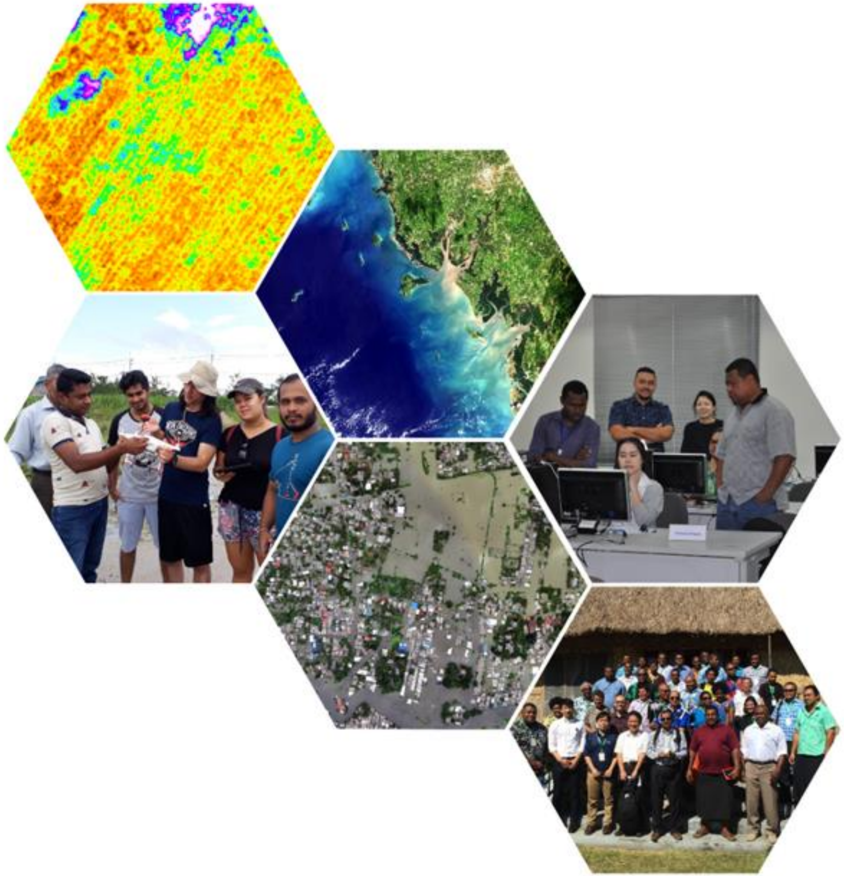

Glacial Lake Mapping

Geoinformatics Center - AIT

Overview

Peer-reviewed paper to follow in the exercise

The paper presents a semi-automated approach, based on a radar signal intensity threshold between water and non-water feature classes followed by post-processing including elevations, slopes, vegetation, and size thresholds,

INTERNATIONAL JOURNAL OF REMOTE SENSING
https://doi.org/10.1080/01431161.2019.1569789

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Towards automated mapping and monitoring of potentially dangerous glacial lakes in Bhutan Himalaya using Sentinel-1 Synthetic Aperture Radar data

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ABSTRACT

The majority of glacial lakes around the world are located in remote and hardly accessible regions. The use of remote sensing data is therefore of high importance to identify and assess their potential hazards. However, the persistence of cloud cover, particularly in high mountain areas such as the Himalayas, limits the temporal resolution of optical satellite data with which we can monitor potentially dangerous glacial lakes (PDGLs). The ability of Synthetic Aperture Radar (SAR) satellites to collect data, irrespective of weather and at day or night, facilitates monitoring of PDGLs by without compromising temporal resolution. In this study, we present a semi-automated approach, based on a radar signal intensity threshold between water and non-water feature classes followed by post-processing including elevations, slopes, vegetation and size thresholds, to delineate glacial lakes in Sentinel-1 SAR images in Bhutan Himalaya. We show the capability of our method to be used for delineating and monitoring glacial lakes in Bhutan Himalaya by comparing our results to 10 m resolution Sentinel-2 multispectral data, field survey data, meteorological data, and a time series of monthly images from January to December 2016 of two lakes. Sentinel-1 SAR data can, moreover, be used for detecting lake surface area changes and open water area variations, at temporal resolution of six days, providing substantial advantages over optical satellite data to continuously monitor PDGLs.

ARTICLE HISTORY
Received 29 August 2018
Accepted 6 January 2019

1. Introduction

The majority of glaciers in the Himalayas have been retreating and losing mass over the last decades (Bolch et al. 2012; Brun et al. 2017; Azam et al. 2018). As the glaciers have receded, numerous supraglacial lakes have formed on the surface of the low gradient debris-covered glaciers that have stagnant glacier tongues (Reynolds 2000; Bolch et al. 2008; Quincey et al. 2007; Benn et al. 2012; Nie et al. 2017). Supraglacial lakes have a higher capacity to absorb incident solar radiations than the glacier ice and consequently enhance melting and downwasting of the debris-covered ice (Sakai et al. 2000; Ragettli, Bolch, and Pellicciotti 2016; Mertes et al. 2017). Most supraglacial lakes are perched

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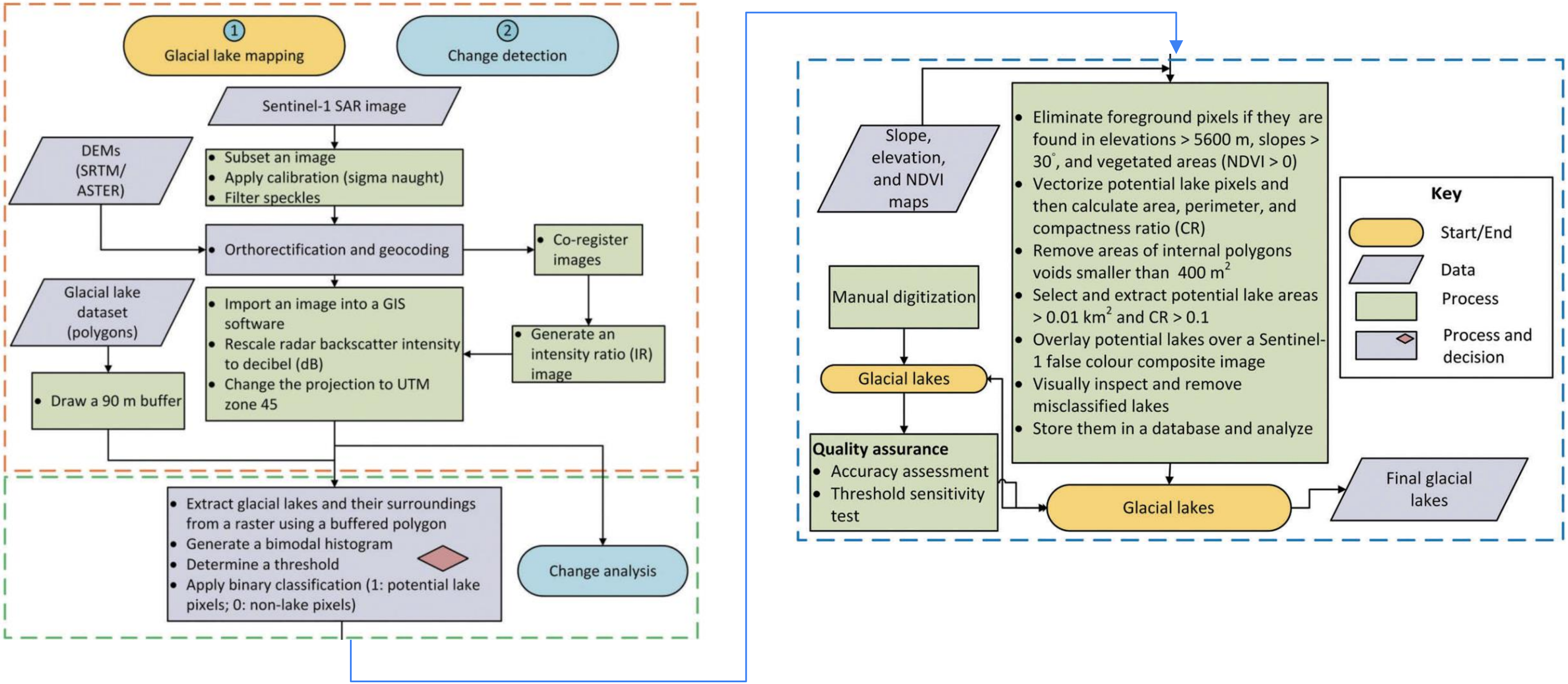
Supplemental data for this article can be accessed here.

Wangchuk et al. (2019). *Towards automated mapping and monitoring of potentially dangerous glacial lakes in Bhutan Himalaya using Sentinel-1 Synthetic Aperture Radar data. Int. Journal of Remote Sensing*, https://doi.org/10.1080/01431161.2019.1569789

Overview

Methodology



Overview

Data and Software

In this exercise, we will use QGIS software. The following data are available:

- Sentinel-1 Interferometric Wide (IW) swath mode product.
  - Radiometric Terrain Correction (RTC) data generated by ASF Vertex (check the Tutorial on Searching and Obtaining Satellite Data). GLO-30 Copernicus DEM is also included here.
  - Date: 27 September 2017, 02 September 2023
  - Spatial resolution 10m
- Sentinel-2 Level-2A product
  - Atmospherically corrected Surface Reflectance (SR) products from Level-1C products.
  - Date: 17 October 2017, 16 September 2023
  - Spatial resolution: 10m (B2, B3, B4, B8, TCI, AOT, WVP), 20m (B5, B6, B7, B8A, B11, B12, AOT, CLD, SCL, SNW, WVP), 60m (B1, B9, AOT, CLD, SCL, SNW, WVP)
- Glacial lake inventory data of Bhutan (Ukta et al., 2011)
  - Data was produced using ALOS/AVNIR-2 data from the years of 2007 and 2010
  - Full dataset is freely available from https://www.eorc.jaxa.jp/ALOS/en/dataset/bhutan_e.htm
- Area of Interest (AOI) shapefile
  - Covered the area of Luggye Tsho, Thorthomi Tsho, Raphstreng Tsho, and Bay Tsho.

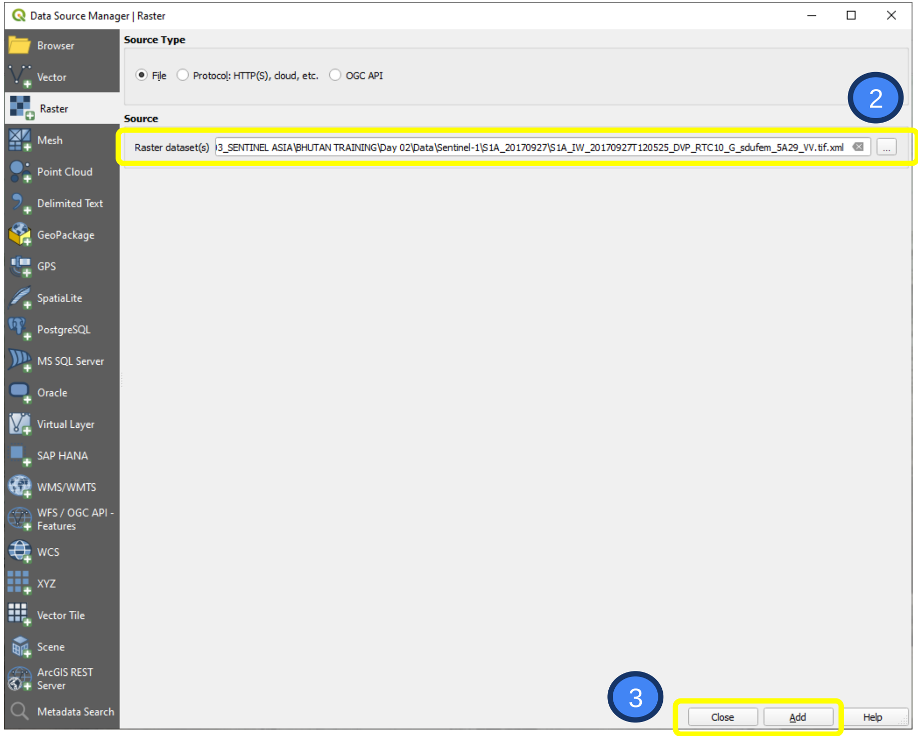
Glacial Lake Mapping

Follow Along: Open Sentinel-1 RTC data (27 September 2017)

1. In the Menu Bar, click on Layer → Add Layer → Add Raster Layer.

2. In Data Source, click on the Browse ... button and navigate to the file S1A_IW_20170927T120525_DVP_RTC10_G_sdufem_5A29_VV.tif in the data folder.

3. With this file selected, click Add, then Close. The data you specified will now load.



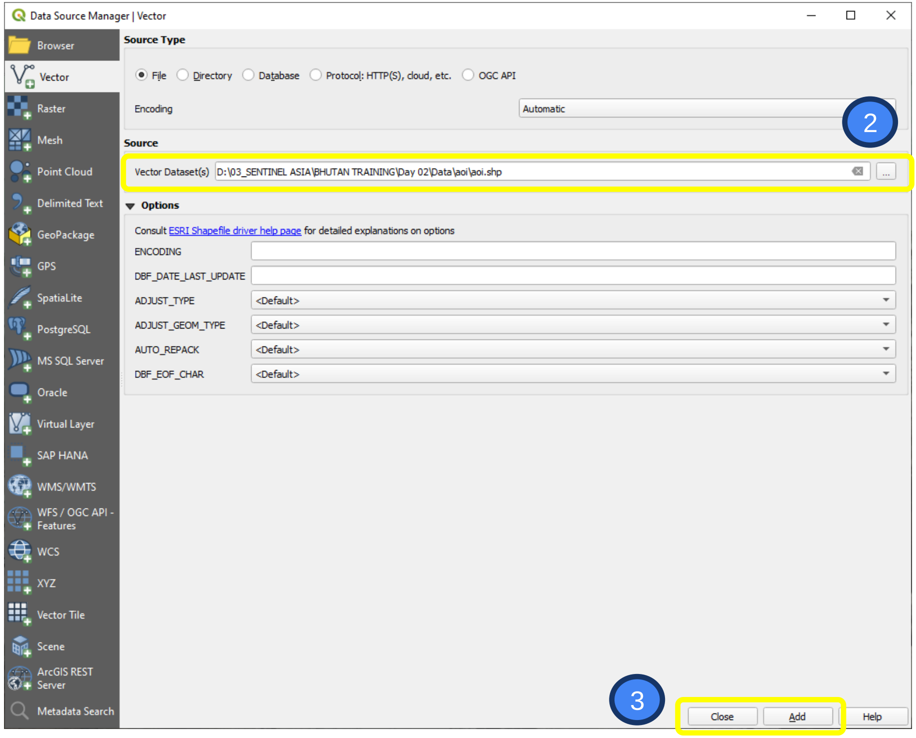
Glacial Lake Mapping

Follow Along: Open Area of Interest (AOI)

1. In the Menu Bar, click on Layer → Add Layer Add Layer → Add Vector Layer.

2. In Data Source, click on the Browse ... button and navigate to the file aoi.shp in the data folder.

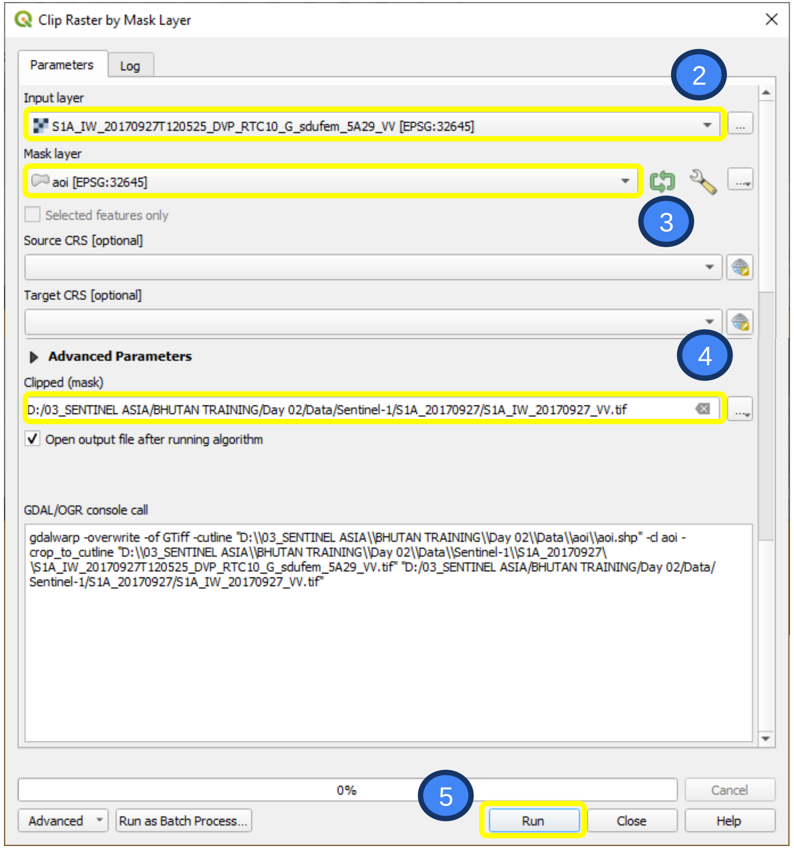
3. With this file selected, click Add, then Close. The data you specified will now load.



Glacial Lake Mapping

Follow Along: Clip the Sentinel-1 image

1. Click on Raster → Extraction → Clip Raster by Mask Layer.
2. In the Input Layer, select S1A_IW_20170927T120525_DVP_RTC10_G_sdufem_5A29_VV
3. In the Mask Layer, select aoi.
4. Save the result to S1A_IW_20170927_VV.tif
5. Click Run.



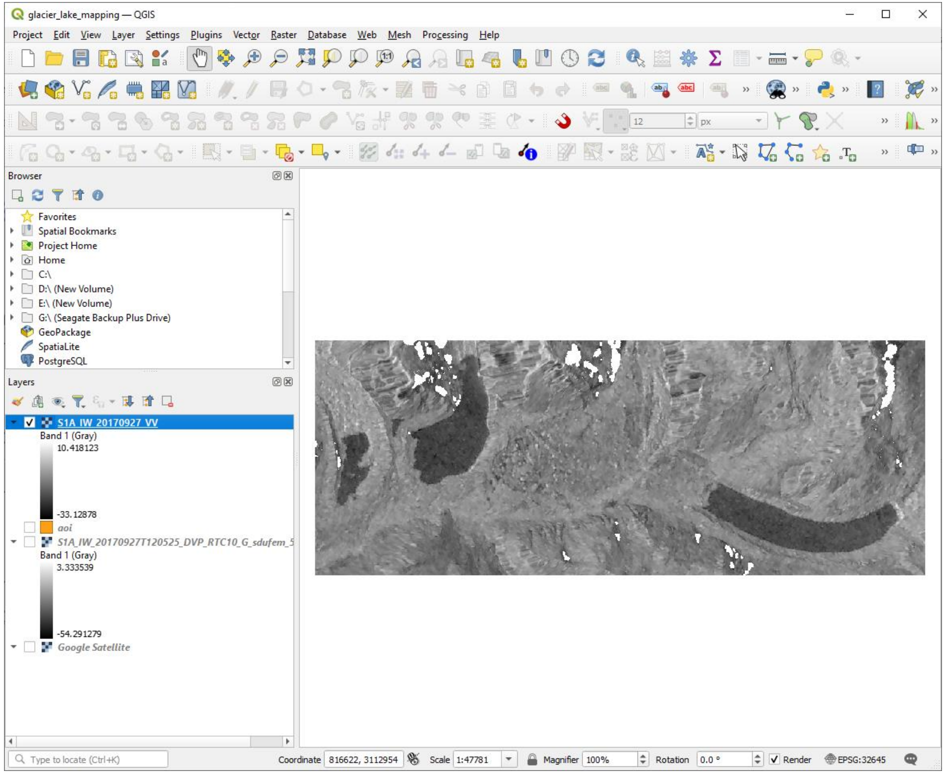
Glacial Lake Mapping

Follow Along: Save your work!

You can open the clipped image and observe the object on the image. Can you visually identify any glacial lakes here?

Now would be a good time to save your work.

1. In the Menu Bar, click on Project → Save As
2. Save the map in the working folder and call it glacier_lake_mapping.qgs

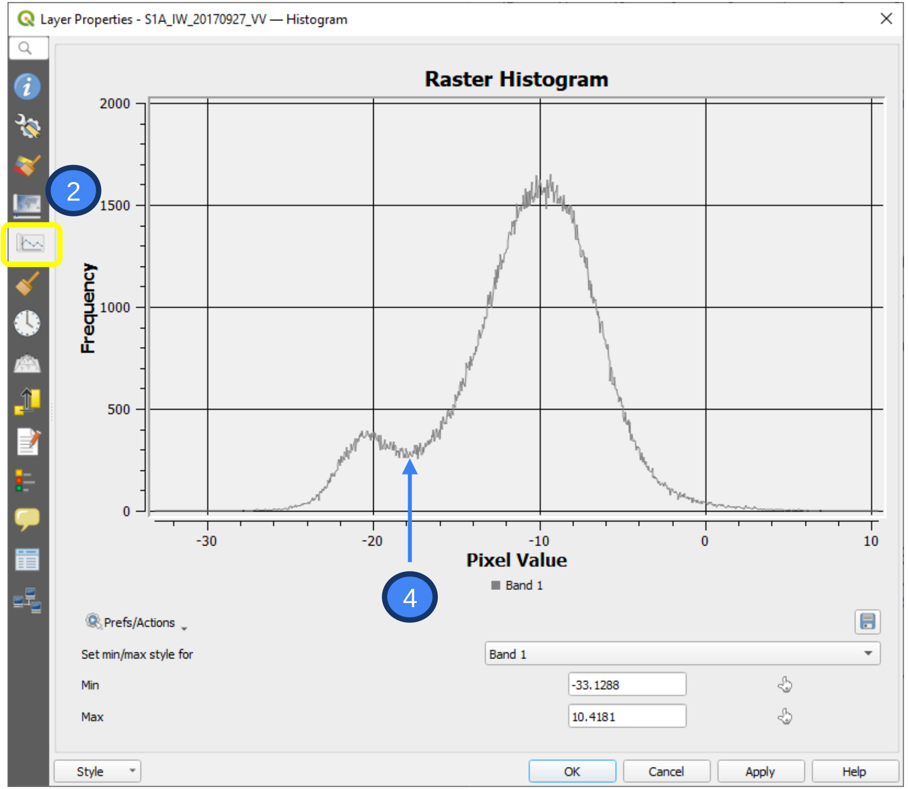


Glacial Lake Mapping

Follow Along: (Option 1) Determine a threshold value

We will determine the threshold based on the histogram of the whole clipped image.

1. Right-click on the S1A_IW_20170927_VV layer in the Layers list and select the menu item Properties in the menu that appears.
2. Select the Histogram tab 
3. In the Raster Histogram window, click Compute Histogram [Compute Histogram] button.
4. A histogram is calculated. Notice there are two peaks: the left tail represents glacial lake pixels with low backscatter, and the right tail represents non-water pixels with high backscatter.
5. Determine the threshold by identifying the pixel value in between water and non-water: ~-17.5 dB



Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value

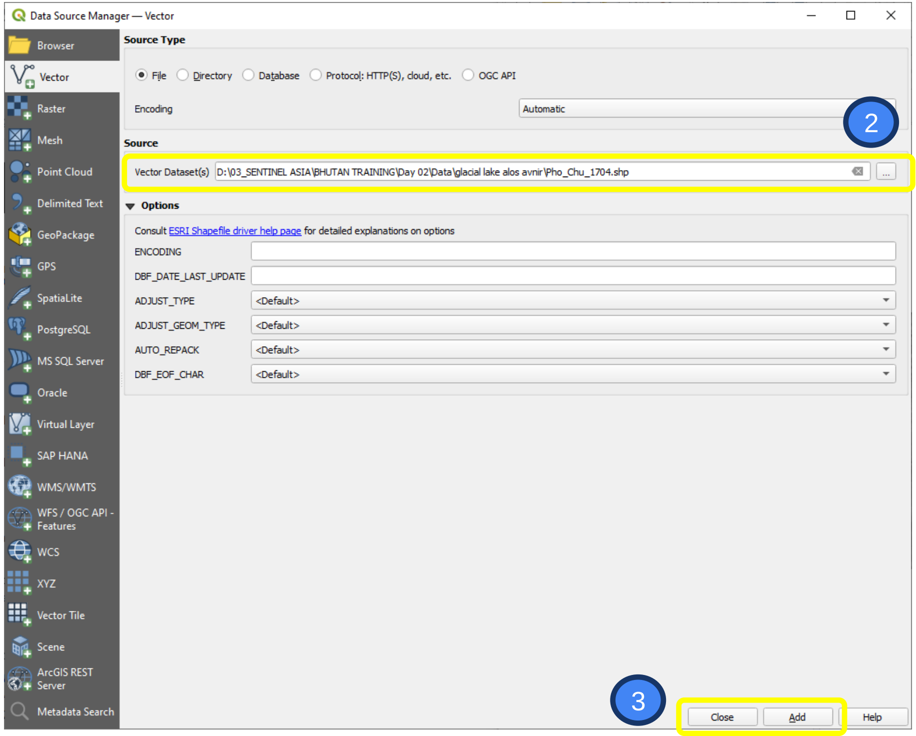
We can also determine the threshold based on the histogram of the specific known lakes. The available glacial lake inventory will be used here.

Open glacial lake inventory of Pho Chu:

1. In the Menu Bar, click on Layer → Add Layer Add Layer → Add Vector Layer.

2. In Data Source, click on the Browse button and navigate to the file Pho_Chu_1704.shp in the data folder.

3. With this file selected, click Add, then Close. The data you specified will now load.



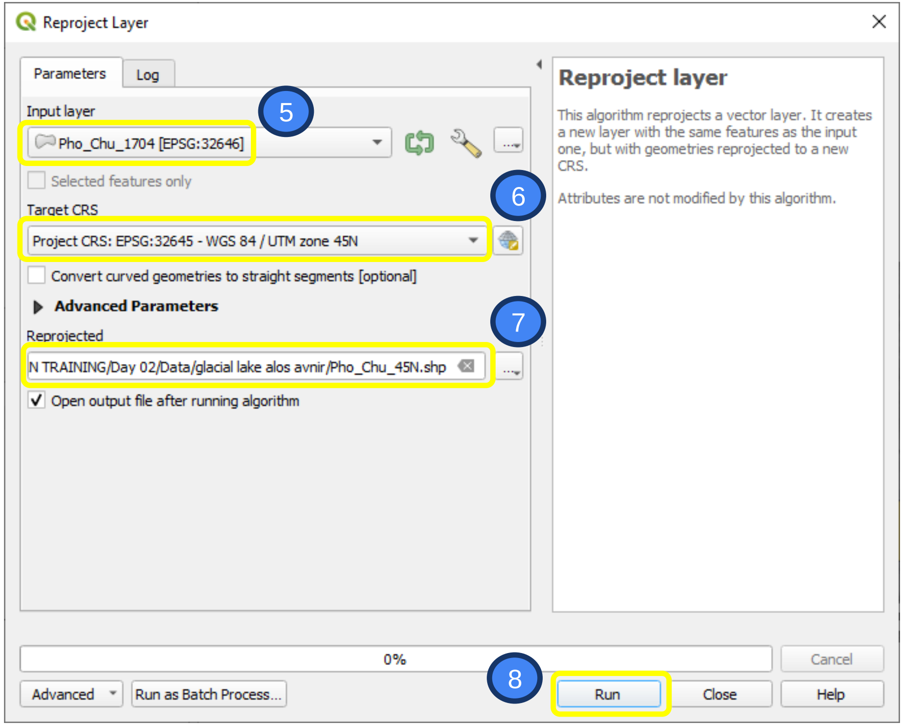
Note: In the paper, the Otsu algorithm was used to determine the threshold automatically. We'll not do it now because we cannot do this process directly in QGIS, but it is possible to write a Python script to then run it in QGIS.

Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value

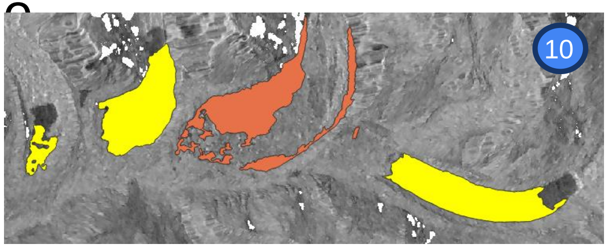
The inventory data comes in another different projection: UTM Zone 46N. We will reproject the data first to match our satellite data's projection: UTM Zone 45N.

4. In the Menu Bar, click on Vector → Data Management Tools → Reproject Layer.
5. In the Input Layer, select Pho_Chu_1704.
6. In the Target CRS, select Project CRS: EPSG:32645 – WGS 84 / UTM zone 45N.
7. Save the result to Pho_Chu_45N.shp.
8. Click Run.



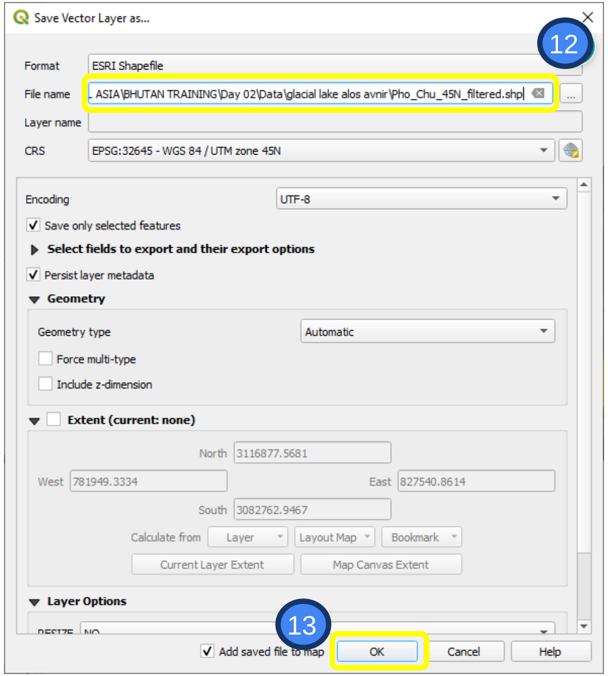
Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value



We will only select the glacial lakes that include in the AOI. We will also exclude the Thorthomi Tsho because it has almost no water features on this specific image date.

9. In the Tool Bar, click on Select Features by Area or Single Click button.
10. Select the lake polygons from Pho_Chu_45N layer over the AOI (exclude Thorthomi Tsho) using your Shift and left-click mouse. The selected polygon will be highlighted in yellow color.
11. Right-click on the Pho_Chu_45N layer in the Layers list, click Export → Save Selected Features Ss…
12. Save the result to Pho_Chu_45N_filtered.shp.
13. Click OK.

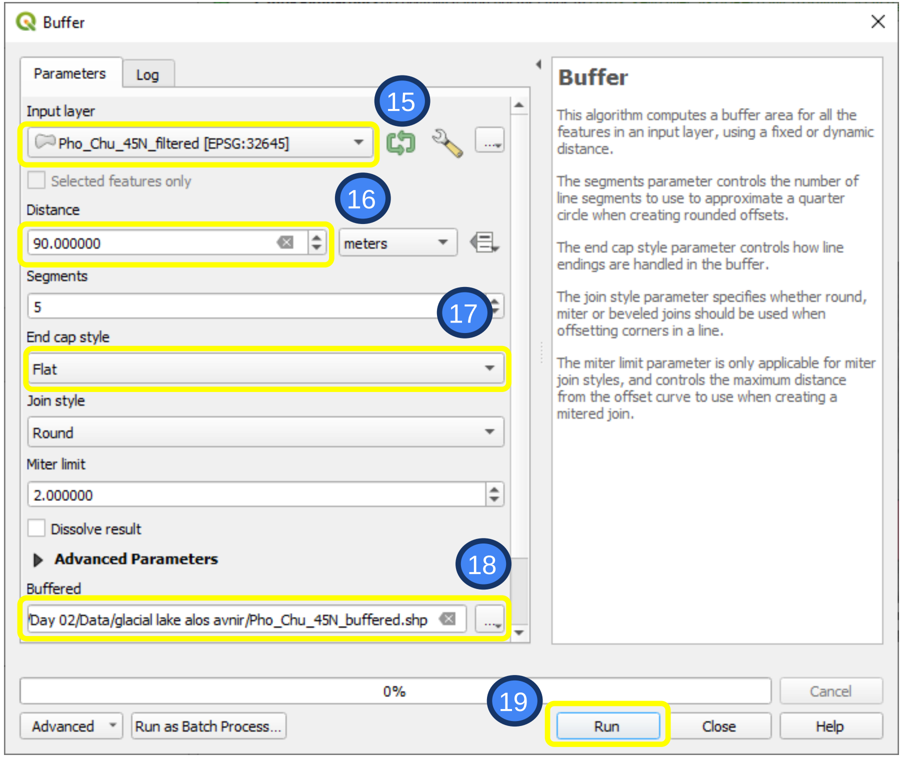


Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value

We will create a 90m buffer around the glacial lakes to include the non-water area surrounding the lakes.

14. In the Menu Bar, click on Vector → Geoprocessing Tools → Buffer.
15. In the Input Layer, select Pho_Chu_45N_filtered.
16. In the Distance, type 90.
17. In the End cap style, select Flat
18. Save the result to Pho_Chu_45N_buffered.shp.
19. Click Run.

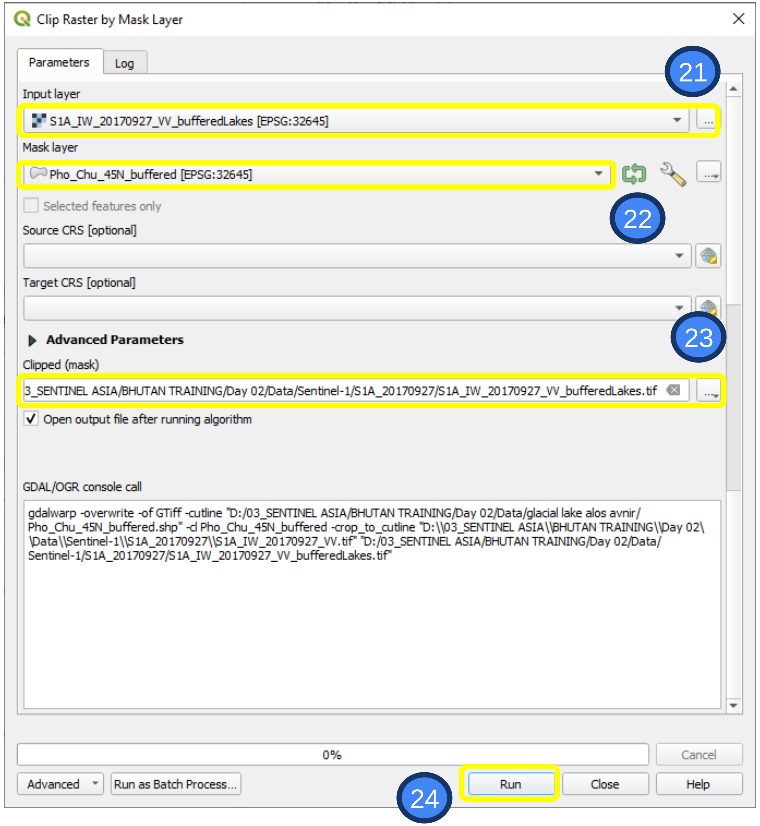


Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value

We will use this buffered lakes to clip the image. This step ensures the normalization of the frequency of occurrence of water and non-water pixels to obtain a bimodal histogram.

20. Click on Raster → Extraction → Clip Raster by Mask Layer.
21. In the Input Layer, select S1A_IW_20170927_VV
22. In the Mask Layer, select Pho_Chu_45N_buffered.
23. Save the result to S1A_IW_20170927_VV_bufferedLakes.tif
24. Click Run.



Glacial Lake Mapping

Follow Along: (Option 2) Determine a threshold value

We will determine the threshold based on the histogram of the buffered lakes image.

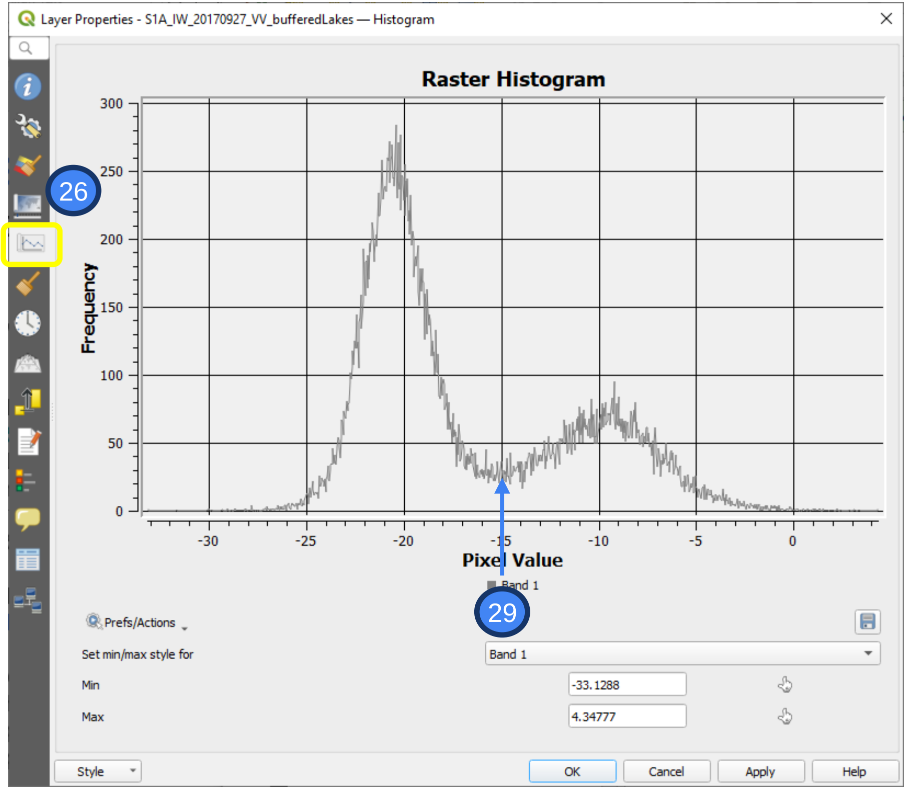
25. Right-click on the S1A_IW_20170927_VV_bufferedLakes layer in the Layers list and select the menu item Properties in the menu that appears.

26. Select the Histogram tab 

27. In the Raster Histogram window, click Compute Histogram [Compute Histogram] button.

28. A histogram will be calculated. Notice there are two histogram peaks: the lower value refers to water pixels, while the higher value refers to non-water pixels.

29. Determine the threshold by identifying the pixel value in between water and non-water: ~ -15 dB

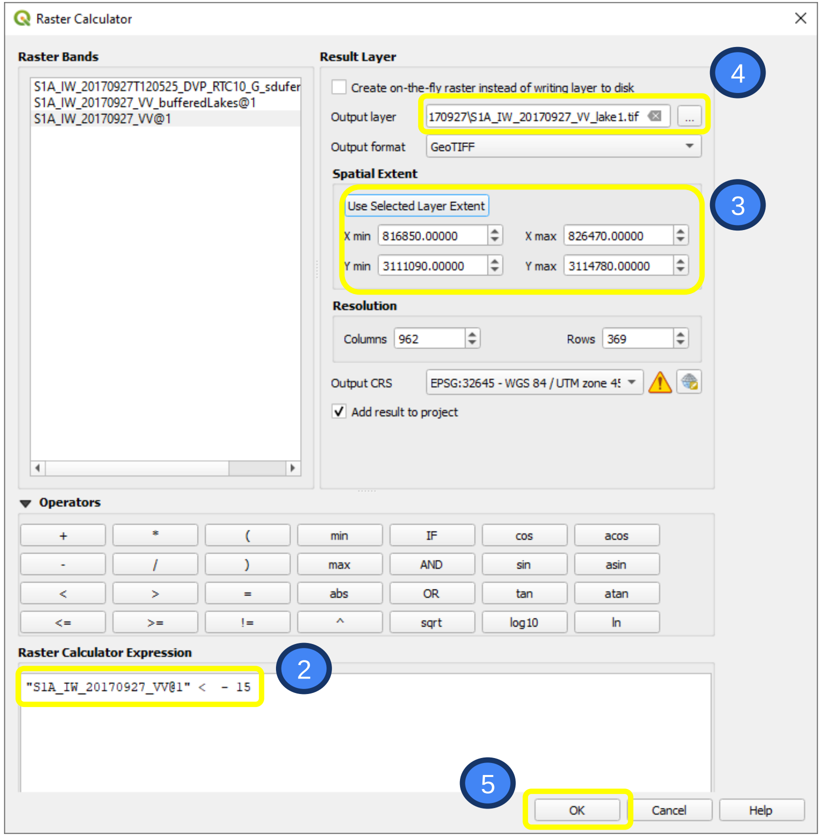


Glacial Lake Mapping

Follow Along: Create a binary map bases on the threshold value

We will use the threshold value from the second option's result: -15 dB. The average threshold value given in the paper is -14.52 dB, which is not far from our result.

1. Click on Raster → Raster Calculator.
2. In the Raster Calculation Expression write: " S1A_IW_20170927_VV " < -15
3. In the Spatial Extent, define the extent based on the aoi.
4. Save the result to S1A_IW_20170927_VV_lake1.tif
5. Click OK.



Glacial Lake Mapping

Follow Along: Create a binary map bases on the threshold value

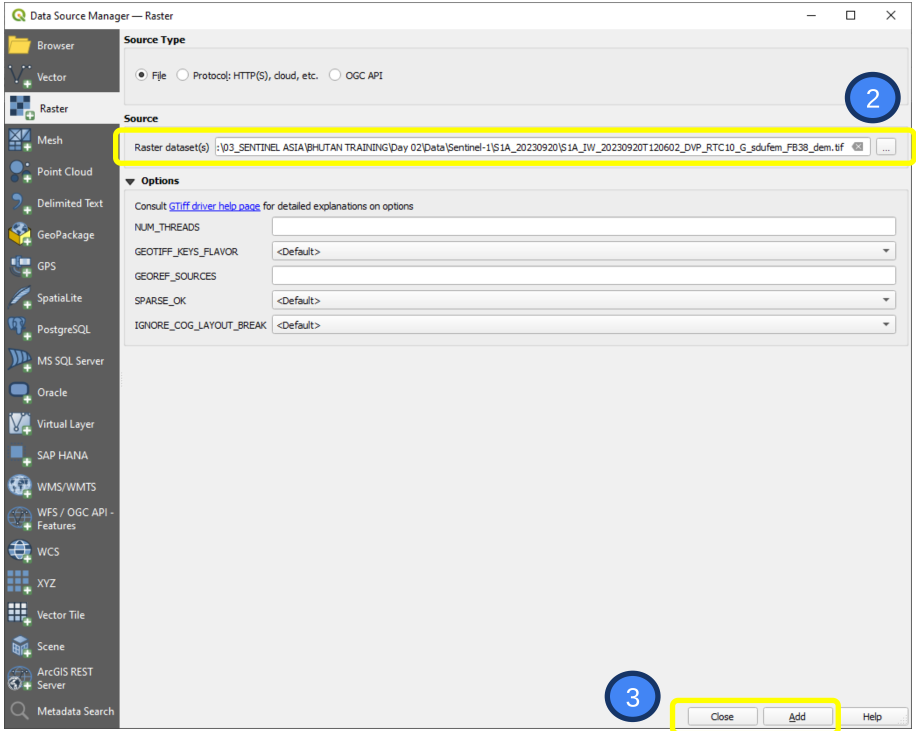
Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in elevation > 5,600m

We will remove pixels found at elevations above 5,600m, where glacial lakes are hardly found above this elevation threshold in the Himalayas (Zhang et al., 2015)

Open the DEM

1. In the Menu Bar, click on Layer → Add Layer → Add Raster Layer.
2. In Data Source, click on the Browse button and navigate to the file S1A_IW_20170927T120525_DVP_RTC10_G_sdufem_5A29_dem.tif in the data folder.
3. With this file selected, click Add, then Close. The data you specified will now load.

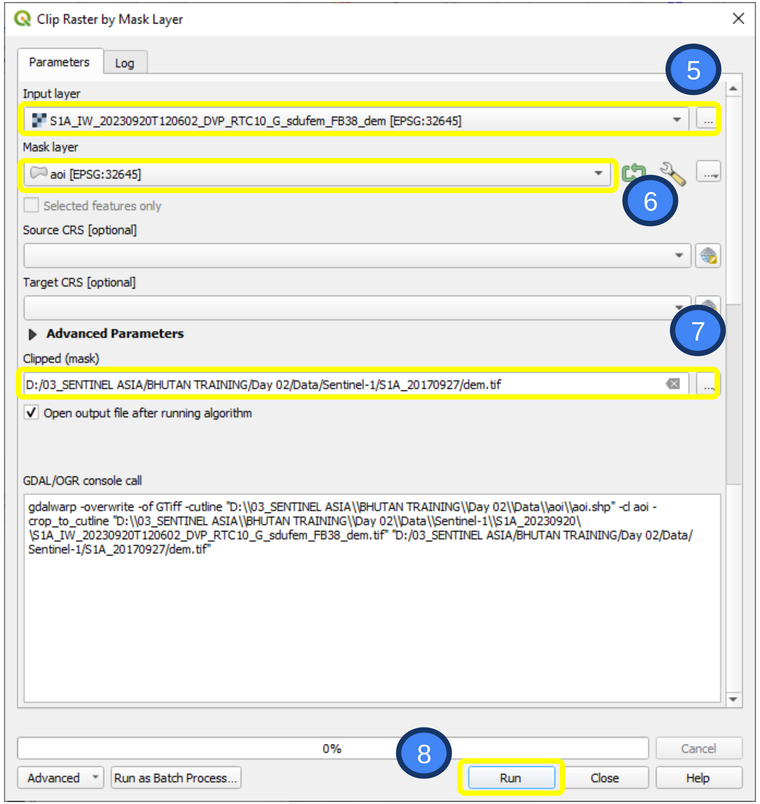


Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in elevation > 5,600m

Clip the DEM based on AOI

4. In the Menu Bar, click on Raster → Extraction → Clip Raster by Mask Layer.
5. In the Input Layer, select S1A_IW_20170927T120525_DVP_RTC10_G_sdufem_5A29_dem
6. In the Mask Layer, select aoi.
7. Save the result to dem.tif
8. Click Run.

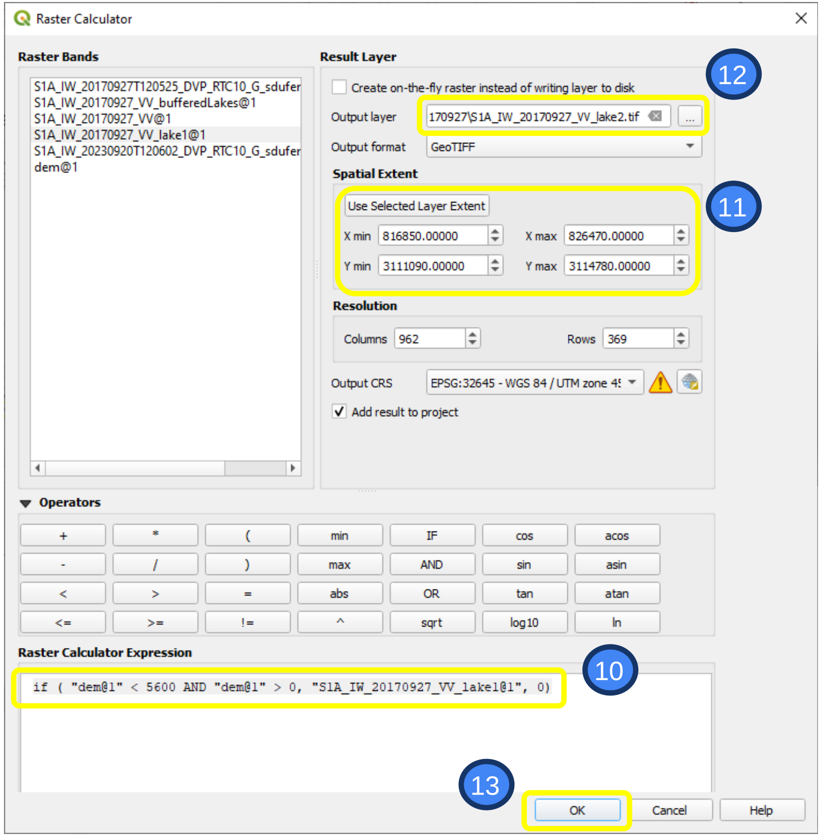


Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in elevation > 5,600m

Use Raster Calculator to remove elevation above 5,600m.

9. Click on Raster → Raster Calculator.
10. In the Raster Calculation Expression write: if ("dem@1" < 5600 AND "dem@1" > 0, "S1A_IW_20170927_VV_lake1@1", 0)
11. In the Spatial Extent, define the extent based on the aoi.
12. Save the result to S1A_IW_20170927_VV_lake2.tif
13. Click OK.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in elevation > 5,600m

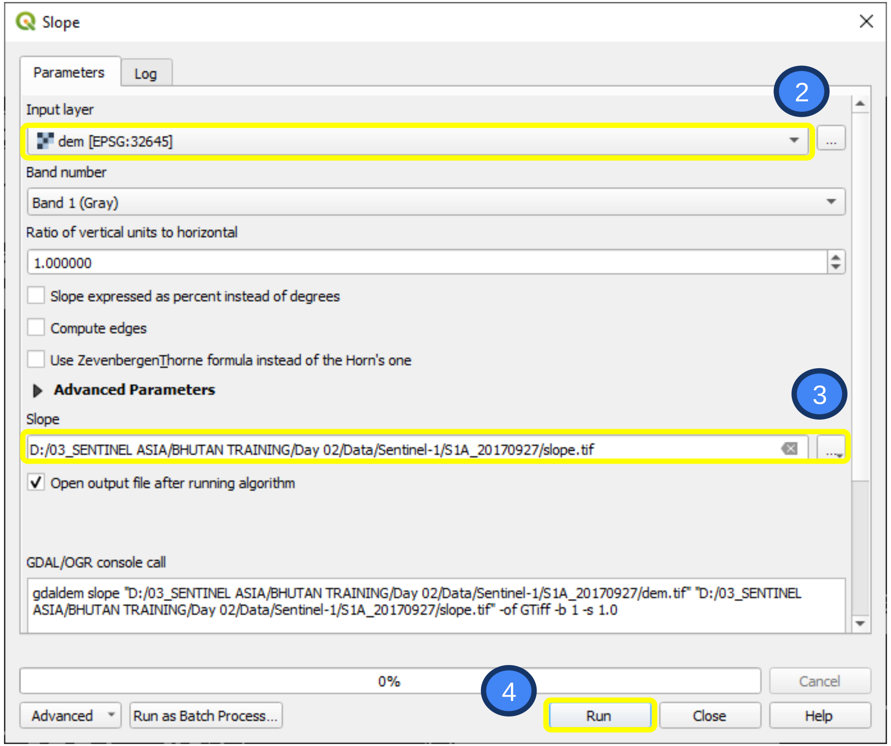
Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in slope > 30 deg.

We will remove misclassified pixels in the regions of steep slopes.

Calculate the slope from DEM:

1. Calculate Slope: Raster → Analysis → Slope.
2. In the Input Layer, select dem
3. Save the result to slope.tif
4. Click Run.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in slope > 30 deg.

Use Raster Calculator to remove elevation above 5,600m.

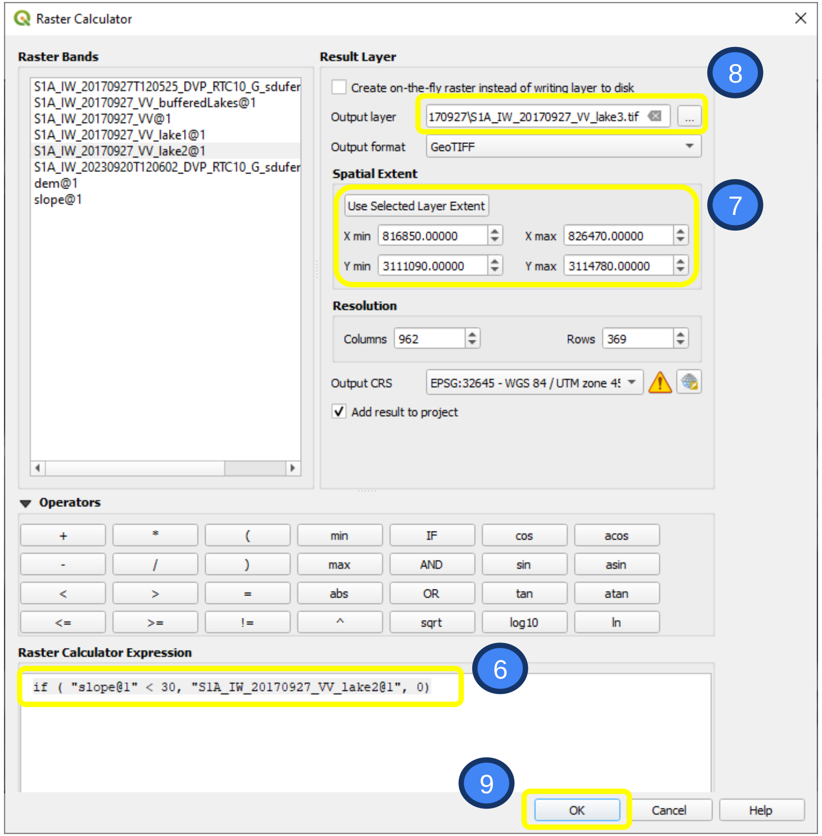
5. Click on Raster → Raster Calculator.

6. In the Raster Calculation Expression write:
   if ("slope@1" < 30,
   "S1A_IW_20170927_VV_lake2@1", 0)

7. In the Spatial Extent, define the extent based on the aoi.

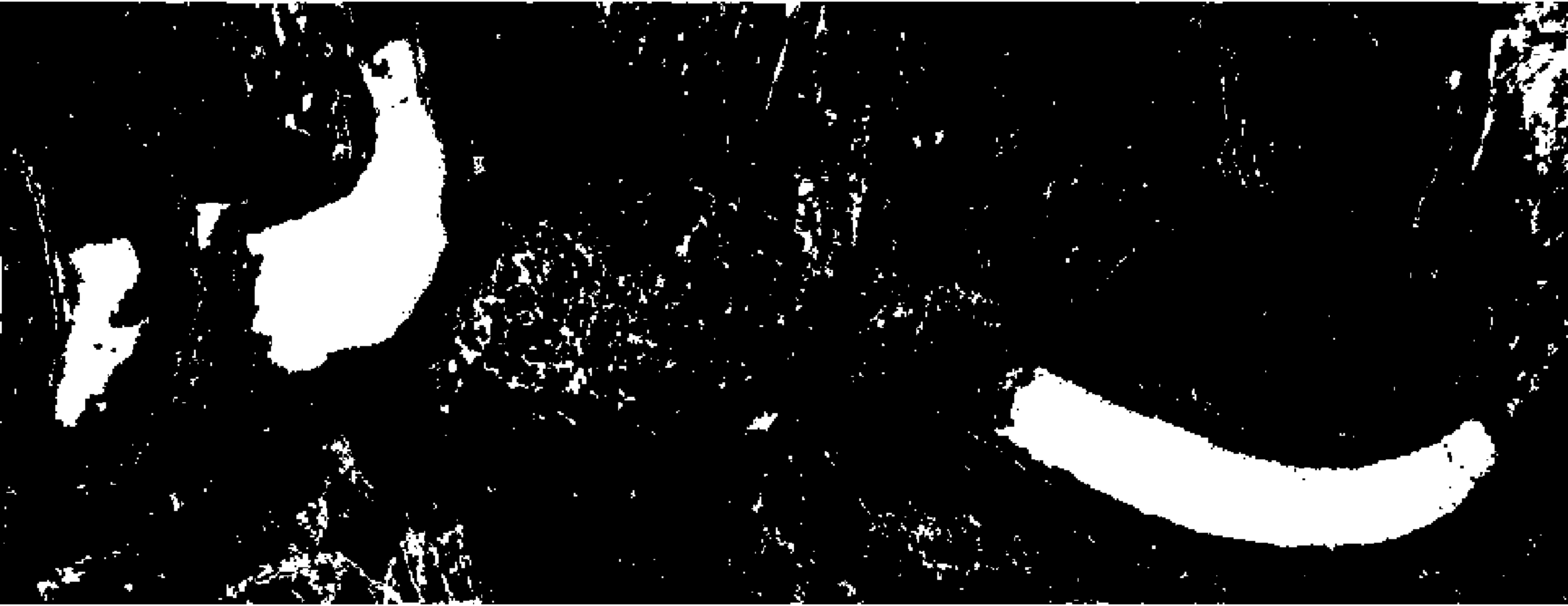
8. Save the result to
   S1A_IW_20170927_VV_lake3.tif

9. Click OK.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in slope > 30 deg.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in NDVI > 0

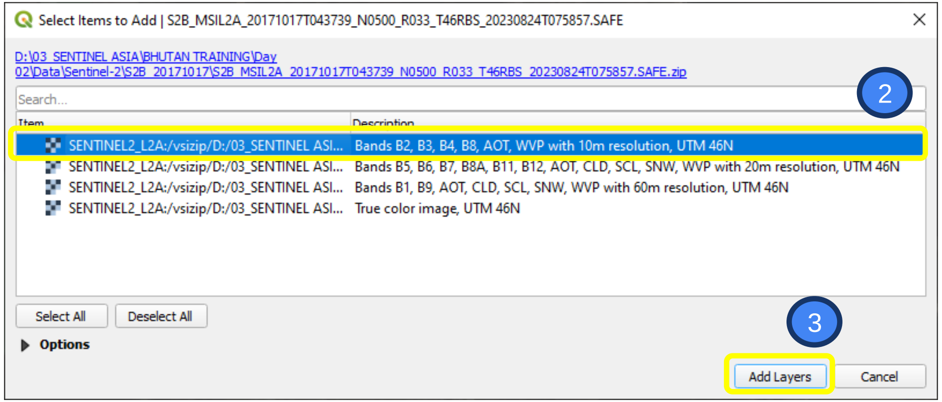
We will use Sentinel-2 data on 17 October 2017 to calculate the Normalized Difference Vegetation Index (NDVI) to remove vegetated areas.

Open the Sentinel-2 data

1. Drag and drop the Sentinel-2 zip file to the Map View or Layer List.

2. Select the first layer that contain B2 (Blue), B4 (Green), B4 (Red), and B8 (Near Infrared) bands.

3. Click Add Layers.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in NDVI > 0

Clip the Sentinel-2 data based on AOI

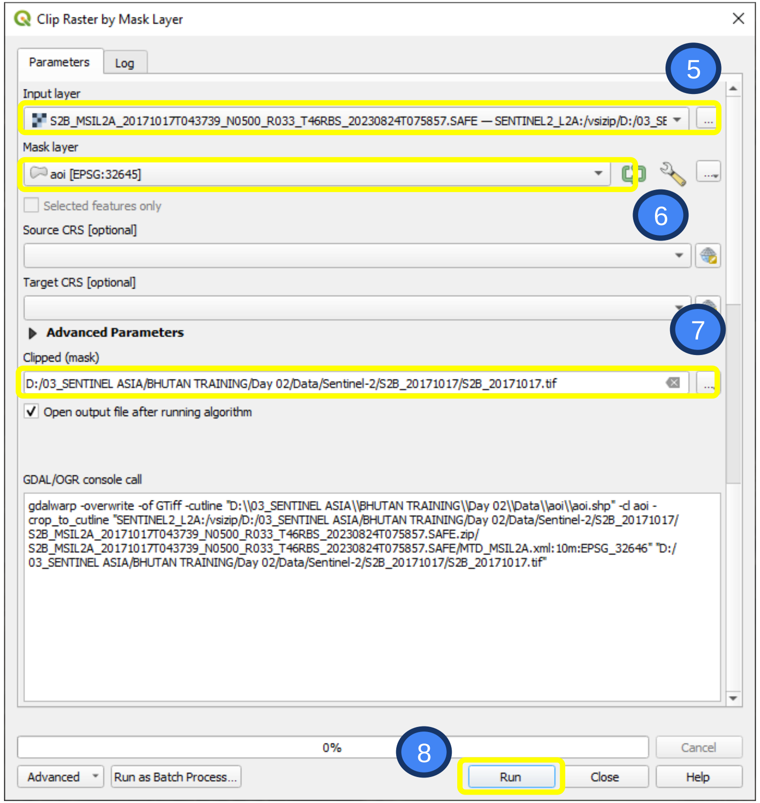
4. In the Menu Bar, click on Raster → Extraction → Clip Raster by Mask Layer.

5. In the Input Layer, select S2B_MSIL2A_20171017T043739_N0500_R033_T46RBS_20230824T075857.SAFE.zip

6. In the Mask Layer, select aoi.

7. Save the result to S2B_20171017.tif

8. Click Run.



Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in NDVI > 0

Calculate NDVI using the following equation:
(B8:NIR – B4:RED) / (B8:NIR + B4:RED).

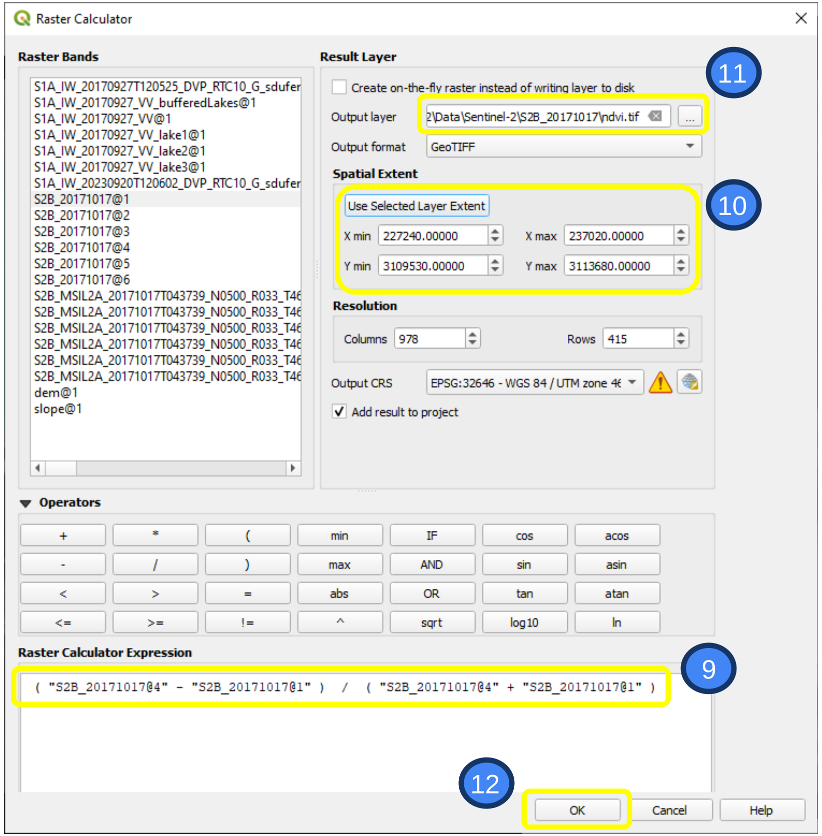
9. Click on Raster → Raster Calculator.

10. In the Raster Calculation Expression, write:
("S2B_20171017@4" - "S2B_20171017@1") / ("S2B_20171017@4" + "S2B_20171017@1")

11. In the Spatial Extent, define the extent based on the aoi.

12. Save the result to ndvi.tif

13. Click OK.

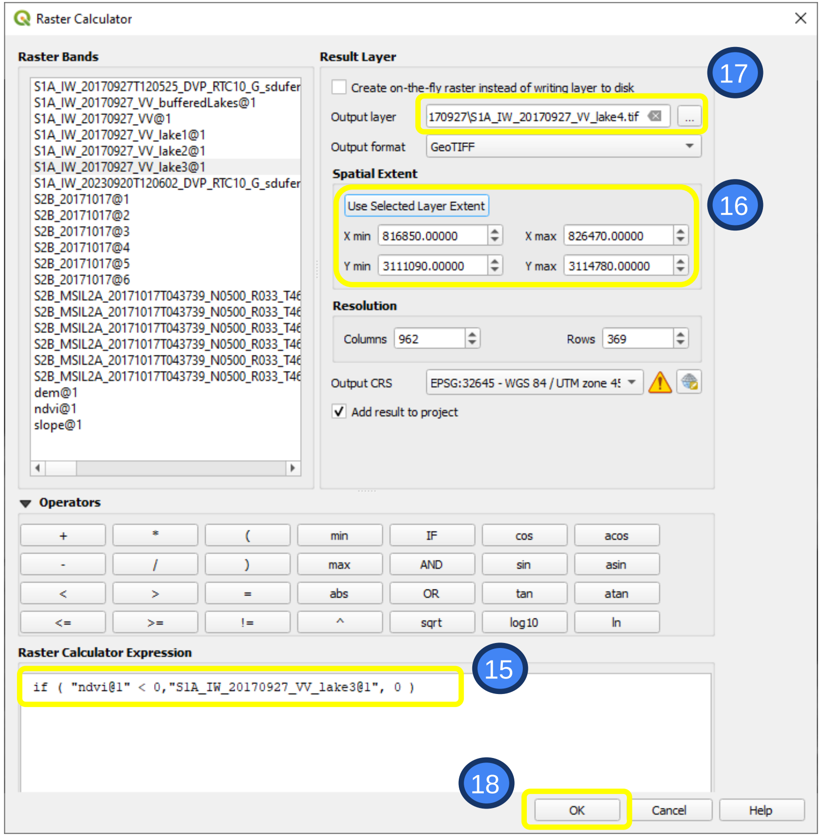


Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in NDVI > 0

Use Raster Calculator to remove pixels with NDVI above zero.

14. Click on Raster → Raster Calculator.
15. In the Raster Calculation Expression write:
    if ("ndvi@1" < 0, "S1A_IW_20171017_VV_lake3@1", 0)
16. In the Spatial Extent, define the extent based on the aoi.
17. Save the result to S1A_IW_20171017_VV_lake4.tif
18. Click OK.



Post-Processing: Glacial Lake Mapping

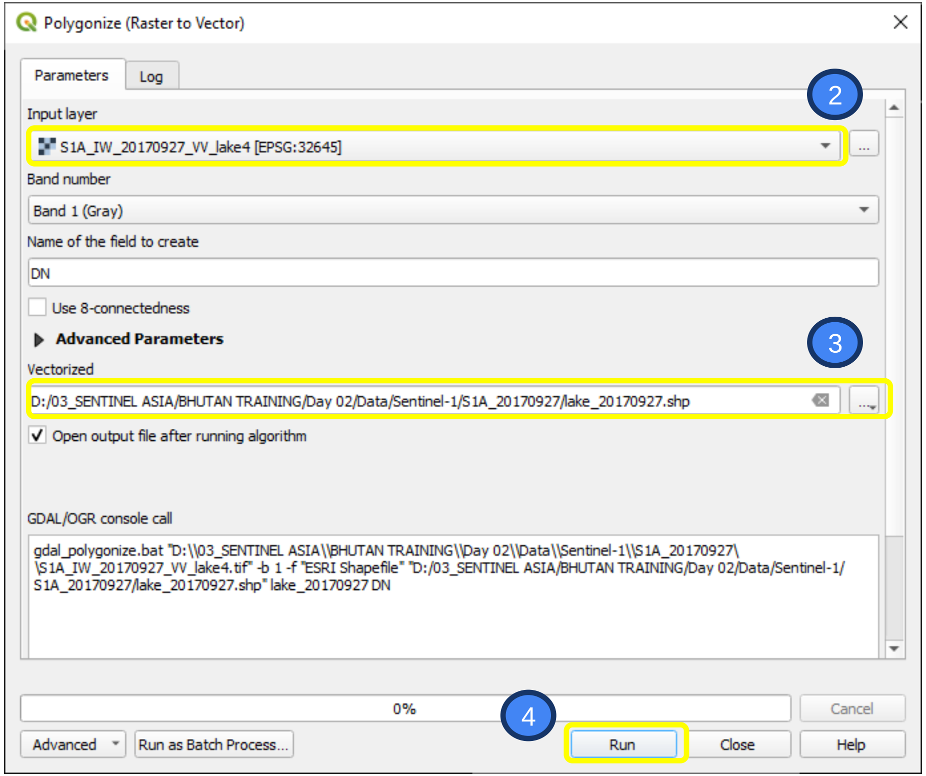
Follow Along: Eliminate pixels found in NDVI > 0

Post-Processing: Glacial Lake Mapping

Follow Along: Vectorize potential glacial lake pixels

We will convert the raster of potential glacial lake to polygons.

1. Click on Raster → Conversion → Polygonize (Raster to Vector)…
2. In the Input Layer, select S1A_IW_20171017_VV_lake4
3. Save the Vectorized result to lake_20170927.shp
4. Click Run.

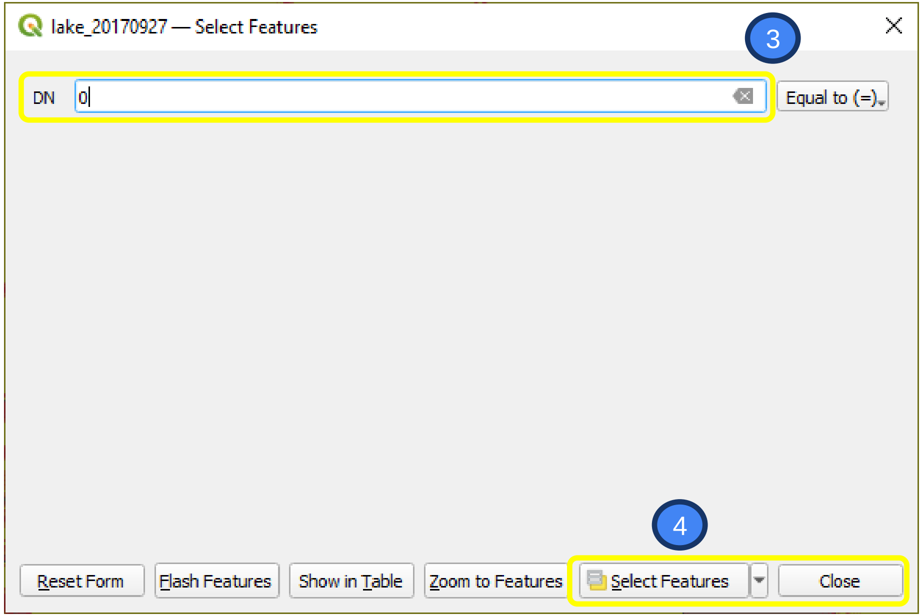


Post-Processing: Glacial Lake Mapping

Follow Along: Remove non-water polygons

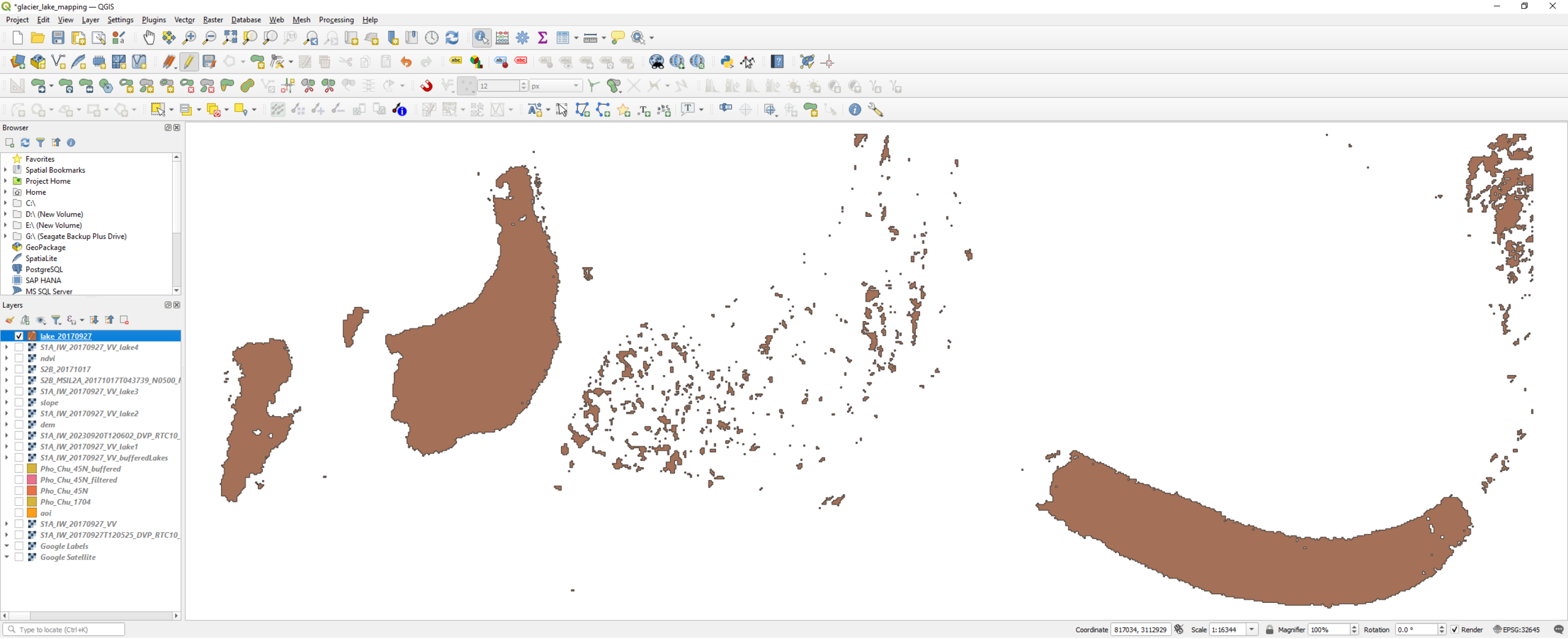
We will modify the polygons to clean the results further. First, let's remove non-water polygons.

1. In Toolbars, activate the editing mode by clicking the Toggle Editing button.
2. In Toolbars, click Select Features by Value button.
3. In the DN value, write 0.
4. Click Select Features, then Close.
5. In Toolbars, click Delete Selected button to delete non-water polygons.



Post-Processing: Glacial Lake Mapping

Follow Along: Remove non-water polygons

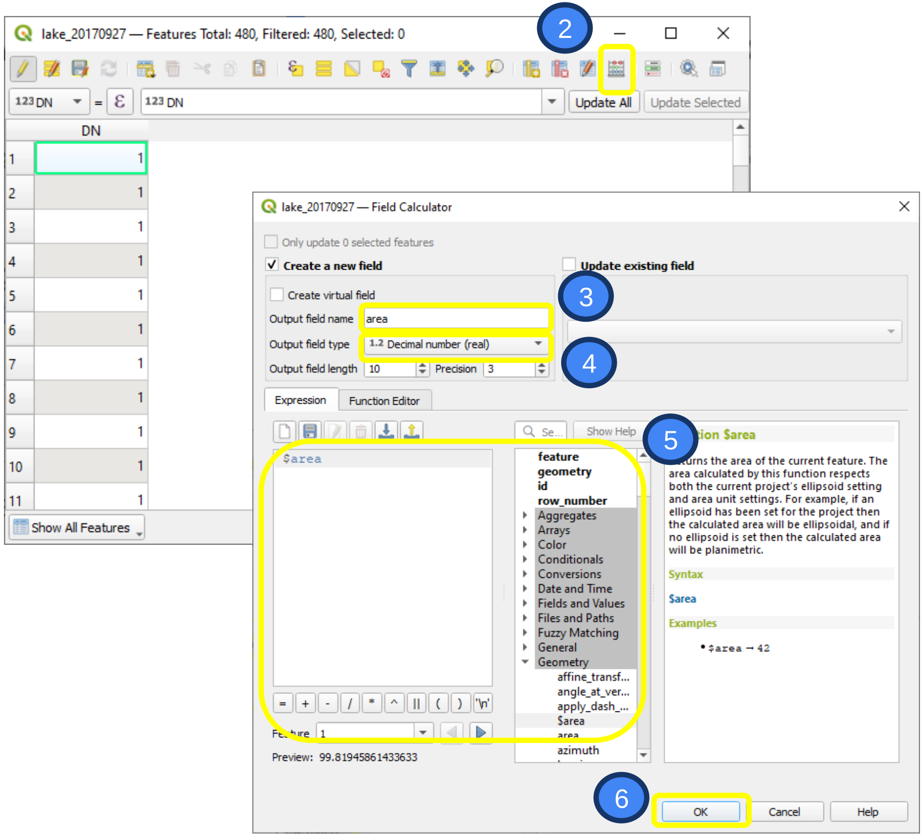


Post-Processing: Glacial Lake Mapping

Follow Along: Calculate area, perimeter, and compactness ratio (CR)

Calculate area of each polygon in the attribute table.

1. Right-click on the layer, then click Open Attribute Table
2. In the Table Toolbars, click Open Field Calculator button.
3. In Output field name, write area.
4. In Output field type, select Decimal number (real).
5. Expand the Geometry and double-click $area. The text will be added to the Expression box.
6. Click OK.



Post-Processing: Glacial Lake Mapping

Follow Along: Calculate area, perimeter, and compactness ratio (CR)

Calculate perimeter of each polygon in the attribute table. The Polsby-Popper test will

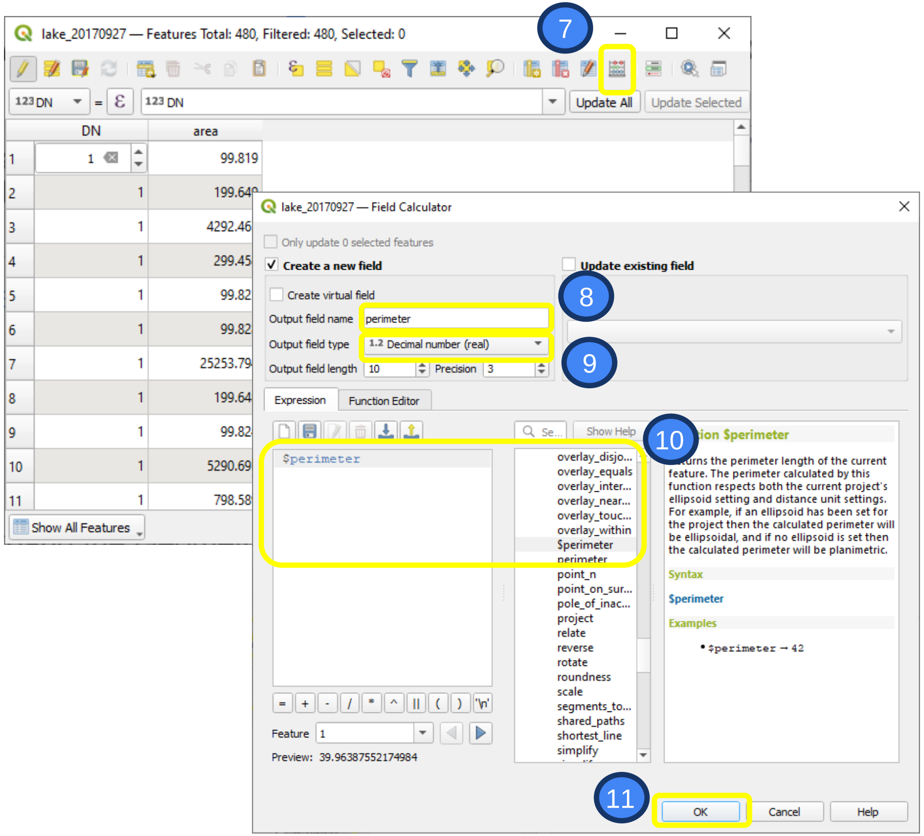
7. In the Table Toolbars, click again Open Field Calculator button.

8. In Output field name, write perimeter.

9. In Output field type, select Decimal number (real).

10. Expand the Geometry and double-click $perimeter. The text will be added to the Expression box.

11. Click OK.



Post-Processing: Glacial Lake Mapping

Follow Along: Calculate area, perimeter, and compactness ratio (CR)

Calculate CR of each polygon in the attribute table. The Polsby-Popper test will be used to measure the compactness of a shape.

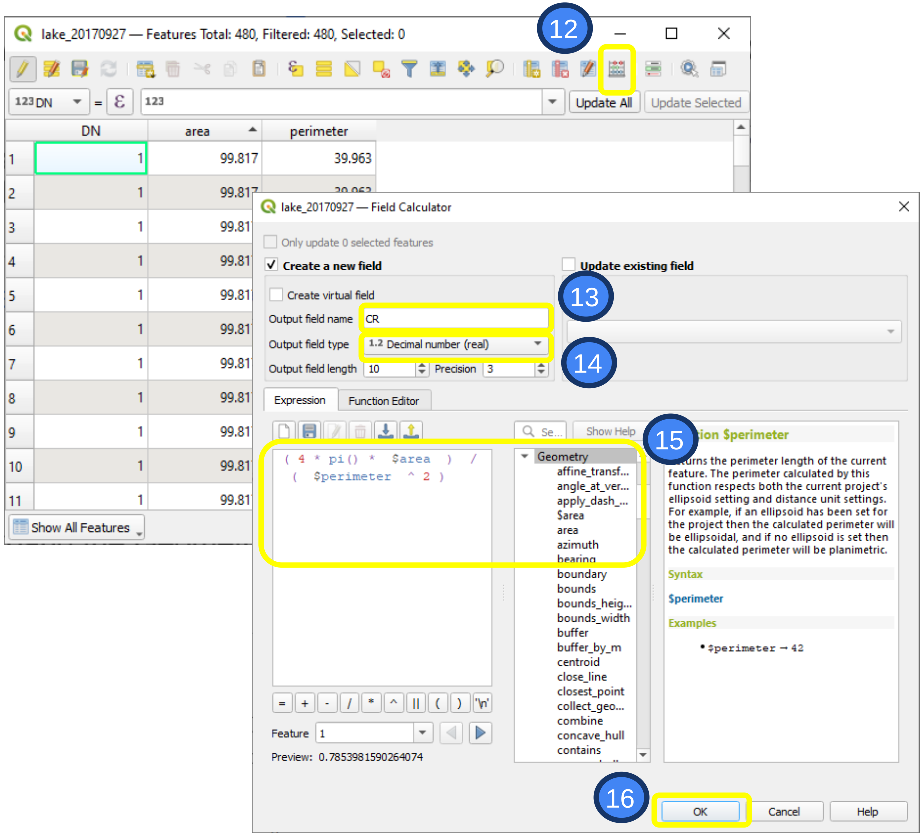
12. In the Table Toolbars, click again Open Field Calculator button.

13. In Output field name, write CR.

14. In Output field type, select Decimal number (real).

15. Write this equation in the Expression box: (4 * pi() * $area) / ($perimeter ^ 2)

16. Click OK.

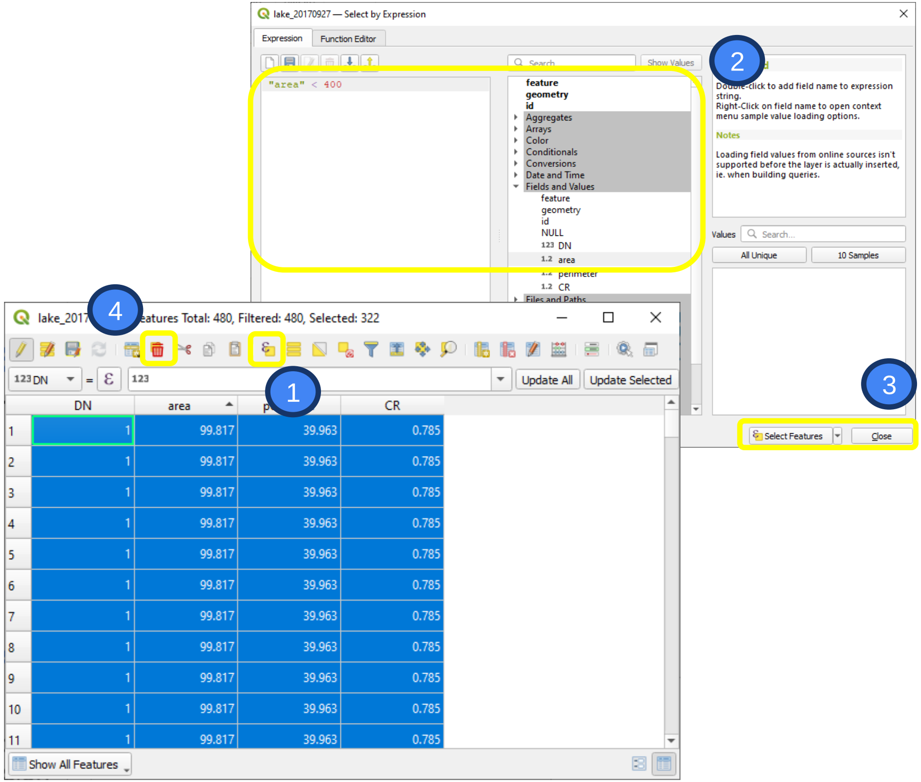


Post-Processing: Glacial Lake Mapping

Follow Along: Remove areas of internal polygons voids < 400 m2

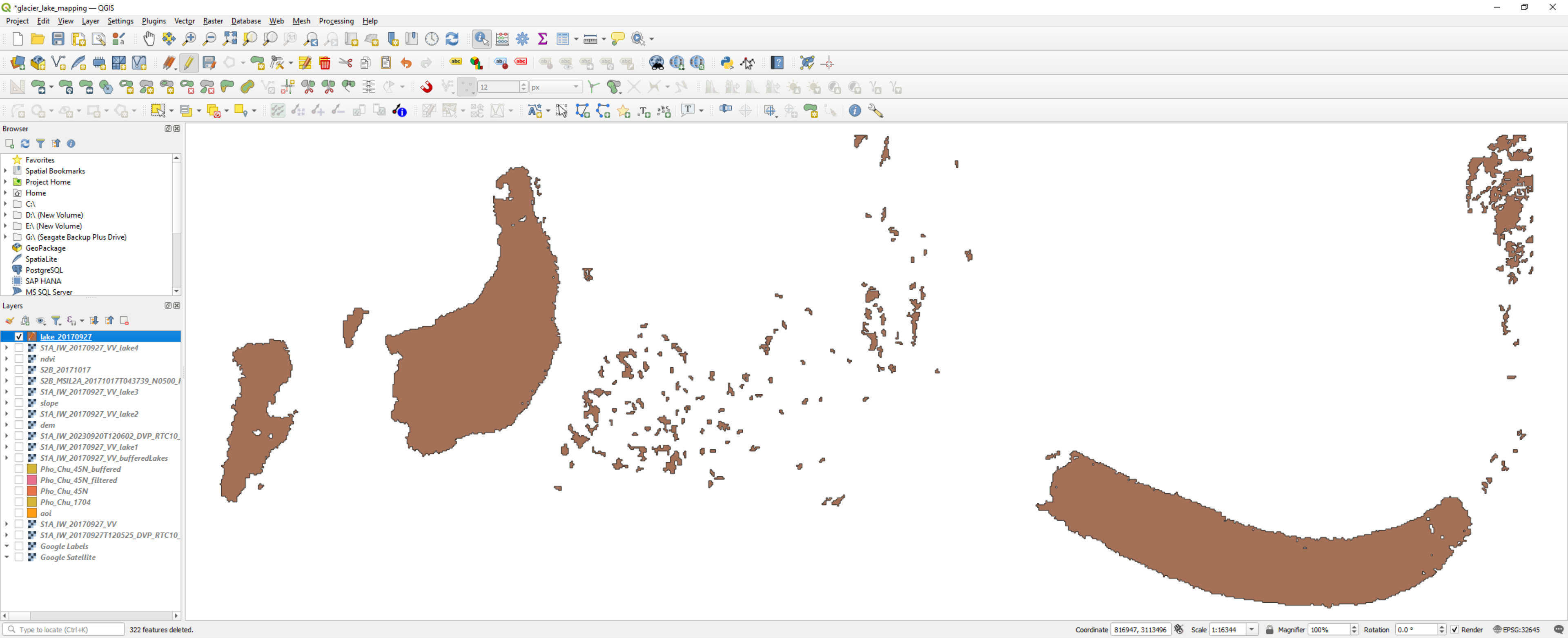
We will remove small size pixels that may not correct represents a glacial lake.

1. In the Table Toolbars, click Select features using an expression button.
2. Expand the Field and Values and double-click area. The text will be added to the Expression box. Complete the expression: "area" < 400
3. Click Select Features, then Close.
4. In the Table Toolbars, click Delete selected features button.



Post-Processing: Glacial Lake Mapping

Follow Along: Remove areas of internal polygons voids < 400 m2

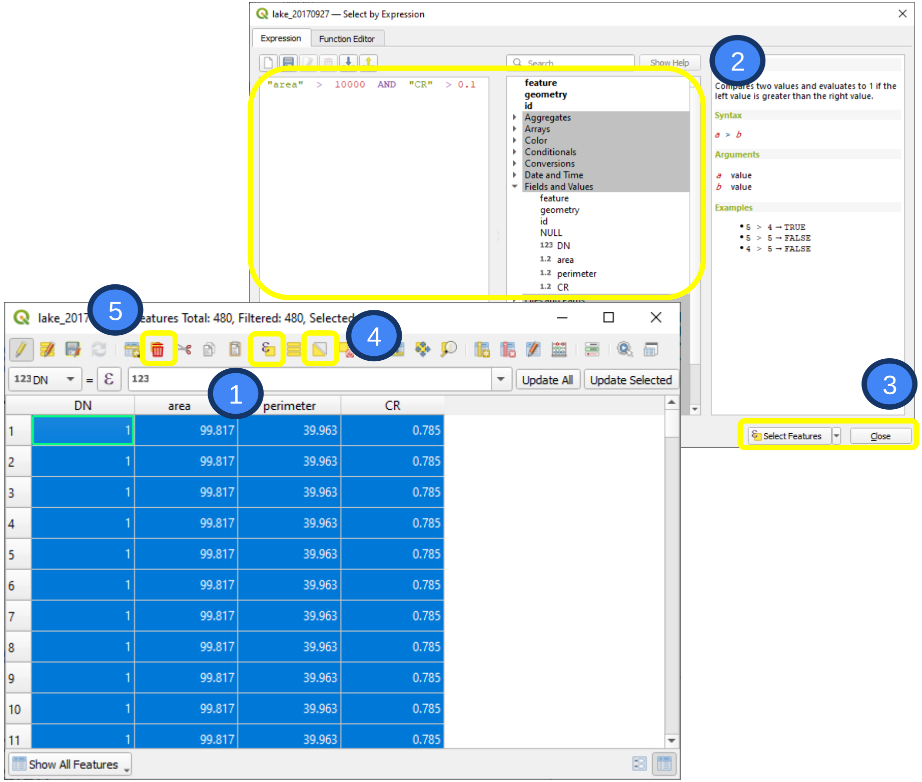


Post-Processing: Glacial Lake Mapping

Follow Along: Select and extract potential areas > 0.01 km2 and CR > 0.1

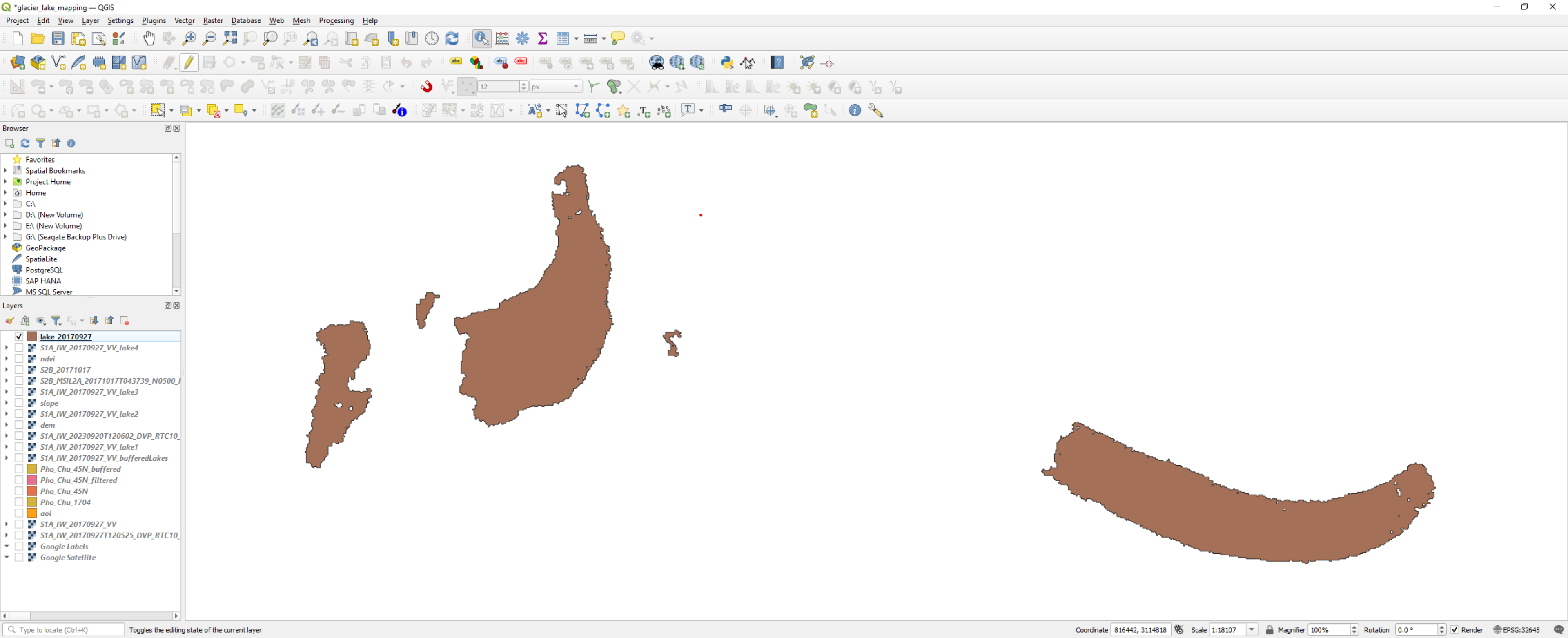
Potential lake areas will be selected based on the criteria on the size of area and compactness ratio.

1. In the Table Toolbars, click Select features using an expression button.
2. Expand the Field and Values and double-click area and CR to use them in the Expression box. Complete the expression: "area" < 1000 AND “CR" > 0.1
3. Click Select Features, then Close.
4. In the Table Toolbars, click Invert selection button.
5. In the Table Toolbars, click Delete selected features button.
6. In Toolbars, click Toggle Editing button to close the editing mode. Don’t forget to click Save button in the confirmation box.



Post-Processing: Glacial Lake Mapping

Follow Along: Select and extract potential areas > 0.01 km2 and CR > 0.1

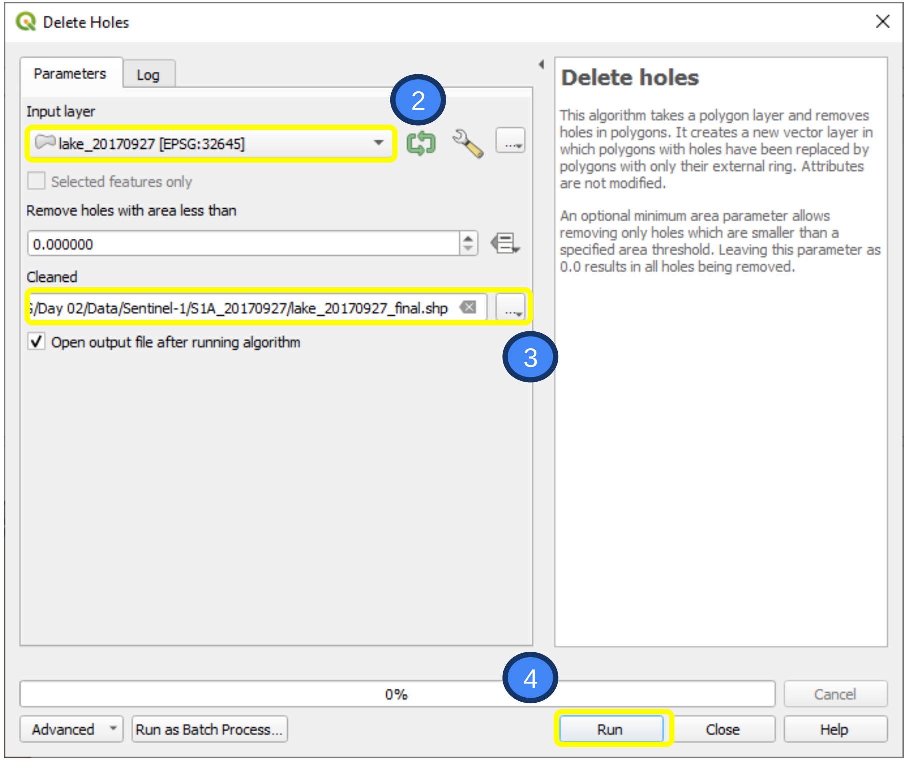


Post-Processing: Glacial Lake Mapping

Follow Along: Fill in the holes in the polygons

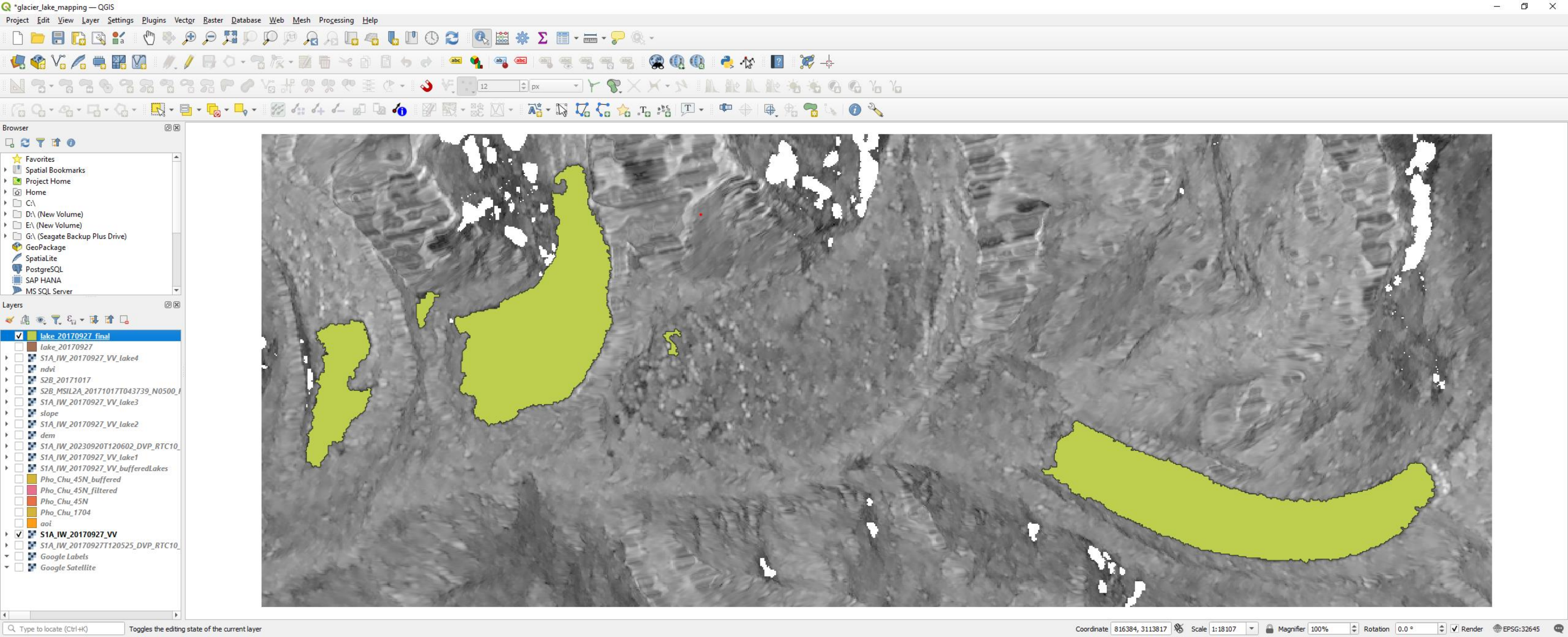
To finalize the post-processing, we will fill in the holes in the glacial lake polygons.

1. Click on Processing → Toolbox. Search for Delete Holes tool.
2. In the Input Layer, select lake_20170927
3. Save the result to lake_20170927_final.shp
4. Click Run.



Post-Processing: Glacial Lake Mapping

Final Glacial Lake Map



Next…

We've completed the exercise for glacial lake mapping using QGIS software.

- We used the Sentinel-1 RTC data on 27 September 2017 to extract glacial lake features, with the additional data from ALOS/AVNIR-2 glacial inventory, as well as Sentinel-2 data and GLO-30 Copernicus DEM for post-processing.

- You can also process the more recent Sentinel-2 RTC data on 02 September 2023 following the same step-by-step method. The result can be used to perform multi-temporal analysis and evaluate the changes of glacial lake between 2017 and 2023.

THANK YOU

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