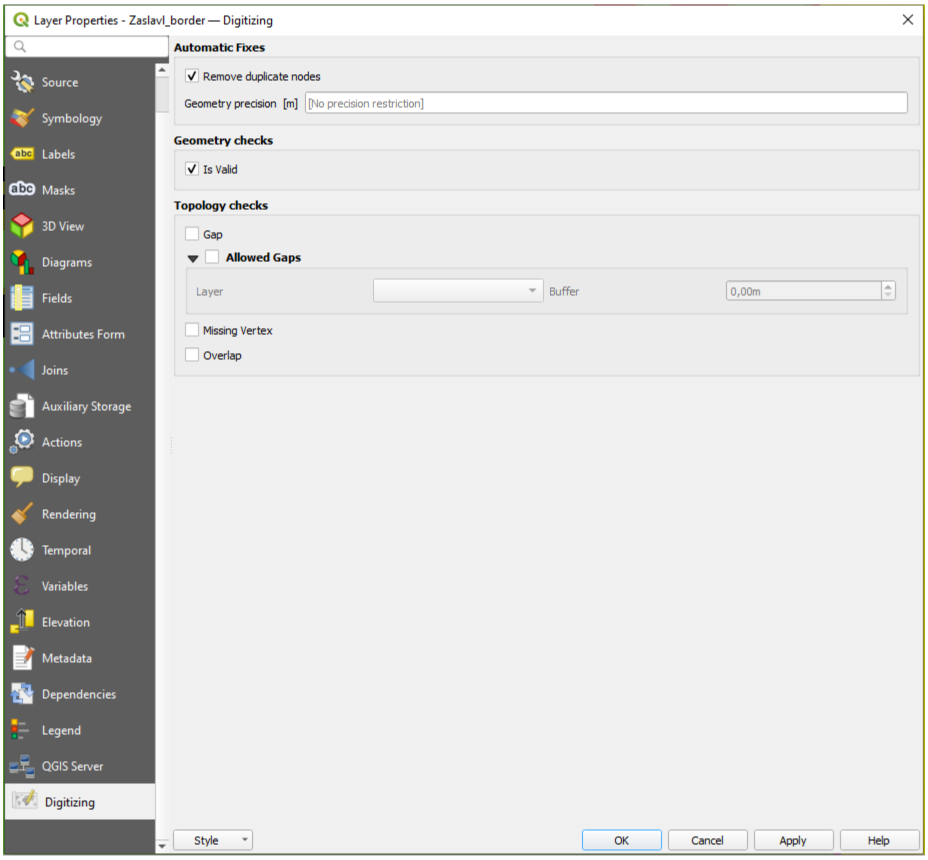



Figure 90. – Adding digitizing parameters

***Step 4***: Create a vector polygon feature in the layer "ZaslavlBorder". Switch to edit mode. With a dedicated layer legend window, click on the icon *Toggle Editing*. To add a polygon, click the icon *Add polygon feature* and the mouse cursor converts into the symbol. The border of Zaslavl town is shown in the raster map by the red dash-dotted line. Starting with **any point** of the town border line sequentially click the left mouse button, specifying vertices, gradually proceed with cursor around the city border line and clicking produce series of vertices. Click the right mouse button when you finish.

When vectorizing, if you have reached edges of the map area and you need to pan the image to move the visibility boundaries, hold the **Space** key and move the mouse without clicking buttons, then release it. You can Zoom in for more effective digitizing is possible also using the mouse wheel. The point that ends polygon input is indicated by right-clicking the mouse key.

If necessary, edit a created polygon, , use the *Vertex tool*, which allows you to delete nodes or change their locations, add new ones by double click. Exit edit mode clicking the *Toggle editing* icon a second time. Save ( icon) layer changes.

***Step 5.*** Symbolize the "ZaslavlBorder" layer as follows (right-click on the layer in the legend window → *Layer Properties ZaslavlBorder* → *Symbology*). Set the *Move* slider “opacity” around 25 % for the *Single Symbol* option ( icon) → *Fill*. For the Simple Fill option use settings as shown in fig. 91. Click Apply and OK.

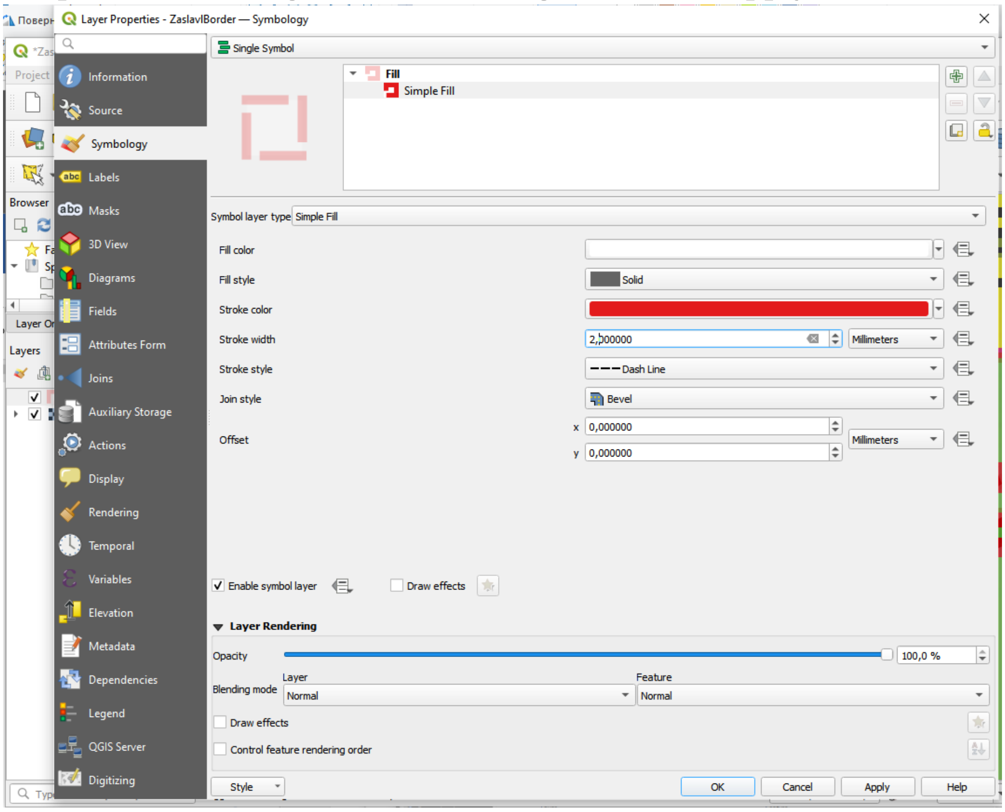



Figure 91. – Settings for ZaslavlBorder layer in Symbology panel

***Step 6.*** Create a new vector layer for *Knyaginka* river (*Layer* → *Create layer* → *New shapefile layer*). The *New Shapefile Layer* dialog box can also be invoked by the keyboard shortcut Ctrl + Shift + N. *Geometry type* – line string. Layer coordinate system: WGS 84 / UTM zone 35N. Additional dimensions – *M*. In addition to the default field with id *type* integer = 10 characters, add the text fields to the attribute table: and *Knyaginka* – 25 characters. After all the necessary parameters have been set, click OK. The new layer *Knyaginka* will be added, fig. 92.

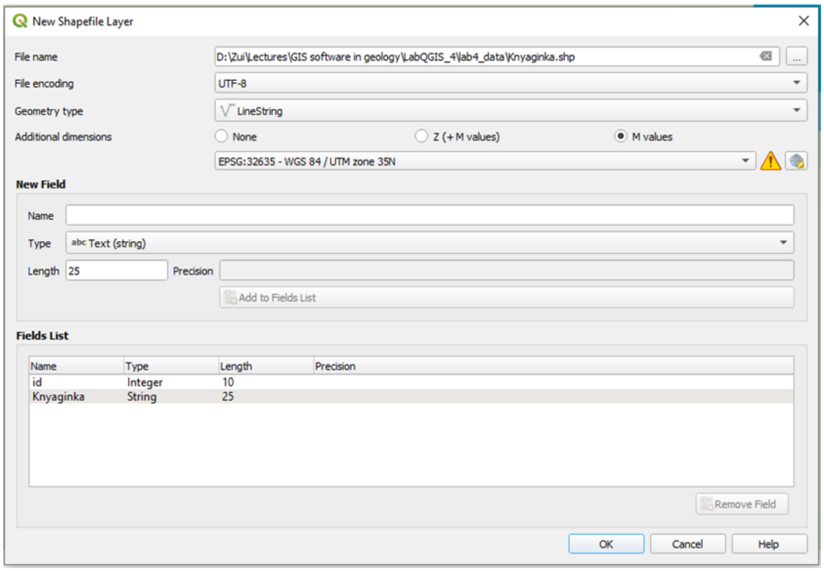



Figure 92. – Creating the vector layer Knyaginka river

***Step 7.*** Start editing the created layer Knyaginka.shp. Zoom in the Zaslavl raster layer to be able distinguish small details along the river valley. Toggle editing icon for editing. Using the Add Object (points) tool, digitize the Knyaginka river located on the territory of the raster Zaslavl map. When finishing with its digitizing right-click the mouse button and the Knyaginka – Feature Attributes panel pops up, you may leave it as is and click OK, fig. 93. Click once more the and a new Stop Editing panel reminding if you wish to save or discard digitizing, click Save button (the icon).

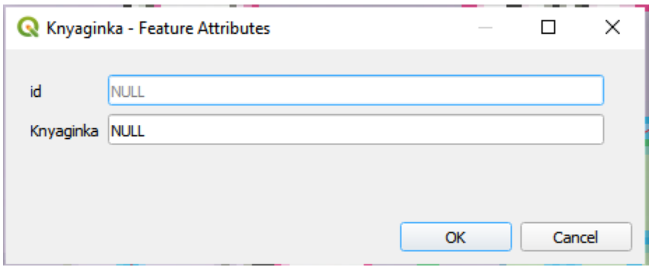



Figure 93. – Knyaginka – Feature Attributes panel

Symbolize the "Knyaginka" layer as follows (right-click on the layer in the legend window → *Layer Properties Knyaginka* → *Symbology*). Set the blue color, slider “opacity” leave 100 % at the *Line* option ( icon), select the *Solid line* with *Stroke width* – 1.6 for *Simple Line* option. Other options are shown in fig. 94. Click Apply and OK. The created map will look like in fig. 95.

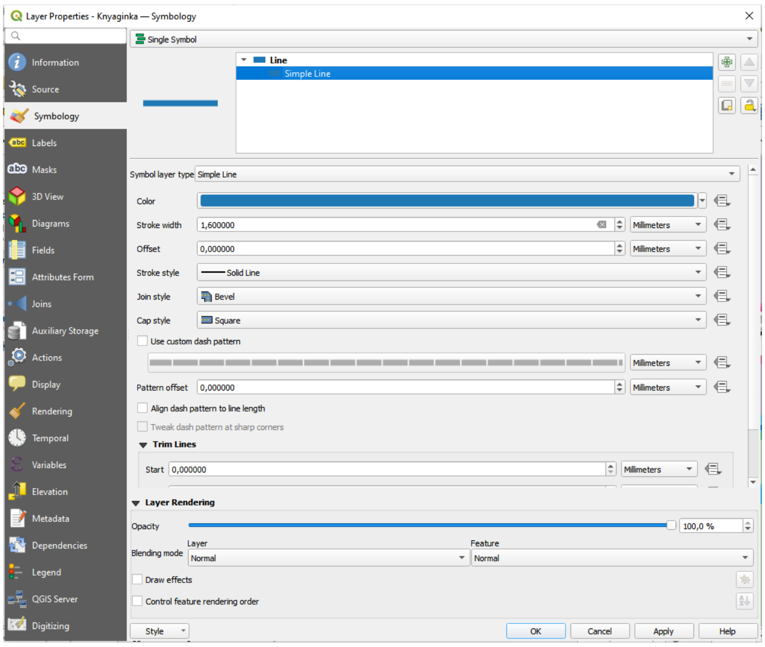



Figure 94. – Knyaginka – Symbology panel

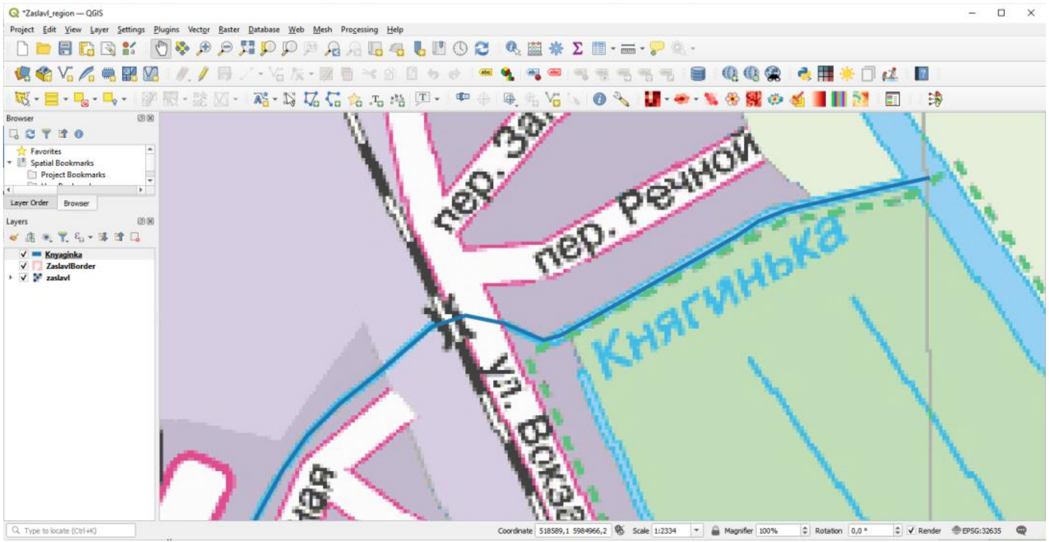



Figure 95. – Finishing the digitized vector layer Knyaginka river

***Step 8***. Do the same for the second river *Chernitsa*. Start editing the creating layer *Layer* → *Create layer* → *New shapefile layer*. Again, in the dialog panel: *Geometry type* – Line string. Layer coordinate system: WGS 84 / UTM zone 35N. Add two text fields to the attribute table: *type* and *Chernitsa* 10 and 25 characters respectively. Select *M* values. After all the necessary parameters have been set, click OK, similar to fig. 94. The new layer *Chernitsa* will be added. Digitize it as described above for *Knyaginka* river. Finish digitizing and the symbology in the way, shown above for Knyaginka river. Now both layers (Knyaginka and Chertitsa) were added to the project.

***Step 9.*** Create a new vector layer "*Kanal*". The similar algorithm will be used below for the main canal of the Vileika-Minsk water system to those used for the Knyaginka river. Zoom in the raster map, and so on. After finishing digitizing the Kanal right-click the mouse button and then click OK at the Kanal layer and open the Properties panel, do similar settings in it and save related files ( icon) for the *Kanal* layer.

***Step 10***. When three vector files for waterways were created, indicate three waterways *Knyaginka*, *Chernitsa* and *Kanal* layers with pressed *Ctrl* key, add the group rivers clicking the  icon on the panel of layers and name it as “Waterways”. Layers *Chernitsa*, *Knyaginka* and *Kanal* will be placed below the created group file *Waterways*,

***Step 11.*** Create a new vector layer "roads" *Layer* → *Create layer* → *New shapefile layer*). Layer coordinate system: WGS 84 / UTM zone 35N. Add two text fields to the attribute table: *type* and *name* 10 and 20 characters respectively. Select *M* values. After all the necessary parameters have been set, click OK, fig. 96. The new layer *roads* will be added.

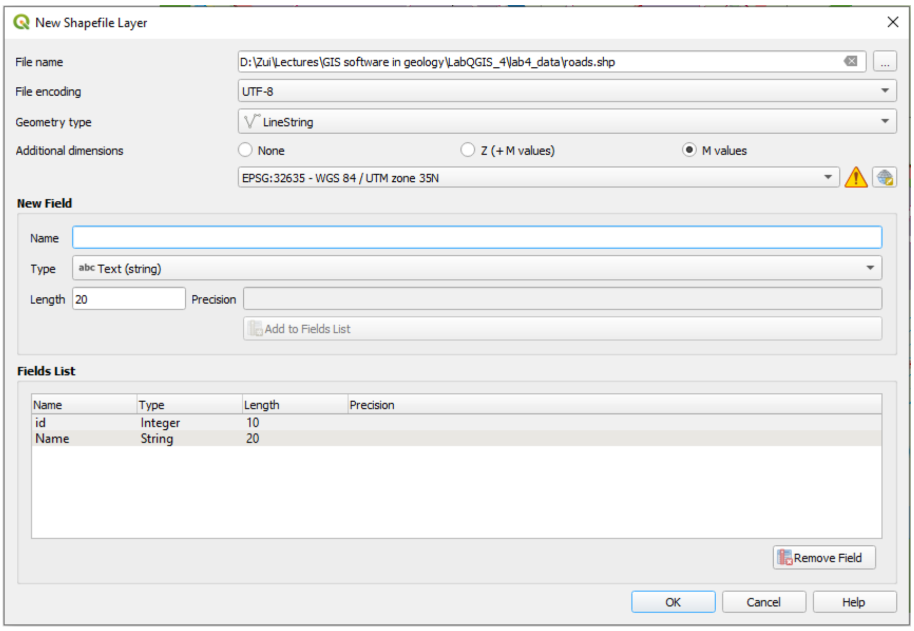



Figure 96. – Creating the vector shapefile roads

***Step 12.*** Start editing the created layer *roads.shp*. Zoom in the Zaslavl raster layer to such an extent to be able distinguish small details along the selected street. Toggle editing  icon for editing. Using the  Add Object (points) tool, digitize the selected street(s) located on the territory of the raster Zaslavl map (similar algorithm will be used later for each of main streets). After finishing digitizing the first street (left-clicking a number of points) right-click the mouse button and then click OK at the roads feature attribute panel. Save your edits by clicking on the *Save edits*  icon and don’t exit edit mode (don’t click the Toggle editing icon). Open *roads* → *Properties* → *Symbology* and select the line color – orange, width – 2.60, Opacity – 100 %. Click Apply and OK. Continue editing (same shapefile *roads*) with the next street. Repeat same algorithm until you’ll finish with all main streets. After saving the last street, exit from the *Edit* mode (click *Toggle editing* icon). When you’ll finish your work the map Zaslavl and vicinity looks like shown in fig 97.

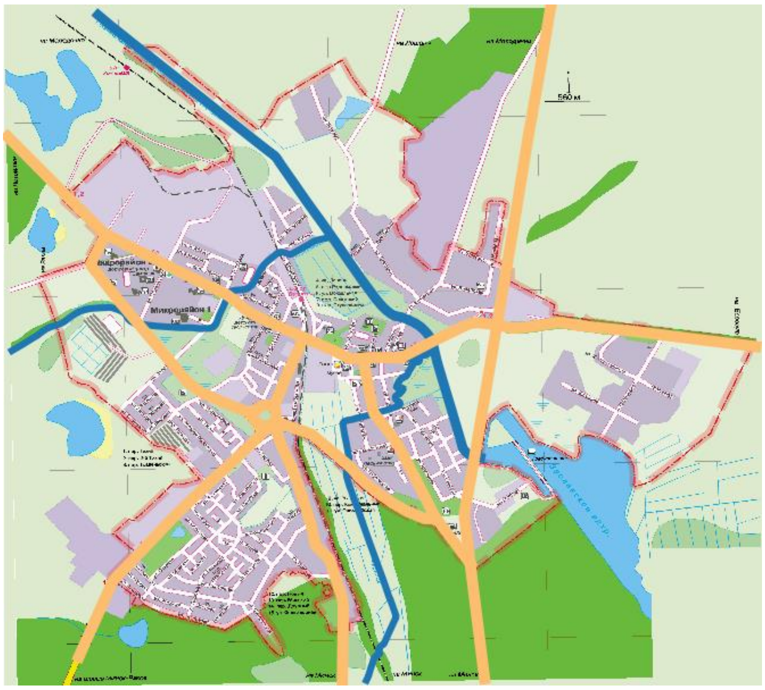


Figure 97. – Zaslavl town with surroundings and five vector shapefiles overlaid

The current Layers panel view corresponds to fig. 98.

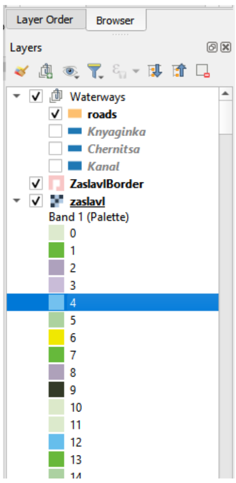



Figure 98. – View of the panel “Layers” after adding waterways and roads

***Step 13.*** Add the *railway_Mo* shapefile to the project (located in the source data folder) containing the railway roads of the Minsk region. Open the geoprocessing tool *Clip*, fig. 99.

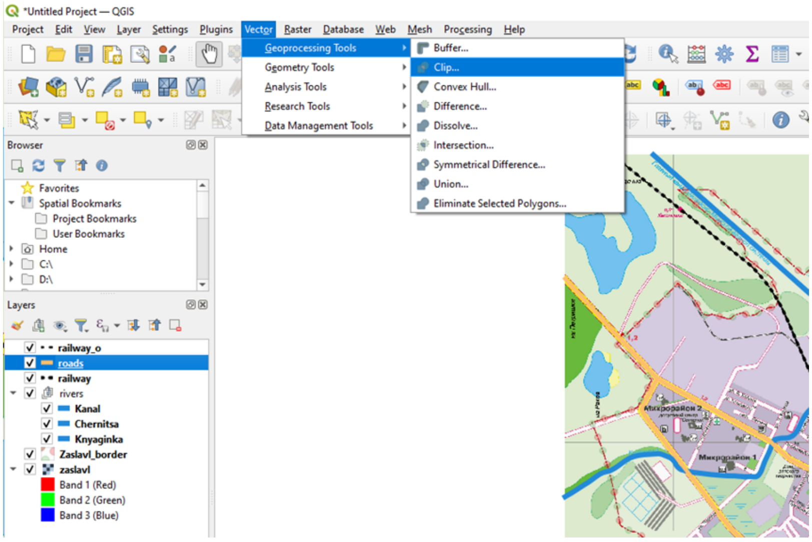



Figure 99. – Open Clip algorithm

We will cut out the railway along the border of the city of Zaslavl. In the window that opens, select as the source of vector layer “railway_Mo” as the cropping layer. Save the result in your folder with the name “railway_Zaslawl.shp” (fig. 100). Add the created file to the project (check the “Open output file after running algorithm”). Deactivate, or delete the layer “railway_Mo” from the project.

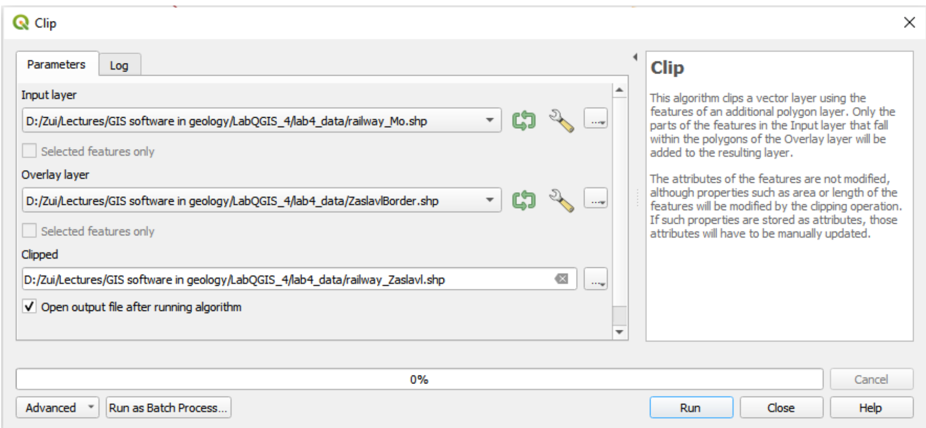



Figure 100. – Clipping the “railway_Mo” layer Zaslavl town border

***Step 14.*** Symbolize the railroad layer with the *Single Symbol* ( icon). On the *Symbology* tab of the *Layer Properties* dialog box, click on the first level of the sign (Line) and in the *Signs* group that appears, select *Colorfull*, *Greyscale* (fig. 101). Change the color of the lines that make up the symbol to black and white.

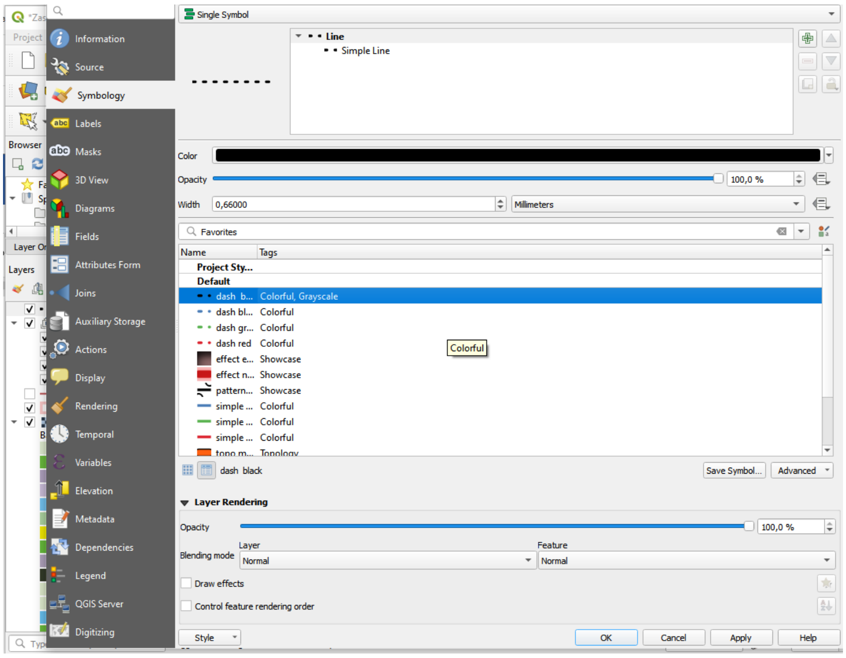


Figure 101. – Symbolizing the “railway_Zaslavl” layer

***Step 15.*** Add a shapefile of the *buildings_Zaslavl_prj.shp* to the project. Set the layer's *Drawing* type to *Single Symbol* values, *Stroke style* – no stroke, *Color* – to brown.

***Step 16***. With the *Crop* geoprocessing tool, you we will complete the cutting of the *roads* layer outside the border of the city of Zaslavl. As above, see fig. 99) activate the tool ***(****Vector → Geoprocessing Tool → Clip*).

In the dialogue window, select *roads.shp* as the *Input layer*, select the *Overlay layer* – "ZaslavlBorder". For clipped result to your folder type in the *Clip* window "*roads_o.shp*". To add created file to the project, check “Open output file after running algorithm” and click Run button, fig. 102.

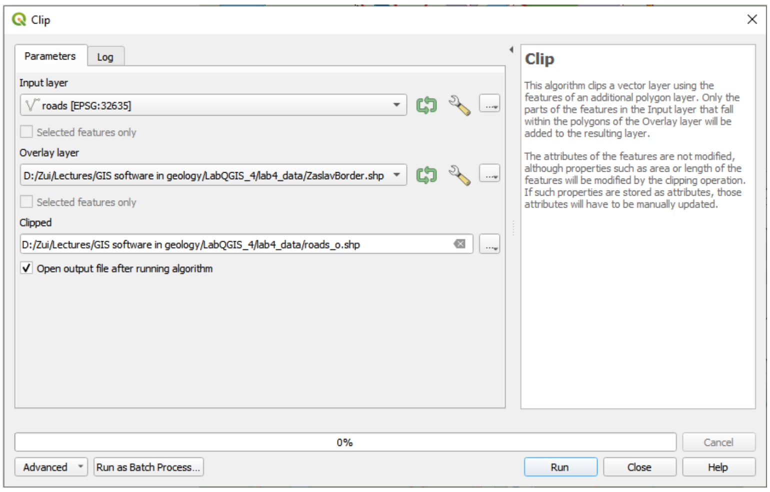


Figure 102. – Clip dialog panel

Symbolize the created shape file *roads_o.shp*. Open *roads_o* → *Properties* → *Symbology* and select the *Line color* – orange, *Width* – 1.60, *Opacity* – 100 %. Click *Apply* and OK. Switch off the layer *roads*.

***Step 17***. Add a point shapefile *entertainment_Mo* to the project, containing some tourist sites in the Minsk region. Clip the added layer along the city boundary (*Vector* → *Geoprocessing Tools* → *Clip*). Save the result to your folder under the name "entertainment_Zaslavl.shp". Symbolize the layer with red circle. Use CRS WGS 84 / UTM zone 35N EPSG: 32635, and "File encoding" – UTF 8. Add the created shapefile to your project (click *Apply* and OK).

Remove (or uncheck) the "*entertainment_Mo*" layer from the project (right-click the layer name *Remove Layer/Group*, or – ctrl + D ( icon).

***Step 18.*** Start editing the "entertainment_Zaslavl" layer. As a source of information about tourist attractions in the city of Zaslavl, use the map of Zaslavl.bmp, Zaslavl_turistik_map.jpg and Internet resources. Adjust the location of existing features using the *Vertex Tool* – *Current Layer* ( icon) in the *Digitizing Toolbar* panel. To create new objects when necessary, use the *Add Point Feature* ( icon) of the same panel. When creating the latter, assign a number to each object, fill in the *name* and *tourism* field (museums or viewpoints). Symbolize the entertainment_Zaslavl layer with *Categorized* ( icon) value, click *Classify*. Click *Apply* and OK, fig. 103. After all objects have been digitized, save your changes to the layer and finish editing.

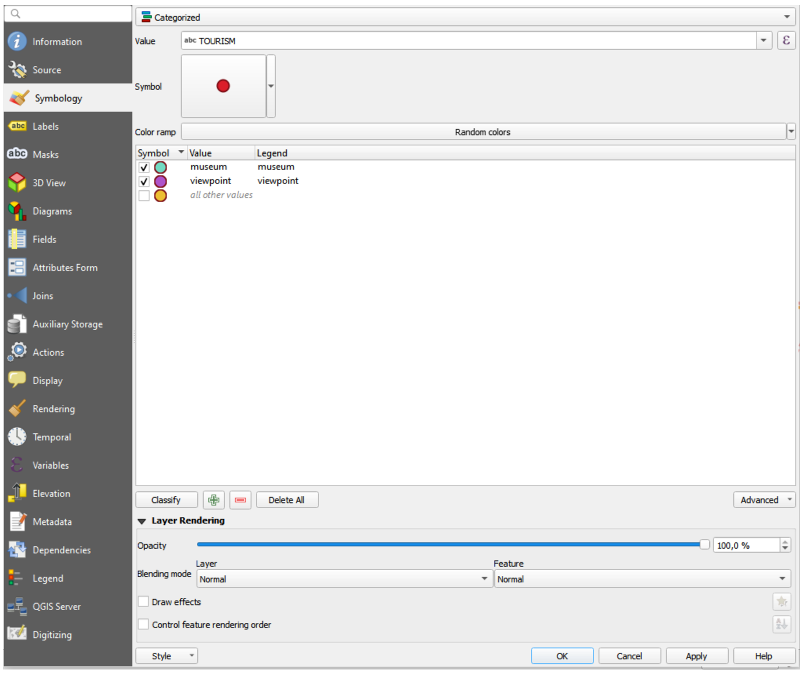



Figure 103. – Categorizing the entertainment_Zaslavl layer

Another way to show points of interest is to add viewpoint.shp and museum.shp as separate layers to the project.

***Step 19.*** Placing text annotations. The *Text Annotation* tool provides the ability to place formatted text in a callout on a QGIS map. Choose a tool *Text Annotation* (*Attributes* toolbar) and click the feature to label. Mouse pointer becomes . Overlay it over the red star or other point of interest your mouse pointer and right-click. You will see Edit icon and click it and the *Annotation Text* dialog box with various options will pop up, fig. 104. The frame appears with white background on default. Click the "Frame style" and select, e.g. light-yellow background color. Type the required text, edit its font, style and size. Do same with the frame size, its position and other parameters of the created annotation. Click once more the icon *Text Annotation* (*Attributes* toolbar), the *Text Annotation* panel disappears.

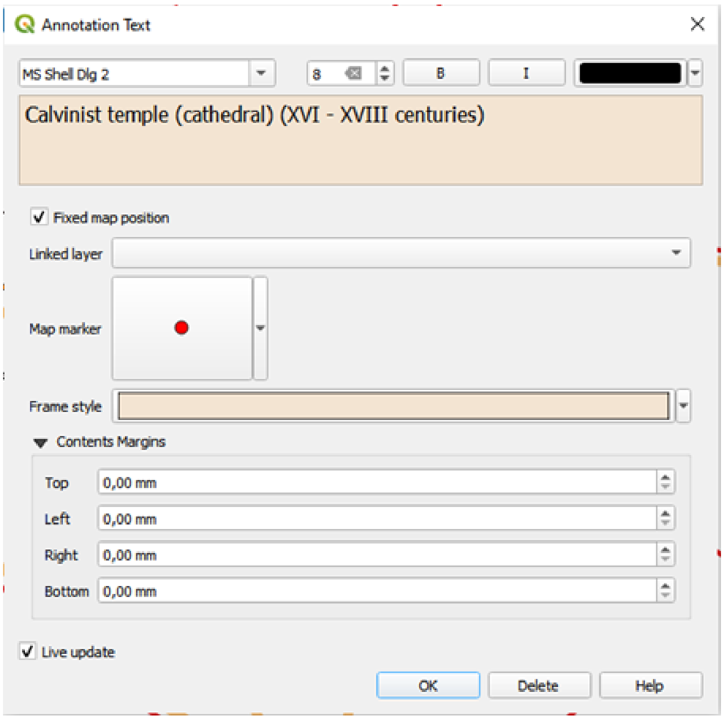



Figure 104. – The Annotation text panel

Underwrite with the help of annotations a few more objects adjust other parameters when necessary and click OK. Finally put again the mouse pointer inside the frame on your map with white background on default, catch the upper side of the frame and adjust its size to required dimensions and move its frame to desired position. The text annotations were added. You can create other text annotation yourself. The final view of the map is shown in fig. 105.

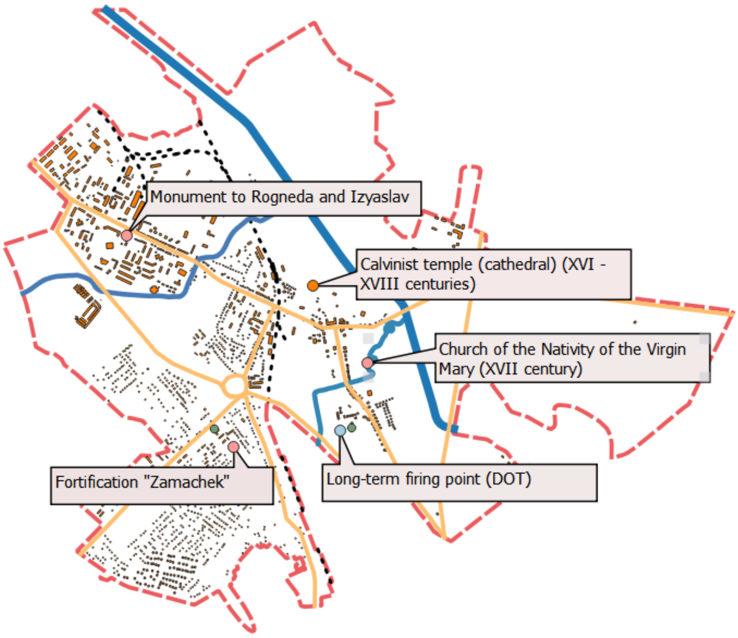



Figure 105. – View of the map with annotations

**II. Creating actions in QGIS**

Actions in QGIS allow you to add a number of extras to the map functions. For example, you can create actions to display image, organize a web search or generate a report from a database by value.

***Step 1.*** Using Internet resources, find a few photographs of tourist sites in the town of Zaslavl and save them to a working folder with the *.jpg extension (for instance: Zaslavl_1.jpg, Zaslavl_2.jpg, Zaslavl_3.jpg).

***Step 2.*** Open the attribute table of the "entertainment_ Zaslavl" layer. Turn on layer edit mode (Toggle Editing Mode). Click on the *New Field* ( icon). In the *Add field* window, specify *Name - hot_link*, *Type – Text (string)*, *Length – 60*, fig. 106. Fill in the *hot_link* field for individual tourist objects, writing down the full path to the corresponding image file (fig. 107). Save your changes. Exit edit mode.

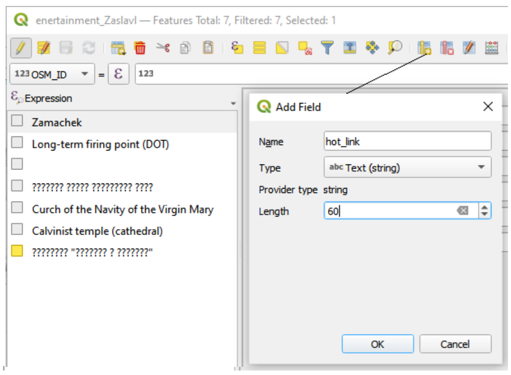



Figure 106. – Add Field panel

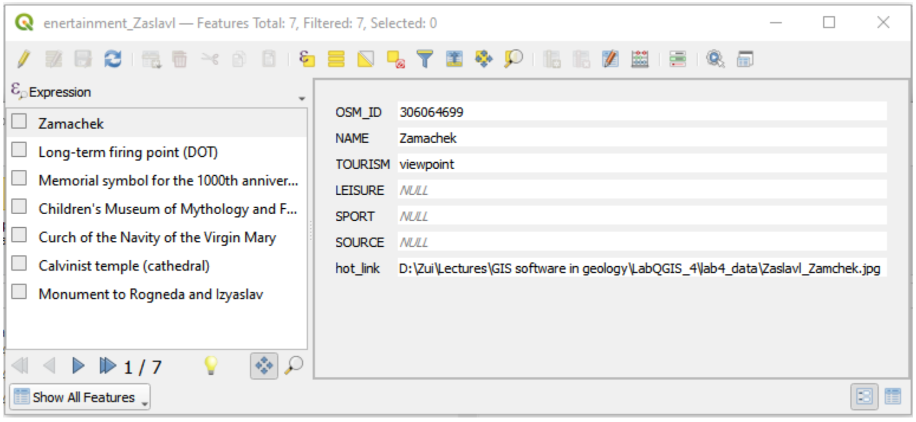
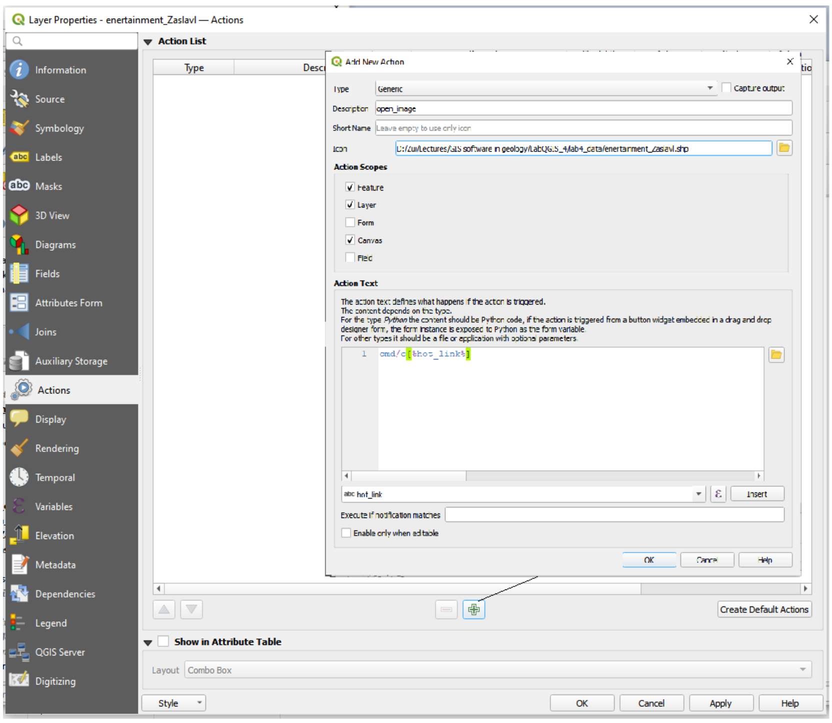



Figure 107. – Enertainment_Zaslavl – Features Total panel

***Step 3.*** Right click on the layer name "enertainment_Zaslavl" in the legend and open the layer *Properties* window. Select the *Actions* tab. To create a new action, click on the *Add a new action* button. In the drop-down "Action List" from of the dialog box that opens, select the *Generic* one, in the *Description* line type *open_image*. In the action window, type cmd /c. Choose those *hot_link* field in the dropdown list containing field names layer "entertainment_Zaslavl.shp" and click *Insert*. Now your text action looks like this: cmd /c[%"hot_link"%], fig. 108. Add action to the list for this layer by clicking OK. Action created. On the *Actions* tab of the Layer Properties dialog box, click *Apply* and OK.




108. – Layer properties and actions

***Step 4.*** Zoom in on the area of interest in the map window using the *Zoom in* tool. On the attribute panel, activate the *Actions* tool and click on the symbol of the corresponding tourist object in the map window, fig. 109.

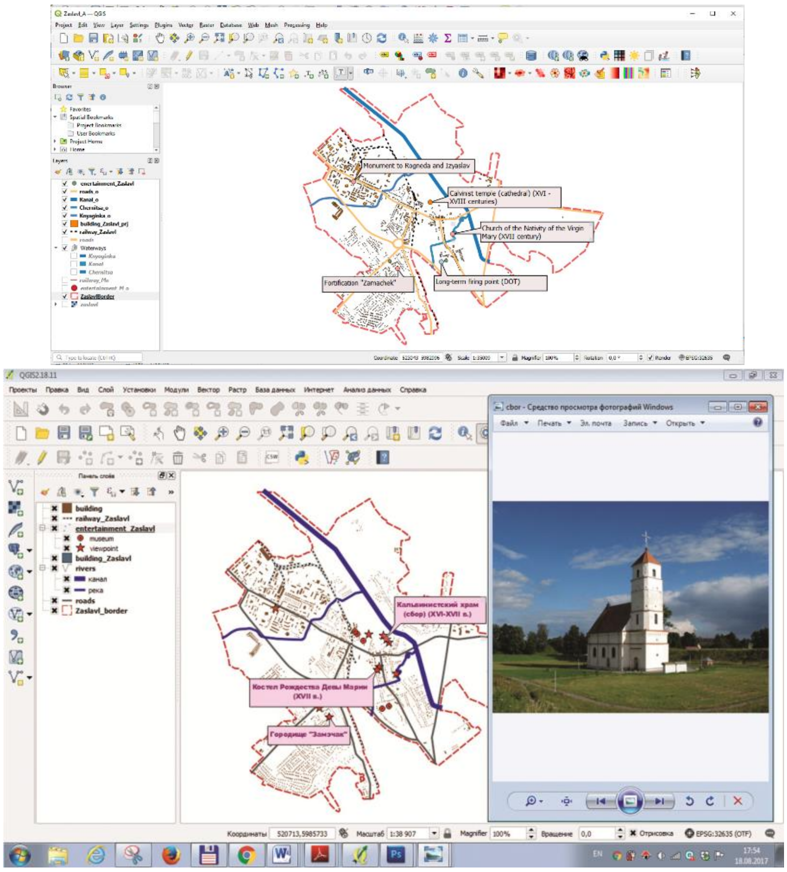



Figure 109. – Adding a photo

## III. Create a map layout

QGIS uses a map builder to create map layouts. The latter allows you to add the following elements: QGIS map, legend, scale bar, images, shapes, arrows, and text boxes. When creating a layout, you can resize, group, align, and change the position of each element, as well as setting their properties. The finished image can be printed or exported to a bitmap. In addition, the layout can be saved as a template and reused in another session.

***Step 1.*** Before you start working on the map layout, make sure that the vector layers look the way you want them to. Turn off the visibility of the raster, delete the "railway_Mo" and "entertainment_Mo" vector layers. Open the map builder dialog (*Project → New Print Layout*) or click the icon. Name the new layout "Touristic_map". Click OK, fig. 110.

The layout editor window can be conditionally divided into the following areas: 1) menu bar, 2) toolbars, 3) display window of a “sheet of paper”, 4) floating windows (panels), 5) status bar, fig. 111.

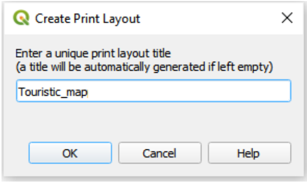



Figure 110. – Create Print Layout

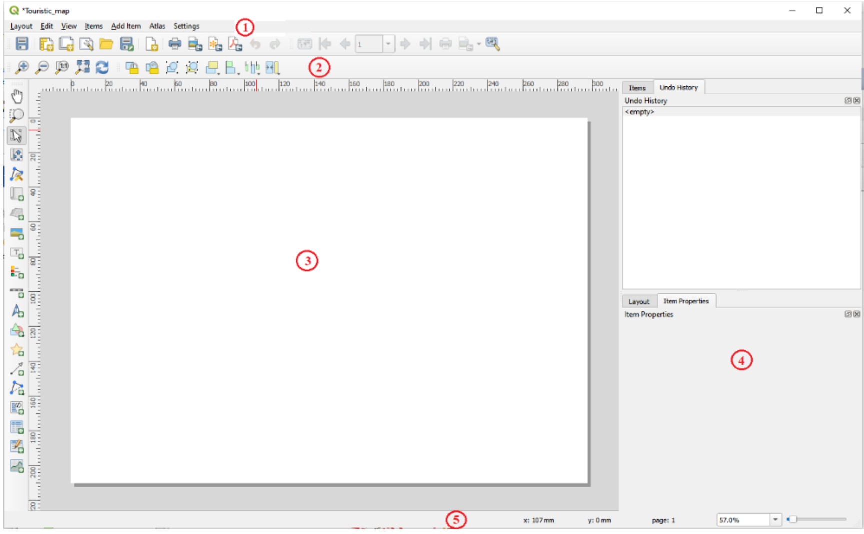



Figure 111. – Print Layout panel

Floating panels include the following tabs: *Layout*, *Items*, *Item Properties*. On the *Layout* tab, you can set change the paper size and orientation, set the print quality in dpi and activate check snapping to the grid with a given step, Project, Global Layout variables and others, fig. 112.

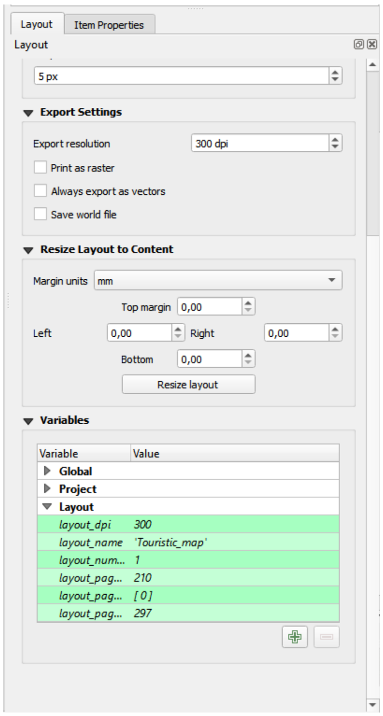



Figure 112. – Layout tab

The *Item Properties* tab is used to display and edit properties of the selected element.

The *Items – History* panel displays a history of all changes made to the layout. Here you can both undo the changes made and redo previously undone actions.

***Step 2.*** To add a QGIS map to the layout, click the button  *Add Map* to the layout toolbar and draw a rectangle on the layout sheet. The added map can be displayed in one of three modes, which can be selected on the *Item Properties* tab when the map is selected:

● *rectangle*. An empty rectangle with text is displayed "Map";

● *cache*. Draws the map at the current screen resolution;

● *rendering*. Selecting this mode means that when zooming in the *Composer* window, the map will be redrawn, but only up to the maximum resolution to save space.

On the *Item Properties* tab, you can adjust the image scale and other elements. You can resize the map, do other corrections, fig. 113, and moving one of the blue markers in the corners. To move layers within a map, select it, then click the button  *Interactively Edit Map Extent* and move the layers inside the object by holding down the left mouse button.

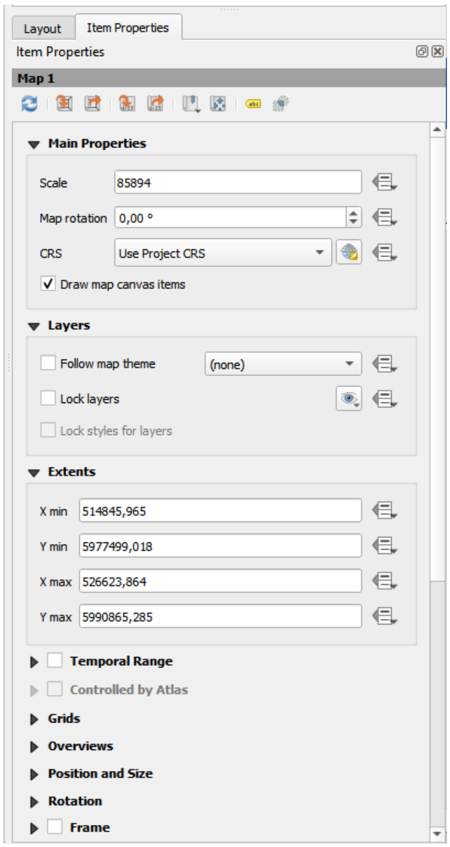
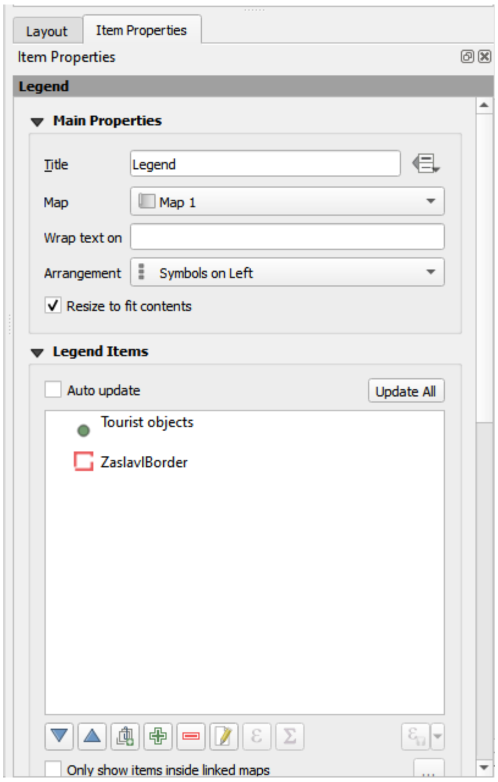



Figure 113. – Fragment of the Item Properties tab

***Step 3.*** Add a legend to the map layout by clicking the button *Add Legend*, move the mouse to the desired location layout, and by pressing and holding the left mouse button, drag cursor by drawing a rectangle, names of layers appear. With the legend selected in the window Layout *Item Properties*, change the "Title" to "Legend". Disable the *Auto Update* option. In the list of Legend Item Properties, change the name "entertainment_Zaslavl" (double click on this element) to "Tourist objects", "museum" to *museums*, "view point" to *monuments of culture and architecture*. Remove from list other layers with the selected element, click *Delete* (fig. 114).



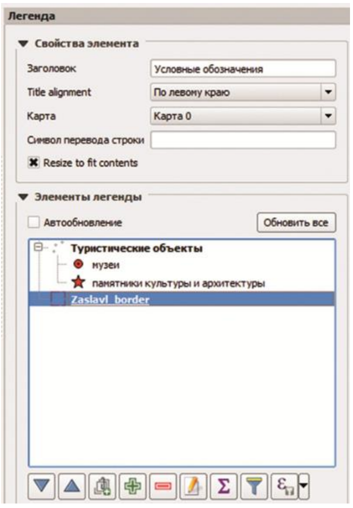




Figure 114. – Creating the Legend at the Item Properties tab

***Step 4.*** Add a scale bar to the map layout using (*Layout → Touristic Map → Add Scale Bar*) and draw a rectangle, where Scale Bar appears. Using the *Scale bar* (*Item Properties*) dialog, set: "Segments" *left* – 0, "Segments" *right* – 4. Select the "Scalebar Units" – *kilometers* and "Label for units" – *km*. Check the radio button for *Fit Segment Width*. Other options are in fig. 115.

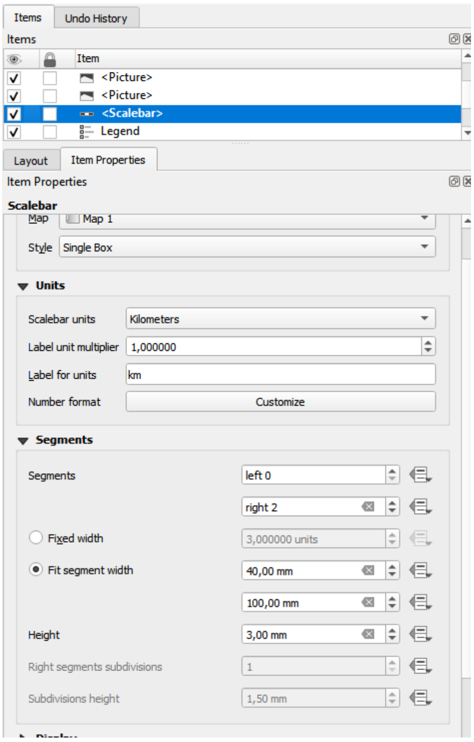



Figure 115. – Formatting the Scalebar at the Item Properties tab

***Step 5:*** Use the  *Add Picture* tool to add the photos used to create the activity to the layout. Check the radio button "Raster image". The path to the image is written when the image is selected in the *Item Properties* window, *Image source* field.

***Step 6:*** Select all the images and group them by clicking on the  *Group items* icon.

***Step 7.*** To add a title, click the  *Add Label* button, place the cursor at the top of the map, and then, holding down the mouse button, drag out a rectangular frame. In the frame with default text "loren lpsum" of *Main Properties* dialog box of the "Label" group, in the *Appearance* subsection, set the *Font* to Times New Roman, the *Style* to bold, and its size to 24. As the title of the map, enter "Tourist map of the town of Zaslavl". Edit the size of the text window and its position on the map, fig. 116.

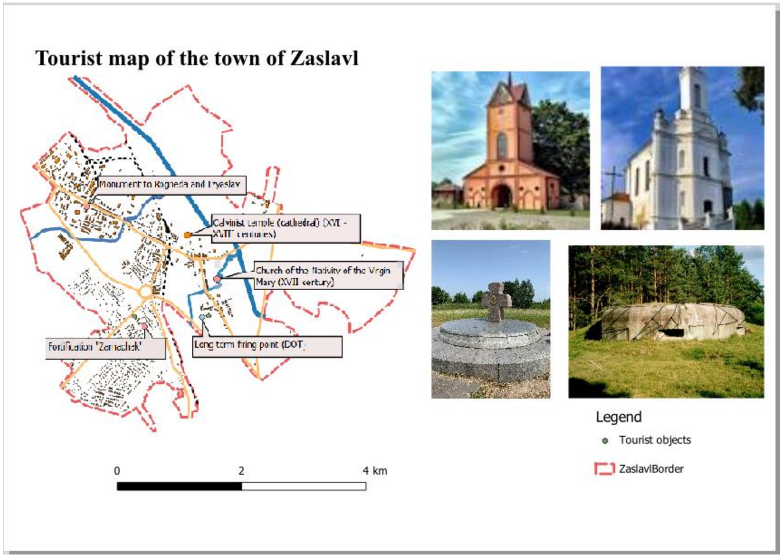



Figure 116. – Tourist map of Zaslavl town

***Step 8***. Export the created layout (*Project – Import/Export – Export Map to Image*) to a bitmap image for subsequent cartographic printing. In the panel "Save Map as Image" that appears click Save with the name "Tourist map.jpg" in your folder.

### 2.5. Laboratory work 5. Receiving basic spatial characteristics of objects in QGIS

**The purpose of the laboratory work**: to learn an algorithm for obtaining the main spatial characteristics of objects in QGIS**.**

**Initial data:**

● shapefile containing borders of Belarusian regions (*regions_ RB.shp*);

● shapefiles containing the river network (*rivers_RB.shp*) and lakes of the Republic of Belarus (*lakes_RB.shp*);

● shapefile of cities in the Republic of Belarus (*towns_RB.shp*).

**Laboratory progress**

Like most modern GIS, QGIS makes it possible to automatically calculate spatial characteristics (coordinates, areas, perimeters, etc.) for objects in vector layers. At the moment, QGIS implements the following tools for calculating spatial characteristics:

● tool *Vector → Geometry Tools*) permits to add field(s) to the layer with geometry information: *xcoord*, *ycoord* for a point layer, length for a line layer, area, perimeter for a polygon layer. Supports three ways of calculating spatial characteristics: 1) in the layer coordinate system; 2) in the project coordinate system;

3) on an ellipsoid. When calculating on an ellipsoid, point coordinates are returned by default in decimal degrees, and lengths and areas are returned in meters, regardless of the view or layer coordinate system. You can specify the *Ellipsoid for calculations* on the *General* tab of the *Project Properties* dialog box. By default, this is the WGS 84 universal ellipsoid;

● a set of functions for calculating spatial characteristics in the field calculator.

***Step 1***. Open QGIS Desktop 3.34.6. Add the following vector layers to the project, located in the source data folder: *regions_RB.shp*, *lakes_RB.shp*, *towns_RB.shp* (*Layer → Add layer → Add vector layer*). Place the layers in the project in the following order from top to bottom*: rivers_RB*, *towns_RB*, *lakes_RB*, *regions_RB*. These layers will be shown in random colors.

***Step 2*** Define the coordinate system of the *rivers_RB.shp* shapefile. To do this, right-click the specified layer in the *Layers* window and select *Properties* from the context menu. On the *Source* tab of the *Layer Properties* dialog box, in the *Assigned Coordinate Reference System (CRS)* section, information on the shapefile's coordinate system will be displayed. The coordinate system of the layer is the projection 32635 WGS 84 / UTM zone 35N, the units of measurement are meters, fig. 117.

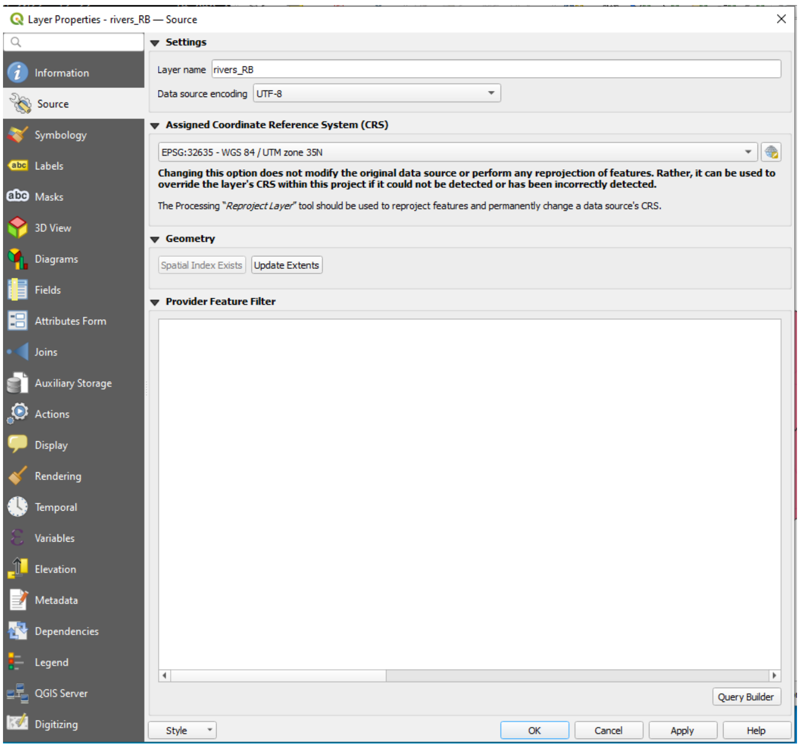



Figure 117. – Layer properties – rivers | Source panel

***Step 3.*** Calculate the areas and perimeters of lakes, for which in the menu *Vector*, go to *Geometry Tool → Add Geometry Attributes...*, fig.118.

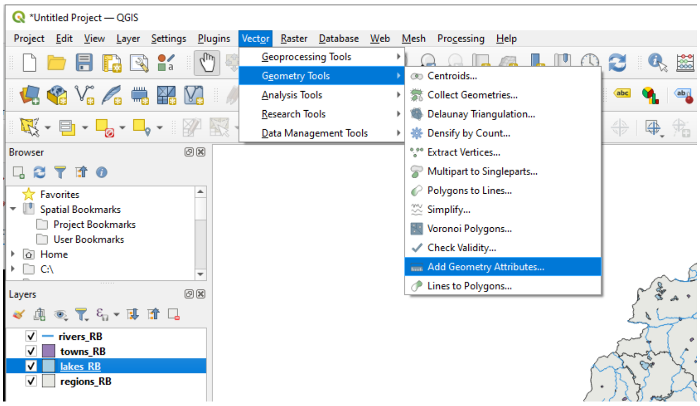



Figure 118. – Work with geometry tools

In the dialog box that opens, Specify "lakes_RB" as the Input layer. In the field *Calculate using* set *Layer CRS*. The *Added geom info* field is set to [*Create temporary layer*] by default, leave it as is (the temporary layer will be deleted after finishing the session with QGIS). Click the *Advanced options* ( icon) and select in the *Invalid feature filtering* window change *Use Default* for *Do not Filter (Better performance)*, fig. 119. Let's leave the rest set by default. Click *Run*, fig. 120

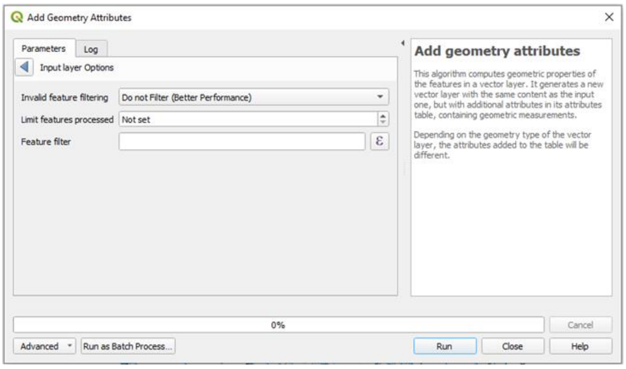



Figure 119. – Advanced options panel

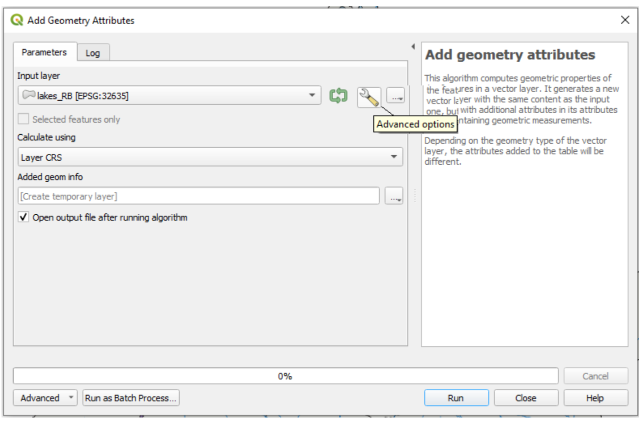



Figure 120. – Work with geometry tools

After the features are computed, the "*Added geom info*" layer will be added to the project. Check the result. Open the layer's attribute table (right-click on the layer name in the table of contents → *Open attribute table*) and click it, fig. 121. There are two new columns "area" and "perimeter", fig 122.

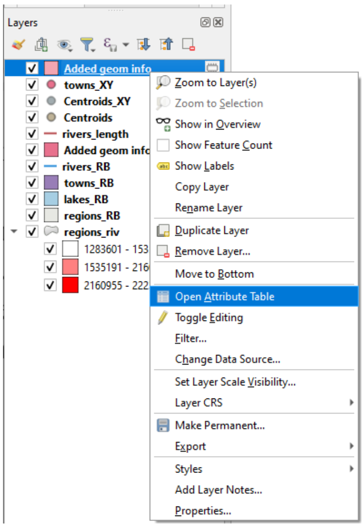


Figure 121. – Add geometry info panel

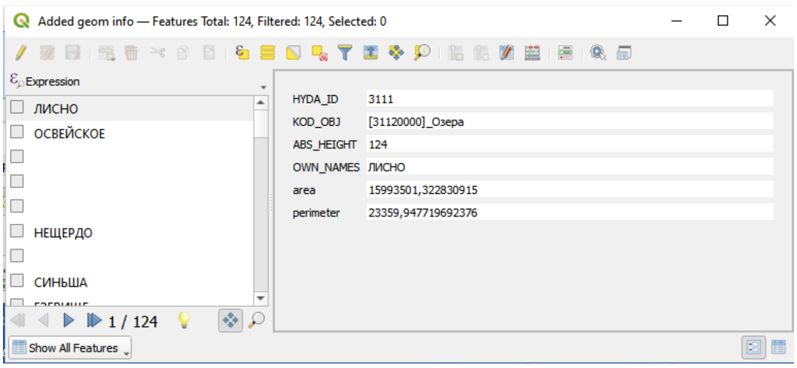


Figure 122. – Added geom info panel

***Step 4.*** Obtaining main statistical indicators for the "*area*" field. From the *Vector* menu, choose *Analysis Tools* → *Basic Statistics for Fields…*, click it, fig. 123.

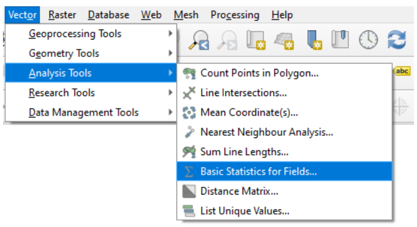


Figure 123. – Basic statistics for fields

In the dialog box, for Input Layer select *Added geom info*. In the drop-down list of "Field to calculate statistics on", select the "*area*". Leave the default value in the field Statistic [optional] field, fig. 124. Click *Run*. The calculated indicators (minimum value, maximum value, range, sum, mean value, median, standard deviation, etc.) will be displayed in the *Log* window, fig. 125. The list can be copied to clipboard when necessary.

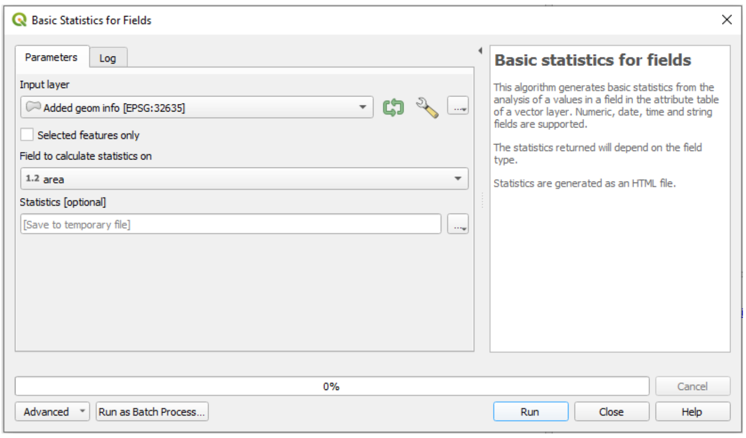



Figure 124. – Basic statistics for fields

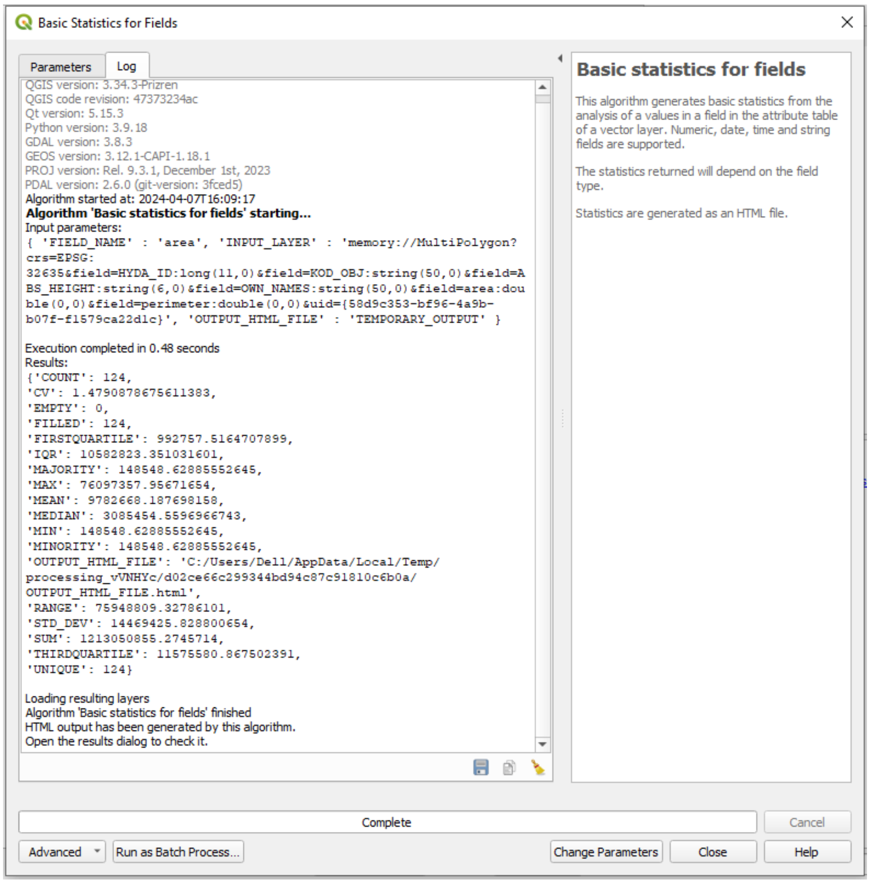



Figure 125. – Basic statistics for lakes in Belarus

***Step 5***. Calculate the total length of rivers within the regions of Belarus. As for the “area” statistics from the *Vector* menu, choose *Analysis Tools → Sum Line Lenghs…* and click it, fig. 126. The *Sum Line Length* dialog panel pops up the polygon is *regions_RB*, the original vector layer is *rivers_RB*. Next line (*Lines length field name*) specify "LENGTH" – a field with information about the length of a linear objects. In the *Lines count field name* field, type COUNT. Save the result as a file to your folder called "rivers_length.shp", fig. 127.

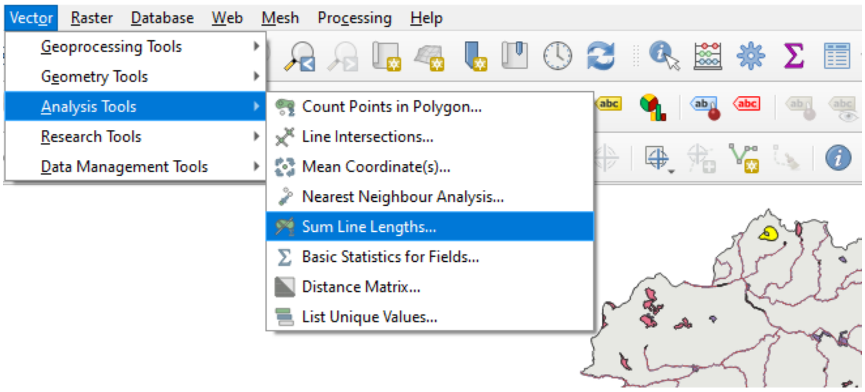



Figure 126. – Selecting Line Length panel

Go to the menu *Vector → Analysis Tools* and you take *Sum Line Lengths...* and click it, fig. 126. The *Sum Line Length* dialog panel pops up. As the original *Lines* layer select "rivers_length", for *Polygon* – "regions_RB". Next line (*Lines length field name*) specify "LENGTH" – a field with information about the length of a linear object. In the *Lines count field name* field, type COUNT. Click the *Advanced options* ( icon) and select in the "Invalid feature filtering" window change *Use Default* for *Do not Filter* (*Better performance*), see fig. 105. Save the result as a file to your folder called "regions_riv.shp", fig. 127. Click *Run*.

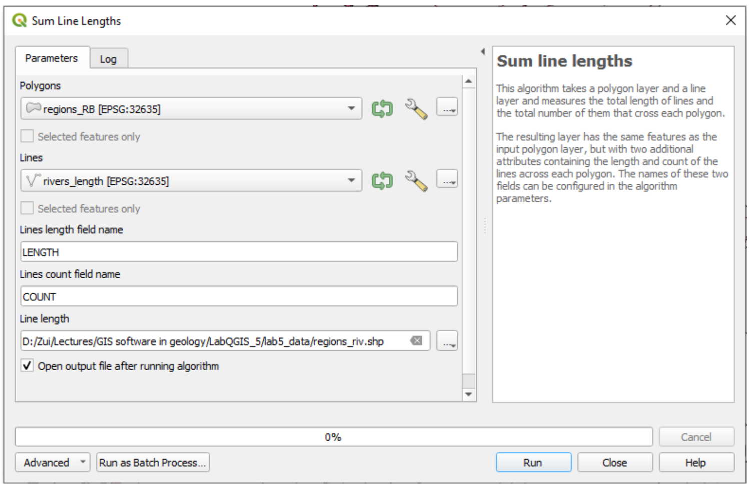



Figure 127. – Sum Line Lengths panel

The Attribute table for river lengths with added rows LENGTH and COUNT is show in fig. 128.

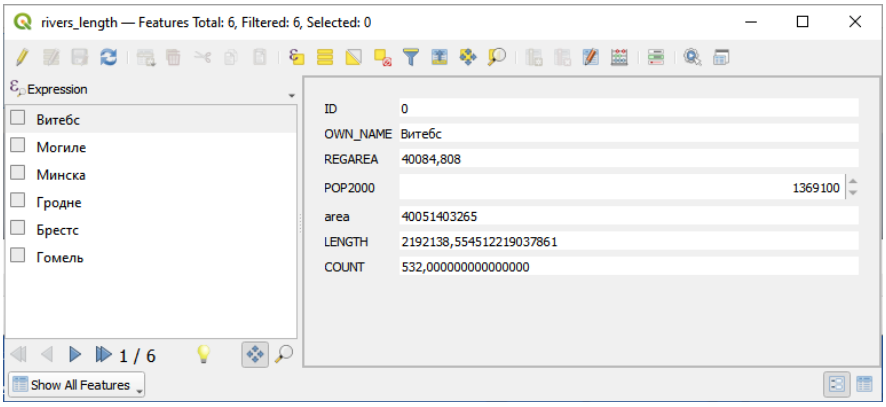



Figure 128. – Table of attributes for rivers divided into 5 regions

After the algorithm is executed, the "Line length" layer will be added to the project, rename it to "river lengths". Symbolize the layer with a *Graduated* ( icon) over the LENGTH field. *Number of classes* – 3. Mode – *Equal Count* (*Quantile*), fig. 129. Click *Apply* and OK, The territory of Belarus, indicating into 3 classes, lengths of rivers is shown in fig. 130.

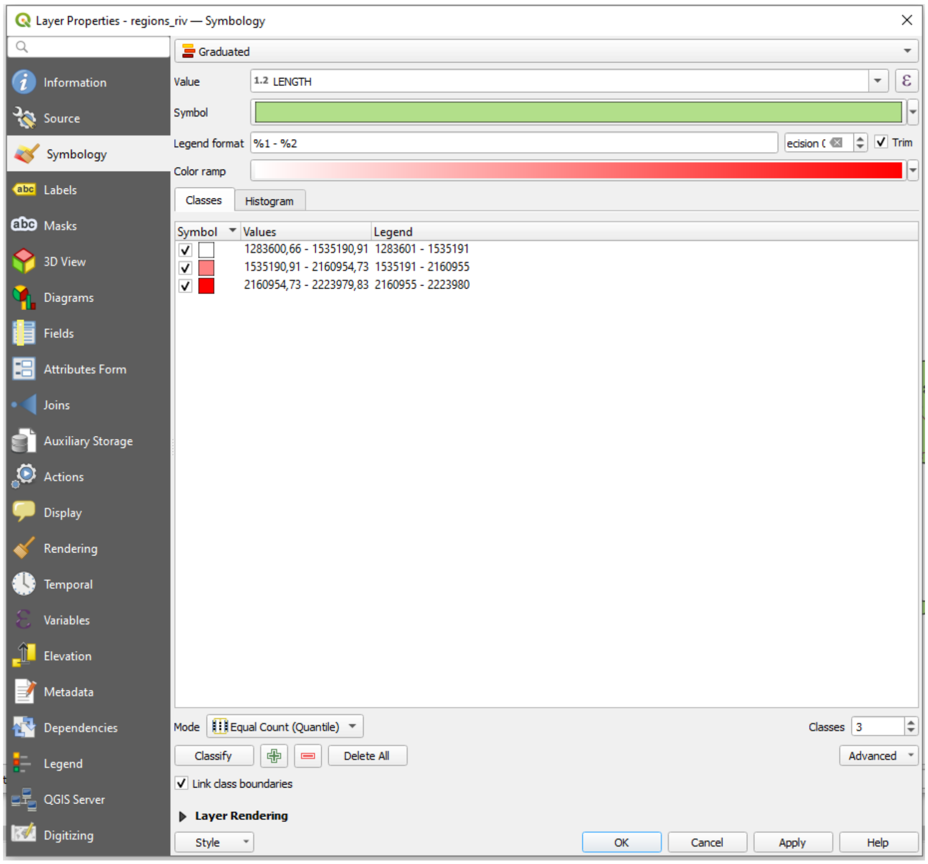



Figure 129. – Symbolizing river lengths

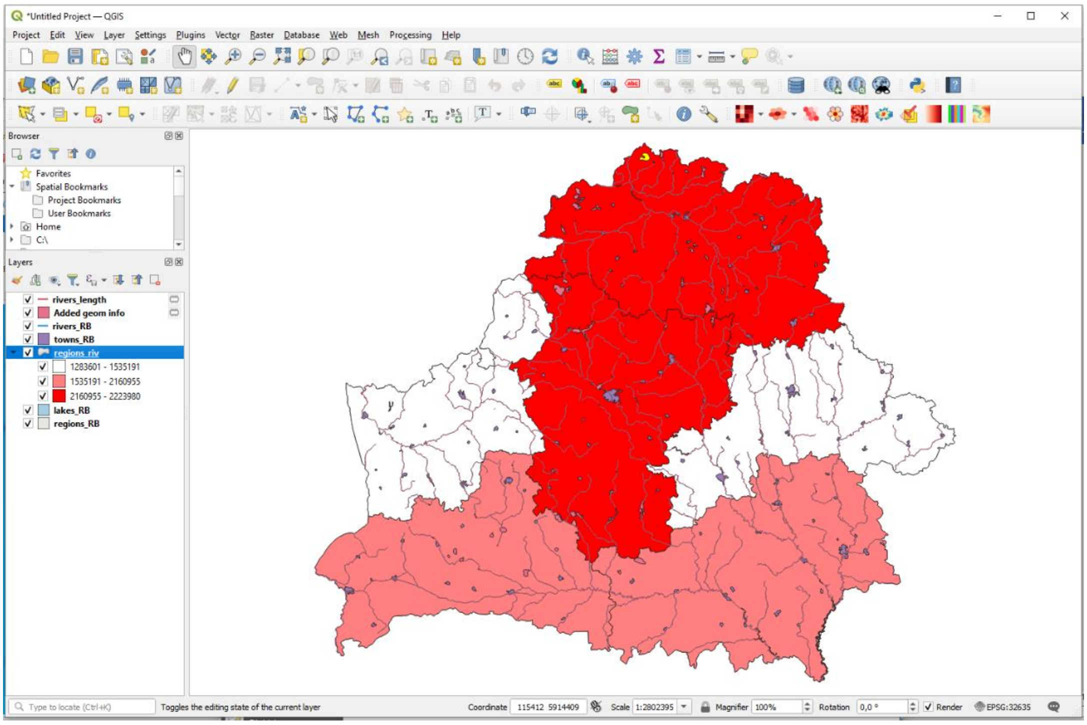


Figure 130. – Symbolizing river lengths for Belarus

***Step 6*** Convert the "towns_RB" polygon layer to a point layer. To do this, in the *Vector* menu, select *Geometry Tools* → *Centroids*, fig. 131. The *Input layer* is "towns_RB". Save the centroids as a temporary layer, click Run, fig. 132. Open the output *Centroids* layer added to the Layers panel after executing the algorithm, fig. 133.

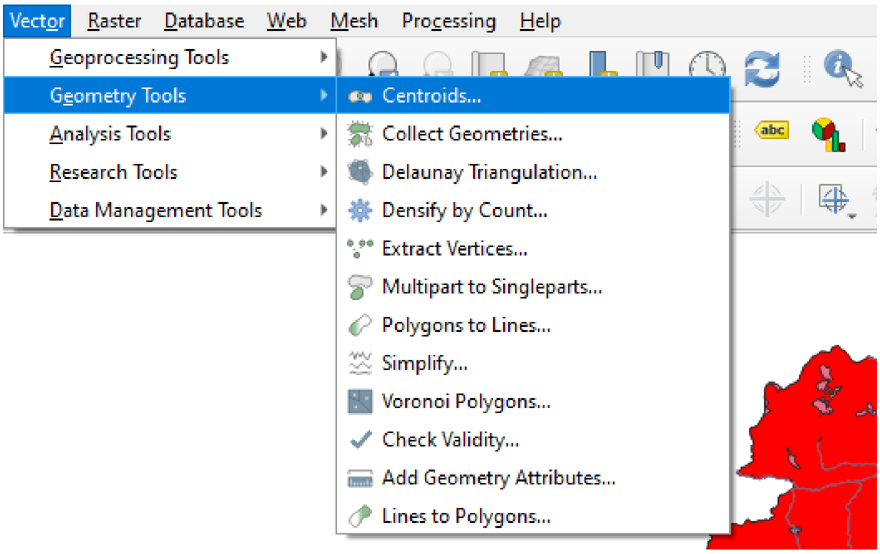



Figure 131. – Creating centroids for towns_RB

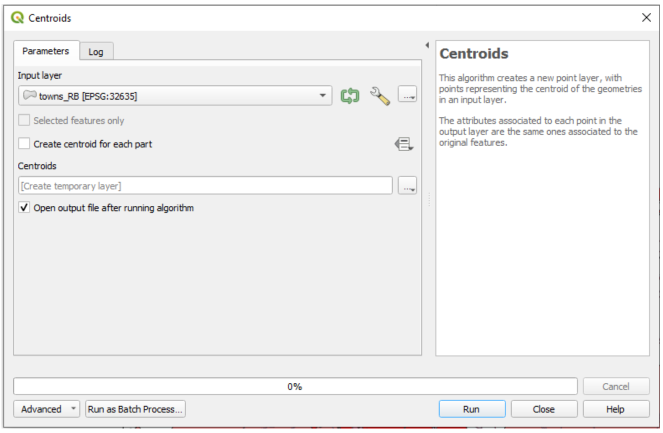



Figure 132. – Creating centroids for towns_RB

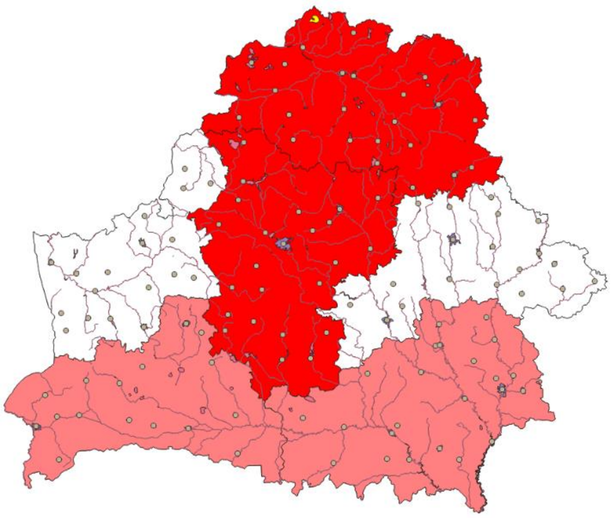


Figure 133. – Centroids of polygons towns_RB

***Step 7.*** Calculate coordinates of the cities in the layer's coordinate system. From the *Vector* menu, select *Geometry Tools / Add Geometry Attributes*, fig. 134. Set the Source Layer to *Added geom info*. Save results the file "*Centroids_XY*", fig. 135. Results with determined coordinates for centroids shown in fig. 136.

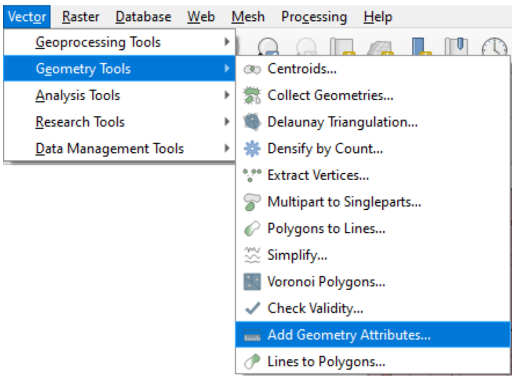



Figure 134. – Starting to determine coordinates for centroids of towns_RBx

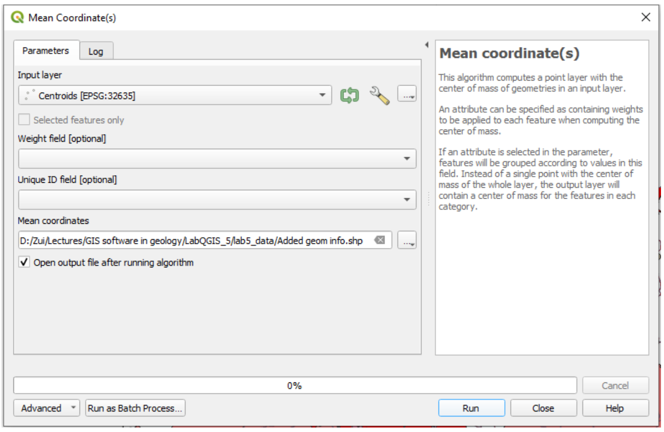



Figure 135. – Starting to determine coordinates for centroids of towns_RBx

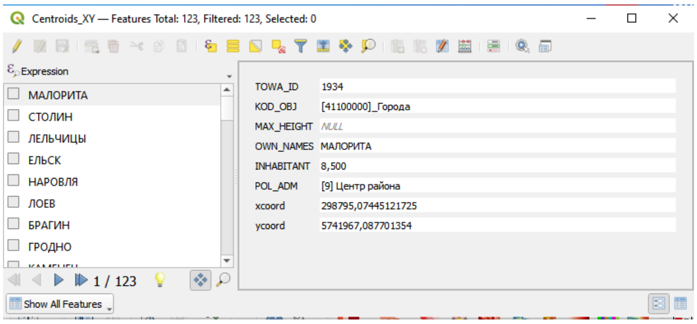



Figure 136. – Coordinates *x* and *y* determined for centroids of towns_RBx

***Step 8.*** Calculate the coordinates of the cities in the Project coordinate system. First, set the geographic coordinate system for the project to WGS 84. From the *Projects menu*, select *Project Properties*, fig. 137.

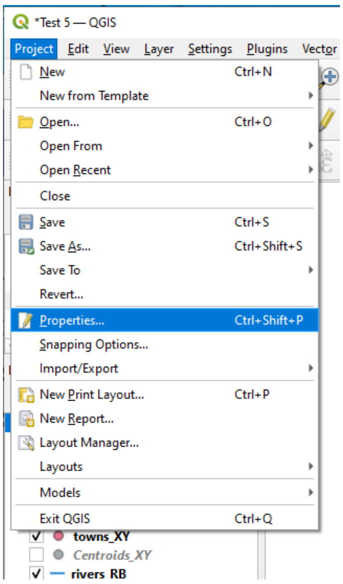



Figure 137. – Project – Properties menu

Switch to the *CRS* tab in the *Project Properties* panel. Set the project coordinate system to WGS 84 / UTM zone 35N. Click *Apply* and OK.

Like in the Step 7, calculate coordinates of the cities in the Project's coordinate system. From the *Vector* menu, select *Geometry Tools / Add Geometry Attributes*, see fig. 134. Set the Source Layer to *Added geom info*. Save results the file "towns_XY.shp".

Open the attribute table of the shapefile "towns_XY" (right-click on the layer name in the table of contents → *Open attribute table*). The attribute table contains two sets of coordinates calculated in the layer coordinate system and the project coordinate system, fig. 138.

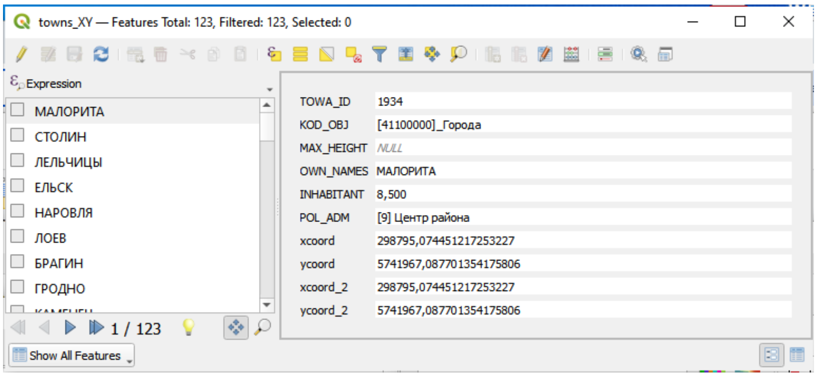



Figure 138. – Attribute table for towns

***Step 9***. Using the field calculator. The attribute table field calculator allows you performing calculations based on existing attribute values or predefined functions.

*Table 2. Field calculator functions for obtaining spatial characteristics*

| Function | Geomet type | Description |
|---|---|---|
| **$x** | Point | Returns the X-coordinate (longitude) of a point |
| **$y** | Point | Returns the Y (latitude) coordinate of a point |
| **$length** | Line | Returns the line length |
| **xat** | Line | Returns the X-coordinate (longitude) of the nth point of the line (index starts at 0; negative values are counted from the last index value) |
| **yat** | Line | Returns the Y coordinate (longitude) of the nth point of the line (index starts at 0; negative values are counted from the last index value) |
| **$perimeter** | Polygon | Returns the perimeter of a polygon |
| **$area** | Polygon | Returns the area of a polygon |

The *Geometry Tools* group combines functions for working with object geometry. Among them are functions that allow you to get the length of the line, the perimeter, the area of the polygon, etc. (Table 2). When calculating spatial characteristics using the field calculator, all calculations are made in layer units.

Calculate the areas of features in the polygon layer "regions_RB" (the layer with the administrative boundaries of the regions) using the field calculator. To do this, open the attribute table of the layer. Put the layer in edit mode Toggle editing mode (Ctrl + E), fig. 139.

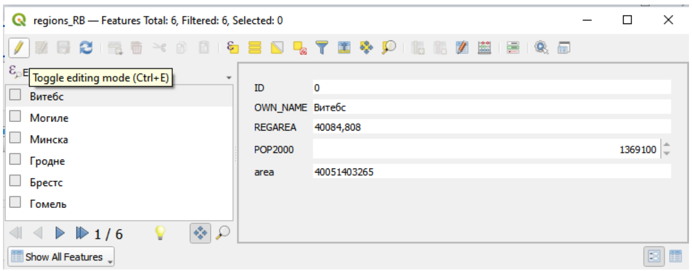



Figure 139. – Entering the editing mode for "regions_RB" – Open Attribute table

Launch the field calculator by clicking on the icon *Open Field Calculator*. In the *Field Calculator* dialog box that opens, check the box next to *Create a new field*. Give the field a name, such as "area". *Output Field type* – decimal number (real), *Output Field Length* – 15. By setting the size, we specify the total number of characters before and after the decimal point, and by specifying the precision – the number of decimal places. Next, select the required calculation function from the list. All functions for calculating the spatial characteristics of objects are in the "Geometry" group. You can add a function to the command line either by writing it manually or by double-clicking on the selected function from the list. After all manipulations, the window should look like in fig. 140.

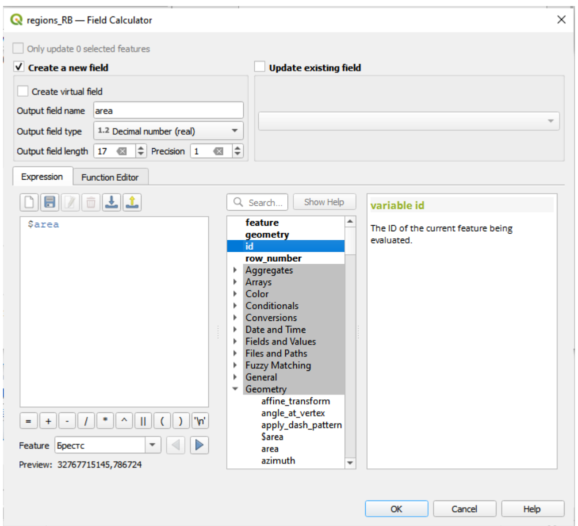



Figure 140. – Field calculator panel

Click OK and check the Attribute table. The new field "area" displays the calculation results. The area is indicated in square meters.

Calculation of spatial characteristics of point, line and polygonal objects using the field calculator is carried out according to a single algorithm: 1) creation and determination of field parameters for calculations; 2) application of one of the calculated functions.

### 2.6. Laboratory work 6. Joining tables in QGIS

**The purpose of the laboratory work:** to learn the algorithm for joining tables by a common field and spatial join in QGIS; creation of charts.

**Initial data:**

● shapefile containing the administrative border of Belarus (*RB.shp*);

● shapefile containing the boundaries of the regions of Belarus (*regions_rb.shp*);

● shapefile of settlements in Belarus (*settlement.shp*);

● data on emissions of pollutants (thousand tons) into the atmosphere from stationary sources for individual cities of Belarus from 2012 to 2016 and on the structure of emissions of pollutants from stationary sources by regions for 2013 (*pollution*) in MS Excel format;

● shape file containing the border of the Brest region (*Brest_region.shp*);

● shape file containing the boundaries of administrative regions Brest region (*Brest_district.shp*);

● shape file of sights (points of interest) (POI) of the Brest region (*poi_point.shp*).

**Laboratory progress**

**I. Joining tables by common field**

As a result of joining tables, data from one table is added (joined) to another, i.e., the result of the operation is a new (modified) table containing fields from two joined tables. The connection is made by a field that exists in both tables. A communication is carried out according to the principle "one to one or many to one (records)". The field name does not have to be the same in both tables, but the data type must be the same. You can join integers with integers, strings with strings, and so on.

***Step 1.*** Open QGIS Desktop 3.34.6. Create a new project. Using the *Layer → Add Vector Layer* tool, load the placed in the folder with the source data, shapefiles: *regions_RB, RB, settlement*. Symbolize the "*RB*" layer as follows (click right-click on this layer in the *Layers* window → *Properties* → *Symbology*): *Single Symbol* () – *Symbol layer type* – Simple line; *Fill color* – no fill; *Fill style* – Solid; *Stroke color* – Red, *Stroke width* – 0.6, fig. 141.

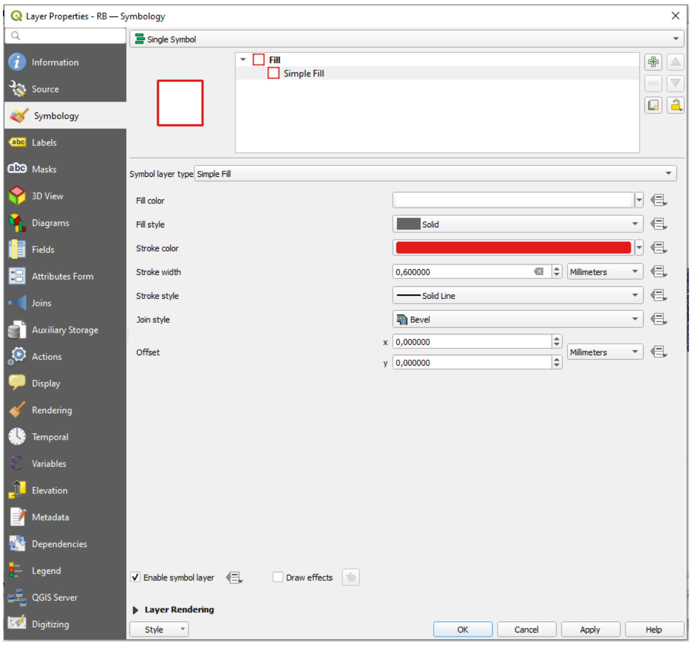



Figure 141. – Symbology panel for *RB*

Render the "regions_RB" layer using the *Categorized* method. In the Color ramp window, enter *YlOrBr*, fig 142.

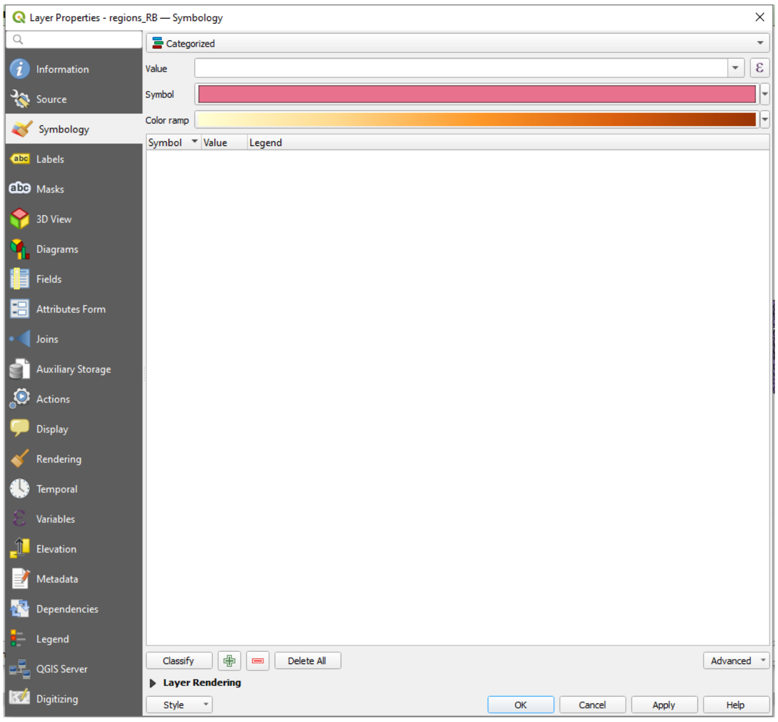



Figure 142. – Symbology panel for *regions_RB*

***Step 2.*** In the "settlement" layer, select the settlements that have the status of a town. Click the  icon menu, then *Select features by expression*... and click it, fig. 143. The *Querry Builder* dialog box pops up.

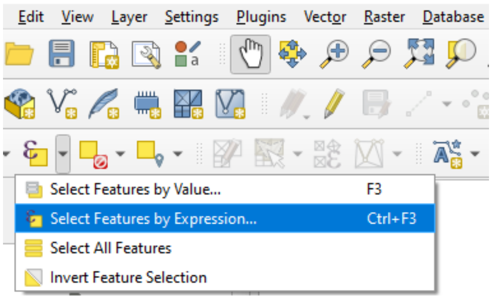



Figure 143. – Starting the Querry Builder

In the middle window expand items: *Fields and values*, *Map layers* and *Operators*, fig. 144. In the *Fields and values* list double-click in the *PLACE* field, it appears in the left window *Expression*, then double click the "=" in the *Operators* list; again highlight the *PLACE* field and in popped up window click *All Unique* button, select *city* in its window and double click it, then double click in the *Operators* list the logical operator "OR"; again click sequentially "PLACE", "=" and "town". The resulting logical expression is shown in fig. 144.

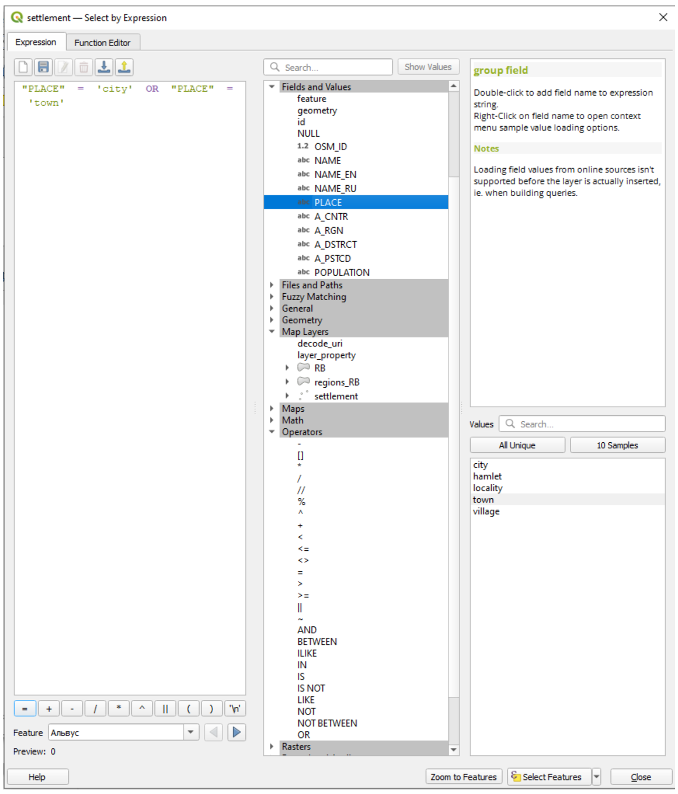



Figure 144. – Selection by expression panel

Finally expand the *Select Features* button and click there *Add to current selection*. As a result, settlements with the city status will be highlighted in the "settlement" layer together with other settlements. Close the *Select by expression* dialog panel.

***Step 3.*** To save your selection as a shape file, right-click *settlements → Export → Save Selected Features as…,* fig. 145. In the panel which pops up type *towns.shp* together with the path to your working folder, fig. 146. The new layer towns.shp will be added to your project. Now you may delete or uncheck the settlements layer, in result your canvas image will look like in fig. 147.

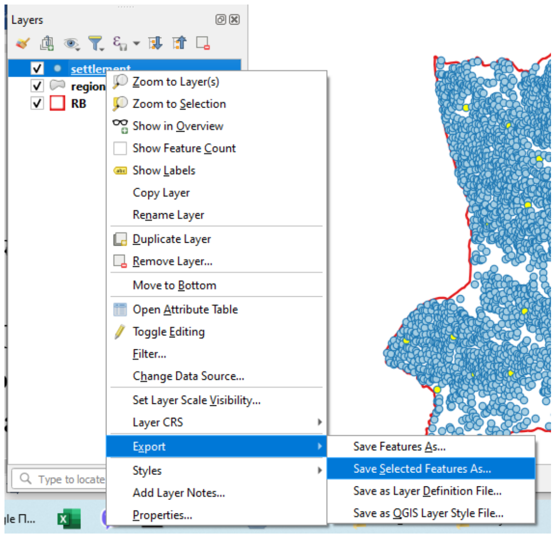



Figure 145. – Saving the selected features

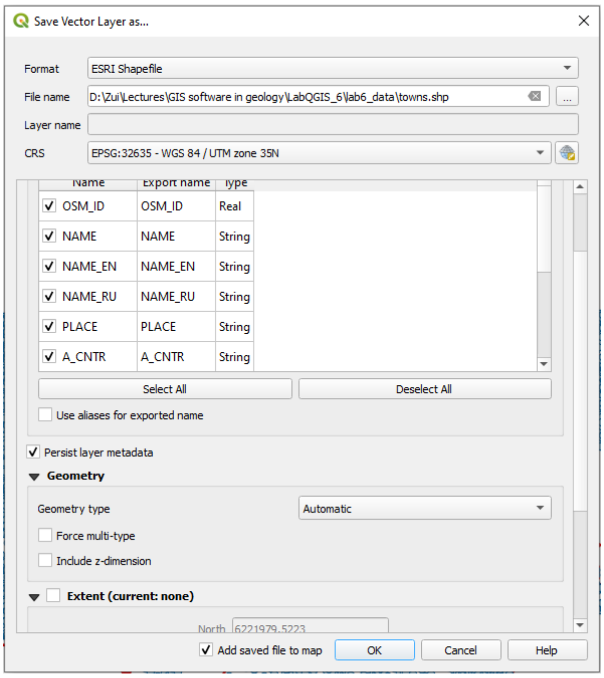



Figure 146. – Saving vector layer panel

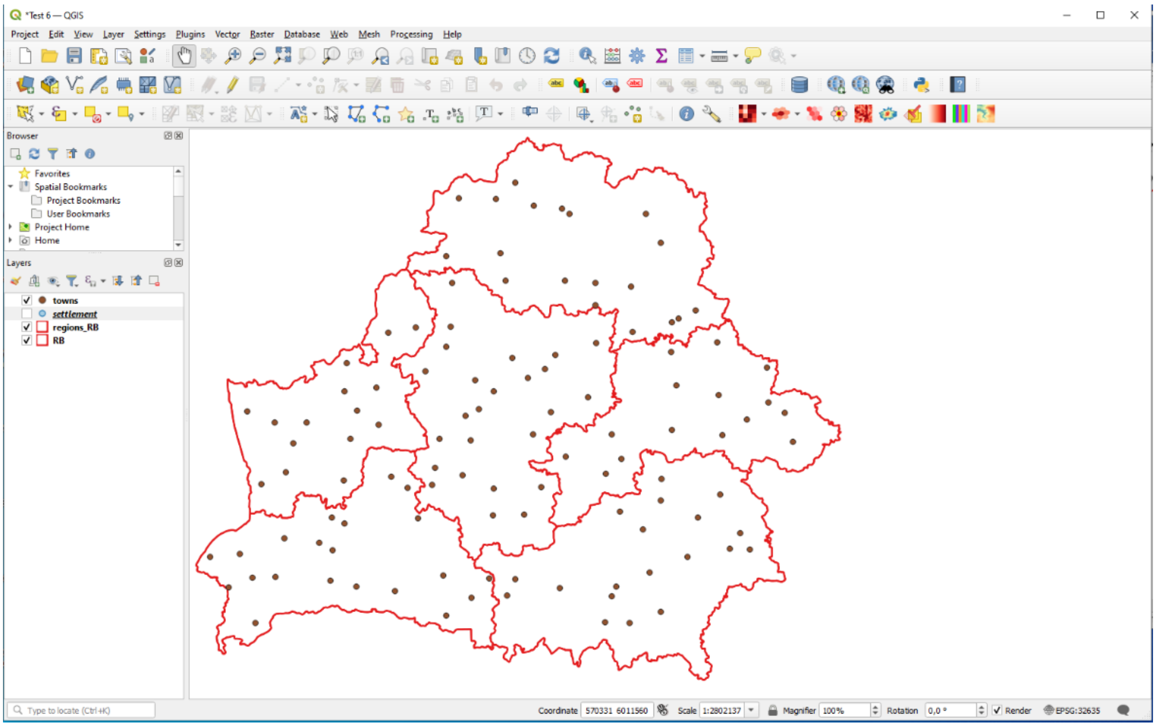


Figure 147. – Resulting image with selected towns

***Step 4.*** Open the "pollution" Microsoft Excel document located in the source data folder. The file contains information on emissions of pollutants (thousand tons) into the atmosphere from stationary sources for individual towns. The document has a "name" column, which will be used as a key when creating a connection. Save the Microsoft Excel sheet "pollution1" as a text file with the extension *.csv (comma delimited).

***Step 5*** Using the  *Add Delimited text Layer…* tool in the *Layer → Add Layer* panel, add the *pollution.csv* file to the project, fig. 148. In the "Data Source Manager | Delimited Text" dialog box, activate in the File Formal – *Semicolon*. In the *Geometry Definition* group activate “X field” and “Y field” as shown in fig. 149. Click Add and OK. The pollution1 table will appear in the layers window.

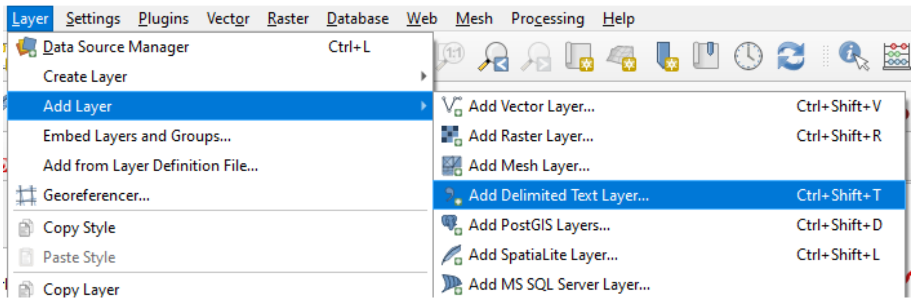



Figure 148. – Creating a layer from text file

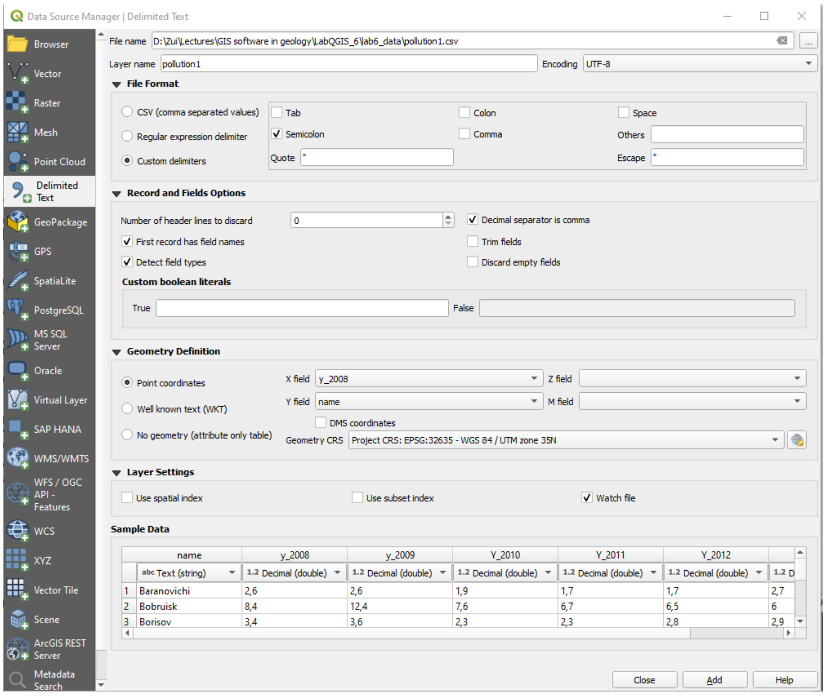



Figure 149. – Creating a layer from text file

***Step 6.*** Add the "pollution1" table (having pollution data with one digit after the *decimal point*) to the project, to the attribute table of the "towns" layer. Click right button on the layer name "towns" and select *Properties*. In the *Layer Properties* dialog box, click the *Joins* tab. Click the  *Add New Join* button. In the dialog box that opens, in the field *Join layer* select *pollution1*, for *Join Field* select – "name", *Target field* – NAME_EN. Check *Cache join layer in memory*. Enable the *Custom field name prefix* option and remove the default prefix (Polution). The *Join fields to* option allows you to select which fields from the join table will be added to the target table. Check all fields to be added, fig. 150. Click OK.

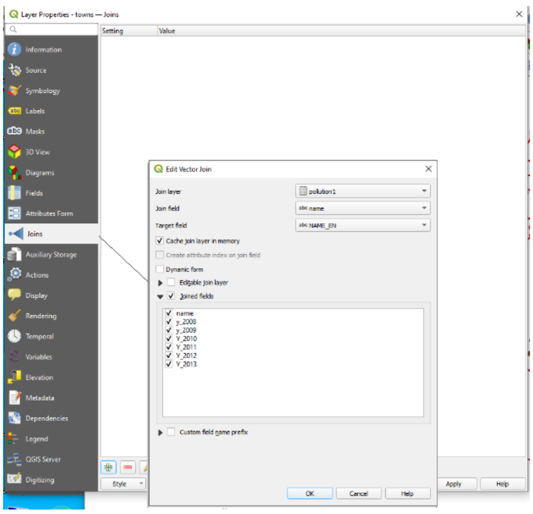



Figure 150. – Open Joins panel

Once created, the joined list will be shown on the *Joins* tab. The tool allows you to edit the parameters of an existing connection. A connection can be deleted by selecting it in the window and clicking the delete connection button .

Open the attribute table of the "towns" layer and check if these two tables have been joined.

***Step 7.*** Using the attached data, construct diagrams that reflect the dynamics of pollutant emissions into the atmosphere from stationary sources for individual towns. QGIS supports the creation of the following types of charts: pie charts, text diagram, histogram and stack bars. Charts are overlaid on an existing vector layer. Open the properties of the "towns" layer (right-click on the layer name in the legend → *Properties*). Click the *Diagrams* window. Select *Histogram* ( icon) from the drop-down list at the top of the panel. In the *Attributes* sector, using the *Ctrl* button, select the added fields pollution1_y_2008, pollution1_y_2009, pollution1_y_2010, pollution1_y_2011, pollution1_y_2012 and pollution1_y_2013, click . These fields, fig. 151, will be used to create the histogram.

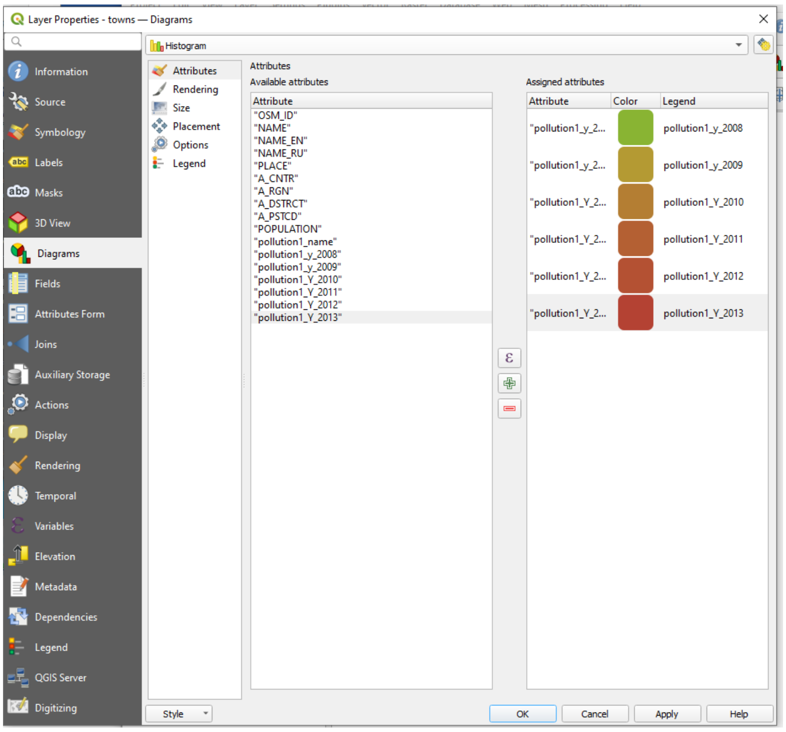



Figure 151. – Layer properties - towns | Diagrams panel

The custom color in rounded squares for the assigned attributes section can be changed for each of added items sequentially by double clicking on each of squares, the color scale is activated and you'll be able to select the desired color. Repeat this operation for each of rounded squares. The color scale will be added to the "towns" layer as well, fig. 152.

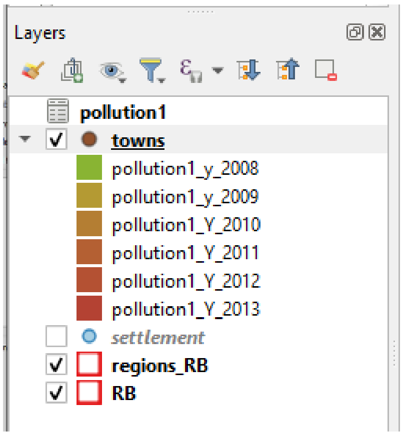



Figure 152. – Towns layer with pollution data

Click the *Rendering* tab at this panel. Drag the slider to set the transparency to 30%. Set the column width to 2.5, fig. 153.

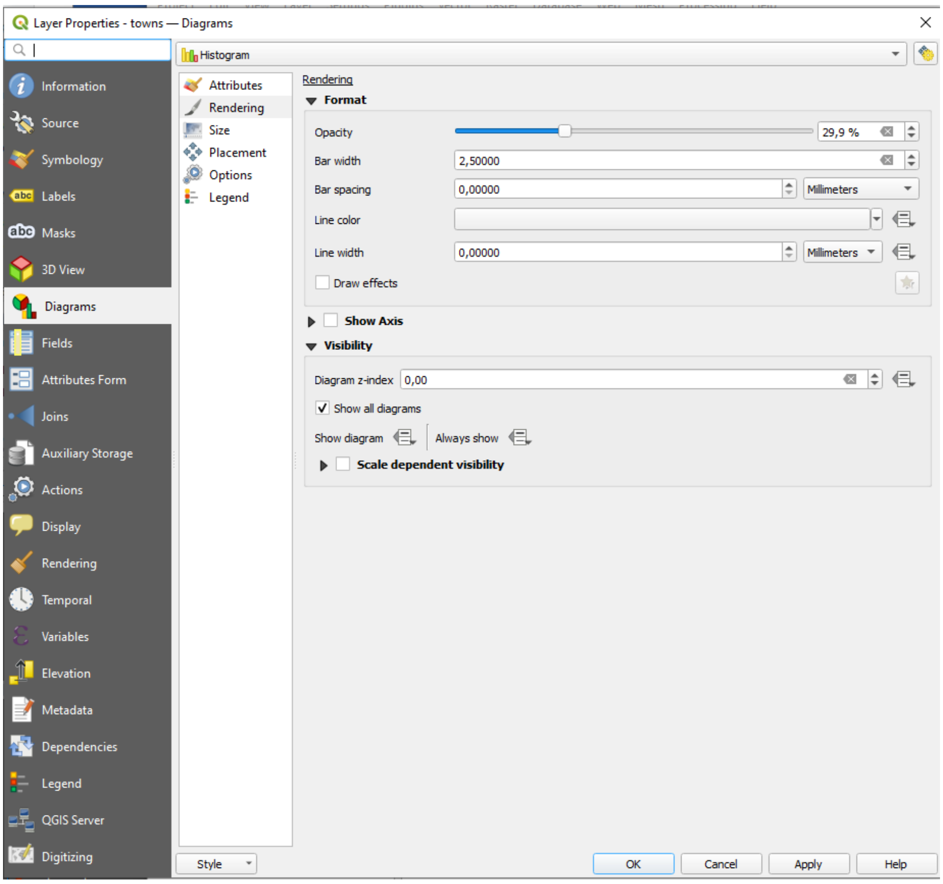



Figure 153. – Layer properties – towns – Diagrams | Rendering

Click here the *Size* tab. In the *Size units* list, select *Millimeters*. Enter pollution1_y_*2012* in the *Attribute* field. Opposite the *Maximum value*, click *Find*. Set the *Bar length* to 15, fig. 154.

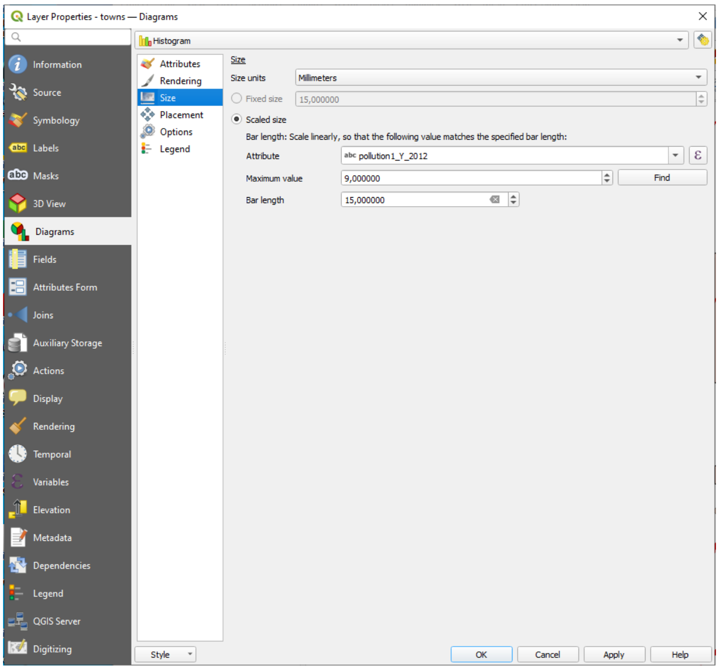



Figure 154. – Layer properties – towns – Diagrams | Size

Click *Apply*, to display the chart in the map area, and OK, fig. 155.

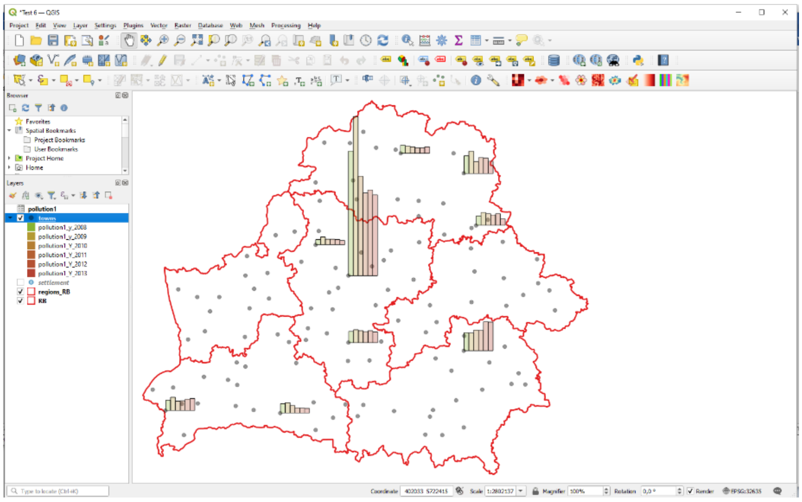


Figure 155. – Pollution histograms

***Step 8.*** Create Pie Charts. Save as a text file *Pollution2a.xlsx* with the *.csv* extension (comma delimited) located in the source data folder. The latter one contains information on the structure of pollutant emissions from stationary sources by regions as for 2013.

Load the text file *Pollution2a.csv* located in the source data folder into the project as a table (*Add Delimited text Layer…* tool in the *Layer* → *Add Layer* panel, add the *pollution2.csv* file to the project, fig. 156. In the Data Source Manager | Delimited Text dialog box, activate in the File Formal – *Semicolon*. In the *Geometry Definition* group activate “X field” and “Y field” as shown in fig. 156, click Add and

OK). The pollution1 table will appear in the layers window. Please note, leave as is the names of regions.

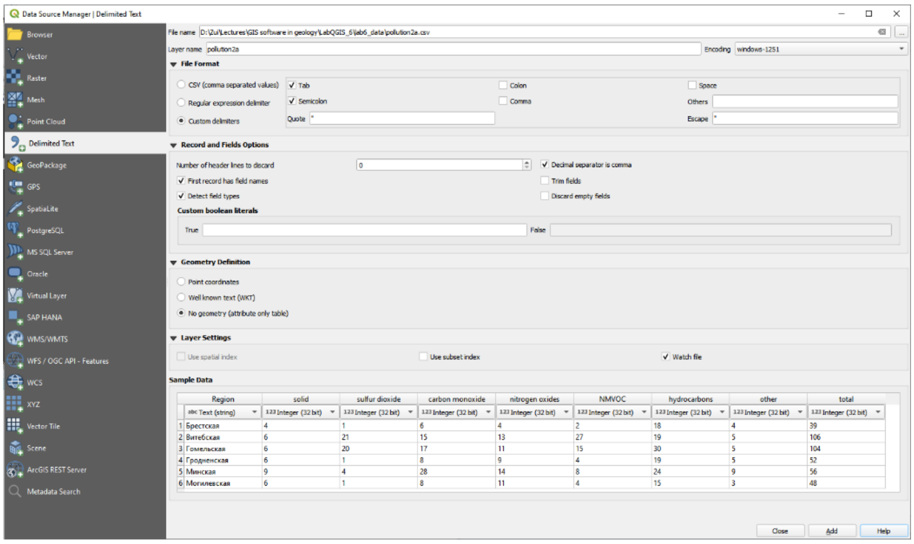


Figure 156. – Adding the pollution table to the project

Attach the "Pollution2a" table to the "regions_RB" layer. Click right button on the layer name "regions_RB" and select *Properties*. In the *Layer Properties* dialog box, click the *Joins* tab. Click the *Add New Join* button. In the dialog box that opens in the field *Join layer* select *pollution2a*, for *Join Field* select – "Region", *Target field* – ID, click OK. Check *Cache join layer in memory*. The *Join fields to* option allows you to select which fields from the join table will be added to the target table. Check all fields to be added, fig. 157. Click OK. The table *pollution2a* will be shown in the Layers panel.

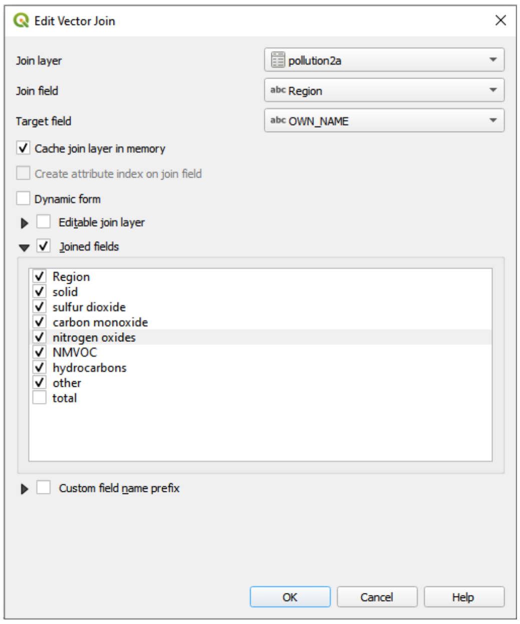
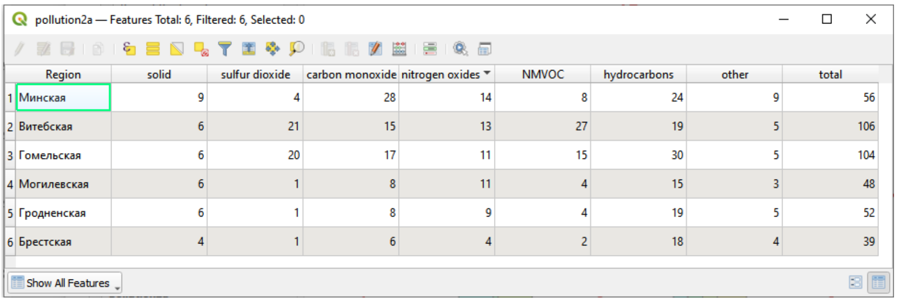



Figure 157. – Add vector join panel

Once created, the joined list will be shown in the *Joins* tab. The tool allows you to edit parameters of the existing connection. A connection can be deleted by selecting it in the window and clicking the (*Delete connection*) button.

Right-click the pollution2a → *Open Attribute Table* in the "Layers" panel and you’ll see its content, fig. 158.



pollution2a — Features Total: 6, Filtered: 6, Selected: 0

| | Region | solid | sulfur dioxide | carbon monoxide | nitrogen oxides | NMVOC | hydrocarbons | other | total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Минская | 9 | 4 | 28 | 14 | 8 | 24 | 9 | 56 |
| 2 | Витебская | 6 | 21 | 15 | 13 | 27 | 19 | 5 | 106 |
| 3 | Гомельская | 6 | 20 | 17 | 11 | 15 | 30 | 5 | 104 |
| 4 | Могилевская | 6 | 1 | 8 | 11 | 4 | 15 | 3 | 48 |
| 5 | Гродненская | 6 | 1 | 8 | 9 | 4 | 19 | 5 | 52 |
| 6 | Брестская | 4 | 1 | 6 | 4 | 2 | 18 | 4 | 39 |

Show All Features

Figure 158. – Pollution2a table content

On the *Diagrams* tab of the *Layer Properties* dialog box, select the chart type – *Pie Chart* ( icon). To create charts, use the attribute fields: *Solids, Sulfur dioxide, Carbon monoxide, Nitrogen oxides, NMVOCs, Hydrocarbons, others*. You can change the color for each of rounded squares double clicking on it and selecting the required one instead of the custom color. An example of selected set for attributes, is shown in fig. 159.

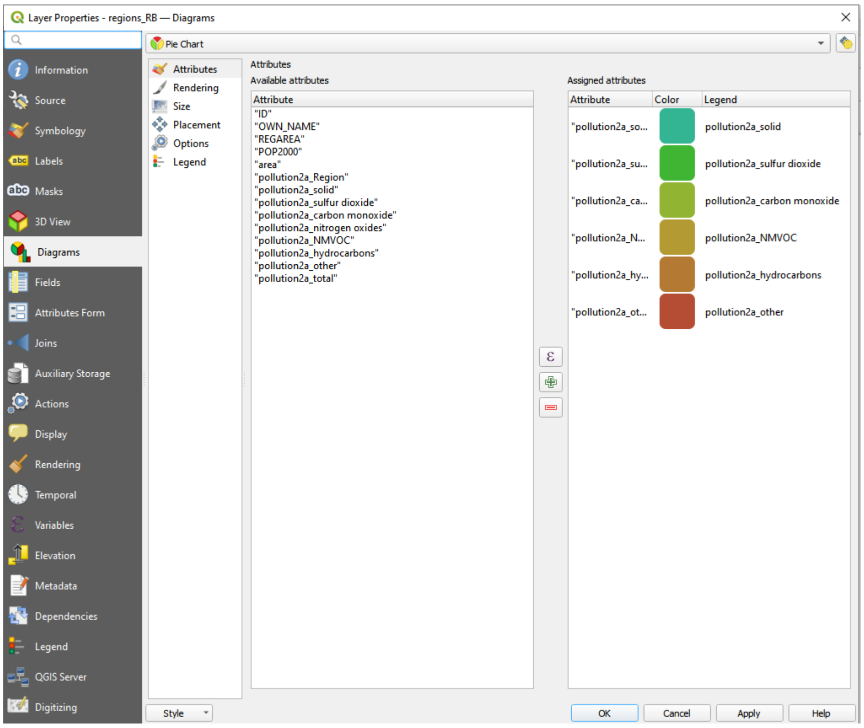



Figure 159. – Adding attributes for Pie Chart panel

The pollution2a subdivided into specified colors for each of included pollutants will be added to the *regions_RB* at the layers panel and circles of different sizes will be drawn within regions of the country, fig 160.

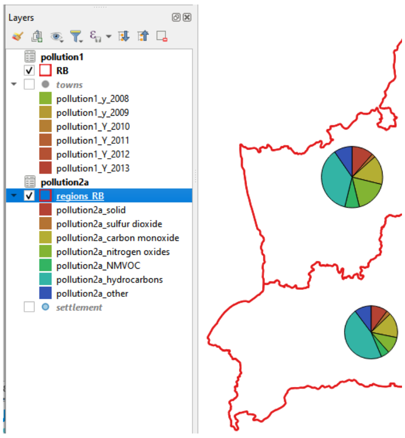



Figure 160. – Layers panel with added pollution2a

Position the charts inside the polygons (Placement tab).

On the *Size* tab, scale you can change the diameter of charts depending on the total amount of emissions ("total" field). By clicking on the *Find* button, set the maximum value. Specify the size equal to 30, fig. 161. Click *Apply* and OK.

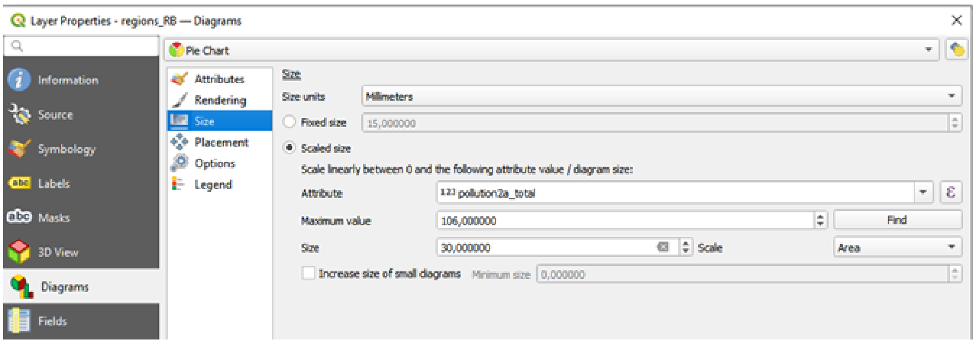
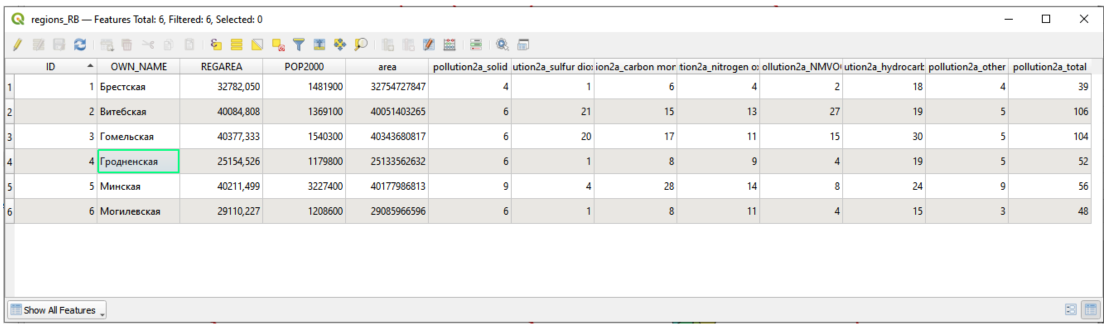



Figure 161. – Selecting parameters of Pie Charts

After finishing with pie charts, you may right-click "regions_RB" → *Open Attribute Table* and the final table looks like in fig. 162.




| | ID | OWN_NAME | REGAREA | POP2000 | area | pollution2a_solid | ution2a_sulfur dio: | ion2a_carbon mor | tion2a_nitrogen o: | ollution2a_NMVO( | ution2a_hydrocarb | pollution2a_other | pollution2a_total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Брестская | 32782,050 | 1481900 | 32754727847 | 4 | 1 | 6 | 4 | 2 | 18 | 4 | 39 |
| 2 | 2 | Витебская | 40084,808 | 1369100 | 40051403265 | 6 | 21 | 15 | 13 | 27 | 19 | 5 | 106 |
| 3 | 3 | Гомельская | 40377,333 | 1540300 | 40343680817 | 6 | 20 | 17 | 11 | 15 | 30 | 5 | 104 |
| 4 | 4 | Гродненская | 25154,526 | 1179800 | 25133562632 | 6 | 1 | 8 | 9 | 4 | 19 | 5 | 52 |
| 5 | 5 | Минская | 40211,499 | 3227400 | 40177986813 | 9 | 4 | 28 | 14 | 8 | 24 | 9 | 56 |
| 6 | 6 | Могилевская | 29110,227 | 1208600 | 29085966596 | 6 | 1 | 8 | 11 | 4 | 15 | 3 | 48 |

Figure 162. – Parameters of Attribute Table for pie diagrams

***Step 9:*** Create a chart legend. There is no standard way to get legends for charts in QGIS. Let's use the following approach. Open *Project → New Print Layout*. In the dialog box that opens, fig. 163, type the file name (e.g. "Test6_Layout") and click OK. The *Test6_Layout* panel opens, it'll be used to create the pollution map, legend (kinds of pollutants), attribute table and corresponding labels. Click Add Map ( icon), then with mouse left button draw the square area and release it. An image of the pollution map will appear within the indicated square, its size and position could be adjusted to the desired extent, fig. 164. Click at any empty location and the bounding square disappears.

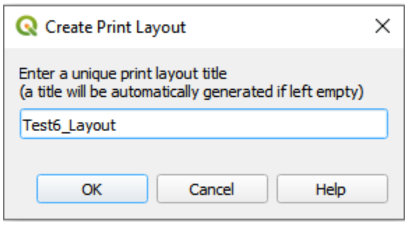



Figure 163. – Starting to create print layout

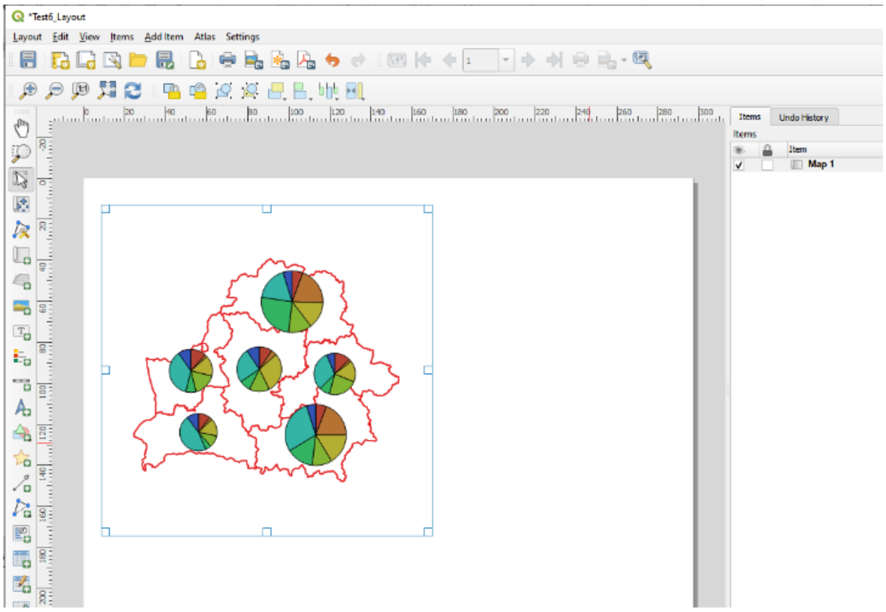



Figure 164. – Adding the pollution map to the layout

In a similar way add the legend (kinds of pollutants), click the *Add Legend*  icon, create a bounding rectangle with the left mouse button and release it, the legend will be added. Then click Add Attribute Table  icon and in a similar way add this table to the layout and adjust its position. Finally add titles of three added images, click the  icon, create the frame and instead of default ("Lorem Ipsum"), fig. 165, type "Pollutions within individual regions", adjust its position and font size.

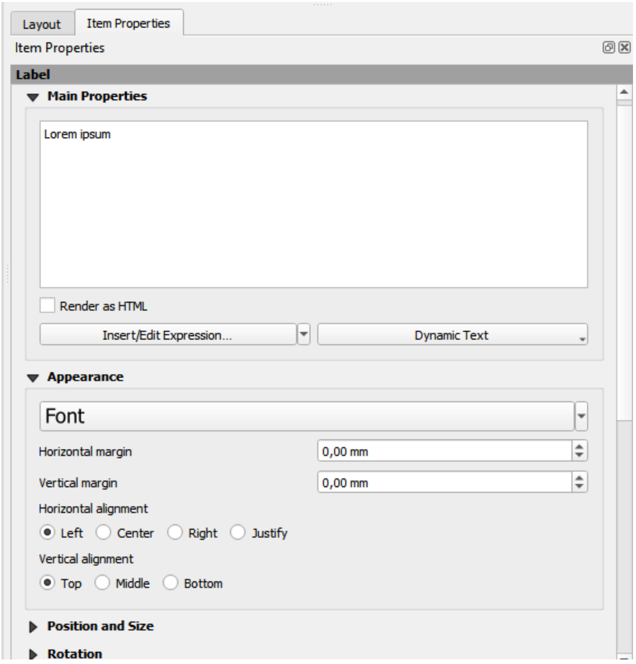
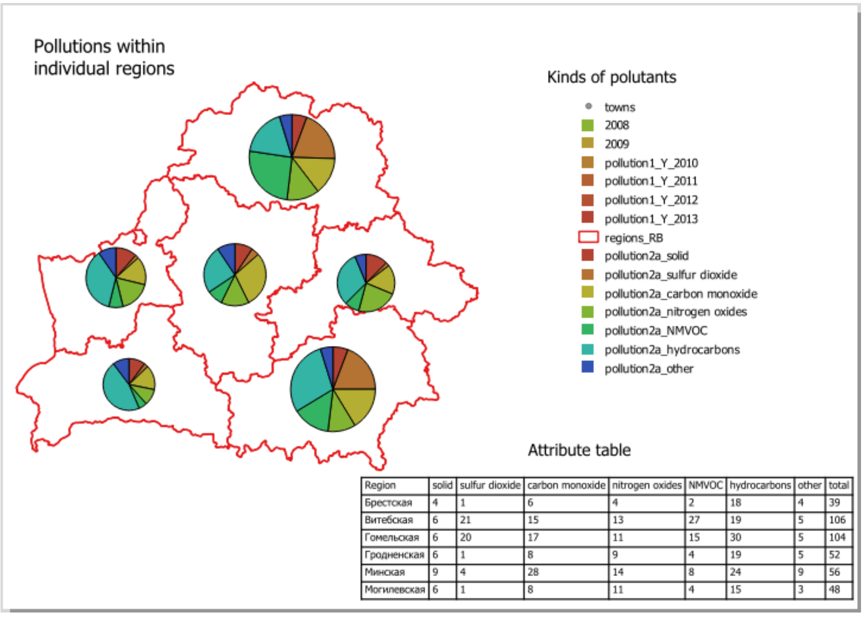



Figure 165. – Adding labels

In similar way create labels "Kinds of pollutants" and "Attribute table" labels. Finally, your layout looks like shown in fig. 166.




| Region | solid | sulfur dioxide | carbon monoxide | nitrogen oxides | NMVOC | hydrocarbons | other | total |
|---|---|---|---|---|---|---|---|---|
| Брестская | 4 | 1 | 6 | 4 | 2 | 18 | 4 | 39 |
| Витебская | 6 | 21 | 15 | 13 | 27 | 19 | 5 | 106 |
| Гомельская | 6 | 20 | 17 | 11 | 15 | 30 | 5 | 104 |
| Гродненская | 6 | 1 | 8 | 9 | 4 | 19 | 5 | 52 |
| Минская | 9 | 4 | 28 | 14 | 8 | 24 | 9 | 56 |
| Могилевская | 6 | 1 | 8 | 11 | 4 | 15 | 3 | 48 |

Figure 166. – A layout of pollutions within regions of Belarus

## II. Spatial Data Connection

A spatial join is similar to an attribute join, i.e., as a result of the join, attributes from one layer are attached to attributes of another related record; however, it is based on a spatial relationship between the objects in these two themes.

***Step 1.*** Create a new project *(Projects → New*). Add shapefiles to the project: *poi_point*, *Brest_region*, *Brest_district* (located in the source data folder). Symbolize the "Brest_region" layer with a Single Symbol ( icon), *Fill* style – no fill, *Symbol layer type* – Simple line, *Stroke style* – Solid line, *Stroke width* – 1.0, *Color* – red.

To display the "Brest_district" layer, use the legend type *Categorized* ( icon) by *Value* NAME. Click *Classify* button. Choose colors of your choice.

***Step 2.*** Select the objects of the "poi_point" layer located on the territory of the Brest region. To perform a selection based on spatial position, clip the poi_point layer within the Brest region area, save results as *Brest_poi_point* (fig. 167) with *Data source encoding* UTF-8 and CRS – 32635 – WGS 84 / UTM zone 35N. The clipped area looks like in fig. 168. Now you may deactivate or remove the “poi_point” layer from the project.

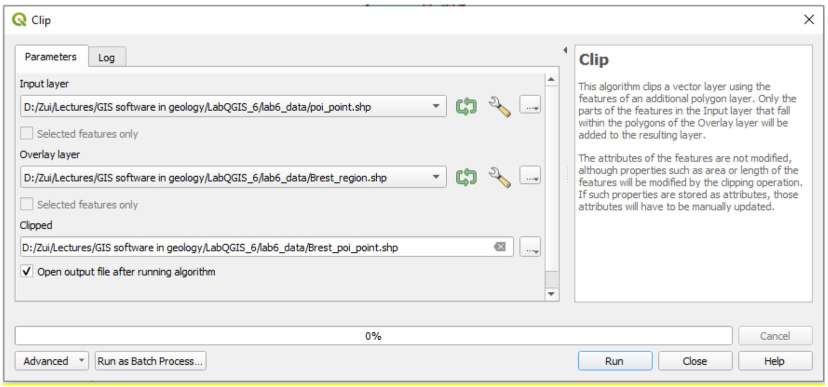



Figure 167. – Clipping points of interest for Brest region

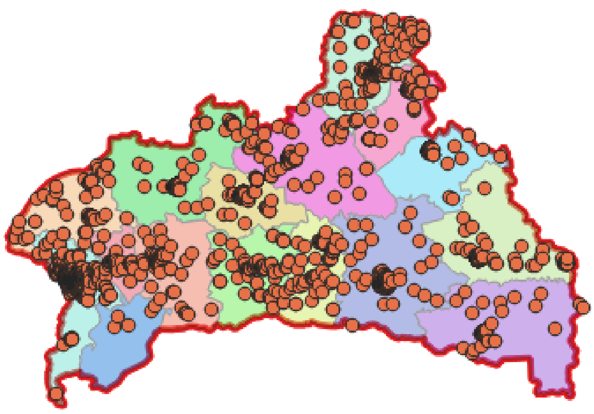


Figure 168. – Brest region classified with poi_points

***Step 3.*** Create a point feature layer containing information about the region's petrol stations. With the Brest_poi_point layer selected open Attribute table and in the appeared panel *Brest_poi_point – Select Features*, click the *Select features using an expression* ( icon). In the *Brest_poi_point – Select by Expression* dialog, write the expression AMENITY = 'fuel' (fig. 169). Click *Select Features* button. Close the window.

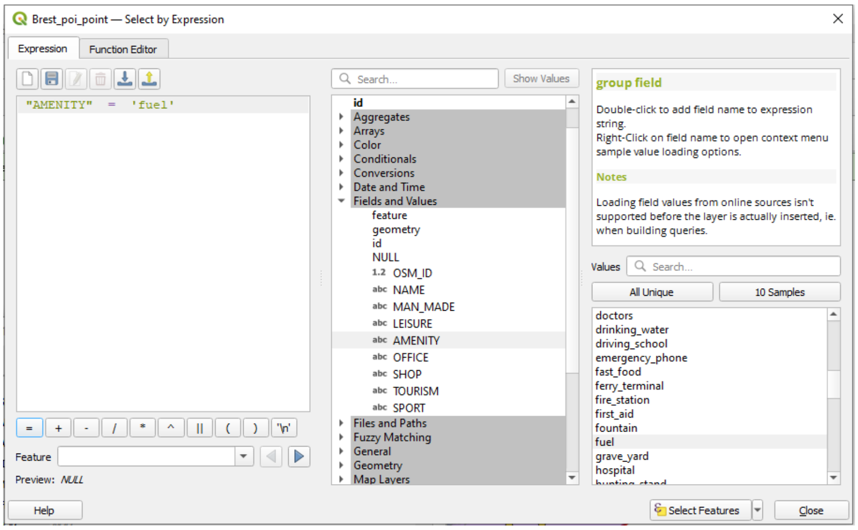



Figure 169. – Selecting fuel filling points within Brest region

The results with the selected features are in the memory. There is no an option to save them as a file in the panel, fig. 169. To do this you need to save your selection into a new vector layer file. To save it, firstly copy them click at the toolbar *Edit* menu *Copy Features*, then click *Edit* → *Paste Features As* → *New Vector Layer* in the desired format. Save the selected objects to a separate file "Brest_fuel_point.shp". Add the created shapefile to the project, fig 170.

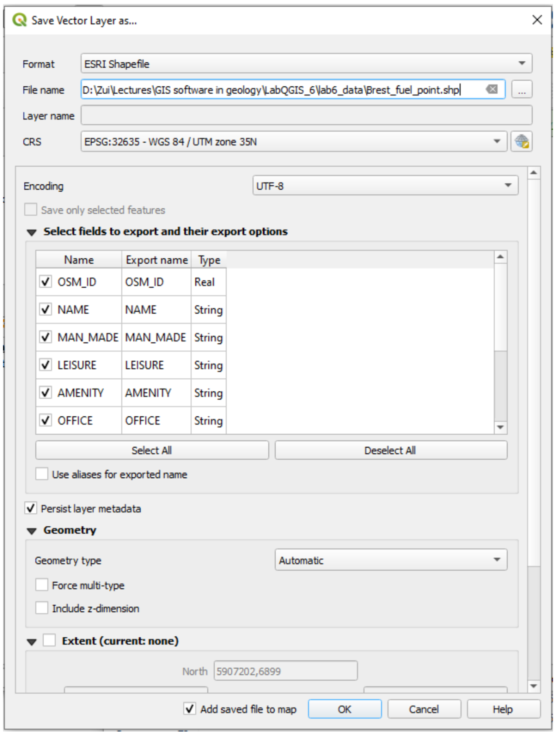



Figure 170. – Saving the file with fuel filling points within Brest region

***Step 4.*** Spatially connect the point layer "Brest_fuel_point" and the polygon "Brest_district". From the *Vector* menu, select *Data Management Tools → Merge Vector Layers*, fig. 171.

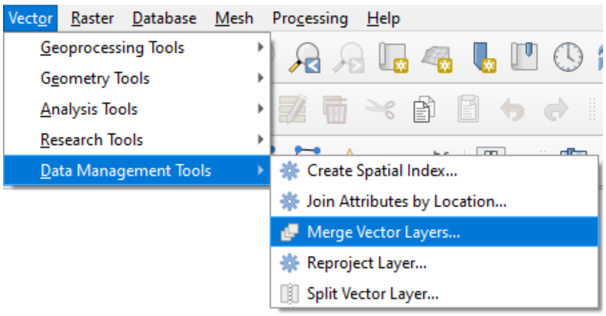



Figure 171. – Merging vector layers

In the *Merge vector Layers* dialog box, specify "Brest_district" as the target feature layer, and "Brest_fuel_point" as the target layer to merge. Enable the *Open output file after running algorithm* option, fig. 172. Click *Run*.

The fuel points within districts of the Brest region as shown in fig. 173.

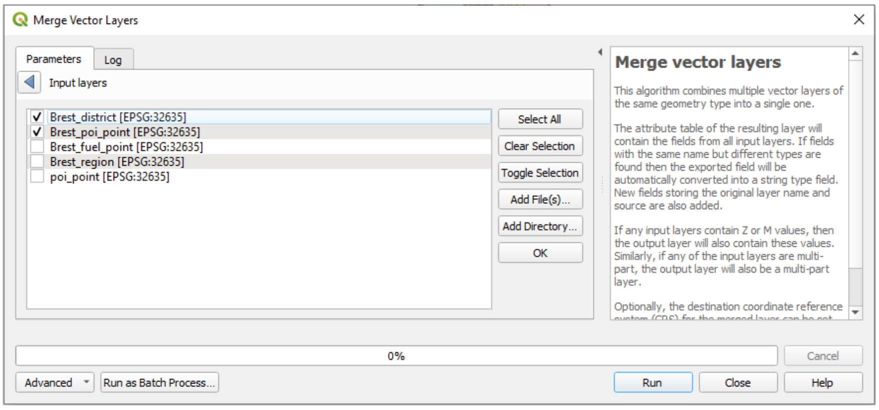



Figure 172. – Merging attributes for districts

Figure 173. – Merging vector layers

## 2.7. Laboratory work 7. Search the shortest route with road graph for QGIS

**The purpose of the laboratory work:** to learn the algorithm for finding the shortest route between two points of a linear vector layer using the *Road* graph.

**Initial data:**

- shapefile containing the boundary of the city of Polotsk (*boundary.shp*);
- shapefile of roads in Polotsk (*roads.shp*).

**Laboratory progress**

The Road graph extension is designed to find the shortest distance on a road graph. Any line vector layer in a format supported by QGIS can be used as a road layer. The main features of the module: calculation of the route, its length and travel time; optimization by criterion of distance or time; route export to a vector layer.

***Step 1.*** Open QGIS Desktop 3.34.6. Create a new project and use the *Add Vector Layer* tool to add the "roads" and "boundary" shapefiles located in the source data folder to the project. Symbolize the "boundary" layer with a Single Symbol ( icon). The *Fill style* is No Brush. *Symbol layer type* – Simple Fill, *Stroke color* – on your choice (e.g.) burgundy, *Stroke width* – 0.8 mm. Transparency – 20 %. Draw the "roads" layer with a solid line in dark brown, fig. 174.

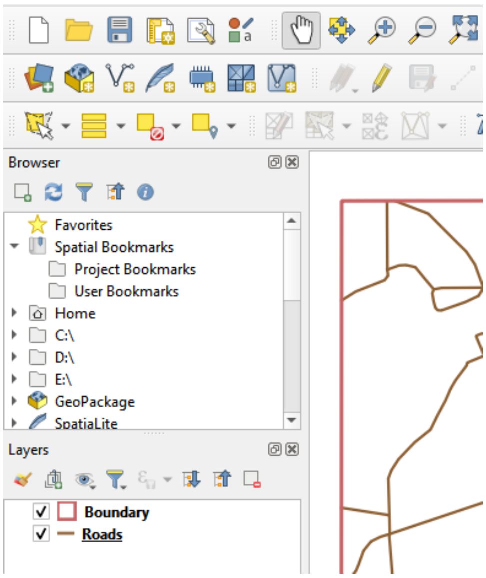



Figure 174. – Calculator for fields panel

***Step 2.*** Activate the Shortest Path: *Processing* → *Toolbars* → *Network analysis* → *Shortest path* (point to point). It includes the following items: Vector Layer Representing Network, Path Type to Calculate (Shortest/Fastest), Start Point, End Point, Advanced Parameters. You can open and learn it.

***Step 3.*** Examine the attribute information of the “roads” layer (right-click on the layer name in the legend area → *Open Attribute Table*). The *HIGHWAY* field contains information about road types in terms of their importance in the road network. So, **primary** are the central thoroughfares of the city, **secondary (track)** are the main thoroughfares of the city districts, **tertiary** are the main streets in relation to other small streets / alleys, **unclassified** are small streets / alleys, mainly with non-residential buildings along the street, **residential and living_street** are small streets / alleys, mainly with residential buildings along the street, **service** – service driveways, **pedestrian** – pedestrian streets, **cycleway** – paths for cyclists, **footway** – sidewalks, paths, **track** – field and forest roads.

Let's fill in the *MAXSPEED* field, which contains information about the permissible speed on the section of movement.

Switch to edit mode. With the "roads" layer selected in the legend window, right-click on the tool *Toggle edit mode*. On the toolbar, select *Open field calculator*. In the window that opens, check the *Create a new field* option, specify the *Field* name – maxspeed1, *Type* – an integer. In the *Functions* (middle) window, expand the *Fields and Values* list and double-click *MAXSPEED*. Click OK. A new numeric field with the copied values of the *MAXSPEED* attribute will be created, fig. 175.

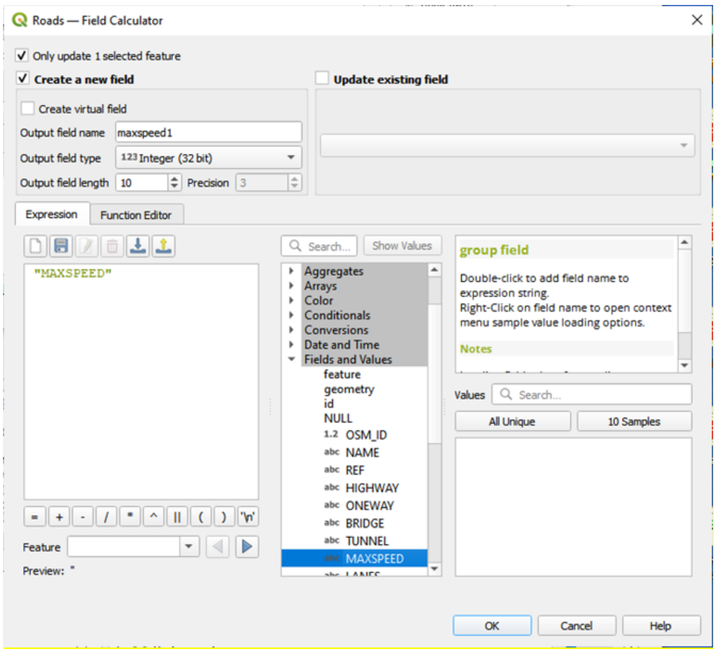



Figure 175. – Calculator for fields panel

***Step 4***. In the Attribute Table for "roads" click *Toggle editing mode*, then click icon *Select objects that meet the condition* button. In the *Select features using an expression* dialog box that opens, do the following: txpand the *Fields and Values* list and double-click *HIGHWAY*, then double-click the "=" operator. Select ‘primary’ from the list that appears. Click the *Select Features* button, fig. 176. Close the panel.

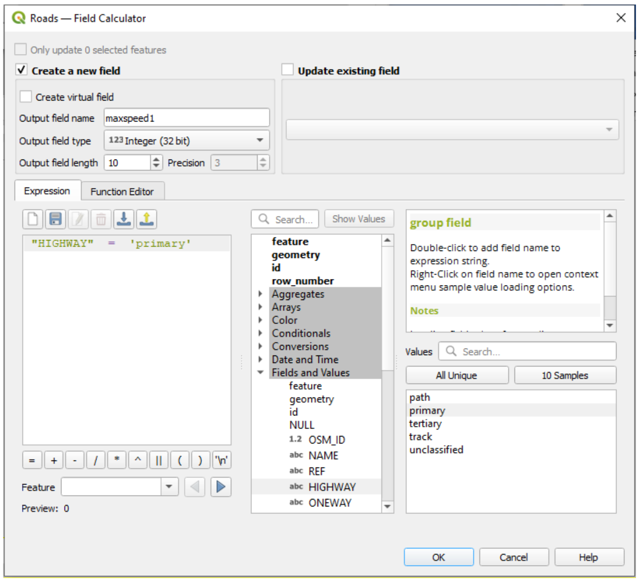



Figure 176. – Select by expression – roads panel

In the attribute table, we will display only selected objects. To do this, in the lower left part of the *Attribute Table* window, select *Show Selected Features* from the drop-down list, fig. 177.

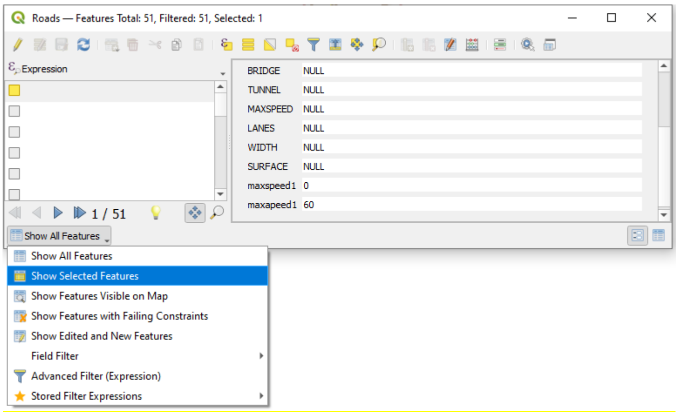



Figure 177. – Road parameters assigning

For most of the selected objects, the maximum speed is already set *(maxspeed1* field). For selected objects with unspecified speed, replace the NULL value with 60 in the *maxspeed1* field.

Similarly, select the main highways of the city districts (*HIGHWAY* = 'track') and for objects with unspecified speed, replace the NULL value with 60 in the *maxspeed1* field.

Highlight main streets in relation to other small streets/lanes (*HIGHWAY* = 'tertiary'). Use the  *Field Calculator* to automatically fill in the *maxspeed1* field. In the dialog box, select the *maxspeed1* field from the drop-down list. In the Feature window type, for instance, 40.

In the *Field Calculator*, set the maximum speed for the *unclassified* road type to 40, *service* to 20, *residential* to 20, *living street* to 20, and *primary link* to 60.

Save your changes to the attribute table ( *Save Edits*) within the Attribute Table and exit edit mode. Close the attribute table for the "roads" layer.

***Step 5:*** Create a filter to display a subset of roads that allow vehicular traffic. To do this, in the legend area, right-click on the "road" layer and select *Filter* from the context menu. In the *Query Builder* panel that opens, perform the following sequence of actions: double-click on the field of the *HIGHWAY* attribute table, then on the relational operator "!=" and on the value 'pedestrian'. Next, press the logical *AND* button, select *HIGHWAY* again, then '!=' and double-click the 'footway' value. Similarly, add the 'path' and 'steps' values to the query, fig. 178. After that click OK. As a result, the "road" layer will display roads on which traffic is allowed.

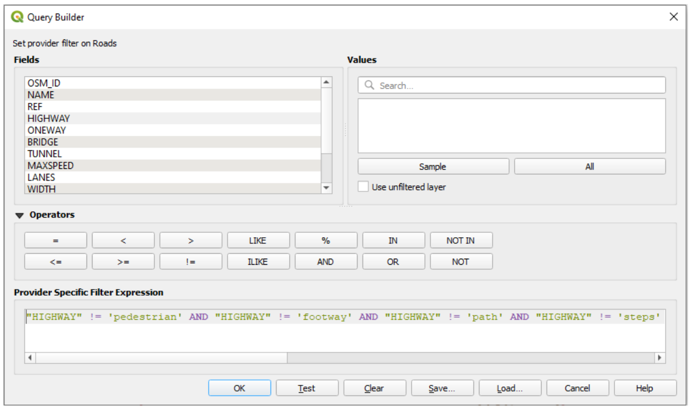



Figure 178. – Query builder panel

***Step 6***. Extract vertices which could be used as ‘Start Point’ and ‘End Point’ for the *Shortest Path* (Point to Point) module. Open in the Vector menu *Geometry Tools – Extract Vertices*, fig. 179.

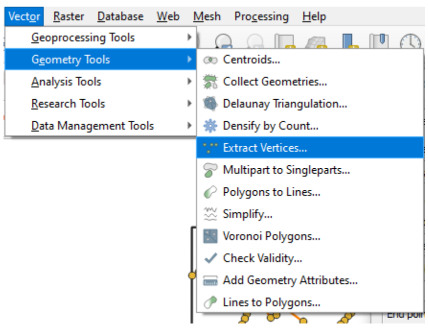



Figure 179 – Selecting Extract Vertices

The extract vertices dialog panel pops up, fig. 180. Open "Roads" for the Input layer and your resulting folder in the "Vertices" window, check the "Open output file after running algorithm". Click "Run". The layer "RoadVertices" will be added to the project.

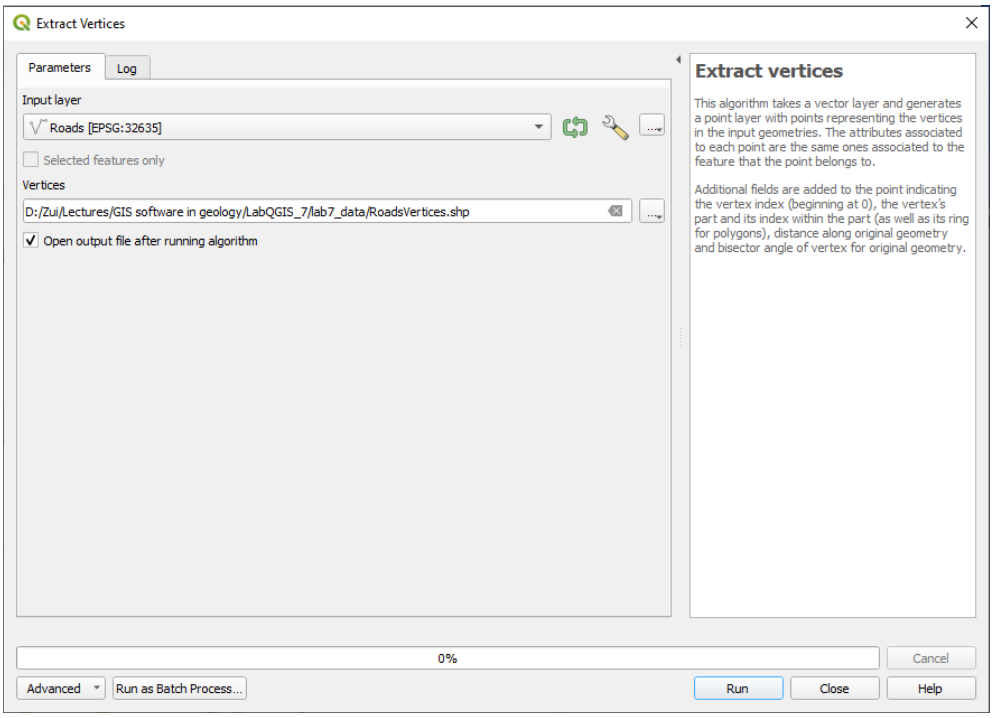



Figure 180. –Extract Vertices panel

Open the Shortest Path: *Processing* → *Toolbars* → *Network analysis* → *Shortest path* (point to point) module. In the dialog panel that pops up it is necessary to enter start and end points. Do this in a following way: In the *Edit* menu → *Select* → *Select Feature*, then select the start vertices, left click it circle, then right-click it and copy its coordinates. Go into already opened *Shortest path* (*Point to point*) panel and right-click in the *Start point* window, these coordinates appear within it. Again, return to *Edit* menu → *Select* → *Select Feature*, then select the end vertices, left click it, then right-click it and copy its coordinates. Go into *Shortest path* (*Point to point*) panel and right-click in the *End point* window, these coordinates appear within it. Other options leave as shown in fig. 181. Click "Run", after finishing calculations click "Close". The Shortest Path layer will be added to the project.

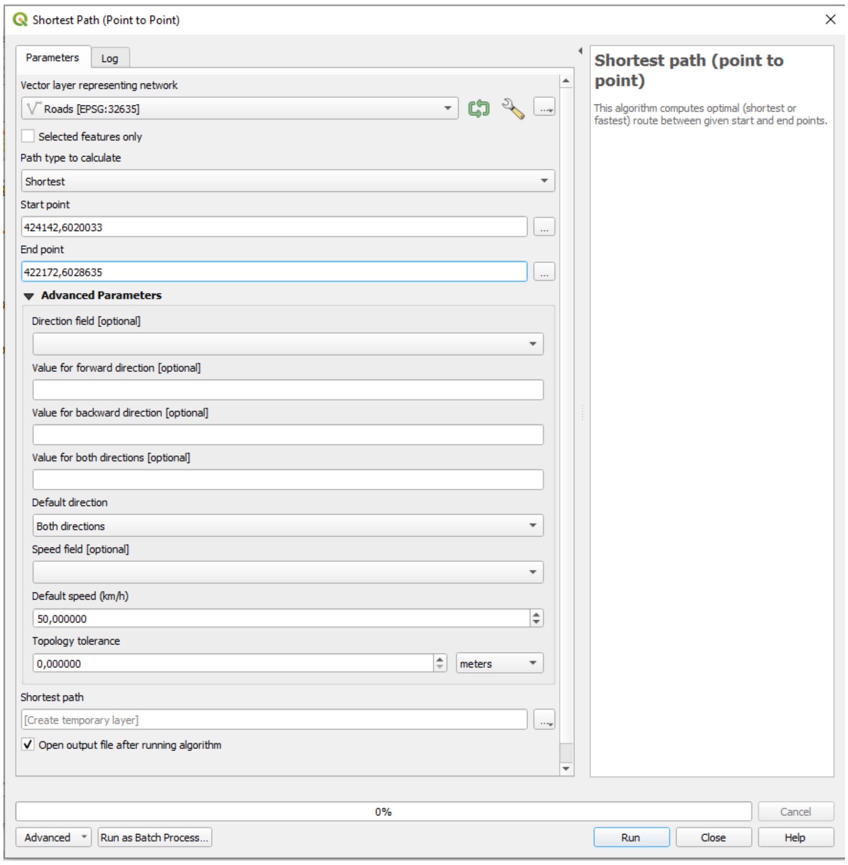



Figure 181. –Extract Vertices panel

Highlight it, open its *Properties* and symbolize it with a "Single Symbol" ( icon). "Symbol layer type" – *Single Line*, other parameters shown in fig. 182.

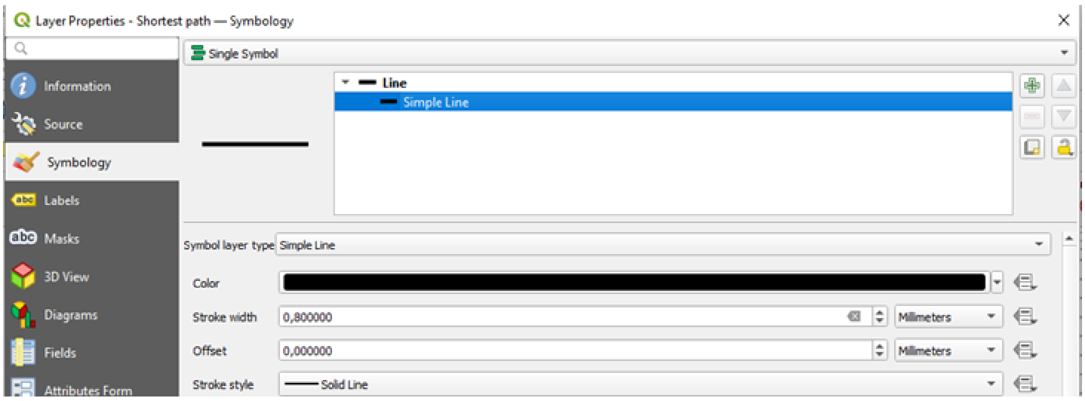



Figure 182. –Symbolizing the Shortest path panel

You can repeat the algorithm with selected *Fastest Path* instead of *Shortest path* in the window "Path type to calculate" for preserving other existing parameters and saving results in the Fastest path.shp in your working folder. In this case, the both lines will coincide. The resulting map looks like in fig. 183.

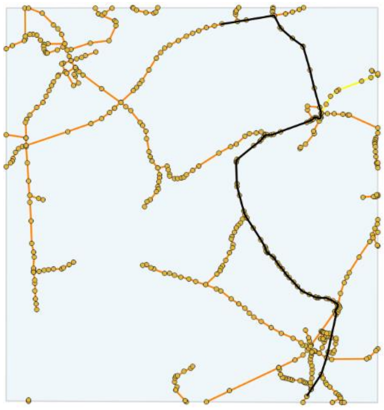


Figure 183. – The shortest path shown in black line

***Step 7.*** To load the *OpenStreetMap* with the local geographic environment of the considered area, open in the *Web* menu: then *QuickMapServices → OSM → OSM Standard*, fig. 184. Click it, the background image will be added to your map with the shortest path in between two selected points (vertices).

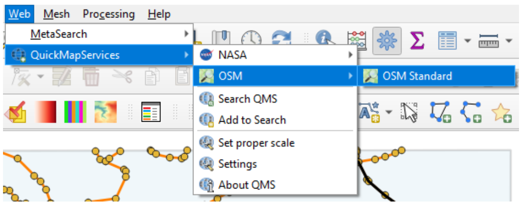



Figure 184. – Loading the OSM Standard to the map

The resulting map with created layers and the position of the *Shortest path* (point to point) module in the QGIS 3.34.6 program package looks like in fig. 185.

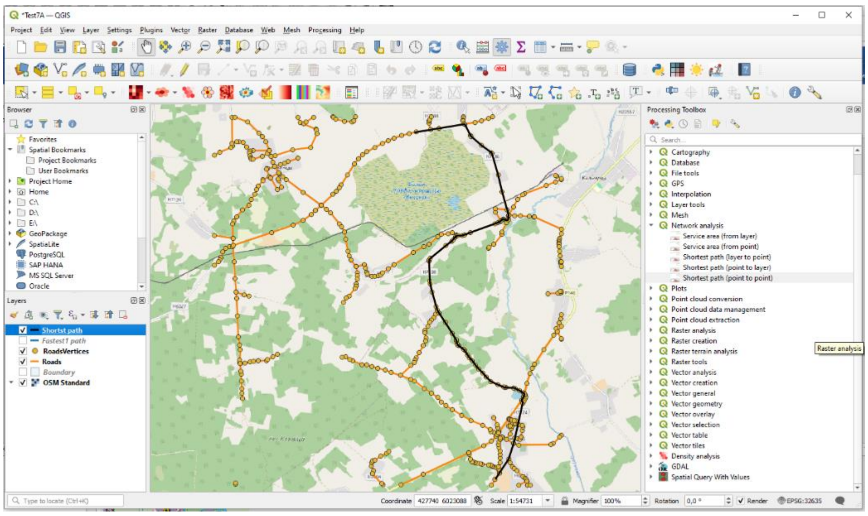


Figure 185. – Map with the shortest path shown in black line

## 2.8. Laboratory work 8. Construction and analysis of a digital relief model

**The purpose of the laboratory work:** to learn the algorithms for interpolation and analysis of hypsometric surfaces implemented in QGIS.

**Initial data:**

- shapefile containing the border of the Vilejka region (*Vilejka_district.shp*);
- shapefile containing the elevation data (*points_relief.shp*).

**Laboratory progress**

***Step 1***. Open QGIS Desktop 3.34.6. Load the shapefiles located in the source data folder into the new empty project: *points_relief* as a set of 1.5 mm circles and *Vilejka_district*. Symbolize this polygon layer of the boundary of the study area "Vilejka_district" with a Single symbol ( icon). The *fill style* – no fill. *Stroke color* – red, *Stroke width* – 0.8 mm, fig. 186.

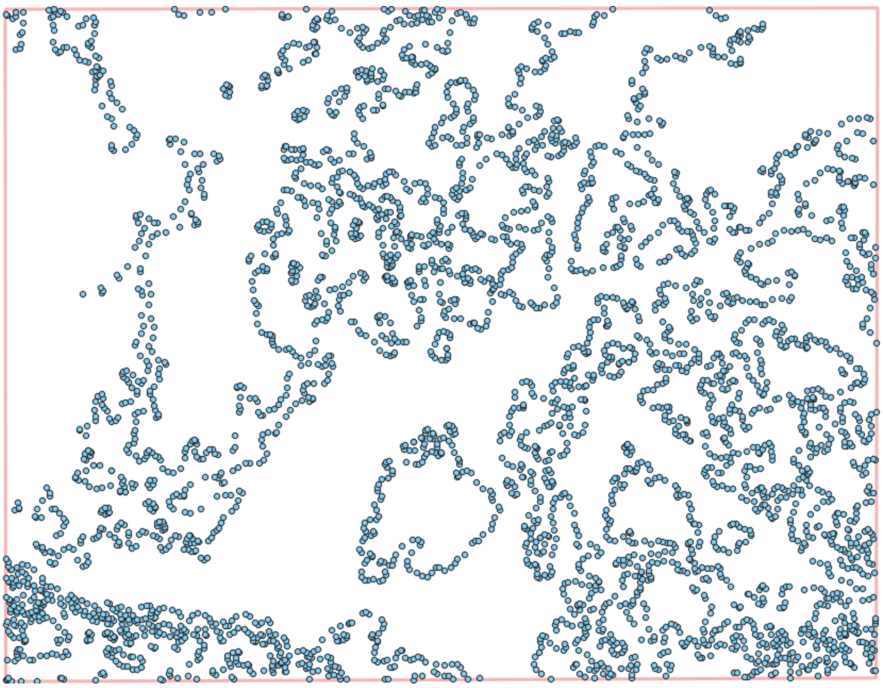


Figure 186. – Vilejka region – source data

To fulfill this exercise, we need three QGIS modules. 1) Interpolation module, which allows you to interpolate a vector point layer using two methods: triangulation (TIN – Triangular Irregular Network), which you can find in the Processing Toolbox (*Interpolation → TIN Interpolation*) and inverse distance weighted (IDW – Inverse Distance Weighted), to open it use: Processing Toolbox (*Interpolation → IDW Interpolation*); 2) the Relief module in the Processing Toolbox (*Raster terrain analysis →*  *Relief*); 3) Raster information module in the Processing Toolbox (*GDAL → Raster miscellaneous →*  *Raster information*.

***Step 2.*** We will create a digital relief model of the Vilejka district of the Minsk region by interpolating the values of the heights of reference points. The QGIS *Interpolation* module allows you to interpolate a vector point layer using two methods: triangulation (TIN – Triangular Irregular Network), which you can find in the Processing Toolbox (Interpolation → TIN Interpolation →) and inverse distance weighted (IDW – Inverse Distance Weighted), to open it use: Processing Toolbox (Interpolation → IDW Interpolation).

***Step 3***. Open the "Processing → Toolbox" (*Interpolation → IDW Interpolation*). In the dialog box that opens, as the input Vector layer, set the *points_relief*, Interpolation attribute – *H*. Click the *Input layer(s)* button (). Change the "Distance coefficient" to 4. In the "Pixel size X" and the "Pixel size Y" resolutions set to 200 pixels. Click the "Set to current map canvas extent" button, coordinates of four map corners will filled in together with the map CRS. Check the "Open output file after running algorithm". In the Interpolated window, save the raster to your folder under the name "relief.bmp". Leave the rest of the parameters set by default, fig. 187.

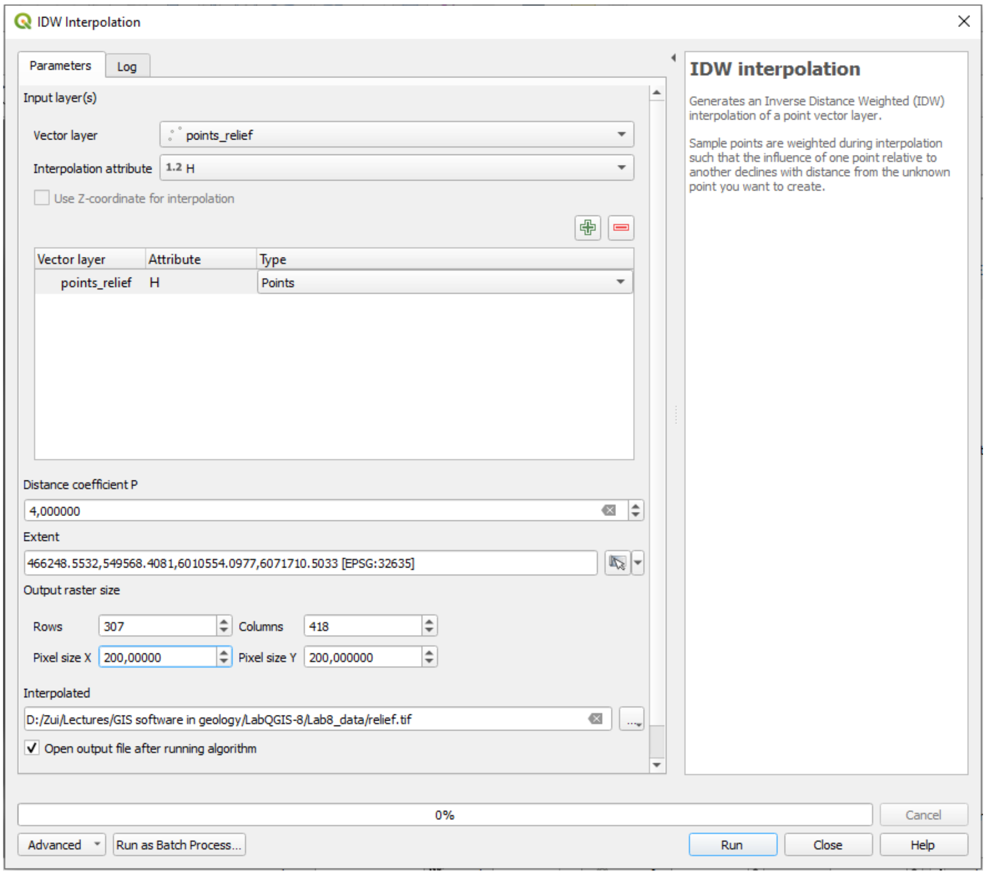



Figure 187. – Dialog panel of the IDW interpolation

After you fill required parameters at the IDW dialogue panel, click *Run* and when calculations will be finished, click *Close*. A grayscale image will appear on the screen, it will look like in Fig. 188.

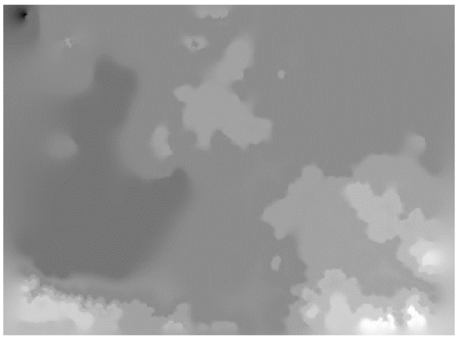


Figure 188. – Grayscale image of elevations within the region

***Step 4.*** Cut the interpolation model on the topic "Vilejka_district". To do this, in the *Raster* menu, select *Extraction → Clip Raster by Mask Layer*. In the appeared dialog box, select "Input layer" – *relief*. "Mask layer" – *Veliejka_district*, "Clipping mask" *relief_IDW.tiff*. The raster is saved in the GeoTIFF format. Activate "Match the extent of the clipped raster to the extent of the mask layer" and the "Open output file after running algorithm", for – "Mask Layer" select *Vilejka_district*, fig. 189. Click OK. Close the *Clip Raster by Mask Layer* dialog panel.

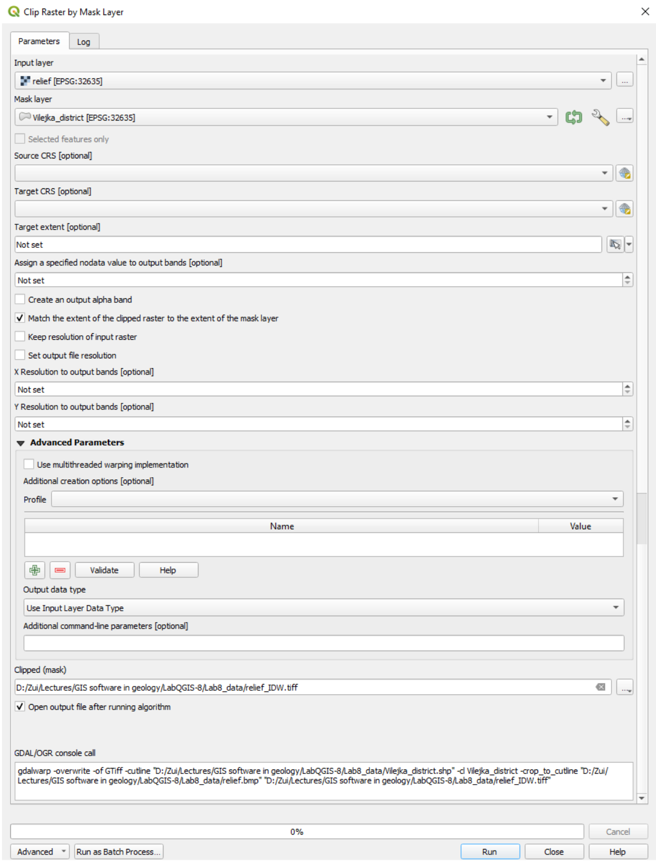



Figure 189. – Clipping panel

Turn off the visibility of the "point_relief" layer.

***Step 5.*** Once loaded, the relief_IDW layer is displayed in grayscale. Open the layer properties (right-click on the layer name in the legend → *Properties*). Click the

"Symbology" tab. Change the rendering style in the "Render type" field from *Singleband gray* to *Singleband pseudocolor*. "Interpolation" is *linear*. Select an appropriate color map in the "Color ramp", for example *Turbo*. Click the "Classify" button. Other parameters are shown in fig. 190. Apply the settings you have made. Close the window.

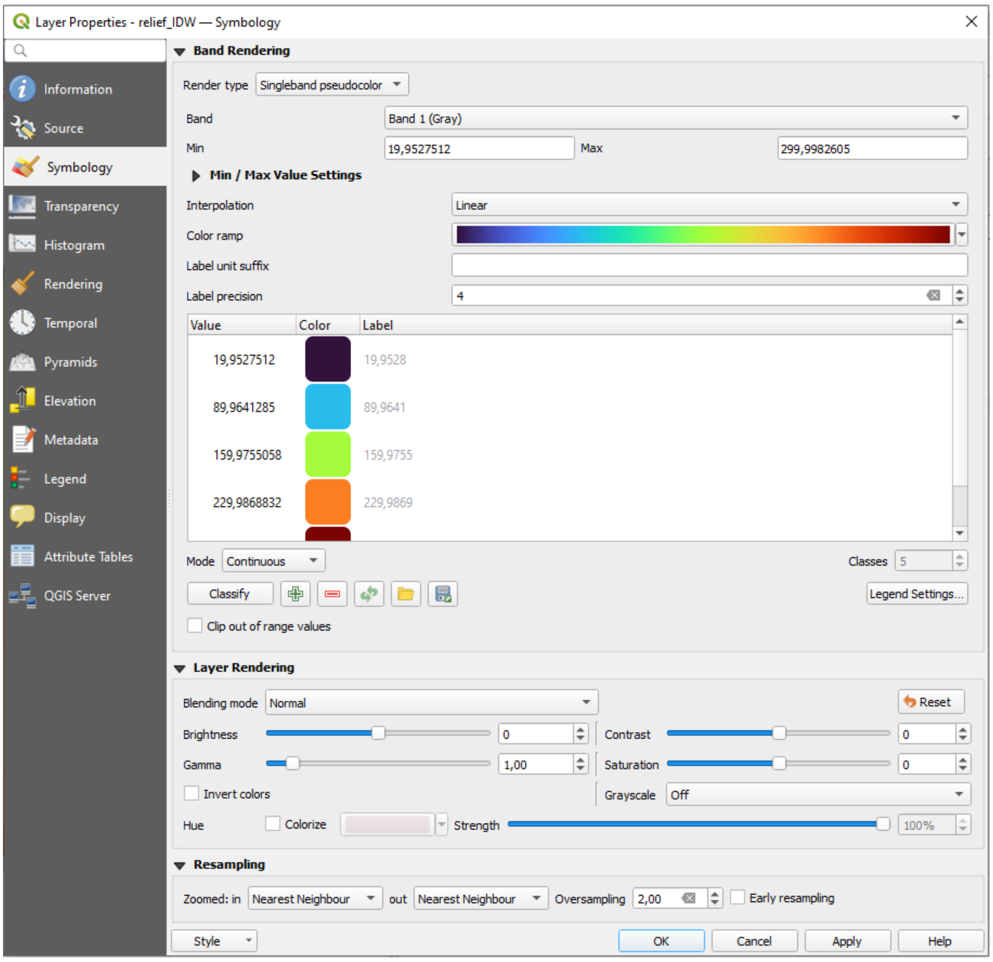



Figure 190. – Adjusting the IDW pseudocolor

***Step 6.*** Similarly, open the Processing Toolbox (*Interpolation → TIN Interpolation*). In the dialog box that opens set the *points_relief* as the input Vector layer. Interpolation attribute – *H*. Click the *Input layer(s)* button ( ). In the "Pixel size X" and the "Pixel size Y" set to 200 pixels. Click the "Extent" button. In the Interpolated window, save the raster file under the name "relief_TIN.shp". Leave other parameters set by default, fig. 191.

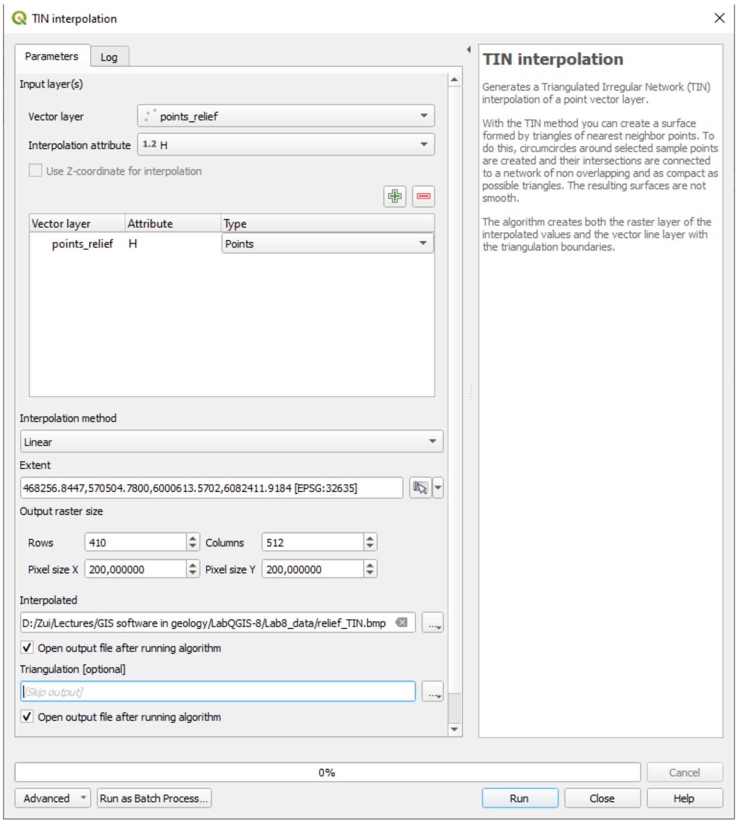



Figure 191. – Dialog panel of the TIN interpolation

After you fill required parameters at the TIN dialogue panel, click *Run* and after finishing calculations click *Close*. Save the TIN method under the name "relief_TIN". The layers *relief1* and *relief_TIN* will be added to the project, fig. 192.

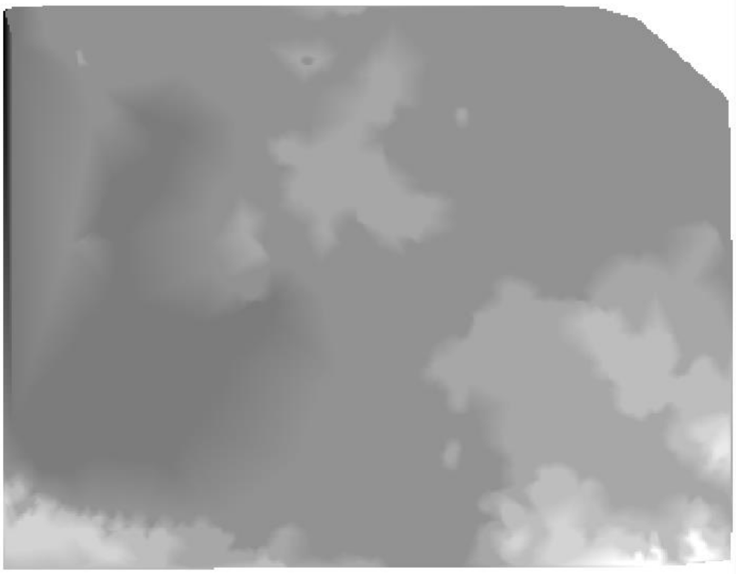


Figure 192. – Dialog panel of the TIN interpolation

The *relief_TIN* layer is displayed in grayscale. Symbolize the layer with "Single Channel Pseudo Color" style. To do this open the layer properties (right-click on the layer name in the legend → *Properties*). Click the "Symbology" tab. Change the rendering style in the "Render type" field from *Singleband gray* to *Singleband pseudocolor*. "Interpolation" is *linear*. Select an appropriate color map in the "Color ramp", for example *Turbo*. "Mode" – *Equal intervals*. Click the "Classify" button. Other parameters are shown in fig. 193. Click Apply and OK, after finishing the algorithm close the window.

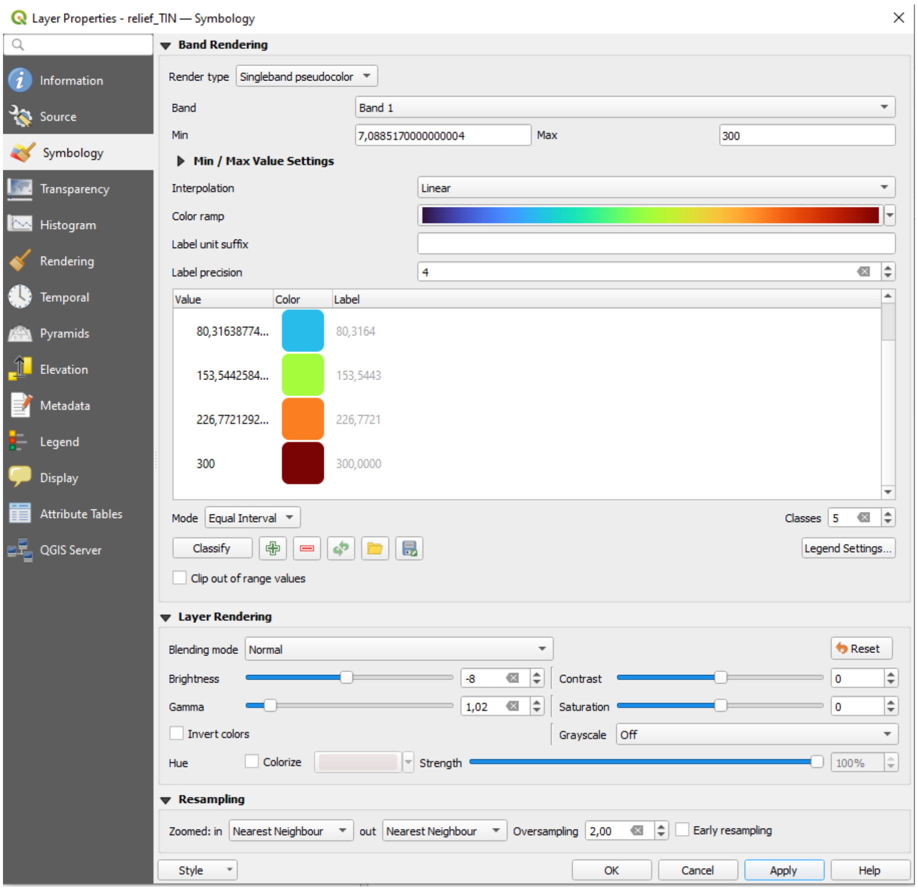



Figure 193. – Adjusting the TIN pseudocolor

***Step 7.*** Create a hillshade theme (a hillshade bitmap is used to give the image a three-dimensional look). In the *Processing* →*Toolbox* open the "Relief" module (*Raster terrain analysis* → *Relief*).

In the dialog box that opens, specify relief_IDW as the relief layer. Save the Elevation layer to your folder under the name "Hillshade_IDW". Set the Z factor to 2. Check the boxes "Open output file after running algorithm" and "Generate relief classes automatically", fig. 194. Click OK. The Hillshade_IDW layer will be added to the project.

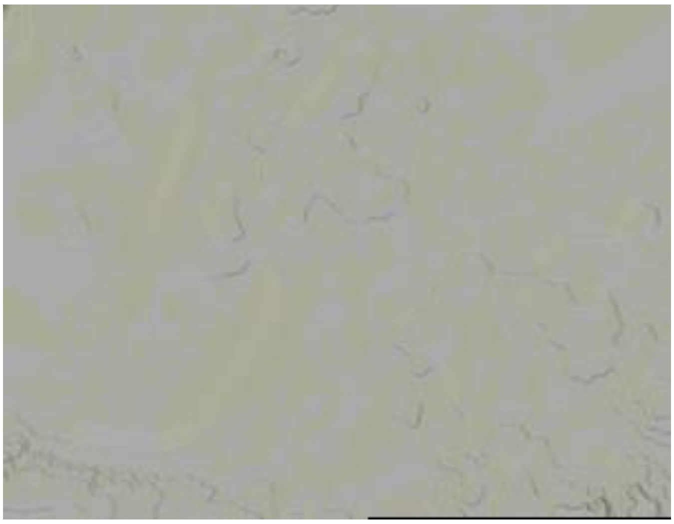


Figure 194. – Hillshaded view for relief_IDW

***Step 8*** Combine the light-shadow hillshading and a digital elevation model (DEM). To do this, turn off the visibility of the "relief_IDW" layer. In the legend, place the "Hillshade_IDW" layer below the "relief_IDW" layer. Open the properties of the "relief_IDW" layer (right-click on the layer name in the table of contents → *Properties*). Go to the *Transparency* tab. By dragging the slider, set the optimal overall transparency of the layer, fig. 195.

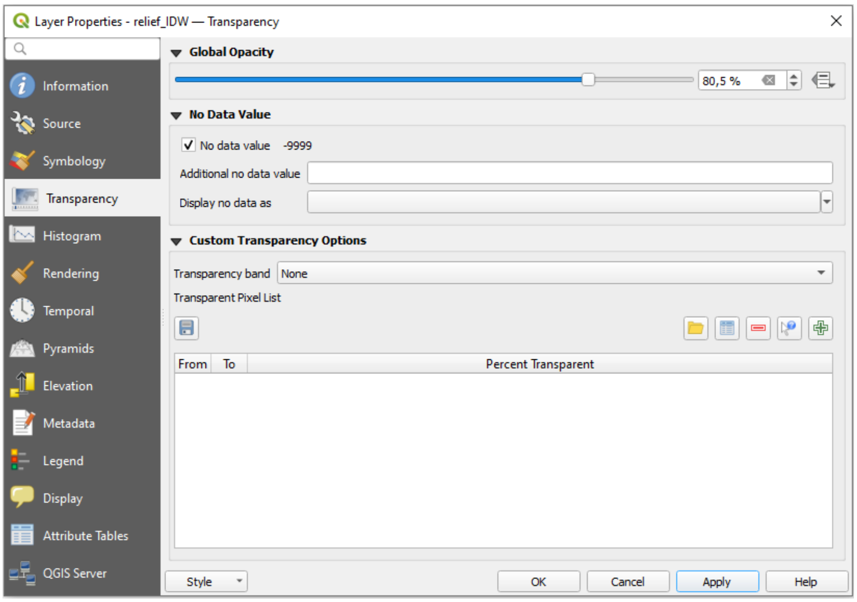



Figure 195. – Adjusting the overall transparency for relief_IDW

***Step 9*** Similarly produce the Hillshade_TIN layer based on "relief1" layer. The dialog panel and Hillshaded view for "relief1" are in fig. 196. In this case, set the Z factor to 12, fig. 196. Save the layer to your folder under the name "Hillshade_TIN". Combine the "relief1" digital model and the appropriate hillshade.

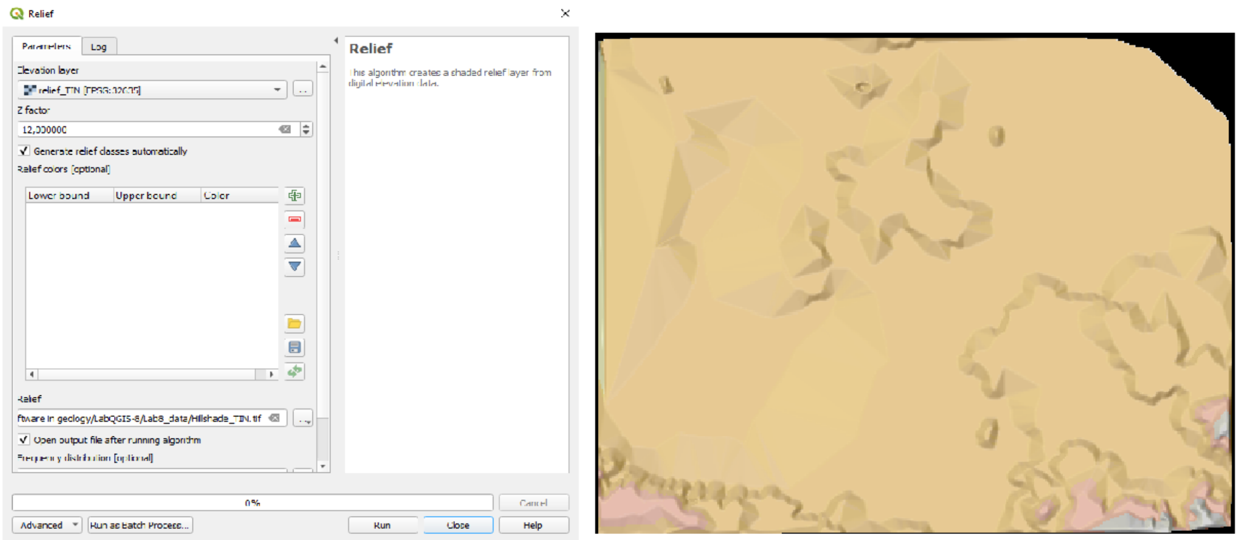



Figure 196. – The Relief_TIN panel (left) and Hillshade_TIN (right)

Results, received using both models IDW and TIN shown in fig. 197. Select the model that, in your opinion, most accurately reflects the real hypsometry of the study area, rename it in the project to "Digital Elevation Model" (*Layer properties* → *Source* → *Layer name*). Delete or disable the second model and its corresponding shadow wash.

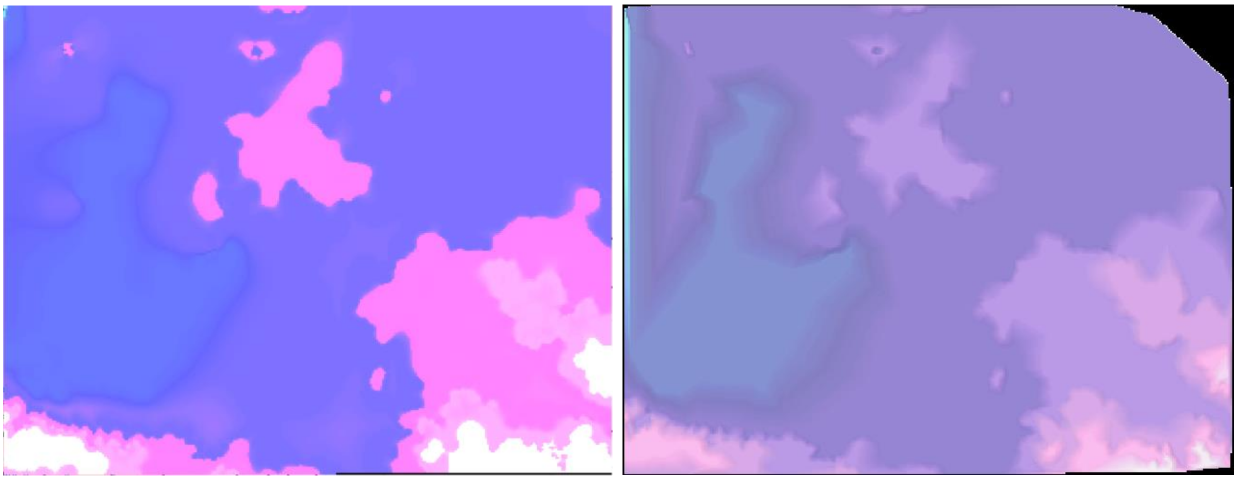


Figure 197. – Comparing versions for models IDW (left) and TIN (right)

***Step 10*** Open properties of the DEM layer. Click the *Histogram* tab to view the distribution of height values in the study area, fig. 198. Click on the *Compute Histogram* button below coordinate axis. Click the Perfs/Actions button and check the options: *Always show min/max markers* and *Update style to min/max* and click here *Recompute Histogram*.

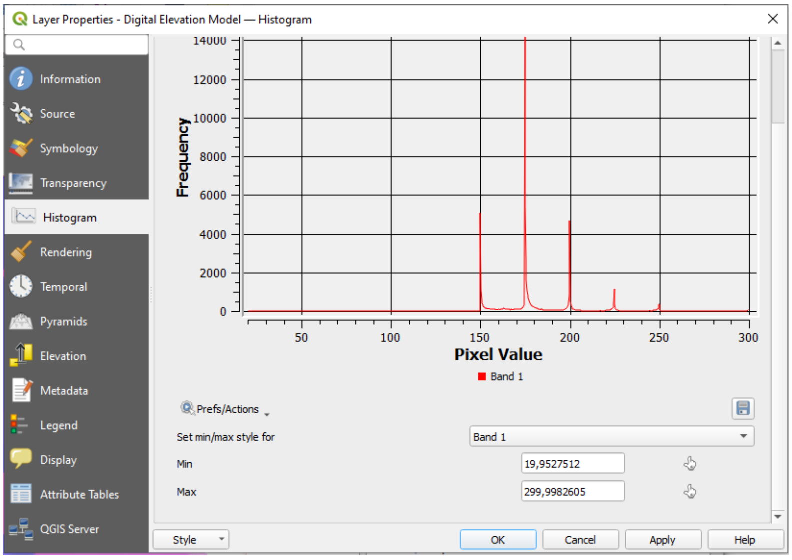



Figure 198. – Digital model of relief | histogram (relief_IDW)

Analyzing the histogram, one can judge the prevailing height marks, maximum and minimum values. In this case, the horizontal axis displays the height values, and the vertical one shows the number (*COUNT*) of cells that fall into each of the classes.

***Step 11.*** Create an isoline layer based on the original raster terrain model. From the *Raster* menu, choose *Extraction → Contour*. In the *Contours* window that opens, specify in the “Input layer” – *Digital Elevation Model* as the source file. Set the Interval between contour lines to 10. Save the contour file to your folder under the name "Contour". Check the “Open output after running algorithm” and “Treat all raster values as valid”. Click Run and OK, fig. 199.

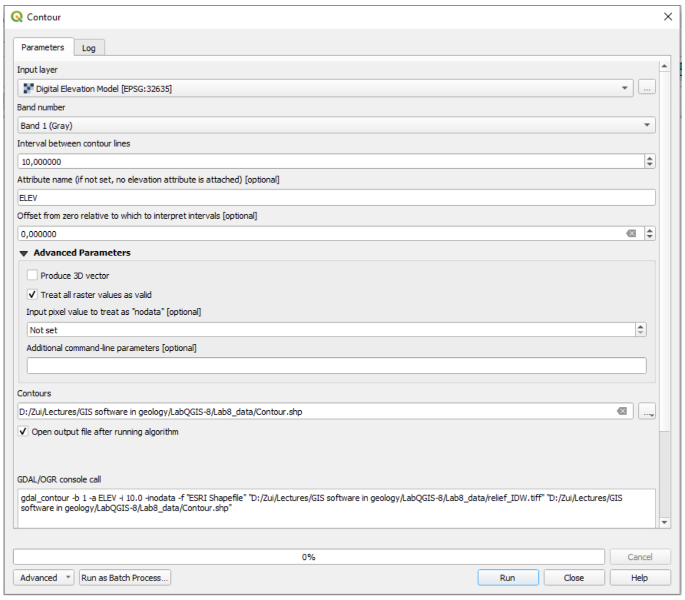



Figure 199. – Contour dialog panel

Select “Single Labels” and “Value” – ELEV. Symbolize the "Contour" layer with a simple black line 0.25 mm wide. Label the isolines (*Layer properties → Labels*) with the values of the “ELEV” field in black color. Choose the font and size of the labels. Place (*watercourses* tab) labels along curves and over lines, fig. 200. The map with isolines is shown in fig. 201.

Turn off the visibility of the "contour" layer.

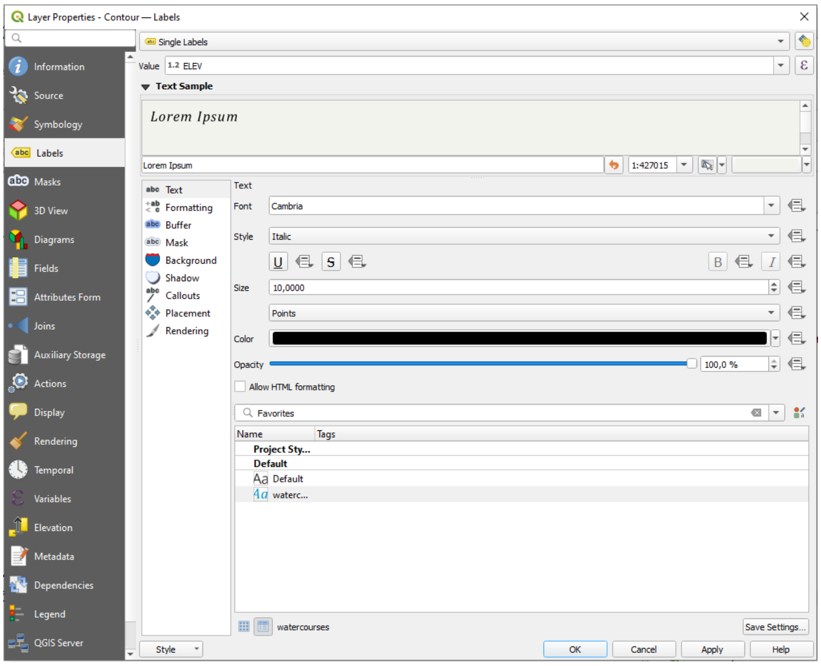



Figure 200. – Labeling of elevation isolines

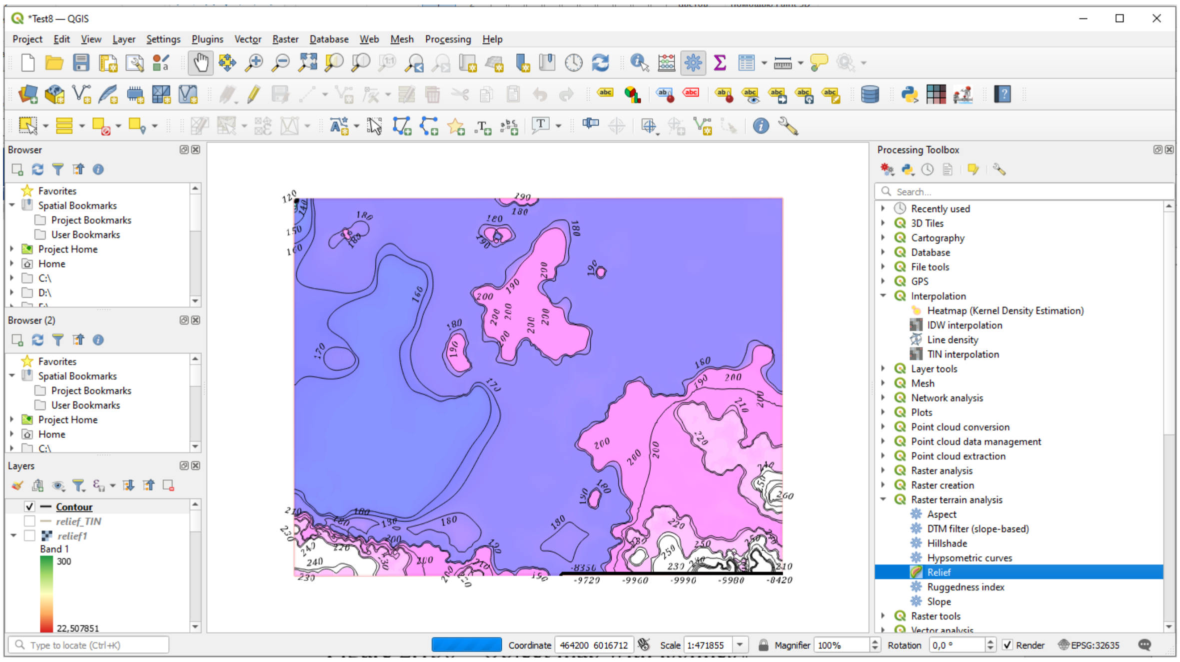



Figure 201. – Relief map with isolines

QGIS enables the analysis and processing of a digital elevation model (DEM) in various ways. The "Relief" analysis module can be used to calculate slope, exposure, ruggedness index. The slope for each raster cell indicates the maximum rate of change of value from that cell to its eight neighbors.

***Step 12.*** Calculate slopes within the study area. From the *Raster* menu, choose *Analysis → Slope*. Create a model with parameters as in fig. 202 (left). In the properties of the resulting draft model, on the *Symbology* tab, change the images from "Singleband gray" to "Singleband pseudocolor". Select the *Blues* color map. Click *Classify*, then *Apply*, fig 202.

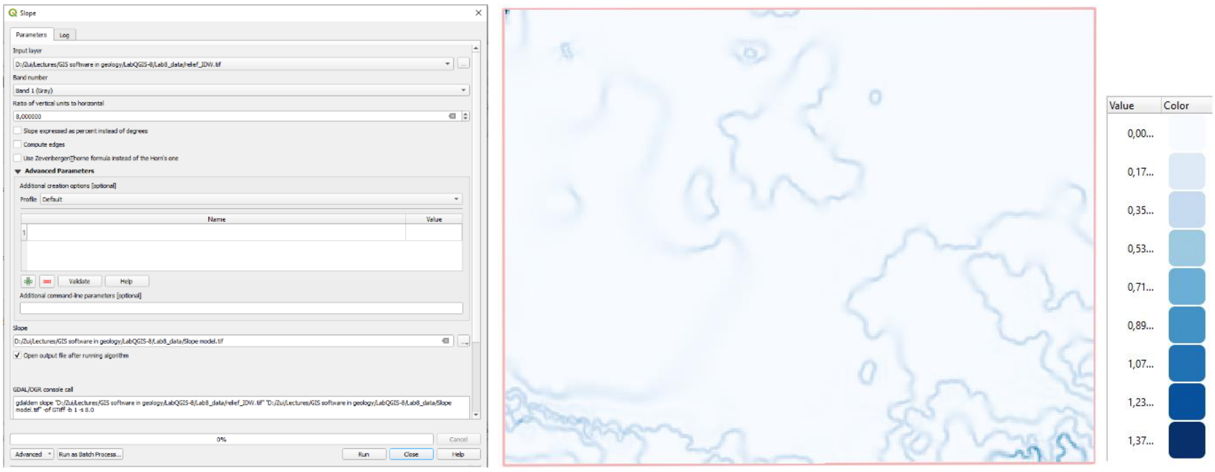



Figure 202. – Slope panel (left) and the map of slopes

***Step 13*** Calculate the slope exposure model for the study area. From the *Raster* menu, choose *Analysis → Aspect*. In the *Input layer* field, select *Digital elevation model*, save the output layer under the name "aspect" in your working folder. Leave the rest of the settings as default. The exposure for each raster cell is defined as the direction of the steepest slope from that cell to its neighbors. It is measured in degrees from 0 to 360° clockwise from the north direction (0° – north, 90° – east, etc., fig. 203.

On the *Symbology* tab for the Properties of the Aspect layer, change the images from "Singleband gray" to "Singleband pseudocolor". Select the *Turbo* color map. Click *Classify*, then *Apply*, you'll get the exposition of slopes like in fig 203.

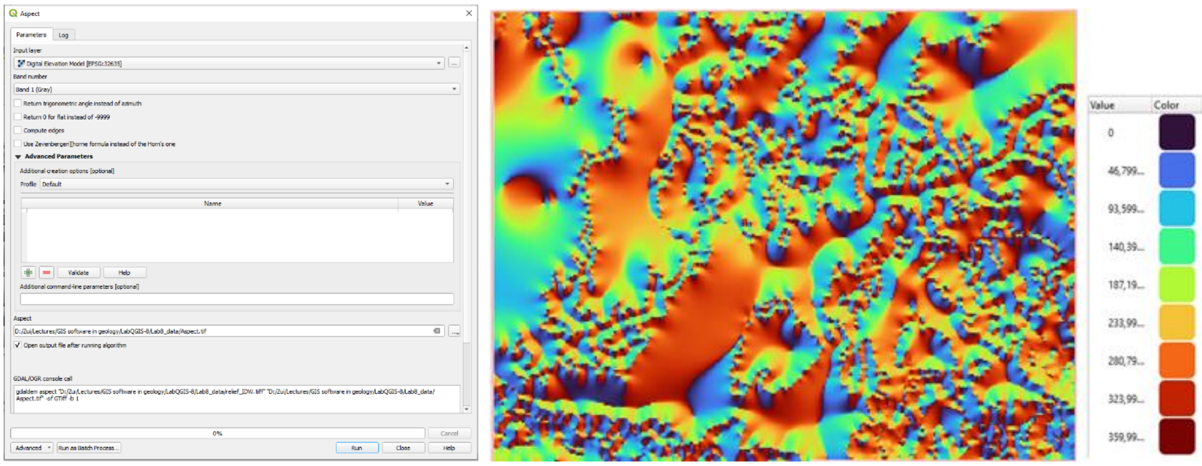



Figure 203. – Aspect dialogue (left) and the Slope exposure model (right)

***Step 14.*** You can use the external *Viewshed Analysis* module to calculate visibility areas. Open the *Module Manager* (*Modules → Manage Modules*). You need the *Visibility Analysis* module, check if it installed. Otherwise open the *Not Installed* tab, by entering part of the module name in the search bar, find the module of interest. Highlight *Visibility Analysis* in the list and click *Install Plugin*. Close the *Module Manager*. Once the extension is installed, the *Viewshed Analysis* icon will appear in the plugins panel (*Processing → Visibility Analysis → Analysis → Viewshed*).

***Step 15*** Create a new *Observer* point shapefile using the icon located on the layer panel. When creating, specify the coordinate system: WGS 84 / UTM zone 35N.

Start an editing session for the created layer. Use the *Add Object Anywhere* tool to create an observer position. After that, end the editing session by agreeing to save the changes.

***Step 16.*** Calculation of visibility zones. From the *Processing → Visibility Analysis → Analysis* choose *Viewshed*.

Calculation of visibility zones. Open *Vievshed* (*Processing → Gdal → Raster miscellaneous→ Vievshed*). In the dialog box that opens, specify *relief_idw.tif* in the empty "Input layer" window put cursor and click, it will convert into the hair cross (⊕), move it into your map and overlay the created "observer" circle, click it and coordinates will be added to the "Observer location window". Set the "Maximum distance from observer to compute visibility" you can choose it arbitrary, for instance like shown in fig. 189. Enter the file name *viewshed.tif* with a path to its location. Check the "Open output file after running algorithm". Click *Advanced → Algorithm settings* and select "Do not filter (Better performance)", set the rest parameters similar to those shown in fig. 204. At the main panel click *Run* and *Close* after finishing the algorithm.

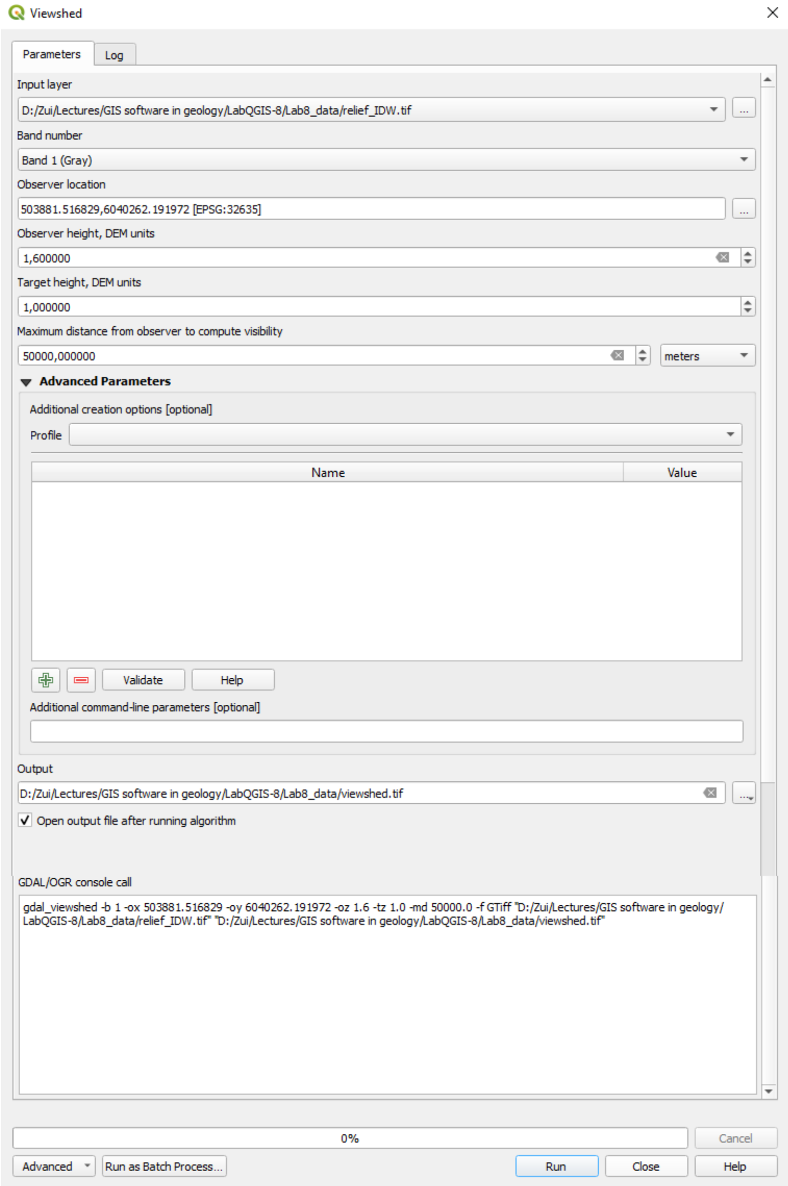



Figure 204. – The dialogue panel for *viewshed*

It should be noted that the coordinate system of the terrain model and *Observation* points must be the same. The *Search radius* parameter sets the radius of the analyzed area around each observation point. The *Maximum distance from observer to compute visibility* and *Target height* metrics allow you to set heights for both the observer and the target. The default *Observer height* is 1.6, which is the eye level of a person of average height.

As a result of the visibility analysis, the extension will create a raster whose cells will contain a code indicating whether they are visible from the observation point or not. For data selected for the example and chosen color scale (viewshed → *Properties* → *Singleband pseudocolor* → *say* – *RdBu* with "Invert colors") the received viewshed looks like in fig. 205. Depending on the position of observation point you can get the different image.

Figure 205. – The *viewshed* image for our selection of parameters

### 2.9. Laboratory work 9. Getting started in GRASS GIS via QGIS GUI

**Lab Objective:** To learn the algorithm for creating a GRASS dataset in QGIS and performing raster GIS analysis operations while creating the least cost path**.**

**Initial data:**

● shapefile containing the boundary of the study area (*boundary.shp*);

● shapefiles containing the river network of the study area (*rivers.shp*);

● shapefile containing railways (*railway.shp*) and motor roads of the study area (*roads.shp*);

● recreation center location shapefile (*start_point.shp*);

#### Laboratory progress

Extensions (plugins, modules) make up a significant and dynamically developing portion of QGIS functionality. *GRASS plugin* is an extension included in the QGIS core, one of the graphical interface options for the multifunctional GIS GRASS. Abbreviation GRASS (Geographic Resources Analysis Support System) is a well-known open source GIS with a wide array of useful GIS functions. It was first released in 1984.

The main component of the Data is the *Data Catalog* which shows the GRASS GIS hierarchical structure consisting of Database, Location and Mapset.

**GRASS Database** (directory with projects)

Running GRASS GIS for the first time, a folder named "grassdata" is automatically created. Depending on your operating system, you can find it in your $HOME directory (*nix) or My Documents (MS Windows).

**Location** (a project)

A Location is defined by its coordinate reference system (CRS). In the case of the default Location, it is a geographic coordinate reference system WGS84 (EPSG: 32635). If you have data in another CRS than WGS84, you should create a new Location corresponding to your system.

**Mapset** (a subproject)

Each Location can have many Mapsets for managing different aspects of a project or project's subregions. When creating a new Location, GRASS GIS automatically creates a special Mapset called PERMANENT where the core data for the project can be stored.

When working with GIS GRASS, all data used must be stored in a user-defined directory, which in GRASS terminology is called a geodatabase (DATABASE), fig. 206. This is a regular directory that can be located anywhere in the directory tree on the user's computer or on the network. Within this directory, GRASS data is organized as projects, contained in subdirectories called LOCATIONs.

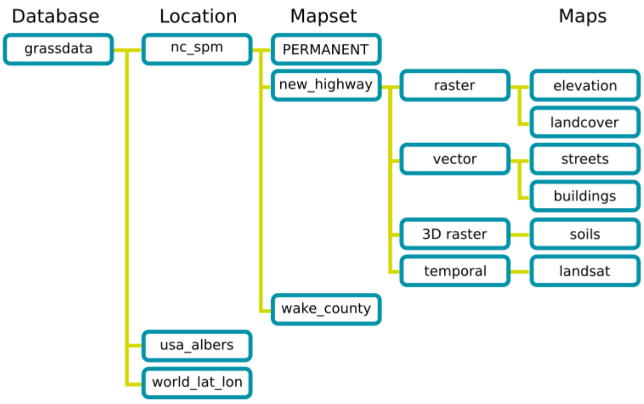



Figure 206. – GRASS GIS Database structure as visible to the user

The project area is defined by the coordinate system and spatial scope. Each area can contain multiple MAPSETs that are used to separate projects into different themes, sub-regions, or as separate sets for different working group members. In any area, at least one set must be defined, the name of which is PERMANENT. The latter is automatically generated by GRASS and, in several text files, contains basic information about the given area, such as coordinate system and projection parameters (PROJ_INFO and PROJ_UNITS).

*GRASS GIS Database*. All data for GRASS GIS must be in GRASS GIS Database which is a directory (visible on the disk) containing subdirectories which are GRASS Locations. User can have one or more of Databases on the disk.

GRASS GIS Databases can be safely copied or moved as any other directories. Don't be confused with (relational) databases which are used in GRASS GIS to hold attribute data and might be part of the *GRASS GIS Database*. From user point of view, GRASS GIS Database with all its data in it is similar to, e.g. *PostGIS*, database, as it stores all information inside in a specific format and is accessible by specific tools. GRASS GIS Databases is in GRASS GIS often called GISDBASE or DATABASE.

*GRASS Locations*. Location is a directory which contains *GRASS Mapsets* which are its subdirectories. All data in one *Location* have the same projection (coordinate system, datum). Each *Location* must contain Mapset called *PERMANENT*. Typically, a *Location* contains all data related to one project or a geographic area (geographic location or region). Alternatively, *Location* can simply contain all data in a given projection.

*GRASS Mapsets*. Mapsets contains the actual data, mostly geospatial data, referred to as maps in GRASS GIS. Mapsets are a tool for organizing maps in a transparent way as well as a tool for isolating different tasks to prevent data loss. Mapsets are used to store maps related to one project, smaller project, specific task, issue or subregions.

*The role of the PERMANENT Mapset*. When creating a new Location, GRASS GIS automatically creates a special Mapset called PERMANENT where the core data for the Location are stored.

Since the maps in PERMANENT Mapset are visible from all the other Mapsets, it can be used to store the base maps (base cartography), data common to all projects or needed for different analyses done is separate Mapsets.

**I. Creating a GRASS GIS dataset**

***Step 1.*** Open GRASS GIS 8.3.2 supplied together with QGIS 3.34. It permits using GRASS GIS functionality and/or visualize GRASS GIS vector and raster layers. When activating the module, two icons and (*Open GRASS tools* and *Display Current Grass Region*) will be added to toolbars.

***Step 2***. Use the *Add vector map layer* tool to add the *Mass_points*, *roads*, *Railway, rivers, Boundary, start_poin*t shapefiles located in the source data folder to the QGIS project.

***Step 3***. Specify the directory for the GRASS database by clicking the icon (*Create new location in current GRASS database*) and in the "Define new GRASS Location" panel which appears, fill in the "name" window, for instance "newLocation", "Location", or simply – "My Location" and click "Next" button, fig. 207. Another panel "Select Coordinate Reference System" pops up with a variety of possibilities to do this. Check the radiobutton "Select CRS from a list by EPSG or description" and click "Next". In one more panel, which appears "Define new GRASS Location" select "32635 WGS 84 / zone 35N" and click "Next", fig. 208. In the next panel "Select Datum Transformation” simply click OK, fig. 209.

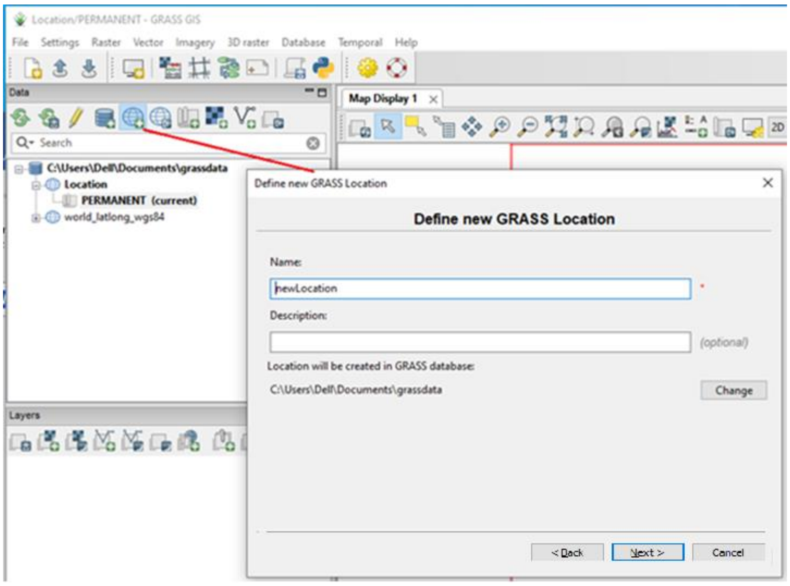



Figure 207. – Creating a new location

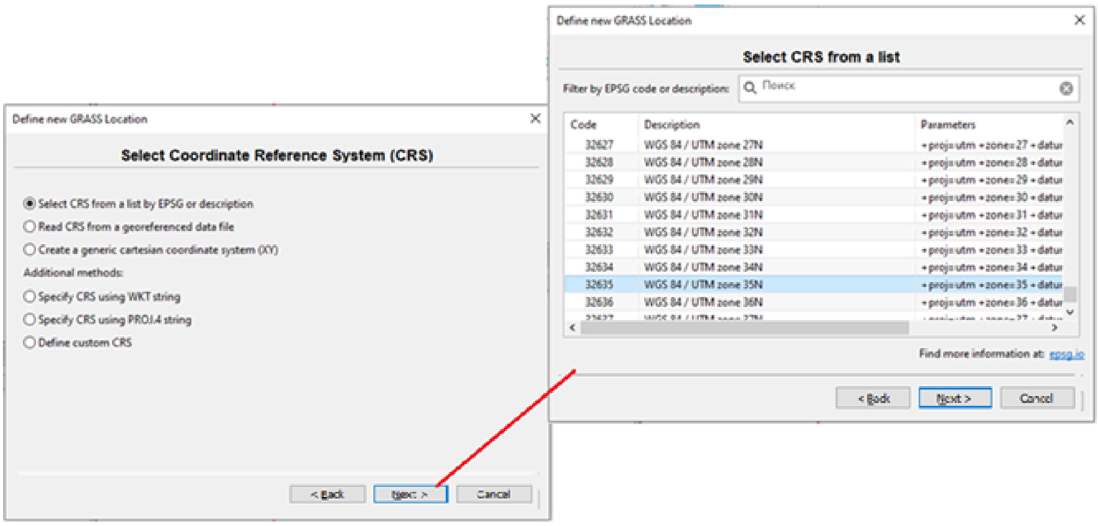



Figure 208. – Selecting a coordinate reference system

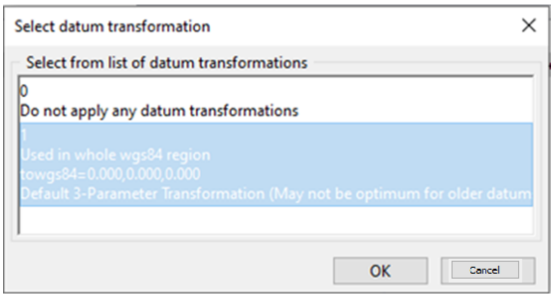



Figure 209. – The select datum transformations window

In the final panel "Define new GRASS Location" (Summary) which opens with definitions for the project, click "Finish". The "Locations" directory will be added to your GRAS GIS project, fig. 210. The directory, names of layers and sets must contain Latin characters.

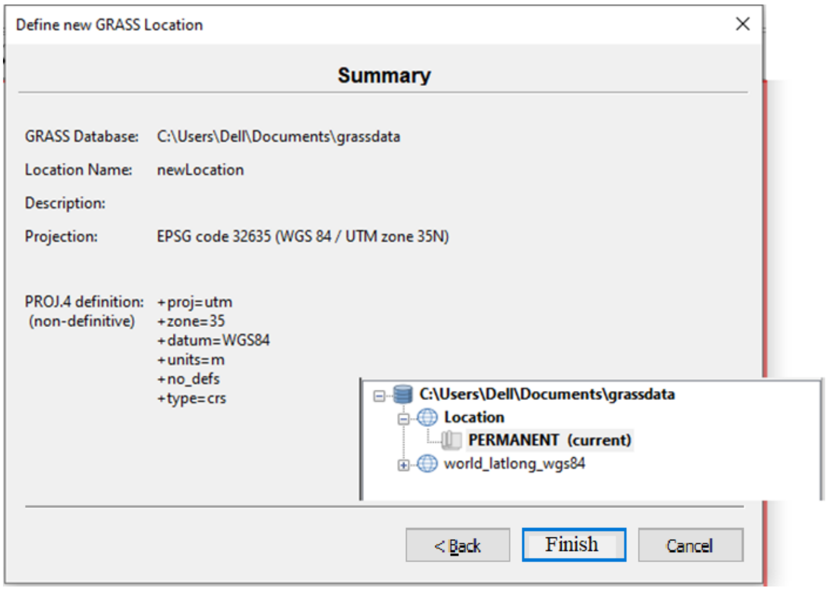



Figure 210. – The Summary panel

***Step 4.*** GRASS data are stored in a tree directory structure. The GRASS Database is the top-level directory in this tree structure. The GRASS location is a collection of maps for a particular territory or a project. The GRASS region defines a workspace for raster modules. The default region is valid for one location. It is possible to set a different region in one mapset. The GRASS mapset is a collection of maps used by one user. A user can read maps of all mapsets in the location but he can open for writing only his mapset (owned by user).

At this step, you need creating a mapset. To do this open *Plugins* → *GRASS* → *New Mapset* and click it, fig. 211.

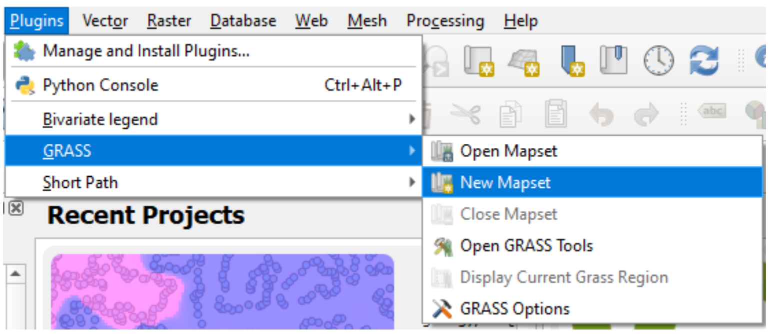



Figure 211. – Starting to create a new mapset

The GRASS Database panel appears, set within its window "Database directory", for instance *C:\users\Dell\grassdata* and click the "Next" button. It invokes another "GRASS Location" panel. Put the name, e.g. *Test9* into the "Create new location" window and click "Next", fig. 212.

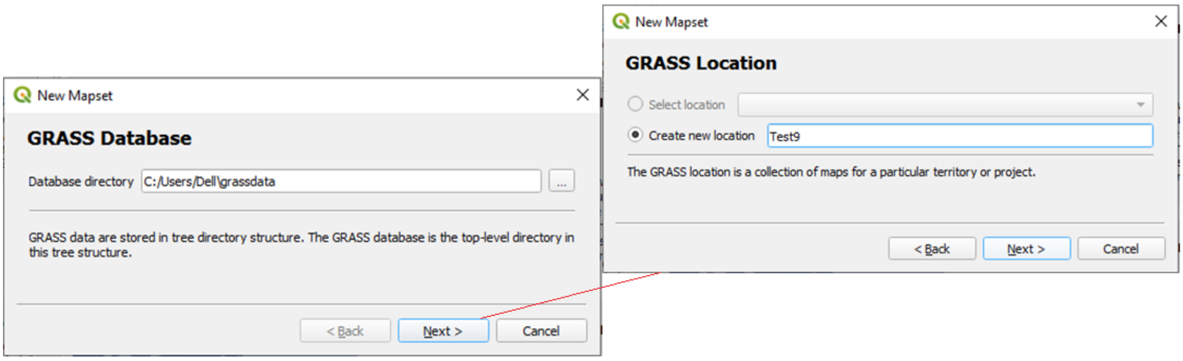



Figure 212. – GRASS Database position (left) and the name of GRASS Location (right)

The new panel appears to select the region of the world for which you'll create maps. Select, for example here "Belarus" (*Byelarus* in the highlighted list) in the dropdown menu when clicking the corresponding arrow. Clicking the "Next" button invokes the "Mapset" panel, where you need entering a name of the mapset, for instance – *new_mapset*, click "Next" again, fig. 213. The final panel with the information on successful creating and set a current working mapset pops up, fig. 214. Click OK to close it.

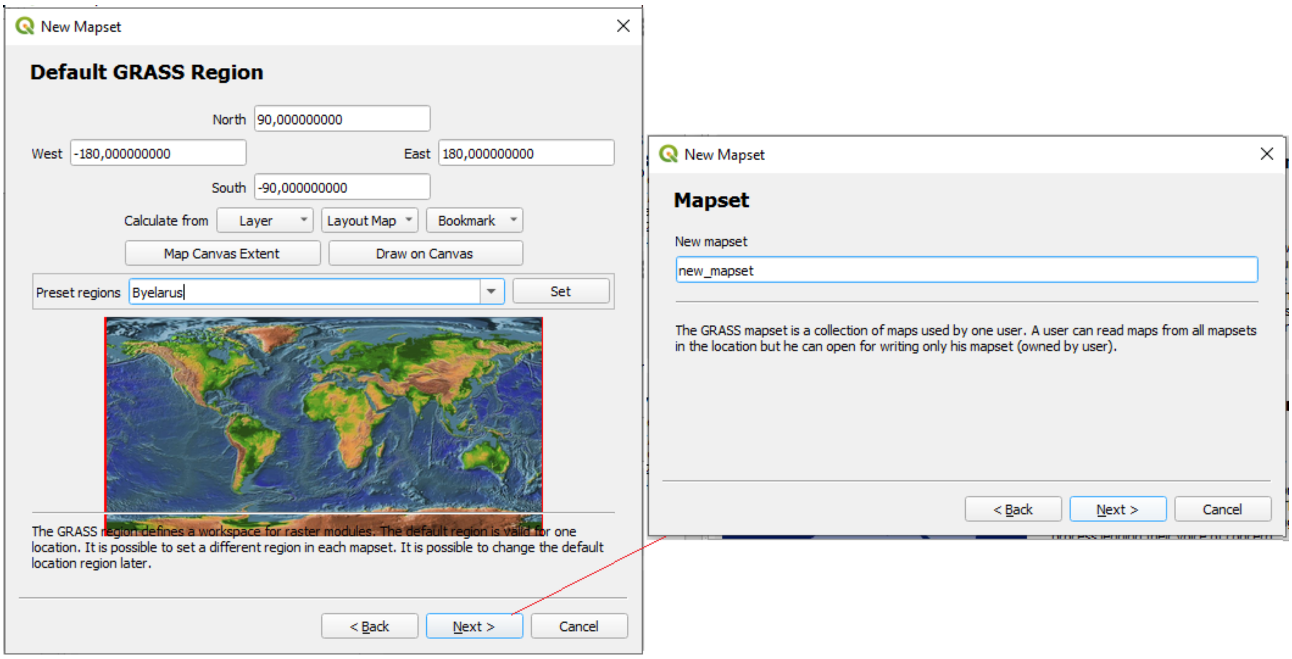



Figure 213. – Selecting the region and the name of a mapset

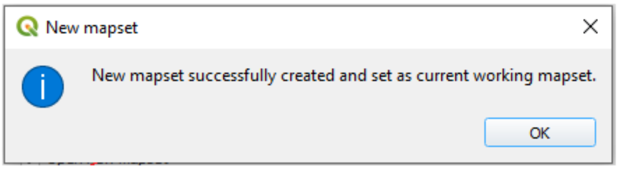



Figure 214. – Final panel creating of a mapset process

Now both icons  (Open GRASS Tools) and  (Display Current GRASS Region) become accessible. Clicking GRASS Tools () you can see accessible the list of "GRASS MODULES", fig. 215.

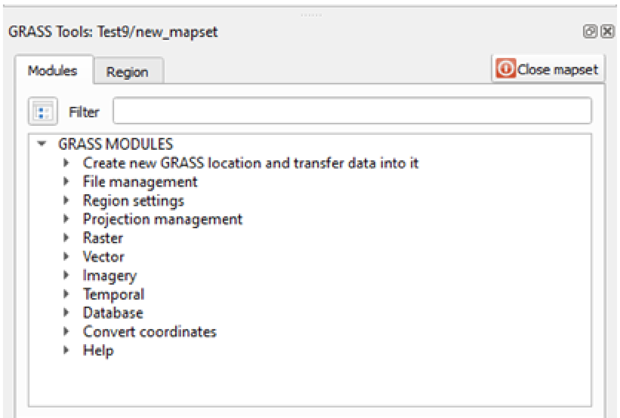



Figure 215. – List of GRASS modules

Import the vector layers loaded into the QGIS project into the created GRASS GIS database. On the GRASS toolbar, click the  (*Open GRASS Tools*) icon. The GRASS tool window will appear. On the "GRASS MODULES" tab open *File Management → Import into GRASS → Import Vector into GRASS → v.in.ogr.qgis Import loaded vector* (fig. 216).

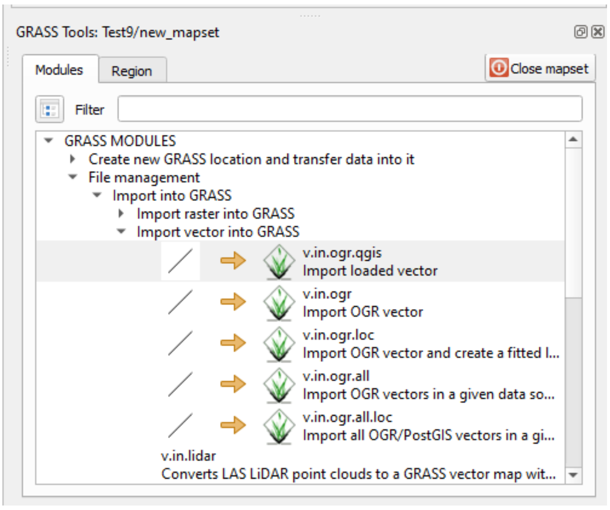



Figure 216. – GRASS GIS - loading a vector file

The tab of the activated tool *Module* is added to the *GRASS Tools* window: *v.in.ogr.qgis*. Load the vector layers *Boundary.shp* from your source folder (*Layer – Add layer – Add vector layer*) into QGIS. Symbolize loaded layers on your choice. An example is shown in fig. 217.

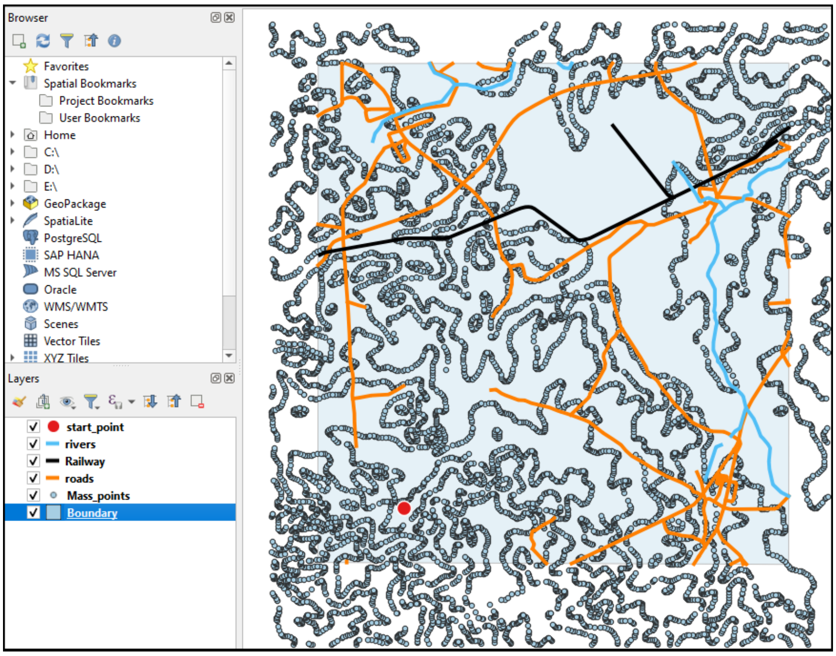



Figure 217. – Source map with loaded vector layers

In *GRASS Tools* window (see fig. 201) click "*v.in.ogr.qgis*" from the *Loaded layer* drop-down list, select "Boundary". Name the output layer "boundary1". Click *Run* (fig. 218).

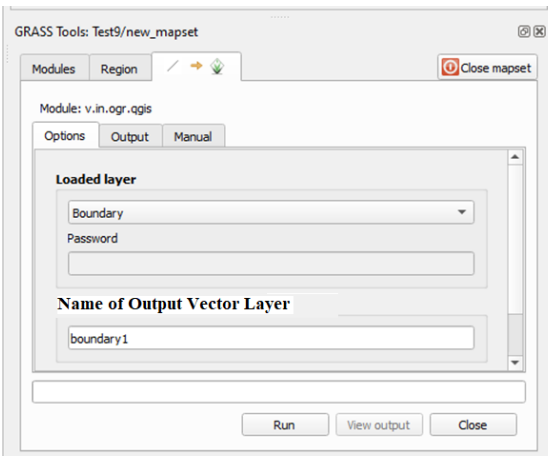



Figure 218. – Selecting the layer in GRASS instruments

When *Successfully finished* appears, click the *View output* button, then click "Close". The feature layer "boundary1" imported into GRASS will be added to the QGIS map window. Similarly, repeat these steps click "*v.in.ogr.qgis*" at the "Modules" panel, from the *Loaded layer* drop-down list, select and download sequentially the

"Mass_points", "roads", "railway", "rivers", and "start_point" layers to the "study_area" set and to the QGIS map window, naming "mass_points1", "roads1", "railway1", and "rivers1", "start_point1" respectively.

If there will be some unsuccessful attempt (*Finished with error*) to create one of "*1" layers (for instance – railway1) you may click "Close", then "Reset" in the "Region" subpanel and continue working.

***Step 5*** Remove or disable the "Mass_points", "roads", "railway", "rivers", and "start_point" layers from the QGIS project. Symbolize the "rivers1" layer with a "Single symbol" ( icon), *Layer type* – "Simple line", *Line style* – "Solid line", *Line color* – blue, "Widths" – 0.5 mm. For the "roads1" layer, change the color of the line to graphite, set the Width to 0.8 mm.

Draw the railroad layer with a "Single symbol" (). On the *Symbology* tab of the *Layer Properties* dialog box, click on the first sign level (Line) and in the *Signs* group that appears, select *Dash black*. Change the color of the lines that make up the symbol to black and white.

***Step 6.*** Click the icon *Display Current GRASS Region* in the GRASS toolbar. The border of the current GRASS region will be displayed as a red line in the QGIS map window. Region display GRASS can be disabled/enabled using the icon . Region definition (setting spatial characteristics) in GRASS is important for working with raster data. All newly created raster will have the spatial coverage and resolution of the current GRASS region (regardless of their original coverage and resolution). Let's reduce the border of the current GRASS region to the border of the boundary1 layer. To do this, in the floating *GRASS Tools* panel, go to the *Region* tab. Click the *Select the extent by dragging on canvas* button. Place the cursor on the QGIS map area and, by pressing the left mouse button, select the rectangle corresponding to the "boundary1" layer. Click the *Apply* button in the *Region* tab of the *GRASS Tools* panel, fig. 219.

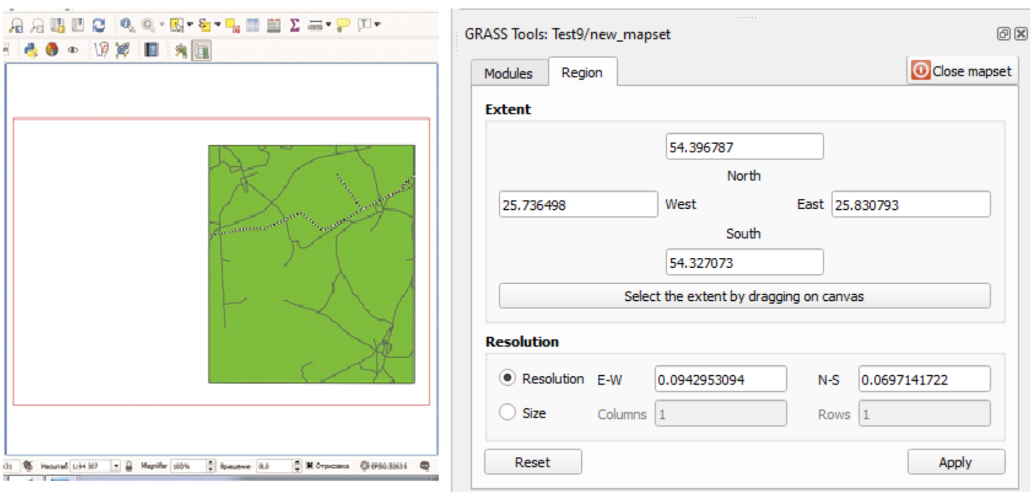



Figure 219. – Selected area

***Step 7***. The point layer "mass_points1" is a set of elevations. Build a digital elevation model based on this layer. Select *GRASS Modules → Raster → Surface Processing → Surface Interpolation* in the *Open GRASS Tools* panel. In the list of interpolation tools, select *v.surf.rst – Regularized spline with tension raster interpolation based on vector points* to open the tool options window, fig. 220.

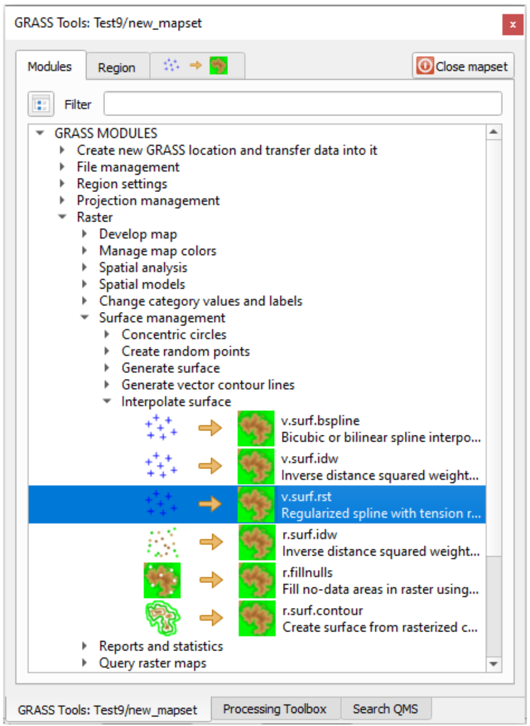


Figure 220. – Selecting the surface interpolation dialogue

Set the source vector layer to "mass_points1", Attribute fields to *H* in the tool tab. Leave the other options at their defaults. In the Name for *Output surface elevation raster* map window, type *relief* and click *Run*, fig. 221.

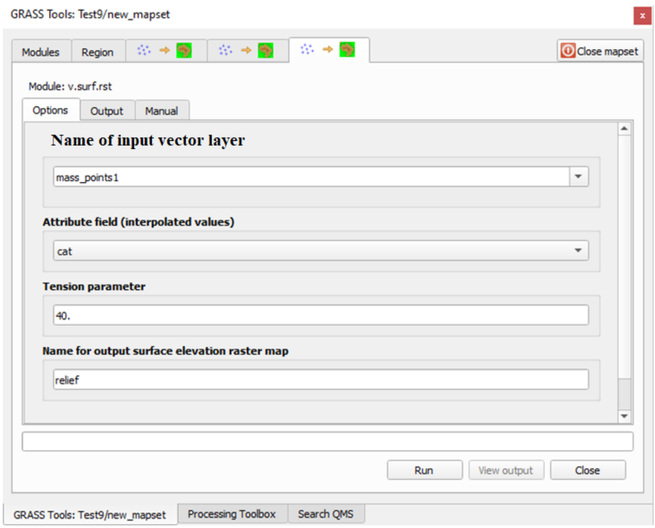


Figure 2.221 – GRASS dialogue panel

The process will take some time. When the "Output window" displays *Successful*, click *Open Output* and then *Close*. Tre results of an interpolation looks like shown in fig. 222.

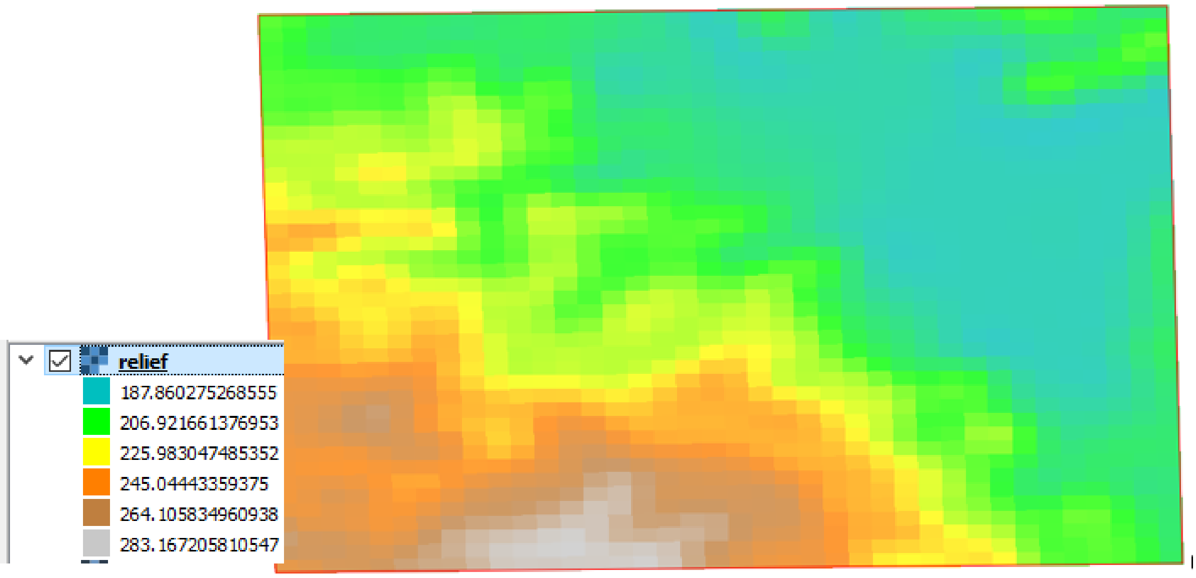



Figure 222 – Relief of the area

**II. Finding a path with the minimum cost**

***Step 8.*** GIS analysis of distances. The main task of the GIS analysis is to obtain the optimal path with the lowest cost from the road to the recreation center, located within the study area, taking into account a number of terrain features (relief slope and land use type). The digital elevation model of the study area was obtained at the previous step. The reclassified land use type raster (*landuse.tif*) is located in the source data folder.

Computing the optimal path involves several steps:

1. Slope calculation using r.slope.
2. Reclassify the slope raster using rules.
3. Combining the reclassified raster.
4. Calculate the total cost of the move raster using r.cost.
6. Finding the optimal way to move.

Calculate *slopes* within the study area. In the list of *Open GRASS Tools*, select *(Raster → Spatial Analysis → Terrain Analysis → r.slope*). Select in the tool tab the “relief” layer created in the previous step as the input hypsometric surface. Name the output surface "slope" (fig. 223). Click *Run* and after finishing the algorithm, click *View output*, the image will be overlaid to the raster map, fig. 224.

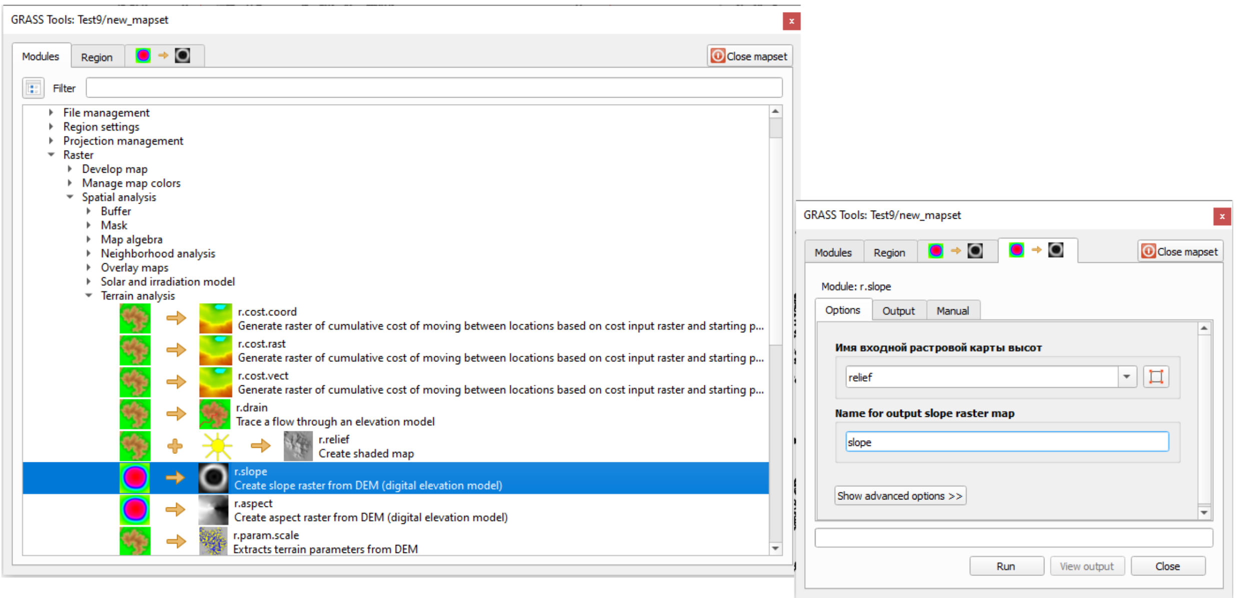



Figure 223. – Working with GRASS – terrain analysis - slope

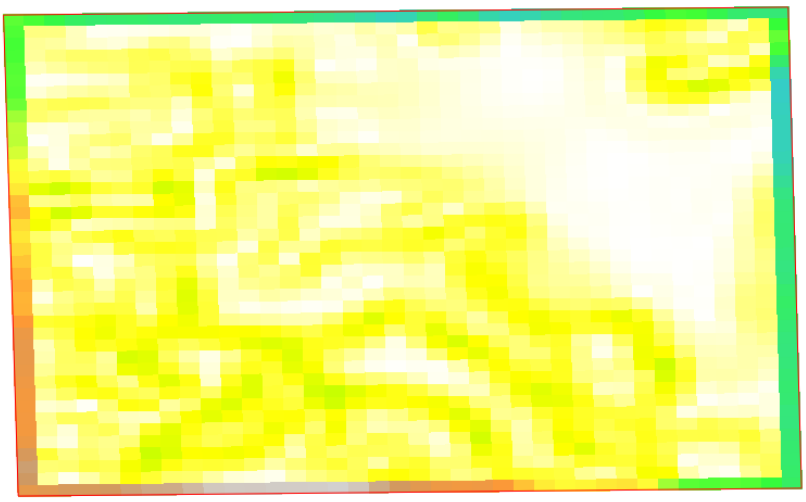


Figure 224. – Terrain analysis – slope image

***Step 9:*** Reclassify the slope raster. To perform the operation, you need to create a text file with reclassification rules. We use a scale from 1 to 5 by assigning a value to the five cells with the largest in within the study area a slope (3.6–4.5º), and one – the smaller (< 0.9º). Open *Notepad* (*All Programs* → *Accessories* → *Notebook*). Type the following few lines in the program window (no spaces in between symbols):

0: 0.9 : 1 : 1
0.9 : 1.8 : 2 : 2
1.8 : 2.7 :3 :3
2.7 : 3.6 : 4 : 4
3.6 : 4.5 : 5 : 5

The first two numbers on the line, separated by a colon (0:0.9), indicate the range of values in the input raster. The last two (1:1) here are the new value of the specified range in the output raster. Save the reclassification rules to a text file *slope_reclass.txt*.

In the list of *Open GRASS Tools*, select *r.recode – Recode categorical raster using reclassification rules* (*Open GRASS Tools → Raster → Change category and label values*). Select *slope* as the input raster in the tool tab. Specify *slope_reclass.txt* in the *File containing recoding rules* field. Save the output raster in your folder as "slope_reclass" (Figure 225). When the reclassification is complete, click *Open Output* and then *Close*.

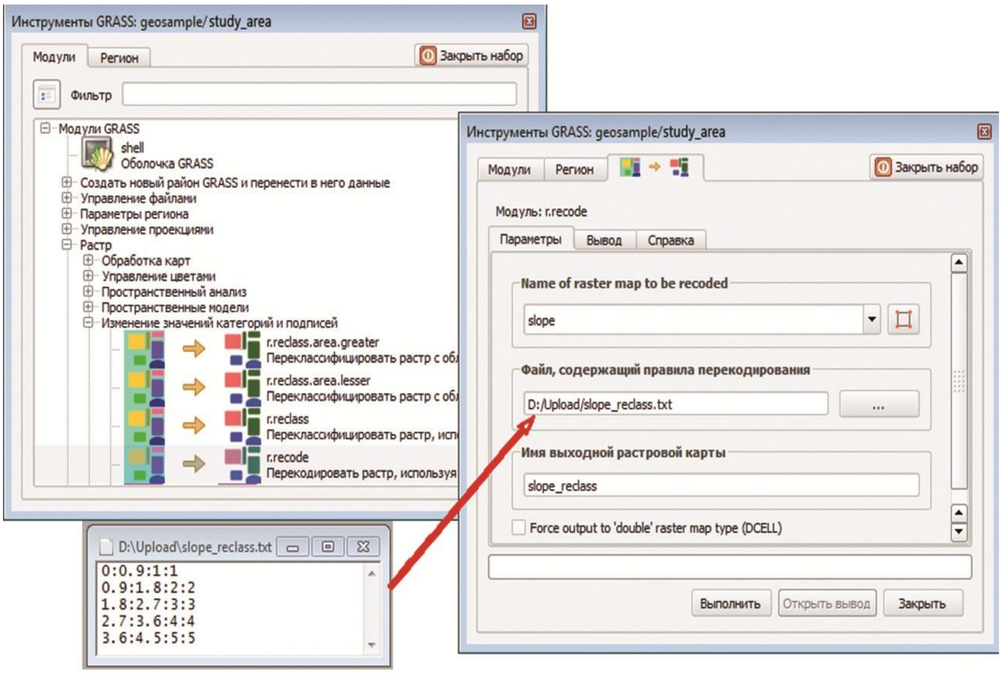



Figure 225. – Slope – reclassification steps

The reclassified slope image is shown in fig. 226.

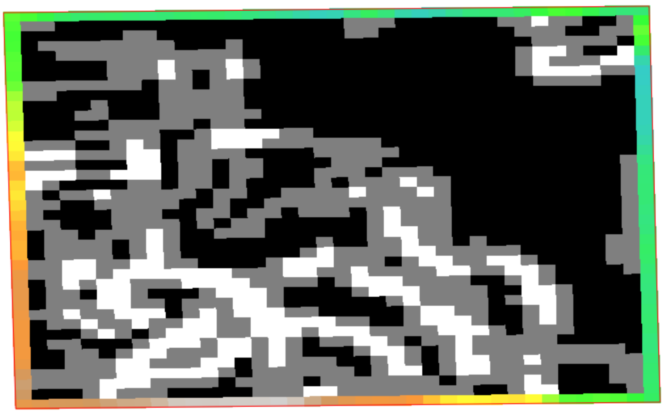


Figure 226. – Reclassified slope image overlaid the relief

***Step 10.*** Using the *Add Raster Layer* tool, add the *1_landuse* raster to the QGIS project located in the source data folder. Specify the coordinate system for the layer: WGS 84 / UTM zone 35N. Open *File Management → Import into GRASS → Import Raster into GRASS → Import Rasterinto GRASS from QGIS view → r.in.gdal.qgis – Import loaded raster* in the *GRASS Modules* tab of the *Open GRASS Tools* panel. Select "landuse" as the loaded layer in the *r.in.gdal.qgis* tab. Enter *landuse_reclass* in the *Name* of *output raster map* field, and click *Run*. After finishing the algorithm click "View output" and the layer will be added to your project, fig. 227.

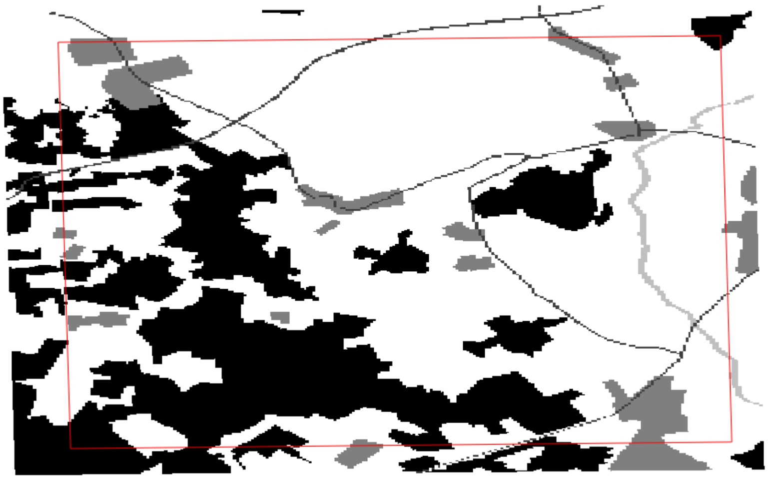


Figure 227. – Landuse reclassified

***Step 11.*** Combine the reclassified *slope_reclass* and *landuse_reclass* datasets. Go to *Raster → Spatial analysis → Map algebra* in the *Modules* tab of the *Open GRASS Tools* panel,. Activate the tool *r.mapcalc – Graphing raster map calculator*. In the dialog box, using the *Add Map*, *Add operator or function*, and *Add connection* tools, create a diagram as shown in fig. 228. When a tool is selected, the corresponding elements (layers, operators) become available in the list below. Type *slope_landuse* in the *Output* field, and click *Run*. After the operation is completed, click *Open output* and close the module window.

***Step 12*** Create a cost raster. To do this, on the *Modules* tab, open *GRASS Modules → Raster → Spatial Analysis → Morphometric Analysis → r.cost.vect Create a raster layer of the cumulative cost of moving between points based on a raster of cost values and a vector of starting points*. In the *tool* tab, select *slope_landuse* as the input raster, *start_point* – as the start point feature layer, and *cost* – as the output raster, fig. 229. Click the *More options* button and in the *Cost assigned to null cells line*, specify 1. Click *Run*.

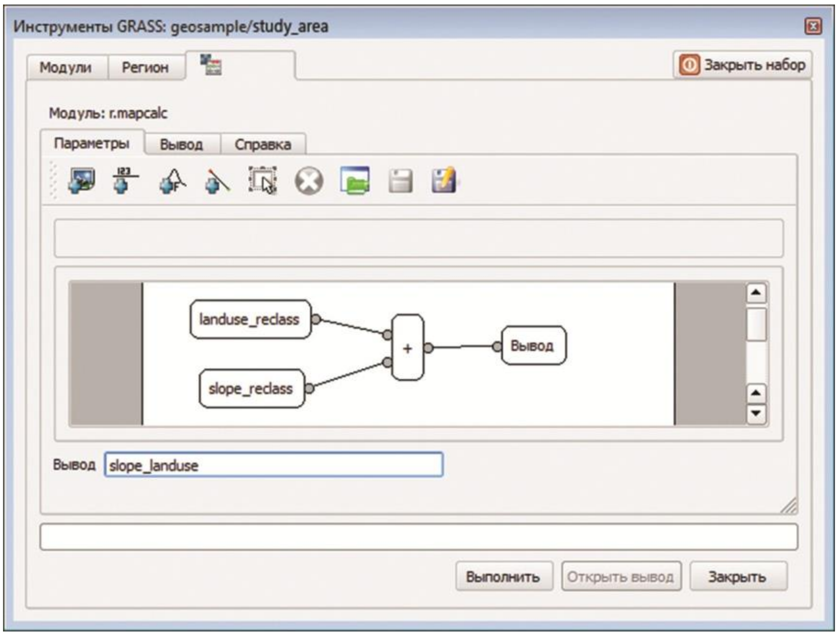



Figure 228. – Hillshade algorithm

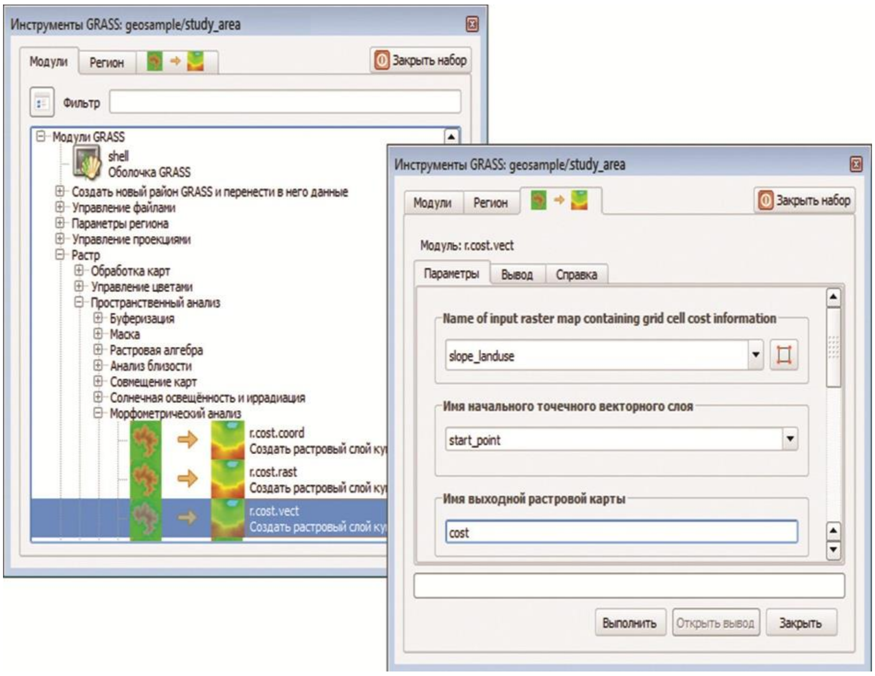



Figure 229. – Adding raster layers

***Step 13*** Calculate using GIS the shortest route from the railroad to the chosen place of your rest. Activate the module *r.drain Generate flow from terrain model* (*GRASS Modules → Raster → Spatial Analysis → Morphometric Analysis*) in the list of GRASS tools. In the module tab in the drop-down list, select the input raster - *cost*, type the name of the output raster (*costpath*), set the coordinates of the starting point of the path, fig. 230. Click *Run*, then *Open Output* and close the module window.

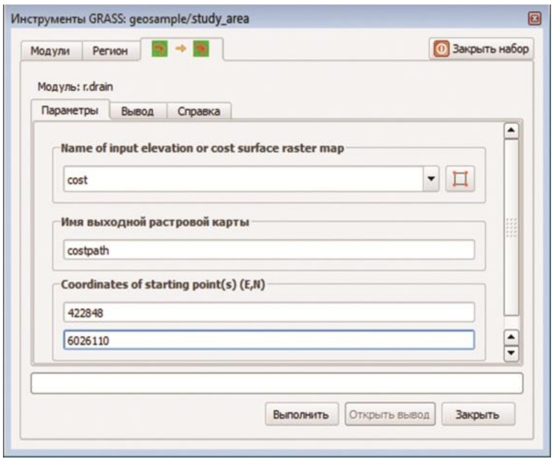



Figure 230. – Analysis of costs panel

***Step 14.*** Open *GRASS Modules → File Management → Data Type Conversion → Raster to Vector GRASS → r.to.vect.line. Convert raster layer to vector lines* in the *Modules* tab of the *GRASS Tools* panel. In the tool tab, select the source raster – *costpath*. Name the output layer "least_cost_path". Click *Run*. Add the resulting layer to the map window. Close the module.

Symbolize the "least_cost_path" layer with a regular symbol, choose the symbol *Construction road*.

For the "cost" layer, set the rendering style to *Single Channel Pseudo Color*. Select the YlOrRed color map In the *Color* field. The mode is *continuous*. Click the *Classify* button, then OK.

Turn off the visibility of the raster layers "relief", "slope", "slope_reclass", "landuse_reclass", "slope_landuse" (fig. 231).

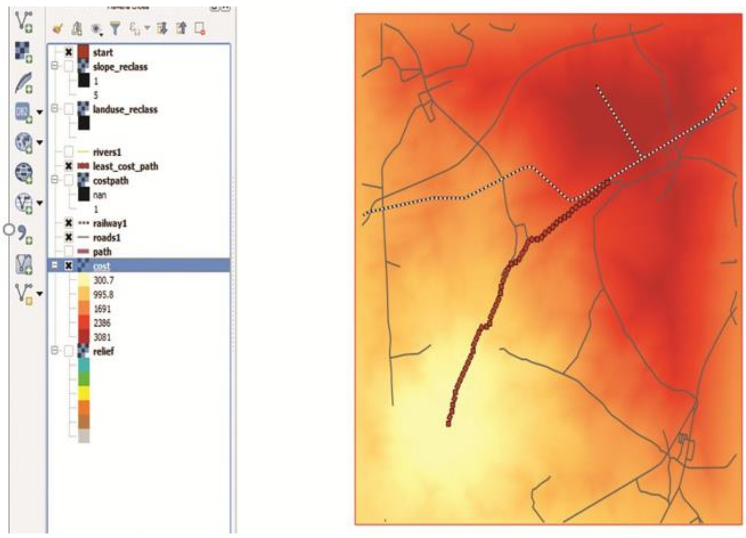



Figure 231 – Final cost path route

# 3. KNOWLEDGE CONTROL SECTION

## 3.1. Questions for the discipline exam

(for parts 1 and 2)

1. The main software products discussed in the course "GIS in Mineral Resource Management".

2. Types of computer hardware and trends in their development. The processor, input and output devices, operational and long-term memory, printers, plotters in computers.

3. Problems solved with the use of computer processing tools. Give some examples.

4. Sources and types of data used for further processing in GIS: Earth remote sensing data, earthquake catalogs, geological maps, data on gravity and magnetic fields, well logs, relief, etc.

5. Using GMT for processing geological and geophysical data and constructing graphs, diagrams, and maps.

6. Main options in GMT software package commands: -R, -J, -B, -O, -K, -G, -g, -I, REM. How to select coordinate systems and projections.

7. How to convert the Post Script output format of graphics in the GMT environment to other formats (jpg, tiff, png, pdf). Show an example of converting to other formats using one of labs completed by you as an example.

8. How to identify the boundaries of lithospheric plates, active faults in the oceans using computer graphics? Consider an example from your tests.

9. Which seaquakes are dangerous in terms of tsunamis? Give an example of the computer test for the Sea of Japan region.

10. Classic (traditional) and modern (modern) methods of writing scripts in GMT

11. The computer software package “QGIS”, its modular structure and interface features. Types of tests fulfilled by you using the QGIS.

12. Vector and raster data, their difference. Layers in QGIS. Raster model for representing spatial data in GIS. Advantages and disadvantages of the raster model.

13. Purpose of bases for storing and processing geological data.

14. Definition of GIS. Basic components and functionality of GIS.

15. GIS classifications. Composition capabilities of GIS software products.

16. Data sources necessary for constructing geological maps, profiles, sections.

17. Data sources for GIS: Satellite data, geodetic technologies, databases.

18. Capabilities of the Surfer software and its use.

19. Using the Geostatistics software modules.

20. Purpose and capabilities of the QGIS software package.

21. Types of geological problems solved using the QGIS software package.

22. Construction of geological sections and profiles using GIS software.

23. General characteristics of the complex of GIS software, products ArcGIS.

24. Overview of additional ArcGIS GIS capabilities.

25. Brief overview of geographic coordinate systems used in mapping.

26. Raster model for representing spatial data in GIS. Advantages and disadvantages of the raster model. The most common raster formats for representing spatial data in GIS.

27. Overview of the vector format and raster data - geodatabase.

28. Methods for classifying quantitative geodata in GIS. Georeferencing raster images.

29. Spatial statistics in GIS.

30. Processing of geological data in GIS.

### 3.2. Abstract topics

The independent work (abstract) includes 8 examples, they are tests (laboratory workss 1 – 9)..

1. Laboratory work 1: QGIS basic techniques.
2. Laboratory work 2: Geographical linking of raster in QGIS.
3. Laboratory work 3: Creating point layers from text data in QGIS. Heat maps.
4. Laboratory work 4: Creating a tourist map in QGIS.
5. Laboratory work 5: Receiving basic spatial characteristics of objects in QGIS.
6. Laboratory work 6: Joining tables in QGIS.
7. Laboratory work 7: Search the shortest route with road graph for QGIS.
8. Laboratory work 8: Construction and analysis of a digital relief model.
9. Laboratory work 9: Getting started in GRASS GIS via QGIS GUI.

### 3.3. Organization of independent work

The independent work is carried out on the basis of the Regulations on independent works of students (undergraduates, students), approved by the Minister of Education of the Republic of Belarus on April 6, 2015.

In the discipline studied, it is planned:

- Performing creative and research tasks;

- Work with published sources, including scientific articles;

- Study of topics and problems that are not covered in lectures;

- Scientific reports;

- Writing thematic reports and essays on problematic topics.

List of recommended diagnostic tools:

- Oral surveys – 25%;

- Interviews – 25%;

- Report on practical work – 25%; - laboratory tests – 25%.

Methodology for generating the final assessment. The final assessment is formed based on three documents:

1. Rules for certification (Resolution No. 53 of May 29, 2012);

2. Regulations on the BSU rating system;

3. Student assessment criteria (passed).

4. The final grade is formed from the rating assessment of the final control of current progress (40%) and the result of the answer at the test (60%).

List of recommended diagnostic tools and methodology for forming the final assessment. The form of the current certification in the discipline “GIS in mineral resource management” is provided by the curriculum for credit. The final assessment is based on three documents:

1. Rules for conducting certification of students, cadets, listeners when mastering the content of educational programs of higher education (Resolution of the Ministry of Education of the Republic of Belarus dated May 29, 2012 No. 53).

2. Regulations on the rating system for assessing students' knowledge in an academic discipline at BSU (Order of the Rector of BSU No. 189-OD dated March 31, 2020).

3. Criteria for assessing the results of educational activities of students in higher education institutions on a ten-point scale (Letter of the Ministry of Education of the Republic of Belarus dated May 28, 2013 No. 09-10/53-PO).

The assessment of the degree of mastery of theoretical material is checked through regular testing. To assess the degree of completion of laboratory work, undergraduates prepare a written report, which is checked by the teacher.

When forming the final grade, a rating assessment of the student's knowledge used, which makes it possible to trace and evaluate the dynamics of the process of achieving learning goals. The rating assessment involves the use of weighting coefficients for the current control of knowledge and the current certification of master's students in the discipline.

Approximate weighting coefficients that determine the contribution of forms (events) of current knowledge control to the assessment of current academic performance: electronic tests (arithmetic average of grades for all electronic tests) – 40%; – written reports on laboratory work (the arithmetic mean of marks for written reports on all laboratory works) – 60%. The final grade for the discipline is calculated based on the assessment of current performance and the answer to the test, taking into account their weighting 10 coefficients. The weight of the assessment for current performance is 40%, the assessment for the test is 60%.

## 4. AUXILIARY SECTION

Full-time education for students

### 4.1. Educational and methodological map for the academic discipline

(for parts 1 and 2)

| Section number. | Title of section, topics, activities | Number of classroom hours | | | | | Independent work | Knowledge control form |
|---|---|---|---|---|---|---|---|---|
| | | Lecture | Practical wor | Seminars | Laboratory | Other | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | **Mineral resources. Introduction** | | | | | | | |
| 1.1 | General introduction to the subject | 1 | | | | | | Oral survey, test |
| 1.2 | Mining technology and excavation of minerals | 1 | | | | | | Oral survey, test |
| 2 | **Main kinds of software packages** | | | | | | | |
| 2.1 | ArcGIS / QGIS. General Introduction and functionality. Geographic space modeling. Representation models. | 2 | | | 2 | 4 | | Oral survey, test |
| 2.2 | GMT, Oasis Montaj. General Introduction and functionality | 2 | | | 2 | 8 | | Oral survey, test |
| 2.3 | Surfer. General Introduction and functionality | 1 | | | | 2 | | Oral survey |
| 3 | **Laboratory practice and tests** | 2 | | | | | | |
| 3.1 | Laboratory models using QGIS software packages. | | | | | 2 | 4 | Report on the laboratory work |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3.2 | Laboratory models using GMT software package. | | | | | 2 | 4 | Report on the laboratory work |
| 3.3 | Laboratory models and Oasis Montaj Viewer software package | | | | | | 2 | Report on the laboratory work |
| 3.4 | Laboratory tests using Surfer software package. | | | | | 2 | 2 | Report on the laboratory work |
| 3.5 | Laboratory tests using Strater software package | | | | | 2 | | Testing |

### 4.2. Recommended reading

(for parts 1 and 2)

**Main**


1. Rocks and the Rock Cycle.
URL: https://serc.carleton.edu/integrate/teaching_materials/mineral_resources/student_materials/unit1reading.html – Access date: 09.09.2024.

2. Types of minerals. URL: https://www.brainkart.com/article/Mineral-Resources_41102– Access date: 09.09.2024.

3. A map of England, showing the mining sites for some mineral resources. URL: https://www.studysmarter.co.uk/explanations/environmental-science/physical-environment/mineral-resources– Access date: 09.09.2024.

4. Gold-bearing quartz vein from California. URL: https://bio.libretexts.org/Courses/University_of_Pittsburgh/Environmental_Science_(Whittinghill)/06%3A_Geology/6.05%3A_Geologic_Resources/6.5.01%3A_Mineral_Resources– Access date: 09.09.2024.

5. Gold crystal. URL: https://geo.web.ru/druza/m-Au_0.htm– Access date: 09.09.2024.

6. Lithium. URL:
https://cyclowiki.org/wiki/%D0%9B%D0%B8%D1%82%D0%B8%D0%B9 – Access date: 09.09.2024.

7. The rust color of hematite (left) and the rust-yellow color of limonite (a variety of goethite, right) have long been used for pigments. URL: https://serc.carleton.edu/integrate/teaching_materials/mineral_resources/student_materials/unit1reading.html. – Access date: 09.09.2024.

8. Global distribution of peatlands. URL: https://www.grida.no/resources/12546– Access date: 09.09.2024.

9. How do we extract minerals. URL: https://www.usgs.gov/faqs/how-do-we-extract-minerals– Access date: 09.09.2024.

10. Zui, V.I. Introduction to GMT. Minsk: BSU. 2023. 51 p. https://elib.bsu.by/handle/123456789/298166 - Access date: 09.09.2024.

11. Zhukovskaya, N.V. Introduction to GIS on the basis QGIS [Введение в ГИС на основе QGIS]. Minsk: BSU. 2018. 132 p. (in Russ.). URL: https://elib.bsu.by/handle/123456789/196241?locale=en

12. Xavier de Lamo. Introduction to QGIS. URL: https://www.google.com/search?q=Xavier+de+Lamo.+Introduction+to+QGIS&rlz=1C1GCEA_enBY1003BY1003&oq=Xavier+de+Lamo.+Introduction+to+QGIS&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIKCAEQABiABBiiBDIKCAIQABiA

BBiiBNIBCTI5MDZqMGoxNagCALACAA&sourceid=chrome&ie=UTF-8 – Access date: 09.09.2024.

13. QGIS Fundamentals: Viewing Spatial Data & Producing a Map. https://samoa-data.sprep.org/resource/qgis-fundamentals-viewing-spatial-data-producing-map-workbook

14. ArcGIS URL: (https://www.esri.com/about/newsroom/arcuser/image_jl/).– Access date: 09.09.2024.

15. What is ArcGIS 9.1? URL: https://www.google.com/search?q=What_is_ArcGIS_Sep2005&rlz=1C1GCEA_enBY1003BY1003&oq=What_is_ArcGIS_Sep2005&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIKCAEQABiABBiiBDIKCAIQABiABBiiBDIKCAMQABiABBiiBDIKCAQQABiABBiiBDIKCAUQABiABBiiBNIBCTM2NzlqMGoxNagCALACAA&sourceid=chrome&ie=UTF-8 – Access date: 09.09.2024.

16. Oasis montaj Help and package documentation

17. Help Menu of the Surfer Release 8.4

18. Surfer. Explore the Depths of Your Data. URL: https://www.goldensoftware.com/products/surfer/features– Access date: 09.09.2024.

19. New 3D Customization Options in the Latest Surfer Release. URL: https://www.goldensoftware.com/new-surfer-3d-customization-options/– Access date: 09.09.2024.

20. Golden software Surfer. URL:– Access date: 09.09.2024. URL: https://www.youtube.com/watch?v=TmJC7vI87Hk

21. Shaded Relief Maps. URL: http://www.innovativegis.com/basis/Courses/GMcourse11/Syllabus/1stClass_reading/About%20Surfer/surfer.html – Access date: 09.09.2024.

## **List of additional literature** (for parts 1 and 2)

1. Bolstad, P. GIS fundamentals: a first text on geographic information systems. GIS fundamentals / P. Bolstad. – Acton, MA White Bear Lake, Minnesota: XanEdu, 2016.

2. Date, C.J. An introduction to database systems. 8th edition (international edition)/ C.J. Date. — Pearson/Addison Wesley, 2003.

3. Diego Berino. Mineral Resources from Exploration to Sustainability Assessment.

4. E-Book on Mineral Sector /

https://www.google.com/search?q=E-Book+on+Mineral+Sector&rlz=1C1GCEA_enBY1003BY1003&oq=E-

Book+on+Mineral+Sector&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigAdIBCTI4OTdqMGoxNagCALACAA&sourceid=chrome&ie=UTF-8 – Access date: 09.09.2024.

5. Fischer, M.M. Geographic information systems, spatial data analysis and spatial modelling: an introduction / M.M. Fischer, H.J. Scholten, D. Unwin // Spatial analytical perspectives on GIS. – Routledge, 2019. – P. 3–20.

6. Fotheringham, S. Spatial analysis and GIS / S. Fotheringham, P. Rogerson. – CRC Press, 2013.

7. Getis, A. Spatial analysis and modeling in a GIS environment / A. Getis // A research agenda for geographic information science. – CRC Press, 2004. – P. 157–196.

8. Graser, Anfita. Learning QGIS / Anfita Graser. – Birmingham: Packt Publishing Ltd., 2016. – 190 p.

9. Lloyd, C. Spatial Data Analysis: An Introduction for GIS Users / C. Lloyd. – OUP Oxford, 2010. – 206 p.

10. Mastering QGIS / Kurt Menke [et al.]. – Birmingham: Packt Publishing Ltd., 2015. – 388 p.

https://www.academia.edu/41009797/Mineral_Resources_From_Exploration_to_Sustainability_Assessment.

11. ME551/GEO551 Introduction to geology of industrial minerals spring 2011. Basic concepts: Geology, mining, and processing of the industrial minerals. Virginia, 187p. URL: https://slideplayer.com/slide/5798628/ – Access date: 09.09.2024.

12. Mineral Resources. UEL: https://www.brainkart.com/article/Mineral-Resources_41102/. – Access date: 09.09.2024.

13. Mineral resources (ppt in colors). URL: https://www3.nd.edu/~cneal/planetearth/Chapt-15-Marshak.pdf

14. Nikos Mamoulis. Spatial Data Management: Synthesis Lectures on Data Management / N. Mamoulis. Morgan & Claypool Publishers, 2011.

15. Pimple, Eric. Programming ArcGIS 10.1 with Python Cookbook /Eric Pimple. – Birmingham: Packt Publishing Ltd., 2013. – 304 p.

16. Shekhar, S. Encyclopedia of GIS / S. Shekhar. – New York, NY: Springer Berlin Heidelberg, 2017.

17. Shellito, B.A. Introduction to Geospatial Technologies / B.A. Shellito. – New York: W. H. Freeman and Company, 2018.

18. Toms, S. ArcPy and ArcGIS – Geospatial Analysis with Python. – Birmingham: Packt Publishing Ltd., 2015. – 224 p.

19. Tripp, G.C. ArcGIS Pro 2.x Cookbook / G.C. Tripp, G.T. Corbin. – Birmingham – Mumbai: Packt Publishing, 2018.

20. Wise, S. GIS Fundamentals, Second Edition / S. Wise. – Boca Raton: CRC Press, 2014.

22. Yeung, G., Albert K. W. Spatial Database Systems: Design, Implementation and Project Management / Albert K. W. Yeung, G. Brent Hall. Springer, 2007.

23. Zandbergen, Paul A. Python Scripting for ArcGIS / Paul A. Zandbergen. – Red-lands, California: ESRI Press, 2013. – 353 p.

### 4.3. Electronic Resources

(for parts 1 and 2)

1. State enterprise “Belgeothenter” [electronic resource] (Государственное предприятие «Белгеоцентр» : http://www.belgeocentr.by/normativnaya-baza – Access date 21.04.2024.

2. BSU electronic library [electronic resource] (Электронная библиотека БГУ): https://elib.bsu.by/ – Access date 21.04.2024.

3. Zui, V.I. Introduction to GMT. Minsk: BSU. 2023. 51 p. https://217.21.43.28/handle/123456789/9122/browse?type=title&sort_by=1&order=ASC&rpp=20&etal=-1&null=&offset=5 – Access date: 09.09.2024.

4. Zhukovskaya, N.V. Introduction to GIS on the basis QGIS [Введение в ГИС на основе QGIS]. Minsk: BSU. 2018. 132 p. (in Russ.). URL: https://elib.bsu.by/handle/123456789/196241?locale=en – Access date: 09.09.2024.

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