QGIS and Open Data for Hydrological Applications – Exercise Manual

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Contents

1 Preface

A Geographic Information System (GIS) can be a useful tool for preparing the input of models and tools. Furthermore, in this era of Open Data ample open access data is available that can easily be retrieved from the internet and integrated in open source desktop GIS software, such as QGIS.

These exercises will guide you through different steps that are needed to preprocess data to be used in models and tools. In the first exercise you will learn how to register a scanned topographic map and use it as a backdrop for digitizing vector data. In the second exercise you will learn how to import data from spreadsheets into a GIS and to use it to join tables, manipulate the attribute table and interpolating the data to a continuous raster layer. In the third exercise you will download open access data from OpenStreetMap and use it for further analysis and conversion. The geodatabase will also be introduced in this exercise. In the fourth exercise you will use map algebra for spatial planning. Finally, you will learn how to delineate catchments and streams form digital elevation models and to present them in maps or in an interactive webpage.

The exercises have been developed for different MSc programmes at IHE Delft and tailor made trainings in Uganda, financed by the Vitens Evides International (VEI) fund. I would like to thank Jan Hoogendoorn and Jonne Kleijer, GIS experts from VEI, for their contribution to these exercises. The Adjumani dataset was developed by VEI and the National Water and Sewerage Corporation (NWSC) in Uganda. I’m thankful for their permission to use the dataset for educational purposes.

In the near future we will further update the exercises and distribute it as Open CourseWare so the whole community can use the course materials.

2 Introduction

2.1 Learning objectives

After following this step-by-step tutorial you will be able to:

- Use QGIS in its main functionalities, also in conjunction with plugins
- Digitize features from a scanned map or satellite image
- Import tabular data in a GIS
- Do simple vector analysis
- Interpolate point data
- Convert vector and raster data
- Reproject vector and raster data
- Use map algebra
- Use online data
- Perform catchment and stream delineation

2.2 Software requirements

During the next exercises we will make use of the following software:

- QGIS ver 3.4 (Madeira) or higher,
- Google Earth,
- Firefox Mozilla
- MS Excel or OpenOffice Calc

You need an internet connection to download plugins or to use the open access data.

2.3 Preparation

Please note that QGIS is already installed on the laptops of IHE Delft participants. Please do not change the version and skip this section. The exercises have been tested for QGIS 3.4.

1) Download QGIS from http://www.qgis.org/en/site/forusers/download.html
2) Install QGIS
3) Install the exercise data from http://ocw.unesco-ihe.org

2.4 Convention

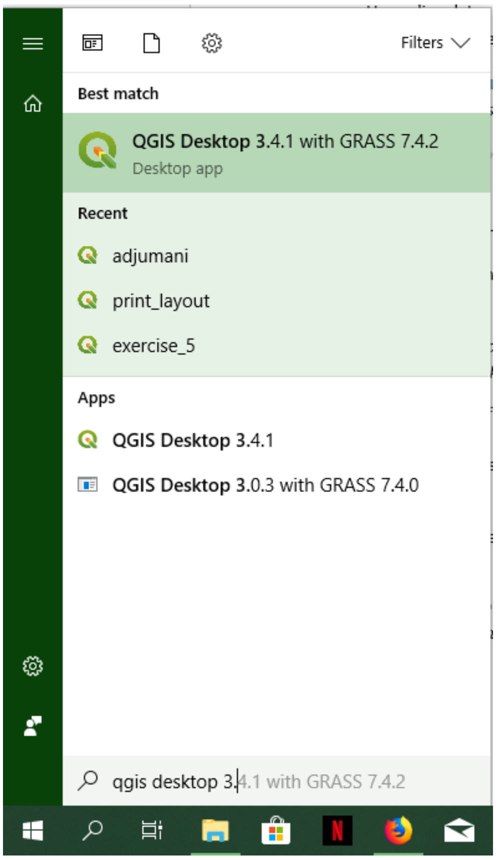
Throughout this guide we have used three different fonts according to what kind of operation we wanted to point at:

- Calibri, is used for the main text
- *Times New Roman, Italic, is used to identify software commands*
- `Courier New is used for text input, that is text that you have to write in the software, or for file names`

3 Getting familiar with QGIS

3.1 Start QGIS 3

You can start QGIS 3 Desktop by looking for it in the Start menu or using the search function. Make sure you open the **QGIS Desktop with Grass** in order to have all functionality we need.



3.2 The screen

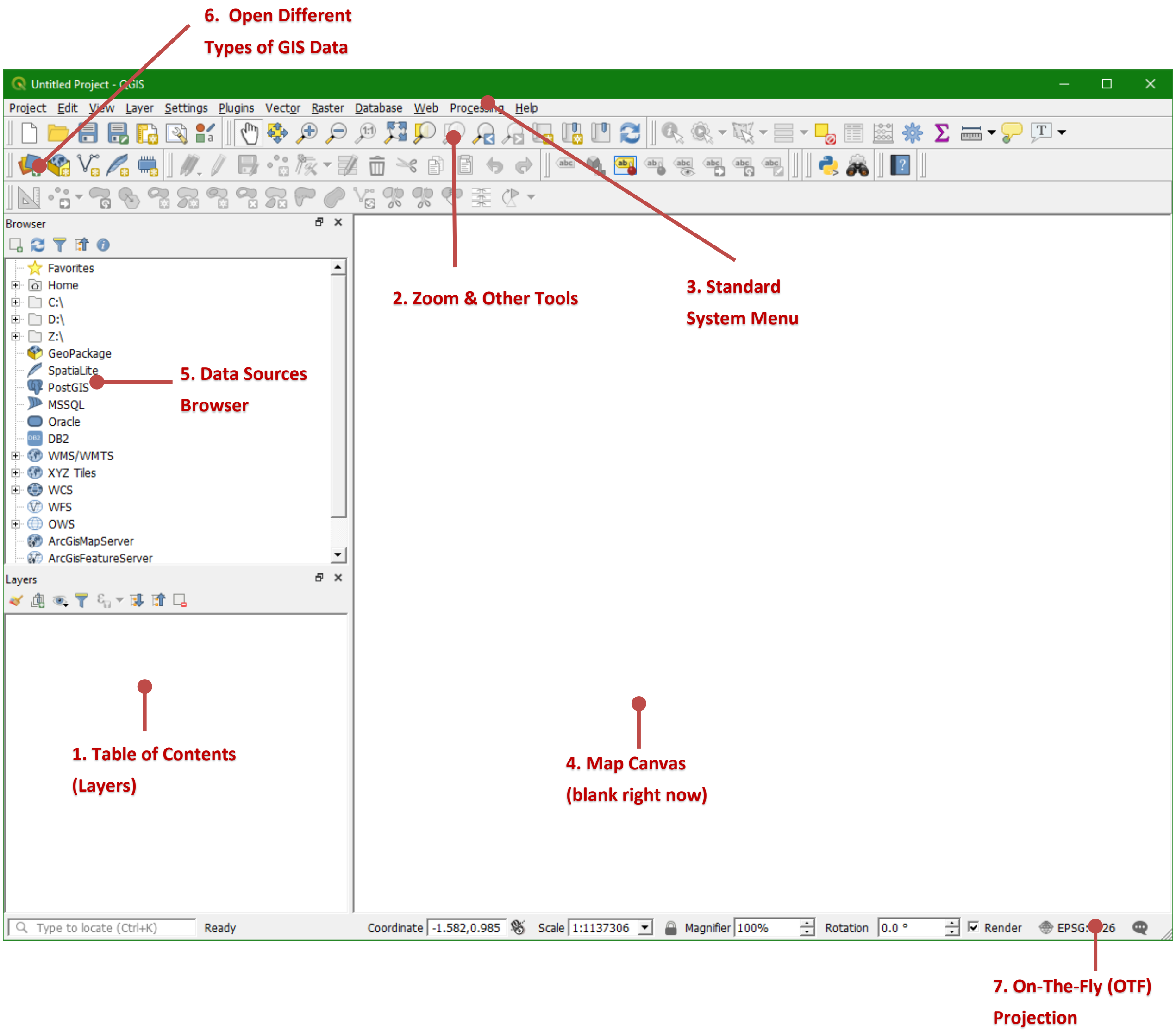
Like many commercial GIS also QGIS has a "traditional" GIS layout.

It is made of the Standard System Menu or Main Menu (we will refer to Main Menu in the following pages) which is always on the top of the software's window, of standard toolbars like the Zoom Tools, or others that can be activated clicking in the Main Menu *View* and then *Toolbars*.

On the left hand side there is the Table of Content (Layers list) area, where all the layers displayed are shown. To the left of this space there is a vertical toolbar, the Manage Layers toolbar.

In the centre of the window is the Map Canvas, where all maps will be displayed.

More information about the QGIS Graphical User Interface can be found here:
http://docs.qgis.org/2.18/en/docs/user_manual/introduction/qgis_gui.html


6. Open Different
Types of GIS Data
Untitled Project - QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Processing Help
2. Zoom & Other Tools
3. Standard
System Menu
Browser
Favorites
Home
C:\
D:\
Z:\
GeoPackage
SpatiaLite
PostGIS
MSSQL
Oracle
DB2
WMS/WMTS
XYZ Tiles
WCS
WFS
OWS
ArcGisMapServer
ArcGisFeatureServer
5. Data Sources
Browser
Layers
1. Table of Contents
(Layers)
4. Map Canvas
(blank right now)
Type to locate (Ctrl+K)
Ready
Coordinate -1.582,0.985
Scale 1:1137306
Magnifier 100%
Rotation 0.0 °
Render
7. On-The-Fly (OTF)
Projection

Exercise 1: Digitizing from a scanned map

4 Digitizing from a scanned map

4.1 Introduction

In order to use hardcopy maps in a GIS, they need to be scanned and georeferenced. Georeferencing is also needed for raw remote sensing images, such as aerial photographs and satellite images.

For the best result, choose a map sheet that is clean and does not have too many folds. Use a scanner that is large enough to scan the whole map. The resolution of the scanner should be large enough (e.g. 1200 dpi) to have enough detail in the resulting raster maps.

For georeferencing we need to link locations on the scanned image to coordinates. There are two ways:

1. Collect ground control points (GCPs) at locations that are clearly visible in the image, such as bridges and junctions.
2. If the hardcopy map contains a coordinate grid, you can use the printed grid as a reference. Make sure that you know the projection of this grid, which usually is stated on the map.

In this exercise we will use a scanned map of Mount Marcy (USGS, 1979) (`Mount_Marcy_New_York_USGS_topo_map_1979.JPG`), which we will georeference with the coordinate grid printed on the map. You can find the data (Data Exercise 1) on the OpenCourseWare website (http://ocw.unesco-ihe.org/course/view.php?id=11). Save the map on your hard drive (e.g. `D:\QGIS_Exercises\Exercise_1\Mount_Marcy_New_York_USGS_topo_map_1979.JPG`

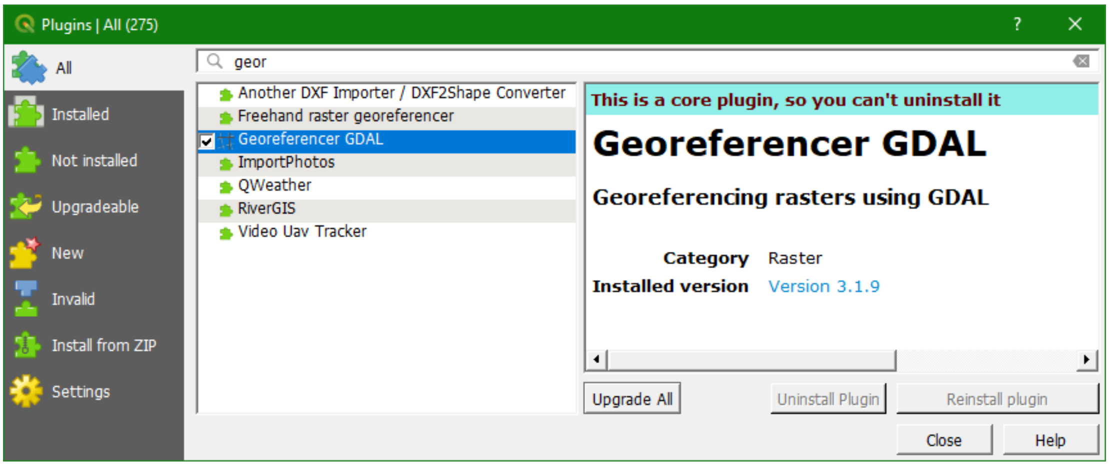
4.2 Choosing the projection

Have a look at the scanned map and try to find the projection that has been used. You can use any image viewing software for this. Which projection was used? Look for the EPSG code in http://www.spatialreference.org and write it down.

4.3 Enable the Georeferencer GDAL plugin

The *Georeferencer GDAL plugin* is a core plugin, which means that it is already installed. In order to use it, you need to activate it. This works as follows:

1. In the main menu go to *Plugins* → *Manage and install plugins…*
2. Search for *Georeferencer GDAL* and check the box
3. Click *Close* to close the dialogue



4.4 Importing the scanned map into the Georeference GDAL plugin

1. From the main menu choose *Raster* → *Georeferencer…*

2. Click the Open Raster button 
3. Browse to the `Mount_Marcy_New_York_USGS_topo_map_1979.JPG` file
4. A window will open where you have to specify the *Coordinate Reference System (CRS)* of this input map. It does not yet have a CRS, so you can click *Cancel*.

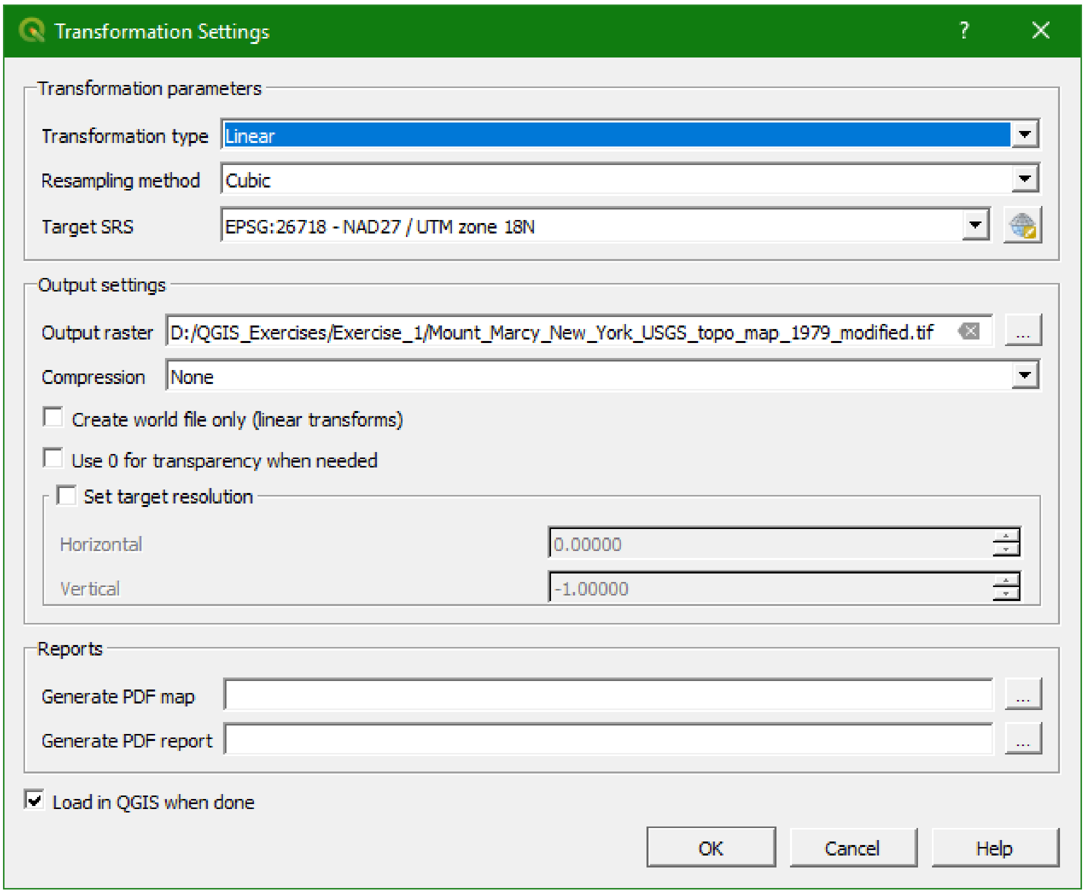
4.5 Setting the transformation parameters

First we have to set the transformation settings (see also screenshot on next page).

1. In the menu choose *Settings* → *Transformation Settings…*
2. Here you can choose:
    a. Different transformation types. A simple linear transformation can be used if the map is not much deformed. The other ones can be tried when more deformation exists. **We will start with a linear transformation.**
    b. Resampling method: if you need the pixel values in further calculations, it is best to choose the nearest neighbour option. This resampling method will preserve as much as possible the original pixel values by choosing the nearest one. Visually, however, this method results in a "blocky" map. If the purpose is only for visual use, for example as a backdrop for digitization of vector layers, then it is better to choose another resampling method. **Here we will use the cubic method**, which uses the average of the 4 nearest pixels.
    c. Target SRS: here choose the code that you have noted before; `EPSG:26718`. You can choose it by clicking  and using typing 26718 in the filter field.

    Browse to the folder where you want to save the georeferenced map. The tool automatically adds `_modified` to the file name. So in our case the georeferenced file will be named `D:\QGIS_Exercises\Exercise_1\Mount_Marcy_New_York_USGS_topo_map_1979_modified.tif`

    Keep the other settings on default and check the box *Load in QGIS when done*. The dialogue should look like the one below.



4.6 Adding Ground Control Points (GCPs)

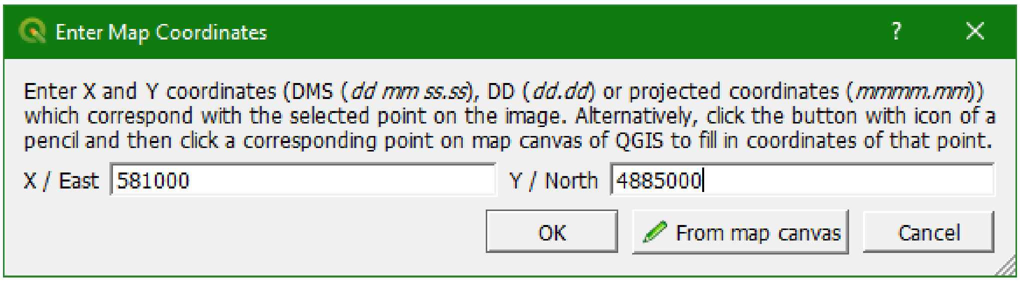
In order to link the file coordinates to real world coordinates, we need to indicate Ground Control Points (GCPs) with known coordinates. We can derive these coordinates in different ways:

- The easiest way is to use the coordinate grid on the scanned map if this is available and if it is in a known projection. We click on a node in the grid and type the corresponding X and Y coordinates in the dialogue.
- Using a reference map in the QGIS map canvas that has already been georeferenced. In this way we can obtain the right coordinates by clicking on the reference map.
- Using GCPs that were measured in the field using a GPS.

Here we will use the coordinate grid that is printed on the map.

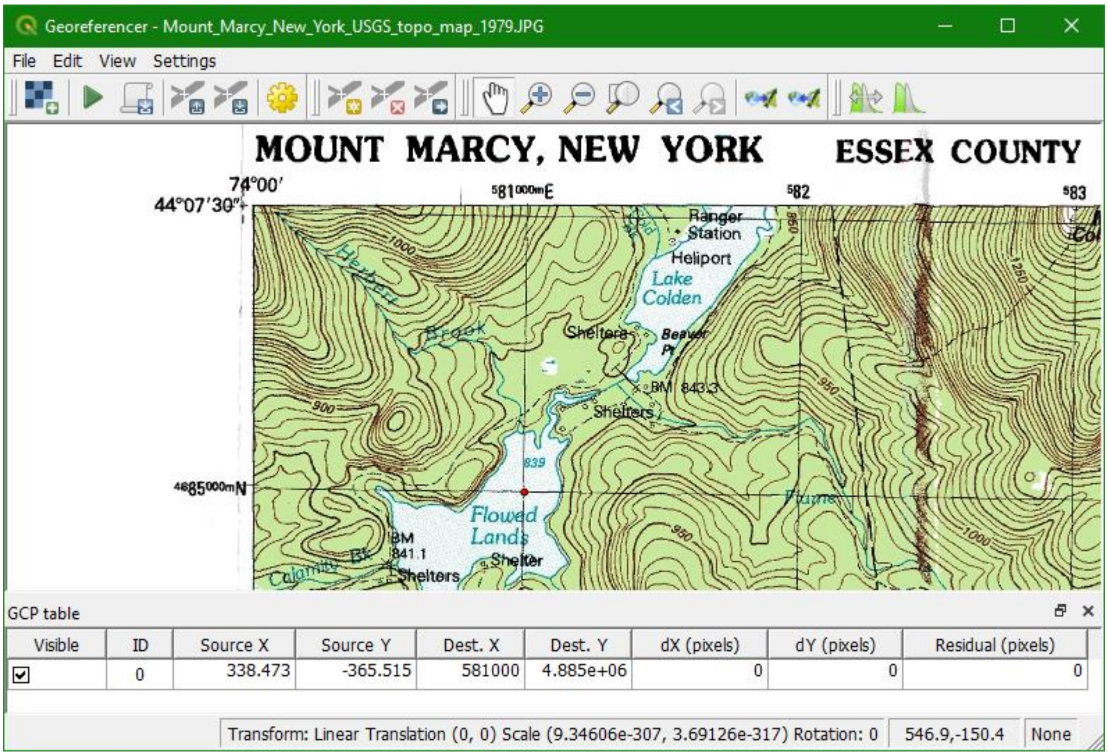
1. Zoom in on the node with coordinate 581000 East and 4885000 North.
2. Click the *Add Point* button  to add a GCP.

3. Enter the map coordinates in the pop-up window:



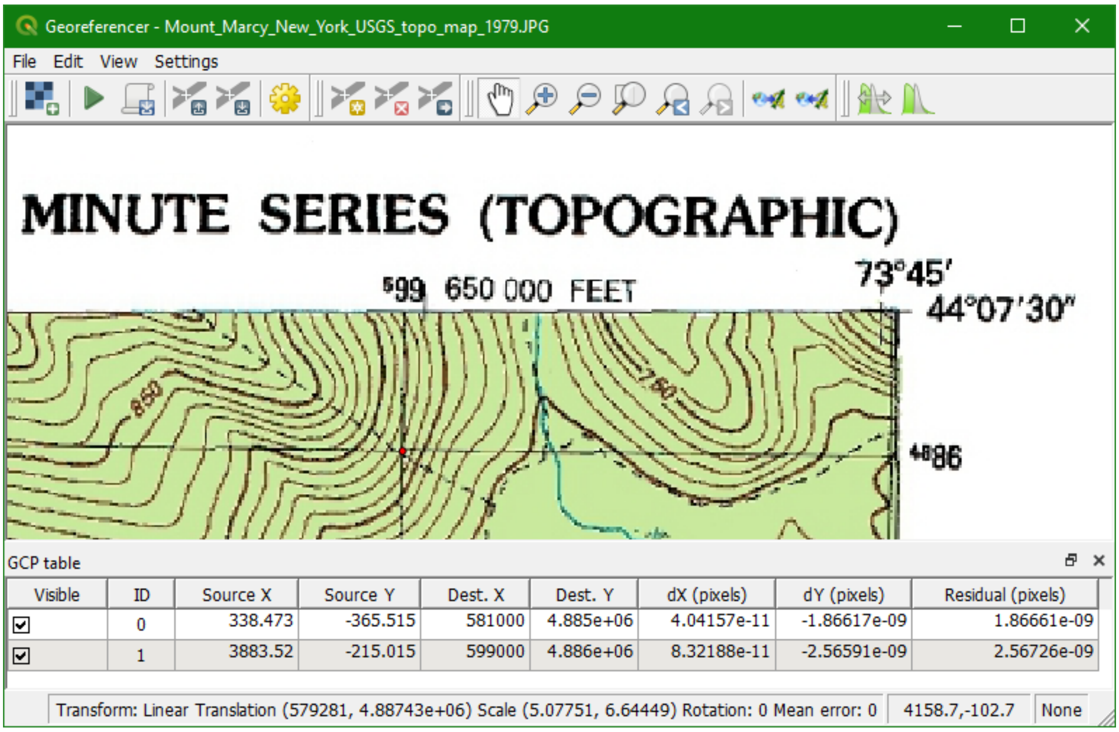
If you have a reference map in the QGIS map canvas, you can use the From map canvas button to capture the coordinate and perform an image to image georeferencing. Here we will only type the coordinates form the map grid.

4. Press *OK*. Now your screen should look like this:

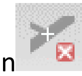


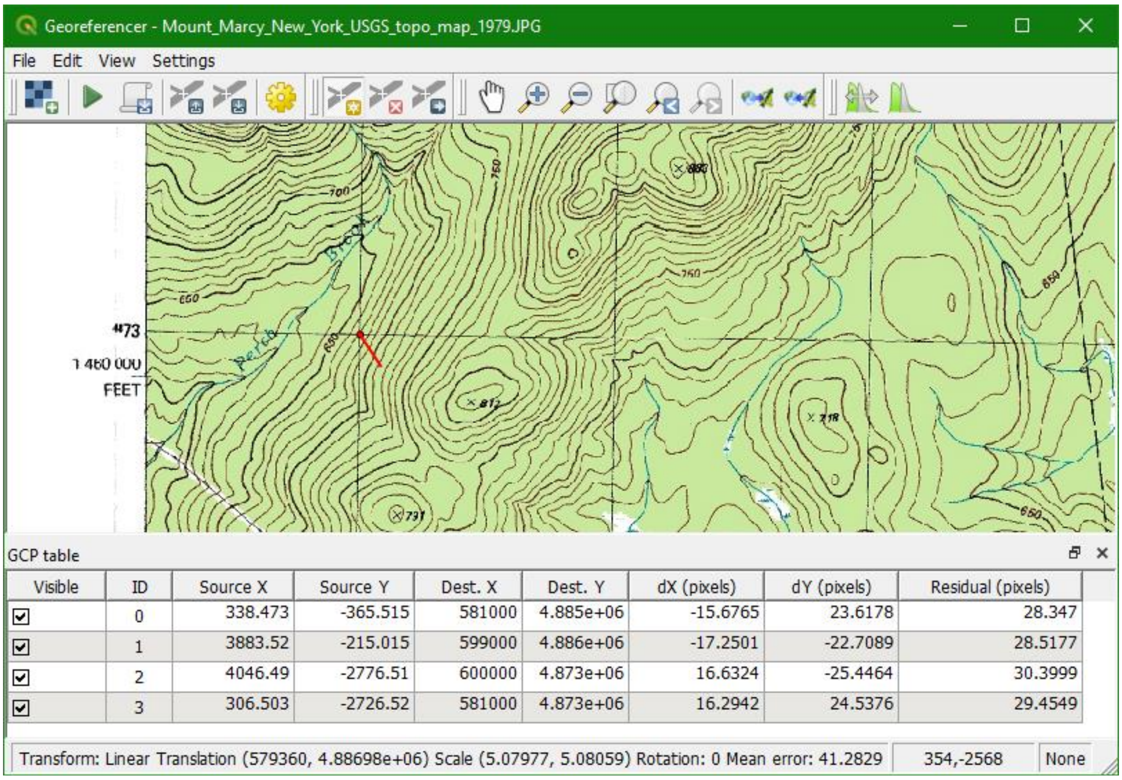
The red dot is the location that you have referenced. In the table below the map, you can see the Source X and Source Y coordinates. These are the unreferenced file coordinates. Their values depend on which pixel you clicked for placing the GCP, so it can differ from the screenshot above. Dest. X and Dest. Y show the real world coordinates that you have linked to this location. The other fields of the table have to do with estimated accuracy and will be filled in after adding more points.

5. Let’s choose a second GCP in the upper right corner of the map and proceed in a similar way as with the first GCP. Your screen should look like this:



You can see that some error statistics have been calculated. With only two points this does not make much sense. The minimum amount of GCPs for a linear transformation should be 4.

6. Add in a similar way a GCP in the lower left and the lower right corner of the map. If you made a mistake you can remove the GCP by using the *Delete point* button . Your screen should look like this:



At the bottom of the screen you can see the estimated mean error (40.2829 pixels in our case). The error is also visualized at the GCPs using a red line. Obviously your values will not be exactly the same.

There are two ways to reduce the error:

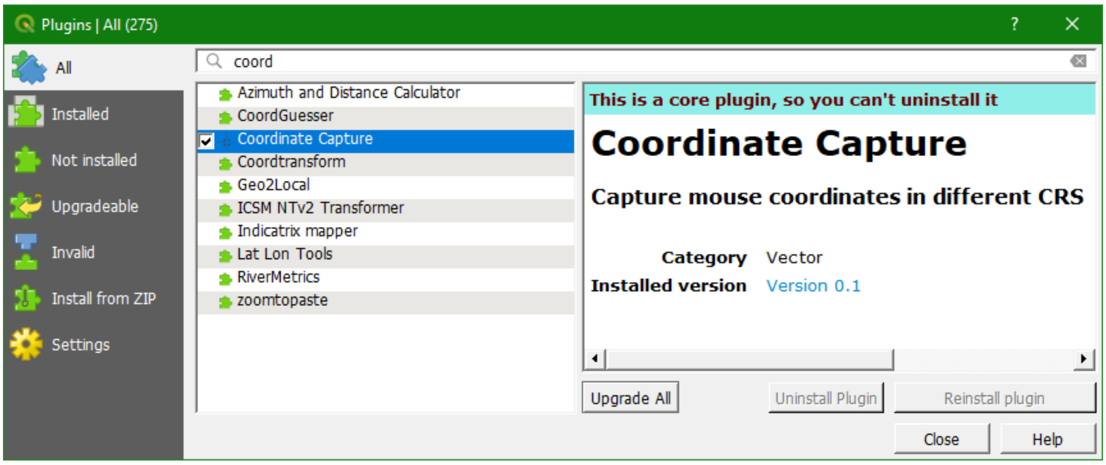
a. Use the  button (move GCP point) to place the GCPs really at the nodes where the grid lines cross. You need to zoom in to select the right pixel. Note that the mean error is not automatically updated. You need to change the transformation type to something else and then back.
b. If option a. doesn't reduce the error, we can change the transformation type. If we change to another transformation type in the transformation settings, the error values will be recalculated.

We'll apply option b.

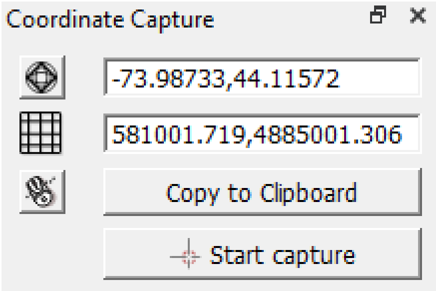
7. In the menu go again to *Settings* → *Transformation Settings…* and now let's select a 1st order polynomial (*Polyniomial 1*) instead of the linear transformation. Keep the rest as it was. Click *OK* to return to the GCP table. Now you can see that the mean error has been reduced to a fraction of a pixel, which is acceptable. If you don't see a mean error < 1 pixel, than you have to check the GCP locations and correct them.

8. Now we can start georeferencing using the  button. After some calculation time the georeferenced map appears in the QGIS map canvas. You can close the Georeferencing plugin. It will ask if you want to save your GCPs. You can click *Discard* if you don't want to use them. If you save them, you can load them again in the Georeferencing plugin.

9. In order to verify the result you can use the Coordinate Capture plugin. If it is not activated yet you can do it by choosing from the menu: *Plugins* → *Manage and Install Plugins…* . Then search for the *Coordinate Capture plugin* and check the box to activate and click *Close*:



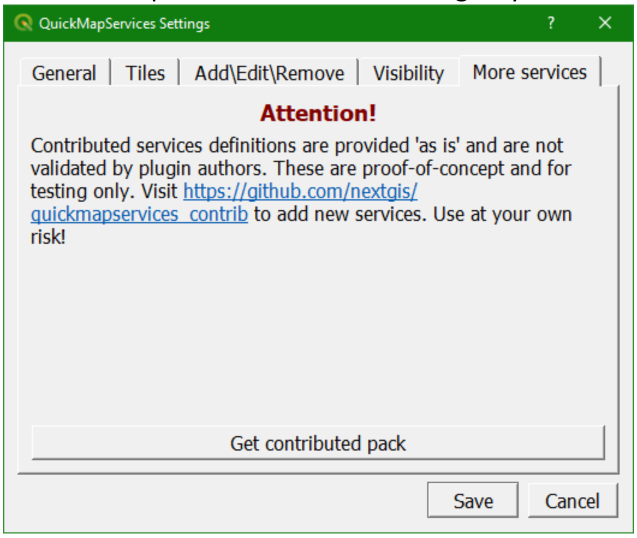
10. A panel has appeared under the layers list. Here you click on *Start capture*. Click on a grid node in the map and the coordinates are displayed in the panel:



The first field shows the coordinates in the Geographic Reference System (Lat/Lon coordinates), the second field shows the coordinates in the projection of the project. Read the coordinates from the side of the map and verify if they are correct.

Another way to verify the result is to use the web maps as a backdrop. The *QuickMapServices* plugin provides easy access to many web maps such as Google satellite and OpenStreetMap.

11. If not yet installed, install the *QuickMapServices* plugin: in the main menu choose *Plugins* → *Manage and Install Plugins…* and search for the *QuickMapServices* plugin and install.
12. After installing, choose from the main menu *Web* → *QuickMapServices plugin* → *Settings*
13. Now choose the *More services* tab and click *Get contributed pack*. Click Save when the contributed pack is installed. This will give you access to many more useful web maps.



14. Go back to the main menu and choose *Web* → *QuickMapServices plugin* and try some of the options.
15. This is a good moment to save your QGIS project (`.qgz` file). Choose from the main menu *Project* → *Save as…* and save it as `D:\QGIS_Exercises\Exercise_1\Exercise_1.qgz`.

The project file contains references to all layers, styles, projections, extent and zoom level of the Map Canvas. Save your project regularly!

4.7 Digitizing vector layers from a georeferenced backdrop

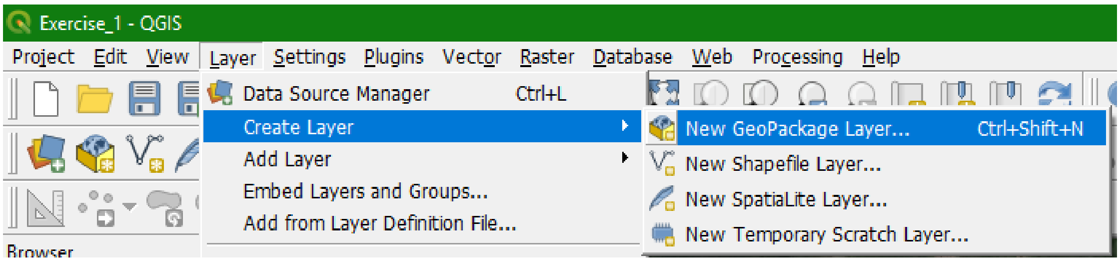
Our georeferenced scanned map can now be used as a backdrop to digitize vector layers. Vectors can be points, (poly)lines or polygons. In this exercise we are going to digitize:

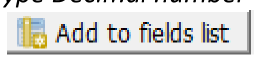
- Mountain tops as points
- Rivers as (poly)lines
- Lakes as polygons

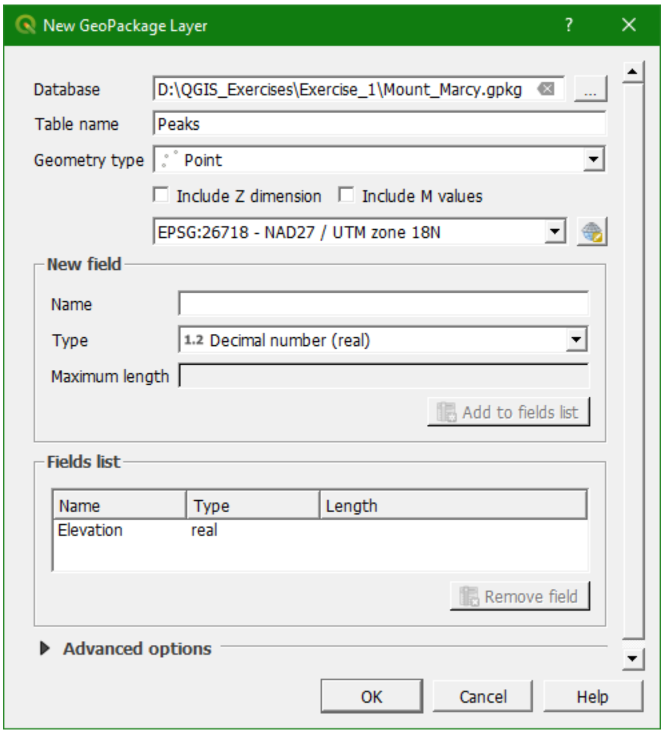
We will create these vector layers in a GeoPackage spatial database. In that way we have all layers together in one file, instead of using separate shapefiles.

The following steps guide you through the process.

1. First we have to create an empty shapefile. In the main menu select *Layer* → *Create Layer* → *New GeoPackage Layer…*



2. In the *New GeoPackage Layer* dialogue we first select the Database filename by clicking  . Then browse to the folder where you want to store the GeoPackage and save it to `D:\QGIS_Exercises\Exercise_1\Mount_Marcy.gpkg`. For *Table name* we choose *Peaks*. For *Geometry type* we choose *Point*. Make sure `EPSG:26718` is chosen as projection.
3. Create a new field with the *Name* `Elevation`, *Type Decimal number (real)* and click  .
4. Click *OK*.
5. The empty layer has now been added to your layers list.



6. In order to start digitizing, you have to toggle to edit mode. Click on the `Peaks` layer so it is selected.

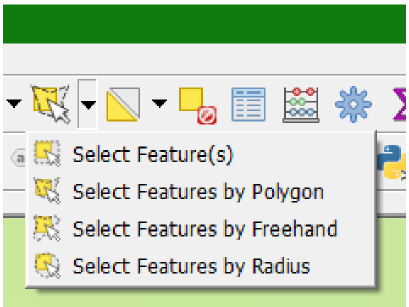
7. Click on to toggle to editing mode. Now the other editing buttons become active and a pencil before the layer name shows that we are editing the layer.

8. In the topographical map navigate to a spot height of a mountain. They are indicated with x and an elevation value. If you have found one, zoom in and click the *Add Feature button* .

9. Move the mouse to the mountain top. The cursor changes in a crosshair. Click on the mountain top.

10. A dialogue with a form shows up. `fid` is the feature id that is automatically generated. It's a unique integer number for each feature. The other attribute that we have to fill in is `Elevation`. We type there `738` in this case.

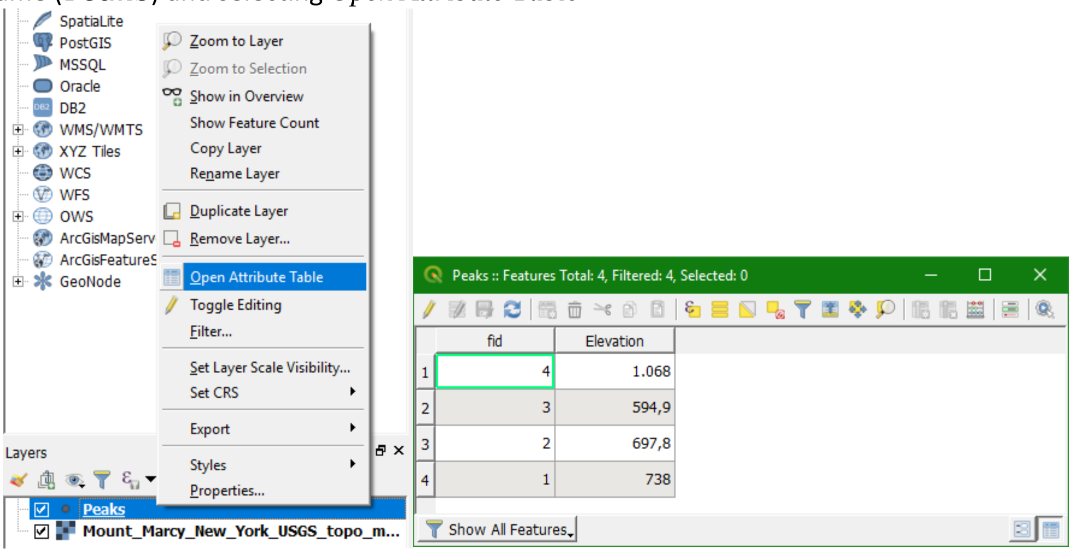
11. Repeat this step for a few other peaks. If you made a mistake, you can use the vertex tool to move the feature or use one of the select options to select the point feature



and click to delete the selected point feature. These buttons can be used to undo/redo something. Use to save the edits.

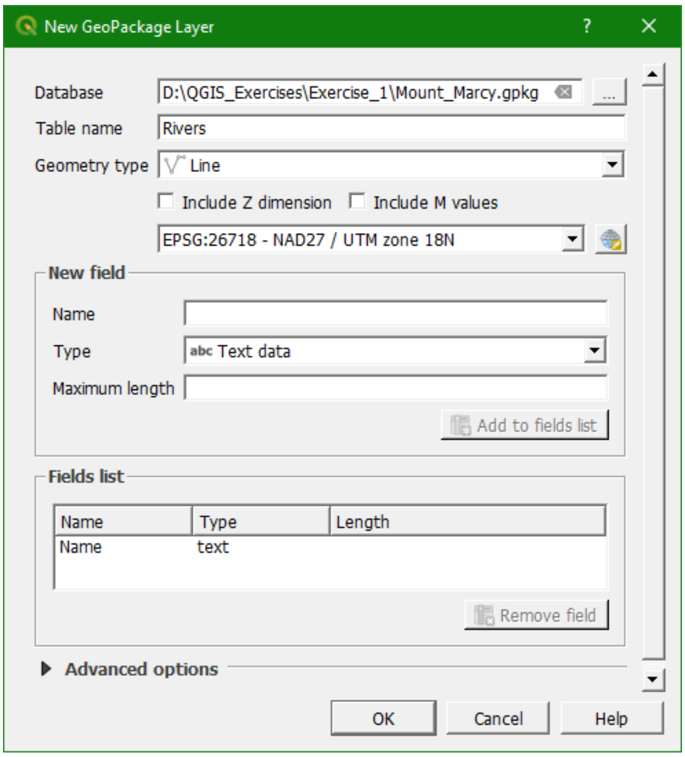
12. When done, click again on the button to toggle editing. If you didn't save edits yet, it will ask you to *Save* or *Discard*. With *Discard* you can always undo your edits until the last time it was saved.

13. You can check the attribute table of your new point vector layer by right clicking on the layer name (`Peaks`) and selecting *Open Attribute Table*

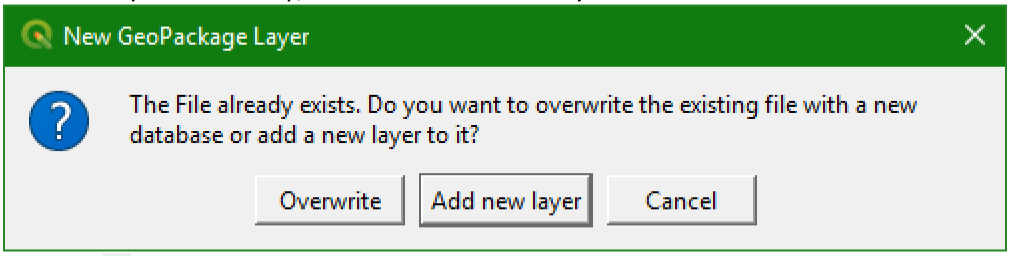


Now you can see the attributes that you have added and their *fid* and elevation values.

14. Our next task is to digitize line features. The procedure is similar to creating a point layer. In the *New GeoPackage Layer* dialogue first browse to the existing *Database* `D:\QGIS_Exercises\Exercise_1\Mount_Marcy.gpkg`. Give a new Table name: `Rivers` and *Geometry type Line*
15. As a new attribute we add `Name` with the type *Text data*. Check if the dialogue resembles the one below and click *OK*.



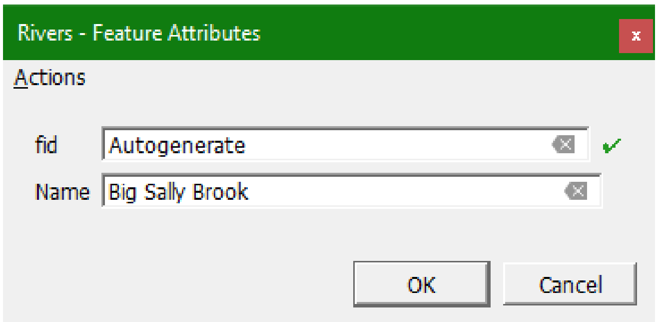
16. QGIS will tell you that the file already exists and if you want to overwrite the database or add the new layer. Obviously, we choose *Add new layer*.



17. Click on to add a new line feature. Zoom and pan on the map to find a stream to digitize.

18. Click on the starting point of the line (node) and click when necessary to make a vertex. You can use the zoom and pan buttons to trace the stream. You can also change the symbology to visualize clearer the line that you are digitizing. After you placed the end node of the line, click right. You can use the spacebar to pan during digitizing.

19. In the dialogue, fill in the name of the river.



20. Repeat these steps for a few streams and save your edits. Check the attribute table.
    <u>Extra:</u>
    - If you want to add tributaries that connect to streams, play around with the snapping settings (Click right on a toolbar and choose *Snapping Toolbar*).
    - Try to find out how to combine all tributaries into one river feature.

21. Finally we are going to create a polygon vector layer for some lakes. Try to find out yourself how to do this. It is very similar to the procedure for lines. The only difference is that the first node should be the same as the last node in order to close the polygon.
    <u>Extra:</u>
    - Try to find out how to deal with islands in the lakes

4.8 Image to image registration

Try to use the *Georeferencer* plugin to register the scanned map (JPG file) to a satellite image from the *QuickMapServices* Plugin. In this way you can perform an image to image registration. Please make sure you use the right projection. Does the image to image registration give better results?

This whole exercise can be viewed in a screencast at: https://youtu.be/m12ZXpGBoDc

Exercise 2: Importing tabular data into GIS and interpolation

5 Importing tabular data into a GIS

5.1 Introduction

After this exercise you are able to import tabular data into a GIS. In this example we are going to import a table with the daily average temperature on September 1st 2013 at several meteorological stations in the Netherlands. The data was downloaded from the KNMI Data Centre (KNMI, the Royal Netherlands Meteorological Institute, http://data.knmi.nl), but reformatted for the purpose of this exercise.

In this exercise we'll use the following data:

- `KNMI_20130901_tday.xls`: table with average daily temperatures for different stations
- `KNMI_stations.xls`: table with station number and coordinates of the location of the stations

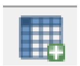
This data can be downloaded from the OpenCourseWare website (http://ocw.unesco-ihe.org/course/view.php?id=11). You can find the data under Data Exercise 2. You can save the files under `D:\QGIS_Exercises\Exercise_2`.

This exercise will guide you through the following steps:

5.2 Convert Excel table to GIS format

There are different ways in QGIS to import tabular data:

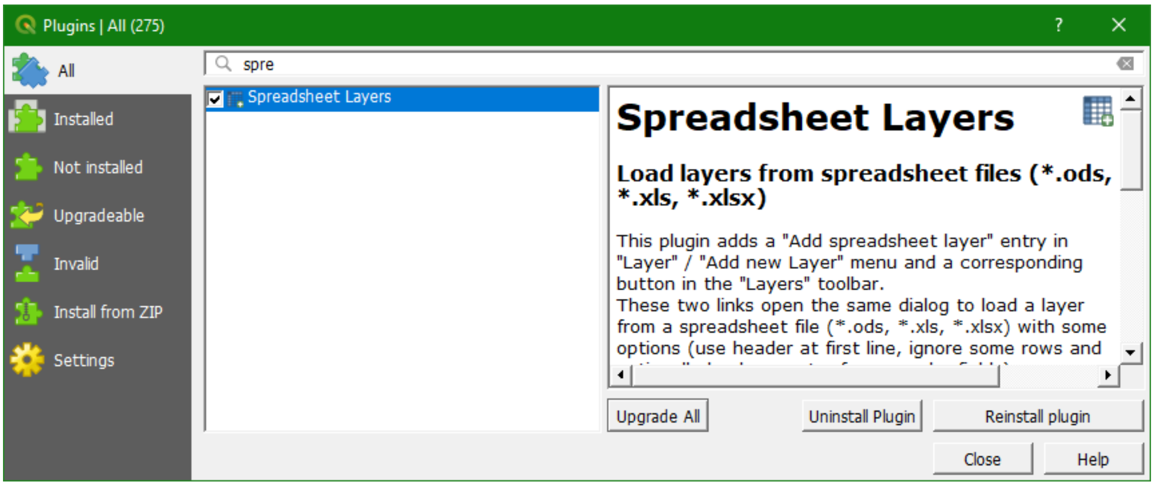
Add delimited text layer: this is the standard importer that requires a comma separated ASCII file.



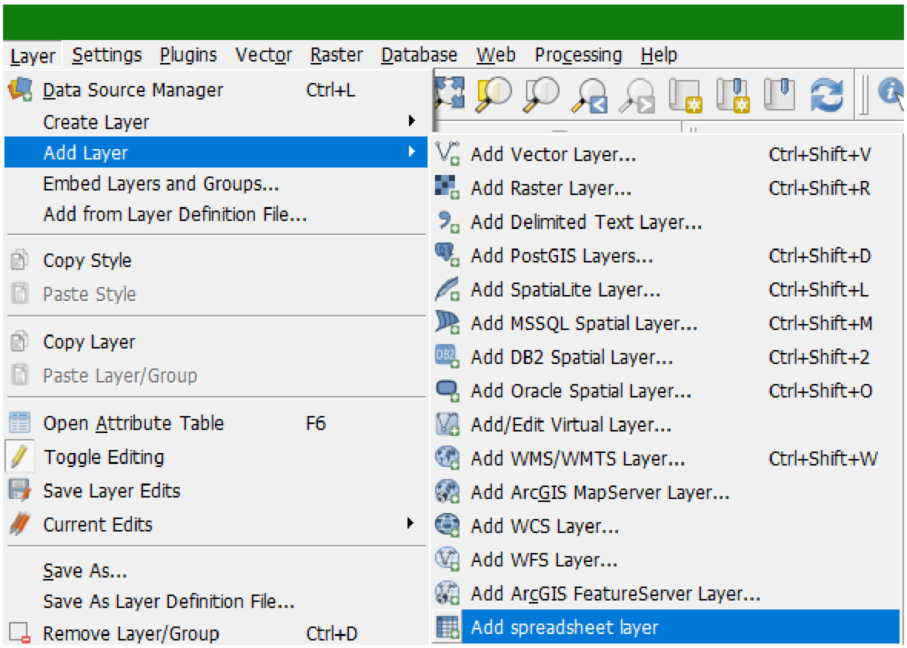
Spreadsheet layers plugin. This tool can open spreadsheet files (*.ods, *.xls, *.xlsx) with some options (use header at first line, ignore some rows and optionally load geometry from x and y fields).

In this exercise we'll use the *Spreadsheet layers plugin*

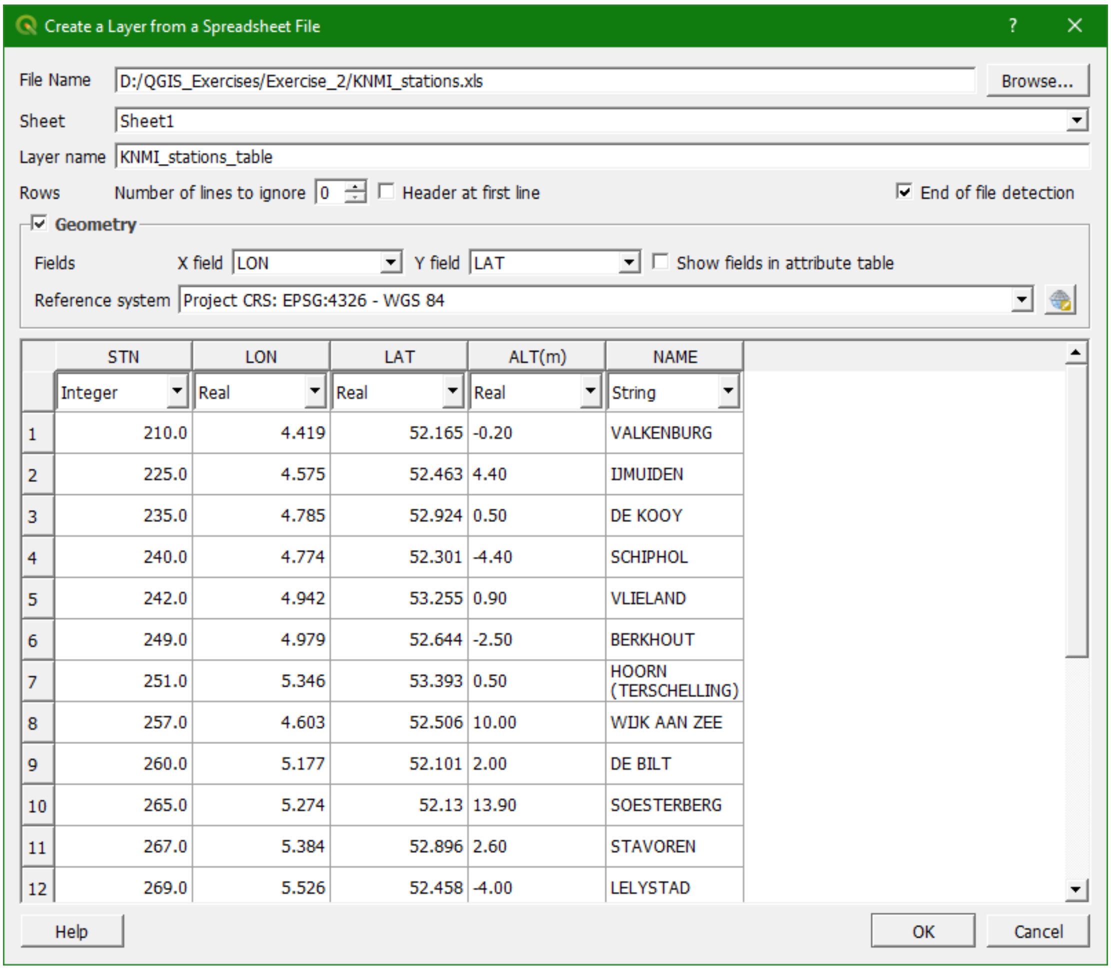
1. Open the files `KNMI_20130901_tday.xls` and `KNMI_stations.xls` in a spreadsheet program (e.g. MS Excel) and check the contents. Which file contains coordinates? Is there a way to link both files? How could we do that?
2. Start QGIS Desktop (make sure you start a new project and not continue the previous one).
3. In the menu go to *Plugins* → *Manage and install plugins...* and check if *Spreadsheet layers plugin* is installed. If not, you should install the plugin. Plugins are developed by the community to add extra functionality to QGIS. With the *Spreadsheet layers plugin* you can import from/export to Excel files for example.



4. Now in the menu choose *Layer* → *Add Layer* → *Add spreadsheet layer*

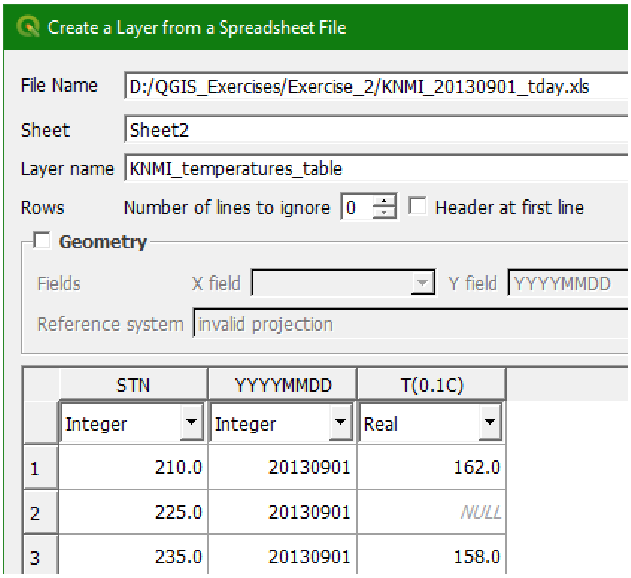


5. In the dialogue browse to the file with the locations of the meteorological stations (`KNMI_stations.xls`).
6. Fill in the dialogue as below. Make sure the right *Geometry Fields* and *Reference system* are chosen. Also indicate the data types correctly for the fields. E.g. `STN` are station numbers and should be imported as *Integer*, while `ALT(m)` should be imported as *Real* numbers.



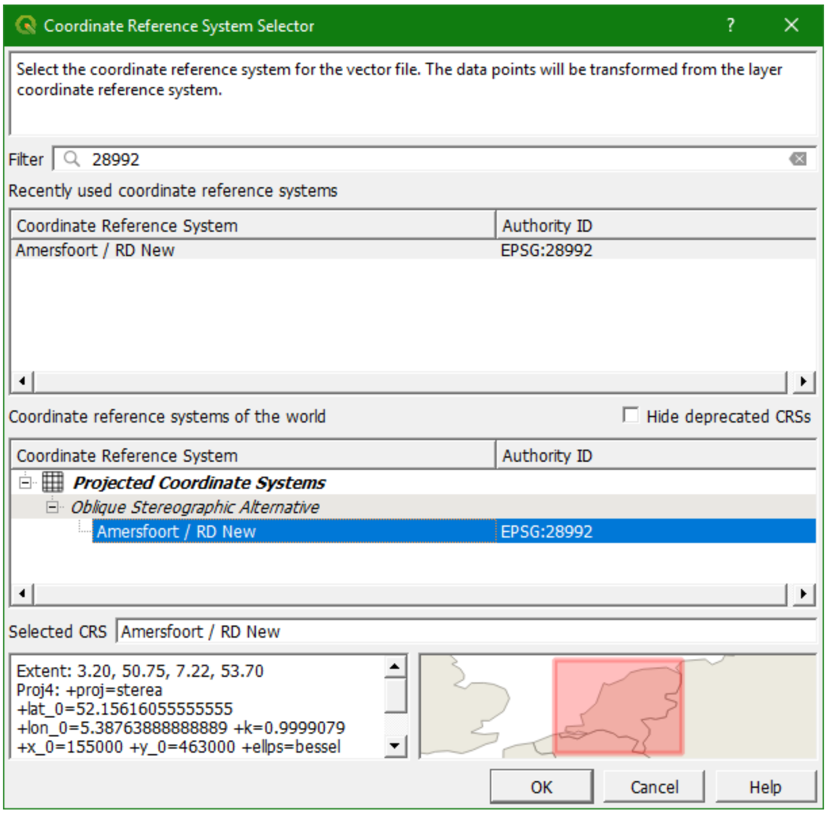
7. Now a map with the meteorological stations is displayed. If you don't see the map, you probably need to zoom to the extent of the map: click right on the layer name (**KNMI_stations_table)** and choose *Zoom to layer*.

8. Now add the table with the temperature data in the same way. Because there is no geometry (coordinates) in the table, we should uncheck the box:



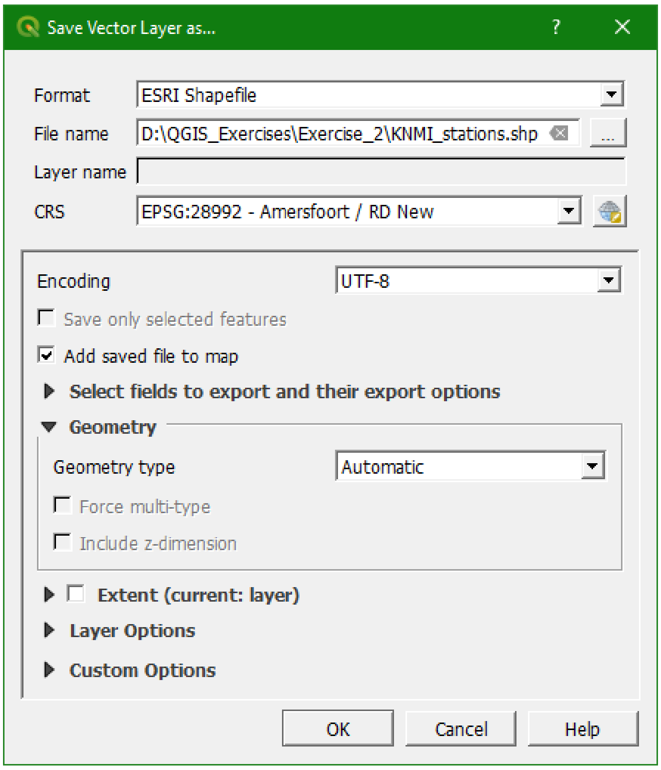
9. The next step is to convert **KNMI_stations_table** to a GIS vector format, i.e. shapefile. Click right on **KNMI_stations_table** and choose *Export* → *Save Features as…*

10. In the dialogue use the ... button to browse to the folder to save the file as `KNMI_stations.shp`. In order to change the projection to the local Dutch projection choose for CRS "Selected CRS" and Browse to Amersfoort / RD New by clicking on the button. Tip: use the *Filter* field to lookup EPSG code `28992`:



Here you see the advantage of using EPSG codes: it standardizes the projection. So it is useful to determine the EPSG code of the projection you want to work within your project. Also note that all maps in your project need to be in the same projection if you want to combine them in a GIS analysis or modelling.

Click *OK*. Now the dialogue looks like the figure (also check the box *Add saved file to map* and make sure that `ESRI Shapefile` is chosen as the *Format*).



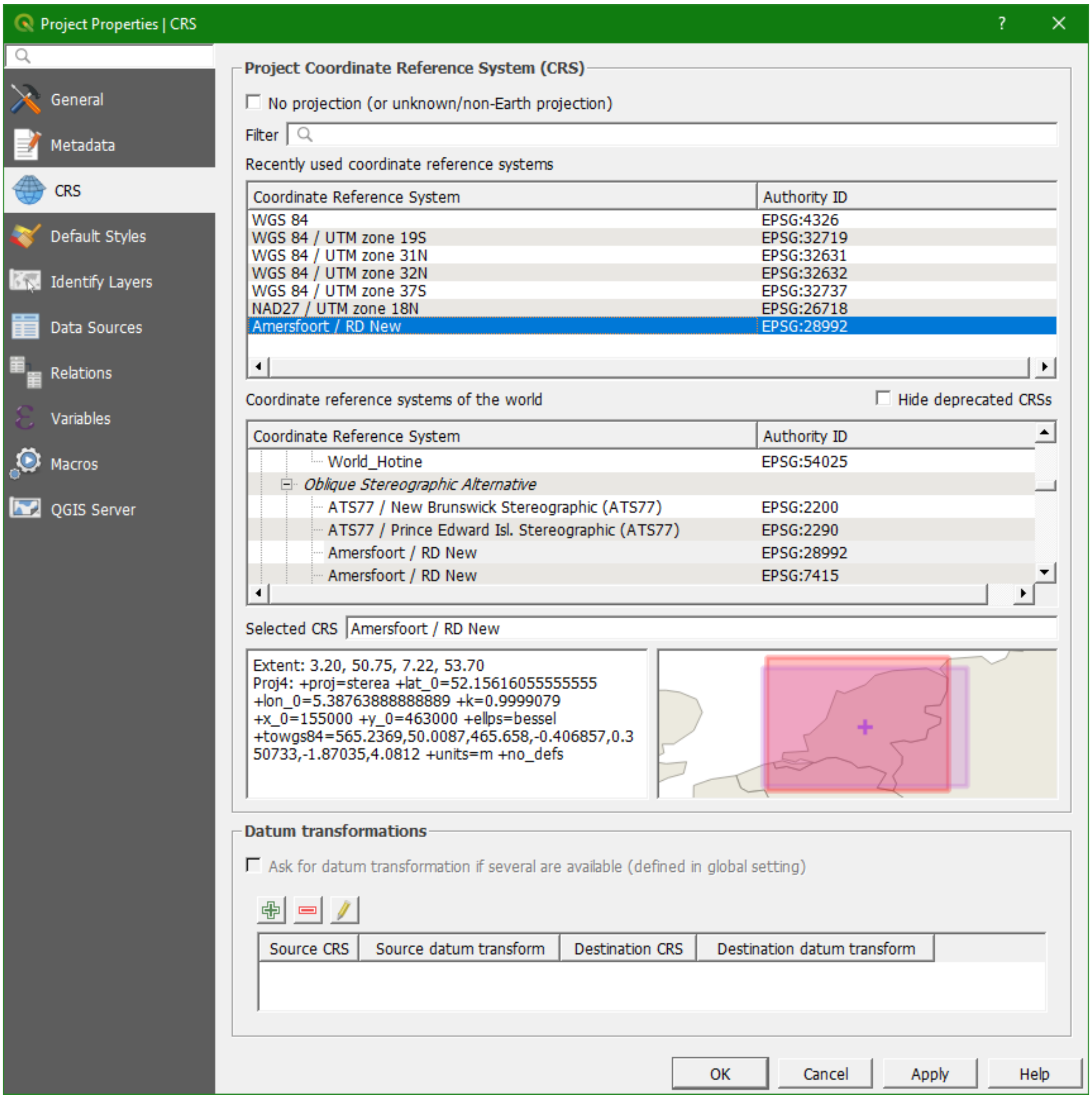
Click *OK* to proceed.

11. Remove the **knmi_stations_table** from the display by clicking right and selecting *Remove Layer…* . Click *OK* to confirm. Be sure to remove the right one. If you hover your mouse over the layer name it will show the file name. With *Remove* you only remove it from the display, the file will still be on your hard disk.

12. Although the `knmi_stations.shp` dataset is in the EPSG 28992 projection (Amersfoort / RD New), the QGIS Map Canvas still uses the EPSG 4326 projection (lat/lon WGS 84) and has reprojected `knmi_stations.shp` ***on the fly*** for visualisation. In order to visualise all layers in EPSG 28992 we have to change the QGIS Project properties. In the menu choose *Project → Properties…*

13. Choose the Coordinate Reference System (CRS) tab.

14. Choose from the recently used coordinate reference systems EPSG:28992 and click *OK*.



Note that the projection of the project is indicated in the lower right of the screen EPSG:28992 . You can always check there if the EPSG code is okay. You can change the on-the-fly projection also by clicking on that EPSG code.

5.3 Join attribute tables

We still have the locations of the stations and the temperature data in separate tables. We have to combine them in one shape file. In GIS terms this is called a "join" operation. We can only join tables if they have a column in common.

15. Check the attribute table of `KNMI_stations` (right click on `KNMI_stations` and choose *Open attribute table*) and in the same way check the `KNMI_temperatures_table`. Which column both attribute tables have in common?

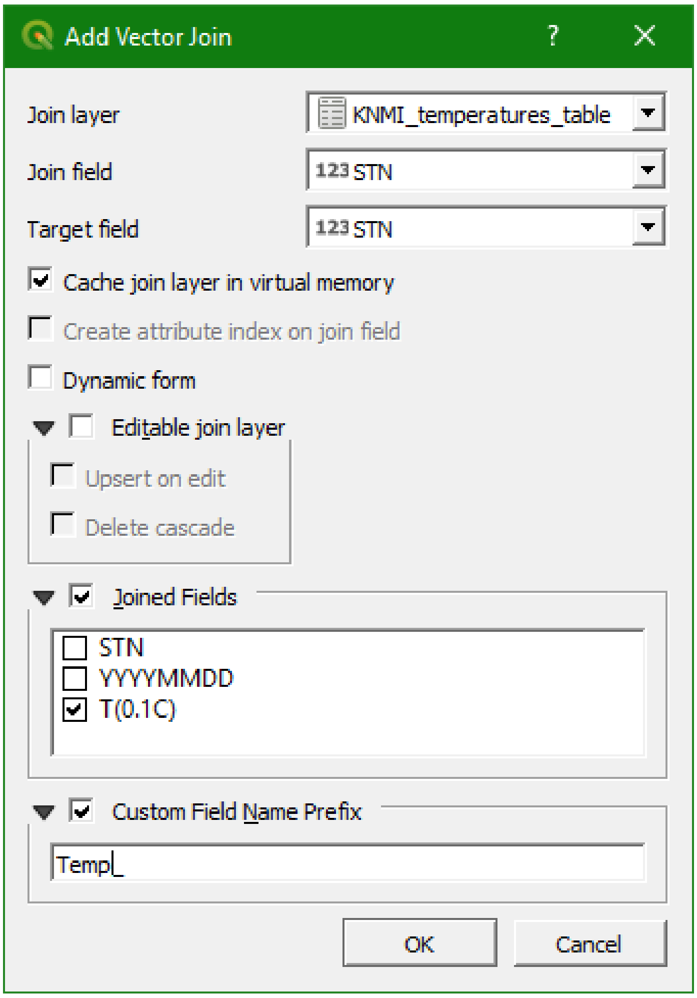
After determining which column both tables have in common we can join the data of `KNMI_temperatures_table` to the attributes of our shapefile `KNMI_stations.shp`.

16. First close the attribute tables.

17. Next, click right on `KNMI_stations` and choose *Properties*.

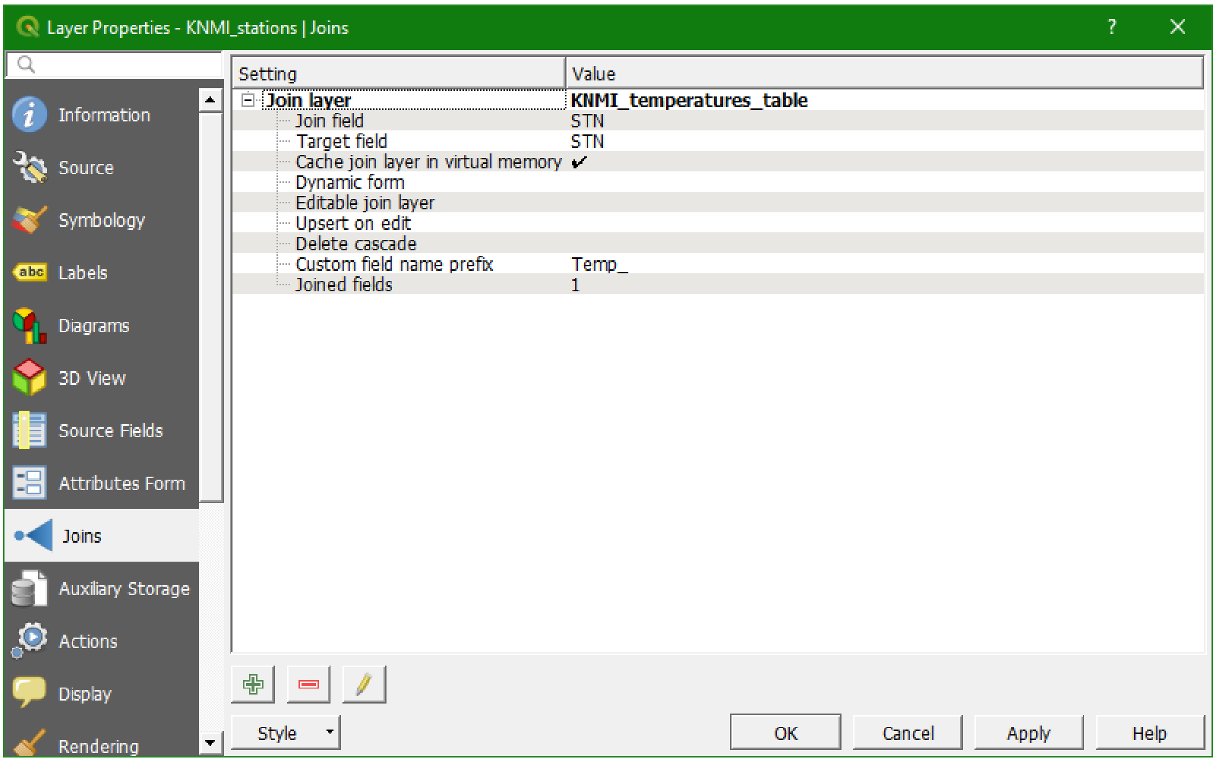
18. In the dialogue choose the button *Joins*  .

19. Click the + sign and choose check if the dialogue looks like this one:



Note that the common field is `STN` (the station number), we join only the temperature field and we give the column the prefix `Temp_`. Click *OK*.

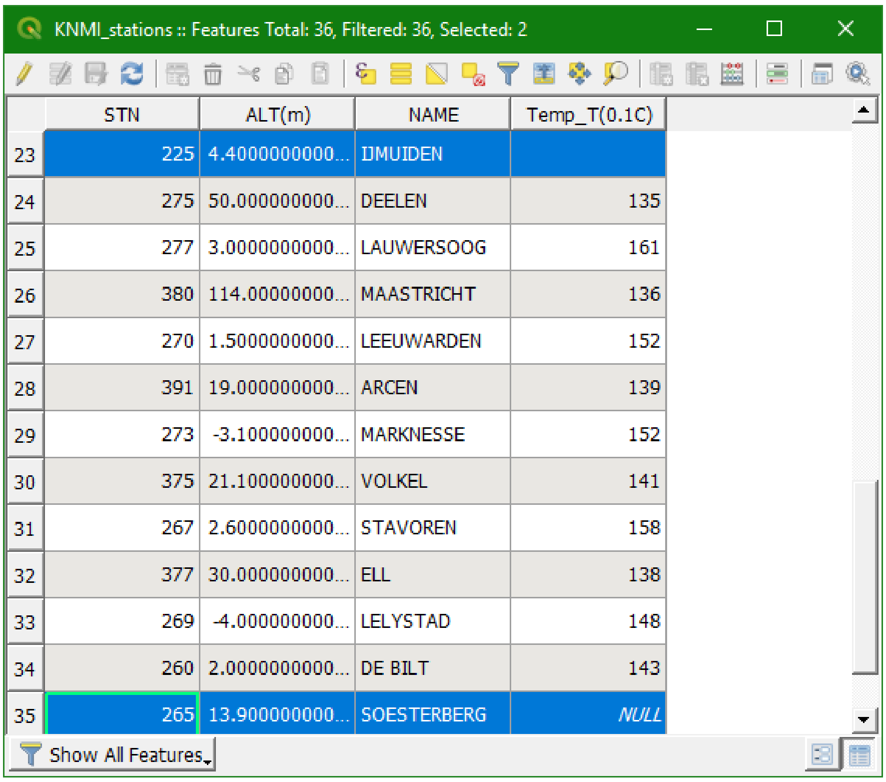
20. Now the *Joins* dialogue looks like this:



Click *OK* to perform the Join operation.

21. Now check again the attribute table of `KNMI_stations`. What happened?

22. First we need to remove the missing values. Click on row numbers with `NULL` or no values for temperature, while keeping the `Ctrl` button pressed. Now the attribute table looks like this:


KNMI_stations :: Features Total: 36, Filtered: 36, Selected: 2

	STN	ALT(m)	NAME	Temp_T(0.1C)
23	225	4.4000000000...	IJMUIDEN	
24	275	50.000000000...	DEELEN	135
25	277	3.0000000000...	LAUWERSOOG	161
26	380	114.00000000...	MAASTRICHT	136
27	270	1.5000000000...	LEEUWARDEN	152
28	391	19.000000000...	ARCEN	139
29	273	-3.100000000...	MARKNESSE	152
30	375	21.100000000...	VOLKEL	141
31	267	2.6000000000...	STAVOREN	158
32	377	30.000000000...	ELL	138
33	269	-4.000000000...	LELYSTAD	148
34	260	2.0000000000...	DE BILT	143
35	265	13.900000000...	SOESTERBERG	NULL

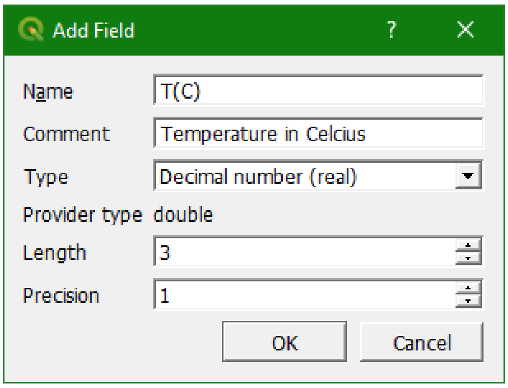
Show All Features

23. In the attribute table click on  above the table to toggle editing mode.

24. Click the  icon (in the toolbar above the attribute table) to remove the 2 features with missing data and save the attribute table by clicking 

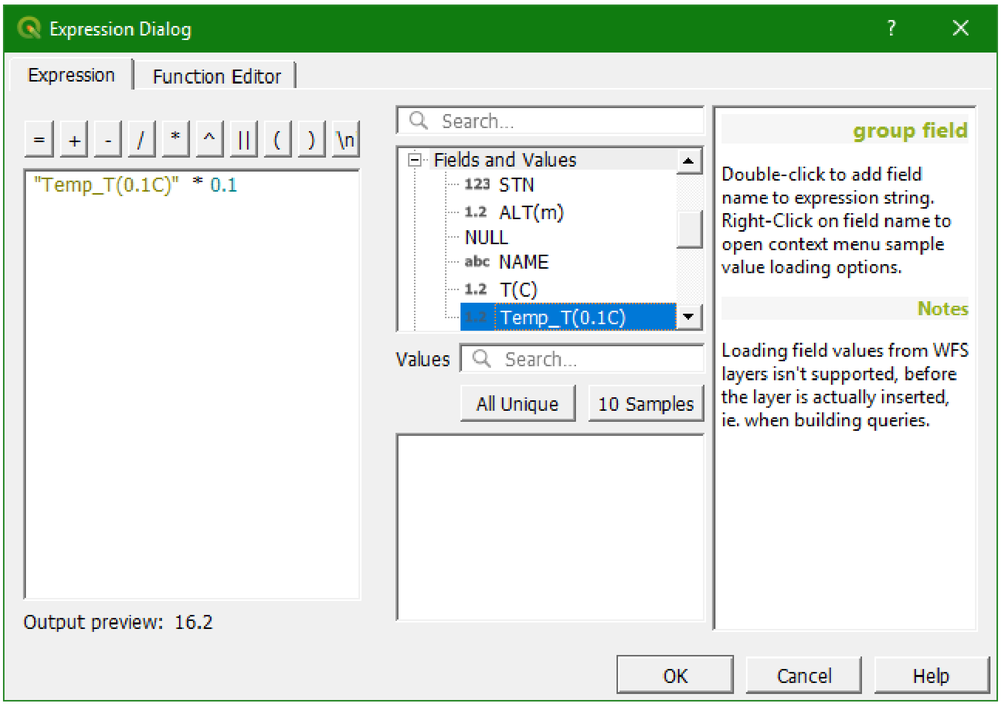
25. The only problem now is that the temperatures in the table are in 0.1 °C. We need to convert the values to °C.

26. Click the *New field* button  to add a new column to the table. And fill in the dialogue according to this screenshot:

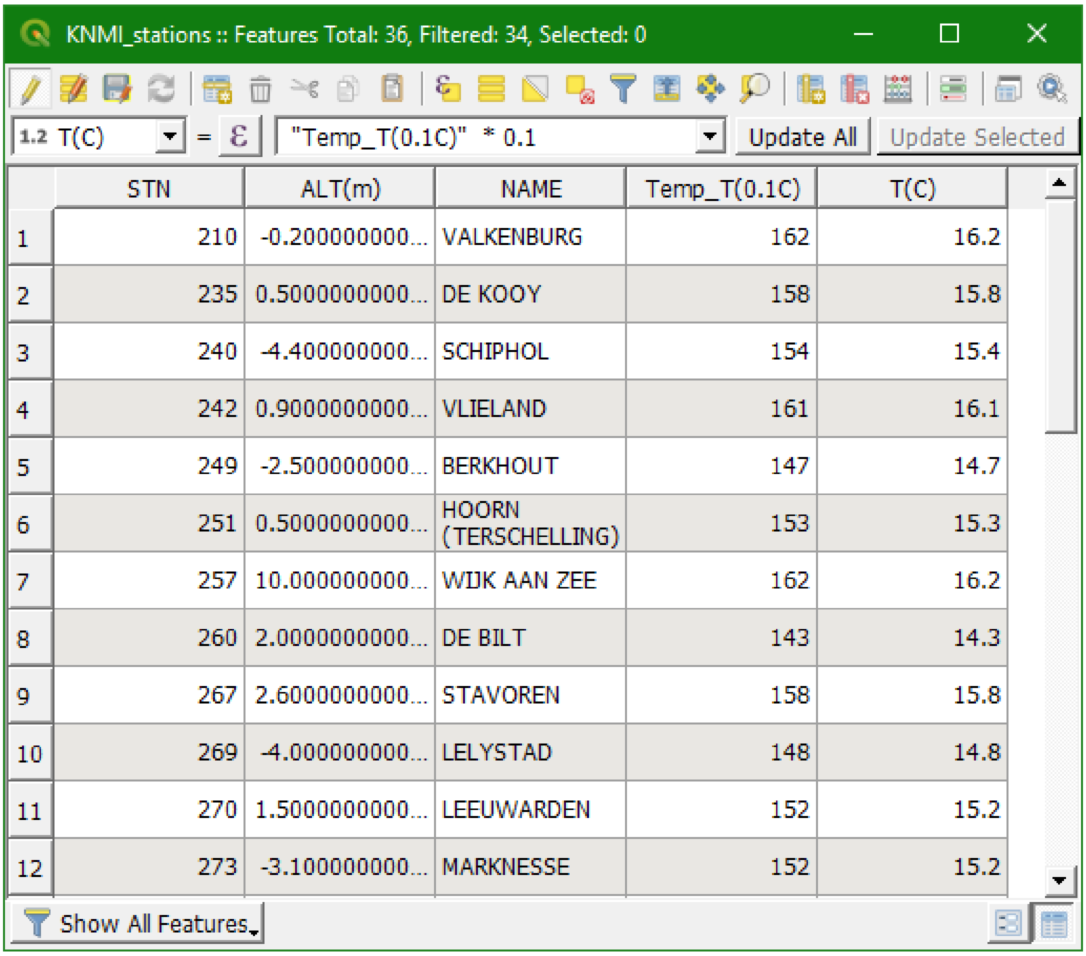


Length is the amount of numbers, *Precision* is the amount of decimals.
Click *OK* to proceed.

27. Now the attribute table shows an extra column with `NULL` values. In order to calculate the right values click  above the table to open the *Field Calculator* dialogue.
Fill the dialogue like the screenshot below. To avoid typos the best practice is to double click on the field name in the middle of the dialogue screen and to click the `*` button. Then type `0.1`. Click *OK* to proceed.



28. Make sure the *Attribute table* window looks like below. **Please note that** `T(C)` **should be indicated as column to assign the calculation to!** Click *Update All*.



	STN	ALT(m)	NAME	Temp_T(0.1C)	T(C)
1	210	-0.200000000...	VALKENBURG	162	16.2
2	235	0.5000000000...	DE KOOY	158	15.8
3	240	-4.400000000...	SCHIPHOL	154	15.4
4	242	0.9000000000...	VLIELAND	161	16.1
5	249	-2.500000000...	BERKHOUT	147	14.7
6	251	0.5000000000...	HOORN (TERSCHELLING)	153	15.3
7	257	10.000000000...	WIJK AAN ZEE	162	16.2
8	260	2.0000000000...	DE BILT	143	14.3
9	267	2.6000000000...	STAVOREN	158	15.8
10	269	-4.000000000...	LELYSTAD	148	14.8
11	270	1.5000000000...	LEEUWARDEN	152	15.2
12	273	-3.100000000...	MARKNESSE	152	15.2

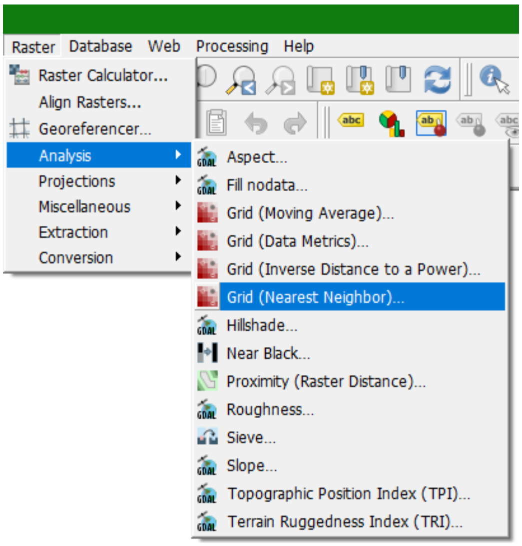
29. Now check the result in the attribute table.

30. Click again on the  to toggle back to non-editing mode. Click *Save* to save the changes when asked and close the attribute table. **If you made a mistake, don't save, but instead choose *Discard* to undo all changes since last save.**

31. Now remove the table `KNMI_temperatures_table` and check the attribute table of **KNMI_stations**. What columns do you see now? What can you conclude about the join function? You could have saved the entire attribute table by saving **KNMI_stations** to a new shapefile using the previously used *Export* → *Save as…* function.

5.4 Interpolate point features to raster

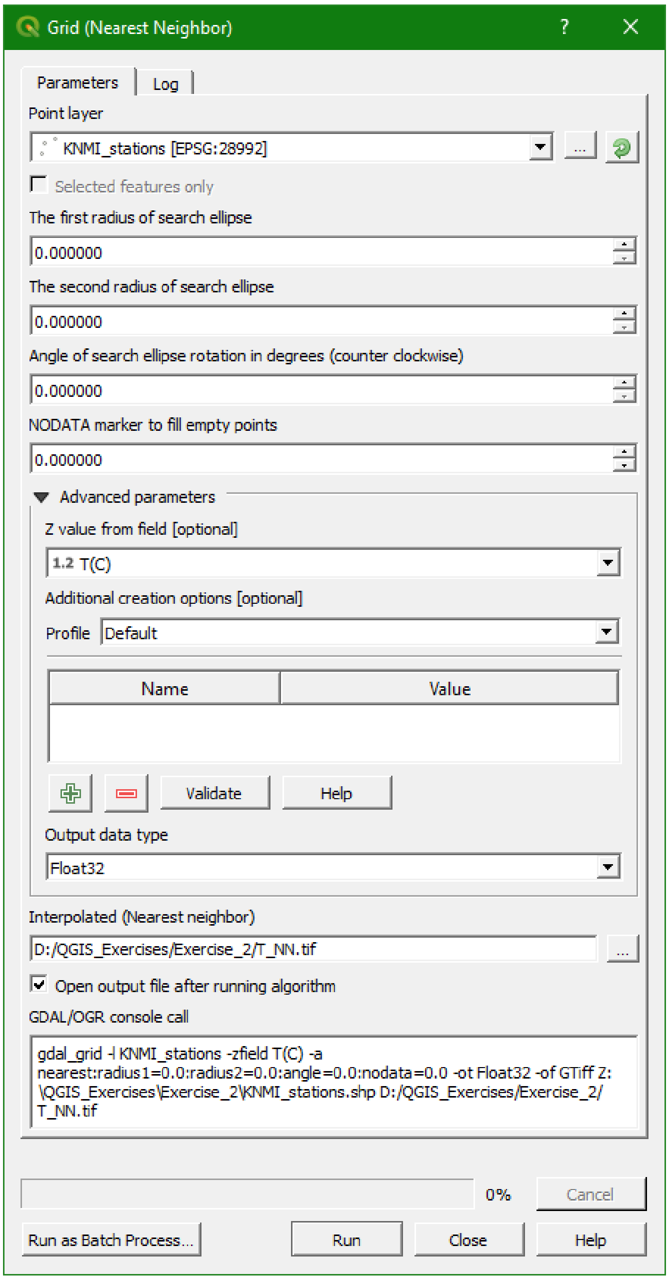
32. The final task is to interpolate the temperature values to a raster. In the menu choose *Raster* → *Analysis* → *Grid (Nearest Neighbor).*



33. In the dialogue specify the output file: `tday_NN.tif` by using the browse window and specifying the `.tif` format.

    Select `T(C)` as *Z value from field*. This is the field that we will interpolate to Thiessen polygons. Check the *Open output file after running algorithm* checkbox. For the rest of the dialogue keep the defaults. The dialogue should now look like the figure.

    Note that the dialogue generates a GDAL command.
    Click *Run* to proceed.
    Click *Close* to close the dialogue.



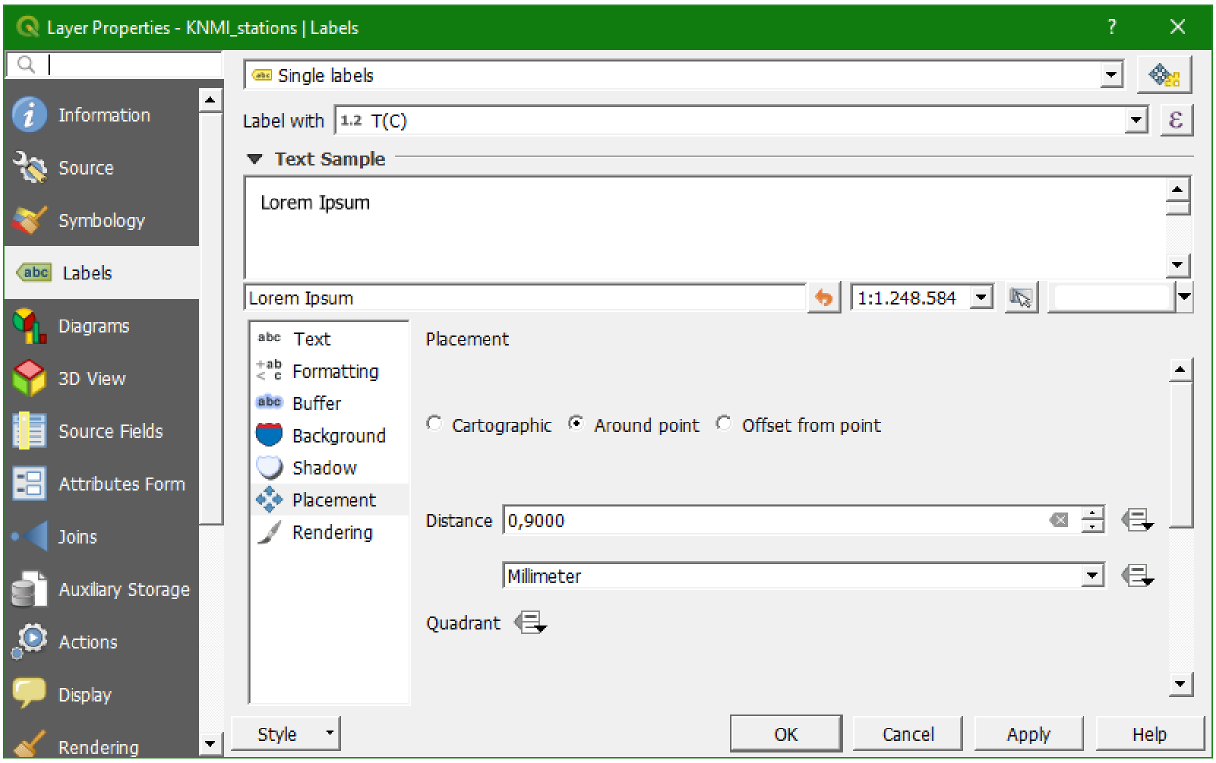
34. The interpolated temperature map is now loaded into the display. It is visualised in greyscale, so you have to set the visualisation options. Click right on the map and select *Properties*.

35. Under the *Symbology* tab, play around with the different options and click *OK* to return to the display.

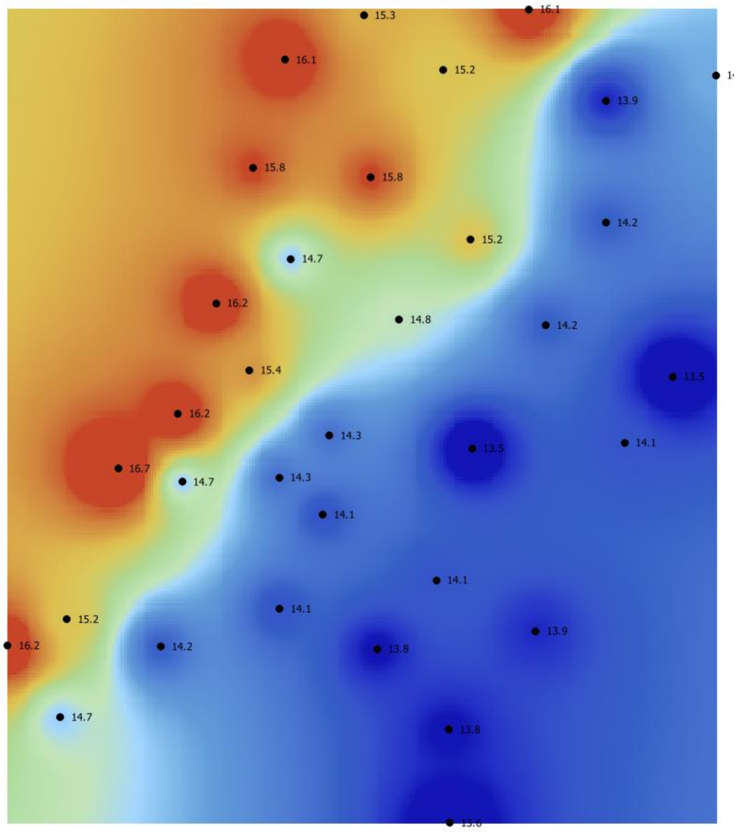
36. Now drag the `knmi_stations` file to the top in order to display the stations on top of the temperature grid.

37. Click right on the `knmi_stations` layer and select *Properties*.

38. Select the Labels icon and choose *Single labels*. Choose `T(C)` as the Field containing the label. Play around with the placement options (see screenshot below) to make a nice map. Click *Apply* to test and *OK* to visualise.



39. Now repeat the interpolation using the Inverse distance to a power (IDW) algorithm (repeat from step 32). Call the result file `tday_IDW.tif`. Visualise the result. Which interpolation method is better? Why? Can you explain the temperature gradient in the map?



40. You can save your QGIS project at this point by choosing from the menu *Project* → *Save as...*. Now you can close QGIS and load the project the next time you use QGIS.

41. We can also plot our newly created GIS data over a topographical map. For this purpose you have to install the **QuickMapServices Plugin**. In the menu go to *Plugins* → *Manage and install plugins...* and install the *QuickMapServices* plugin if it is not yet installed. You can also install the experimental additional services. You can do that under *Web* → *QuickMapServices* → *Settings*.

42. Choose from the menu *Web* → *QuickMapServices* → *OSM* → *OSM Standard*. Make sure your point vector layer is on top.

Extra:

Try to repeat the first part of the exercise with the default QGIS importer for comma separated files.

This whole exercise can be viewed in a screencast at: https://youtu.be/PxLufyvJ9jA

Exercise 3: Importing data from a GPS and conversion to vector layers

6 Importing data from a GPS and conversion to vector layers

6.1 Introduction

In this exercise you will learn how to collect data from a GPS, import the data into QGIS and create point, line and polygon vector layers.

6.2 Preparing the survey

Before going in the field it is important to be well prepared. Fieldwork is expensive and you want to prevent that you will have to go back. In the next sections there are some guidelines.

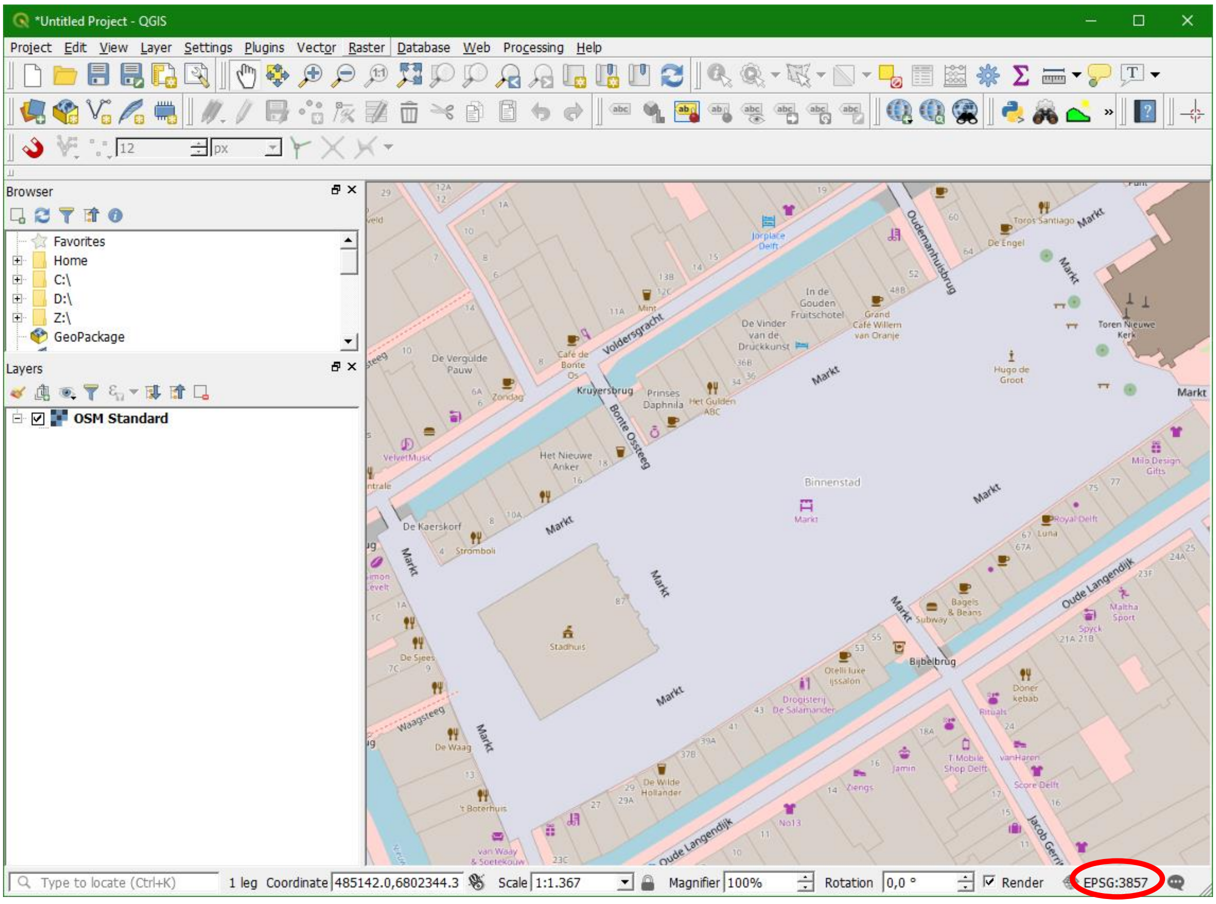
6.2.1 Preparation of maps

Use a GIS to prepare the following maps before going to the field:

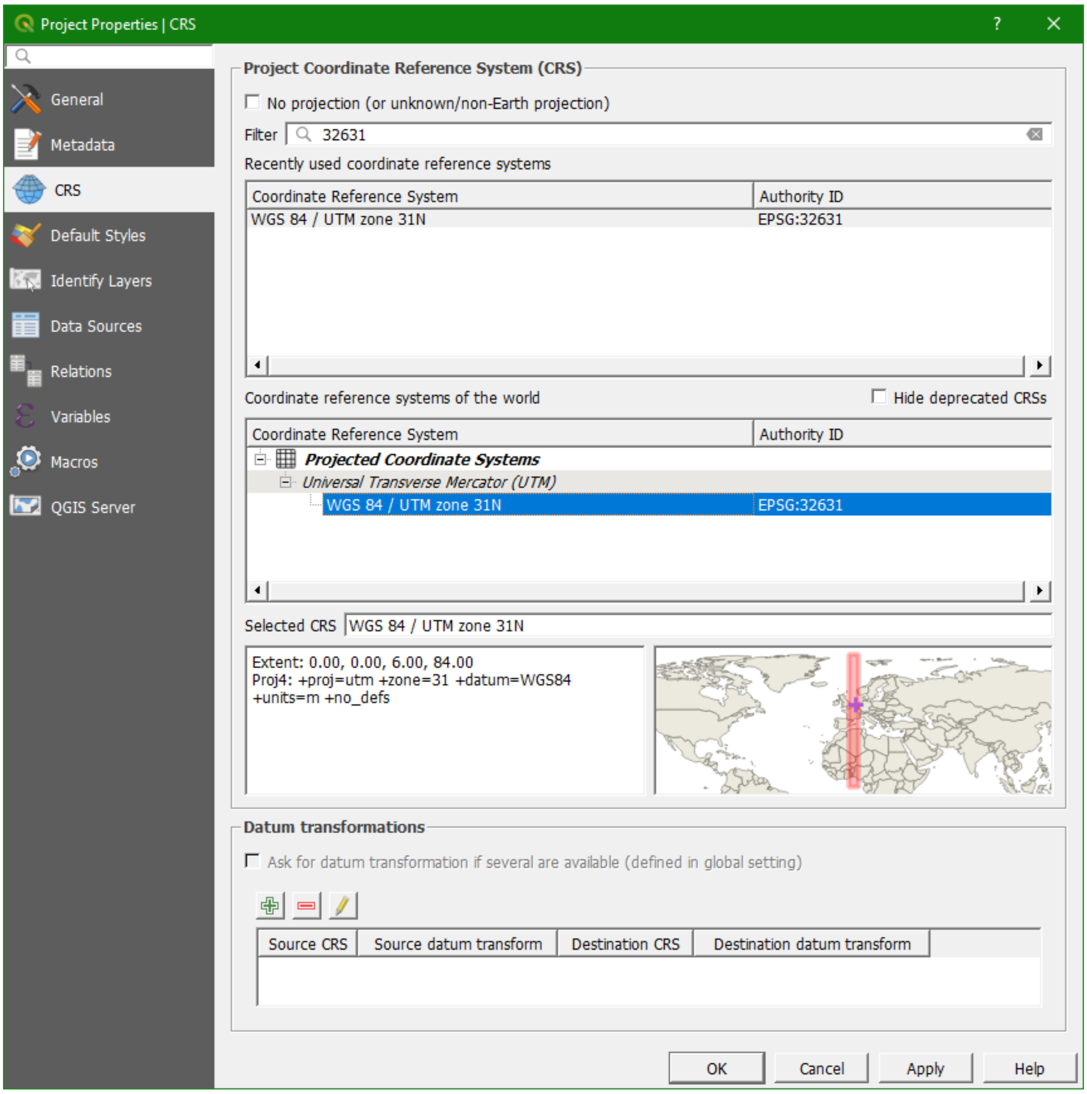
- Use available maps to understand the study area
- Decide on the map projection that you want to use and look for the EPSG code (http://www.spatialreference.org or http://epsg.io:
    - Local projection: if your study area is in one country, you can choose to use a national projection system
    - Global projection: if your study area covers multiple countries, you can choose for a global projection, such as UTM
    - Unprojected: this is not preferred, but you can use latitude, longitude coordinates (EPSG:4326).
- Create detailed maps (1:10,000) with a coordinate grid
- Print several copies of the map for different purposes:
    - Field map, with numbered locations that you want to sample. Digitize the locations in a GIS based on your understanding of the area. It is better to digitize more locations than you can visit, because many will not be accessible in the field.
    - Field map, where you note where you make a field observation, based on the location you measured with the GPS and the grid printed around the map. Make enough of these maps, because they will get dirty in the field. Always use a pencil to write on the maps, because a ballpoint will not work with dust and humidity.
    - Neat map. This is a map with your observation point that you keep at home and that you update every time you come back from the field.

In this exercise we are going to survey de Markt in Delft, the Netherlands.

- ➢ Open QGIS
- ➢ Use OSM Standard from the QuickMapServices plugin to find de Markt (Zoom in on the Netherlands, find Delft, zoom in on de Markt).
  If the plugin is not installed yet, you can do it by choosing from the menu *Plugins* → *Manage and Install Plugins…* . Then look for the QuickMapServices plugin and install it.
  Your screen should be similar to this:

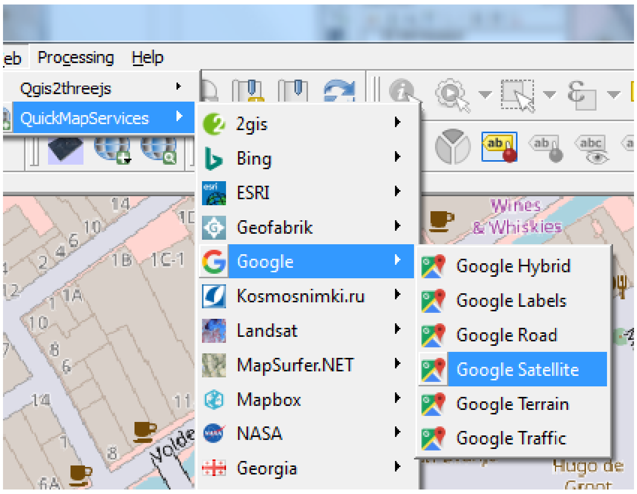


- ➢ Note that the projection of the Map Canvas is EPSG: 3857. In this exercise we will use UTM Zone 31 North/WGS 84. Use http://www.spatialreference.org to find the EPSG code and write it down. You need this also for setting up the GPS.
- ➢ Change the on-the-fly projection to EPSG: 32631, by clicking on the EPSG code in the lower right of the Map Canvas.
- ➢ In the dialogue that follows, select the EPSG: 32631 projection from the list (tip: use *Filter*).



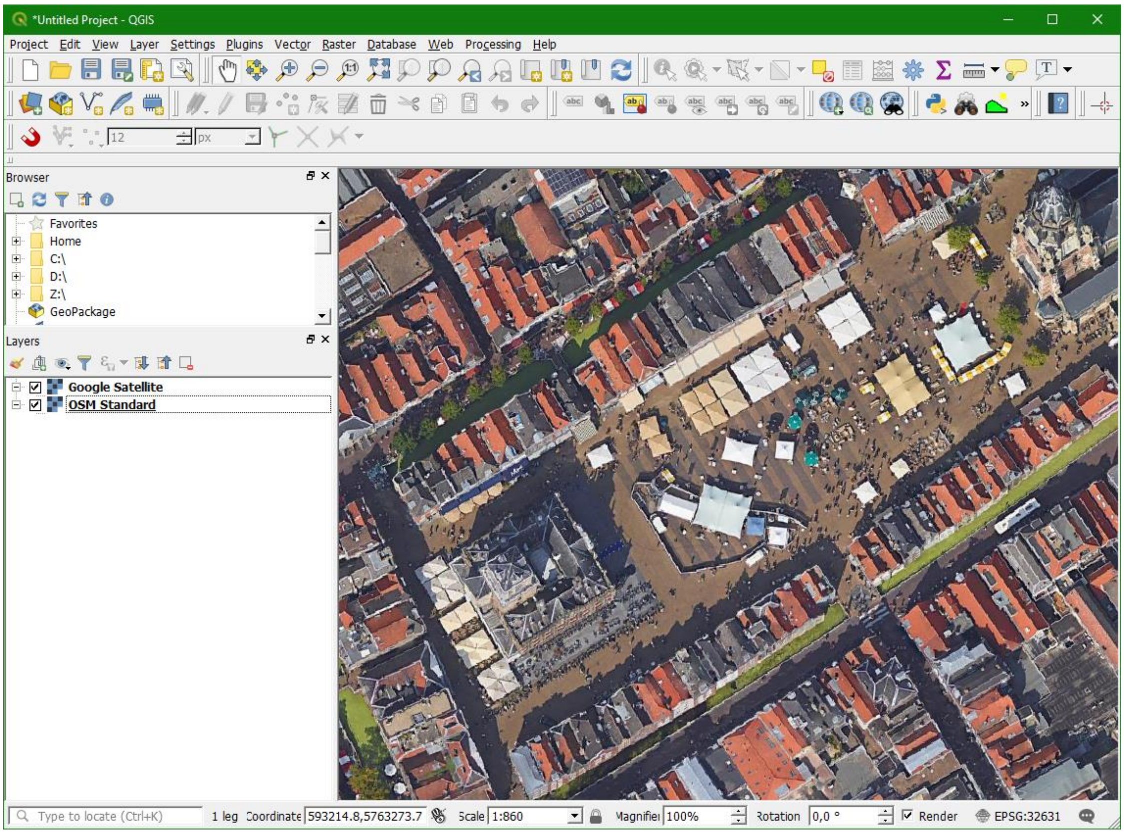
Now the correct EPSG code should be displayed in the lower right of the screen. Zoom in well on the square using the magnifier.

- Now from the *QuickMapServices plugin* choose the Google Satellite data to be displayed. From the main menu choose: *Web* → *QuickMapServices* → *Google* → *Google Satellite*

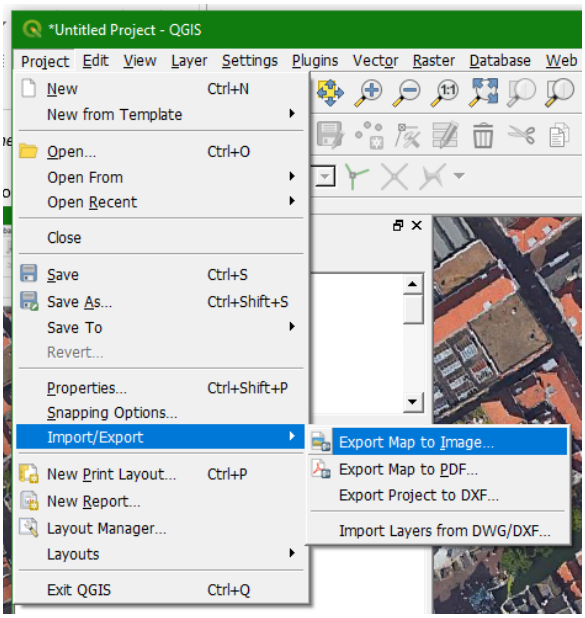


If you don't see this option, you need to go to settings and install the contributed services pack.

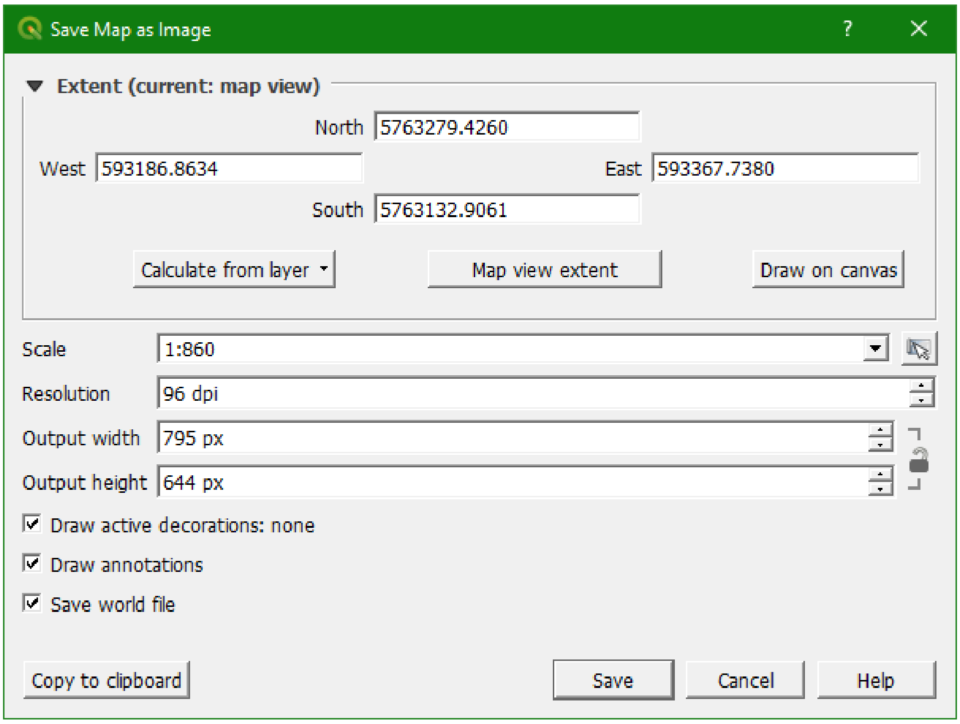
Make sure that the image is on top of the layers list or uncheck the OSM Standard layer.



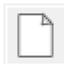
➢ This image can be saved to a GeoTiff, so we can also use it offline. From the main menu choose: *Project* → *Import/Export* → *Export Map to Image…*



➢ Keep the Save Map as Image dialogue as default:



➢ Make a folder `D:\QGIS_Exercises\Exercise_3` and save it as `Markt_Delft_UTM31N.tif`

➢ Start a new QGIS project and discard the current one by clicking  and click *Discard* in the popup that will appear.

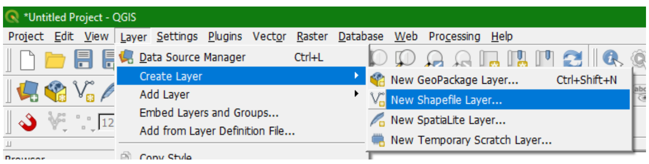
➢ Now add the raster layer `Markt_Delft_UTM31N.tif` clicking the *Open Data Source Manager* button  and then the choose *Raster*  Choose the right projection when the dialogue shows up. Note that this GeoTiff is georeferenced, but it does not contain the projection. It only has a *world file* (`.tfw`) that contains the coordinates. Therefore, the projection needs to be indicated.

Now we are going to prepare your survey by digitizing points on the satellite image that you want to visit in the field, e.g. buildings, statues, trees, etc. For now we only need to digitize Points and give them an observation number. You can use this:

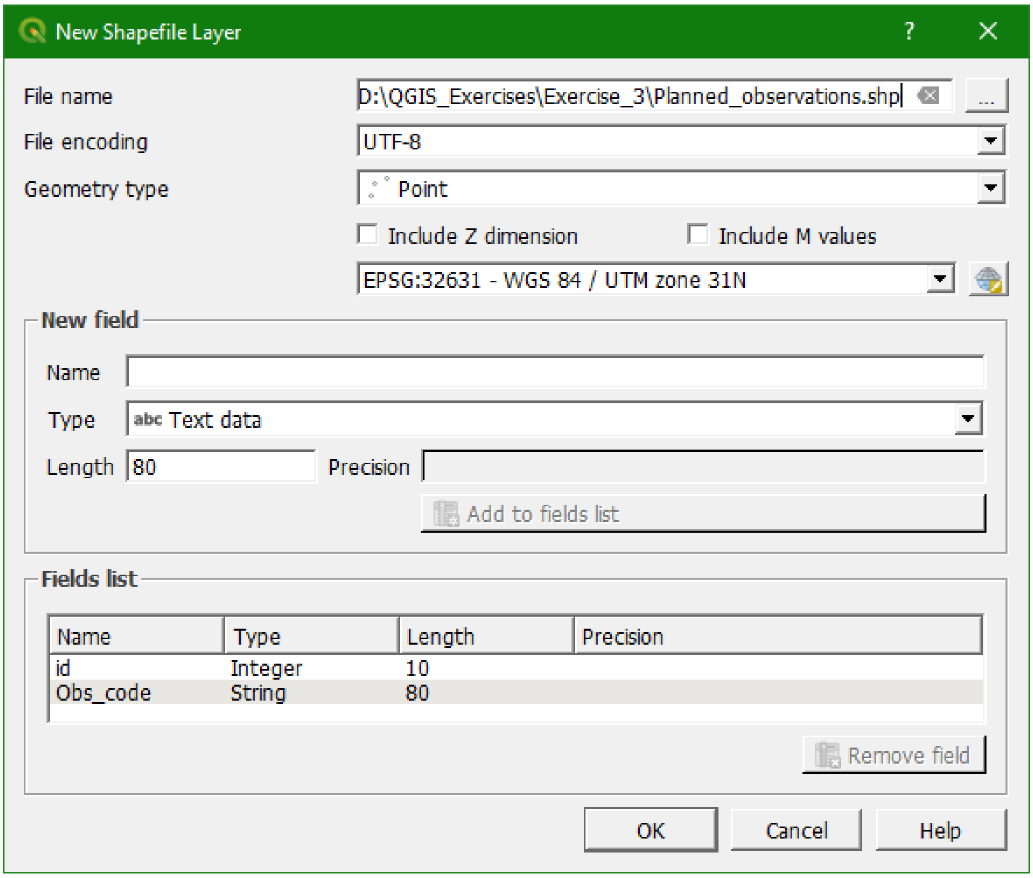
- T01, T02, etc. for trees
- S01, S02, etc. for statues
- B01, B02, etc. for buildings
- R01, R02, etc. for streets

Follow the steps below to do this:

➢ From the main menu select *Layer* → *Create Layer* → *New Shapefile Layer…*

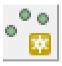


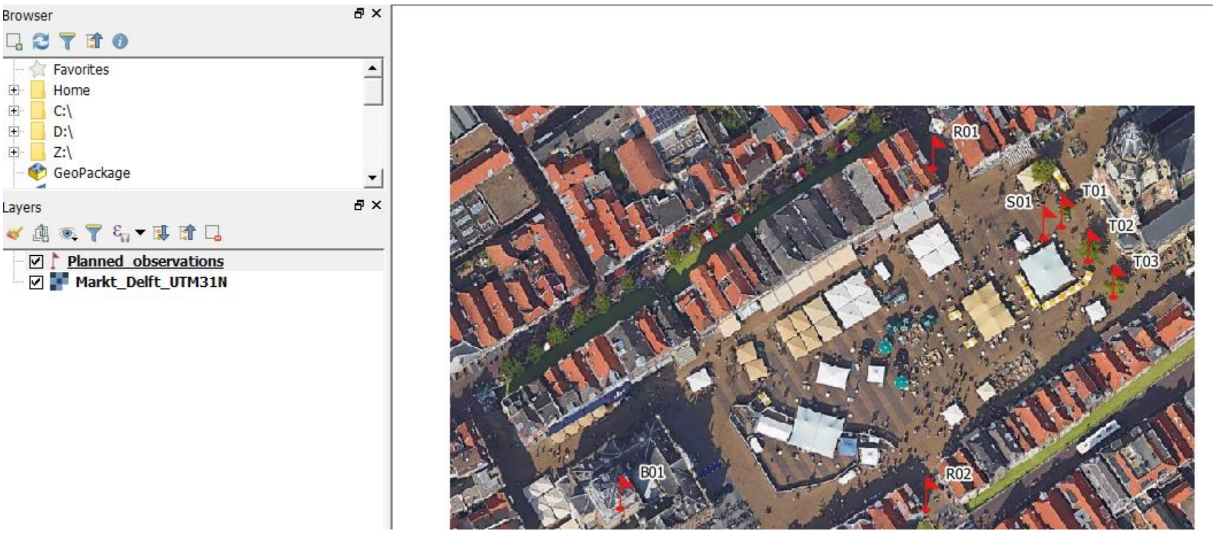
- In the dialogue, choose for the File name `D:\QGIS_Exercises\Exercise_3\Planned_observations.shp`, select the correct projection and create an attribute `Obs_Code` with *Text data* as data type .



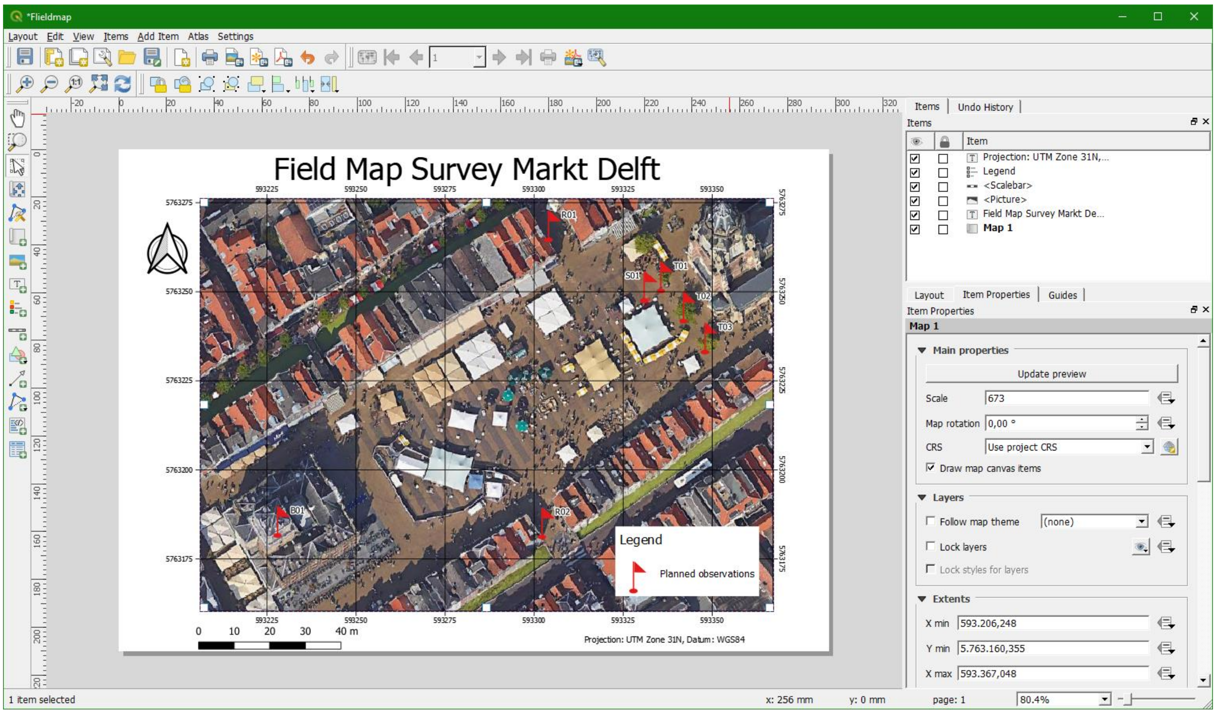
- Click *Add to fields list*
- Click *OK*

The new, empty, shapefile has now been added to your Layers panel.

- Select the `Planned_observations` layer and click  to toggle editing
- Click the Add feature button  to start digitizing the points that we want to survey. Fill in the attributes with the proper code.
- After digitizing toggle off editing by pressing  again and chose *Save*.
- Now style and label the points in such a way that they are clearly visible in the map.



➢ Use the *Print Composer* to make a map with the points and a coordinate grid around. Export the map to pdf and print the map on **A3 format in colour** and take it with you on the survey.



6.2.2 Observation forms

Depending on the purpose of your fieldwork, you need field observation forms. These can be forms to observe land use, geomorphology, geology, household surveys, etc. Whatever form you need, it always needs the following information:

- Observation number
- Name of the observer. This is important if you work in teams. Some observations are subjective (e.g. visual estimation of vegetation cover) and it might be useful to relate it back to the observer. This is also important if you need further information that is not covered with the field forms.

- Date/time. This is very useful to link the observation to other time coded data, such as digital photographs taken at the location, the GPS measurements or measurements from other devices.
- Coordinates (X, Y, Z). Always write down the coordinates that you measure with a GPS at the observation location. The reason is that the device can get damaged or lost. Also you might lose the data when you return the GPS to the laboratory where you borrowed it from.

You can print the field forms and make a strong booklet that you can take into the field or use a notebook. Always fill in the forms with a pencil. Ballpoints don't work with dust and humidity.

After each field day, copy your field form to a neat form or a database on your laptop. Always make a backup and store it in the cloud or on a USB stick that you don't take with you in the field.

➢ Make a field form in your notebook for the survey of de Markt in Delft.

6.2.3 Preparation of the GPS

Before going into the field, please make sure that:

- You have enough spare batteries to take with you
- The GPS is complete with a USB cable
- You have tested that the GPS works and connects to your laptop
- Check GPS settings in the setup page. Check the time zone. The map projection and map datum settings should correspond with the cartographic projection used on your field maps

➢ Prepare the GPS with the guidelines above.

6.3 Surveying using a GPS

You are now ready to use the GPS for measuring your location in the field. Pay attention to the following guidelines:

- Wait marking your location into the GPS or writing down the coordinates until the handheld GPS is receiving sufficient satellites with reasonable strength.
- Apart from writing down in your field book the coordinates, write also down the EPE: Estimated Point Error. It indicates how accurate the GPS reading is horizontally in meters. Accurate GPS readings typically have EPE's around 3-5 m.
- Always use GPS and a together in the field. Always mark your position not only in the GPS or in GPS coordinates but also on your field map and verify that you know where you are.
- Be aware that satellite reception can sometimes be poor under a dense forest canopy, below escarpments and in dense urban areas and hence position computation becomes less accurate. Always check the EPE value.
- The vertical height information (Z coordinate) of the GPS unit can have significantly higher inaccuracy values and is therefore not trustworthy. For a detailed height measurement, more Differential GPS (DGPS) systems or barometric altimeters should be used.

For this exercise, choose an open area that you can use for practicing surveying, e.g. a park or a big square. Try to find 3 types of objects:

- Points (e.g. trees, statues, wells)
- Lines (e.g. paths)
- Polygons (e.g. footprint of a house, terrace of café)

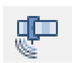
With most handheld GPS it is only possible to mark locations as waypoints. With the waypoints we can store attributes. By default it has a Name and a Comment attribute. We will use the Name field to give a unique code to each feature with a follow-up number. We will use the Comment field to give a unique name to each specific object. This can then be used to convert the groups of waypoints to features in QGIS using the *Points to path* tool form the *Processing Toolbox*.

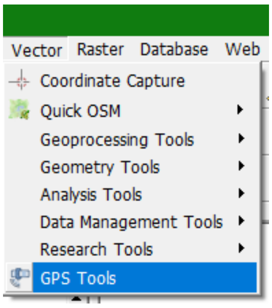
The table below shows how this works:

Name	**Note**	
T01	Tree1	
T02	Tree2	
T03	Tree3	
B01	CityHall	These waypoints form one **polygon**
B02	CityHall	
B03	CityHall	
B04	CityHall	
B05	House	These waypoints form one **polygon**
B06	House	
B07	House	
B08	House	
R01	Street1	These waypoints form one **line**
R02	Street1	
R03	Street1	
R04	Street2	These waypoints form one **line**
R05	Street2	

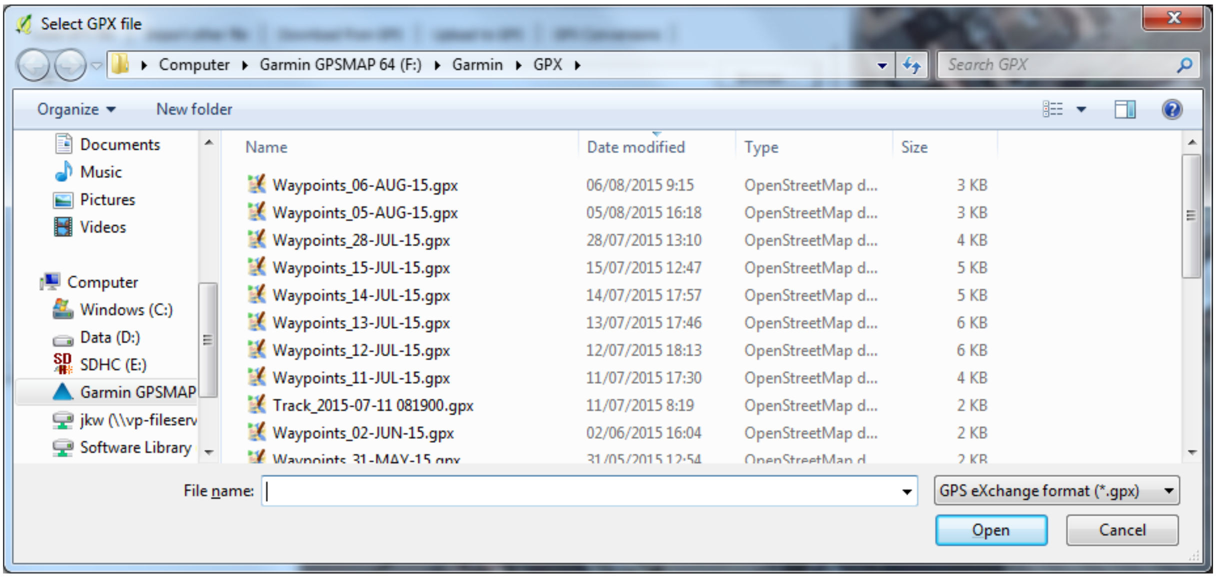
- Mark the waypoints of the objects:
  - For points you only need 1 waypoint per feature. Give the waypoint a code for points, e.g. T01, S01. Also give the feature a unique code in Comments, e.g. Tree1, Statue1
  - For lines you need multiple waypoints per feature and the number needs to be ordered, e.g. R01, R02, R03 are 3 points on the line in that order. Also give the feature a unique code in Comments, e.g. Road1, Road2 or the name of the street.
  - For polygons you need multiple waypoints per feature and the number needs to be ordered, e.g. B01, B02, B03. Also give the feature a unique code in Comments, e.g. Cityhall, Church, etc.
- Fill in your field form for each feature.

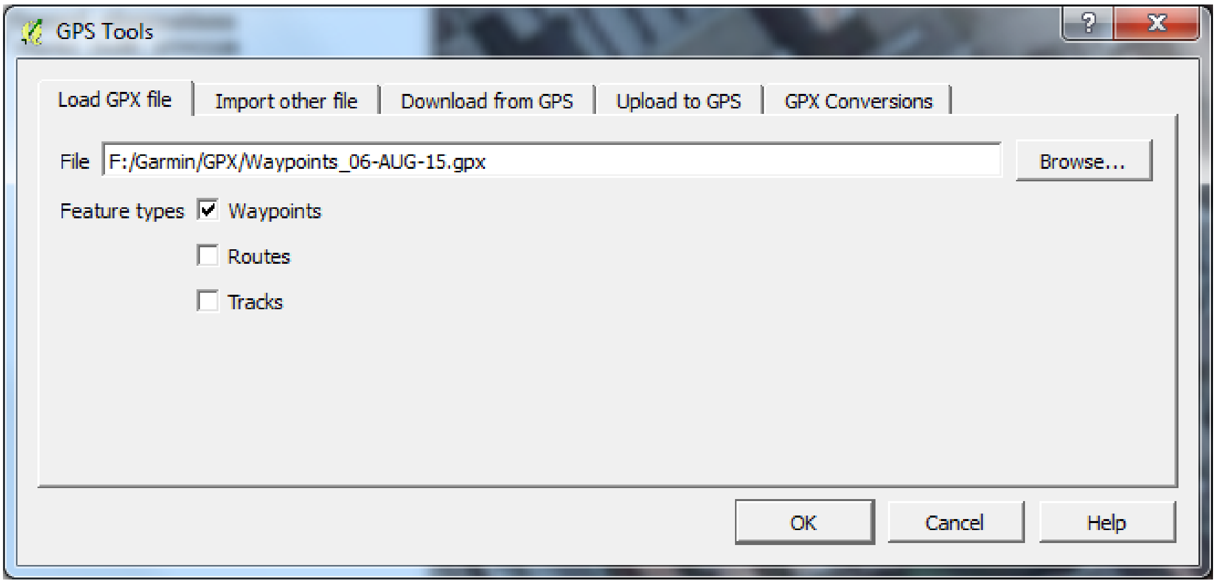
6.4 Importing the GPS data into QGIS

- After getting back from the field, connect the GPS with a USB cable to the laptop.
- When the drivers are correctly installed, the computer will see the GPS as a USB disk. To access the files choose from the main menu *Vector* → *GPS* → *GPS Tools* or use the  button (make sure the *GPS Tools* plugin is installed and/or activated).

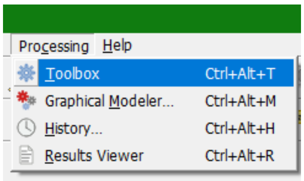


- In the dialogue choose the tab *Load GPX file*
- Browse to the GPS and choose the right GPX file from the GPX folder.





- Only check the box before *Waypoints* and click *OK* to import the data to QGIS
- From the attribute table select the point features and export them as a separate shape file. Do the same for lines and polygons so you have 3 files, one for points, one for lines and one for polygons.
- Open the *Processing Toolbox* panel from the menu: *Processing → Toolbox*



- In the *Processing Toolbox* search *Points to Path*

- In the *Points to Path* dialogue choose the shapefile containing the points that should be converted to lines. As *Order field* choose the observation number. For *Group field* you use the Comments.
- Repeat the same steps for the polygons
- Evaluate the results.

Exercise 4: Map Algebra

7 Spatial planning using map algebra

7.1 Learning objectives

After this exercise you will be able to:

- apply map algebra for raster analysis
- distinguish Boolean, discrete and continuous rasters
- make legends for Boolean, discrete and continuous maps
- understand the use of Nodata
- use logical operators
- calculate distances

7.2 Introduction

The Department of Planning of the (imaginary) oasis Aïn Kju Dzjis is planning to build the National Institute for Oasis Management (NIOM) in their village. They came up with the following conditions for building the complex:

1. No industry, mine or landfill within 300 meters of the new complex;
2. Not on locations presently in use for buildings, water or roads;
3. The slope should be less than or equal to 3%;
4. The distance from an existing road should be less than 500 meters;
5. The area should be contiguous;
6. The area should be greater than, or equal to 2 hectares.

They hired you as a GIS consultant to find the most appropriate locations. You will use map algebra to perform the required multicriteria analysis.

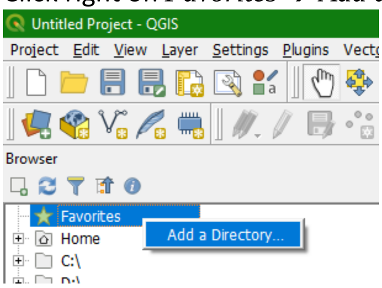
7.3 Preparation

- ➢ Download the data for Exercise 4 from the OpenCourseWare website (http://ocw.unesco-ihe.org/course/view.php?id=11) and store the files in a folder on your harddrive (e.g. `D:\QGIS_Exercises\Exercise_4`).

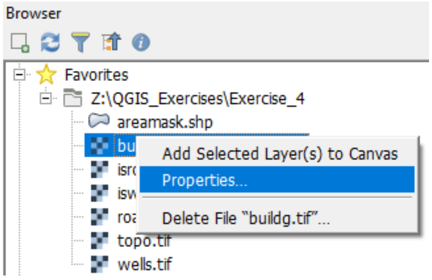
In this exercise you will use the following maps: `buildg.tif`, `iswater.tif`, `isroad.tif`, `topo.tif`, `roads.tif` and `areamask.shp`.

First we are going to add the exercise folder to the Favorites in the Browser Panel.

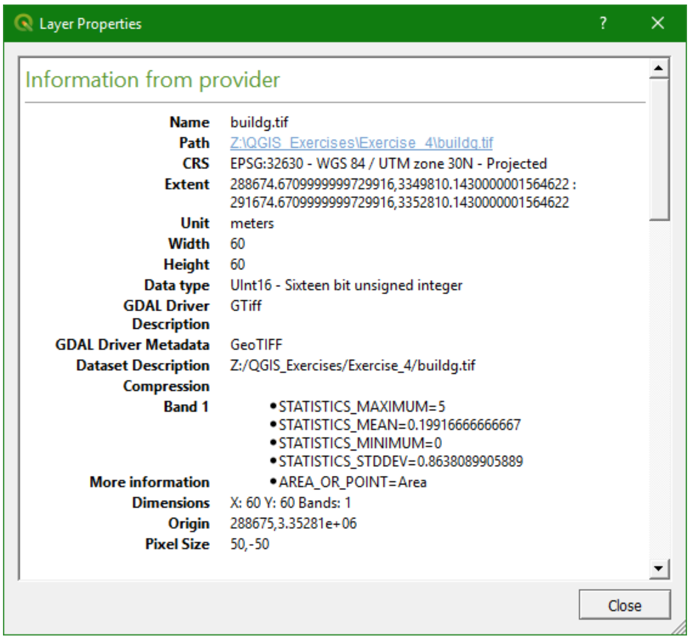
- ➢ Click right on *Favorites* → *Add a Directory…*



- ➢ Click the + to collapse the contents of the folder.
- ➢ Preview the maps and metadata of these raster layers by clicking right on the layer file *Properties*.



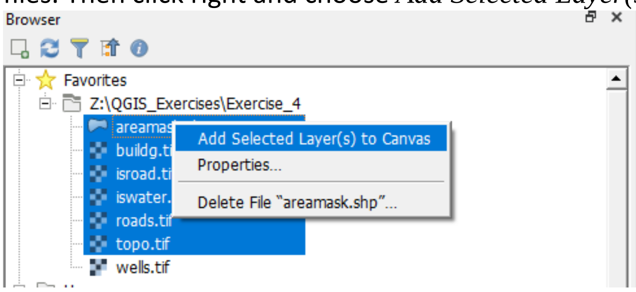
The *Layer properties* window will open, showing the metadata of the layer:



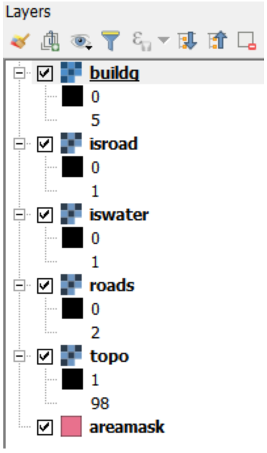
➢ Fill in the table:

Layer	File type	Number of cells	Projection	Cell size	Minimum value	Maximum value
buildg						
isroad						
iswater						
roads						
topo						
Areamask						

➢ Select `buildg.tif`, `iswater.tif`, `isroad.tif`, `topo.tif`, `roads.tif` and `areamask.shp` in the browser pannel. Keep the `<ctrl>` button pressed to select multiple files. Then click right and choose *Add Selected Layer(s) to Canvas*.



➢ Go to the Layers panel and drag the `areamask` vector layer to the bottom.



Rasters normally only store values, so also in this case we need to assign a proper legend to the maps. Let's start with `buildg.tif`.

➢ Click right on the name of the layer and choose *Properties*.

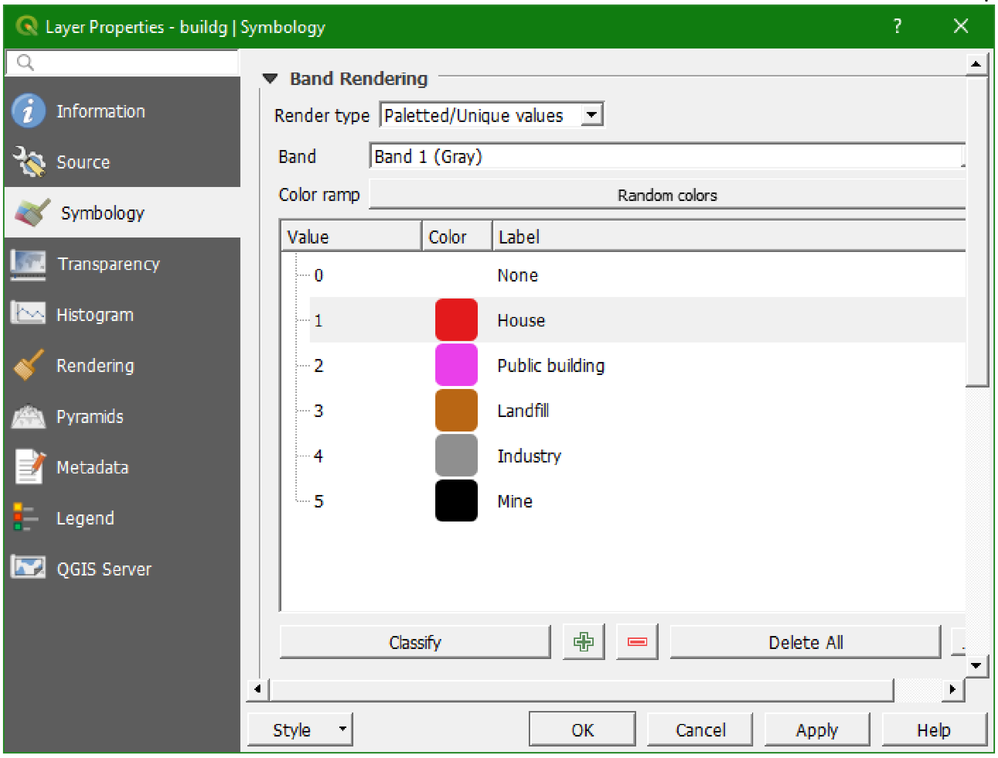
➢ Click on the *Symbology* icon on the left 

➢ Under *Render type* choose: *Paletted/Unique values*

➢ Keep *Random* as *color ramp* type and click *OK*

➢ Click *Classify*

➢ Now use the screenshot below to add the labels to the class numbers. Double click on the label name to do this. Double click on the colour to make it more intuitive like the example.



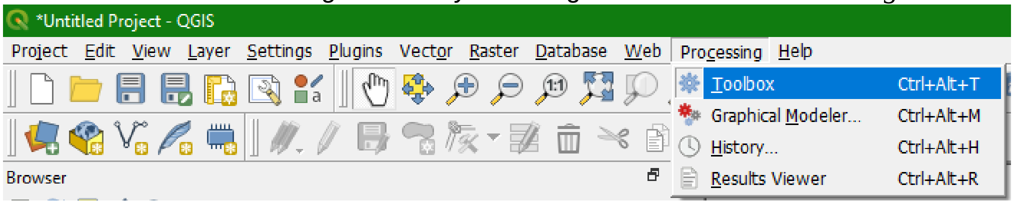
➢ Click *OK* to close the dialogue and look at the result. Is `buildg` a Boolean, discrete or continuous map?

We have now learned that for **discrete rasters** we use the *Paletted/Unique values* render type.

7.4 Using the Processing Toolbox

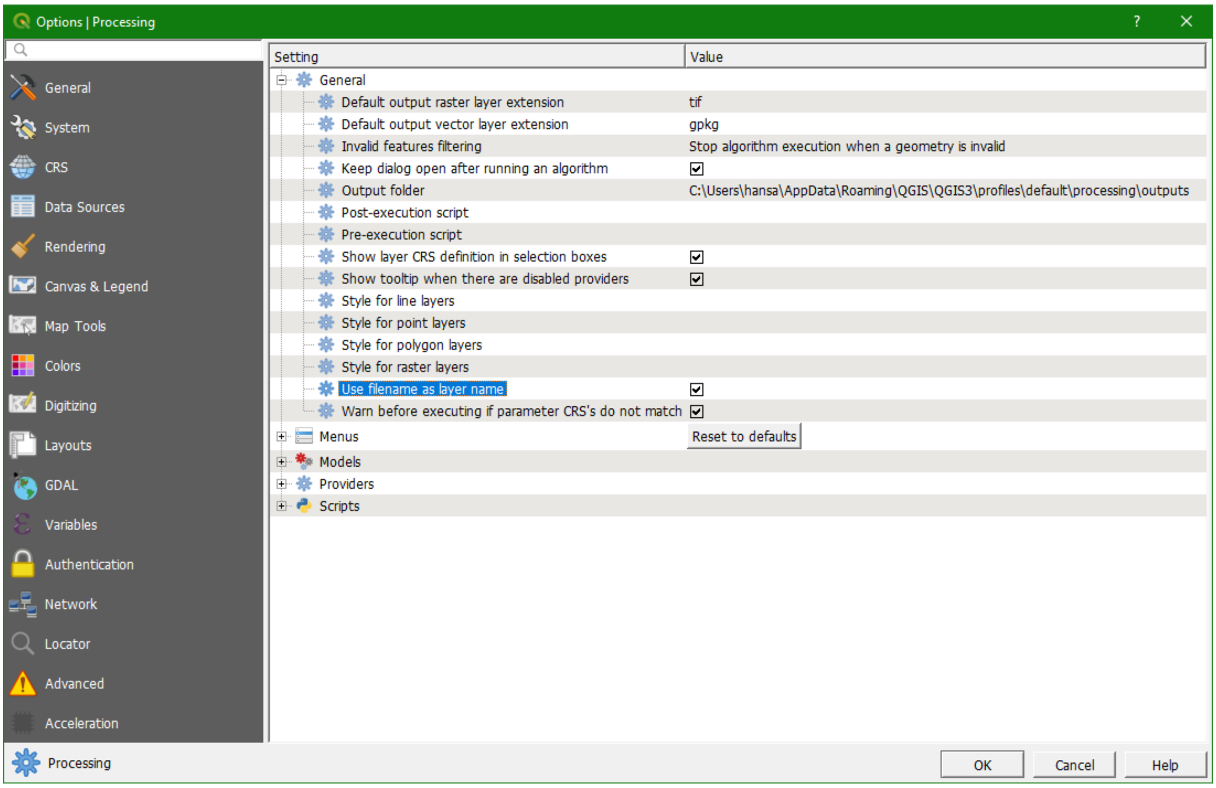
The Processing Toolbox in QGIS provides a lot of tools for processing GIS data. Besides QGIS tools, it also has tools from GDAL, GRASS and SAGA that are very useful.

- First activate the *Processing toolbox* by choosing from the menu *Processing → Toolbox*



First we are going to change a default setting of QGIS. The processing toolbox by default doesn't use the file name of the output as a layer name, which can be confusing.

- In the main menu choose *Settings → Options → Processing*.
- Collapse the General menu by clicking on the plus sign. Then check the box at *Use filename as layer name*:



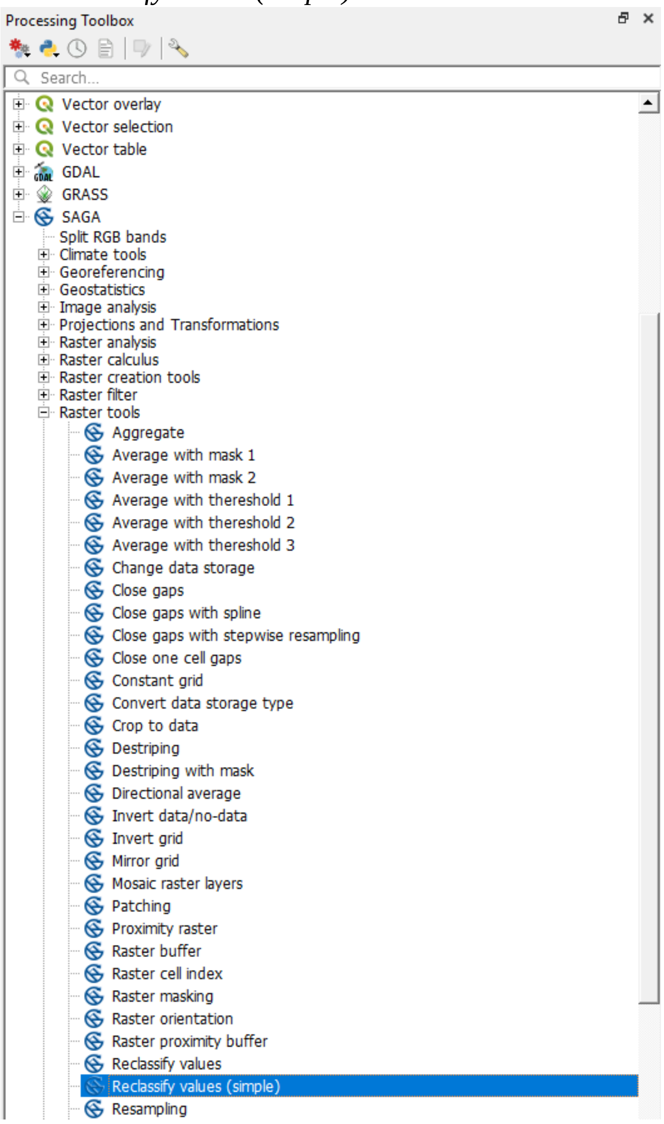
- Click *OK* to close the dialogue.

7.5 Condition 1: No industry, mine or landfill within 300 meters of the new complex

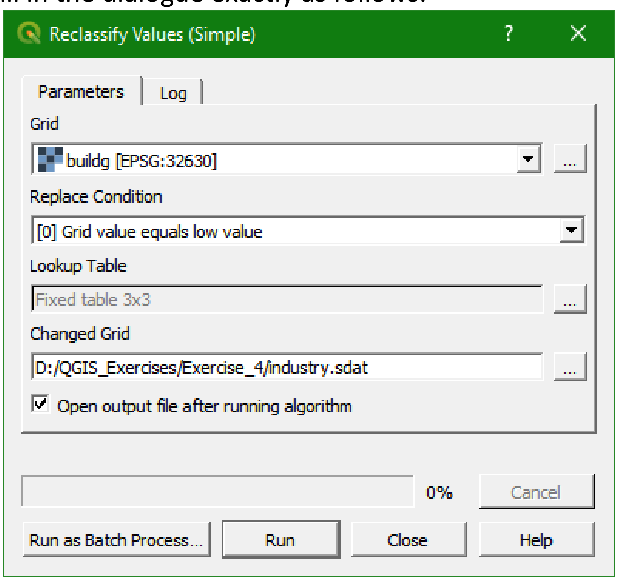
For condition 1 we have to create a grid with only mines, industry and landfills. Then we have to calculate the Euclidean distance to these cells. Let's start with creating a Boolean grid with only mines, industry and landfills. The sections below will guide you through the steps.

7.5.1 Create a Boolean grid with True for industry, mine and landfill, and False for other buildings

➢ Choose in the processing toolbox
SAGA → Raster tools → Reclassify values (simple).

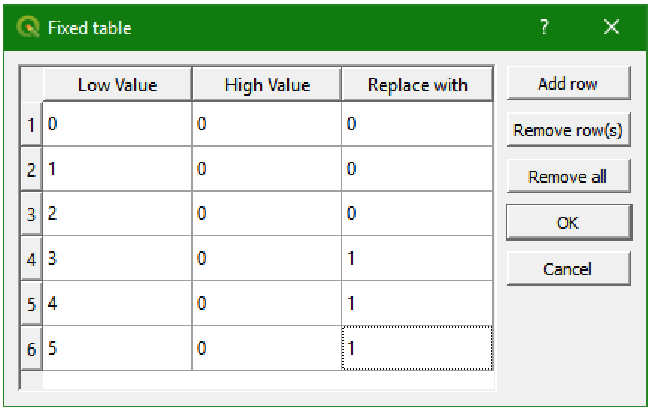


➢ The *Reclassify values (simple)* dialogue appears. We are going to reclassify the `buildg` raster using a **lookup table**. Fill in the dialogue exactly as follows:



- Then go to *Lookup table* and click 

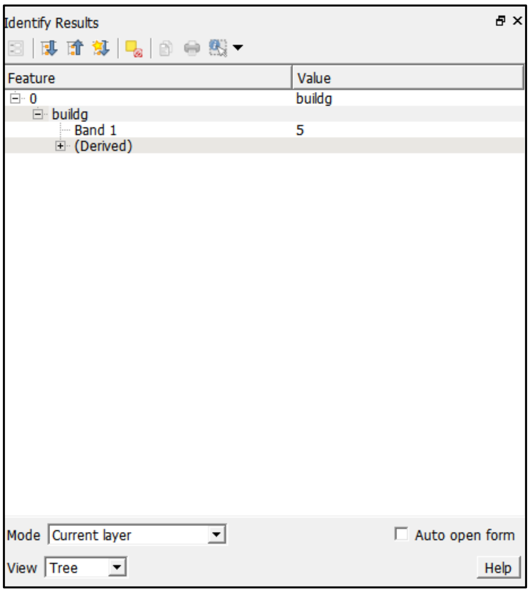
- Fill it like the table below. Note that don't change the second column (*High Value*), because the *Replace Condition* is set to *[0] Grid value equals low value*. We can use the second column if we want to reclassify ranges of pixel values.



	Low Value	High Value	Replace with
1	0	0	0
2	1	0	0
3	2	0	0
4	3	0	1
5	4	0	1
6	5	0	1

- Click *OK* and *Run*. Close the dialogue.

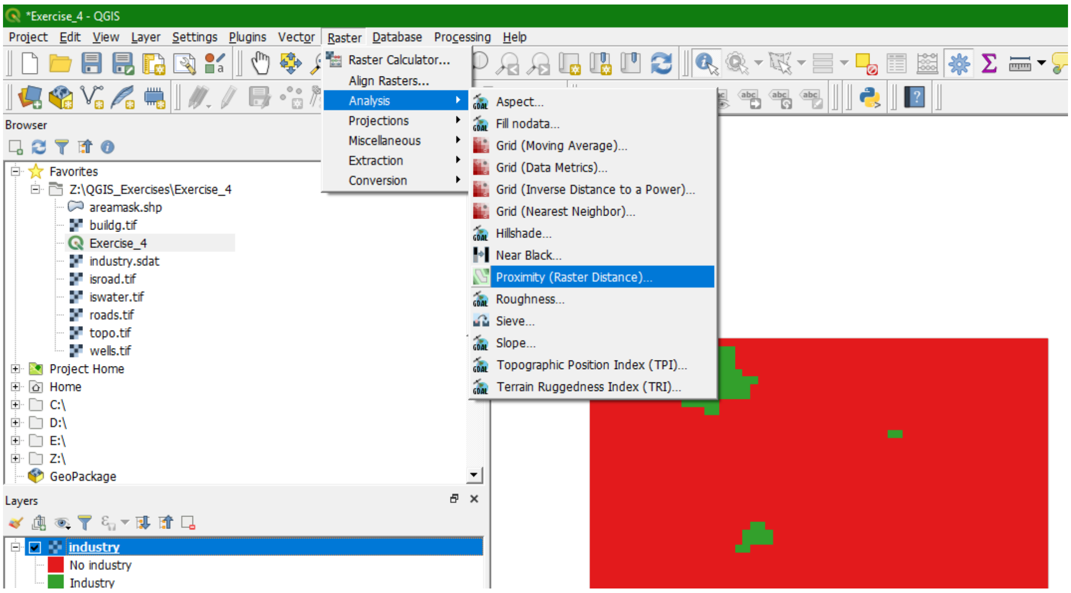
➢ Check the result: 1 for mines, industry and landfills, 0 for the other classes. Use the *Identify tool*  and click on the map. On the panel down right you can find the identify results. It displays the value of the pixel of the selected layer in the *Layers panel*. You might have to resize the columns to see the pixel values.



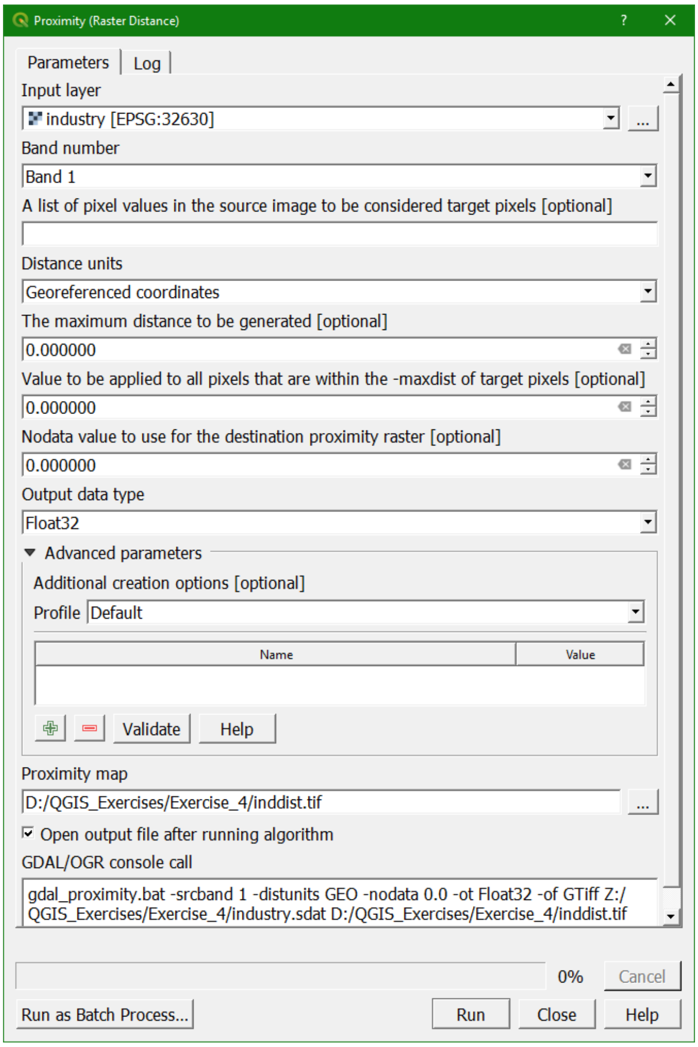
➢ Is `industry` a Boolean, discrete or continuous raster?
➢ Is the legend that QGIS has assigned automatically correct? Give the `industry` layer a nice legend, similar as you did for the `buildg` layer.

7.5.2 Calculate the Euclidean distance to industry cells

➢ Select from the menu *Raster* → *Analysis* → *Proximity (Raster Distance)….*



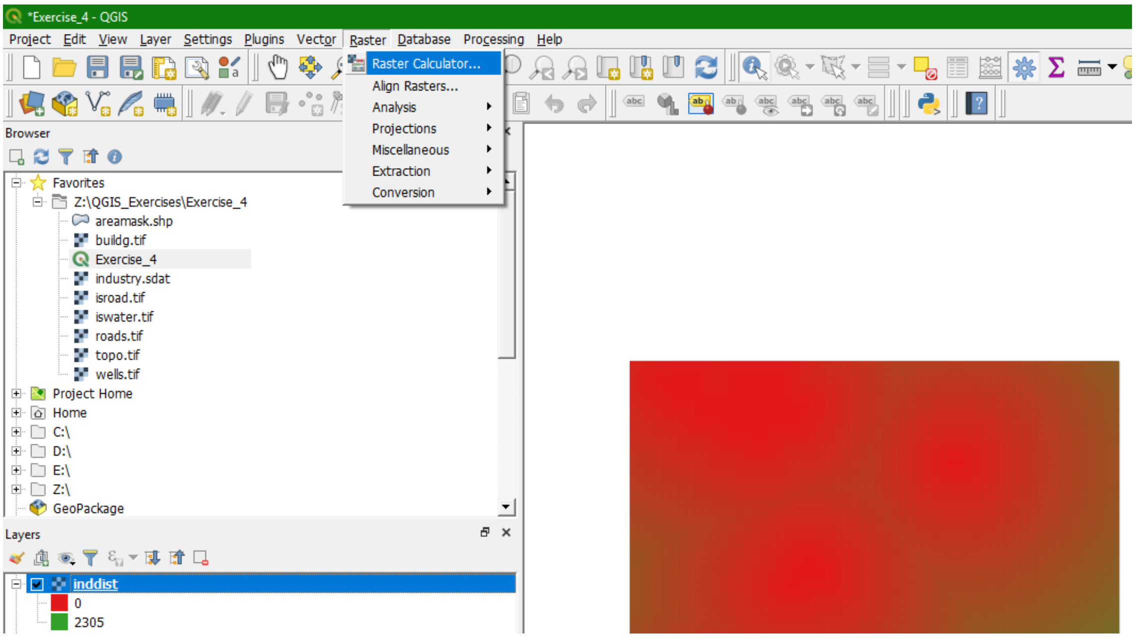
- Fill in the *Proximity (Raster distance)* dialogue as in the screenshot:
  - Make sure the *Input* layer is `industry`
  - Because our raster layer consists of only one band we keep *Band number* as `Band 1`.
  - Choose for *Distance units* `Georeferenced coordinates`. In this way the distances are calculated in meters.
  - We don't choose a maximum distance. The default 0 means that there's no maximum.
  - By default the *Nodata value to use for the destination proximity raster* is set to `0`. This means that the distances will be calculated from all zero cells to the non-zero cells.
  - Name the output *Proximity map* `inddist.tif`.



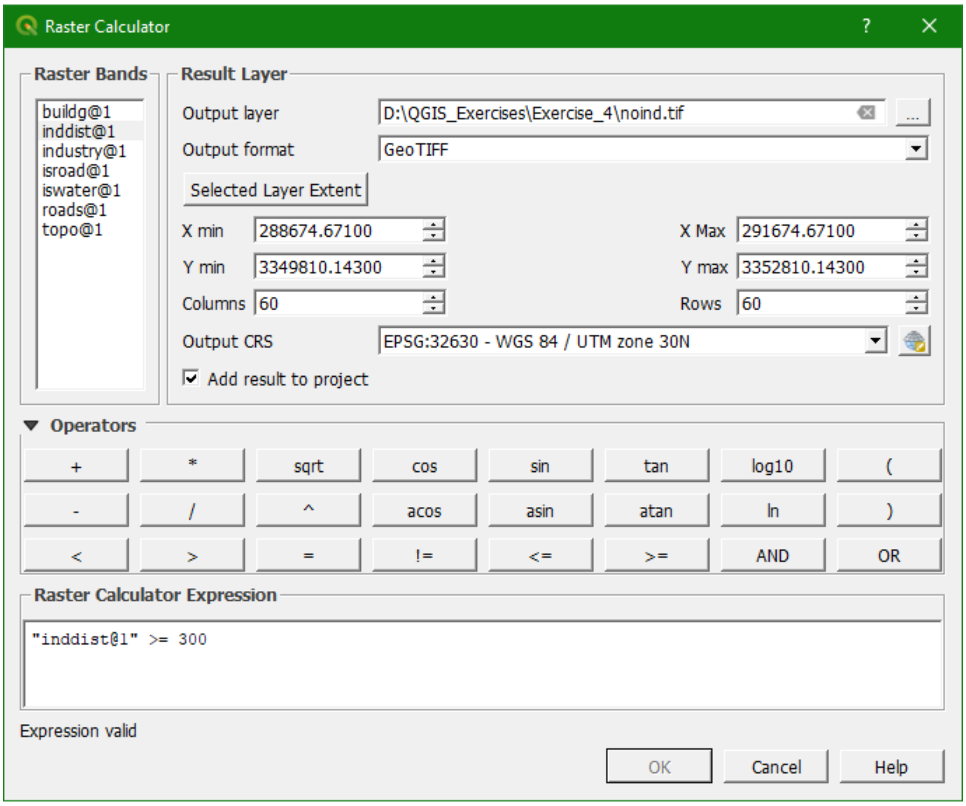
- Click *Run* and *Close*.
- Check the result. Is the `inddist` layer a Boolean, discrete or continuous raster? Make a legend that is appropriate for this raster type using *Singleband pseudocolor* as render type. Use intuitive colours.

7.5.3 Create a Boolean map with True for cells further than 300 meters from industry and False for other cells

Now we need a map with all the pixels further than 300 meters from mines, industry and landfills. In the Menu select *Raster* → *Raster calculator...* .



- Double click on `inddist@1` (@1 means first layer of a stack, but our maps are single layers so all have only @1), click on the **>=** button and type `300`. Call the output layer `noind.tif`. The dialogue should resemble the figure below.



- Click *OK* and view the resulting grid for condition 1. Is the result of condition 1 (`noind`) Boolean, discrete or continuous? Give the right legend.

7.6 Condition 2: Not on locations presently in use for buildings, water or roads

For condition 2 we have to select pixels without buildings, water or roads.

- First we produce a Boolean grid with value 1 for locations without buildings. Use the Raster calculator to do this: `"buildg@1" = 0`. This results in Boolean true (1) for locations without building and false (0) for locations with buildings. Call this map `nobuild`.

- With the raster calculator we search for which pixels have no water and no roads. The pixels without water can be calculated by the following expression: `"iswater@1" = 0`
  Call this map `nowater`.

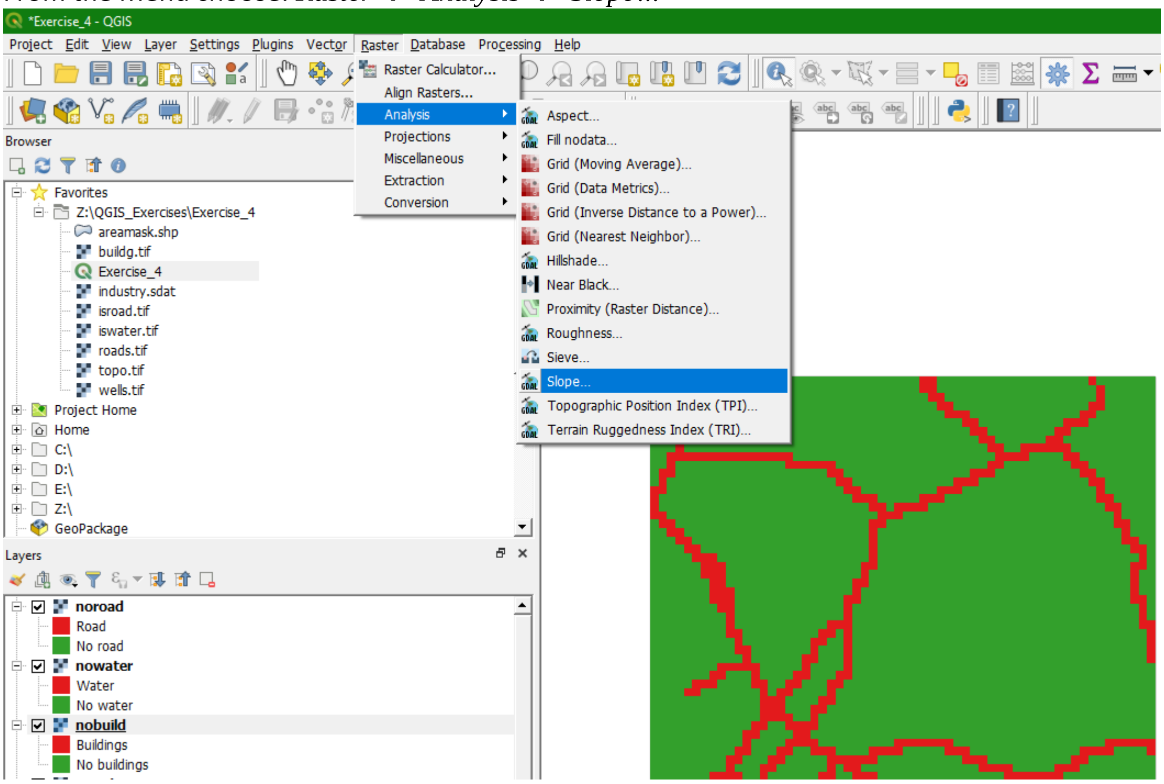
- Do the same for pixels without roads (use the `isroad` layer). Call it `noroad`. Check the results.

- Are `nobuild`, `nowater` and `noroad` Boolean, discrete or continuous rasters? Give the right legend to these layers.

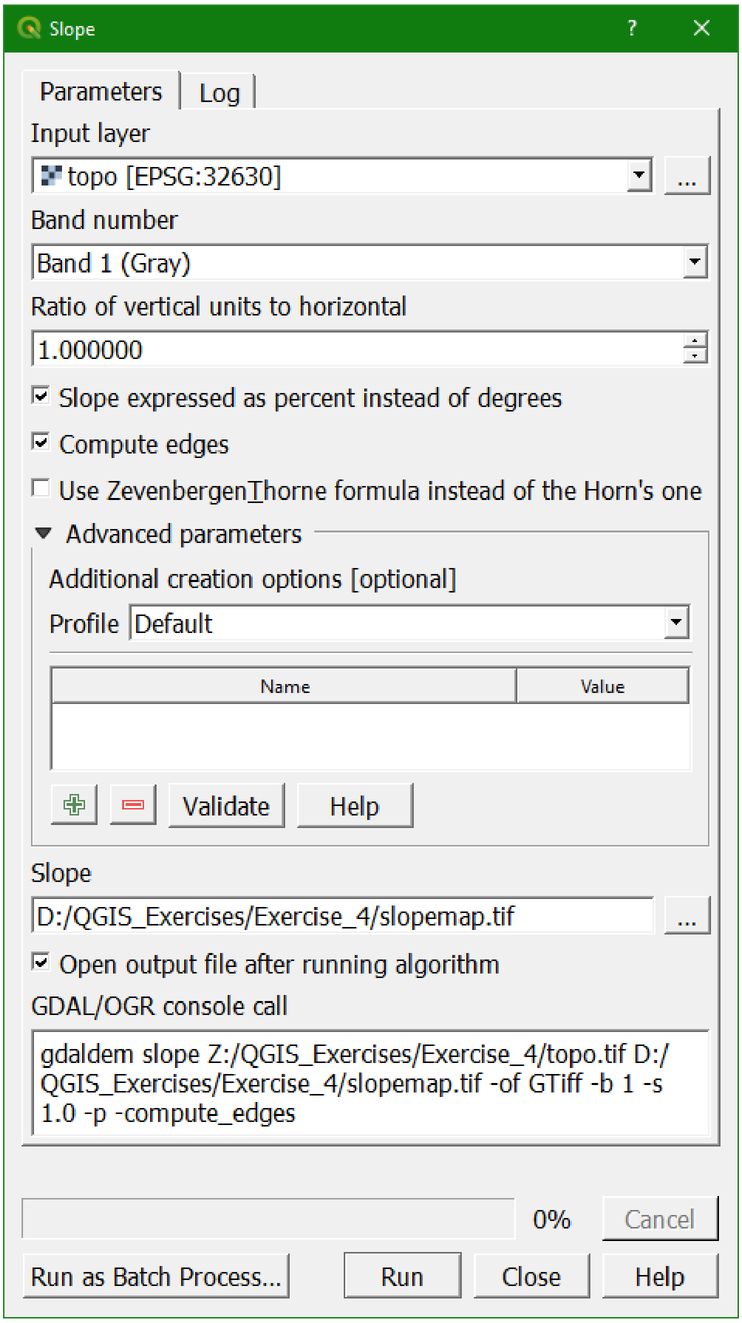
7.7 Condition 3: The slope should be less than or equal to 3%

For condition 3 we have to calculate the slope from the `topo` grid, which contains elevation values.

- From the Menu choose: *Raster* → *Analysis* → *Slope…*



➢ Fill in the dialogue like below. Don't forget to choose `topo` as the *DEM Raster*, check the box before *Compute edges*, choose for *Mode Slope* and choose *Slope expressed as percent (instead of as degrees)*. Keep the algorithm as default, call the output `slopemap.tif`.
Why do we need to compute the edges?
Does this algorithm work with unprojected (lat/lon) coordinates?



➢ Click *Run*, *Close*

➢ Check the result. Is `slopemap` a Boolean, discrete or continuous raster? Give the right legend.
➢ In order to select the slopes less than or equal to 3% use the *Raster Calculator* (`"slopemap@1" <= 3`). Call the output map `nosteep`. Is `nosteep` a Boolean, discrete or continuous raster? Give the right legend.

7.8 Condition 4: The distance from an existing road should be less than 500 meters

Let's first describe what we should do, before we perform the GIS analysis. The steps will follow. Like condition 1, this condition is met by applying the following steps:

1) Creation of a Boolean map with True for tarmac roads and False for other cells
2) Calculation of Euclidean distance from all cells to these roads by:
    a. Calculating the Euclidean distance
    b. Creating a Boolean map with True for cells < 500 m from these roads and False for cells ≥ 500 m from these roads.

First we have to select all the tarmac roads. The table below shows the legend of the `roads` map.

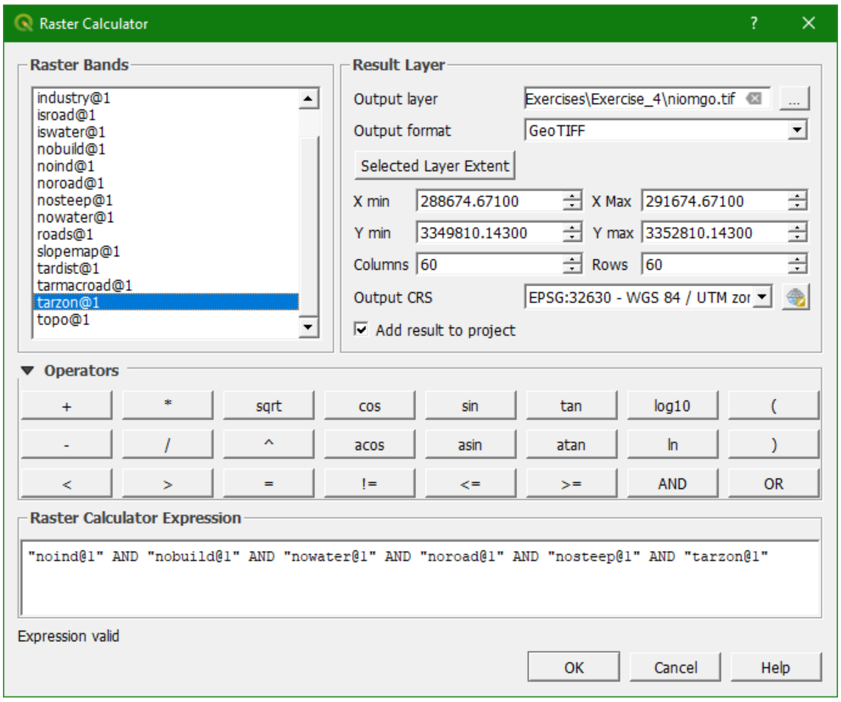
- Make the legend in the same way as we did for `buildg` before. Use this table:

0	No roads
1	Dirt road
2	Tarmac road

- In this case use the *Raster calculator* to assign Boolean *True* (1) for tarmac roads and *False* (0) for the rest of the map. Call the map `tarmacroad`. Check the result. Assign the right legend.
- Now calculate the distance to a tarmac road like you did before (*Raster* → *Analysis* → *Proximity (Raster Distance)…*). Call the resulting map `tardist`. Check the result. Assign the right colours to the legend
- To create a grid with only pixels within a distance of 500 meters from tarmac roads, use the *Raster Calculator*. The equation should be `"tardist@1" < 500`. Check the result. Name it `tarzon`. Assign the right colours to the legend.

7.9 Combine criteria 1 to 4

- Now all the new maps should be combined to create a grid, which satisfies condition 1 to 4. So all pixels with value 1 (True) in `noind, nobuild, nowater, noroad, nosteep` and `tarzon` should be selected. Use the *Raster Calculator*. The dialogue should resemble the figure below.

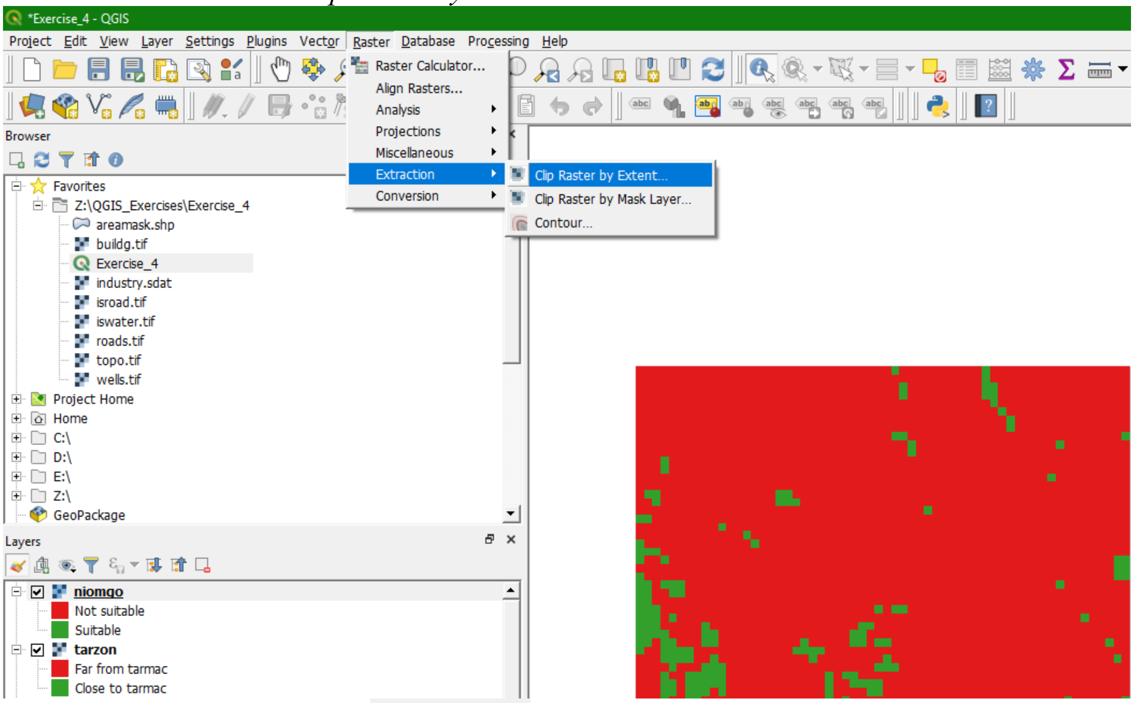


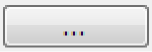
- Call the resulting map `niomgo` and click *OK*. Check the result carefully and give it the right legend.

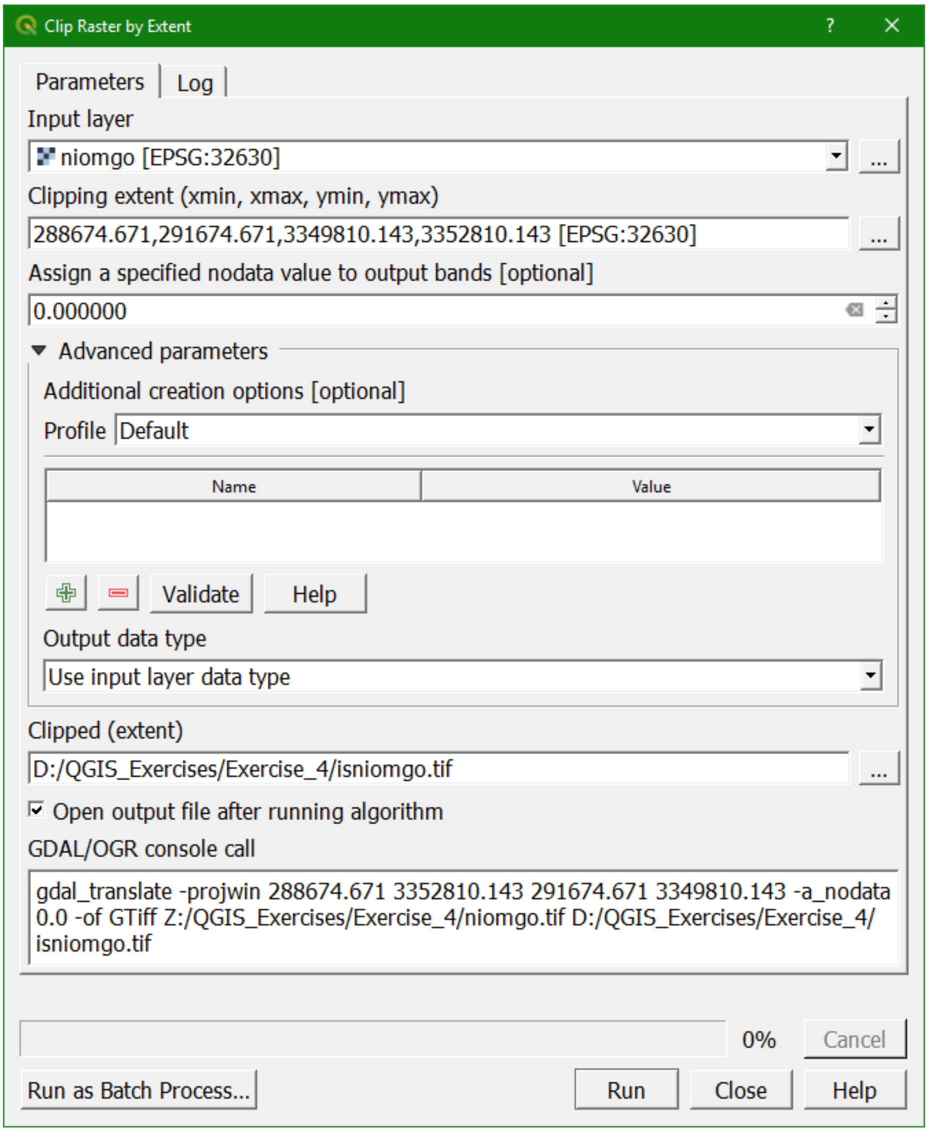
7.10 Condition 5: The area should be contiguous

To satisfy condition 5 the groups of pixels must be clustered and then they will get a unique group number. Then the area must then be calculated for each group. Because Zero values also form a cluster we need to first change them to nodata.

- We can use the clipper tool to change 0 values to nodata in `niomgo`. In the main menu choose *Raster → Extraction → Clip Raster by Extent…*



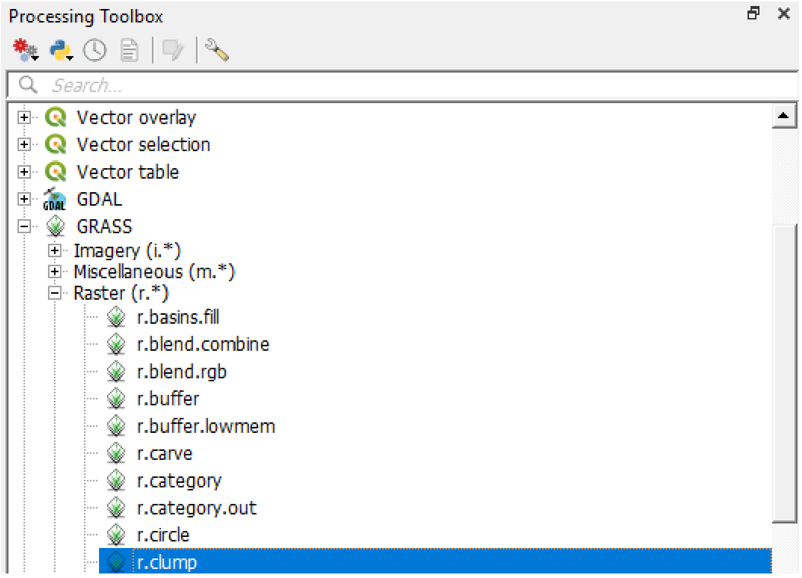
- At *Clipping extent* click on the  button, choose *Layer extent* and choose `niomgo`. It will copy the extent of `niomgo`.
- At *Assign a specified nodata value to output bands* type `0`. In this way we make all zeros nodata.
- Name the result `isniomgo`.



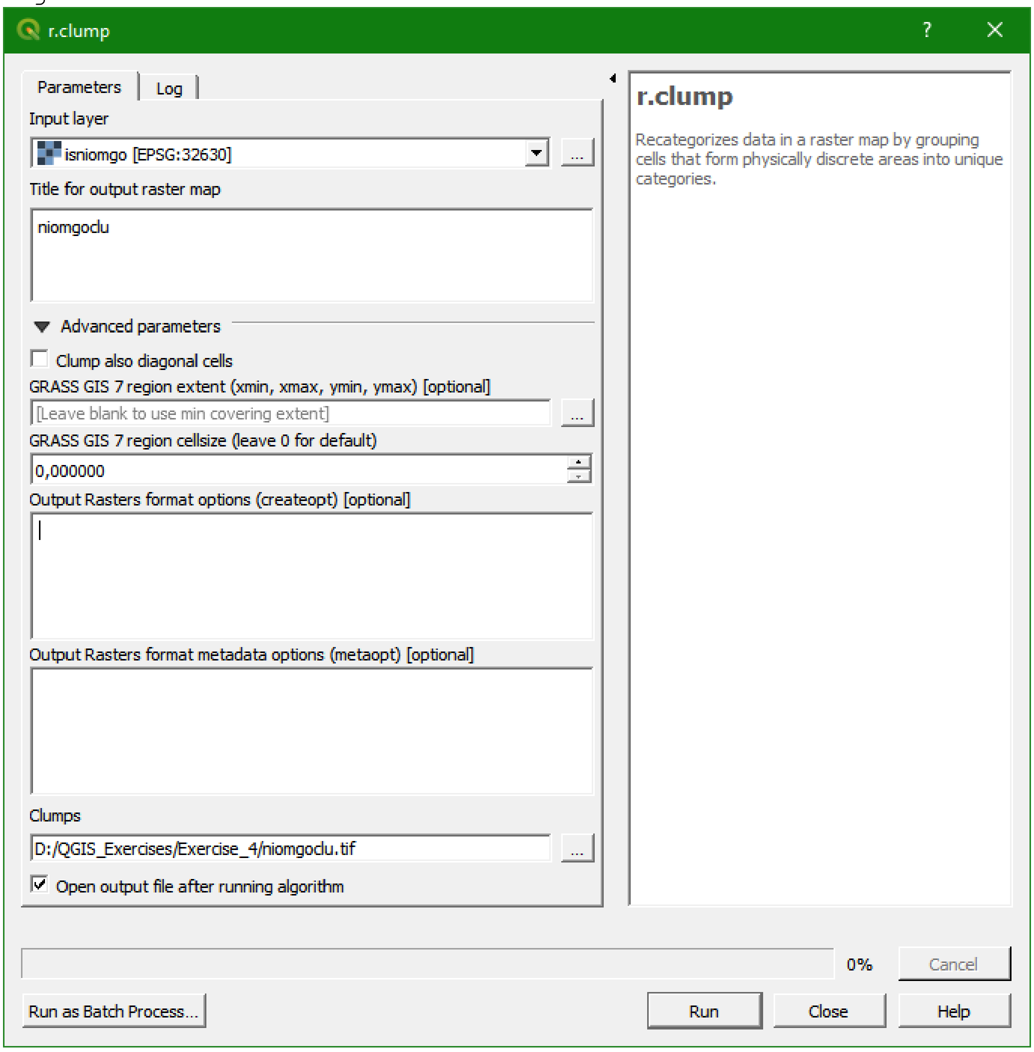
- Click Run and *Close* the dialogue after running.

The method in GIS to give unique values to each cluster of pixels is called **clump**.

- In the toolbox click on the *r.clump tool* (*Grass* → *Raster* → *r.clump*).



- Fill in the dialogue that opens as below. Choose `isniomgo` as *Input layer*, call the output layer `niomgoclu.tif`

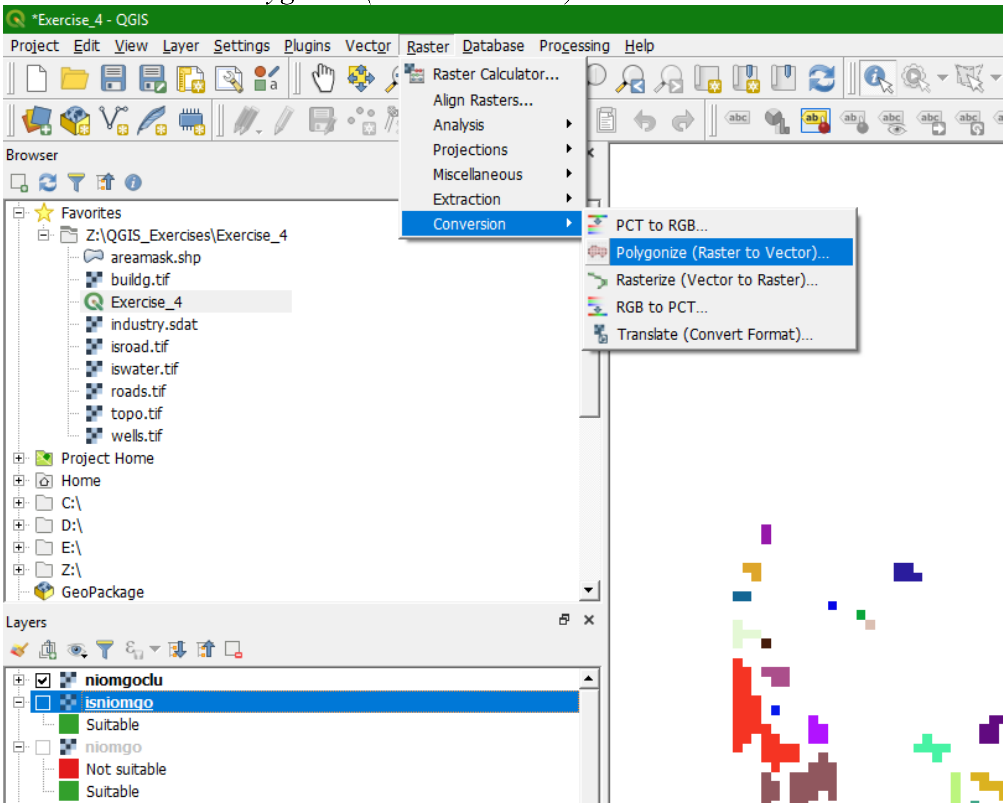


- Click *Run* and *Close* the dialogue when ready.
- Inspect the result? Is the automatically assigned legend okay? Is `niomgoclu` a Boolean, discrete or continuous layer? Assign the correct legend.

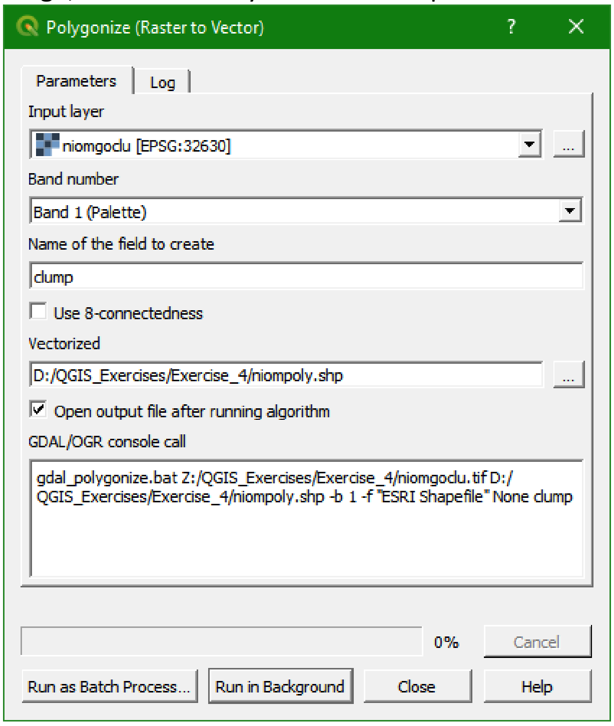
7.11 Condition 6: The area should be greater than, or equal to 2 hectares

Finally, areas greater than 2 hectares can be calculated to satisfy the last condition.
For this last step we have to convert our raster to vector.

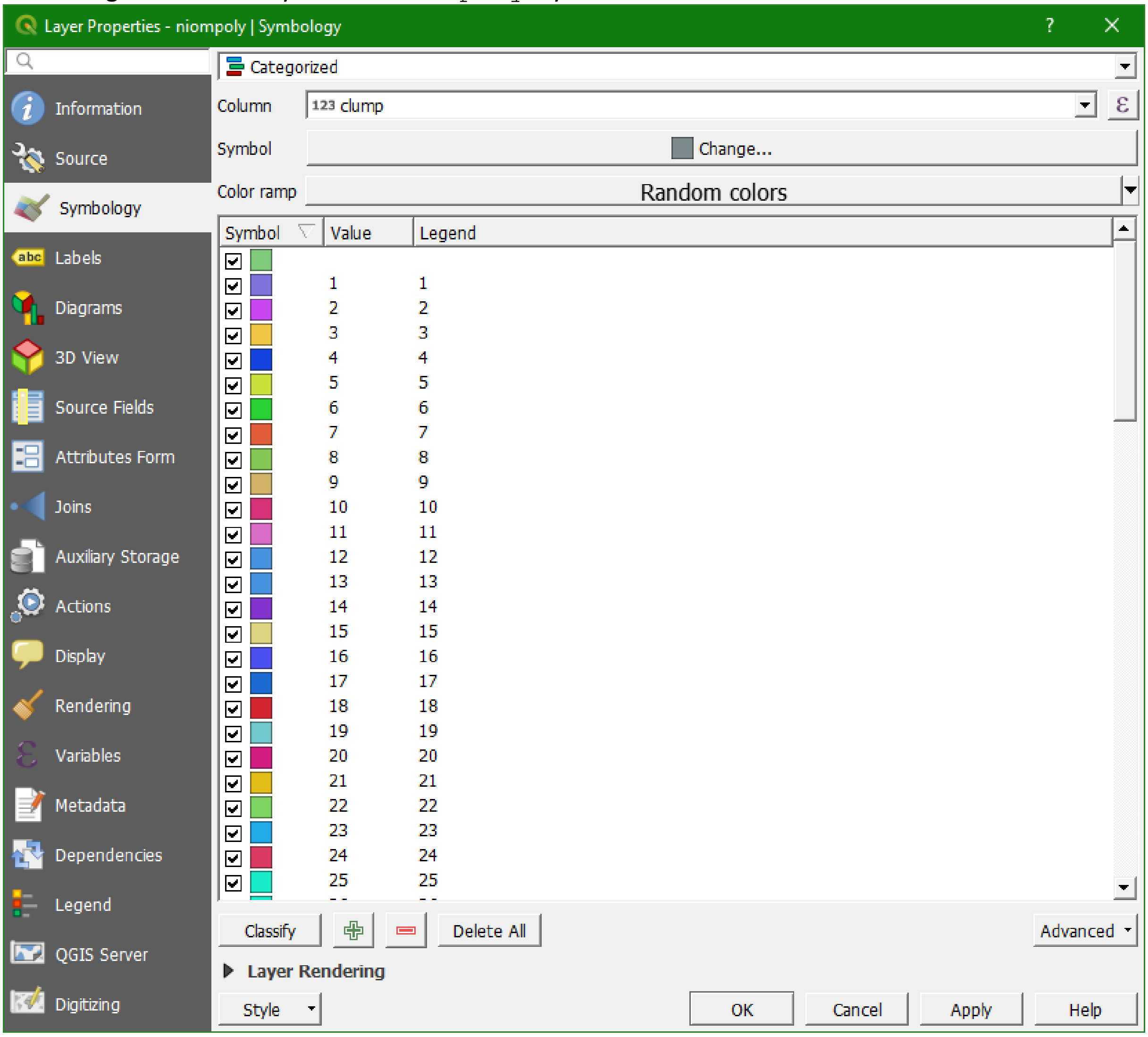
1. In the menu choose:
   Raster → Conversion → Polygonize (Raster to Vector)…



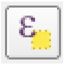
➢ Fill in the dialogue as below. Call the output shapefile `niompoly.shp`. Note that the default vector format is GeoPackage, so make sure you choose shapefile!



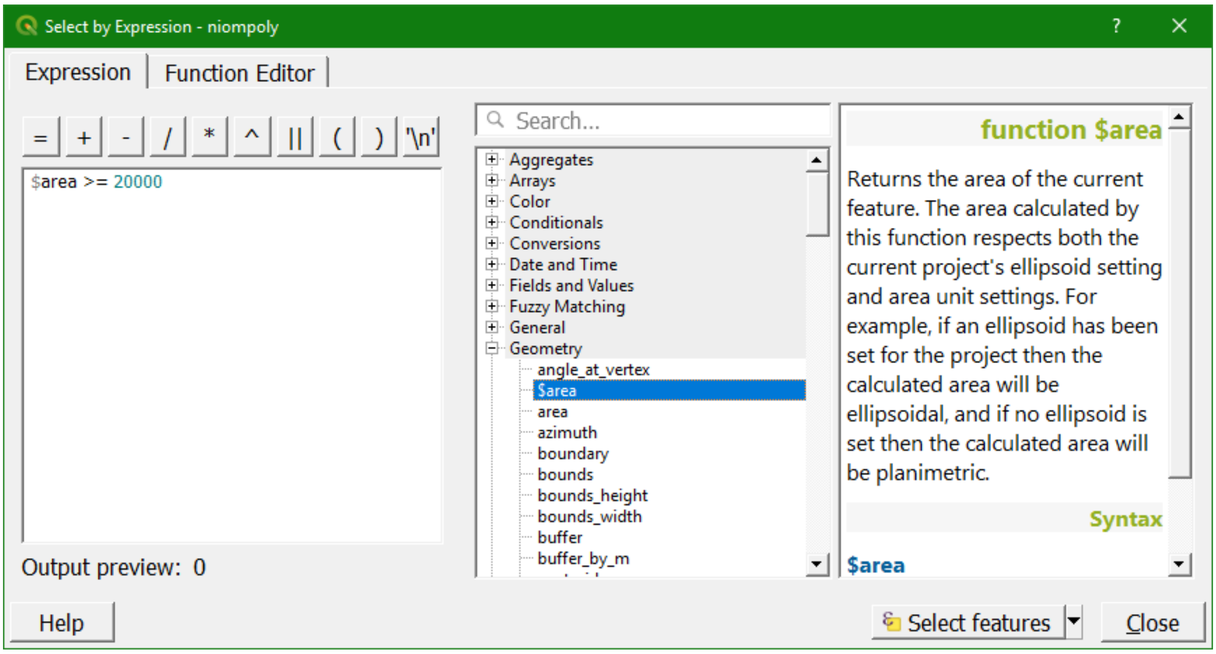
- Click *Run* and *Close* to return to the map canvas where the vector layer is displayed.
- Change the vector style of the `niompoly` layer so it matches with its contents:



In order to visualise the polygons larger than 2 ha, we have to do a selection based on this criterion.

- Open the attribute layer of `niompoly` and click  to open the dialogue for selection based on an expression.

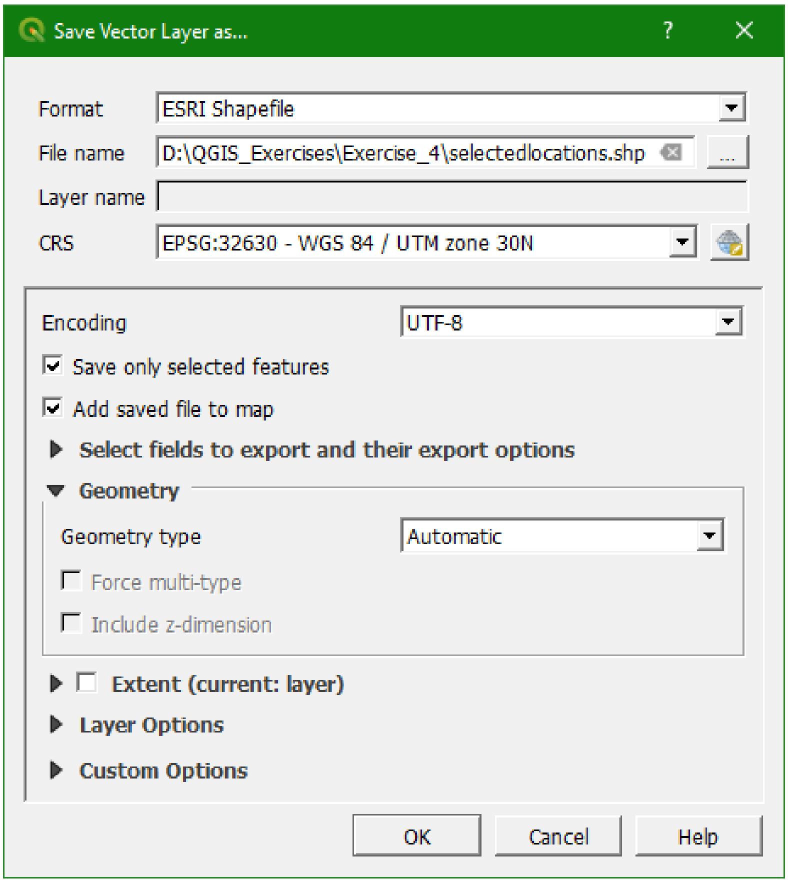
- In the dialogue go to *Geometry* and double click on `$area`. Fill in the dialogue as given below and click *Select features*.



The attribute table now shows 6 selected features. They are also highlighted in the map canvas, giving the answer to the planning issue.

Export the selected polygons to a new shapefile:

- ➢ Click right on the `niompoly` layer name and choose *Export* → *Save Selected Features As*…
- ➢ In the dialogue, name the output file `selectedlocations.shp` and check the box before *Save only selected features*.
- ➢

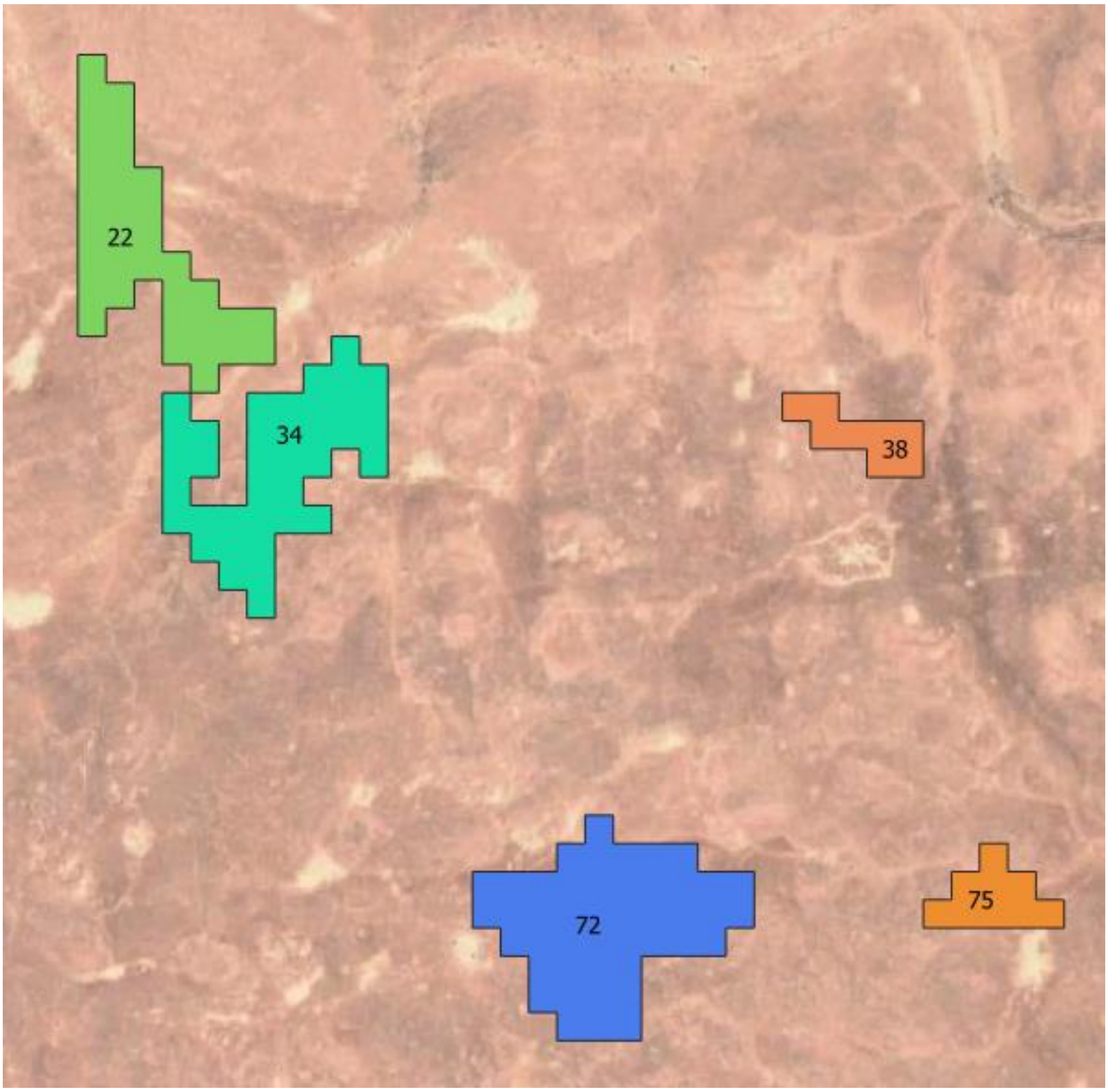


- ➢ Click *OK*.

- Now hide all layers and only show the `selectedlocations` layer. Give the layer the right legend so we can see each location.

- Try by yourself to add a column to the attribute table of the `selectedlocations` layer and to calculate the areas of these locations.
- Visualise the end result with a Google satellite image in the background. Use the *QuickMapServices* plugin.

This whole exercise can be viewed in a screencast at: https://youtu.be/lfZSyBf6o84



8 Inaccessible wells

The Department of Planning of the Aïn Kju Dzjis oasis has consulted you again to report to them which wells in the oasis are inaccessible for the population. They consider wells that lie more than 150 meters from houses or roads as inaccessible. They provided you with a map with all the wells in the oasis (`wells.tif`).

Try to solve this assignment on your own, using the map algebra skills of the previous section. The result should be a raster layer with TRUE for the inaccessible wells and FALSE for the remaining area. Besides `wells.tif` you should also use `buildg.tif` and `isroad.tif`. Make a flowchart of the analysis.

Exercise 5: Catchment delineation

9 Catchment delineation

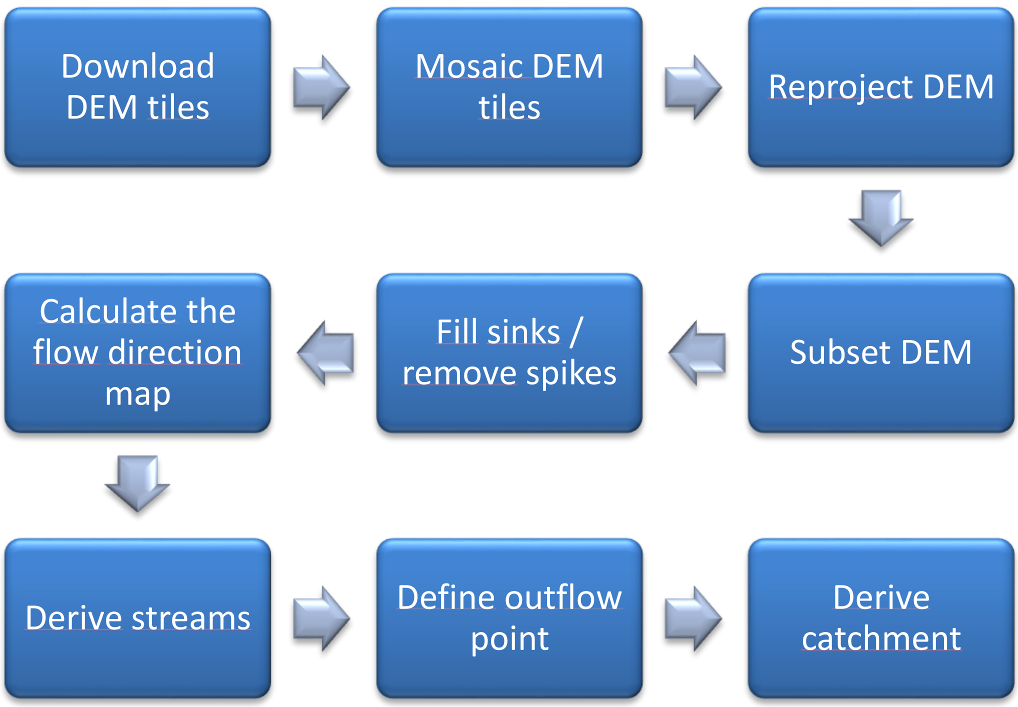
9.1 Introduction

In order to delineate a catchment from a DEM we need to follow these steps:

1) Download the DEM tiles of your study area. Make sure that the tiles cover at least the study area and that the catchment you want to derive is covered completely. Better to take it a bit larger to avoid boundary effects
2) If your study area is covered by multiple DEM tiles, you need to *mosaic* (merge) the tiles to create a single raster DEM layer
3) The DEM tiles might be in a different coordinate system then desired. In that case you have to reproject the DEM layer to the projection you want to use in the study area
4) In the case that the merged tiles are much larger than your study area, you can *subset* (clip) it to a smaller area to reduce calculation time
5) Make a hydrological correct DEM by filling sinks and removing spikes from the raw DEM
6) Calculate the flow direction for each cell
7) Calculate the flow accumulation for each cell: how many upstream cells contribute to the runoff in each downstream cell of the DEM
8) Derive the drainage network
9) Calculate the catchment for the outflow point of the catchment

When a map with the stream network already exists, the procedure can be improved by "burning" the river network into the DEM. In that way the DEM is always lower at rivers and runoff will follow the actual river network. This is out of the scope of this exercise.

This flowchart below summarizes the procedure:

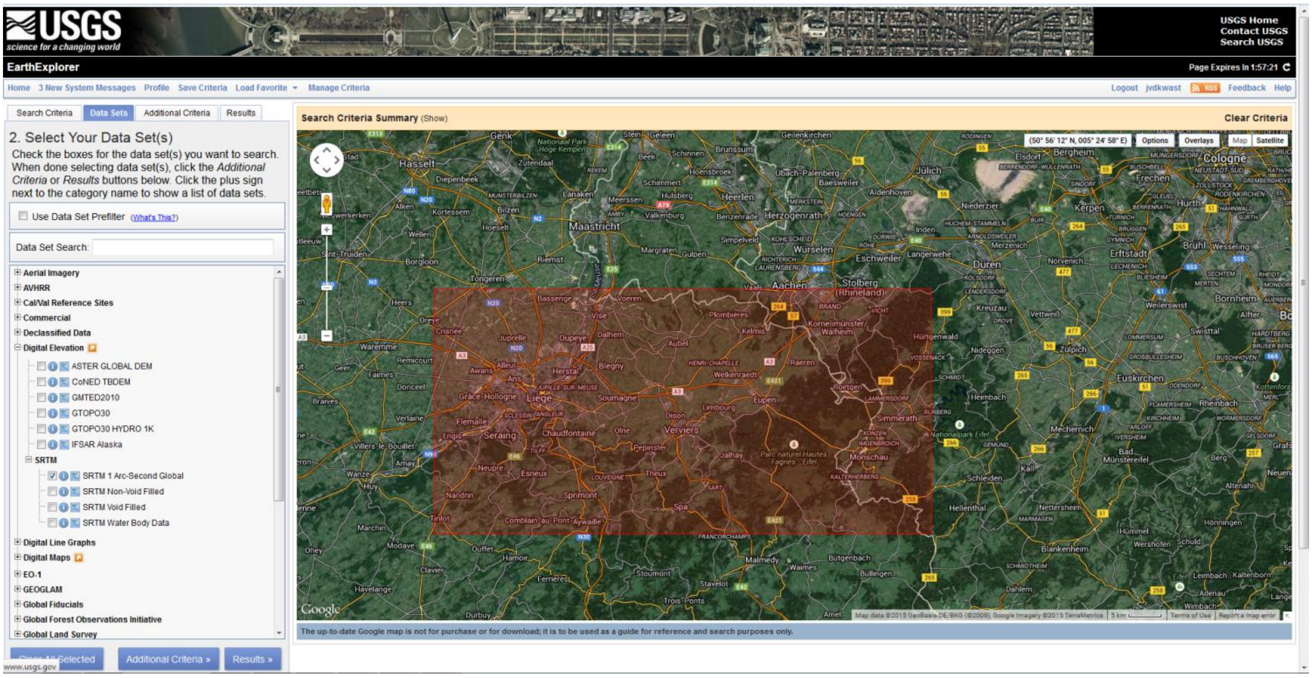


9.2 Download the DEM tiles

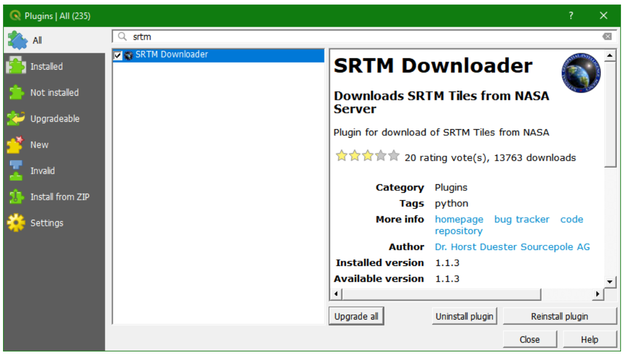
For the Rur study area, we will use 4 tiles from the SRTM 1 Arc-Second global data set. The United States Government announced on September 23 2014 that the highest possible resolution of global topographic data derived from the SRTM mission will be released to public. Since the end of 2014 a 1-arc second global digital elevation model (30 meters) has been released. Most part of the world has been covered by this dataset ranging from 54 degrees south to 60 degrees north latitude except for the Middle East and North Africa area. A description of the SRTM data products can be found here: https://lta.cr.usgs.gov/SRTM1Arc.

For this exercise the tiles `n50_e005_1arc_v3.tif`, `n50_e006_1arc_v3.tif`, `n51_e005_1arc_v3.tif` and `n51_e006_1arc_v3.tif` were already downloaded and provided. Save the data in e.g. D:\QGIS_Exercises\Exercise_5.

If you want to download data yourself, you can use the USGS EarthExplorer (http://earthexplorer.usgs.gov).



Alternatively, you can use the SRTM Downloader plugin to download the tiles directly your map canvas.

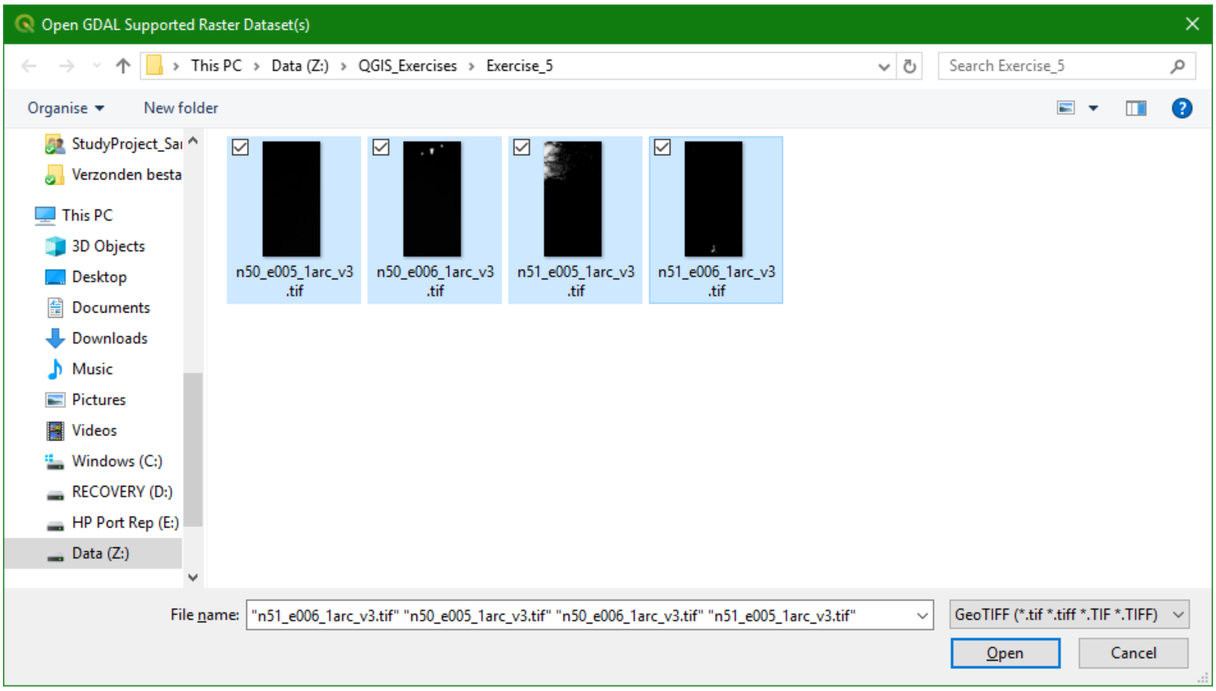


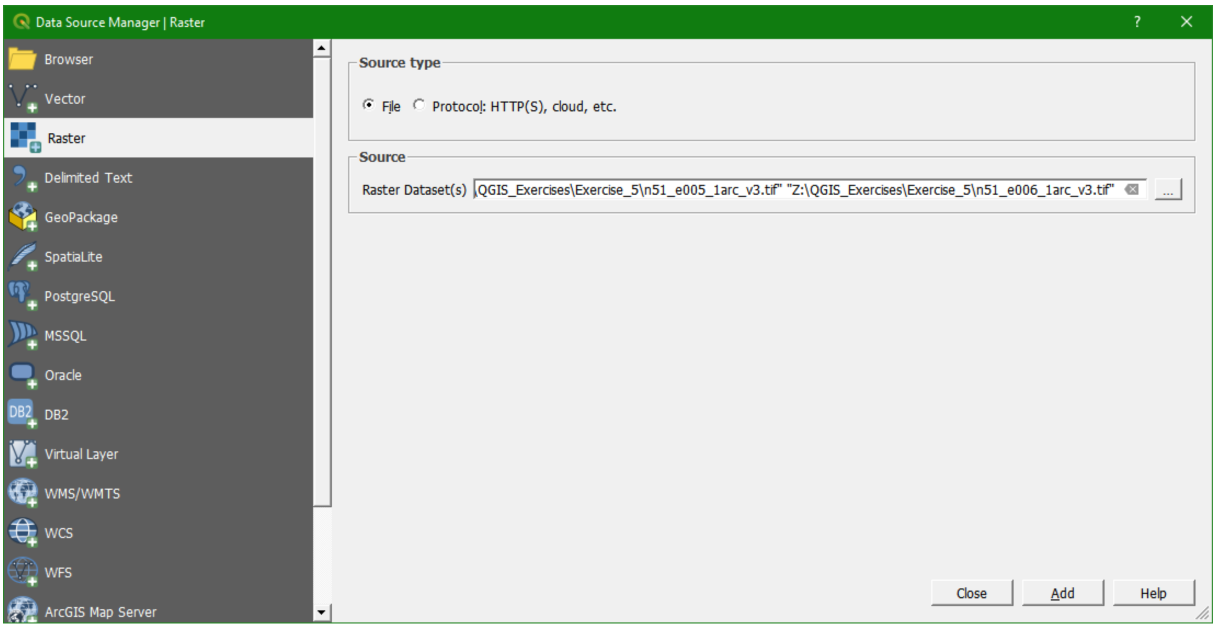
9.3 Load the DEM tiles in QGIS

1) Start QGIS Desktop.

2) Use the *Open Data Source Manager* button  .

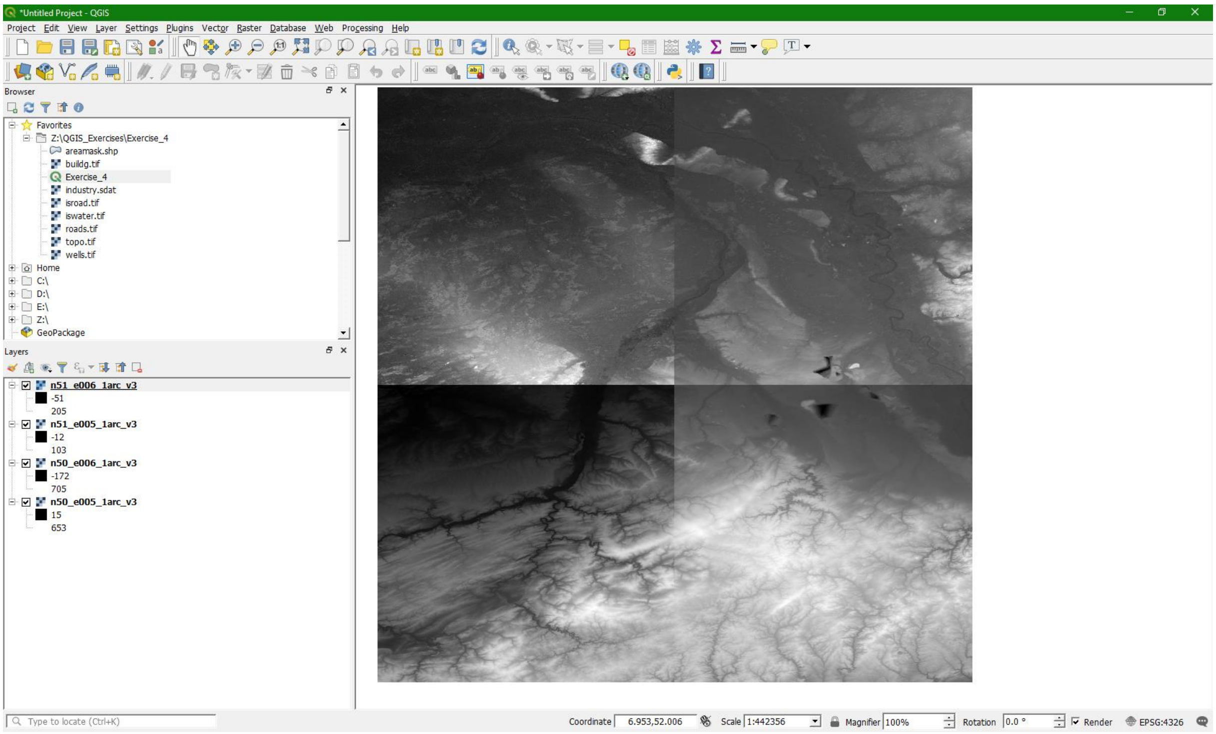
3) Choose Raster and browse up to the folder containing the SRTM tiles (e.g. `D:\QGIS_Exercises\Exercise_5`). Hold the `<Ctrl>` button and select the 4 tiles (`n50_e005_1arc_v3.tif`, `n50_e006_1arc_v3.tif`, `n51_e005_1arc_v3.tif` and `n51_e006_1arc_v3.tif`) by left clicking on the tiles. Click *Open*.





4) Click *Add* and *Close*.

5) You should be able to see this map in the *Map Canvas* (as shown below).



We see the four tiles in greyscale. We can distinguish the tiles, because QGIS automatically stretches the grey values per tile. That means that the grey values are distributed according to the minimum and maximum value of each tile. When we mosaic (merge) the tiles, QGIS will stretch the values for the whole area, using the minimum and maximum value of the merged raster layer. You'll see that in the next section.

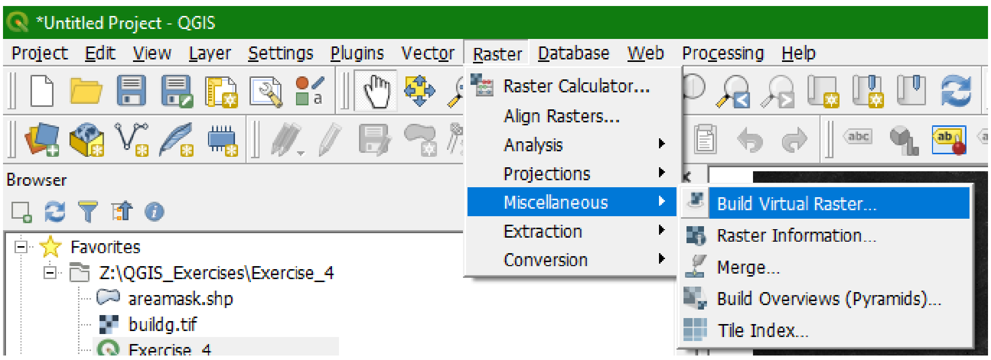
9.4 Mosaic DEM tiles

Before we proceed, we have to merge the four DEM tiles, which in GIS terminology is called mosaic. There are two ways to mosaic the tiles:

- Merge the tiles into one physical file
- Merge the tiles into a virtual file

The first option is slower. If we have many tiles, we prefer to make a virtual file that virtually merges all the tiles. That will be done with the following steps:

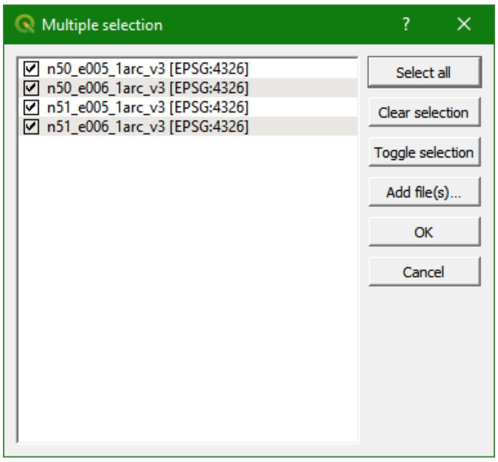
1) In the menu choose *Raster* → *Miscellaneous* → *Build Virtual Raster...*



2) In the *Build Virtual Raster* dialogue you can choose each file individually or merge all files in a directory (folder). We can also merge the files that are visible in the *Map Canvas*. We use the last option:

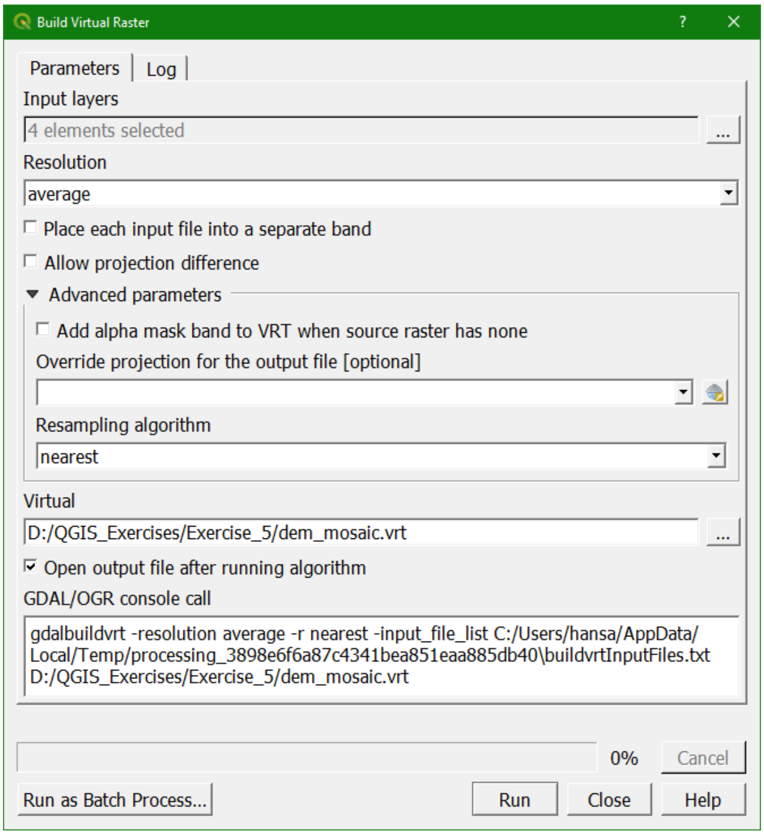
- At Input layers click 

- Use the *Select all* button to select the four tiles and click *OK*.



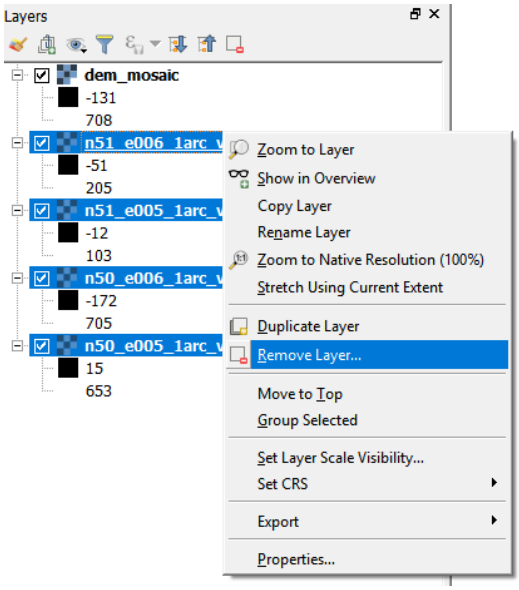
- browse to the location where you want to save the output file (e.g. `D:\QGIS_Exercises\Exercise_5`) and give it the name `dem_mosaic.vrt`
- Resolution is default set to average. In our case the files all have the same resolution (1 Arc Second).
- Uncheck the box before *Place each input file into a separate band*. This needs to be checked only if you want to create a mapstack, i.e. with remote sensing bands.
- Keep the *Resampling algorithm* at the default: `nearest`. This also has no impact, because resampling is not needed.

The dialogue should now look like this:



3) Click *Run* to run the algorithm. Click *Close* to get back to the main screen where you can see the merged DEM. You notice that in the Map Canvas the borders of the tiles are not visible anymore in the merged DEM, because QGIS stretches the greyscale using the minimum and maximum of the entire merged DEM. This is only for visualisation, the values in the tiles are the same as in the mosaic.
4) Click right on the layer and choose *Rename Layer*. Rename the layer to `dem_mosaic`. Renaming is not needed anymore if you have changed the setting as described in Section 7.4.

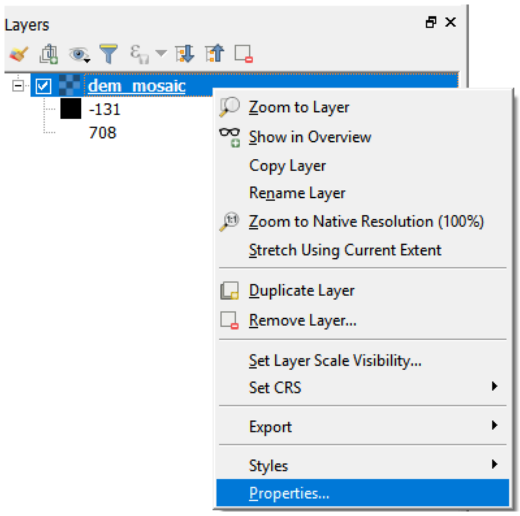
5) Now remove the individual tiles (not the `dem_mosaic`) from the layers list by selecting them while the *Ctrl* button is pressed. Then clicking right one of the tile names and select *Remove Layer…*. Click *OK* to confirm. This will remove the tiles from the screen, but not from the hard disk.



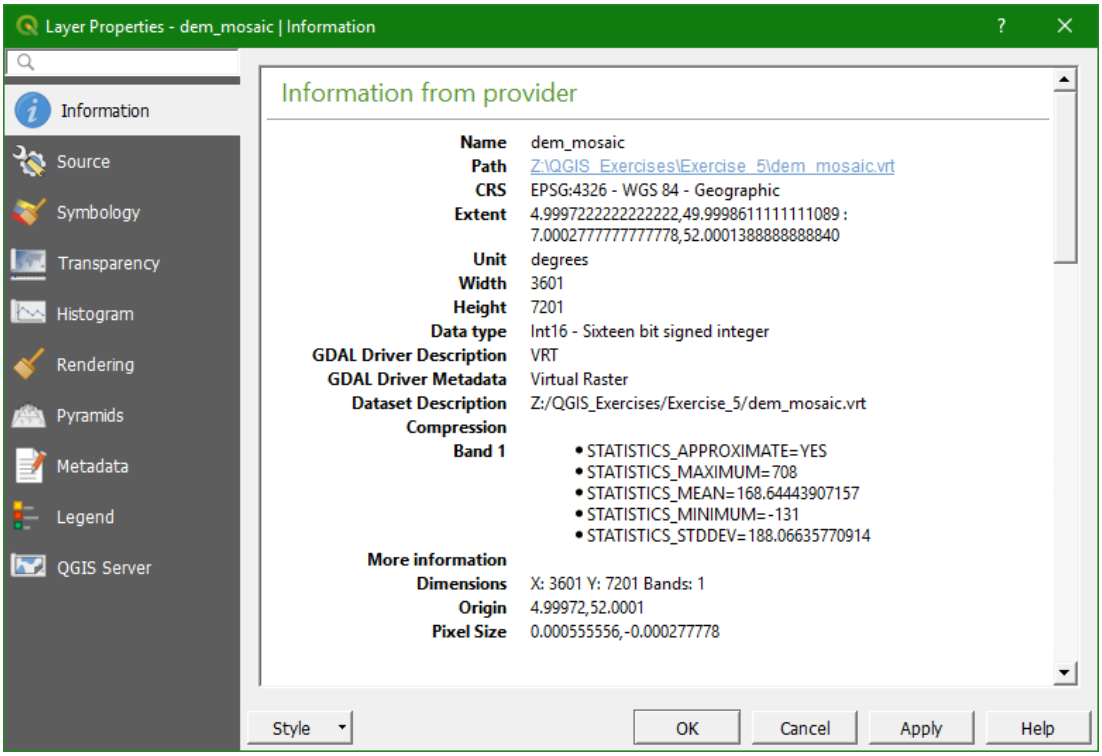
9.5 Reproject DEM

Before continuing, we need to know the projection of the DEM and reproject it to the projection of our project.

1) Right click on the layer's name, and select *Properties*….



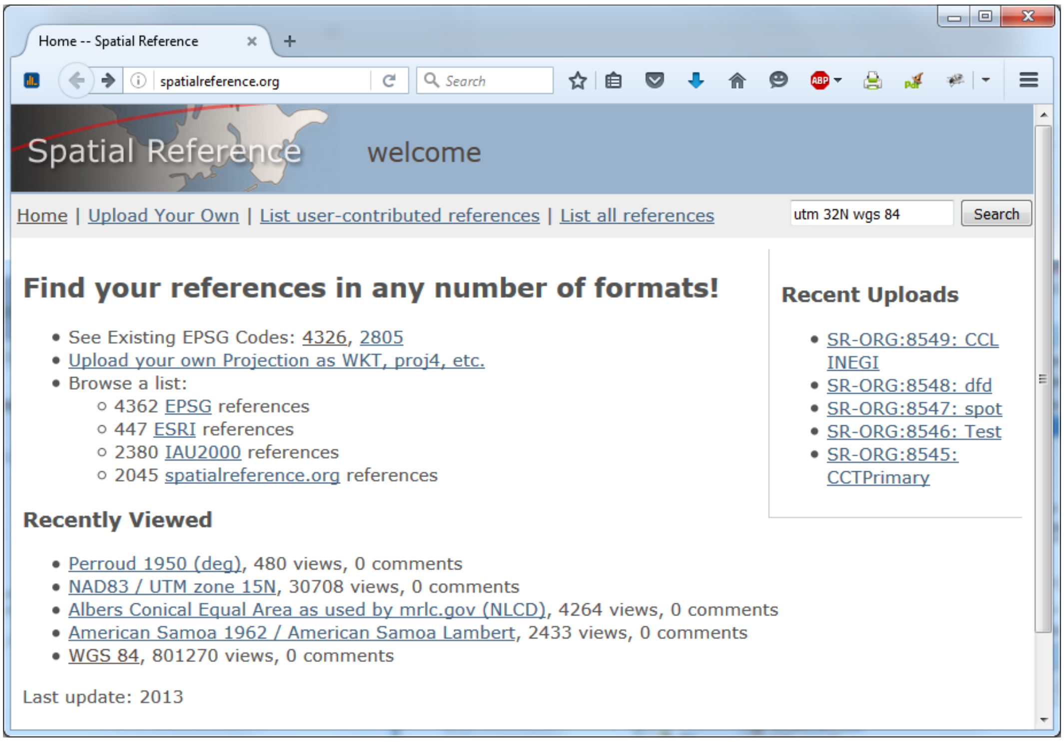
2) In the new window select *Information* (the top tab on the left hand-side of the new window).
3) In the *Information* window check the CRS (*Coordinate reference system*).



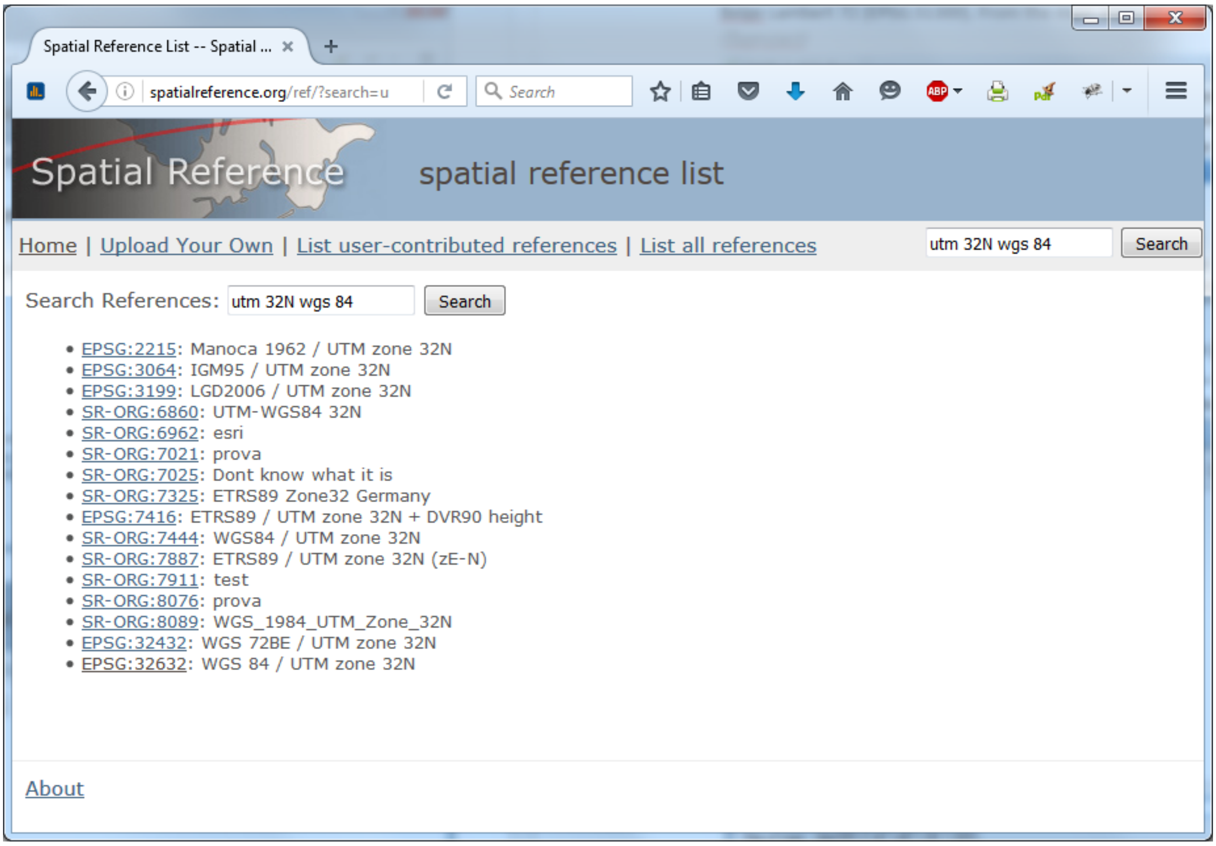
The DEM is in its original Lat/Lon Geographic Coordinate System with datum WGS 84 (EPSG: 4326). We need to convert it into the projection of our project. Because the project covers multiple countries, we will not use a local projection but a global projection: UTM Zone 32 North, with WGS-84 as datum.

We can find the EPSG codes at http://www.spatialreference.org

4) Use the website to search for `UTM 32N`. You can leave QGIS opened and open a browser:

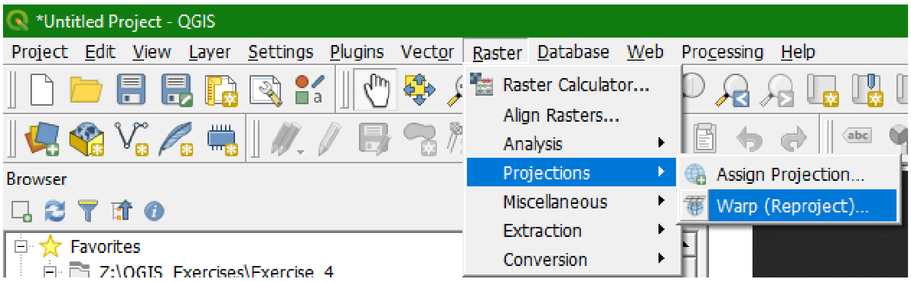


5) The database returns:



We have to look at the EPSG codes. **We will use the EPSG: 32632 throughout this project**. If you click on it you can see more details.

6) Now we are going to reproject the DEM from unprojected (Lat/Lon WGS 84 - EPSG: 4326) to UTM Zone 32 North / WGS 84 (EPSG: 32632). From the main menu choose *Raster* → *Projections* → *Warp (Reproject)*

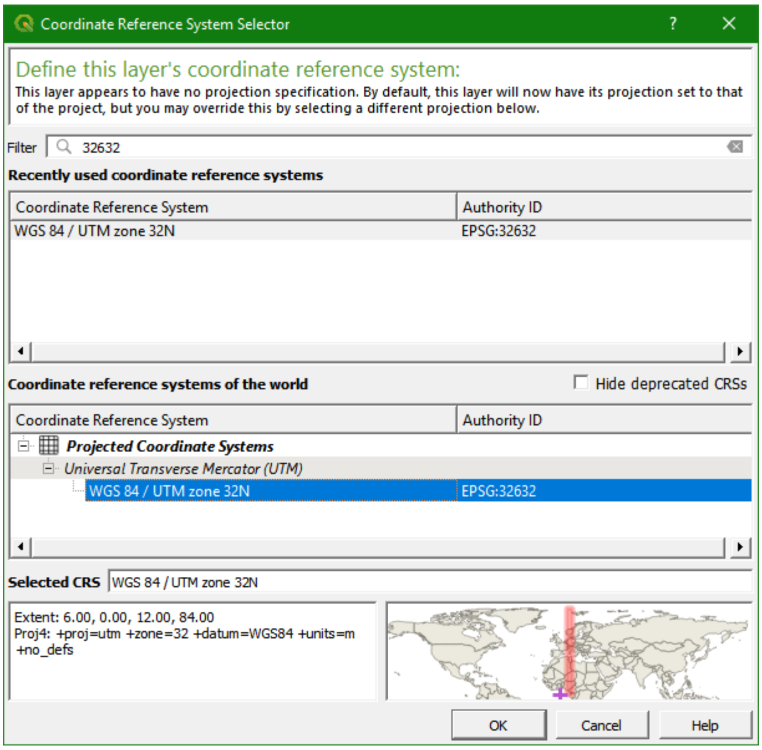


7) In the *Warp* window, click  to choose the *Target CRS*

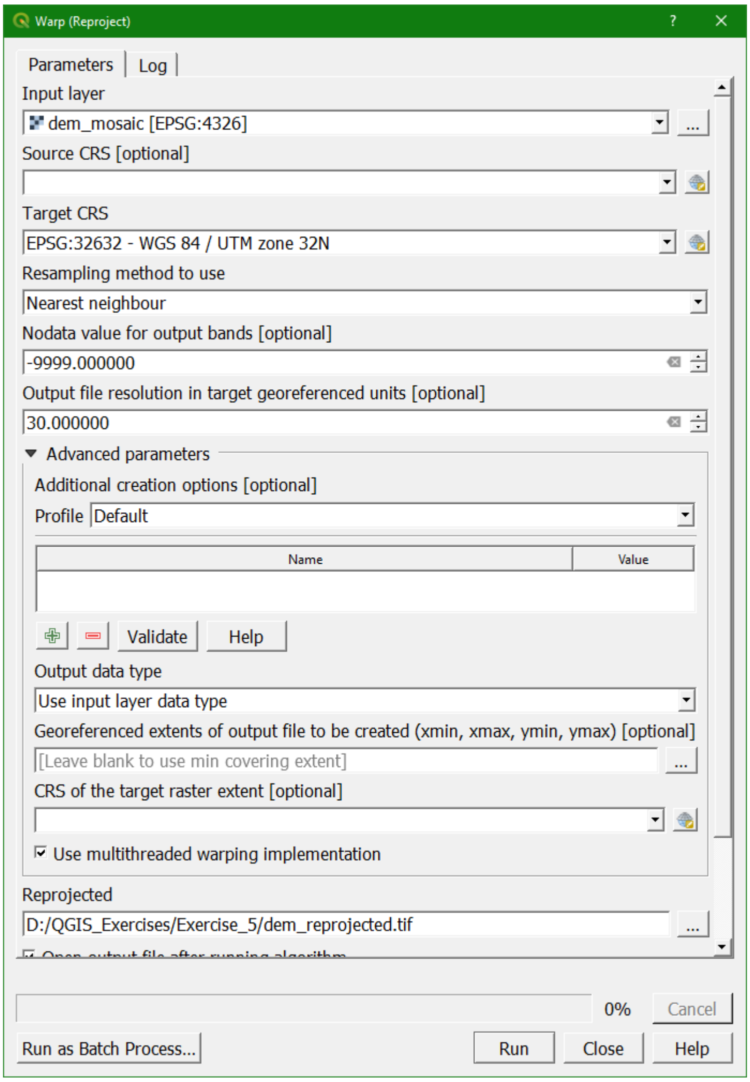
8) In the dialogue that opens type 32632 at Filter and select *WGS... EPSG: 32632* in the middle of the dialogue window and click *OK*.

9) Now complete the dialogue:

- *Resampling method* to use: We choose `Nearest Neighbour` to preserve the elevation values of the original files.
- Set the *No data value for output bands* to –`9999`. Because the raster layer will be reprojected there will be "no data" at the borders. In this way we define that "no data" has a value –`9999` and will not be visualised as "data".
- Set the *Output file resolution* to `30` m.
- Browse to your exercise folder and name the output file `dem_reprojected`

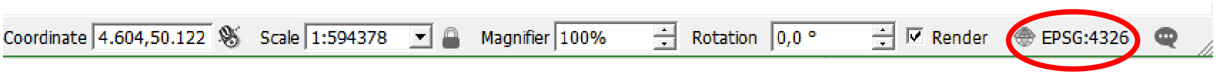


Note the *gdalwarp* command that will be executed in the background.



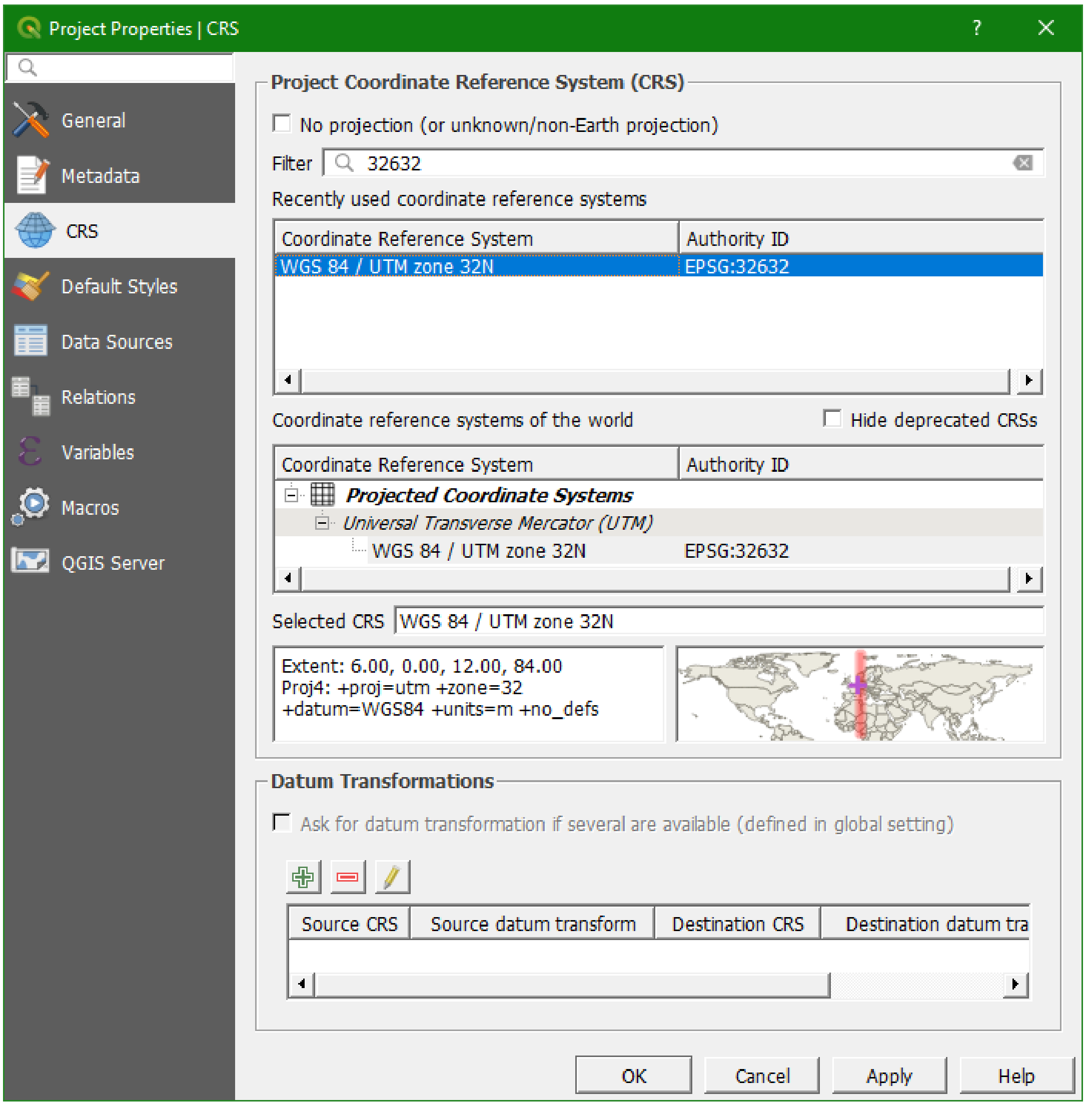
10) Click *Run* to run the algorithm. After running click *Close* to close the window.

Now you will see that the re-projected DEM will appear in the list of Layers. The DEM may seem distorted, as shown in the image below. This is due to the fact that the Map Canvas Projection is still in Lat/Lon, as testified by the coordinates in the lower part of the Map Canvas. And the EPSG code given in the lower right corner. This is due to the **on-the-fly projection**, which causes a difference between the projection in the file and the one that is visualised.

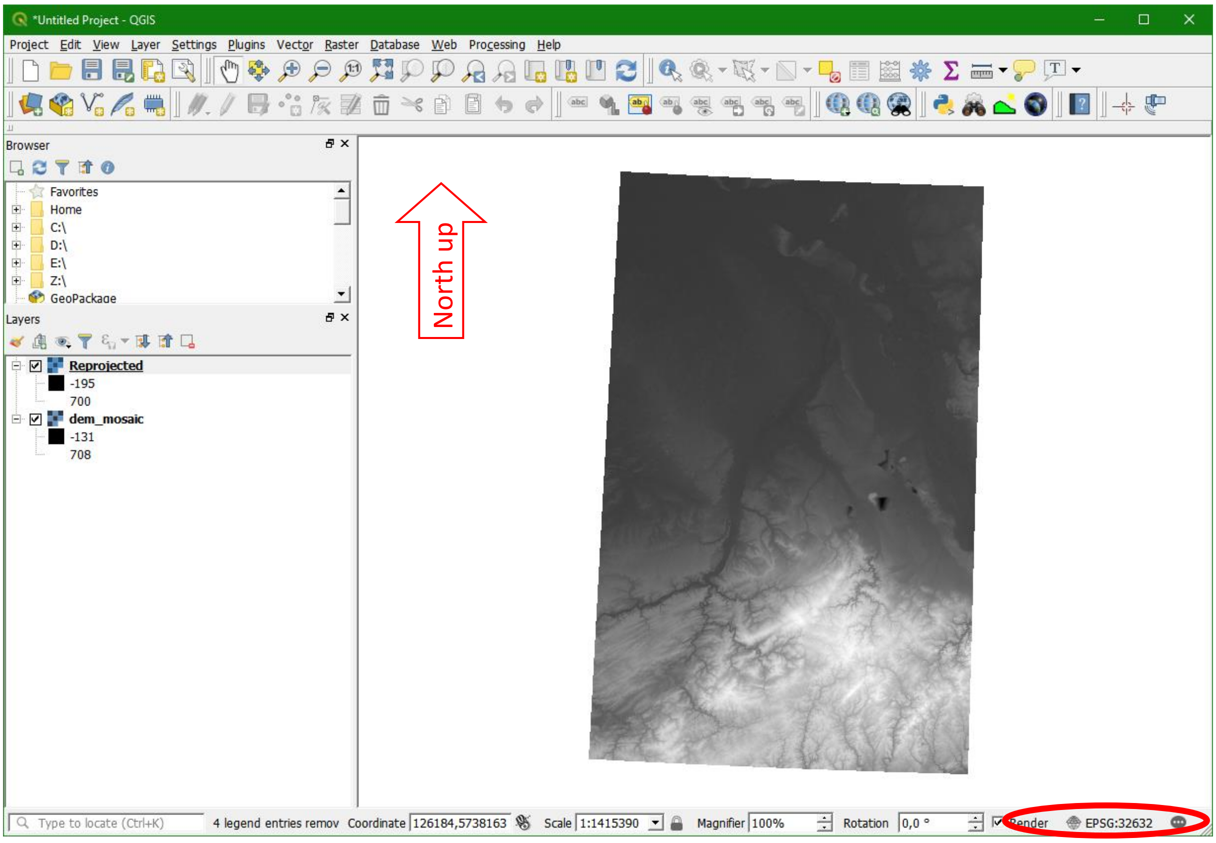


11) To complete this operation, and display properly the new dataset, we need to change the on-the-fly projection of the Project. To do so click on the EPSG: 4326 in the lower right of the screen.

12) In the new dialogue window select the *EPSG:32632 projection* that is already in the list of *Recently used coordinate reference systems*, as shown below, and click *OK*.



In the Map Canvas the DEM is now displayed in the correct position (with the North pointing up), as shown below. The coordinates of the new display are also in meters as we want.



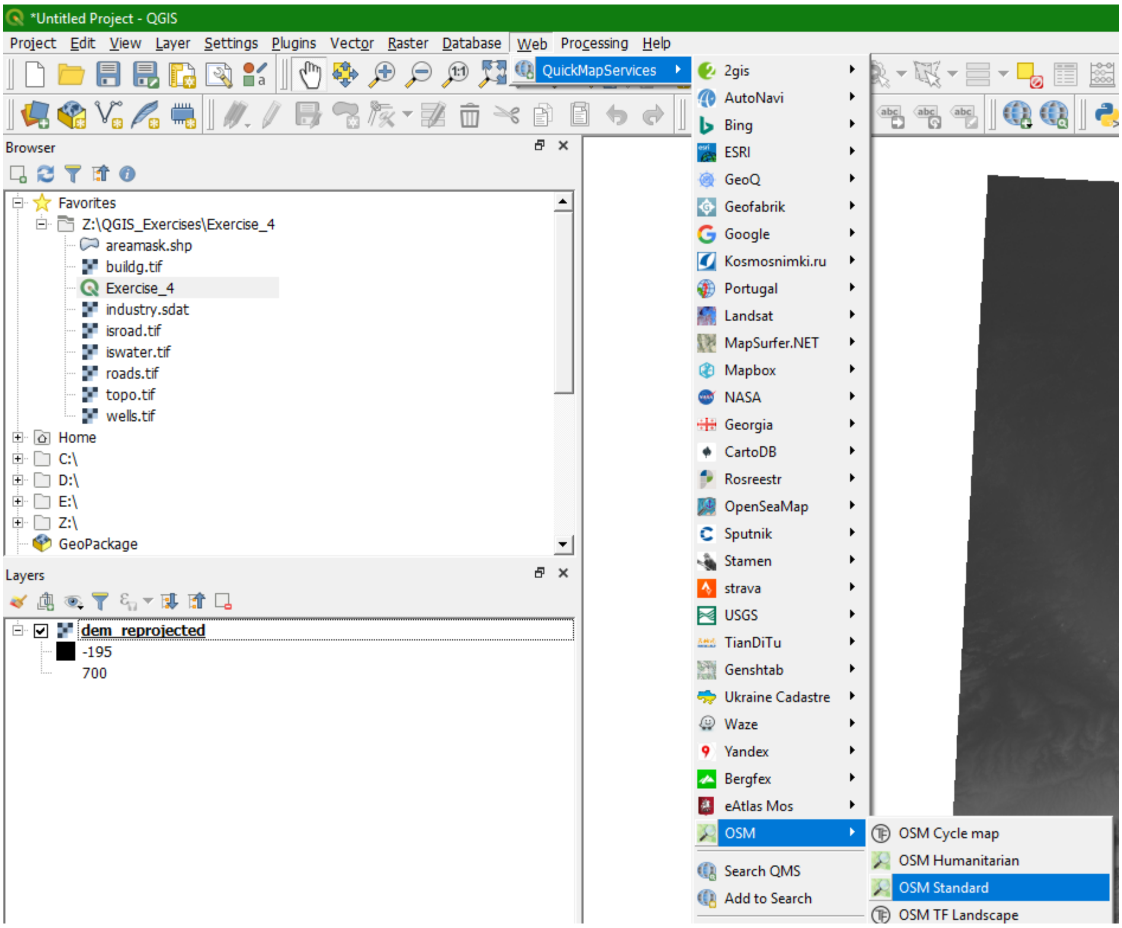
13) You can now remove the file `dem_mosaic`

9.6 Subset DEM

In order to reduce the calculation time of the algorithms, we will subset (or clip) the raster layer.

An easy way to select the boundary of your study area (always make it a little bit bigger to prevent boundary effects) is to use OpenStreetMap. OpenStreetMap contains crowd sourced data (see http://www.openstreetmap.org for more info). If the QuickMapServices plugin is installed, you can add an OpenStreetMap to QGIS as follows:

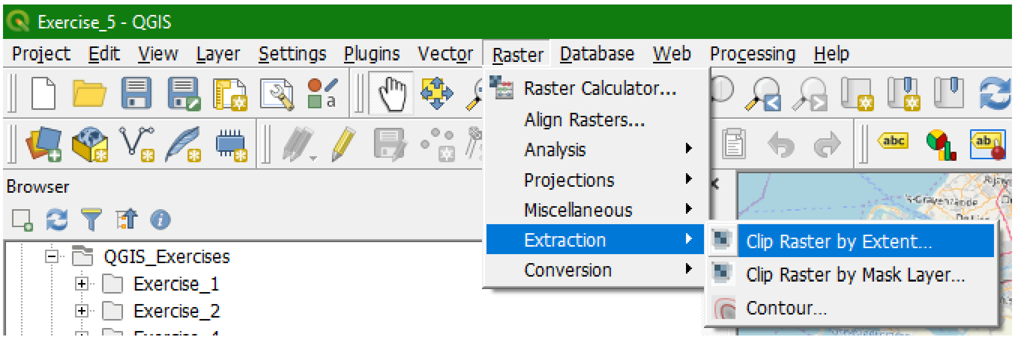
1) In the menu choose *Web* → *QuickMapServices* → *OSM* → *OSM Standard*



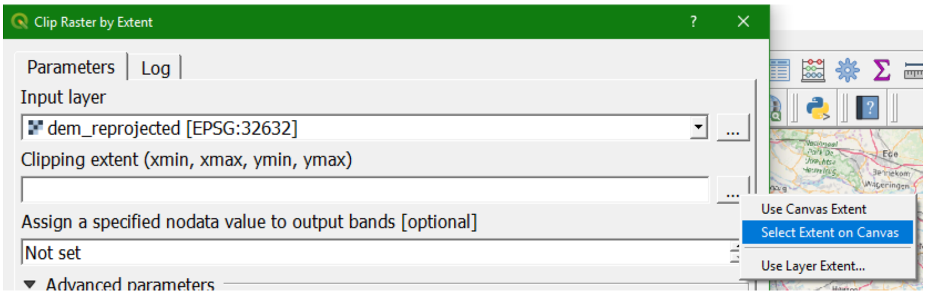
2) Now an OpenStreetMap will be shown in the *Map Canvas*. Temporarily hide the DEM by unchecking the box or dragging the OSM layer to the top.

3) In order to know the approximate extent of the Rur catchment, the exercise data contains a shapefile with the sources and the mouth of the catchment. Open the vector layer `source_mouth.shp`

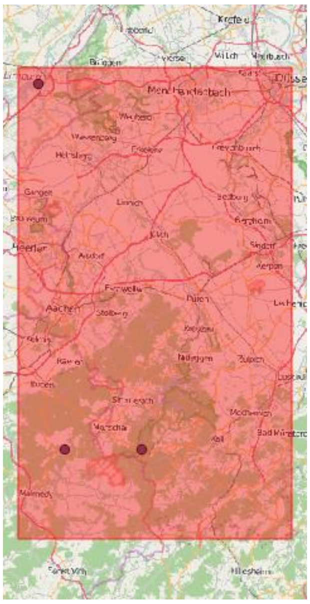
4) Now, from the Main Menu select *Raster* → *Extraction* → *Clip Raster by Extent…* as shown below:



5) In the *Clip Raster by Extent* dialogue choose as *Input layer* `dem_reprojected`. For Clipping extent, click on ... and choose *Select extent on canvas*.

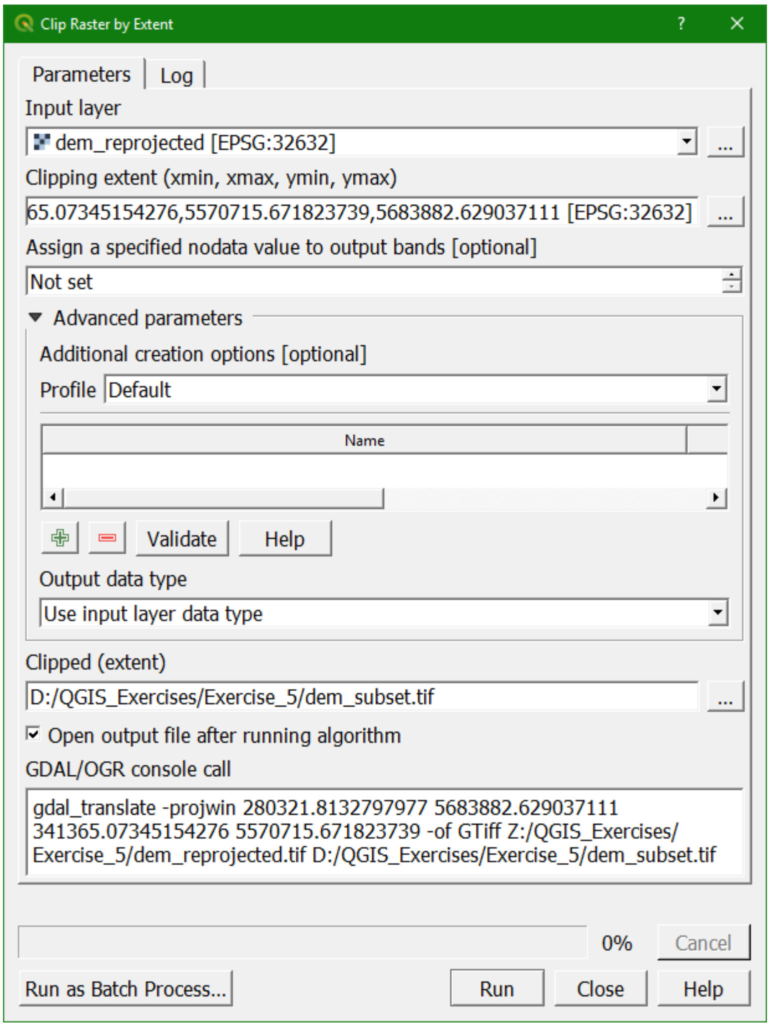


6) Draw a box on the map around the points from the `source_mouth` layer.



7) Give the ouput file the name `dem_subset.tif`. **Use the ... button to browse to the right location (e.g. `D:\QGIS_Exercises\Exercise_5`).**

8) Click *Run* and *Close* the dialogue when ready.

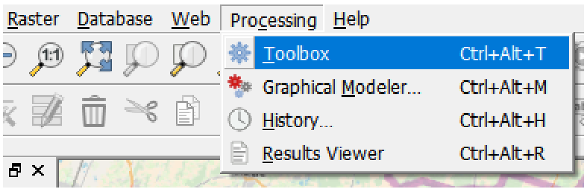


9) Now you can remove `dem_reprojected` from the layers list as we have done before for other layers that are not longer needed.

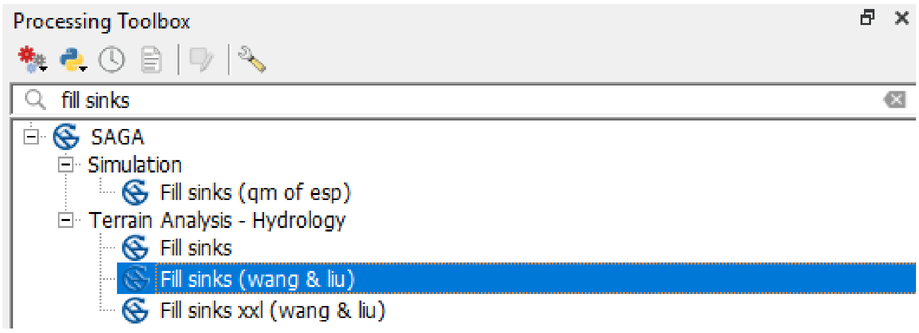
9.7 Fill sinks / remove spikes

Raw, unprocessed DEMs have artefacts such as depressions and peaks. These artefacts are a result of the DEM acquisition process and need to be removed before a DEM can be used for hydrological analysis, like catchment and stream delineation or hydrological modelling. There are several algorithms for filling sinks. Here we will use the algorithm developed by Wang and Liu (2006), which is faster than other algorithms and therefore works better with high resolution datasets.

1) We will use the QGIS *Processing Toolbox*. If you don't see the *Processing Toolbox* at the right of your screen, you can enable it by choosing from the main menu *Processing →Toolbox*

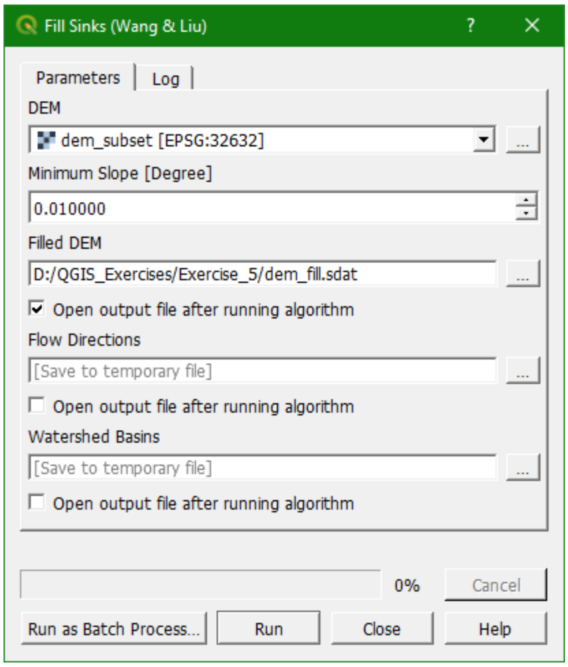


2) In the *Processing Toolbox* use the *Search...* field to search for `fill sinks`



3) Go to *SAGA → Terrain Analysis - Hydrology → Fill sinks (wang & liu).*

You see that there are more algorithms for filling sinks. Each has its own advantages and disadvantages in terms of calculation time, memory usage and accuracy. For your own research you need to make a decision based on the documentation of the algorithms or by analysing the results of several algorithms.

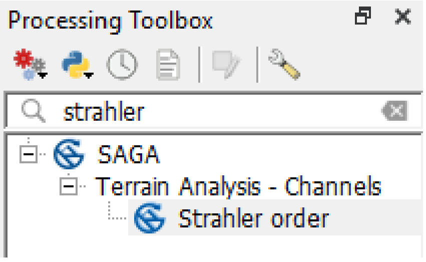


4) In the dialogue keep the defaults. Make sure to select `dem_subset` as the input and define `dem_fill.sdat` as the *Filled DEM*. **Always use the [...] button and *Save to file...* to browse to the right location (e.g. `D:\QGIS_Course\Exercise_5`).** We only need the Filled DEM at this point, so you can uncheck the boxes for opening the output of *Flow Directions* and *Watershed Basins*.
5) Click *Run* and *Close* when done.
6) Now remove `dem_subset` from the layers list, because it is no longer needed.

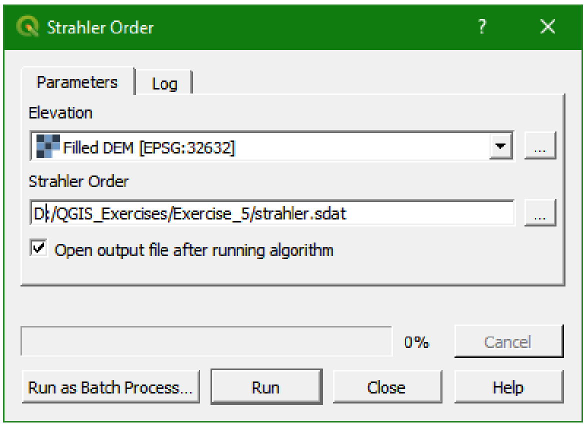
9.8 Calculate Strahler order and determine threshold for streams

Before we can derive the streams from the DEM, we need to determine what we consider streams. For this purpose we use the Strahler order. The higher the order, the bigger the stream.

1) Search for `Strahler` in the *Processing Toolbox* and select *SAGA → Terrain Analysis - Channels → Strahler order*

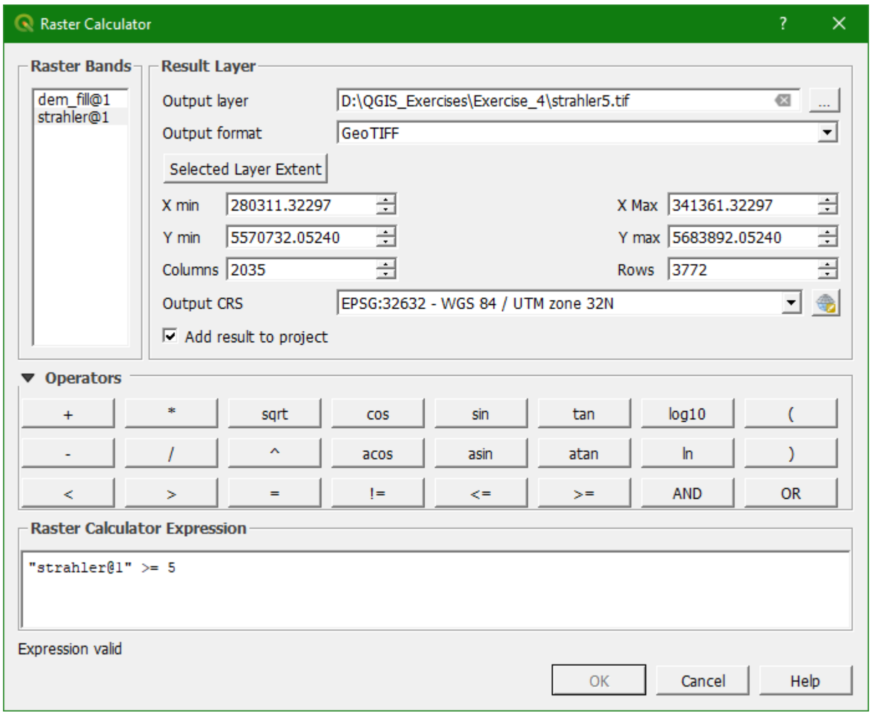


2) In the dialogue select the `Filled DEM` for the elevation. And use `strahler.sdat` as the output filename and click *Run*. Click *Close* when the algorithm is done.



3) Check the result. What are the minimum and maximum values? Is the Strahler raster discreet or continuous? Make a nice legend, where the highest Strahler orders are more blue so you can clearer see what the rivers are.

4) Use the *Raster Calculator* to create a Boolean map with 1 for Strahler order >= 5 and 0 for the other values. Call the output file `strahler5.tif`



5) Make a nice legend where 1 is blue and 0 is transparent. Check the result with the rivers in OpenStreetMap.

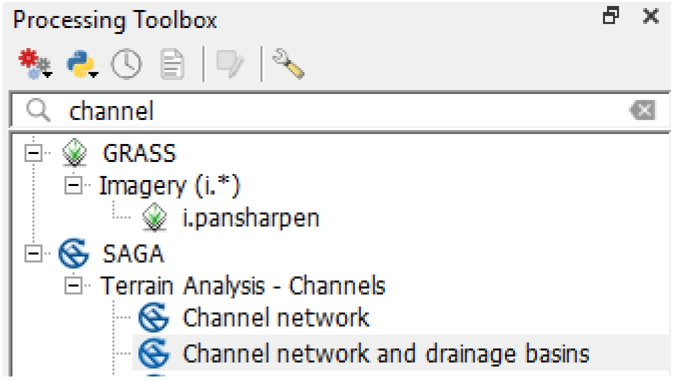
6) Repeat steps 4 and 5 with different threshold values and choose the best result.

9.9 Calculate flow direction, channel network and catchments

Now with our corrected DEM and the threshold value (Strahler order) we can proceed to calculate the flow direction, channel network and catchments in our area. We will use the D8 method for flow direction. The D8 method evaluates the slopes in 8 discrete directions around a pixel.

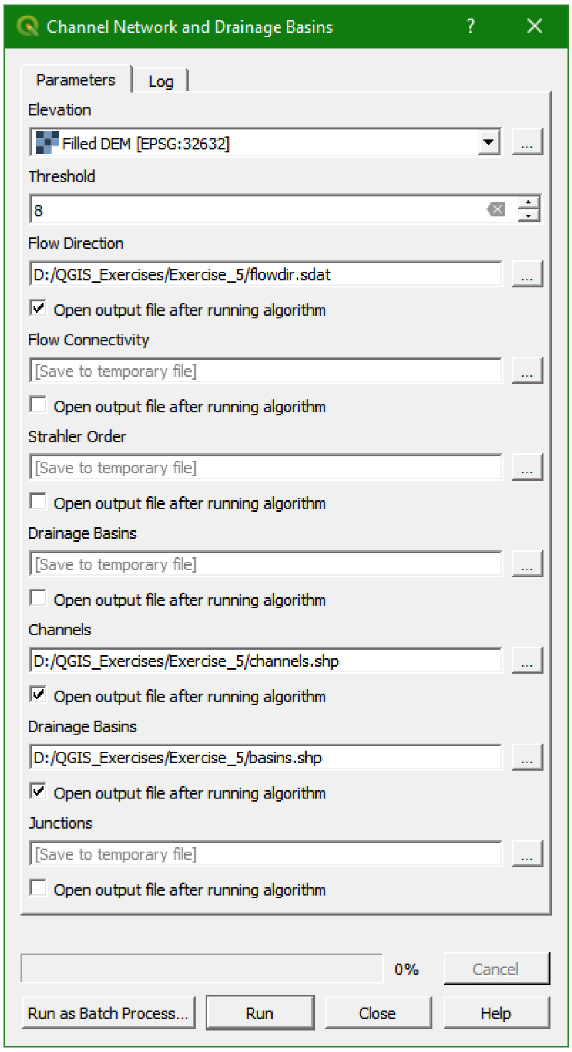
In the *Processing Toolbox* you can also find related tools that use different algorithms. Always check the documentation of the algorithm to find the right one or do a comparative analysis.

1) Search for `Channel` in the *Processing Toolbox* and select
   SAGA → Terrain Analysis - Channels → Channel network and drainage basins

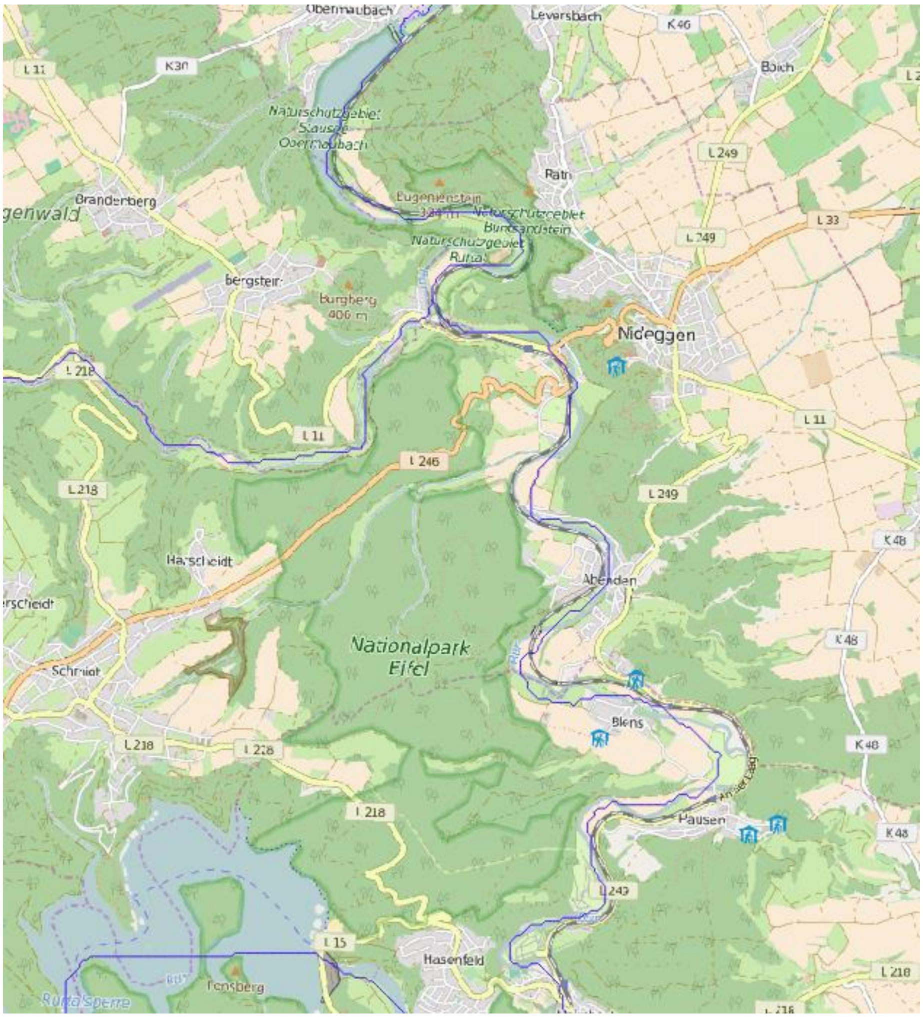


2) In the dialogue select the `dem_fill` for the elevation and put the threshold at the value you found in step 6 of the previous section, e.g. 8. This means that streams with a Strahler order larger than or equal to this value will be considered as rivers. The algorithm will calculate flow direction and the Strahler order to determine the channels and drainage basins.
   Select the checkboxes for the following outputs:
   - *Flow direction* and save it as `flowdir.sdat`
   - *Channels* and save it as `channels.shp`.
   - *Drainage basins* and save it as `basins.shp` (the other one is for raster)

   Always use the [...] **button and *Save to file...* to browse to the right location (e.g. `D:\QGIS_Exercises\Exercise_5`).**
   If the dialogue is similar as below, click *Run*.



3) Inspect the results. Make legends for all these maps (are they discrete, continuous or Boolean?).
   - What does the Drainage Basins map show? Does it already give a good indication of the Rur catchment?
   - What does the Flow Direction map show? What does the legend mean? Make a nice legend using styling.
   - Does the stream delineation map (`channels`) reflect well the flowline of the Rur river? Drag it to the top of the layers list and give it an intuitive style. Overlay the Channels vector on OpenStreetMap to see if the derived streams fit with the rivers on the map (make them different than blue to see the difference with the map. What went well? What went wrong? Why?



9.10 Define outflow point

A catchment is an extent or an area of land where surface water from rain, melting snow, or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. In order to delineate a catchment we need to have two fundamental data:

- the coordinates of our outlet in the same coordinate system as the map we are using
- the channel network that matches the flow directions as calculated from a hydrological correct DEM

The outflow point of the Rur catchment is in Roermond an can be found in the given shapefile `source_mouth.shp`. The channel network that has been derived is in `channels.shp`.

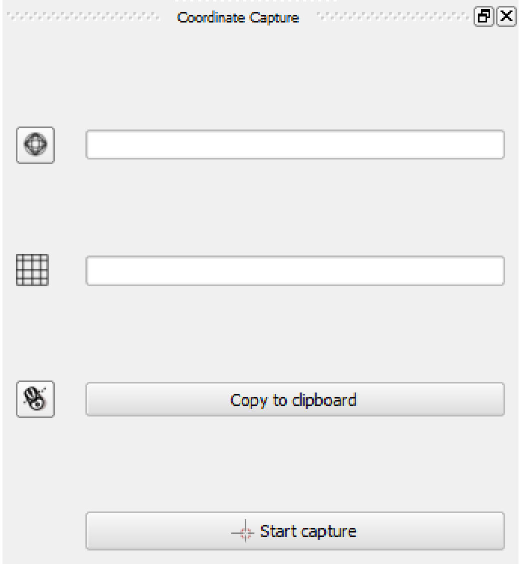
1) Make sure you have the `channels.shp` layer on top of the OpenStreetMap layer from the QuickMapServices plugin.
2) Check that the `source_mouth.shp` (1) has the same projection as `channels.shp`, and (2) that the outflow point is located exactly overlapping the delineated river in `channels.shp`. If the outflow point is not exactly over the delineated river, the catchment will not be delineated. In that case we need to look for a location over the delineated channels as in this example:

Note that there has been some distortion for 3 reasons:

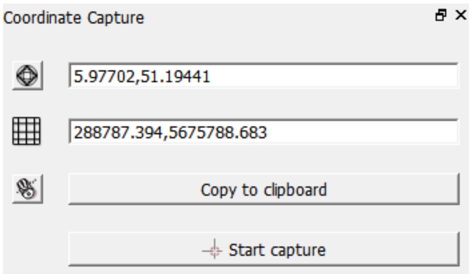
- Incorrect automatic delineation of streams, which can be caused by errors in the DEM or areas that are too flat
- Distortion due to on-the-fly reprojection
- Human influence on the natural course of the channels

3) Now use the coordinate capture tool to get the coordinates of the outflowpoint in `channels.shp`. You can find the coordinate capture tool from the menu: *Vector* → *Coordinate capture* → *Coordinate capture*. Or look for this icon in the icon panel on the left

of the screen: . Note that the plugin needs to be installed and activated (check the box in the *Plugins Manager*). Another panel will show up:



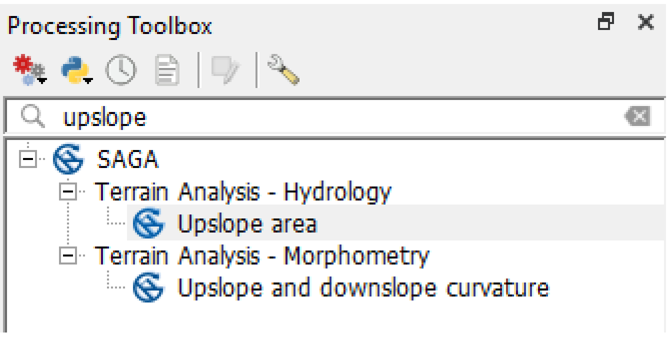
4) Click on *Start capture* and click on a point on the delineated river close to the mouth of the Rur as indicated in the figure. Make sure you capture it from the river in `channels.shp`, because the background map (OpenStreetMap) has not been derived from the DEM and will result in errors in the catchment delineation. What projection are we using? How do you know?



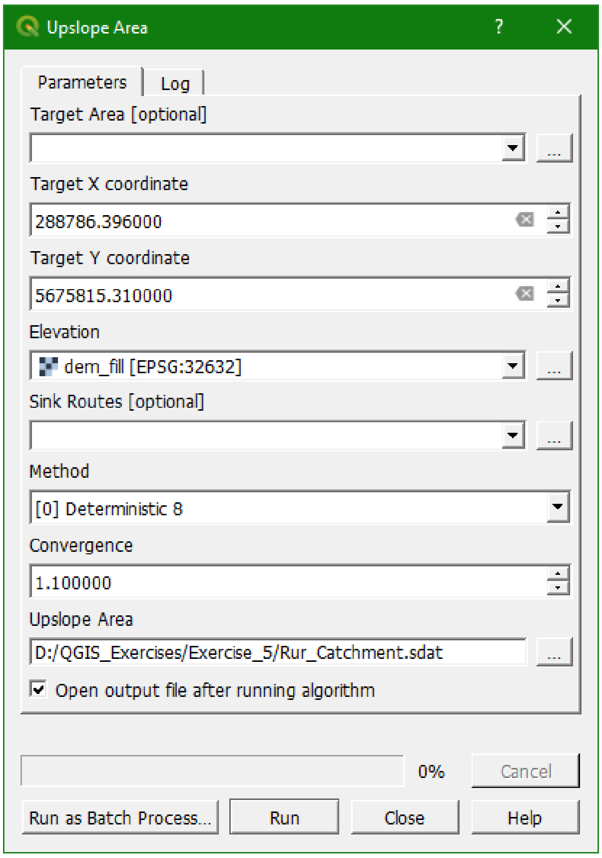
9.11 Delineate catchment

Now we're going to use these coordinates to calculate the upstream area that produces discharge at this point.

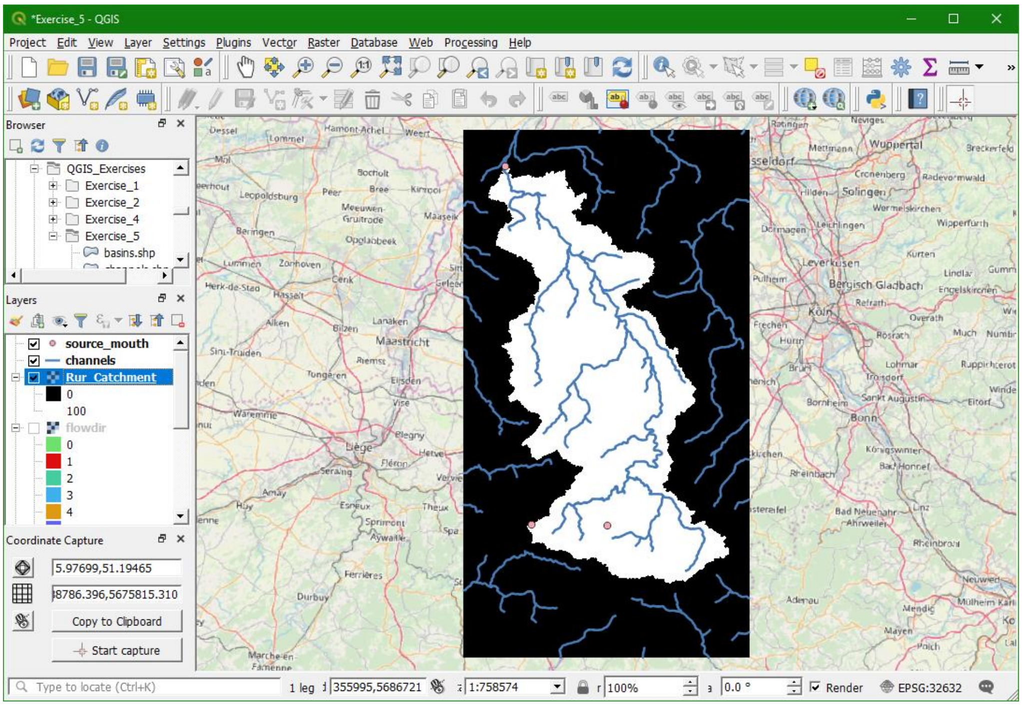
1) In the Processing Toolbox search for `Upslope Area` and choose *SAGA* → *Terrain Analysis - Hydrology* → *Upslope Area*



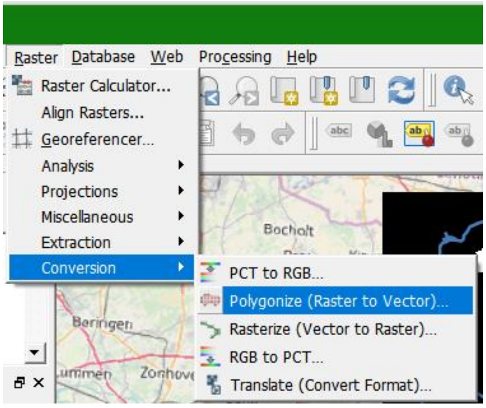
2) Fill in the dialogue as below. Use the coordinates that you captured near the outflow point. For elevation use your filled DEM. Use the default D8 method. Name the output `Rur_catchment.sdat`. Click *Run*. Click *Close* after the algorithm is done.

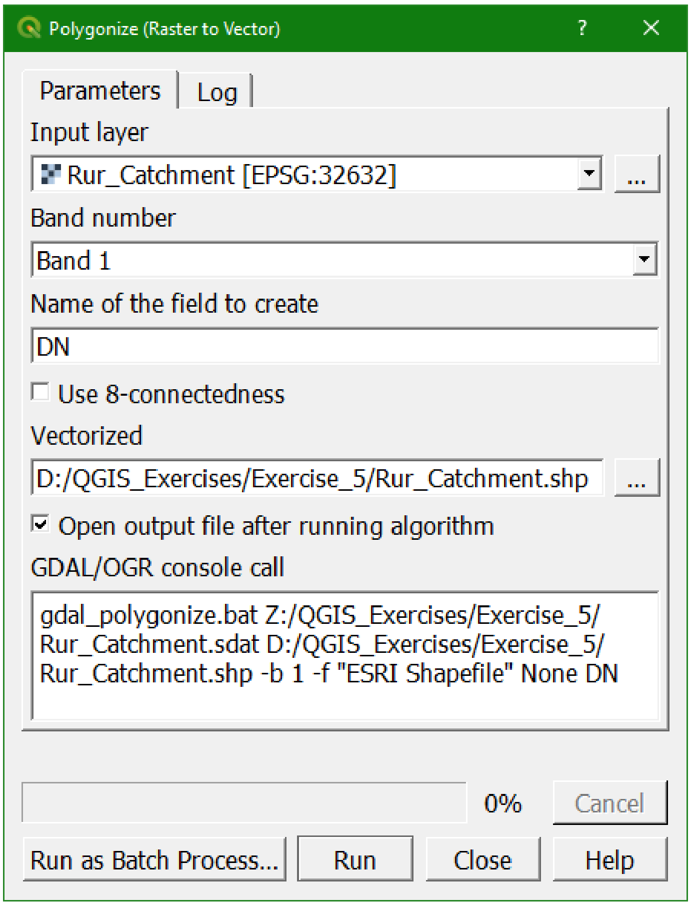


The result should look like the screenshot below.



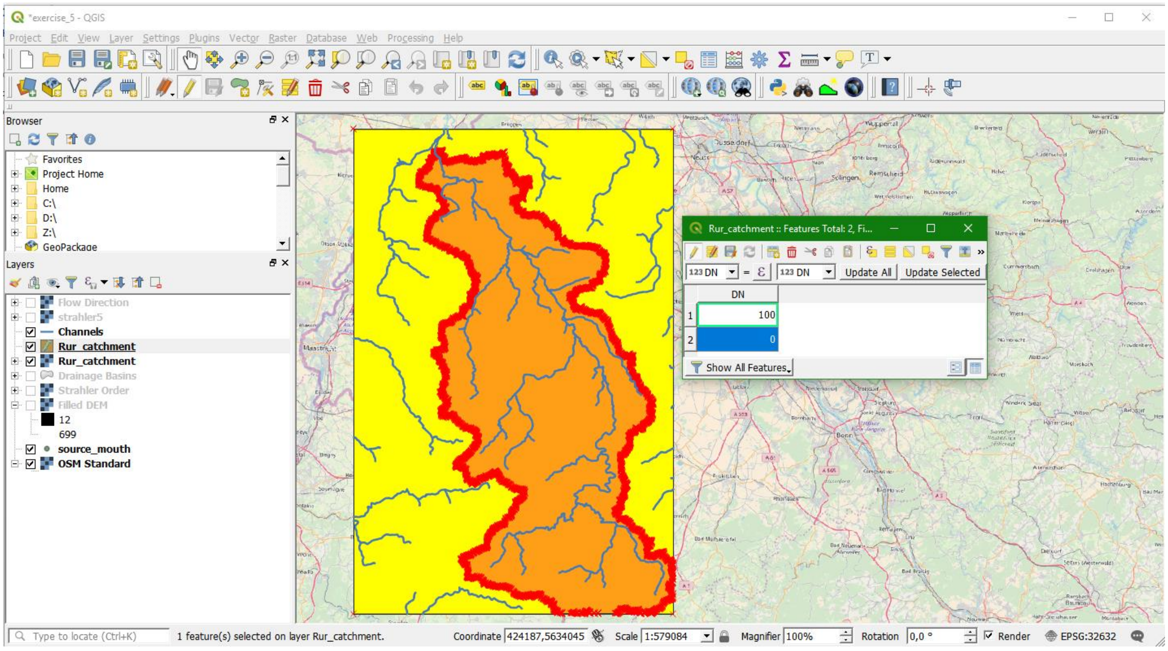
3) In order to overlay the catchment boundary with other data, it is better to convert it from raster to vector (polygon). To convert the raster layer to vector, go to the menu and choose *Raster* → *Conversion* → *Polygonize (Raster to vector).* Make sure you choose the right input and call the output `Rur_catchment.shp`. Click *Run*. Click *Close* to get back to the main screen.



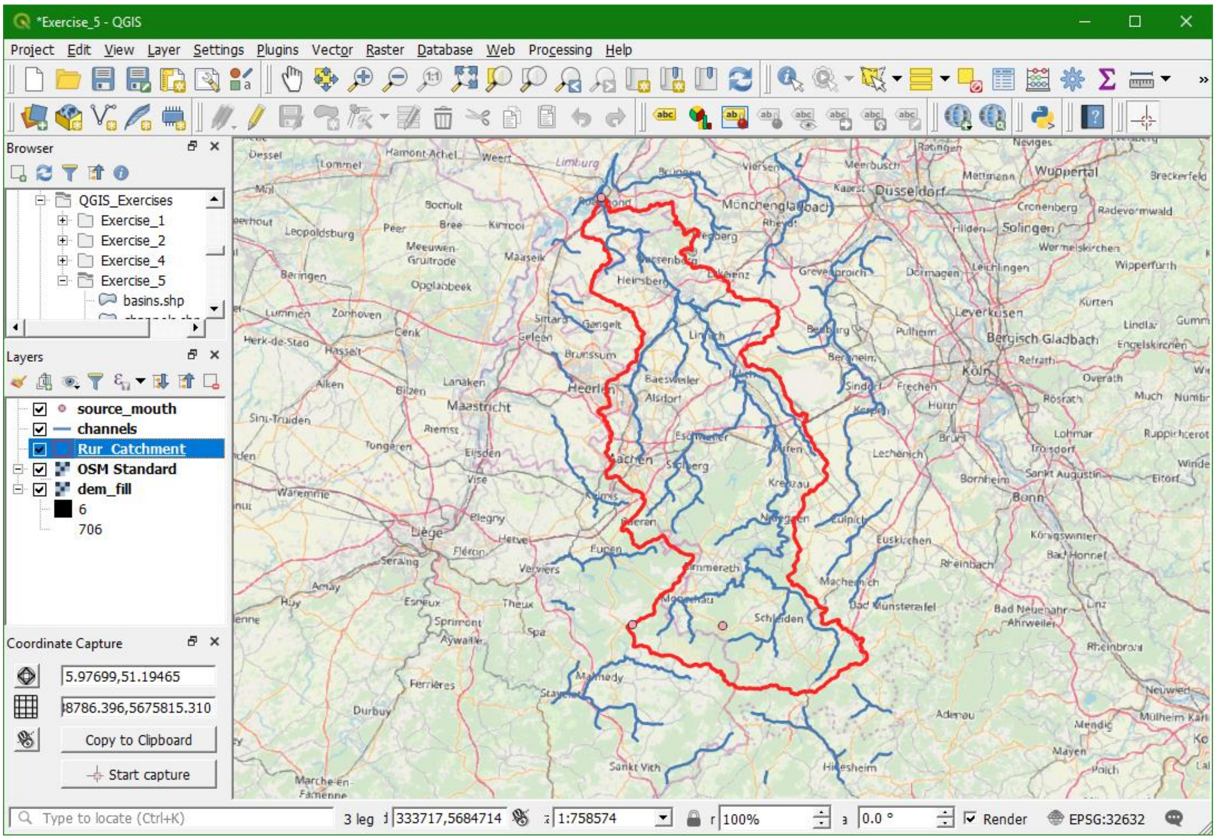


4) Look at the result. Also check the attribute table (Click right on layer name and choose *Open attribute table*). What value has the inside of the catchment polygon? What value has the outside area?

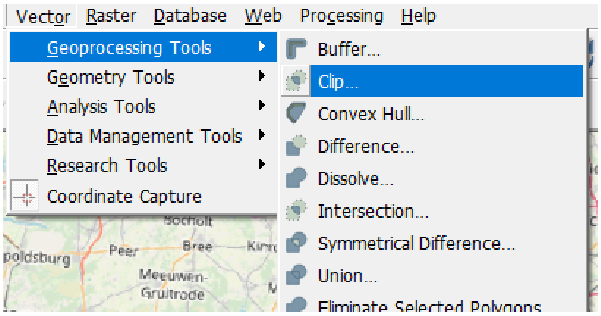
5) Of course we are only interested in the catchment area, so we have to remove the outside polygon. In the attribute table toggle to editing mode by using this button: . Then select the record that you want to remove. The selection will be highlighted in yellow on the map. Then click  to delete the selected feature and toggle off the editing by clicking again  and save the changes.



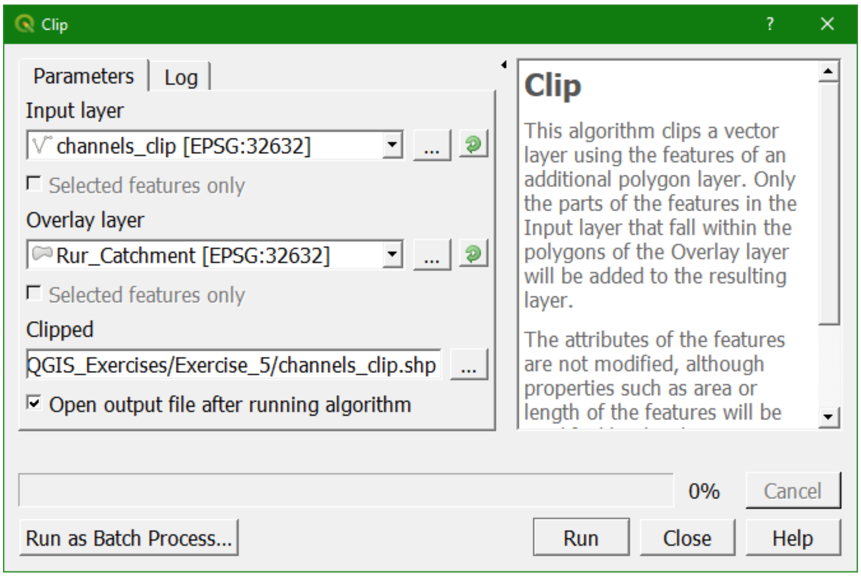
6) Now remove all unnecessary layers from the layers list so that we have only `Source_mouth`, `Channels`, `Rur_catchment`, `OSM Standard` and `Filled DEM` (in that order).



7) We can clip the `Channels` vector layer to see only the streams that are inside the catchment. Go to the menu and select *Vector* → *Geoprocessing Tools* → *Clip*. Sometimes the topology of the catchment polygon has some problems. In that case you can try other clip functions from the *Processing Toolbox*.



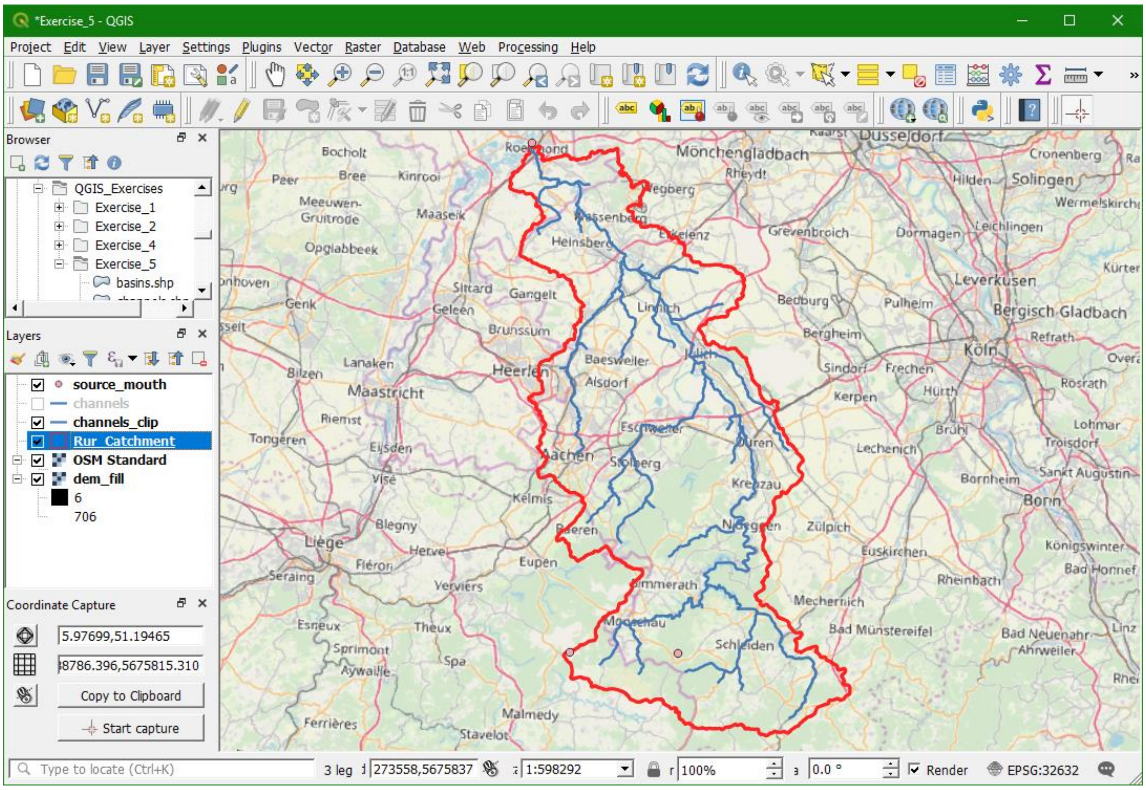
8) Fill in the dialogue as below to use the `catchment` layer as a "cookie cutter" to clip the channels shape file to the catchment extent. Call the output `channels_clip.shp`. Click *Run* to run the tool. Click *Close* to return the main screen.



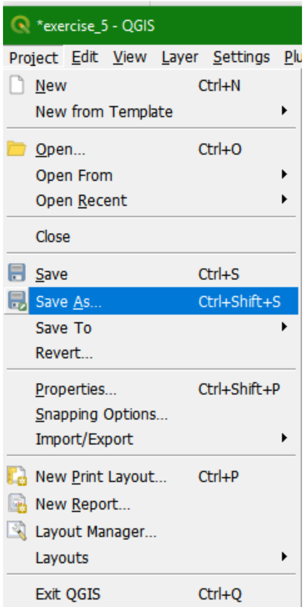
9) Remove `Channels` from the layers list and drag `channels_clip` to the top of the list.

10) Give `channels_clip` an intuitive colour and make the `Rur_catchment` polygon hollow (no fill colour) and give it a thick red border. You can do this by clicking right on the layer name, selecting *Properties...* and go to the *Symbology* tab. *You can also press* `<F7>` *to open the styling dock and set the styling options for different layers from there.*

The result should be similar to this:



11) At this point save your project. Choose from the main menu *Project* → *Save as...*



12) In the dialogue that follows, browse to `D:\QGIS_Exercises\Exercise_5` and save your project as `Exercise_5.qgz`
13) Now try to calculate slope, aspect and hillshade using the functions in the menu *Raster* → *Analysis* or the processing toolbox and make some nice maps with good legends.

This whole exercise can be viewed in a screencast at: https://youtu.be/Ro-RRzMMw-c

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Exercise 6: Using Open Data

10 Using Open Access data

10.1 Introduction

Now that we have defined the boundaries of our study area, i.e. the Rur catchment, we can look for open access data that is available on the internet. In this exercise we will use

- Data from the European Environment Agency (EEA) public map services: http://discomap.eea.europa.eu
- Data from OpenStreetMap: http://www.openstreetmap.org

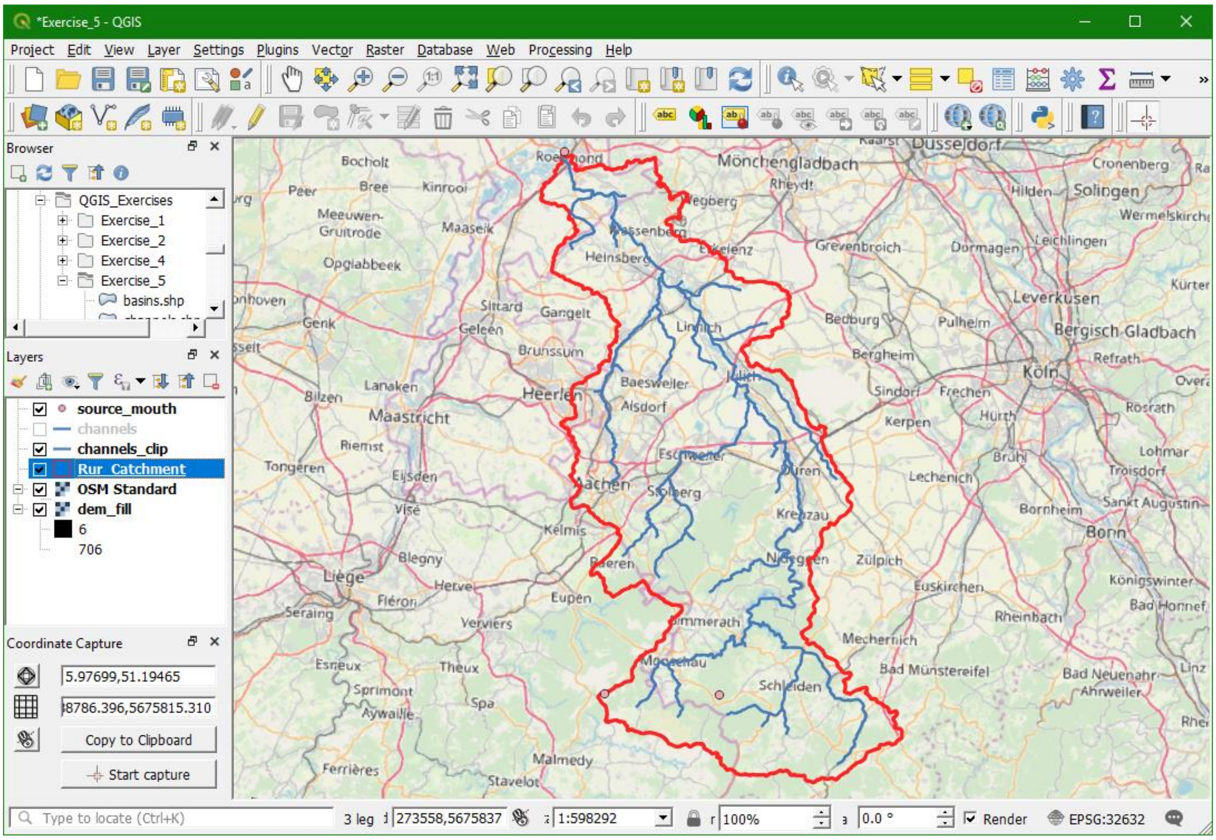
Instead of using a web browser, we will create a live link between the online data and our data in QGIS, using Web Map Services (WMS), which is an open standard for sharing maps through the internet and we will also download vector layers from OpenStreetMap through QGIS.

For this exercise you need the delineation of the Rur catchment and its streams from the previous exercise. You can also download them from the Open Courseware website (http://ocw.unesco-ihe.org).

Before we start, make sure that you have the following layers on your screen:

- Boundary of the Rur catchment
- Streams in the Rur catchment
- OSM Standard backdrop from the QuickMapServices

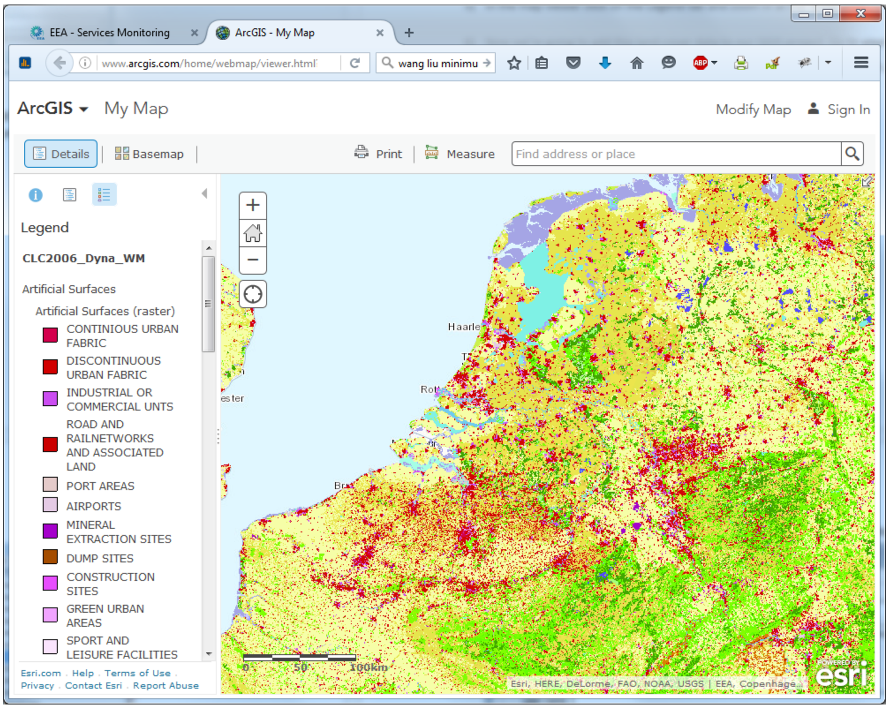
Your screen looks now like this:

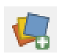


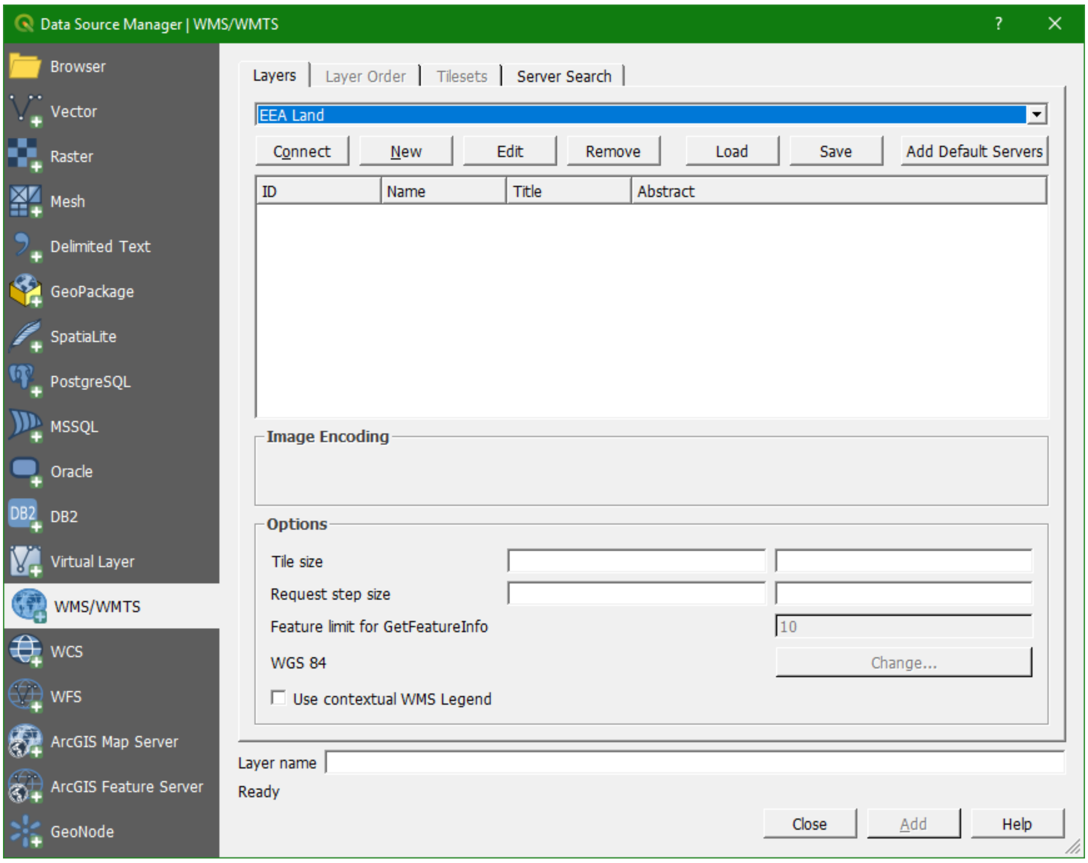
10.2 Adding data from the European Environment Agency (EEA) public map services

The European Environment Agency (EEA) is the agency of the European Union (EU) that provides independent information on the environment, thereby helping those involved in developing, adopting, implementing and evaluating environmental policy, as well as informing the general public. The European Environment Agency provides maps on thematic areas such as air, water, climate change, biodiversity, land and noise. The map services are accessible through http://discomap.eea.europa.eu. In this exercise we will add data from the EEA public map services to our QGIS project.

1) Go to the website http://discomap.eea.europa.eu. There you see a list of themes.
2) Click on Land under Land. Here you can see the EEA datasets related to land cover and their descriptions.
3) Look for the CLC2012 ETRS89 LAEA (MapServer) data and click on *More info* to see what data it contains.
4) Click on the picture of the map on the left to open an interactive map viewer
5) In the map viewer click on the Legend tab and zoom in at the study area.



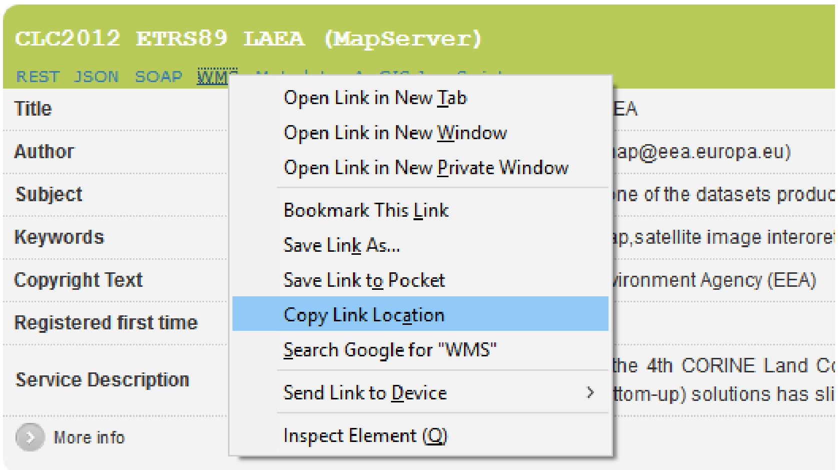
6) Now we're going to add this land-cover data to our QGIS project. Go to your QGIS project. From the main menu choose click the *Open Data Source Manager* button 
7) In the *Data Source Manager* dialogue choose *WMS/WMTS*



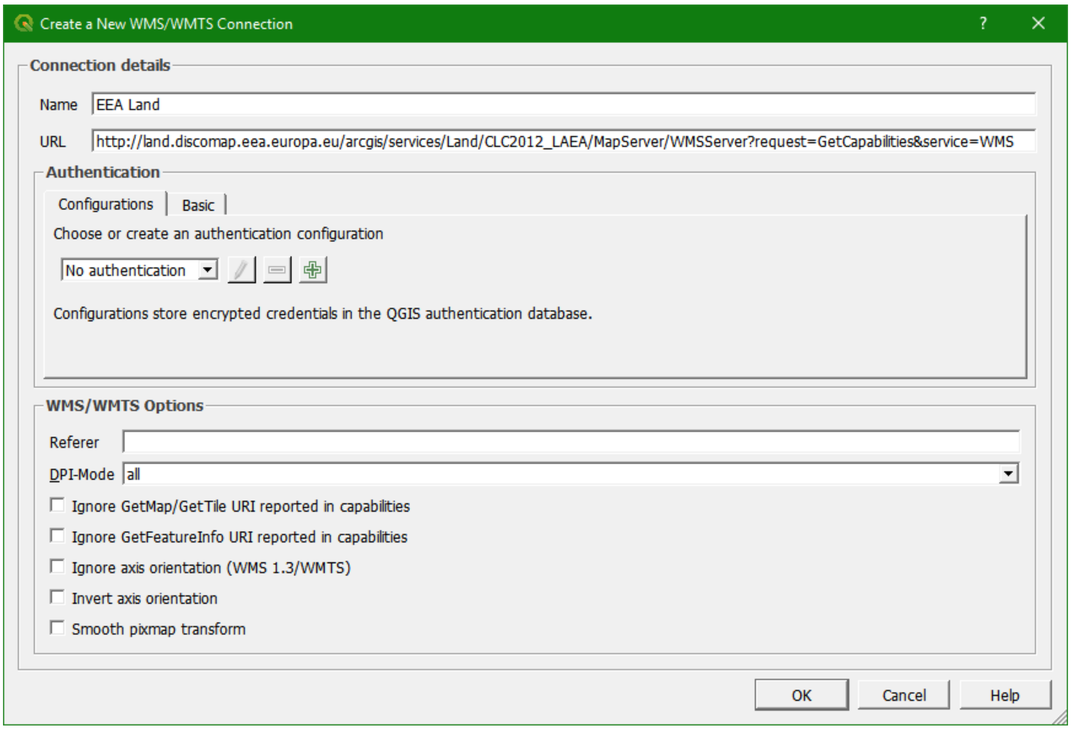
8) In the dialogue that opens click the *New* button.

9) In the dialogue that follows type for *Name*: EEA Land

10) We can find the URL on the website: below the title of the CLC2012 ETRS89 LAEA (MapServer). Click right on WMS and choose *Copy link location*

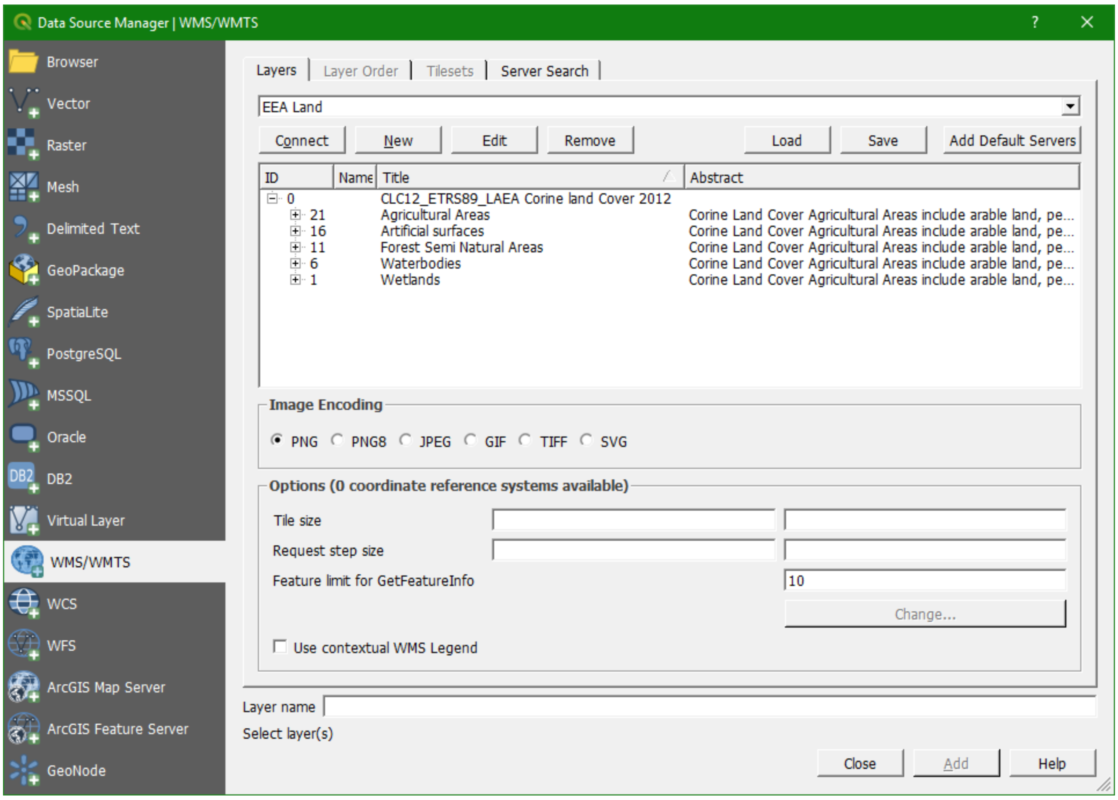


11) Paste the link in the QGIS dialogue (see screenshot below), keep the defaults and click *OK*.



12) Back in the other dialogue window click *Connect*. The layers will now be retrieved from the WMS server

13) Click on *Wetlands* so that it is highlighted, choose PNG for the Image encoding format (this allows transparency) and check the box before *Use contextual WMS legend*. Then click *Add* and *Close* to return to the main screen. Note that WMS layers are georeferenced pictures, not vectors.



- You can see that the source area of the Rur catchment is located in wetlands. What are the names of these wetlands?
- In which country/countries are these wetlands?

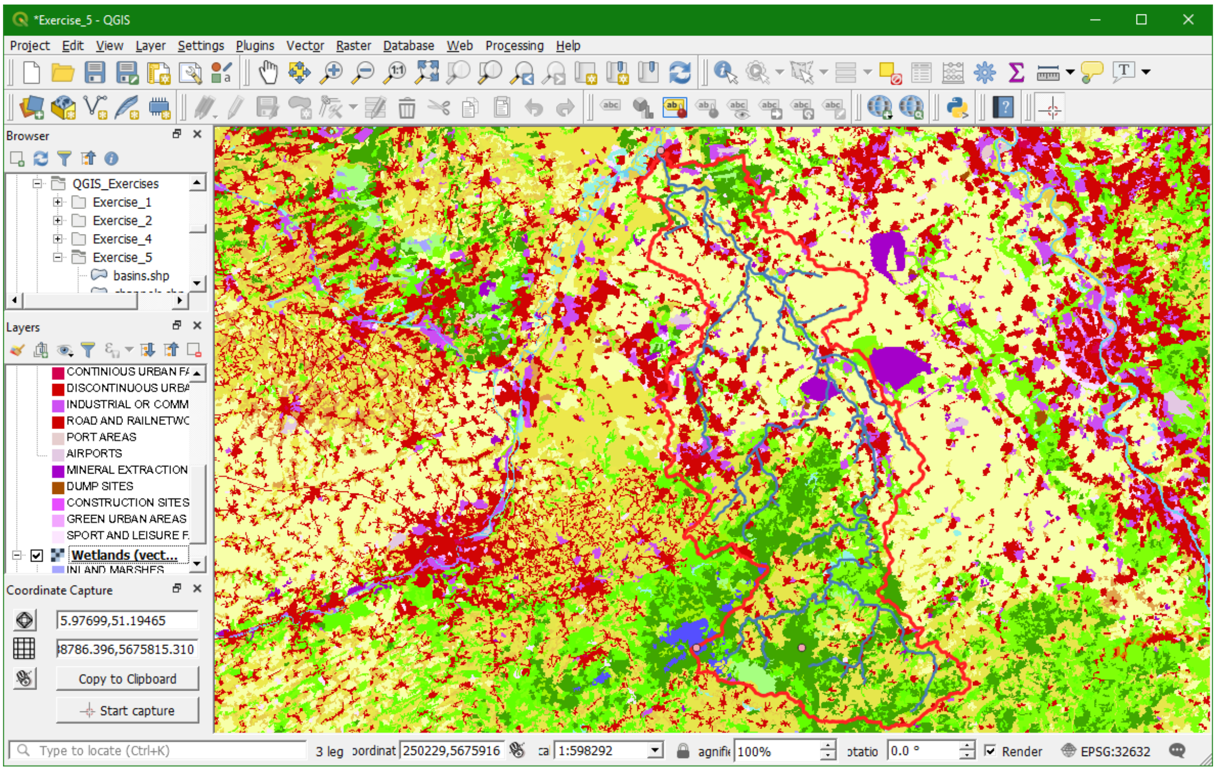
14) Now add in a similar way Artificial Surfaces.

- In the midstream part of the catchment there are some large purple areas. What are these?
- Add Google satellite from the QuickMapServices to have a closer look at these features. Describe what you see.
- What are the other Artificial Surface classes in the map? Can you describe the geographical distribution of population in the Rur catchment?
- What are the largest cities in the catchment?

15) Load the remaining classes.

- Where are the forests and agricultural areas located?

16) Now rearrange the layers as such that you have a map with the catchment boundary, stream network and land cover classes.



17) Save the project before you continue.

If you have time, you can look for more EEA data in a similar way.

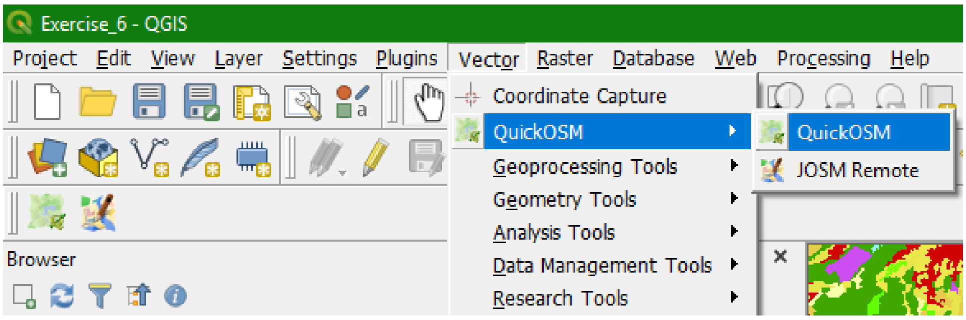
10.3 Adding vector data from OpenStreetMap

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. OSM is considered a prominent example of volunteered geographic information (VGI) or crowdsourcing. There are several ways to use the data:

- Through the interactive map on the OpenStreetMap website (http://www.openstreetmap.org)
- In QGIS through the QuickMapServices Plugin
- In QGIS through the option to download OSM data directly from the internet. There are several ways to do this. In this exercise we'll use the QuickOSM plugin which uses the Overpass API (https://wiki.openstreetmap.org/wiki/Overpass_API).

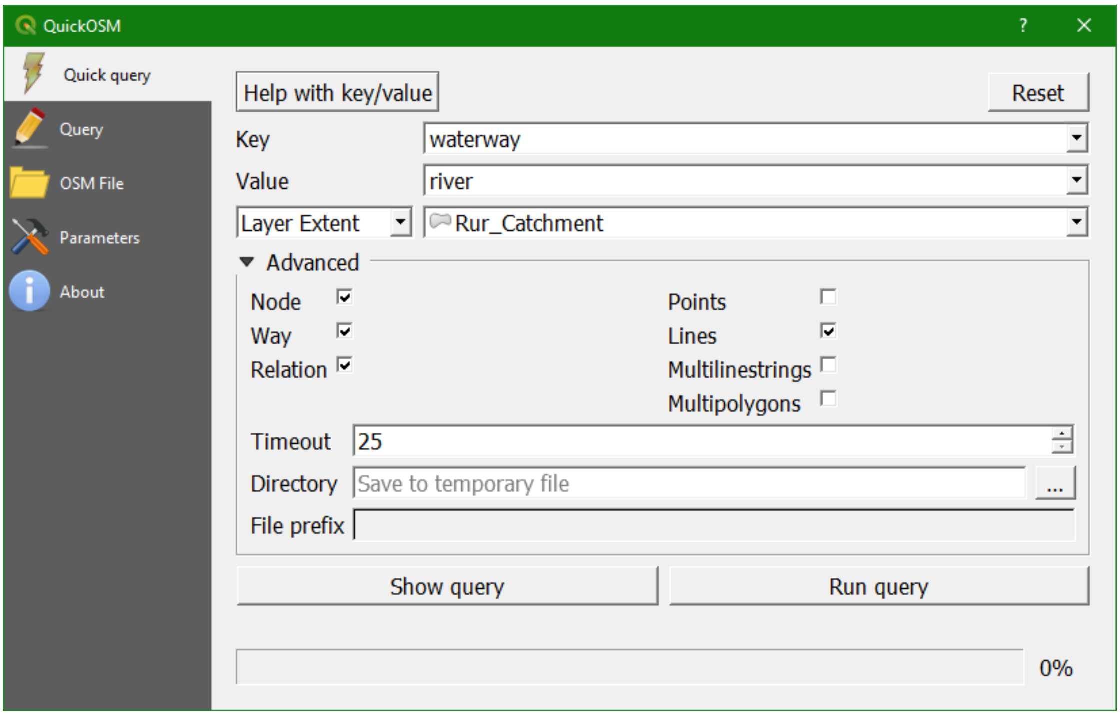
In this exercise we are going to download OSM vector data directly in QGIS for the Rur Catchment. We continue from the previous results, but we only visualise the `Rur_Catchment` and `Channels_Clip` layers. The other layers should be unchecked.

1) Install the QuickOSM plugin through the main menu: *Plugins* → *Manage and Install Plugins*… Search for QuickOSM
2) Open the QuickOSM dialogue by choosing from the main menu: *Vector* → *QuickOSM* → *QuickOSM*

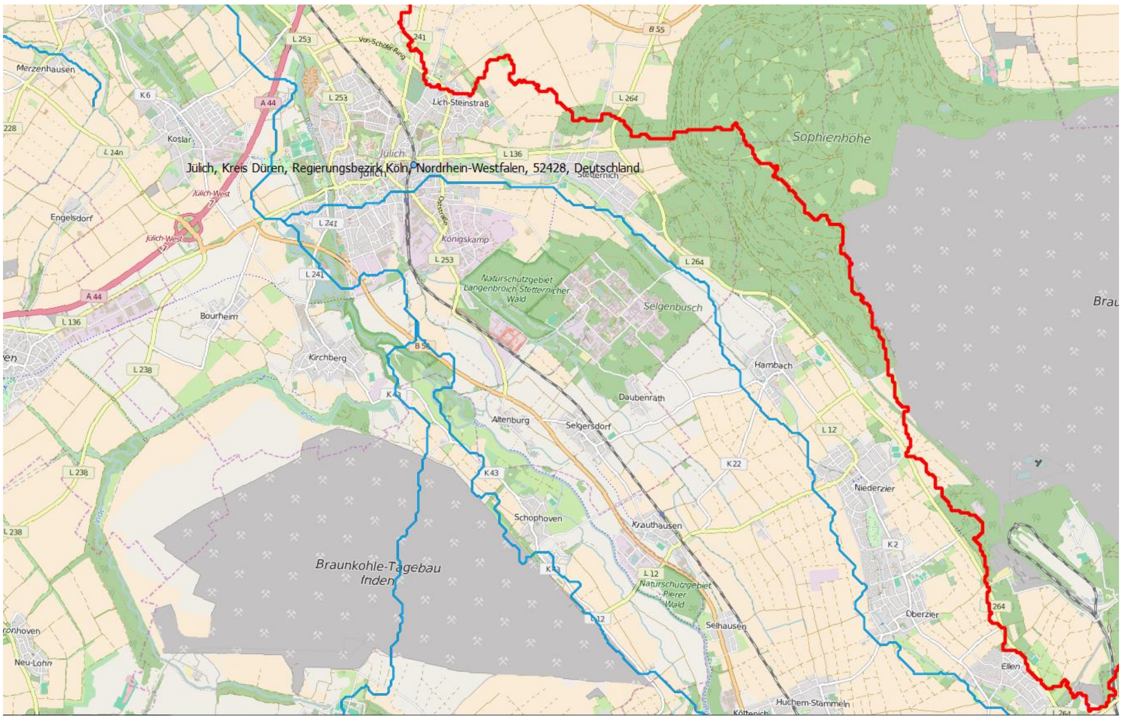


We're first going to download the rivers so we can compare them with the rivers that we have derived before. The OSM data attributes consist of keys and values. To learn more about it, click *Help with key/value*.

3) Choose `waterway` as *Key*, `river` as *Value*. Choose the `Rur_catchment` polygon as the extent. Click the arrow before *Advanced* and make sure only *Node*, *Way*, *Relation* and *Lines* are checked. The dialogue should now look like the screenshot below. Click *Run Query*.



4) Adjust the style and compare the `waterway_river` from OSM with the `Channels_Clip layer`. What do you observe?
5) Let's add the mines in a similar way. The `key=landuse`, `value=quarry`. Don't forget to select *Multipolygons* instead of *Lines*.
6) Try to locate Jülich. You can also use the **GeoCoding** plugin to locate Jülich. You can install it through the menu: *Plugins* → *Manage and Install Plugins*… . Search for GeoCoding. The GeoCoding plugin uses web services (Nominatim and Google) to retrieve the coordinates of an address.
7) Now zoom in on the centre of Jülich (see figure below).



Southeast of Jülich is the Forschungszentrum Jülich, a large research institute. In the south and east we see a large surface mining of lignite. The one in the south is in the Rur catchment.

8) Now compare the OSM derived quarry with a Google Satellite and the EEA artificial surfaces map. What are the differences? Which one is more up-to-date? Google Satellite, EEA or OSM? How does the hydrography relate to the quarry (OSM vs GIS delineated)?
9) Save the quarry polygons as a shapefile: click right on the layer, choose *Save as...*
   In the dialogue, save the file as `quarries.shp` in the right folder using the *Browse* button. Click *OK* to save the shapefile.
10) Now add a few other interesting features (points, lines and polygons), e.g.:
    - Dams: `Key=waterway, value=dam`
    - Lakes: `Key=natural, value=water`
    - Springs: `Key=natural, value=spring`
11) Style the layers with intuitive colours.

11 Create 2D and 2.5D maps

11.1 Introduction

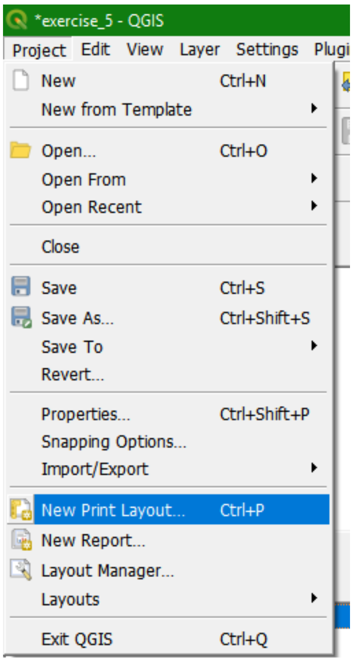
With the GIS data collected in the previous exercises, we are now ready to produce some maps to take with us in the field. In this exercise we will produce two types of maps:

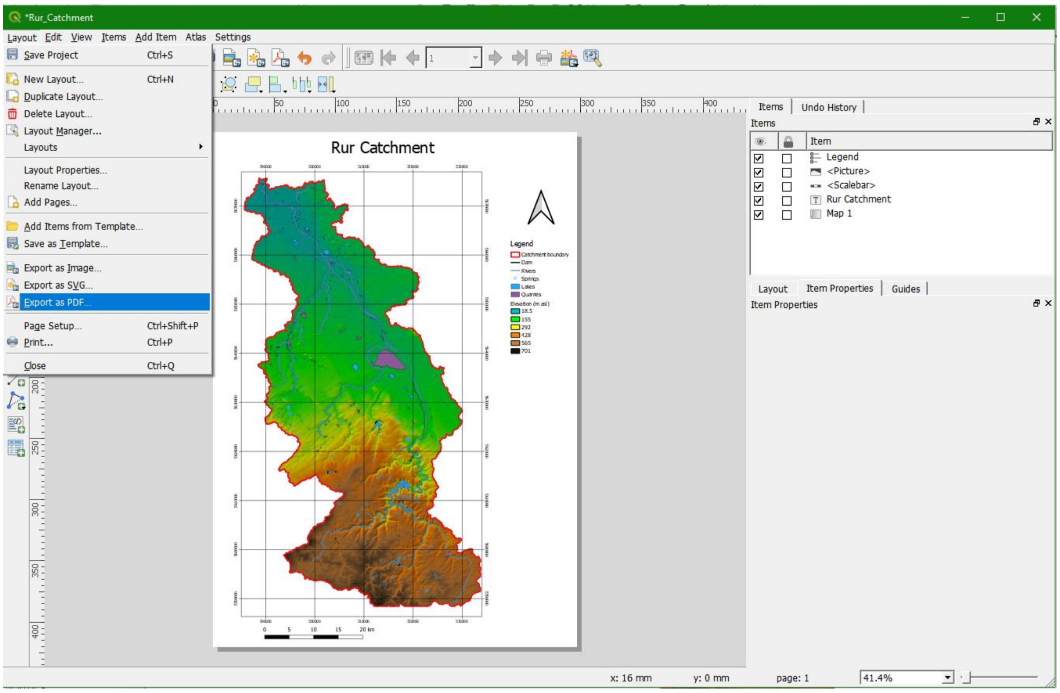
- A PDF map with coordinate grid, north arrow, scale bar and legend (2D)
- An interactive 2.5D map to visualise the layers draped over the DEM

You can make maps through combination of layers that we have collected in the previous exercises.

11.2 Creating a PDF map

1) First arrange the layers on the screen in such a way that all layers you want to have in the map are visible and at the right zoom level. Also verify that the on-the-fly projection is EPSG:32632.
2) Configure the right styling of the layers. Remember to use intuitive colours.
3) Use the Print Composer (*Project* → *New Print Layout*) to create a map with all its properties (North arrow, scale bar, intuitive legend, etc.). Use the instruction video on eCampus.
4) When finished choose from the menu *Layout* →*Export as PDF…*

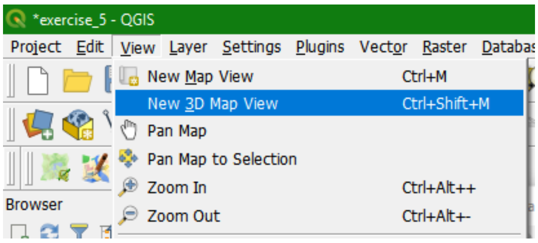




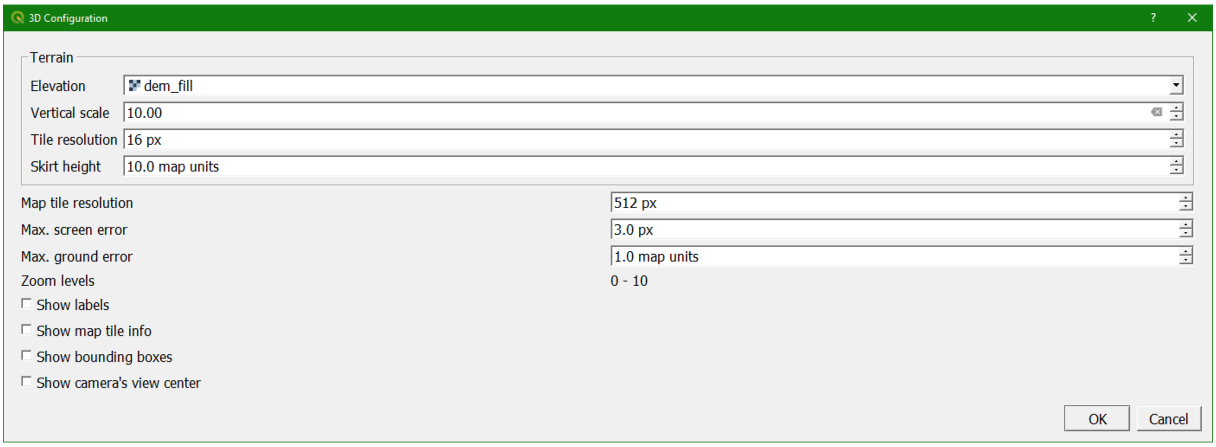
11.3 Creating a 2.5D interactive map

We can drape GIS layers over a DEM and create a 2.5D interactive map.

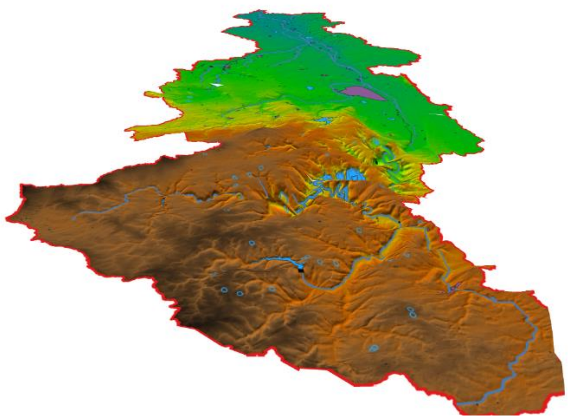
1) Open a new 3D map view by choosing from the main menu: *View* → *New 3D Map View*



2) In the new 3D Map View (*3D Map 1*) click the configuration button 
3) In the *3D Configuration* dialogue choose the `Filled DEM` as *Elevation* and choose `10` for the *Vertical scale* (the area is quite flat so we exaggerate 10 times). Keep the rest as default and click *OK*.

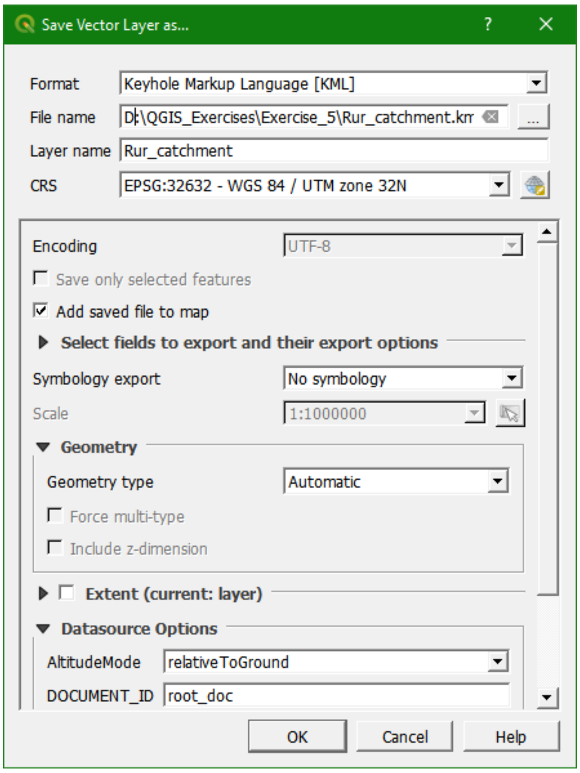


4) Enlarge the window. Use the scroll button of your mouse to zoom in/out. Drag the with the scroll button clicked to create an oblique view. Navigate through the landscape with the mouse or the arrow buttons. With the shift button pressed you can rotate around a point. With the  button you can save the result to a TIFF file to include the 2.5D map in a report.

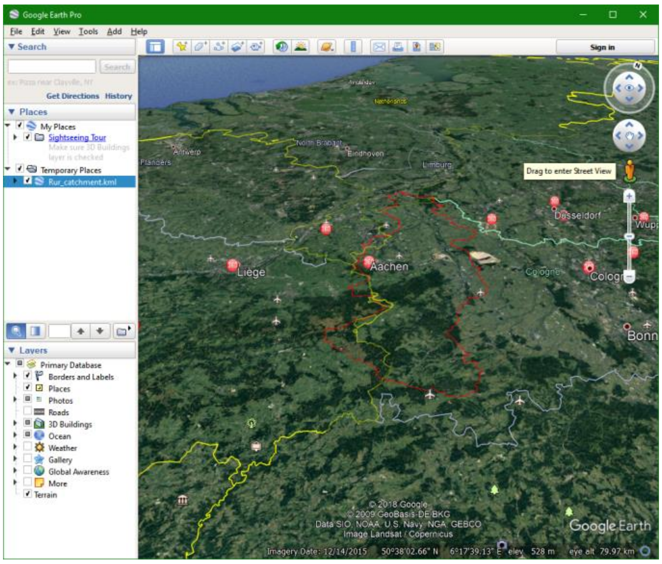


11.4 Export to Google Earth

1) You can also export files to Google Earth. To export the catchment delineation to Google Earth do the following: click right on the `Rur_catchment` layer and select *Export* → *Save features as...*
2) In the dialogue select *Keyhole Markup Language [KML]* as the output format. Choose an output filename and click OK. The resulting file can be opened in Google Earth by double clicking on the filename in Windows Explorer.



Note that the CRS does not matter. A KML file will always be saved in the projection that is supported by Google Earth.



Exercise 7: Map design

12 Styling and map design

12.1 Introduction

After this exercise you will be able to:

- Create a GeoPackage with data and styles
- Style vector layers
- Copy, import and export styles
- Design a map

In this exercise we are going to add mainly vector data related to water supply. The exercise encloses the styling of various vector layers and designing of a map with various map item in the print composer.

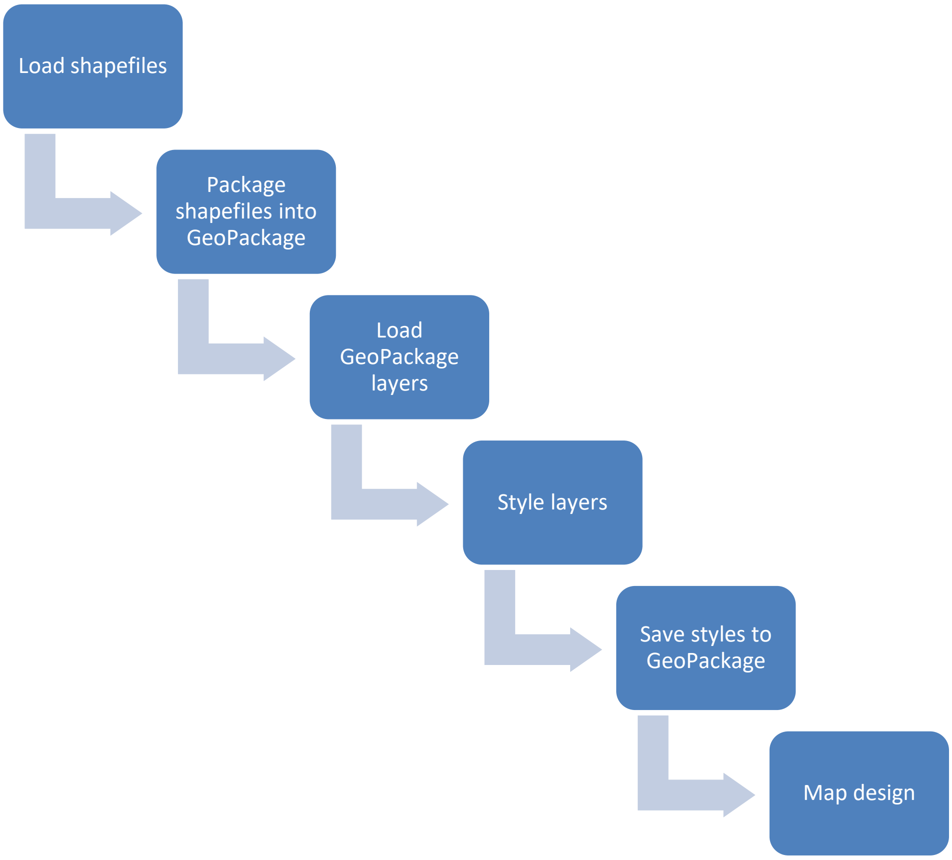
In this exercise we'll use the following data:

- `Area.shp (and associated files)`: polygon of the area of interest
- `Endcap.shp (and associated files)`: points of the endcaps
- `Household_connection.shp (and associated files)`: points of house hold connections
- `Hydrants.shp (and associated files)`: points of the hydrants
- `Pipeline.shp (and associated files)`: lines of the pipelines for the water supply
- `Source.shp (and associated files)`: points of the sources of water
- `Tanks.shp (and associated files)`: points of storage tanks for water

The dataset has been developed by Vitens Evides International and the National Water and Sewerage Corporation in Uganda.

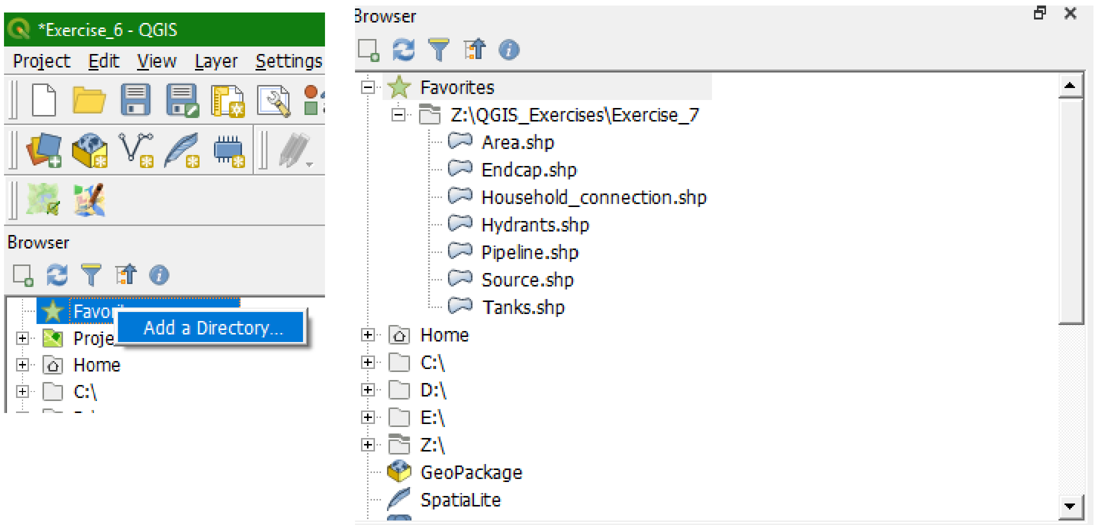
You can download the data for Exercise 7 from the OpenCourseWare website (http://ocw.unesco-ihe.org/course/view.php?id=11) and store the files in a folder on your harddrive (e.g. `D:\QGIS_Exercises\Exercise_7`).

This exercise will guide you through the following steps:

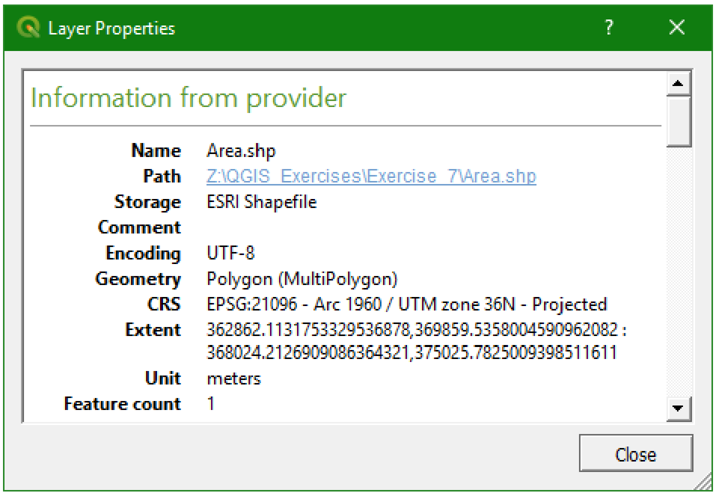


12.2 Creating a Favorite in the Browser Panel

1. Start QGIS Desktop.
2. Add the folder with the data from this exercise to the *Favorites* in the *Browser Panel*: click right on Favorites and choose *Add a directory…*. Then browse to the `Exercise_7` folder. The contents of the folder will now be listed under *Favorites* for easy access.



3. First we check the metadata. Click right on `Area.shp` and choose *Properties…*. What is the projection of this layer? Also check the projection of the other layers in the same way.

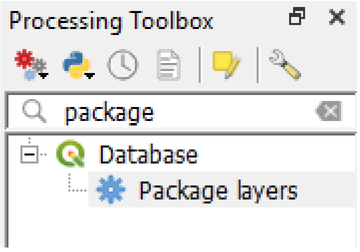


4. Now select all the layers from this exercise with the shift button pressed and drag them to the *Map Canvas*.

12.3 Creating a GeoPackage

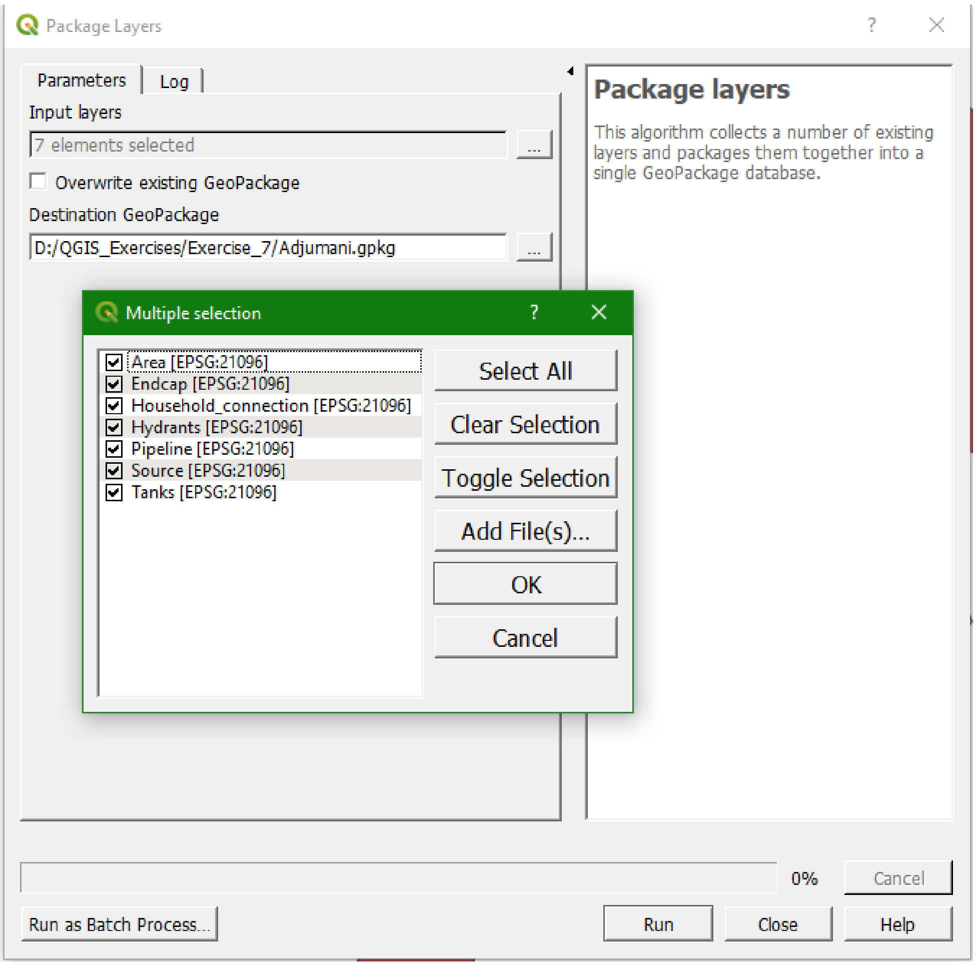
Before we start styling these layers we are going to save them all into a GeoPackage, so we have all the layers together in one file. Later we are also going to add the styles to the GeoPackage.

5. In the Processing Toolbox search for the Package layers tool

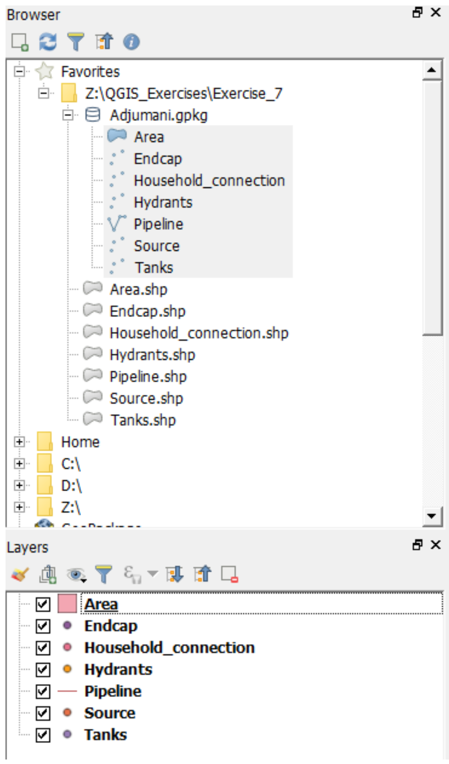


6. Double click on Package layers to open the *Package Layers* dialogue.
7. At Input layers click  and select all vector layers

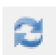
8. Choose `Adjumani.gpkg` as the *Destination GeoPackage*.



9. Click *Run*.



10. Now all the shapefiles have been stored in a GeoPackage you can remove all the shapefiles from the *Layers Panel* (right click → *Remove layer…*).

11. To add the new GeoPackage layers first refresh your Browser panel by clicking .

12. Click the plus sign before `Adjumani.gpkg` to see the layers in the GeoPackage.

13. Select all these layers and drag them to the Map Canvas.

14. Rearrange the layers so all data is visible.

12.4 Styling the vector layers

15. As a background, a satellite image can be used from the *QuickMapServices Plugin*. In the menu choose *Web* → *QuickMapServices* → *Google* → *Google Satellite*.

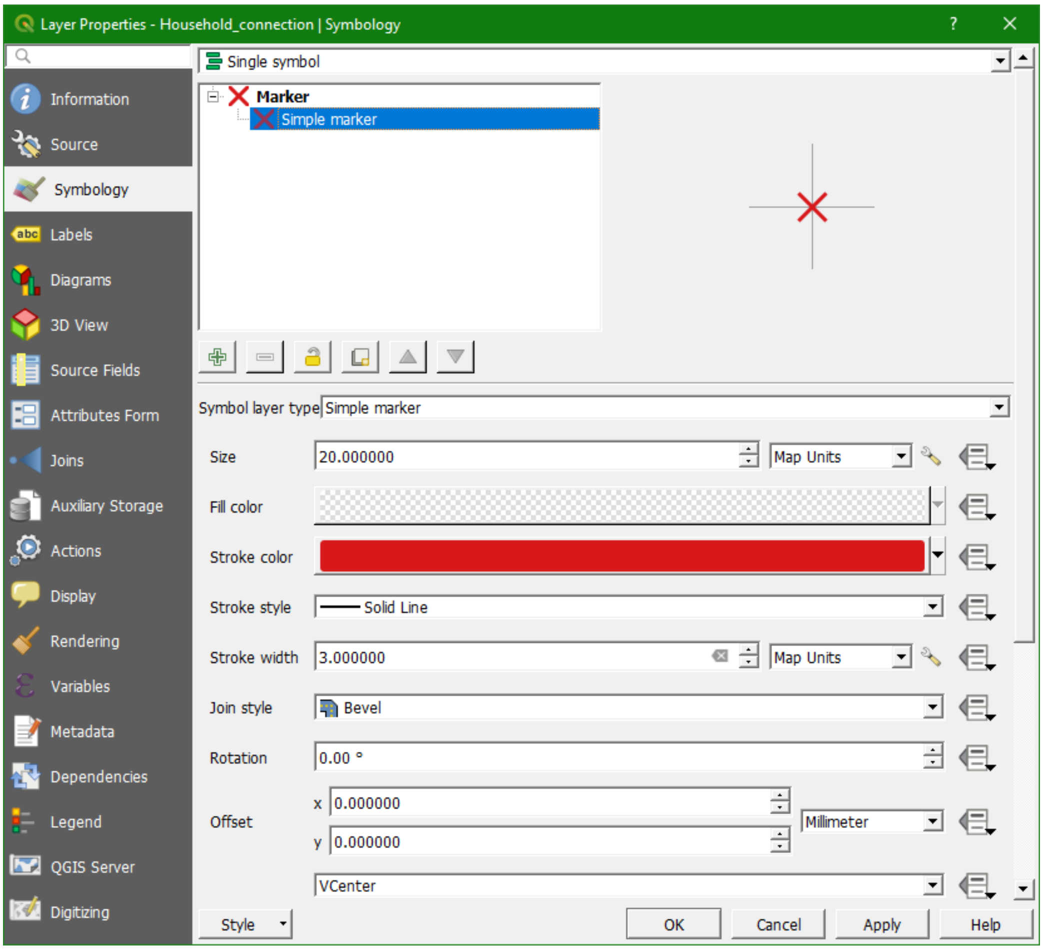
16. Place the vector layers and the Google Satellite image in a useful order by dragging the items in the layers list. For example, background images are normally the lowest layers.

We now start with styling the vector layers. Each layer is appointed a random style when you open it. Styling covers the colours, shapes, sizes, text labels. The styling is done under the properties of each layer (right-click on layer) or by using the *Layer Styling* panel by pressing <F7>.

17. Now choose *Household_connection* → *Properties* → *Symbology*.

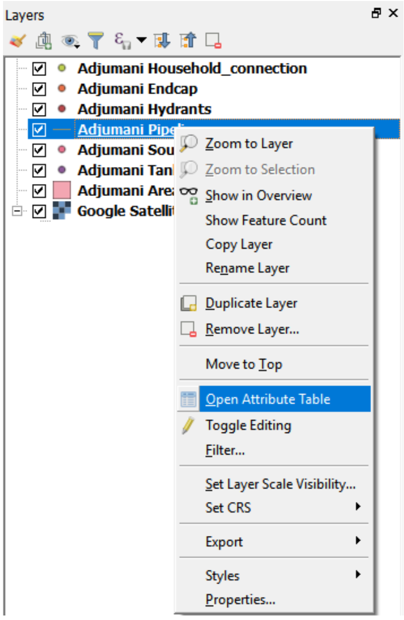
18. For the household connections a red cross will be the symbol to use. In order to do so select *simple marker* → *cross symbol*. The Stroke colour should be red.

19. You can enter for the *size 20 map unit* and for the *Stroke width 3.0 map unit*. You can choose between mm and map units. For millimetres the zooming level does not matter and the symbol always stays the same size, even if you zoom in very closely. When selecting map units, the symbol becomes bigger when you zoom in.

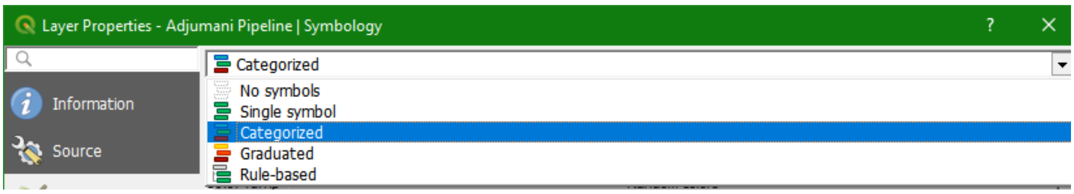


20. Click *OK* to close the dialogue and return to the map canvas.

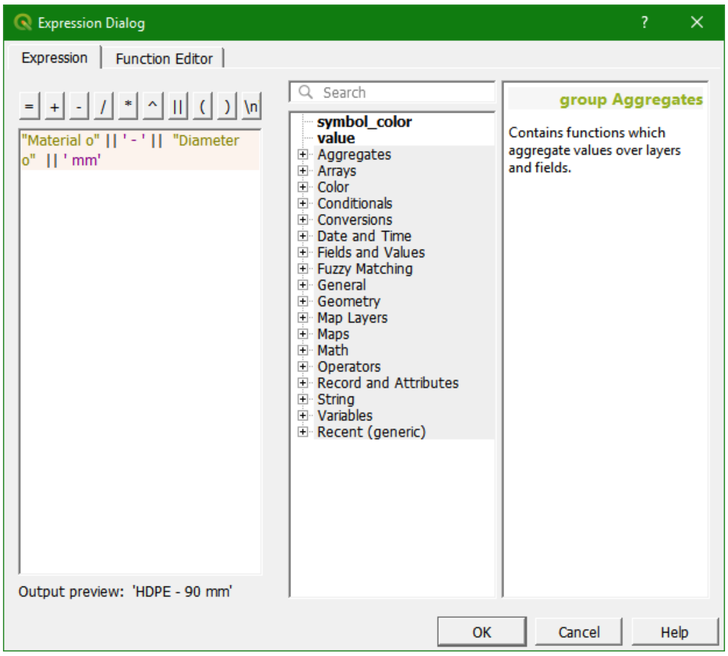
21. Open the attribute table of the `Pipeline` layer. Do this by clicking right on the layer and choosing *Open Attribute Table*. Investigate the type of information that is there.



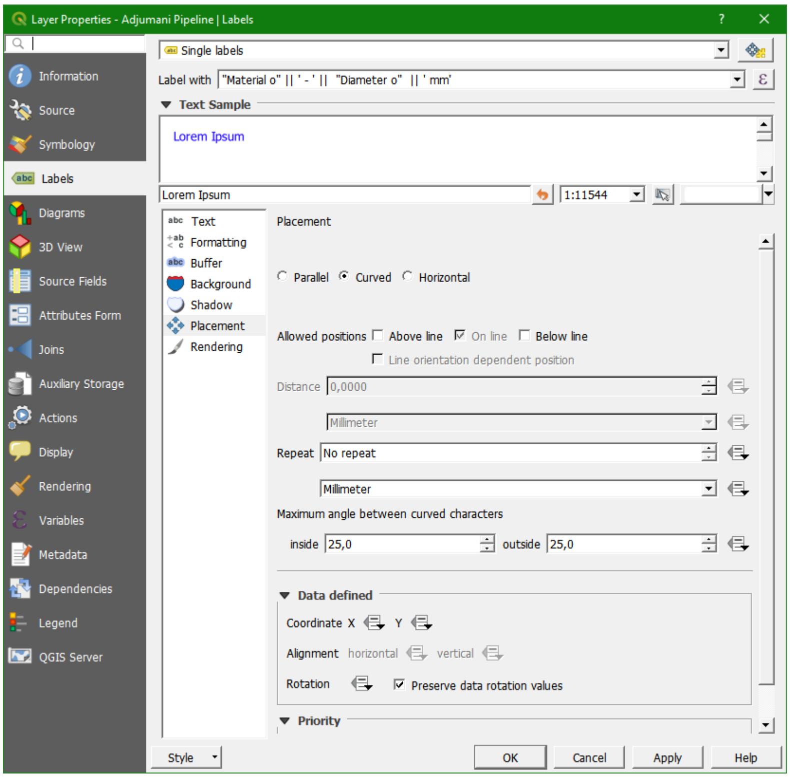
22. Now style the `Pipeline` vector layer by opening its properties. Instead of a *Single Symbol*, select the *Categorized*. In the map, there needs to be a distinction between the transmission lines and the distribution lines. In order to do so, which column do we need to select to categorize on?



23. After the selection of the correct column, click *Classify.* You will find two new symbols for 'Transmission' and 'Distribution'. By *double clicking on the lines* you can modify the style.
24. Choose an appropriate style according to your own insight. Just to remind you – use the map unit for the width of the line. After finishing the styling of the two layers, click *Apply.*
25. The map should also indicate the type of material and the width of the pipeline by not using anymore colours. For that we use text label, which you can also find in the *Layer Properties* tab on the left side. Choose from the dropdown menu *Single labels*. Now you can *select* a column using the drop down list at Label with.
26. If you want multiple columns in the label, you can enter an expression, which is next to the arrow. Click the ε button to enter the following expression:
`"Material o" || ' - ' || "Diameter o" || ' mm'`
    - ➢ The text between double quotation marks (") indicate the column.
      The text between single apostrophe (') is a text of string.
    - ➢ The double vertical bars (||) are necessary to have multiple strings next to each other.
    - ➢ If the preview looks okay, click *OK.*



27. The default text is not yet appropriate. To change this you find a lot of options below the 'Lorem Ipsum', which shows an example of how the text will look.
    - Under TEXT - For font use Tahoma, for size use 10 points, for colour choose blue.
    - Under Buffer - For Size use 1 mm
    - Under Placement – Choose curved, for position tick 'On line' and untick 'Above line'
    - Press *OK*



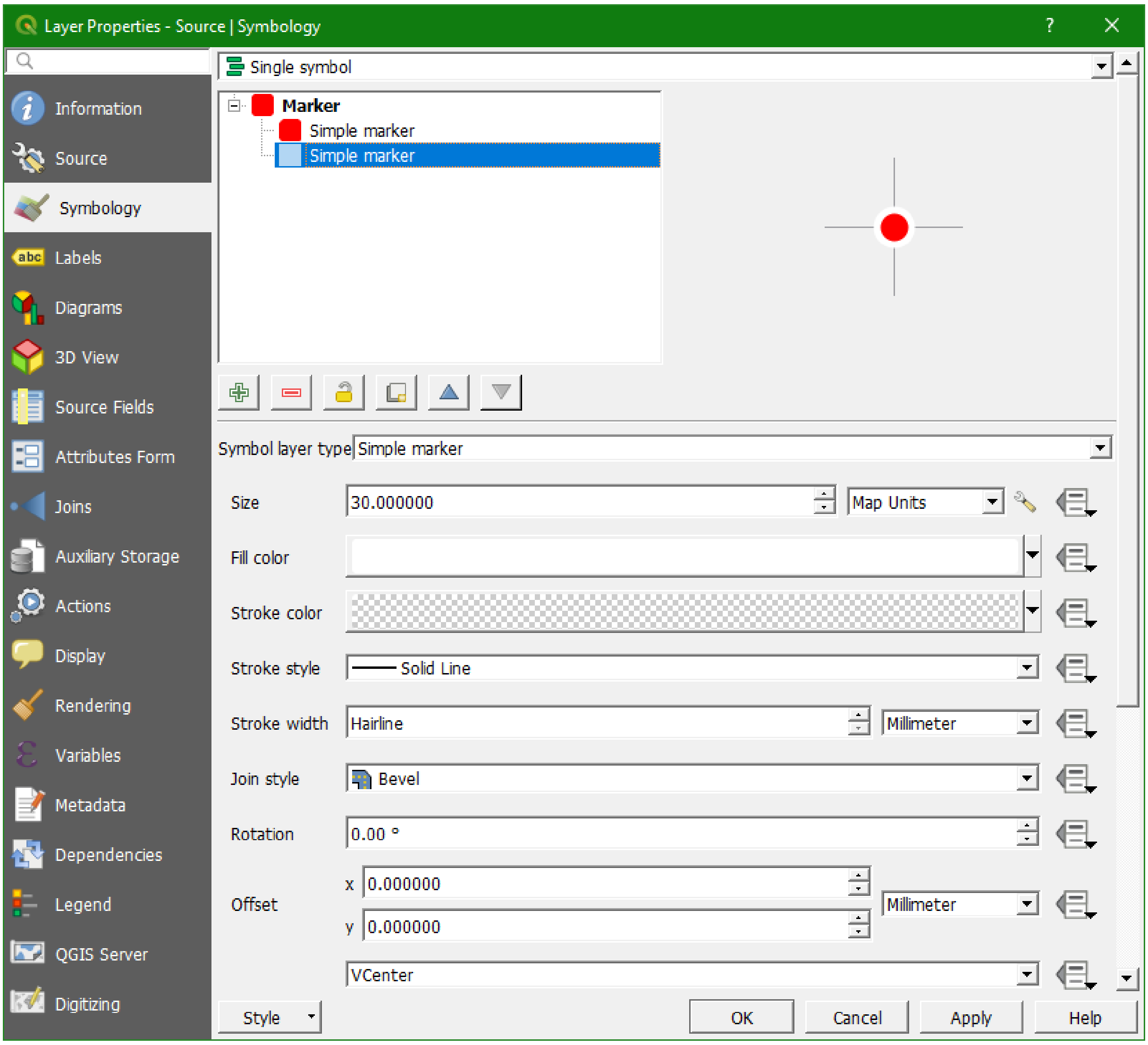
For the `Source` and the `Tanks` layers, the following two symbols will be created:

These are basically two simple markers. Here the marker for the `Source` layer will be discussed.

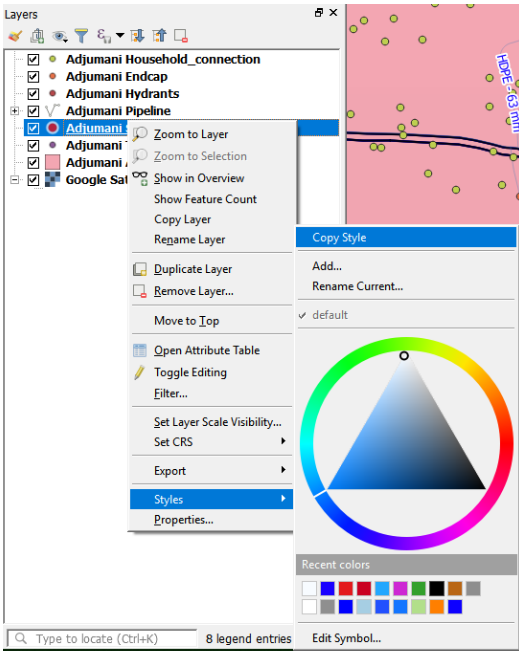
28. Open *Properties…* → *Symbology* and *Add a symbol layer* . Both simple markers should be a circle. For the top circle:
    - Make *Stroke color* transparent
    - Set *Fill color* to red
    - Set size to 20 map units

    For the lower circle:

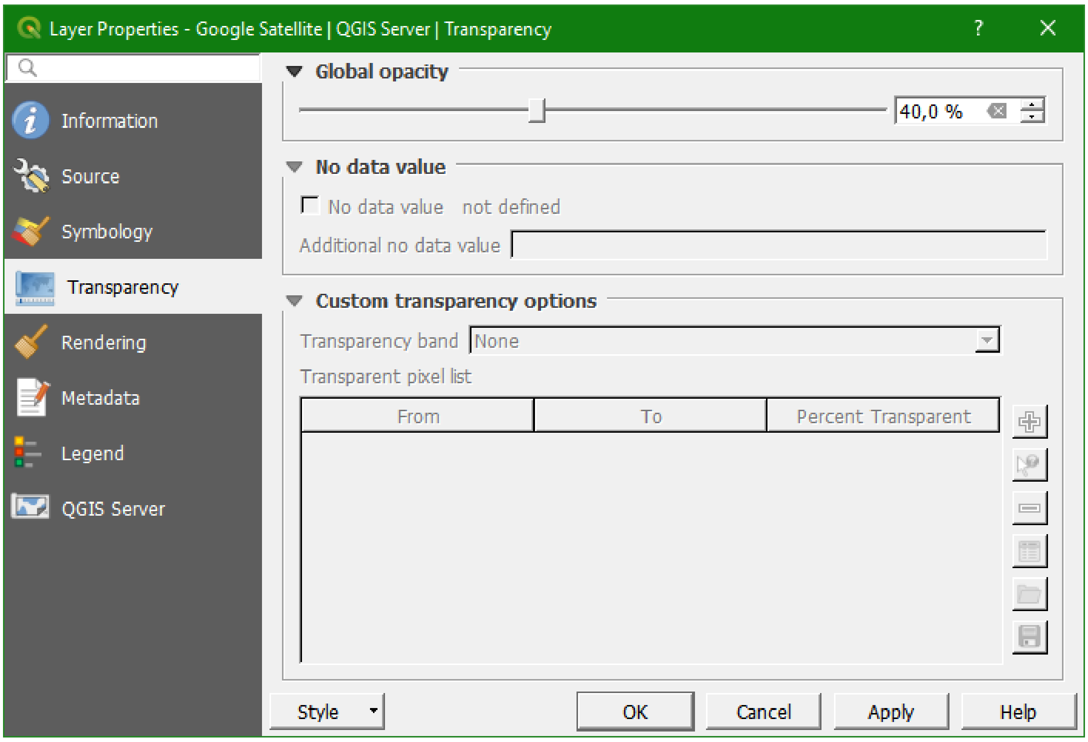
    - Make *Stroke color* transparent
    - Set colour to white
    - Set size to 30 map units



29. Make a similar symbol for the `Tanks` layer as shown before step 25. We can easily do this by copying the style and modifying it. To copy the style of `Source` click right on the layer name and select *Styles* → *Copy Style* → *All Style Categories*.



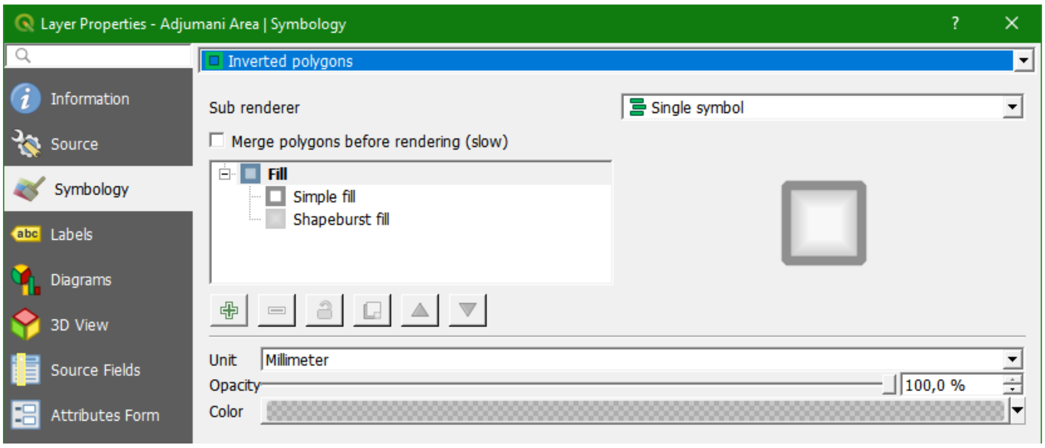
30. Now click right on the `Tanks` layer name and select *Styles* → *Paste Style* → *All Style Categories*.
31. You can now modify the style of the Tanks layer in the Styles dialogue similar to step 25.
32. Design your own symbol for the `Endcap` layer with a label to identify the ID.
33. The background satellite image is too dominant. We can make it transparent. Click right on Google Satellite and choose *Properties*…. Set the Global opacity to 60%.



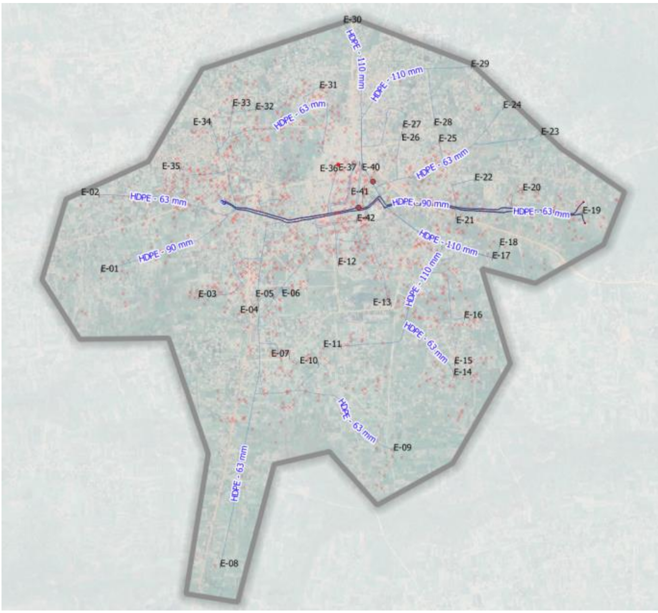
34. Lastly the style of the `Area` polygon layer will be set. Open *Properties…* → *Symbology tab* → *add symbol layer* (the + sign). For the top symbol layer choose the following specifics:
    - Fill is transparent
    - Stroke color is grey
    - Stroke width is 2 mm

    For the bottom symbol layer choose the following specifics:
    - Symbol layer type is *Shapeburst fill*
    - Change the gradient colours to grey and white with 50% opacity
    - Shade to set a distance to 5mm.

35. Lastly *change from 'Single Symbol' to 'Inverted polygons'*. This actually means that you are styling everything outside the selected polygon and click *OK*



The result now looks like this:

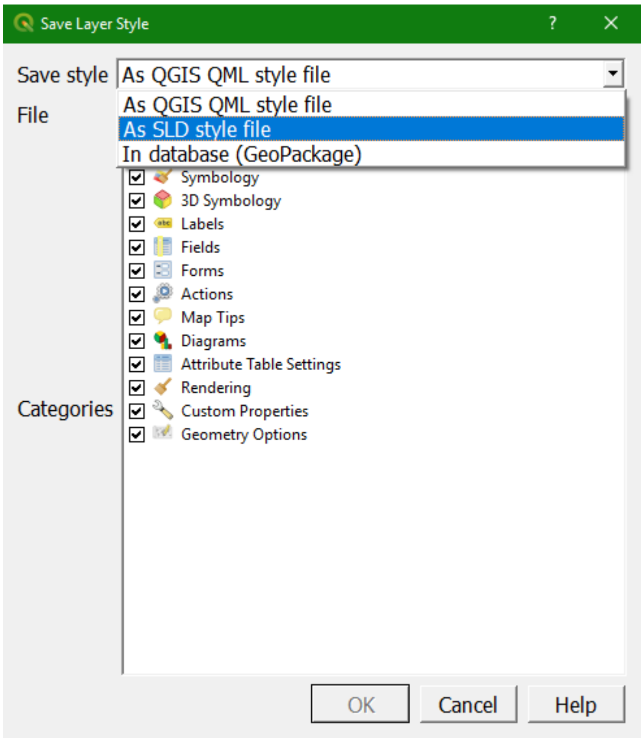


12.5 Saving layer styles

Layer styles are not stored in the GIS files (e.g. shapefile or GeoTiff). They can be stored in your project file (a `.qgz` file), together with the zoom level, on-the-fly projection, etc.

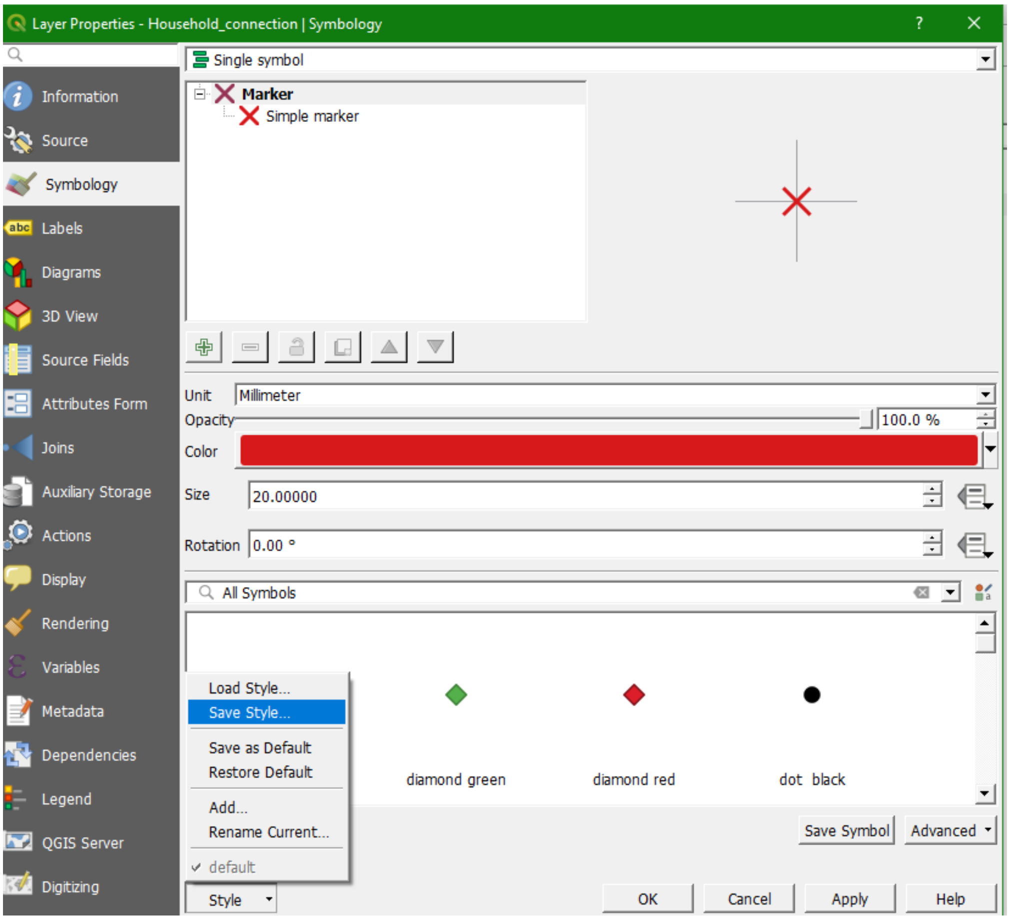
36. Save the project as `Adjumani.qgz`. In the menu choose: *Project* → *Save as…* and save the file to the correct folder.

If you don't want to share an entire QGIS project, but just a layer with its styling, you'll have to save the styling to a file. Similar to an ArcGIS Layer file (`.lyr`) QGIS has its own format, the Layer Definition File (`.qlr`). Please note that these are software specific xml files and not international standards that allow for interoperability among software. For interoperability, it is better to use the Styled Layer Descriptor (SLD) file. SLD's are also used to style online maps.



37. To save the style go back to the Symbology dialogue and select *Style* → *Save Style…*

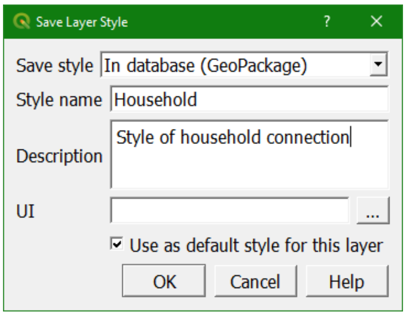
38. In the Save Layer Style dialogue you can choose one of the formats. Let's first save it as an SLD file.



If you would now start a new project and you add a layer, you can also load a saved style from the `.sld` file. Also if you would upload a shapefile to GeoServer, you can use the `.sld` file to style the online map.

A great advantage of a GeoPackage is that also styles can be saved in the GeoPackage, so we really keep everything together in one file that we can easily share with others.

39. Go back to the *Symbology* dialogue and select *Style* → *Save Style…*
40. Now choose *In database (GeoPackage)*
41. In the *Save Style in Database* dialogue give for the *Style Name* the name of the layer and provide a *Description*. Check the box to *Use as default style for this layer* and click *OK*.

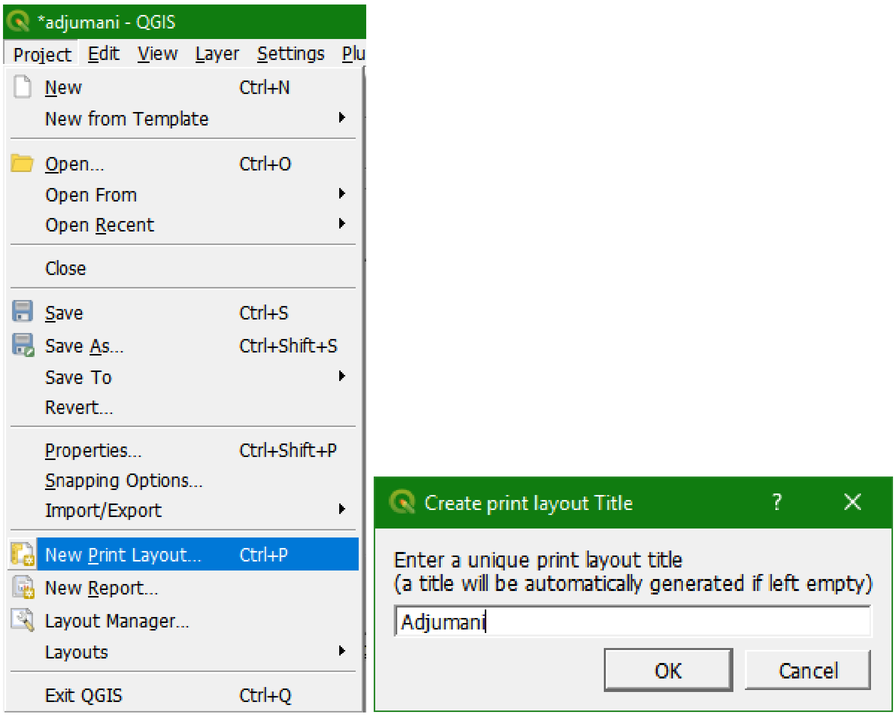


42. Repeat this for all vector layers
43. Check if this indeed works: close QGIS, reopen and load the layers from the GeoPackage again. Don't forget to also add the Google satellite, make it 60% global opacity and reorder the layers. The styles of the vector layers should be as you defined them before.

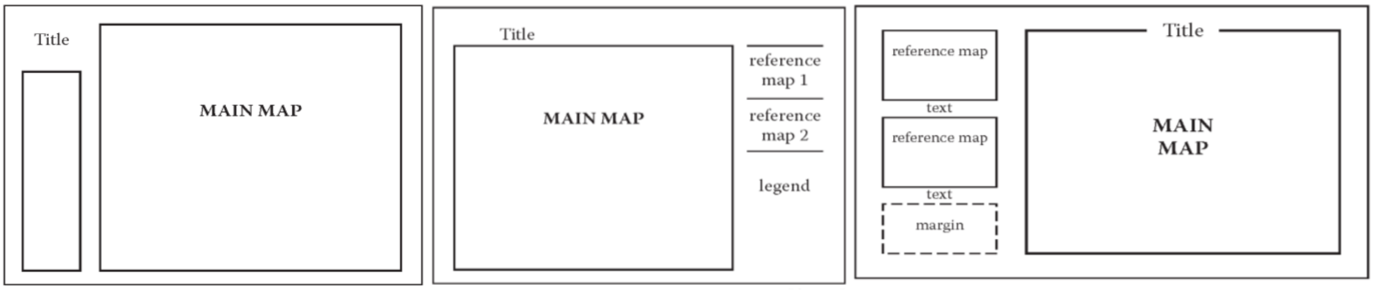
This exercise can be viewed in a screencast at:
https://youtu.be/i95xHt51eqI

12.6 Make a map in the print composer

1. Create under *Project* → *New Print Layout* a new layout and give it an appropriate name, e.g. `Adjumani`.

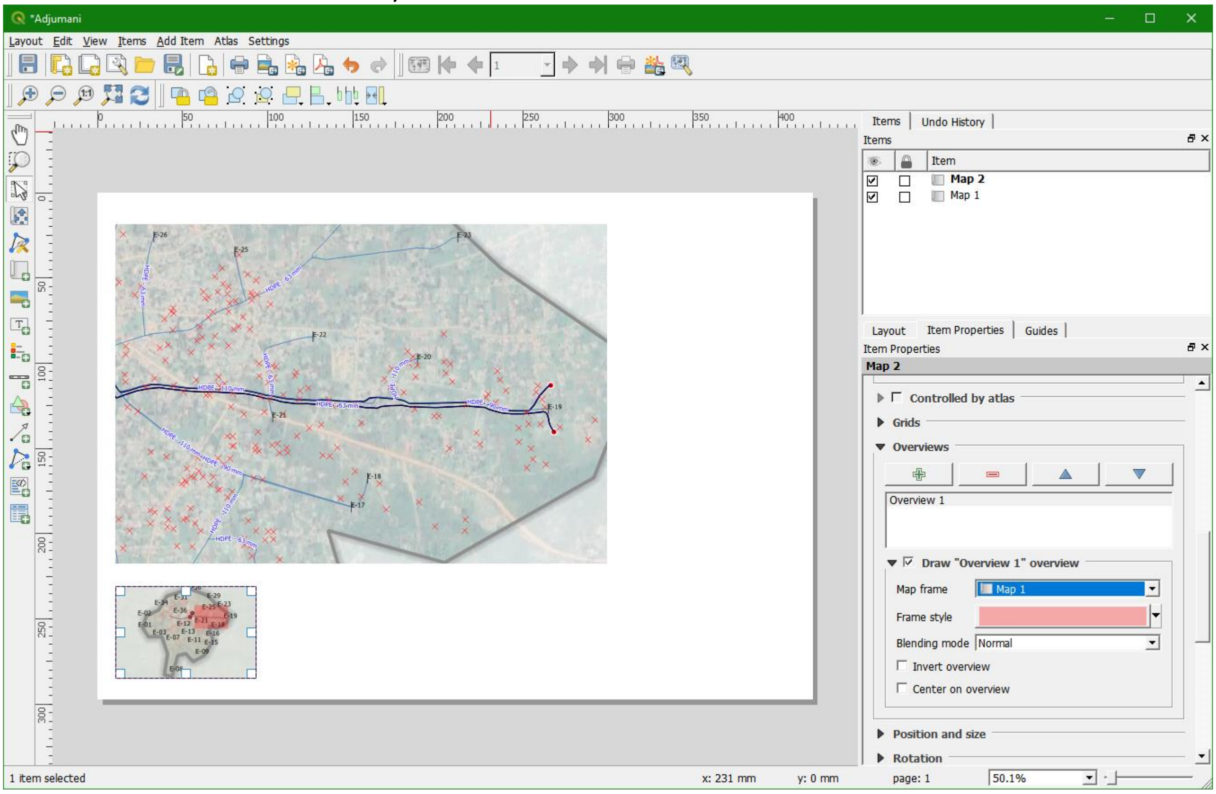


2. Normally, you need to design a map layout before you start to make the map, this means that you already know the general set up of the map and the various items you want to show on the map.



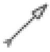
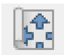
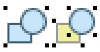
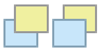
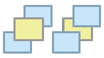
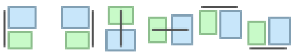
3. To set up the print layout, you need to choose which paper size you want to use (A3/A4 etc.). Click right on the paper and choose *Page Properties*…. The export DPI (dots per inch) is important for the quality of the map. With more dots per inch, you will get a higher quality (and larger size) export product. A DPI of 300 is appropriate for now. You can also choose between 'Landscape' vs 'Portrait' according to your needs. Here we'll make an A3 landscape map.
4. Click the *Add a map* button  and click and drag to insert the map.
Under *Item properties*, you can edit the position on the canvas and zoom in. Find an area of interest to you. You can also use the *Move item content* button .
5. As you are now zoomed in to a part of the city in the map, a small overview map makes it easier to orientate yourself. Again click the *Add a map* button and drag a smaller map. (If you hold shift, it will become perfectly rectangular). Zoom out until you have the whole area in the overview map.

6. To create an overview select the tab *Item properties*. Under Overviews click the + sign to add an overview. Select for *Map Frame* `Map 1`. You can edit the color, transparency and even make it inverse. Choose yourself.



7. Now you will see every layer in the overview map, but we can remove some detail to make it easier to understand. Go back to the *Map Canvas* of QGIS and untick every layer except the `Area` layer.
8. Go back to the *Print Layout* and Select the overview map. Under its *Item Properties* → *Tick Lock Layer for this Map.* Click *Update preview.* Now it will only use the `Area` layer to draw the map and it will be fixed if you *tick the layers back on* for the larger detailed map.
9. Below you find an overview to add other items.
   NOTE: under properties you will find many options per item. The default is often **not** the one you want.
10. Do not forget to *save*  the project file (.QGZ) once in a while.
11. Now add north arrows  logos  scale bars  legends  (sub)titles . to your choosing. Be creative!
12. After finishing the map with your satisfaction, export the map to a pdf  or an image .

	Export to an image format, to PDF or to SVG
	Zoom to full extent, in and out
	Refresh view
	Revert and restore last change

	Add new map from QGIS map canvas
	Add image to print composition (images such as logo, north arrow)
	Add label to print composition (text such as (sub)titles or abstract)
	Add new legend to print composition
	Add new scalebar to print composition
	Add basic shape to print composition
	Add arrow to print composition
	Move content within an item (move within a map to redefine the x, y and scale)
	Group items of print composition and Ungroup
	Raise/Lower selected items
	Move selected items to top/bottom
	Align selected items left / right center / center vertical / top / bottom

References

Wang, L. and Liu, H., 2006. An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling. International Journal of Geographical Information Science, 20(2).

Links

EPSG codes: http://www.spatialreference.org

European Environmental Agency Public Map Service: http://discomap.eea.europa.eu

OpenStreetMap: http://www.openstreetmap.org

QGIS: http://www.qgis.org/

SRTM data description: https://lta.cr.usgs.gov/SRTM1Arc

USGS EarthExplorer: http://earthexplorer.usgs.gov

Screencasts

Screencasts can be found in the following YouTube channel:
http://www.youtube.com/c/HansvanderKwast

Please subscribe for updates.