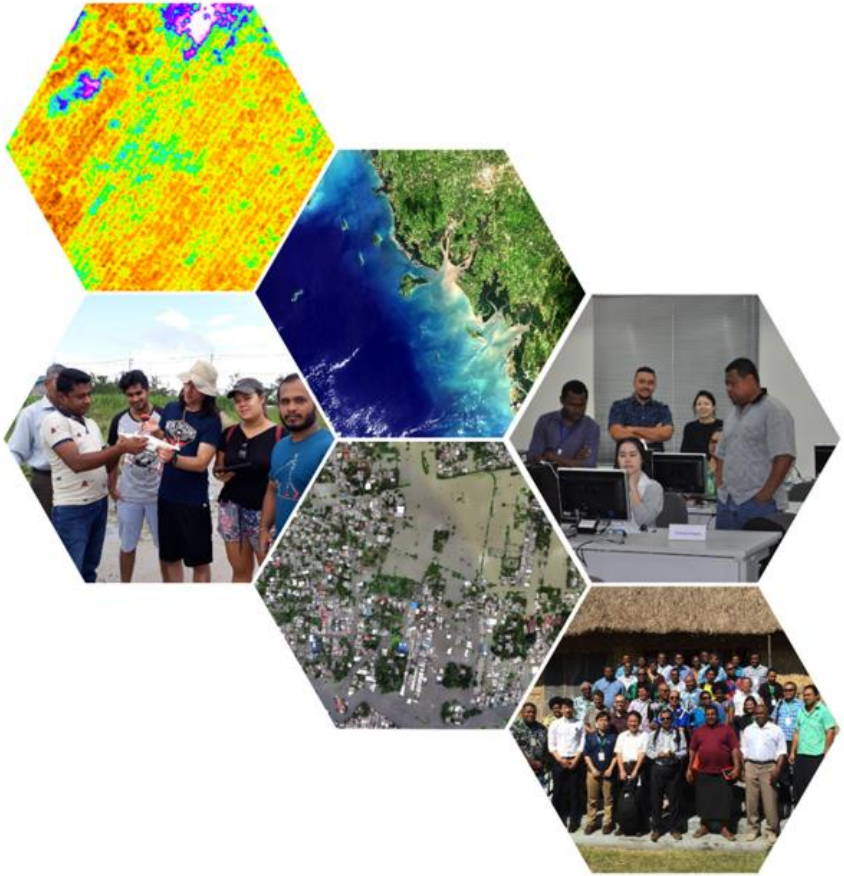

Glacial Lake Mapping

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,

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

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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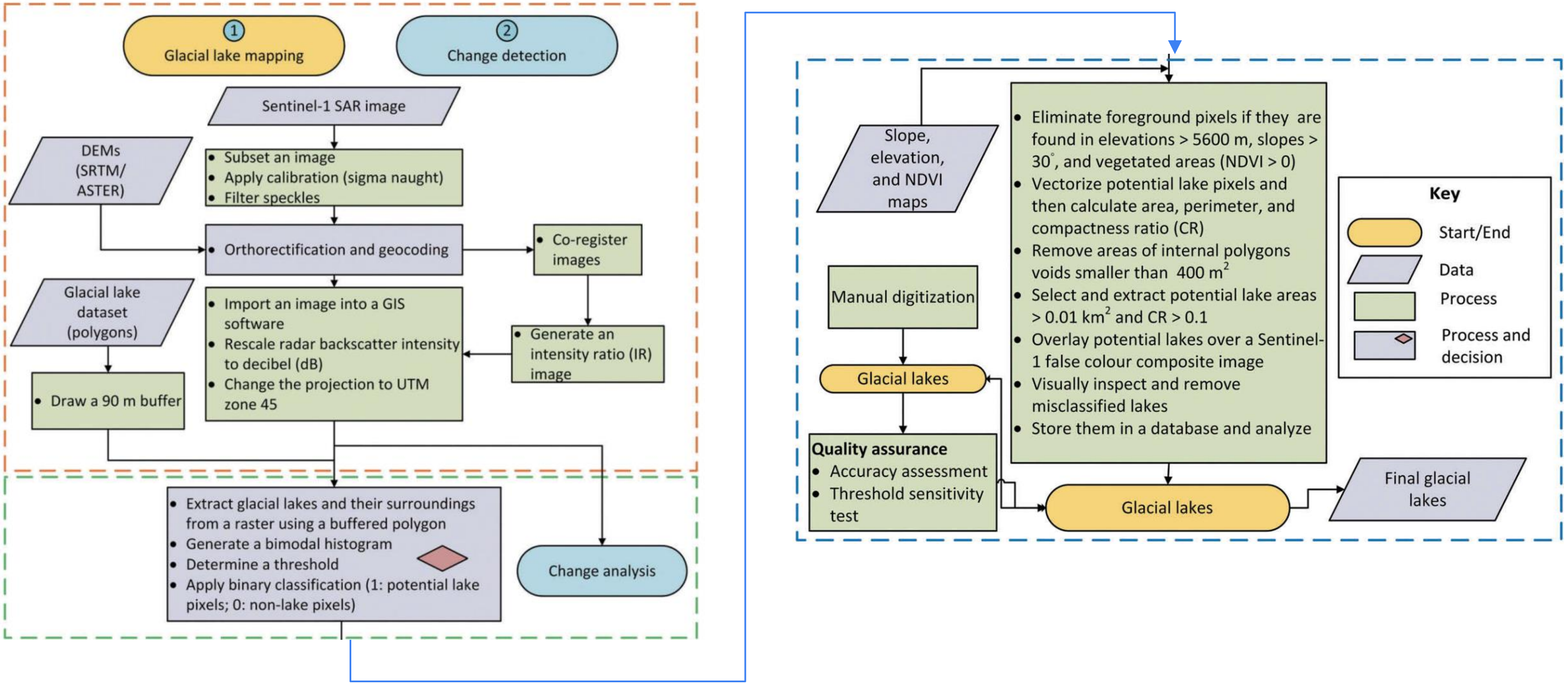
Supplemental data for this article can be accessed here.

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: 05 July 2025
  - Spatial resolution 10m
- Sentinel-2 Level-2A product
  - Atmospherically corrected Surface Reflectance (SR) products from Level-1C products.
  - Date: 29 April 2024
  - 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 (Wang et al., 2020)
  - Data was generated using Landsat data for the year 1990. 2000. 2010, 2015. and 2020.
  - Covered the area of Hindu Kush, Karakoram, Western Himalaya, Central Himalaya, Eastern Himalaya, Nyainqêntanglha, and Hengduan Shan.
  - Dataset is freely available from https://figshare.com/articles/dataset/Glacial_lake_inventory_1990_2000_2010_2015_and_2020_in_the_greater_Himalaya/21708590?file=39643498
- Area of Interest (AOI) in shapefile

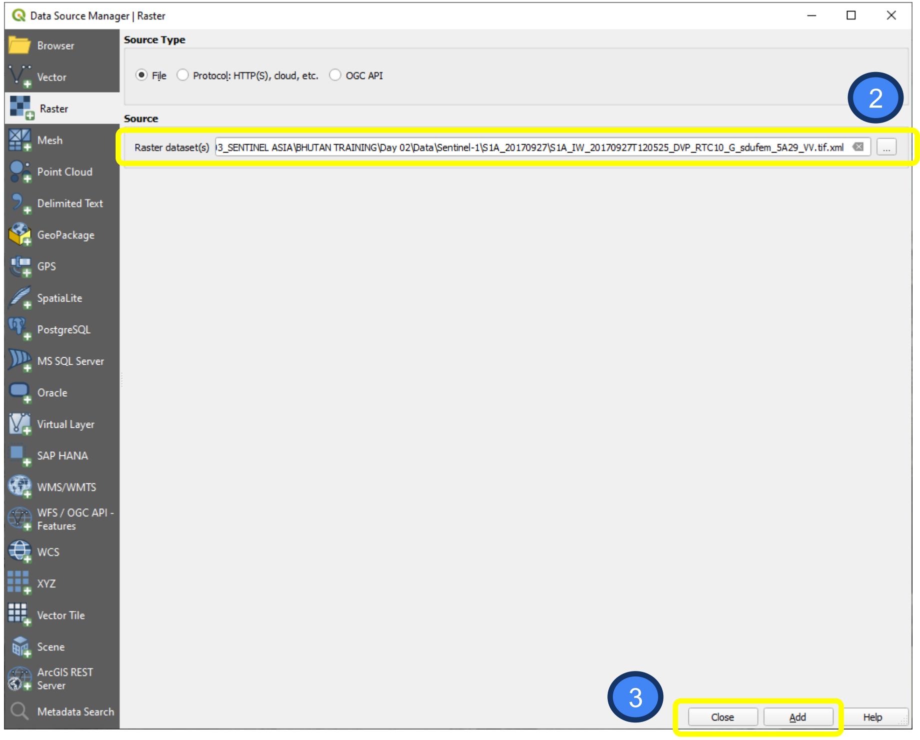
Data Preparation

Follow Along: Open Sentinel-1 RTC data (05 July 2025)

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_20250705T001933_DVR_RTC10_G_gdufem_E688_VV.tif in the data folder.

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



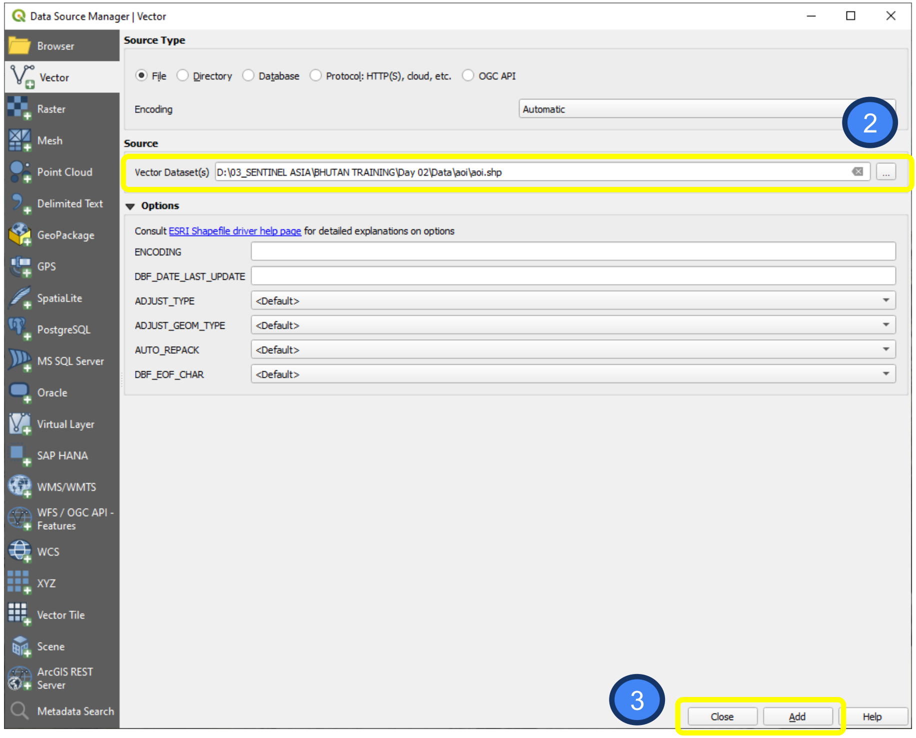
Data Preparation

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.

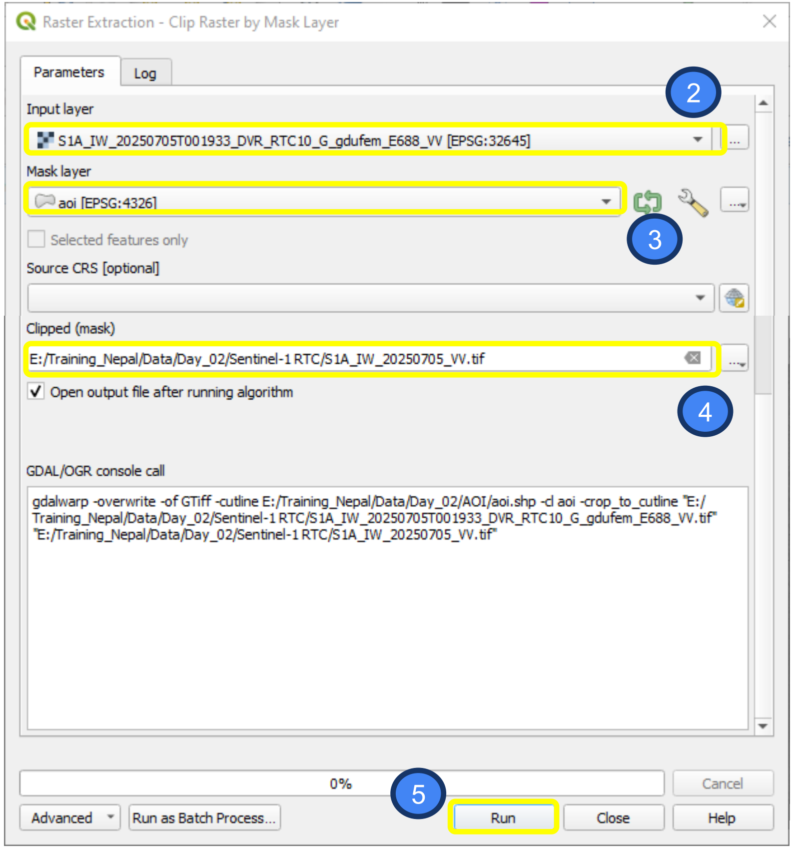
3. With this file selected, click Add, then Close. The data you specified will now load.



Data Preparation

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_20250705T001933_DVR_RTC10_G_gdufem_E688_VV
3. In the Mask Layer, select aoi.
4. Save the result to S1A_IW_20250705_VV.tif
5. Click Run.



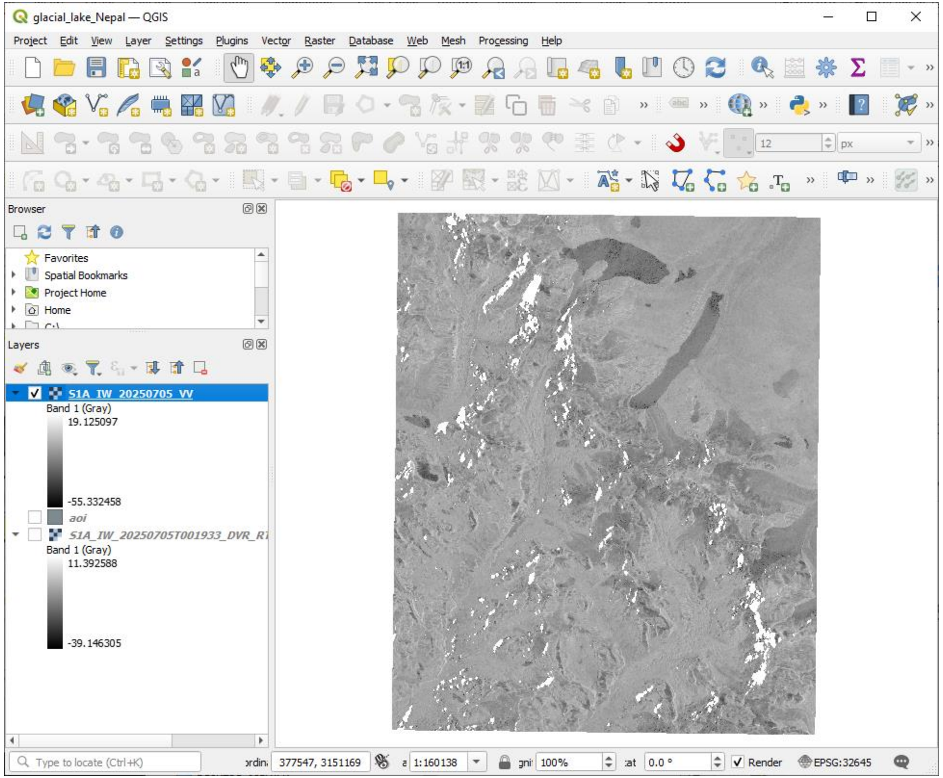
Data Preparation

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 glacial_lake_Nepal.qgs

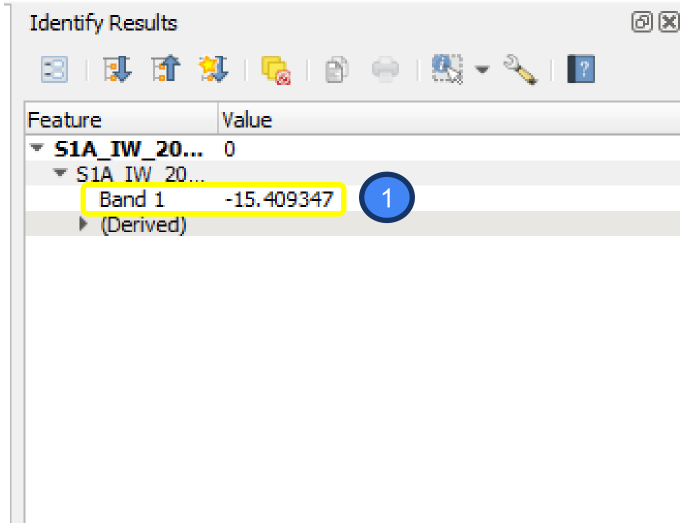


Determine a Threshold Value

Follow Along: (Option 1) Manual visual observation

You can determine threshold values by a manual visual observation. Flooded areas often appear as dark regions in SAR images because open water surfaces cause specular reflection, resulting in lower backscatter returns. Examine the image and incrementally adjusts the threshold value while seeking a value that best separates flooded and non-flooded areas.

1. Use Identify Features  tool to inspect the backscatter value. Click on a specific pixel on the image to find out the value.



Determine a Threshold Value

Follow Along: (Option 2) Histogram analysis

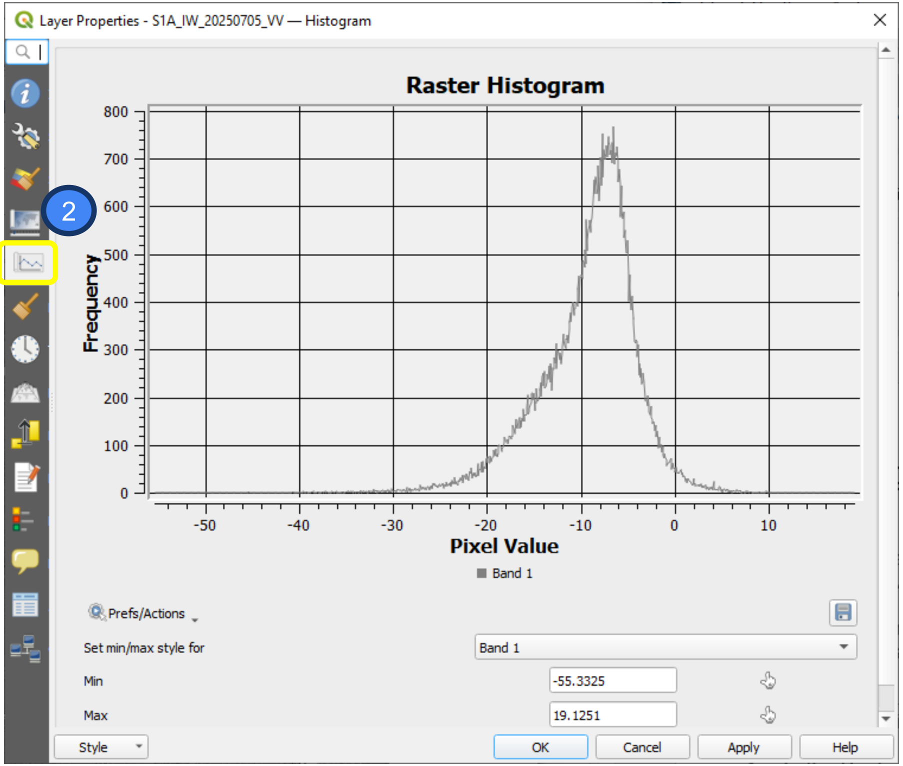
Check the histogram of the whole clipped image.

1. Right-click on the S1A_IW_20250705_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. Ideally, we look for bimodal histograms, where water and land have two distinct peaks in the backscatter value distribution.



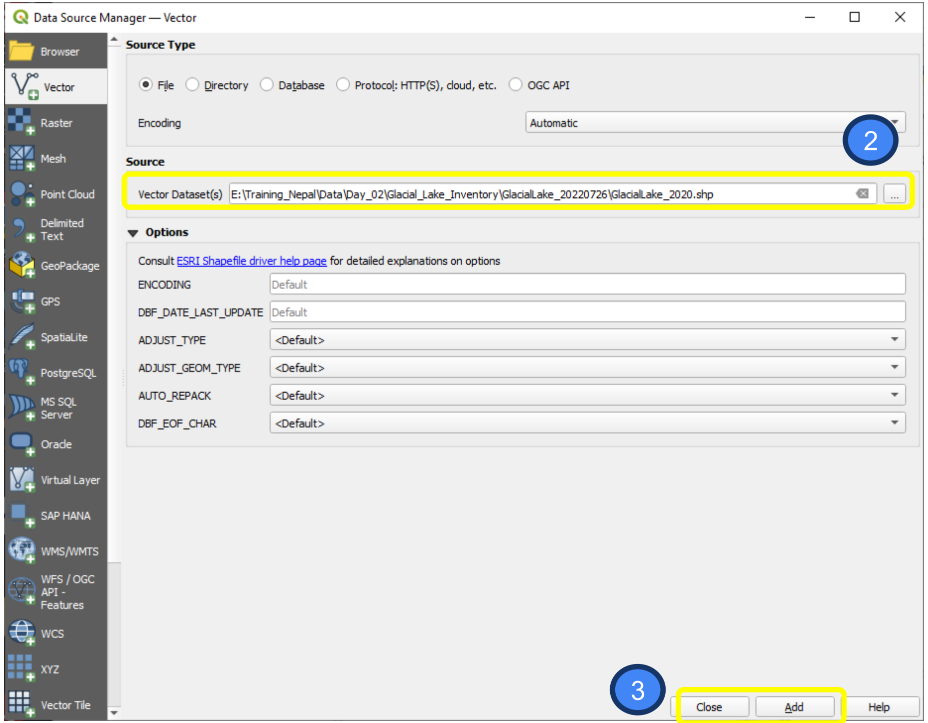
Determine a Threshold Value

Follow Along: (Option 2) Determine a threshold value

Since determining the threshold for the entire image histogram was difficult, we will calculate the threshold based on the histograms of specific known lakes. The available inventory of glacial lakes will be used here.

Open glacial lake inventory:

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 GlacialLake_2020.shp in the data folder.
3. With this file selected, click Add, then Close. The data you specified will now load.



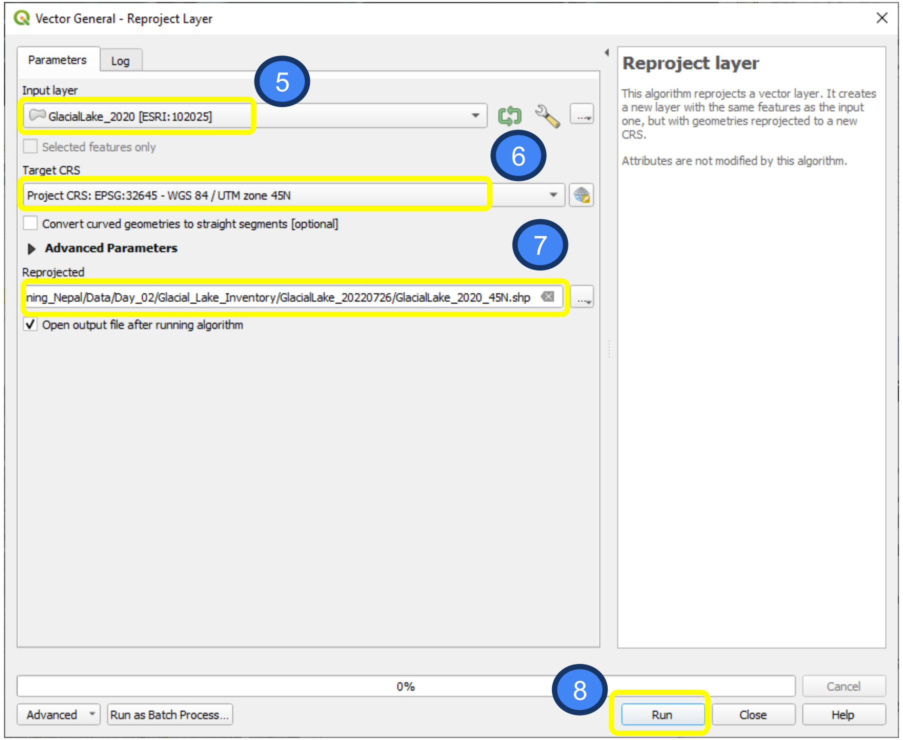
Note: In the paper, the Otsu algorithm was used to determine the threshold automatically. We'll not do it now because we cannot do this process directly in QGIS, but it is possible to write a Python script to then run it in QGIS.

Determine a Threshold Value

Follow Along: (Option 2) Determine a threshold value

The inventory data comes in another different projection: Asia_North_Albers_Equal_Area. 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 GlacialLake_2020.
6. In the Target CRS, select Project CRS: EPSG:32645 – WGS 84 / UTM zone 45N.
7. Save the result to GlacialLake_2020 _45N.shp.
8. Click Run.



Determine a Threshold Value

Follow Along: (Option 2) Determine a threshold value

We will only select the glacial lakes that are included in the AOI.

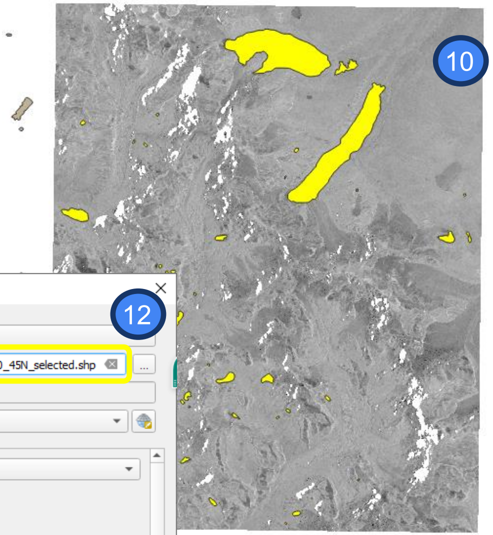
9. In the Tool Bar, click on Select Features by Area or Single Click button.

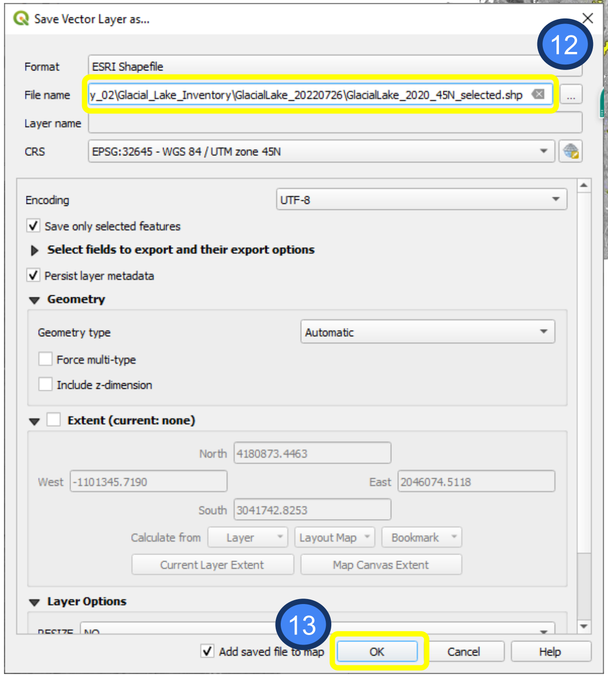
10. Select the lake polygons from the GlacialLake_2020 _45N layer over the AOI using your Shift and left-click mouse. The selected polygon will be highlighted in yellow.

11. Right-click on the GlacialLake_2020 _45N layer in the Layers list, click Export → Save Selected Features As…

12. Save the result to GlacialLake_2020 _45N_selected.shp.

13. Click OK.



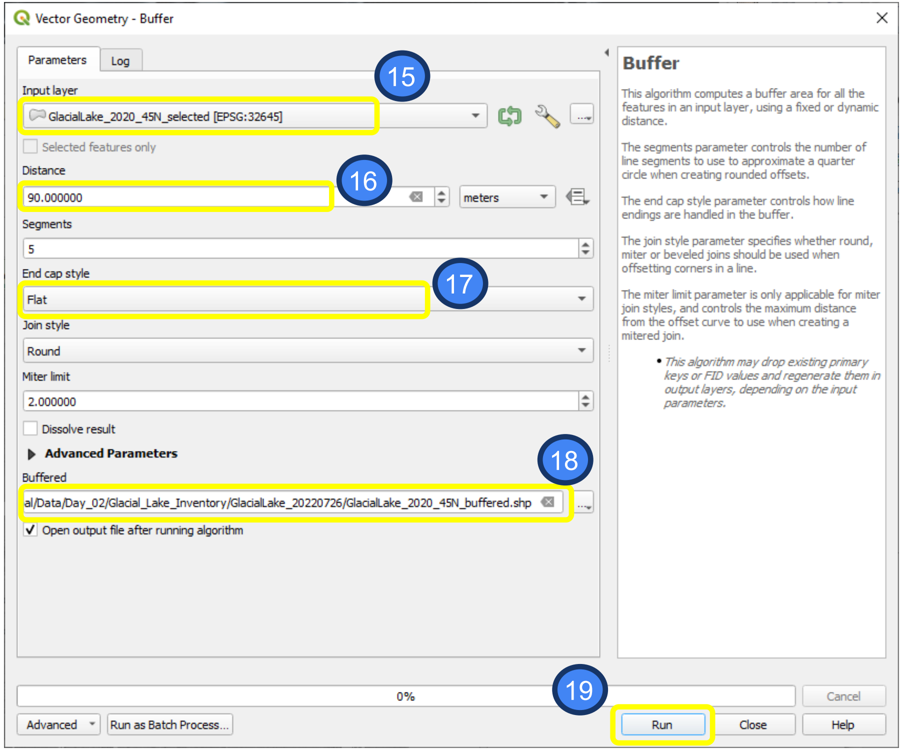


Determine a Threshold Value

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 GlacialLake_2020 _45N _filtered.
16. In the Distance, type 90.
17. In the End cap style, select Flat
18. Save the result to GlacialLake_2020 _45N _buffered.shp.
19. Click Run.

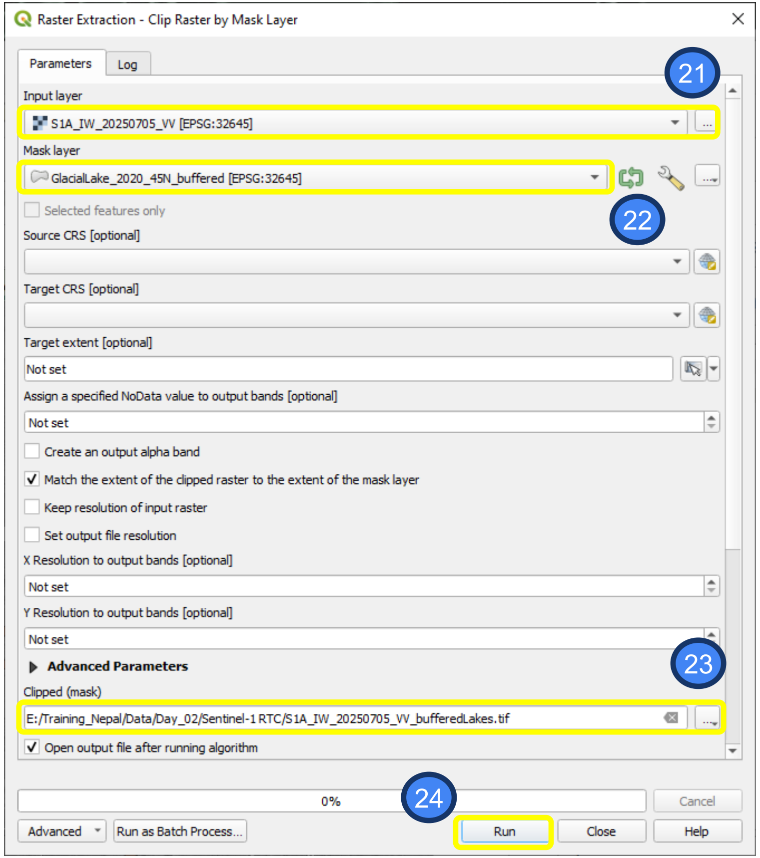


Determine a Threshold Value

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_20250705_VV
22. In the Mask Layer, select GlacialLake_2020 _45N _buffered.
23. Save the result to S1A_IW_ 20250705 _VV_bufferedLakes.tif
24. Click Run.



Determine a Threshold Value

Follow Along: (Option 2) Determine a threshold value

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

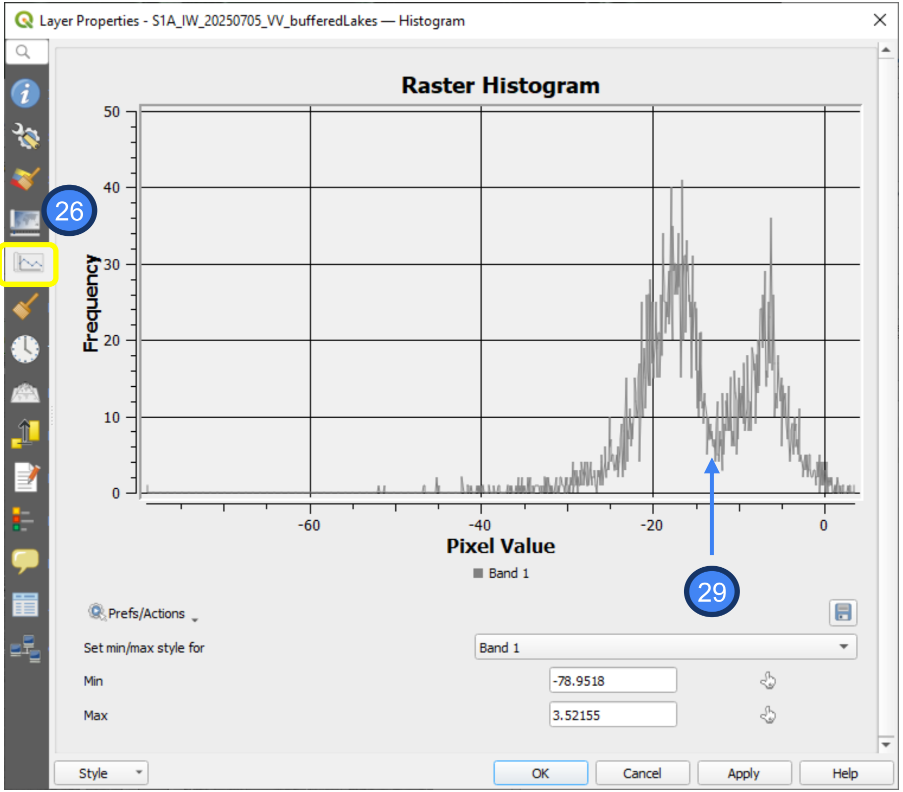
25. Right-click on the S1A_IW_ 20250705 _VV_bufferedLakes layer in the Layers list and select the menu item Properties in the menu that appears.

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: ~ -14 dB

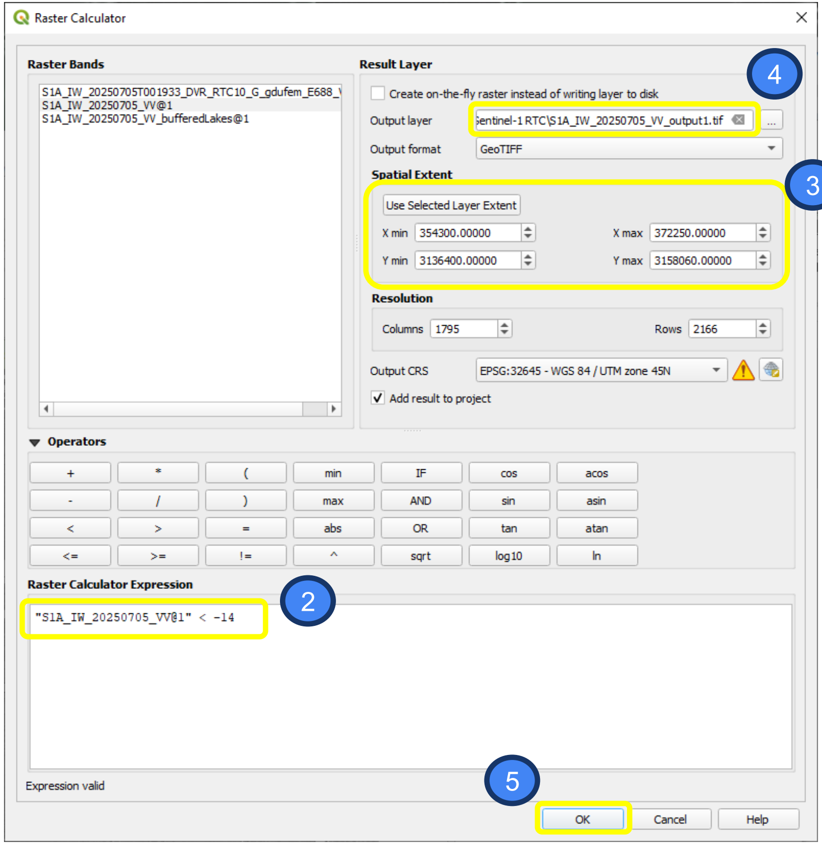


Glacial Lake Mapping

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

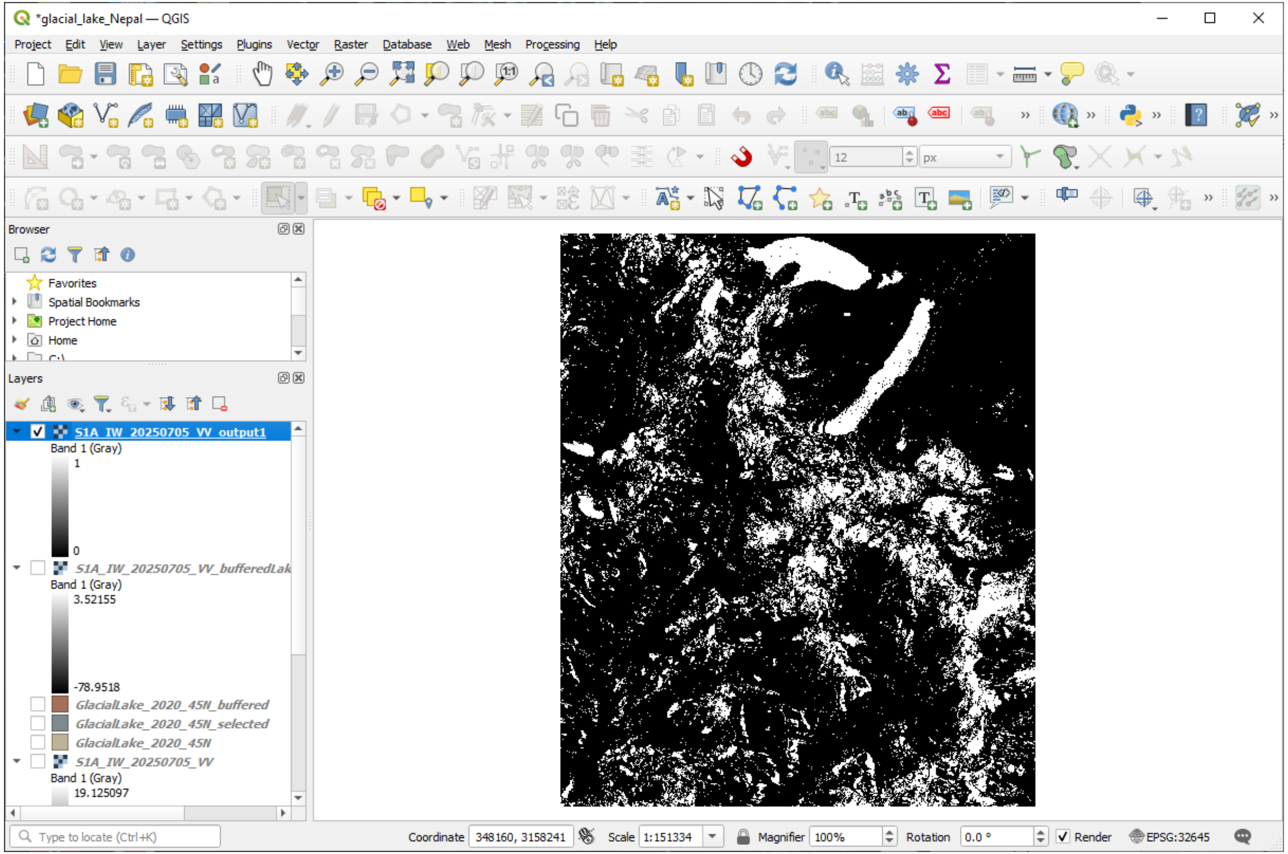
We will use the threshold value from the second option's result: -14 dB. The average threshold value given in the paper is -14.52 dB, which is not far from our result.

1. Click on Raster → Raster Calculator.
2. In the Raster Calculation Expression write: " S1A_IW_20220705_VV@1 " < -14
3. In the Spatial Extent, define the extent based on the aoi.
4. Save the result to S1A_IW_ 20220705 _VV_output1.tif
5. Click OK.



Glacial Lake Mapping

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



Post-Processing: Glacial Lake Mapping

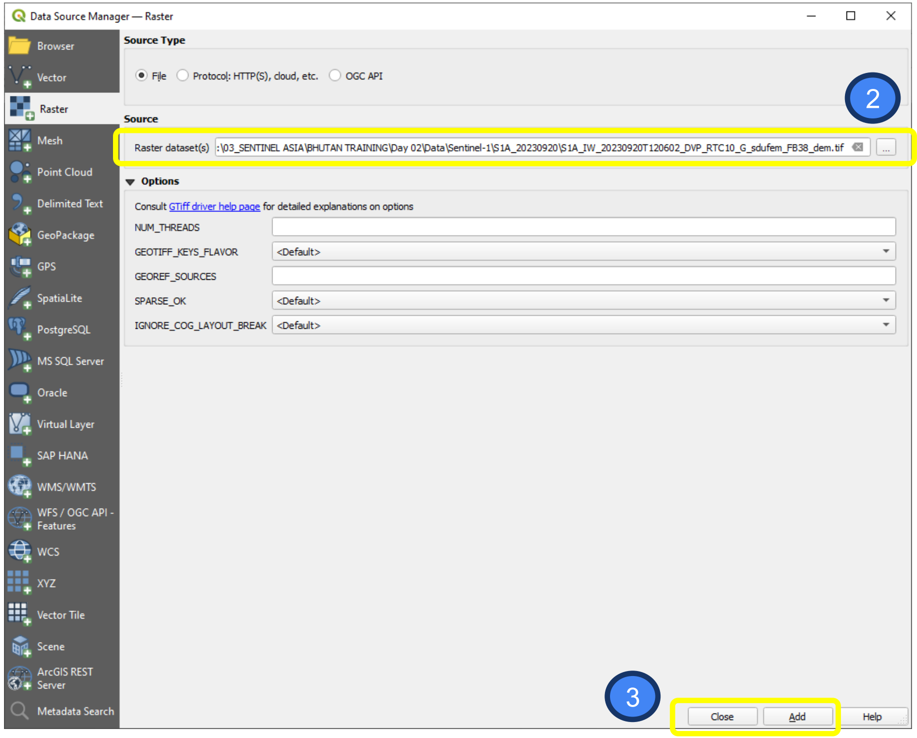
Follow Along: Eliminate pixels found in elevation > 5,600m

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)

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_20250705T001933_DVR_RTC10_G_gdufem_E688_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

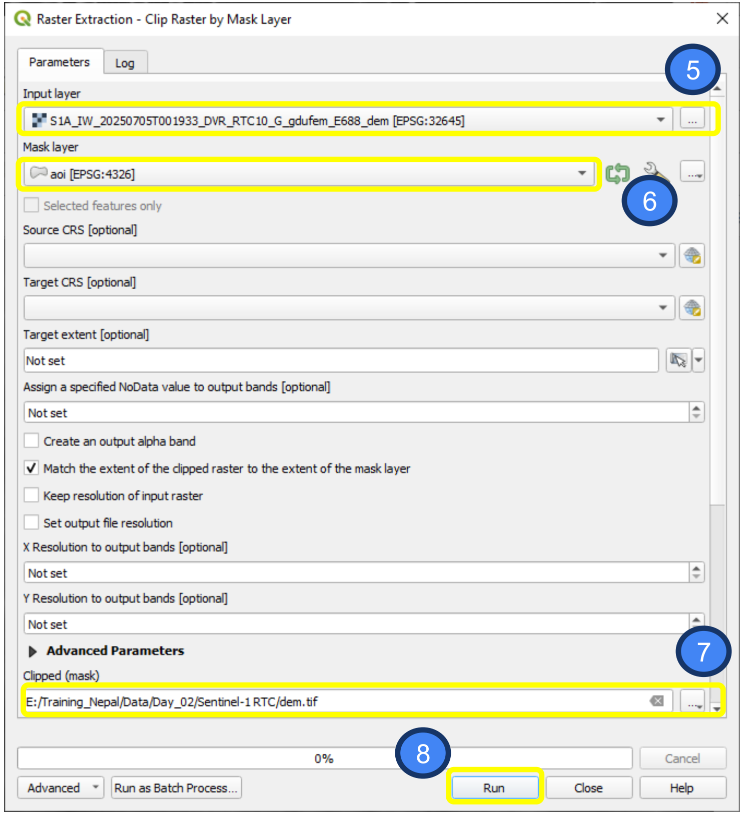
4. In the Menu Bar, click on Raster → Extraction → Clip Raster by Mask Layer.

5. In the Input Layer, select S1A_IW_20250705T001933_DVR_RTC10_G_gdufem_E688_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.

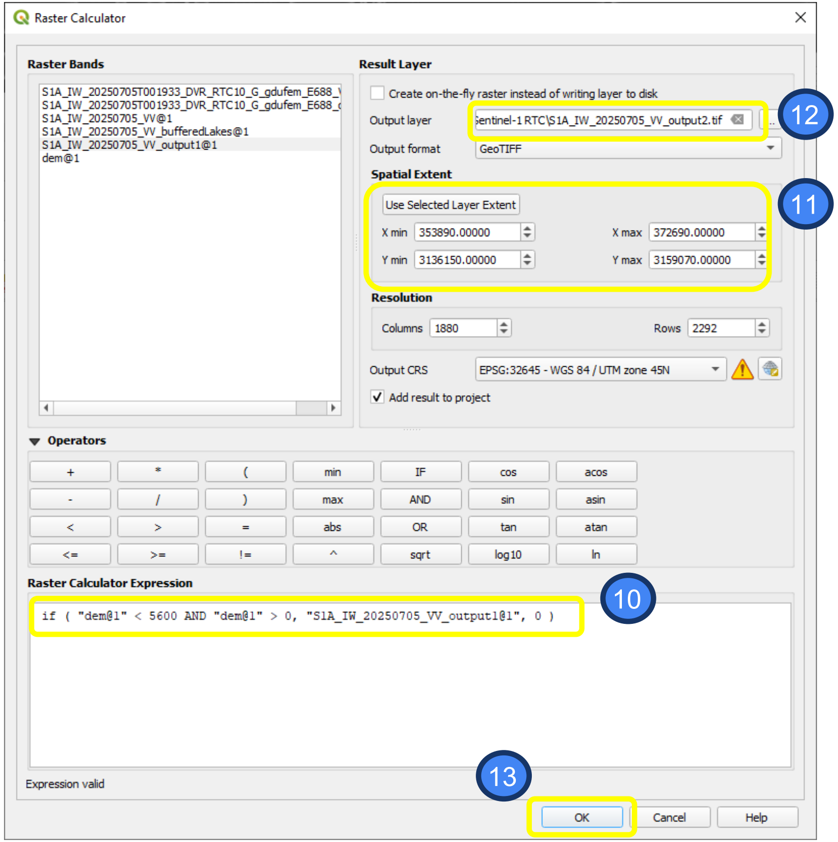
9. Click on Raster → Raster Calculator.

10. In the Raster Calculation Expression write:
    if ("dem@1" < 5600 AND "dem@1" > 0, " S1A_IW_20250705_VV_output1.tif @1", 0)

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

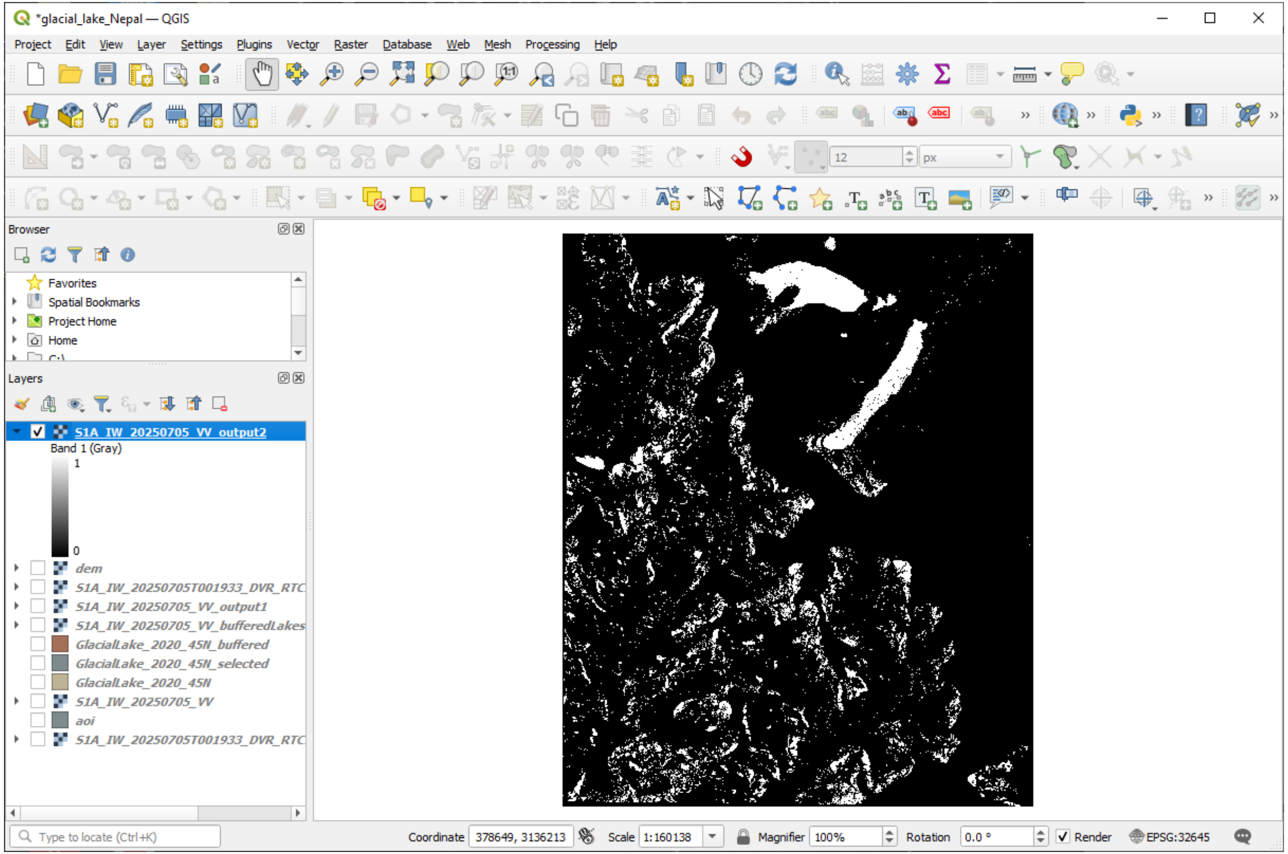
12. Save the result to
    S1A_IW_20250705_VV_output2.tif

13. Click OK.



Post-Processing: Glacial Lake Mapping

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



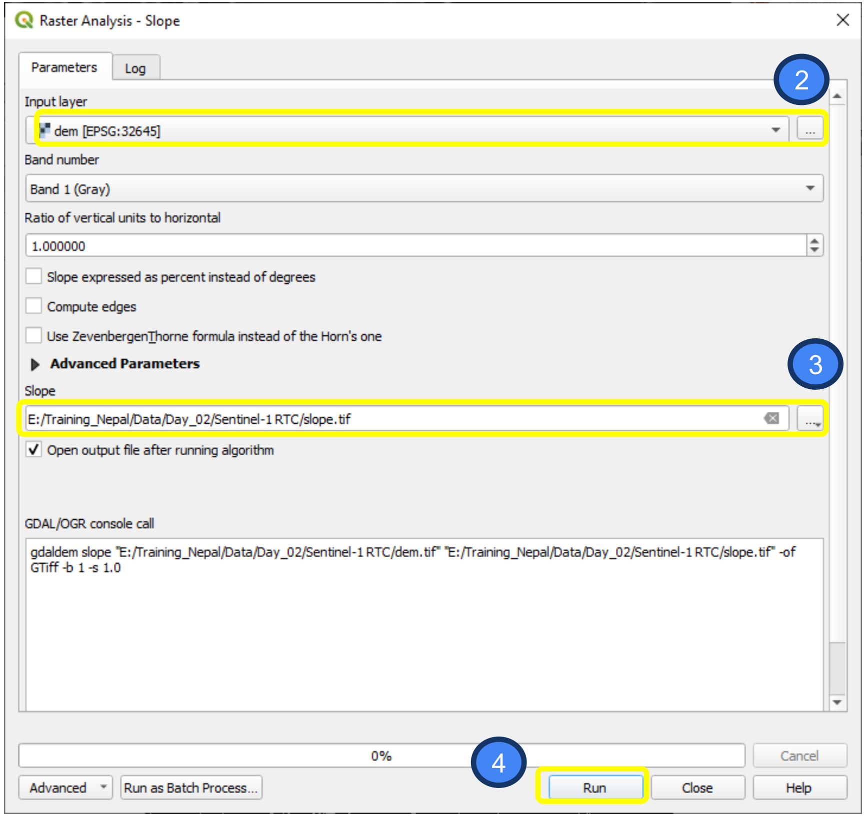
Post-Processing: Glacial Lake Mapping

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.

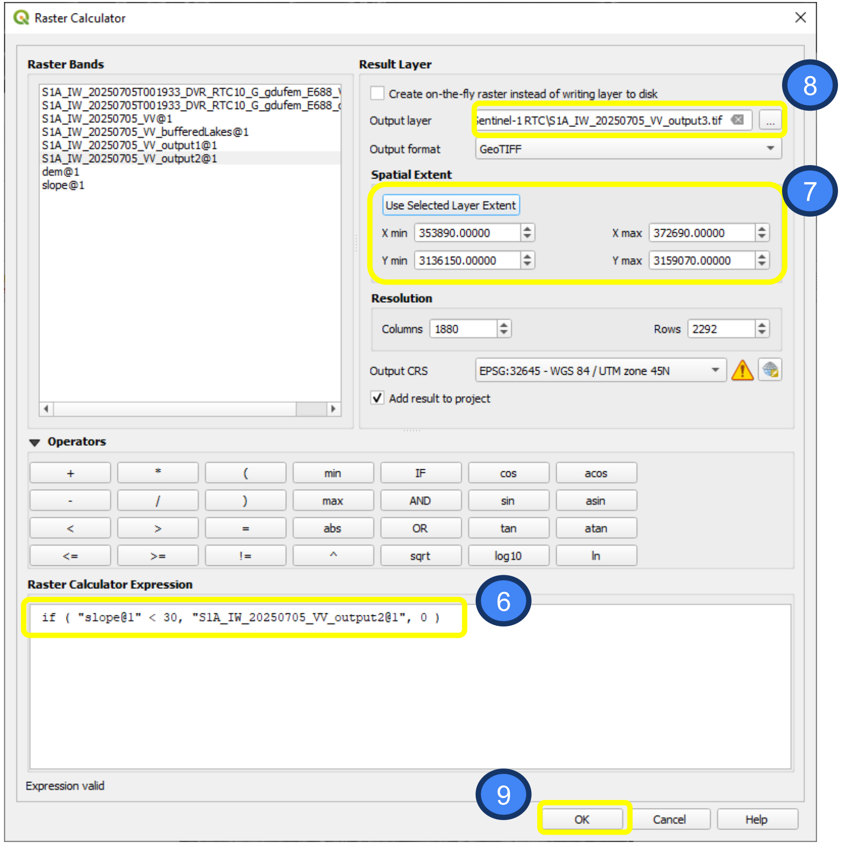
5. Click on Raster → Raster Calculator.

6. In the Raster Calculation Expression write:
   if ("slope@1" < 30, " S1A_IW_20250705_VV_output2.tif@1", 0)

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

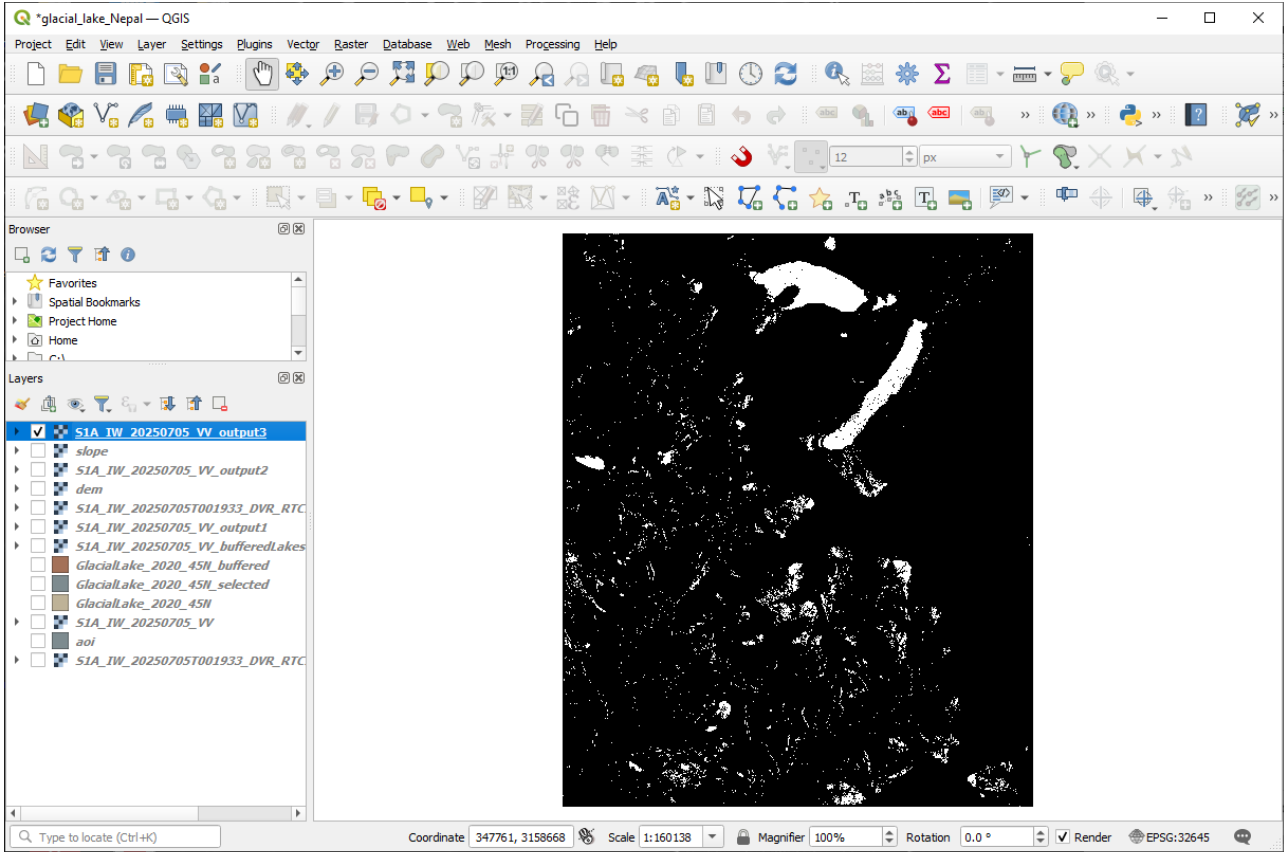
8. Save the result to S1A_IW_20250705_VV_output3.tif

9. Click OK.



Post-Processing: Glacial Lake Mapping

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



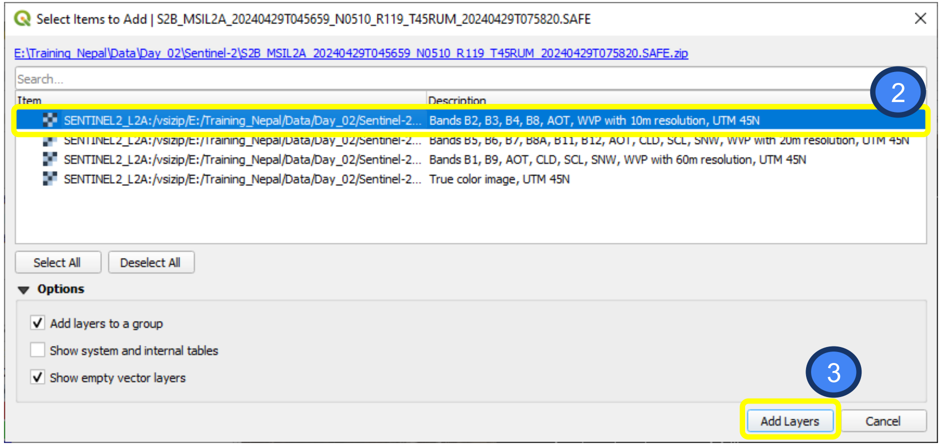
Post-Processing: Glacial Lake Mapping

Follow Along: Eliminate pixels found in NDVI > 0

We will use Sentinel-2 data on 29 April 2024 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), B3 (Green), B4 (Red), and B8 (Near Infrared) bands.
3. Click Add Layers.

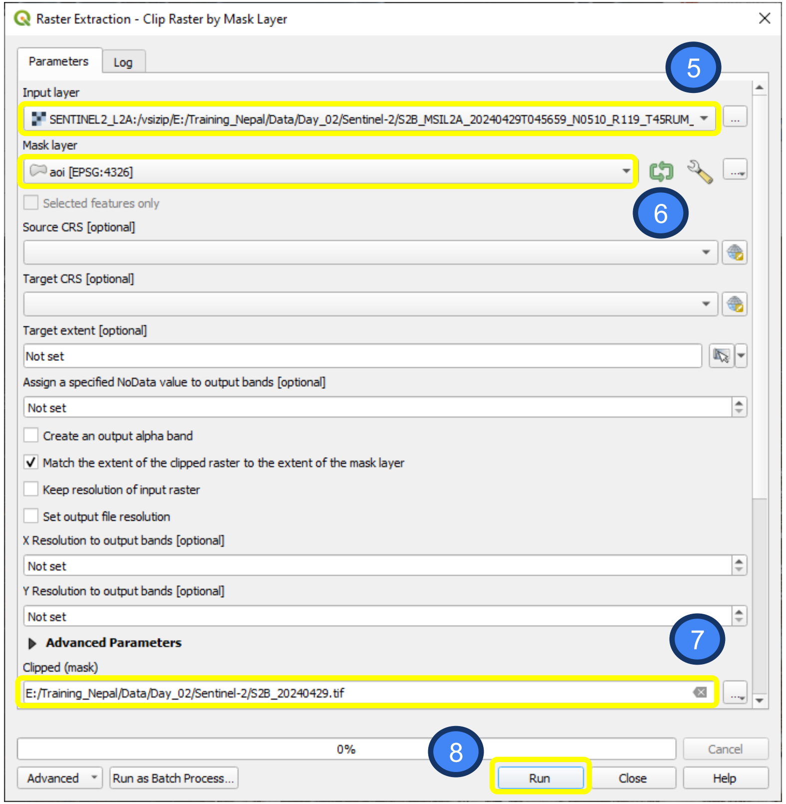


Post-Processing: Glacial Lake Mapping

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_20240429T045659_N0510_R119_T45RUM_20240429T075820.SAFE.zip
6. In the Mask Layer, select aoi.
7. Save the result to S2B_20240429.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).

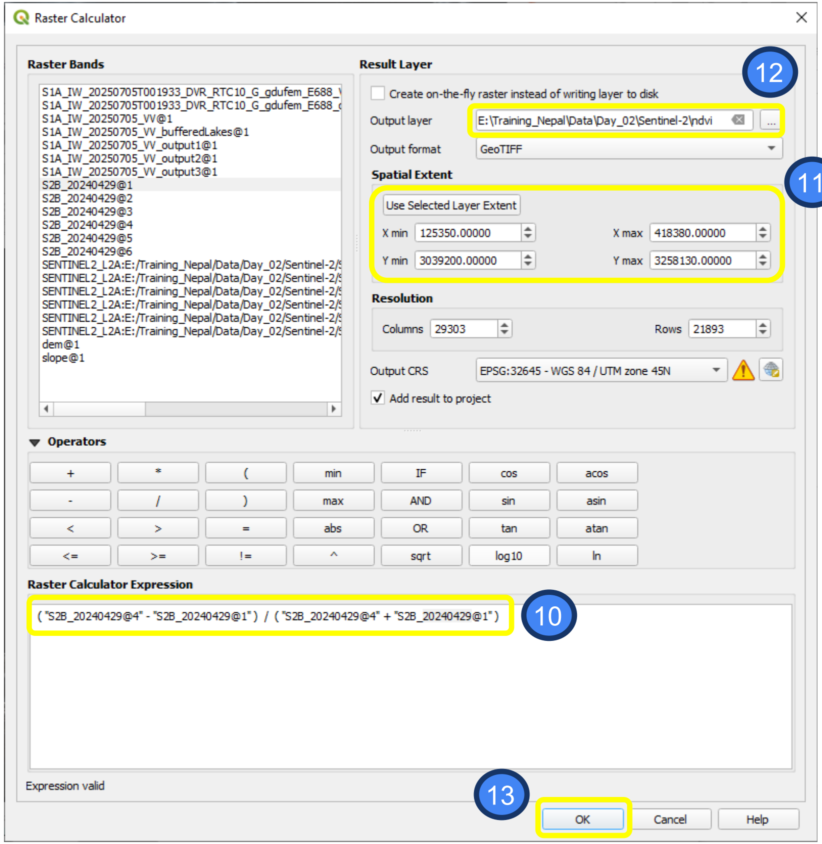
9. In the Menu Bar, click on Raster → Raster Calculator.

10. In the Raster Calculation Expression, write:
("S2B_20240429@4" - "S2B_20240429@1") / ("S2B_20240429@4" + "S2B_20240429@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.

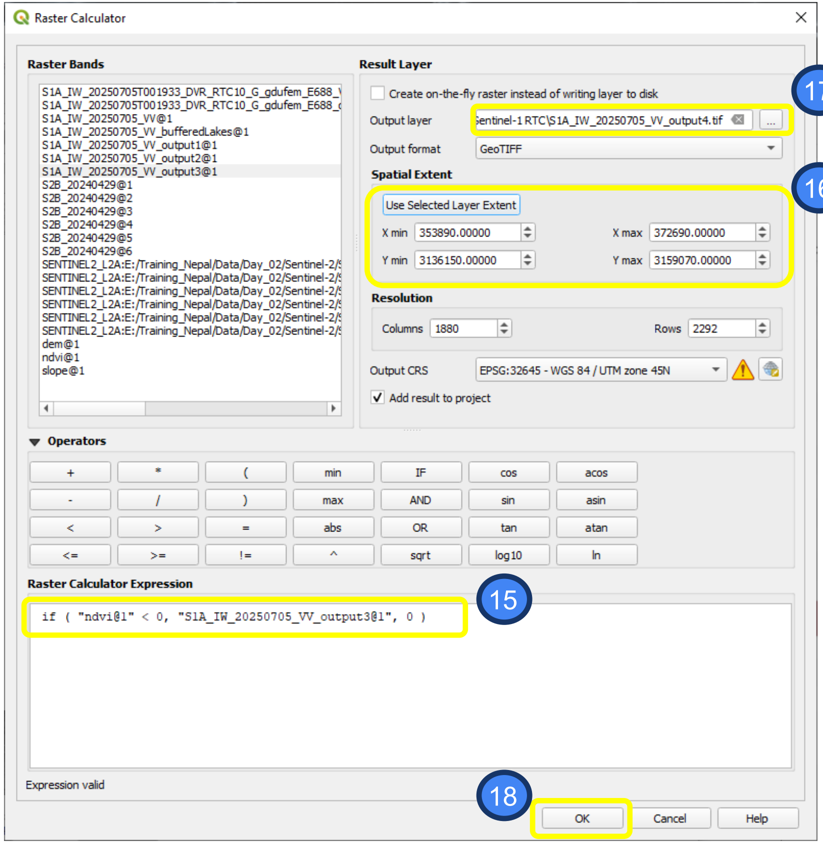
14. Click on Raster → Raster Calculator.

15. In the Raster Calculation Expression write:
    if ("ndvi@1" < 0, " S1A_IW_20250705_VV_output3 @1", 0)

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

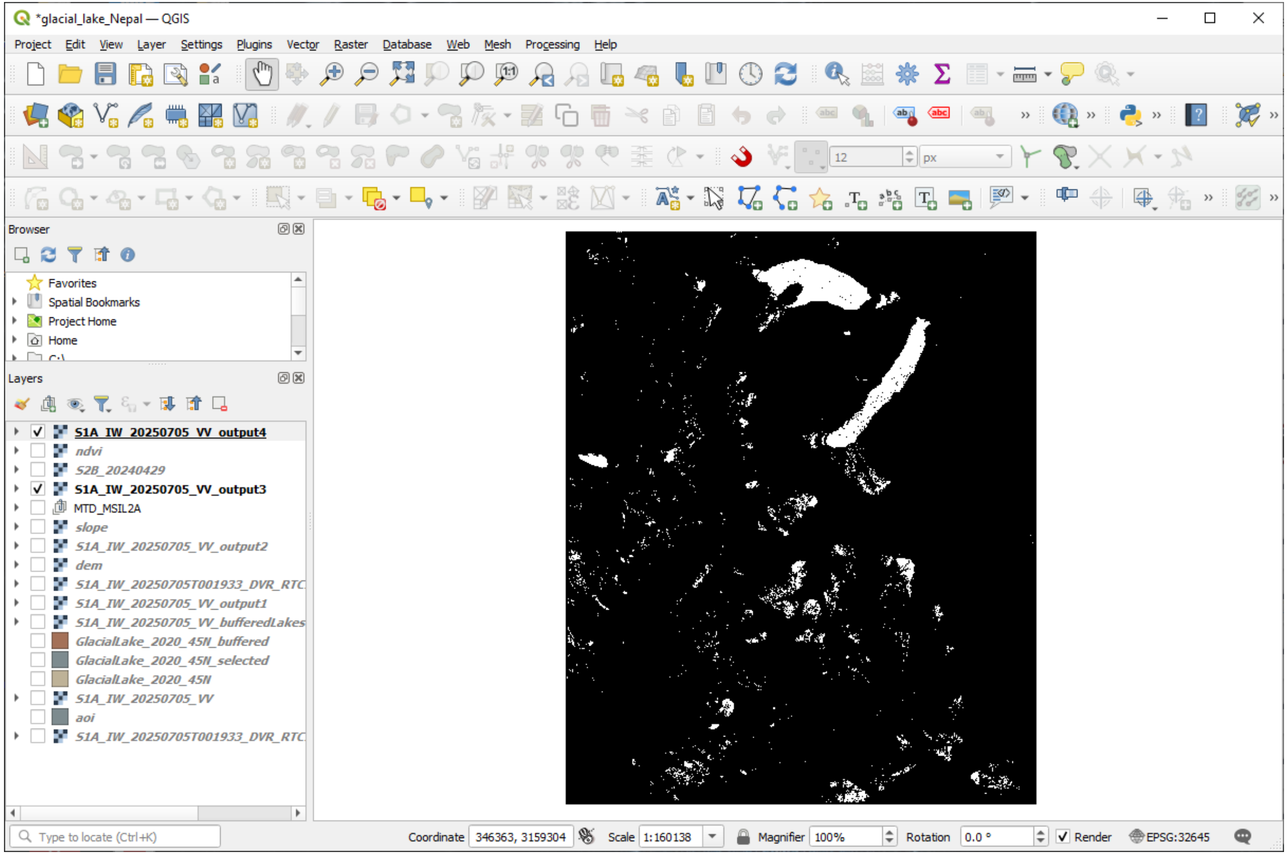
17. Save the result to S1A_IW_20250705_VV_output4.tif

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

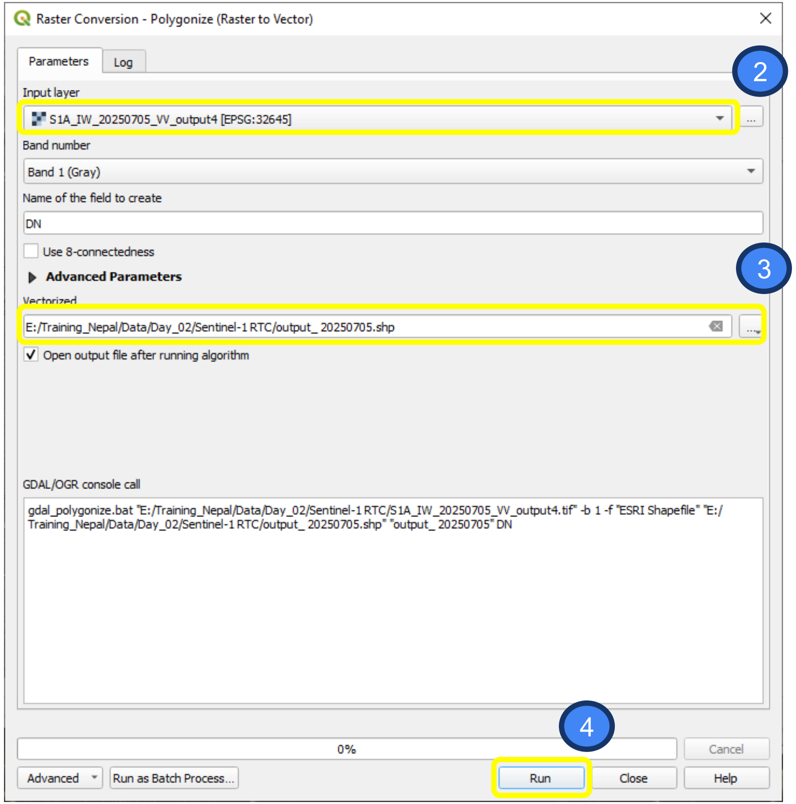
We will convert the potential glacial lake raster to polygons.

1. Click on Raster → Conversion → Polygonize (Raster to Vector)…

2. In the Input Layer, select S1A_IW_20250705_VV_output4

3. Save the Vectorized result to output_ 20250705.shp

4. Click Run.

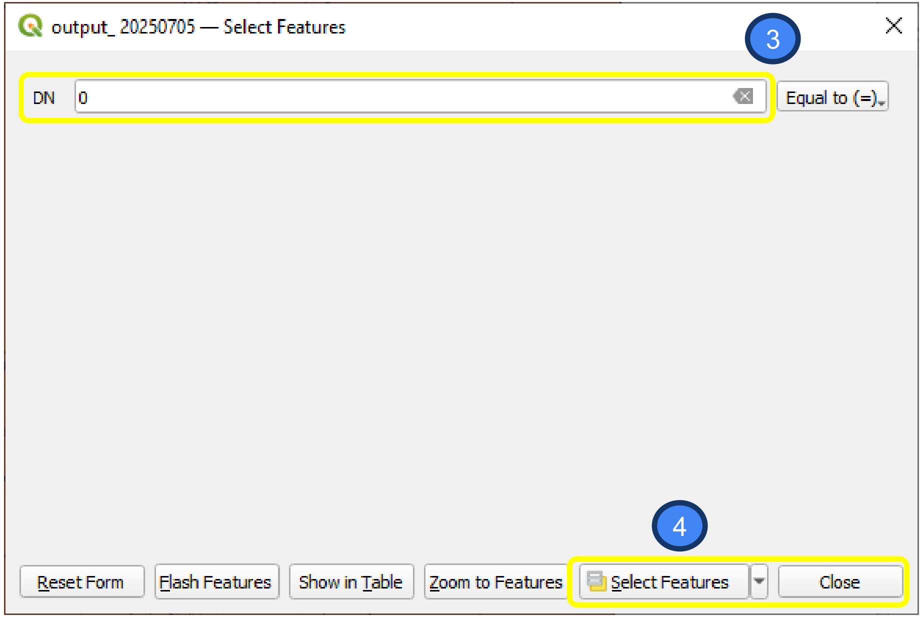


Post-Processing: Glacial Lake Mapping

Follow Along: Remove non-water polygons

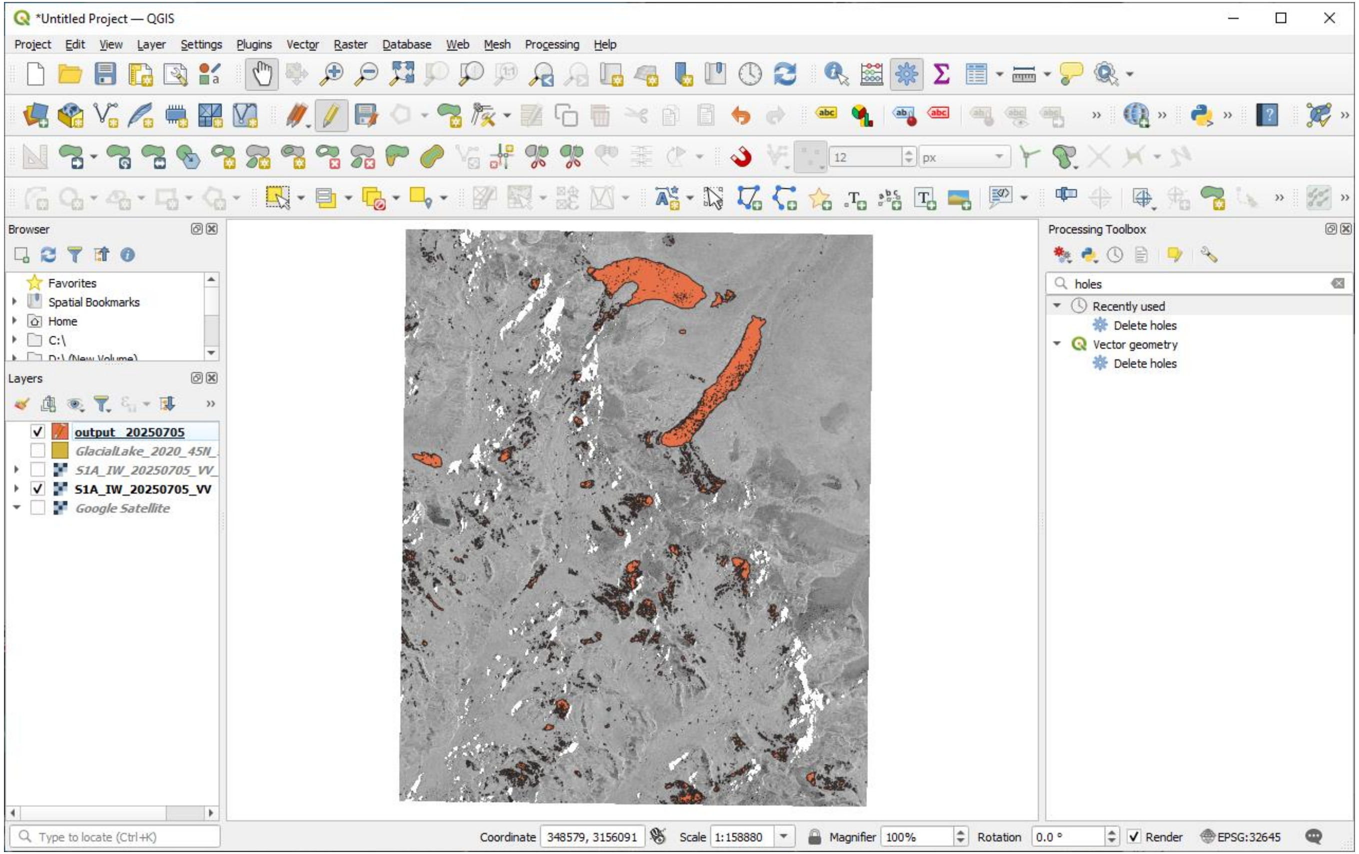
We will modify the polygons to clean the results further. First, let's remove non-water polygons.

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

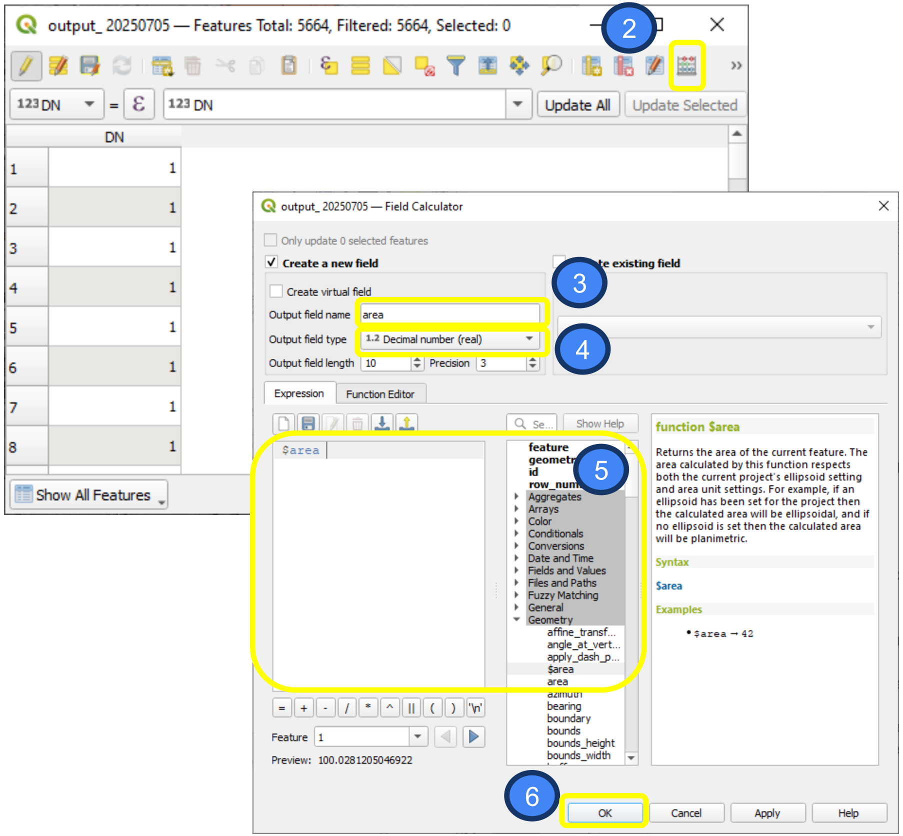


Post-Processing: Glacial Lake Mapping

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 button.
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.

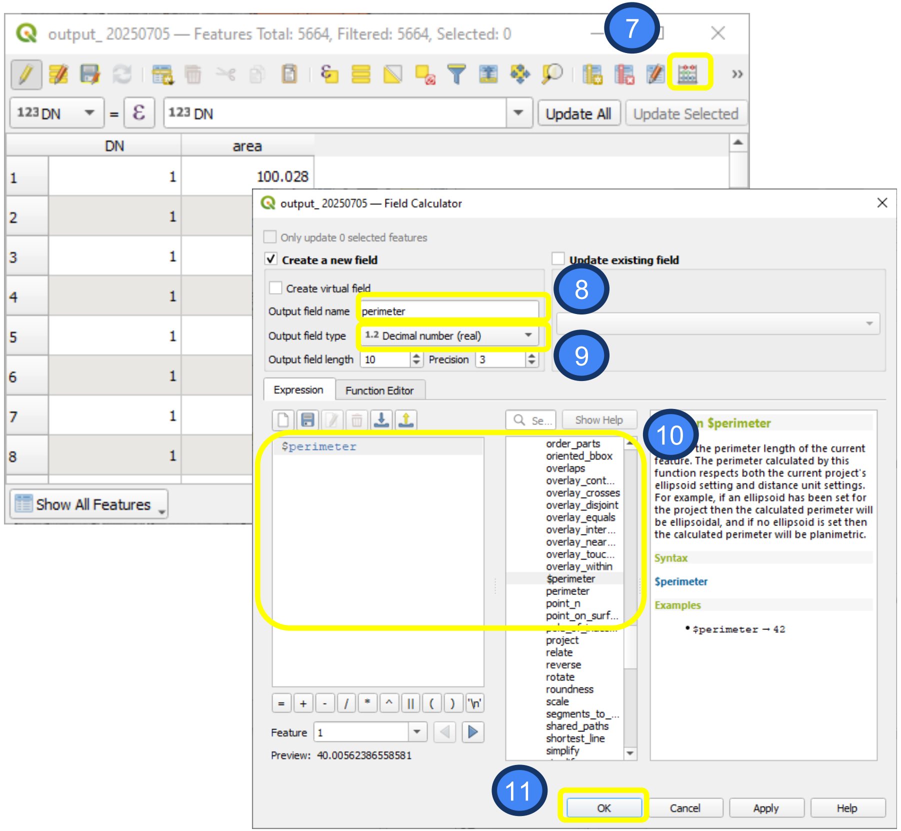
7. In the Table Toolbars, click again Open Field Calculator button.

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.

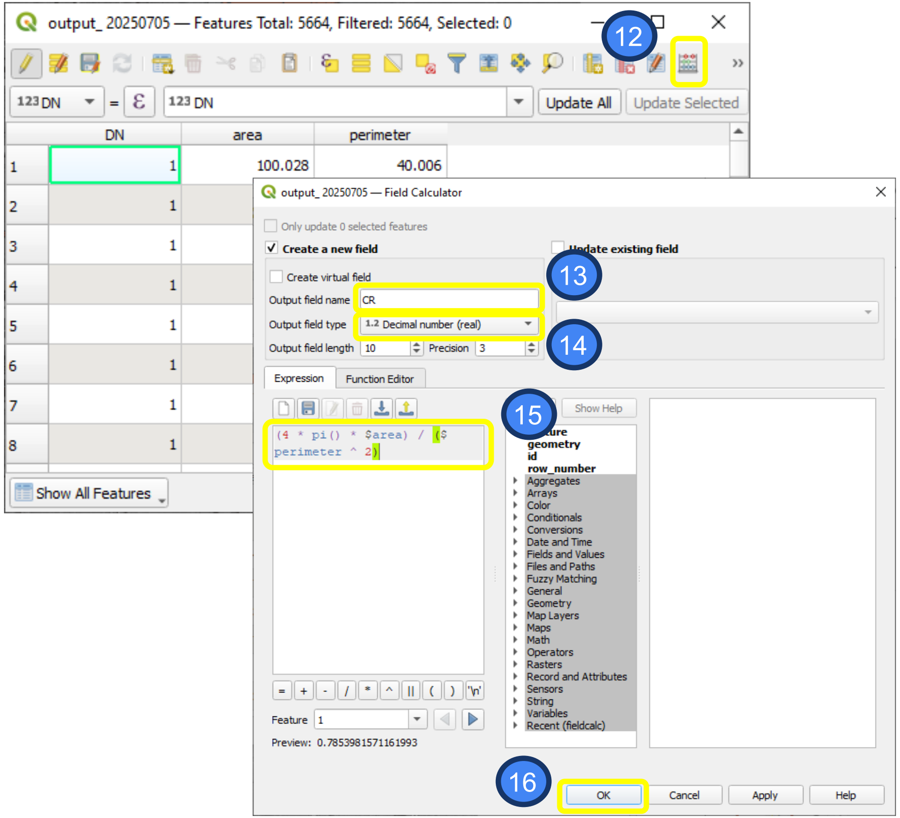
12. In the Table Toolbars, click again Open Field Calculator button.

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.

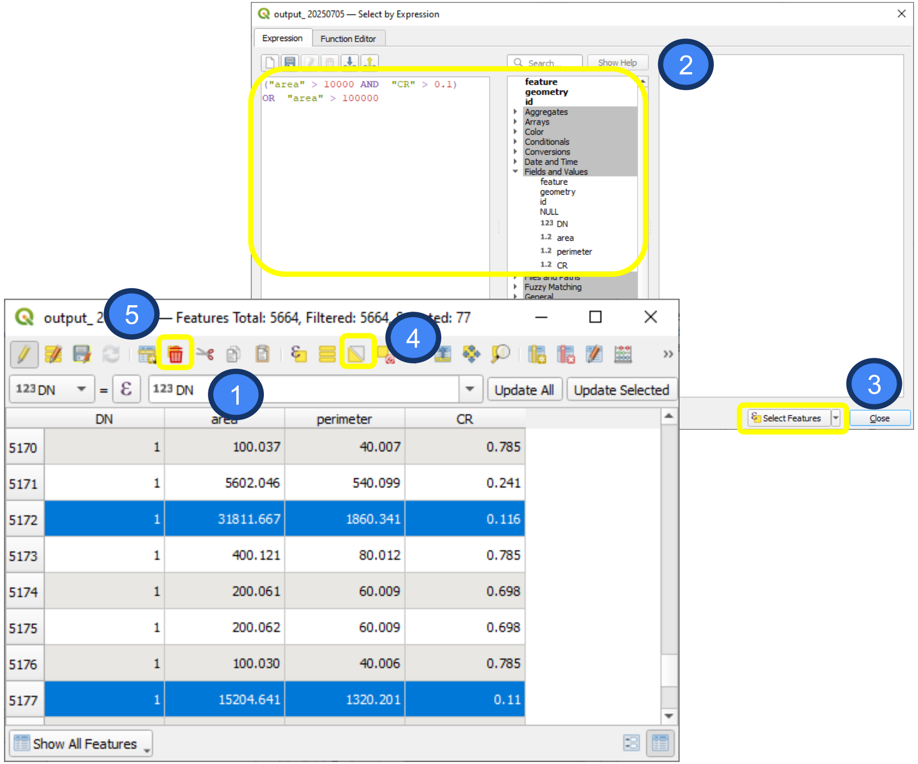


Post-Processing: Glacial Lake Mapping

Follow Along: Select and extract potential areas based on area and CR

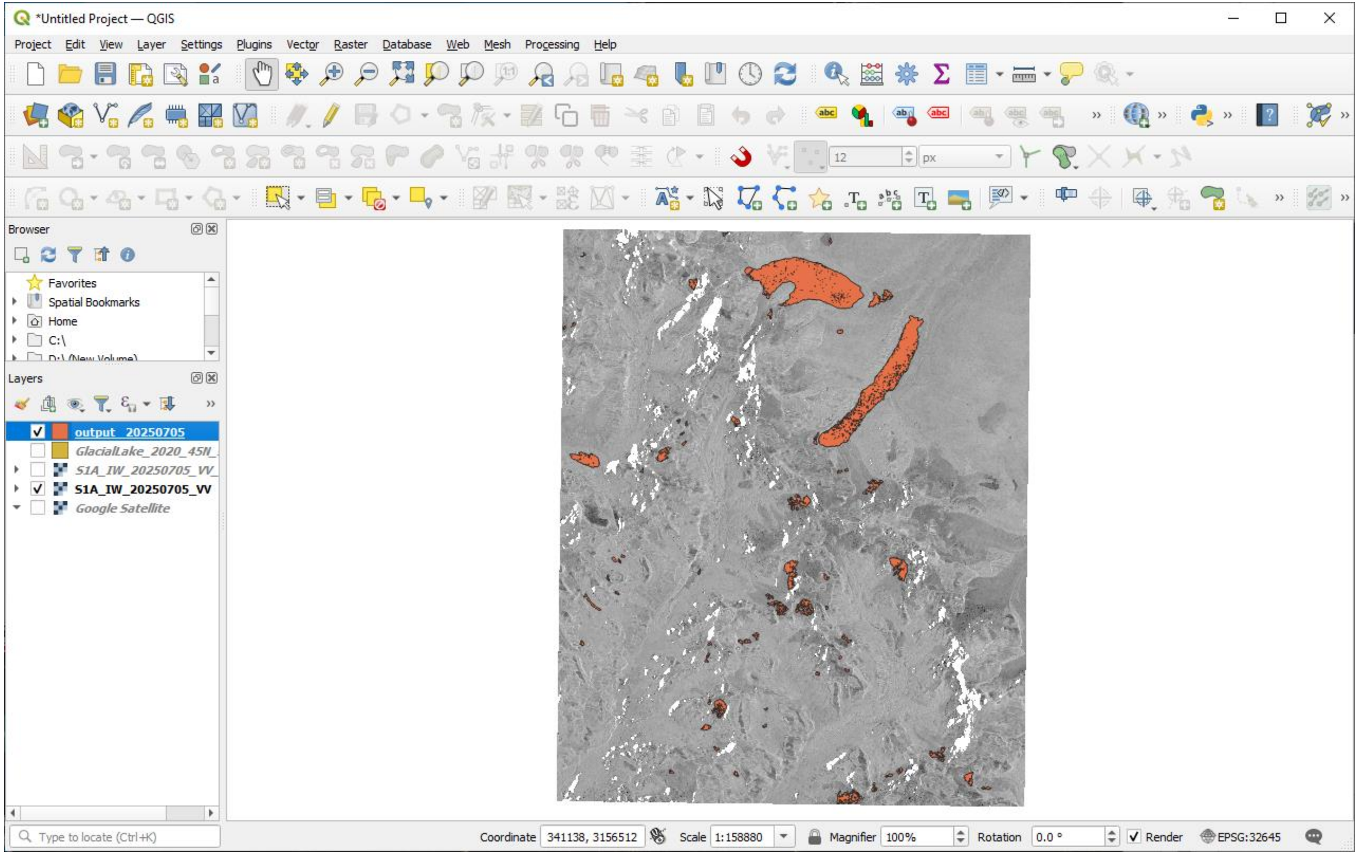
Potential lake areas will be selected based on area size and compactness ratio (CR). All areas of 0.01 sq.km or larger will be included automatically based on size alone. However, for areas between 0.01 sq.km and 0.1 sq.km, selection requires that they also meet a compactness ratio threshold of CR > 0.01.

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" > 10000 AND "CR" > 0.1) OR "area" > 100000
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 based on area and CR

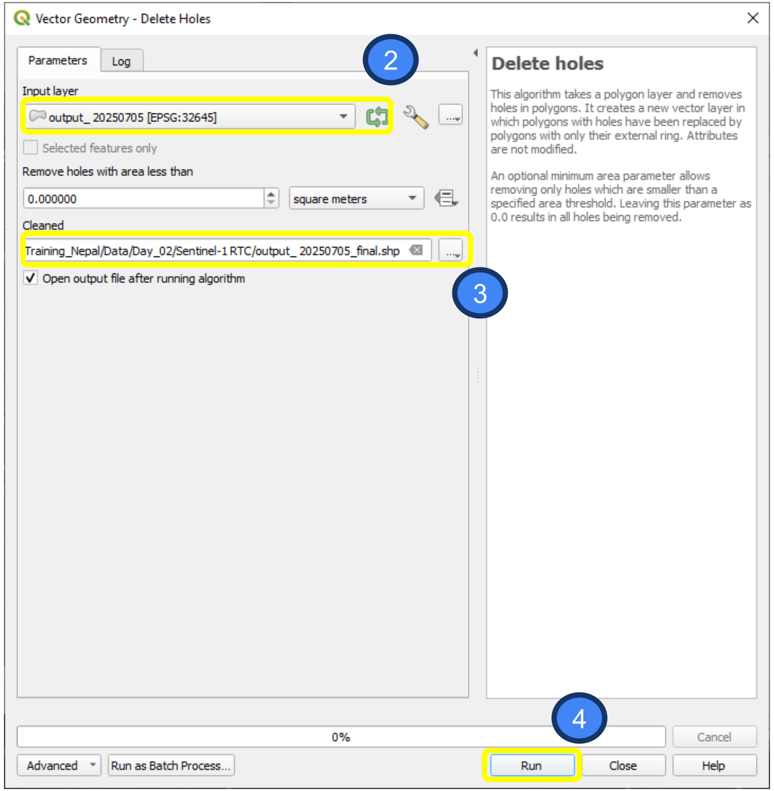


Post-Processing: Glacial Lake Mapping

Follow Along: Fill in the holes in the polygons

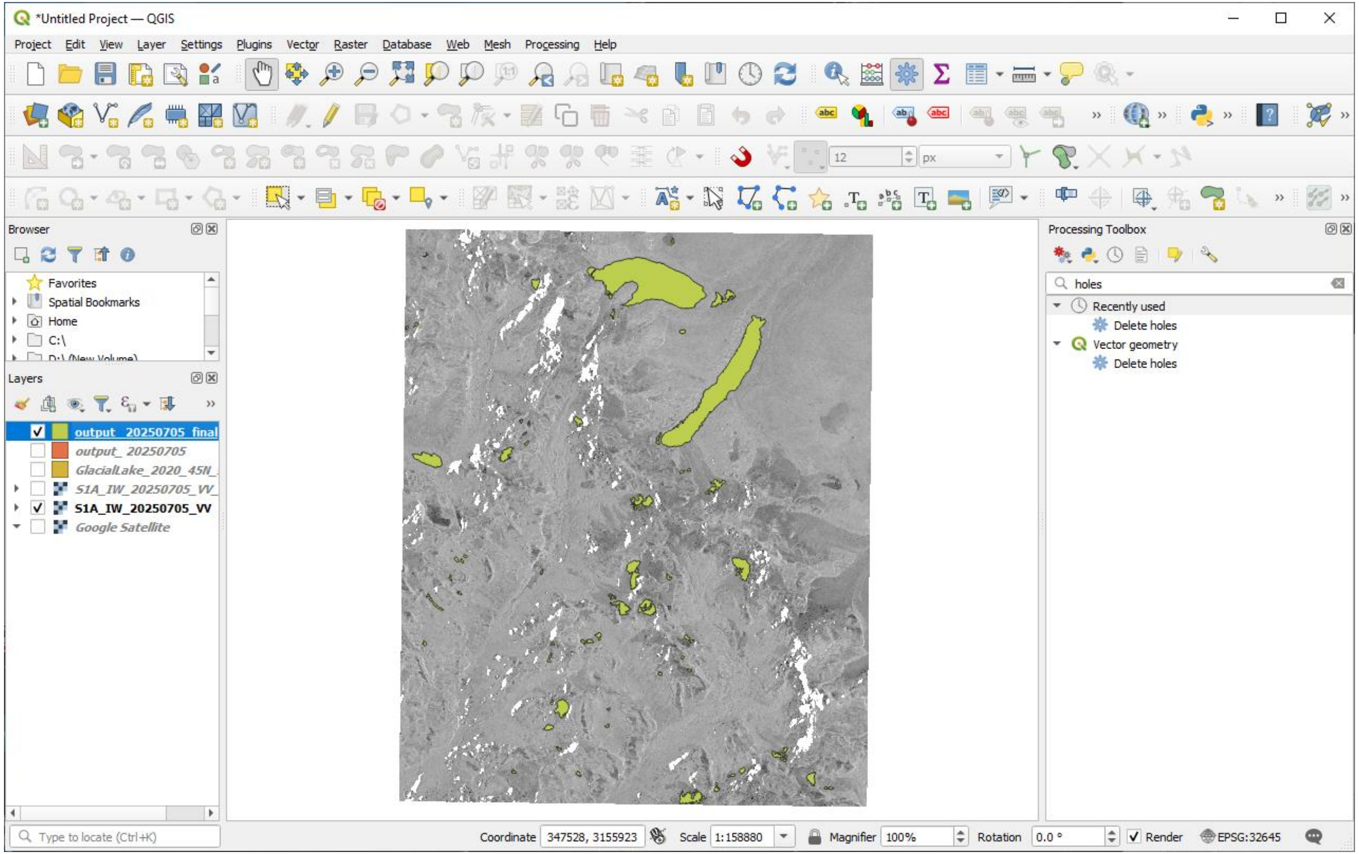
To finalize the post-processing, we will fill in the holes in the glacial lake polygons.

1. Click on Processing → Toolbox. Search for Delete Holes tool.
2. In the Input Layer, select output_ 20250705
3. Save the result to output_ 20250705 _final.shp
4. Click Run.



Post-Processing: Glacial Lake Mapping

Final Glacial Lake Map

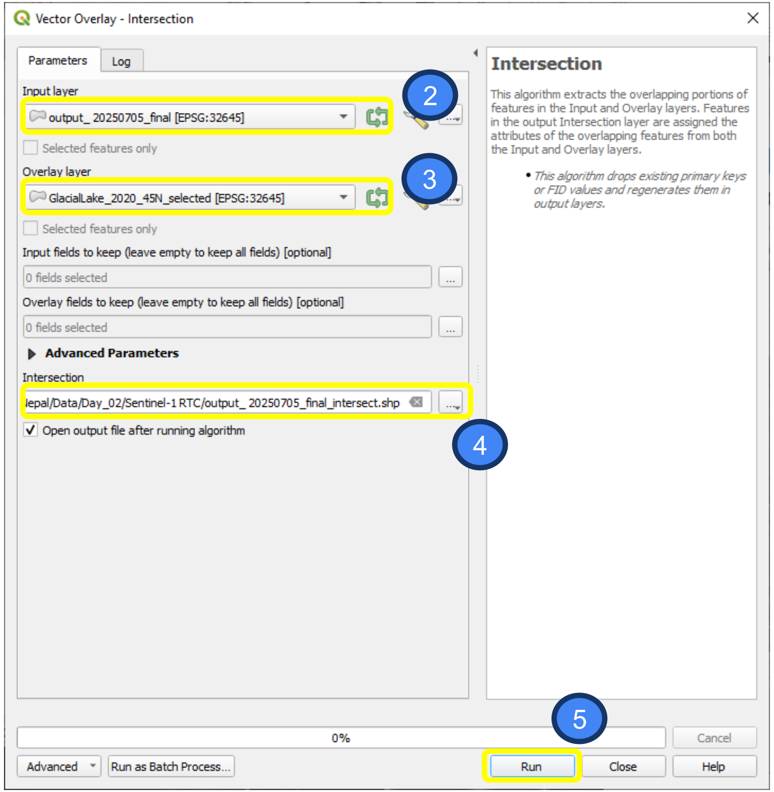


Post-Processing: Glacial Lake Mapping

Follow Along: Intersect with the inventory

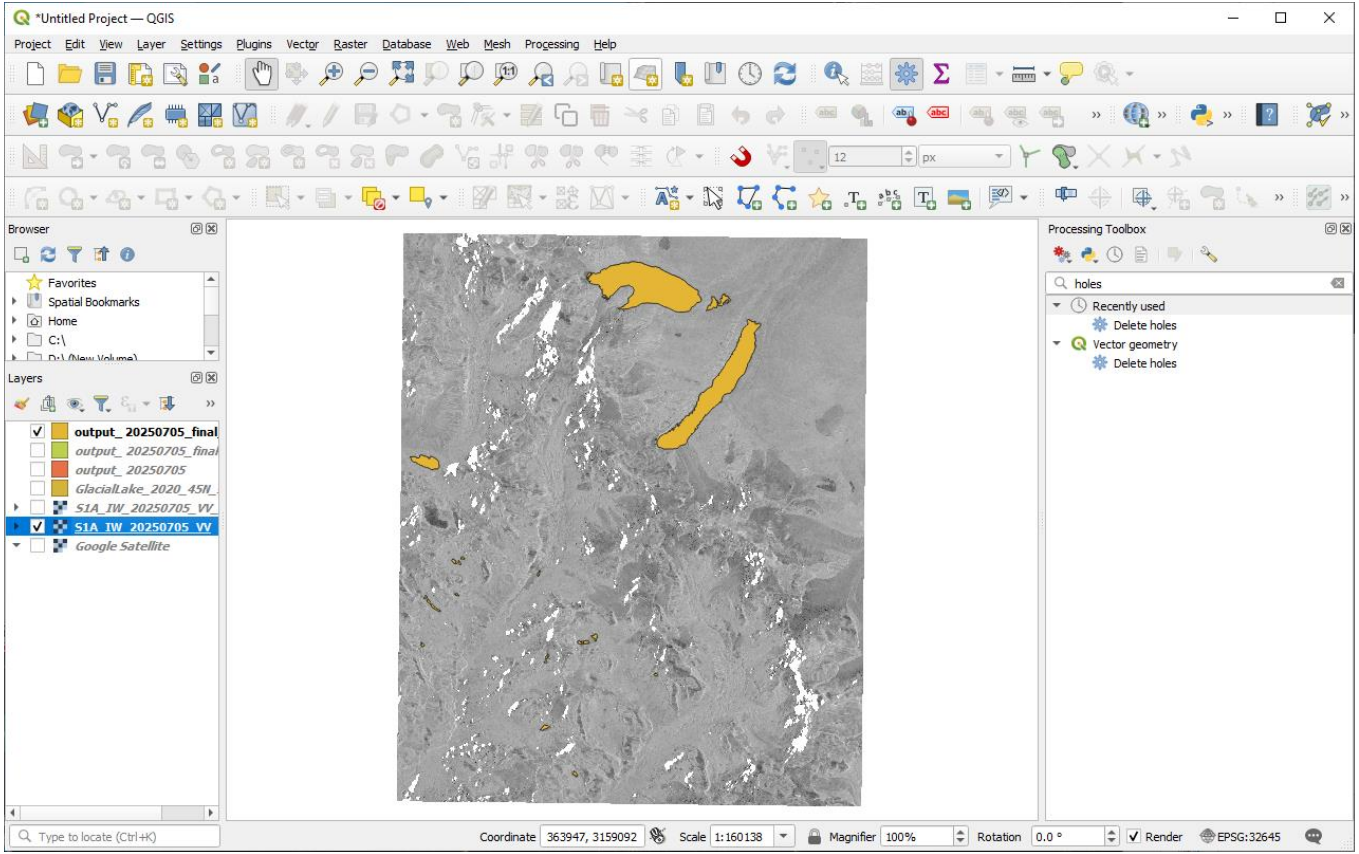
To finalize the post-processing, we will fill in the holes in the glacial lake polygons.

1. In the Menu Bar, click on Vector → Geprocessing Tools → Intersection.
2. In the Input Layer, select output_ 20250705_final
3. In the Overlay Layer, select GlacialLake_2020_45N_selected
4. Save the result to output_ 20250705 _final_intersect.shp
5. Click Run.



Post-Processing: Glacial Lake Mapping

Final Glacial Lake Map after intersect with the inventory



Next…

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

- We used the Sentinel-1 RTC data on 05 July 2025 to extract glacial lake features, with the additional data from Sentinel-2 and GLO-30 Copernicus DEM for post-processing.

- You can also process the archive Sentinel-2 RTC data on 10 July 2024 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 2024 and 2025.

- (Optional) Demo on automatic glacial lake mapping with Python.

THANK YOU

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