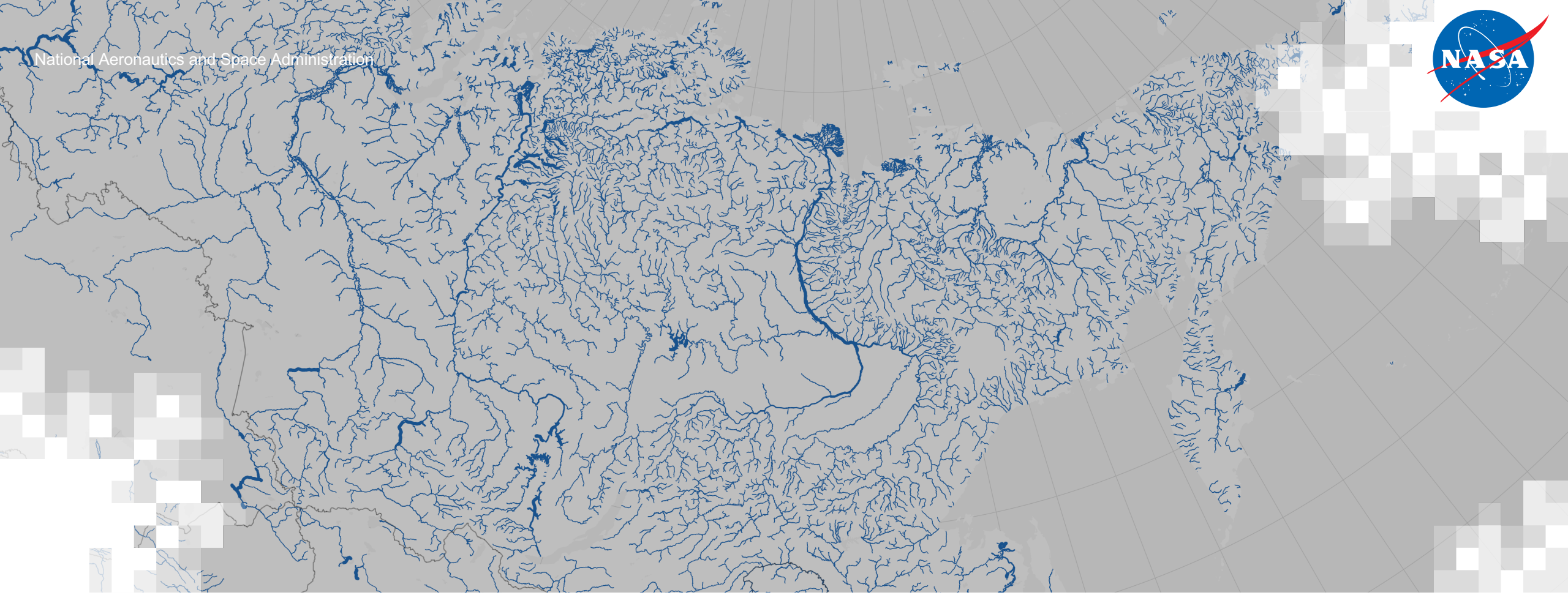

Exercise 2: Using Earth Observations to Monitor Water Budgets for River Basin Management II

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July 28, 2020

Exercise 2

- This exercise will focus on using remote sensing observations downloaded in Session 1 to estimate the water budget components for the Limpopo River Basin.

Glossary

Evapotranspiration = ET

Precipitation = PR

Terrestrial Water Storage = TWS

Objectives

After participating in this training, attendees should be able to:

1. Examine and compare dry and wet season water budget components based on IMERG precipitation, MODIS Evapotranspiration (ET), and GRACE Terrestrial Water Storage (TWS) change

2. Estimate seasonal, basin-averaged, and sub-basin level water budget components

Requirements

- IMERG, MOD16, and GRACE-FO water component data from Session-1 (2019)
- QGIS installed on your computer
- Shapefile folder of Limpopo River Basin saved on your computer
  - https://arset.gsfc.nasa.gov/water/webinars/water-budgets-river-basin

Note

This is a two-part exercise based on remote sensing data analysis using QGIS.

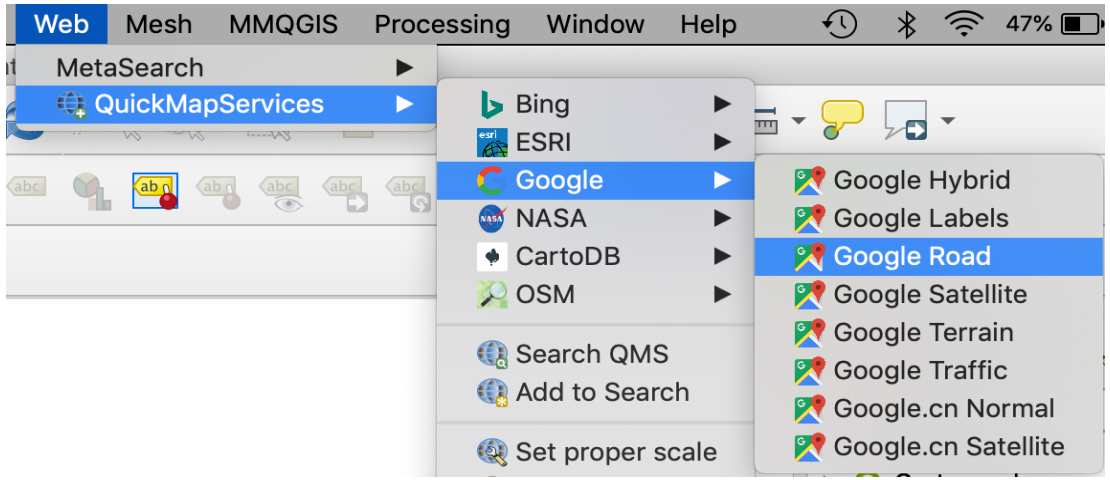
Part 1: Estimate seasonal water budget components

Part 2: Compare dry and wet season water budget components for the Limpopo River Basin

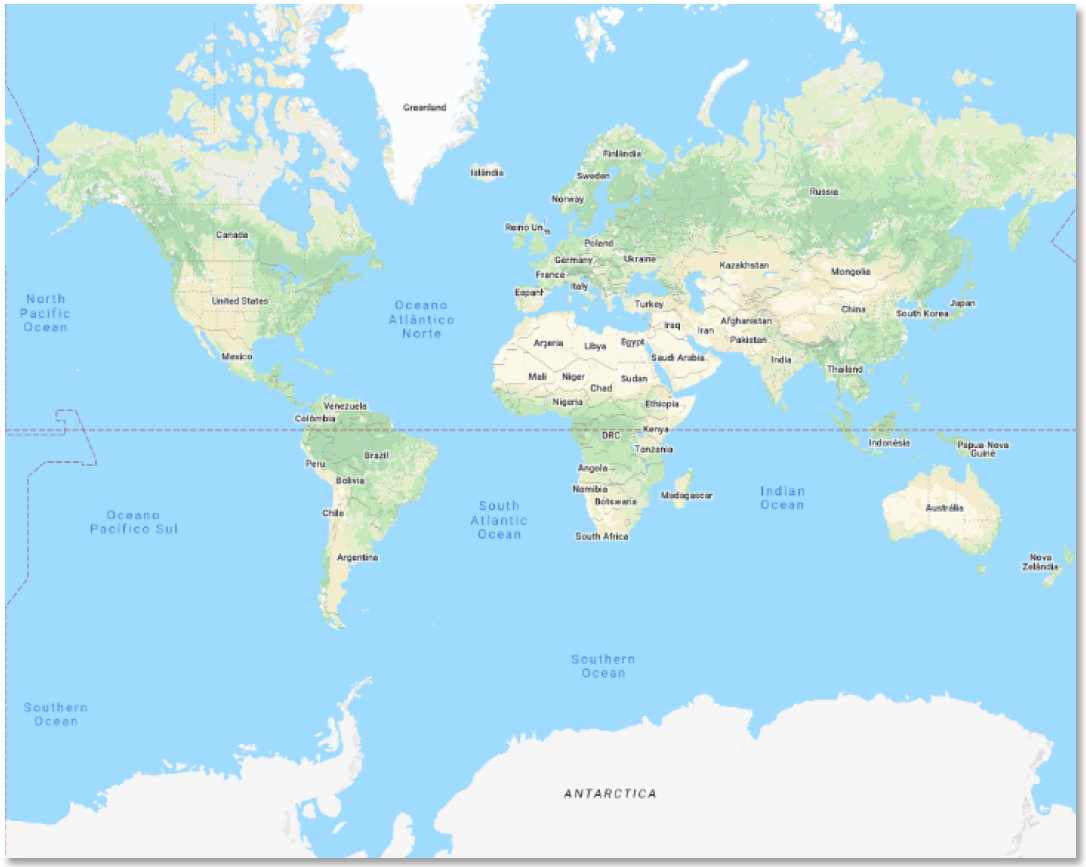
- **Questions based on this exercise will be included in Homework #2.**

Part 1: Open QGIS Project and Add Base Map

1. Open a QGIS project.
2. On the menu bar. Click on **Web → QuickMapServices → Google → Google Road**.

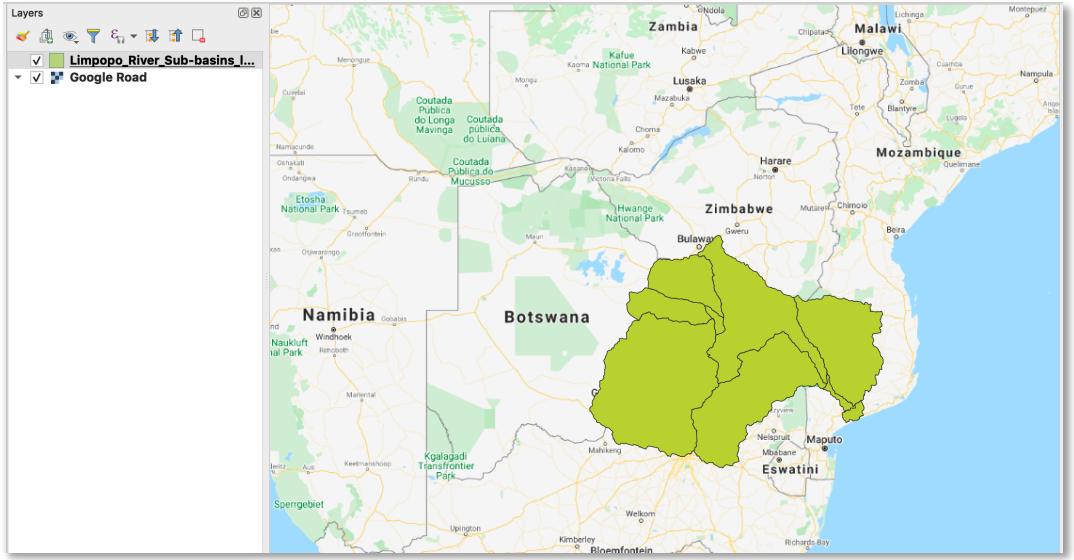


Base Map in QGIS Window



Part 1: Add Limpopo River Basin Shapefile

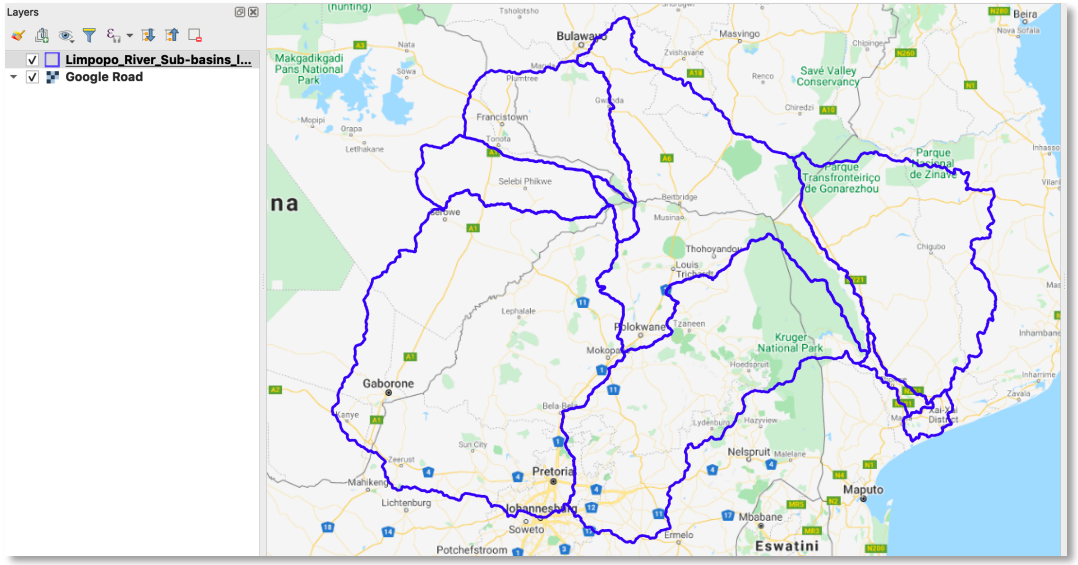
3. Click on the menu on the left bar and click **Add Vector**  to add the file Limpopo_River_Sub-basins_lev04.shp.
4. You will see the shapefile added to the project. Use the top menu bar and select the "Zoom In" tool to zoom into the shapefile and the pan  tool to pan around the map. 



Part 1: Add Limpopo River Basin Shapefile

5. To symbolize the shapefile with an outline, right-click on the layer name → **Properties** → **Symbology**.
6. Click on the down arrow in the **Symbol layer type** window and select **Outline: Simple line**.
7. Click on the down arrow for **Color** and choose a color of the shapefile boundary (this example uses blue).
8. Set the **Stroke width** to be 1.0.
9. Click **OK** to symbolize the Limpopo River Basin shapefile in the QGIS Map View.

Limpopo River Basin with Main Sub-basins



Part 1: Add IMERG Precipitation Rasters

10. In your QGIS map, click on the **Add Raster**  function on the left.

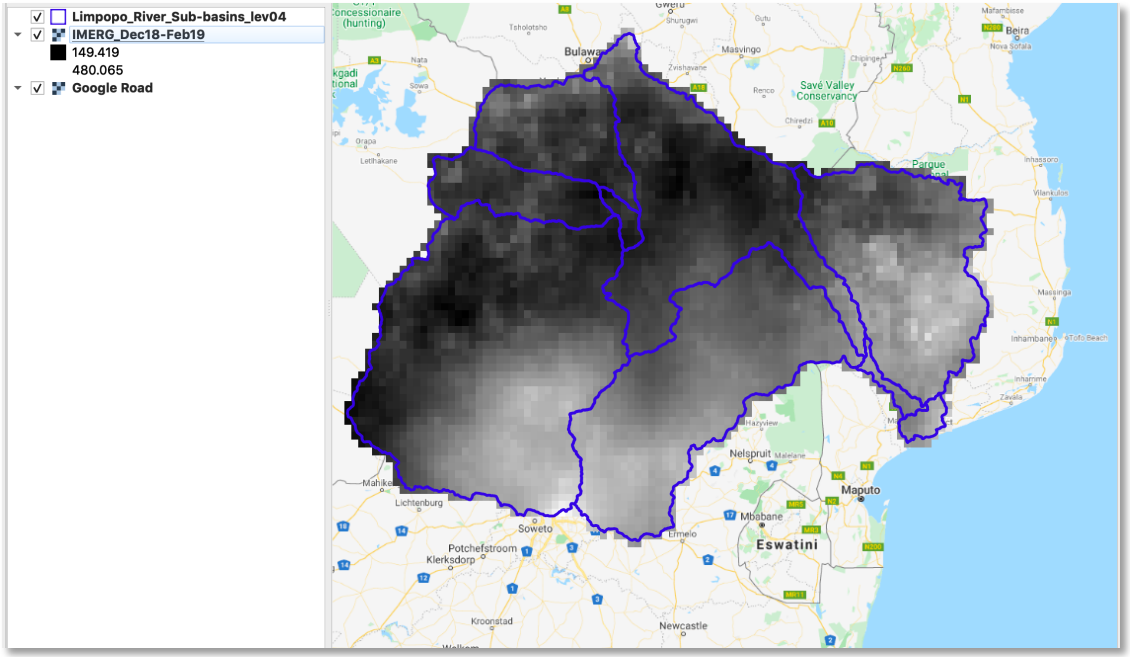
11. Navigate to the IMERG PR data downloaded in Session 1.

12. Select data from the wet season (e.g. IMERG_Dec18-Feb19.tif) and click **Open** and then click **Add** to add the files to your Layers panel.

13. Repeat Step 12 for data from the dry season (IMERG_Jun-Aug19.tif).

***You may need to drag your river basin shapefile to the top of the layers panel after adding the raster files.**

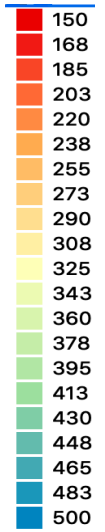
Wet Season PR



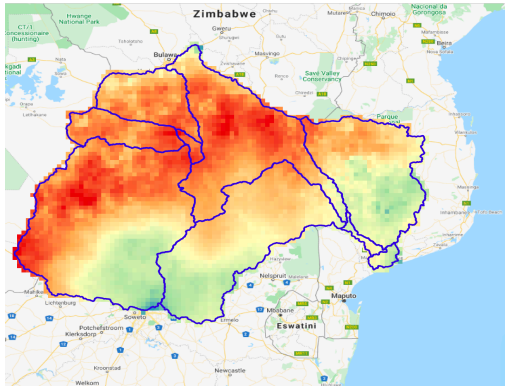
mm

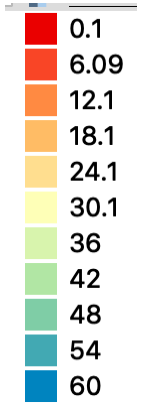
Part 1: Add Symbology to Seasonal PR Rasters

14. Right click on the layer IMERG_Dec18-Feb19 and go to **Properties → Symbology**.
    - Select the **Render Type** as **Singleband pseudocolor**.
    - Next to the **Color ramp** drop-down arrow, select **All Color Ramps → (RdYlBu)** Red-Yellow-Blue color palette.
    - Change the **Min** and **Max** values to **145** and **500** respectively.
    - Below the color display, change the **Mode** to **Equal Interval** and **Classes** to **10** and click **OK**.
    - Repeat the above steps for the layer IMERG_Jun-Aug19, with the **Min** and **Max** values to **0** and **60** respectively, and **Equal Interval** and **Classes** to **10**.



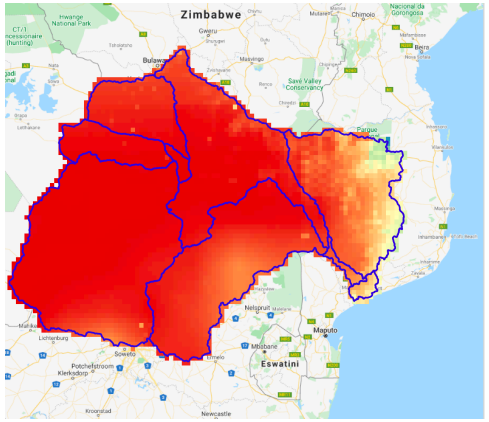
Wet Season PR





mm

Dry Season PR



Part 1: Add MODIS ET Rasters

15. Click on **Add Raster** in your QGIS map, navigate to the MODIS ET data downloaded in Session 1, and upload the 26 MODIS ET (8-day) datasets (e.g. MOD16A2GF.006_ET_500m_doy2018329_aid0001.tif).

16. To sum the ET over the wet and dry seasons, we first need to reclassify all fill values in each dataset and assign a new value of 0. Fill values in each dataset correspond to: Unclassified, Urban, Wetland, Barren or Sparsely Vegetated, Water Body, and Permanent Snow or Ice.

17. In the Processing Toolbox type "reclassify" in the search bar and double-click on **Reclassify values (range)**.

18. In the bottom left corner of the window click on "Run as Batch Process…"

Part 1: Add MODIS ET Rasters

19. Under the Grid column, click on the ellipsis (3 dots) and choose "Select from Open Layers…"

20. Select all 26 MODIS ET (8-day) datasets and click OK.

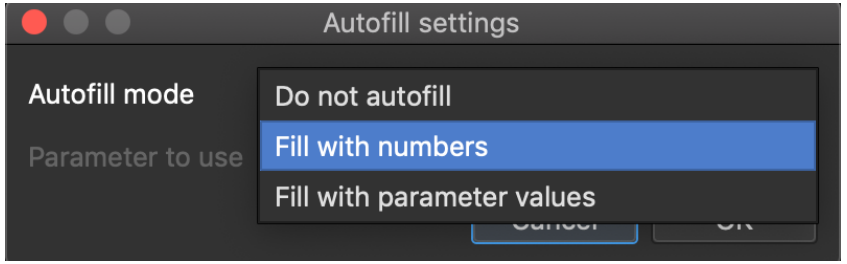
21. Under the column "minimum value (for range)" enter **32760**
    - Click on *Autofill…* and select "Fill Down"

22. Under the column "maximum value (for range)" enter **32767**
    - Click on *Autofill…* and select "Fill Down"

23. Under the column "new value (for range)" enter **0**
    - Click on *Autofill…* and select "Fill Down"

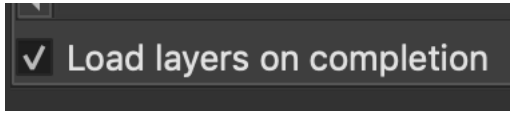
Part 1: Add MODIS ET Rasters

24. Under the column "operator (for range)" select **[0]<=**
    - Click on *Autofill…* and select "Fill Down"
25. Leave the other parameters as default.
26. Under the column "Reclassified Grid," click on the ellipsis (3 dots) and navigate to your working directory. For the first file (e.g. MOD16A2GF.006_ET_500m_doy2018329_aid0001) give it a new name such as MOD16_ET_2019.sdat. and click **Save**.
    - A window will open requesting Autofill settings
    - Select the option **Fill with numbers** and click **OK**

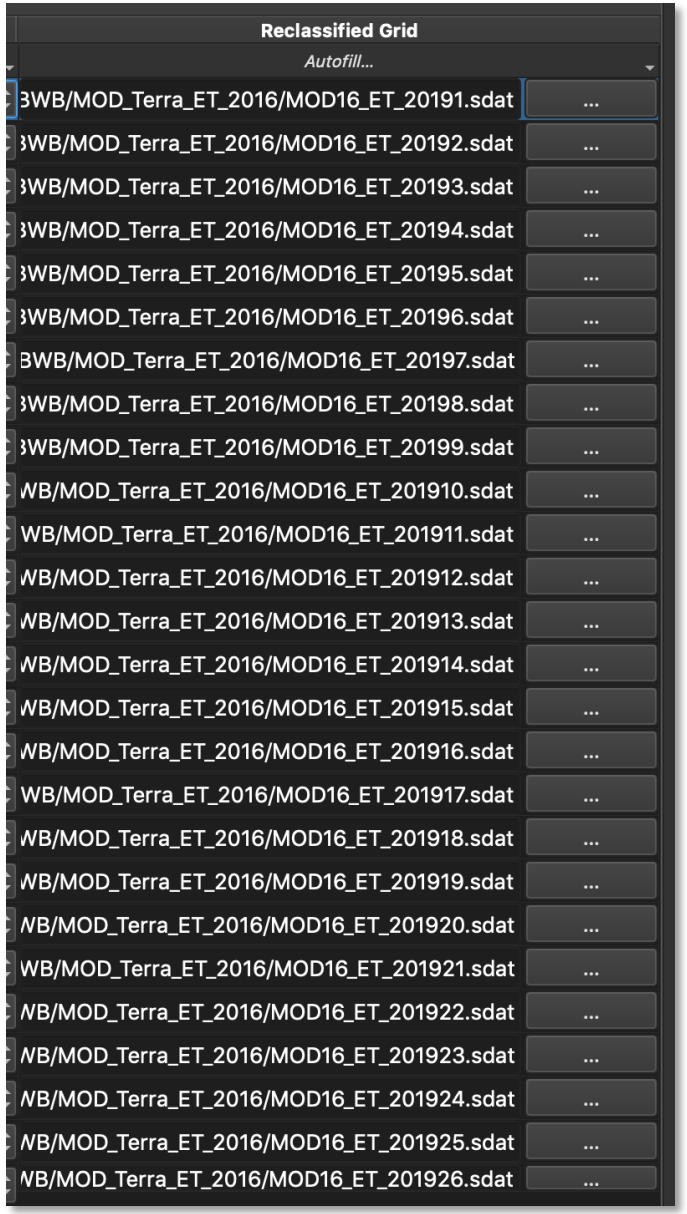


Part 1: Add MODIS ET Rasters

27. Make sure the **Load layers on completion** is checked in the bottom left corner of the window

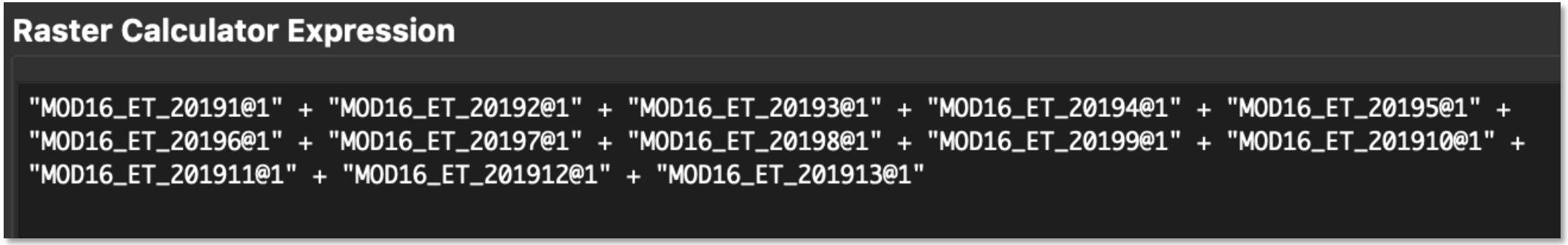


28. Click Run.



Part 1: Add MODIS ET Rasters

29. Next, we'll sum all reclassified 8-day files to derive the total ET for each season.
30. On the menu bar click on Raster → Raster Calculator.
31. For the **wet season**, double-click on each reclassified file one at a time to enter under **Raster Calculation Expression** separated by a **+** operator. These will be the first 13 files you reclassified.
32. In the Output Layer, navigate to your working directory and give the output a name such as **MODIS_ET_DJF19** and click **OK**



Part 1: Add MODIS ET Rasters

33. Repeat steps 30-32 for the dry season (MODIS_ET_2019 [14-26]) and give the output a name such as **MODIS_ET_JJA19**.
34. Remove all ET layers **except for** MODIS_ET_JJA19 and MODIS_ET_DJF19 by left-clicking + Shift to select the ET layers and then click on the icon Remove Layer/Group. 
35. The total ET for each season must be scaled by 0.1 to derive ET in mm:
    - On the top menu bar go to **Raster → Raster Calculator**.
    - In the Raster Bands window, from the list of rasters, double-click MODIS_ET_DJF19.
    - By clicking on the **Operators** and the raster enter the following in the **Raster Calculator Expression:**

      MODIS_ET_DJF19@1 * 0.1

Part 1: Add MODIS ET Rasters

- In the **Output layer** window, navigate to your working directory to save the resulting raster. Enter the name (e.g. **ET_DJF19**) and click **Save**.
- Make sure "Add result to project" is checked and click OK – you will get the raster ET_DJF19 with ET values in mm.

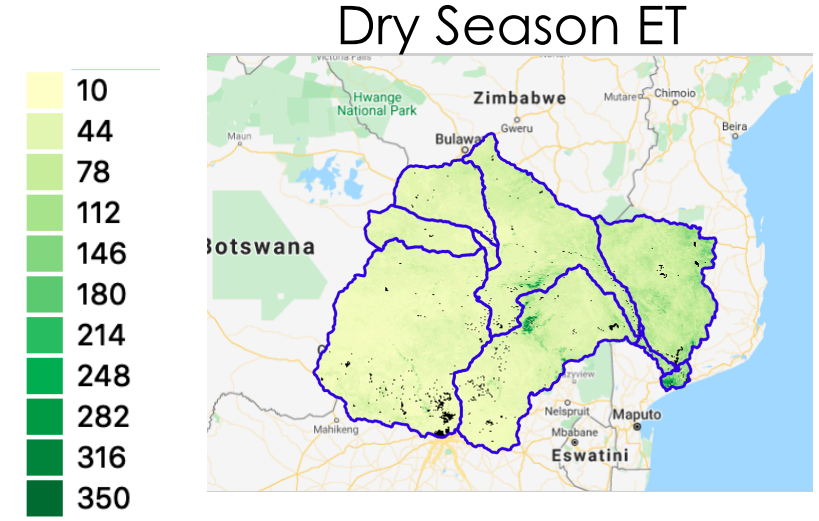
36. Repeat Step 35 for the dry season ET (MODIS_ET_JJA19) and save as **ET_JJA19**.

Part 1: Add Symbology to the ET asters

37. Right-click on the layer ET_DJF19 and go to **Properties → Transparency**.
    - In the **No Data Value → Additional no data value** window add **0.0**, which represents undefined data, and click **OK**.
38. Change the symbology of ET_DJF19 using **Min=30**, **Max=650**, **Equal Interval Classes=10,** and **Color ramp → All Color Ramps =YlGn**.
39. Repeat Steps 37 & 38 for ET_JJA1919 with **Min=30**, **Max=650**, and **Equal Interval Classes=10**.

Wet Season ET

Dry Season ET



mm

Part 1: Add and Process GRACE TWS Rasters

40. Navigate to the GRACE-FO TWS data downloaded in Session 1 and repeat Step 12 to add TWS rasters for December (2018), March, June, and September (2019) (e.g. **GRFO_TWS_Dec18.tif**).

41. The GRACE-FO data are TWS anomalies in meters. To find seasonal TWS change, take the difference between TWS anomalies for March and December for the wet season and multiply by 1000 mm/meter to convert to mm.

Part 1: Add and Process GRACE TWS Rasters

42. On the top menu bar, go to **Raster → Raster Calculator**.

- Double-click on the TWS rasters in the **Raster Bands** window, click on the **Operators** and enter the following in the **Raster Calculator Expression:**

  (GRFO_TWS_Mar19@1 - GRFO_TWS_Dec18@1) * 1000

- In the **Output layer** window, choose the location to save the resulting raster and enter the raster name (we will use **DTWS_DJF19**) and click **Save**.

Part 1: Add and Process GRACE TWS Rasters

- Choose **Select Layer Extent**.
- Make sure "Add result to project" is checked and click OK.
- You will get the raster DTWS_DJF19 with TWS change values in mm.

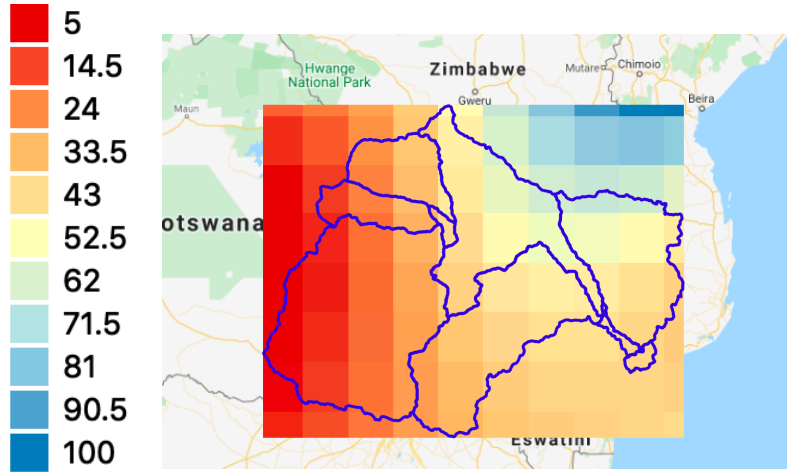
43. Repeat Step 41 for the dry season and change TWS using **Raster Calculator Expression:**

(GRFO_TWS_Sep19@1 - GRFO_TWS_Jun19@1) * 1000

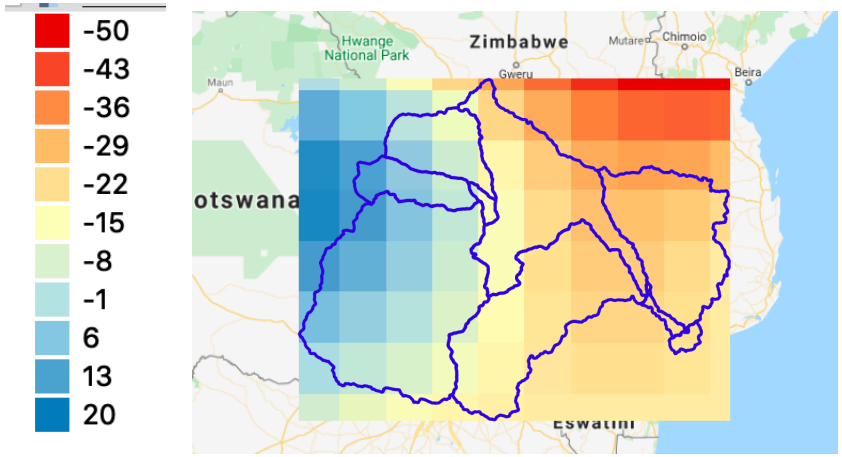
and Output Layer as **DTWS_JJA19**.

44. Repeat Step 14 to add colors to the DTWS rasters setting **Min** and **Max** to **35** and **100** for DTWS_DJF19, and **-50** and **20** for DTWS_JJA19; **Equal Interval Classes to 10** and **Color Ramps** to **RdYlBu**.

Wet Season DTWS



Dry Season DTWS



Compare Wet and Dry Season PR, ET, and TWS

45. To calculate seasonal differences use **Raster → Raster Calculator** and using **Raster Bands** and **Operators** enter the following in the **Raster calculator Expression** one by one.

I. IMERG_DEC18-Feb19@1 - IMERG_Jun-Aug19@1 (**Output Layer** PR_Dif)
II. ET_DJF19@1 - ET_JJA19@1 (**Output Layer** ET_Dif)

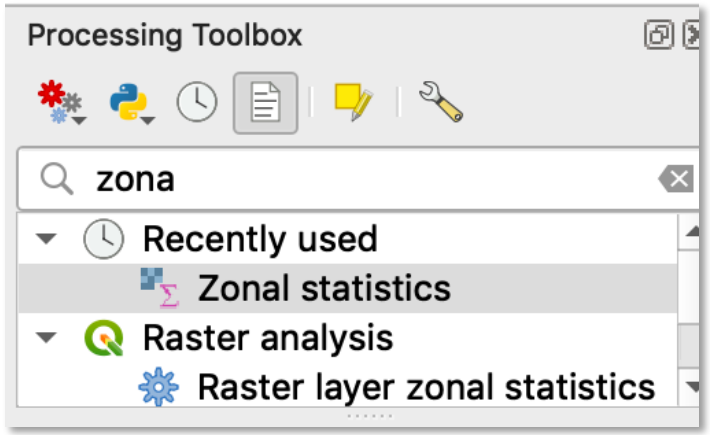
46. Using Step 14 and appropriate **Min**, **Max**, **Equal Interval Class**, and **Color ramp** add colors to the difference maps.
- Note down where the maximum and minimum differences are.

Part 2: Estimate Seasonal Water Budget Components

- Use QGIS **Zonal Statistics** to get the total seasonal PR, ET, and TWS amount averaged over the Limpopo sub-basins
- Use Shapefile **Attributes/Calculator** to get the area of the sub-basins
- Estimate total water amount over the basin using Excel

Part 2: Estimate Seasonal Water Budget Components

1. In the QGIS project click on **Processing → Toolbox**.
2. In the **Processing Toolbox** window on the right of QGIS map, search and select **Zonal Statistics**.
3. In the **Zonal Statistics** window:
   - For **Raster layer**, use the dropdown arrow to select **IMERG_Dec18-Feb19**.
   - For **Vector layer containing zones**, make sure that **Limpopo_River_Sub-basins_lev04** is selected.
   - Enter an **Output column prefix = PRW**.
   - In **Statistics to calculate**, select **Count** and **Mean** and click **OK**, then **Run**.



Part 2: Seasonal Water Amount Estimation

4. Repeat Step 3 for IMERG_Jun-Aug18, ET_DJF19,ET_JJA19, DTWS_DJF19, DTWS_JJA19, but include only **Mean** in the **Statistic to calculate**.
   - Suggest Output column prefix to be **PRD**, **ETW, ETD**, **TWSW,** and **TWSD** respectively for the above rasters.
5. Right-click on the **Limpopo_River_Sub-basins_lev04** layer → **Open Attribute Table**.
   - The Attribute Table will have sub-basin numbers, characteristics, and columns with Count and Spatial Mean for the seasonal water budget component rasters.

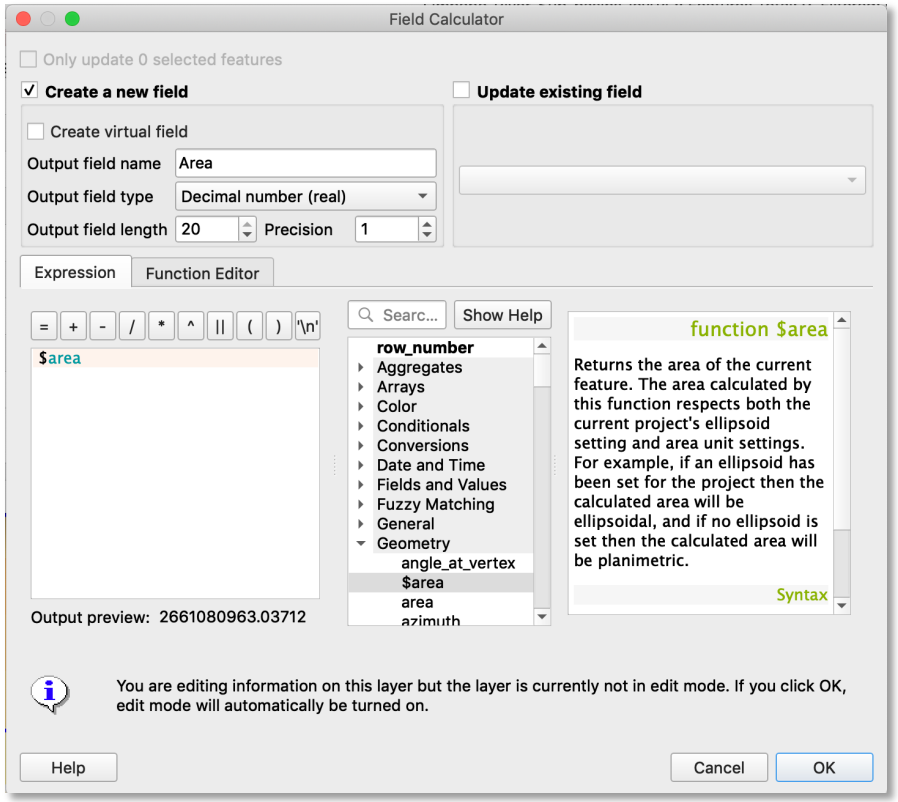
Zonal Statistics in the Attribute Table

PRW_mean	PRD_mean	ETW_mean	ETD_mean	PRW_count	TWSW_mean	TWSD_mean
237.7979619...	3.870173310...	171.0468156...	42.6899816...	252	31.96520779...	-5.56910322...
265.453226...	2.026247132...	128.9472863...	31.58867345...	1175	18.98405313...	-0.14828448...
225.8588814...	2.951106614...	165.4932356...	53.8999649...	672	49.6634976...	-21.2082805...
197.4957673...	0.76403305...	101.2945288...	33.8652433...	23	41.36799174...	-12.3153280...
335.445869...	10.43254282...	214.6706265...	92.08374907...	23	42.55297325...	-22.2238225...
316.9974125...	5.08480908...	187.9033215...	46.8754505...	728	40.1880269...	-19.2355892...
354.350588...	21.85548897...	319.4323563...	144.8421451...	24	41.17469147...	-20.6875959...
317.4081677...	15.13051418...	221.1818675...	78.51655879...	565	50.71074485...	-25.2431852...
219.7215540...	2.068071658...	133.7746667...	38.9836196...	169	23.33972491...	3.96002799...

Part 2: Calculate Area of the Limpopo Sub-basins

6. Right-click on the **Limpopo_River_Sub-basins_lev04** layer → **Open Attribute Table** → **Open Field Calculator** from the top menu bar.

- For **Output field name** type **Area**.
- Select **Output field type** to be **Decimal number (real)** - Select **Output field length** to be **20**.
- Set **Precision** to **2**.
- For **Expression** select **Geometry→ $area** by double-clicking.
- Click **OK**.
- The sub-basin area (in m^2) will be added to the Attribute Table.



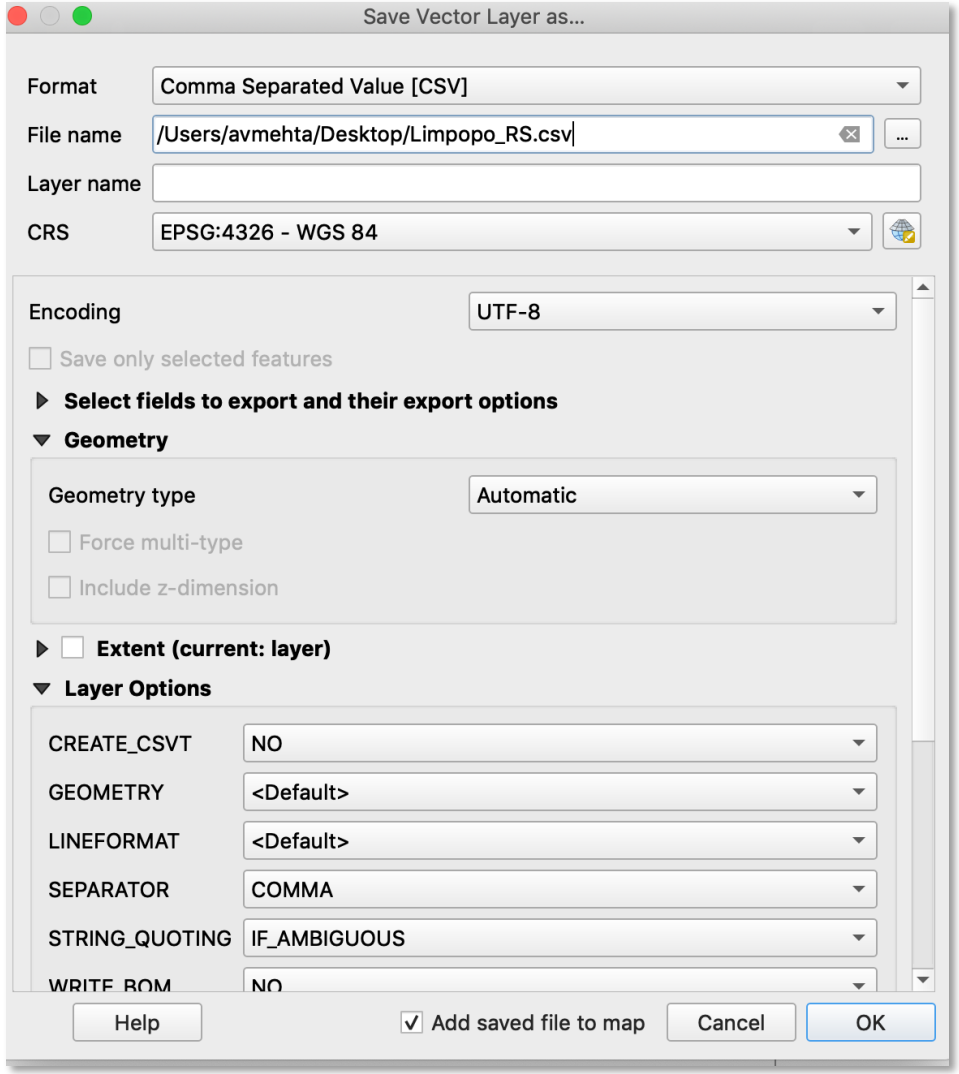
Part 2: Examine Seasonal Water Budget Components

7. Select **Limpopo_River_Sub-basins_lev04**.

- From the QGIS menu bar go to:

  Layer → Save as… to get the **Save Vector Layer as…** window.

- Select **Format** as **Comma Separated Value (CSV)**.
- In the **File name** window, choose the location and name of file to save the Attribute Table (e.g. Limpopo_RS.csv).
- Click OK.



Part 2: Examine Seasonal Water Budget Components

8. Open the CSV file (Limpopo_RS.csv) in Excel or Open Office Spreadsheet.
9. Select a column to the right of the Area column.
10. Enter the following function selecting the first cell under the column header:

    PRW (M2) * the first cell under Area (S2) * 0.001:

    = M2 * S2 * 0.001

    - This will convert the units from mm to m^3.

Part 2: Examine Seasonal Water Budget Components

11. Move the cursor to the bottom right of the calculated cell, left-click, and drag down to convert all sub-basins for PRW from mm to m^3.
12. Repeat steps 9-11 for PRD, ETW, TWSW, and TWSD, multiplying each top value of the column by Area * 0.001 (e.g. N2 * U2 * 0.001) and then dragging down.

Part 2: Examine Seasonal Water Budget Components

13. Now that we've converted all units from mm to m^3, we will sum each column to determine the totals for the entire Limpopo River Basin and convert each total to billions of cubic meters.
14. Below each converted column enter the function **=sum(T2:T10)**, replacing the column identifier (e.g. U,V,W,X,Y) with the correct identifier corresponding to your spreadsheet.
15. Repeat Step 14 for each converted column to determine the totals for the entire basin.

Part 2: Examine Seasonal Water Budget Components

16. Lastly, we will multiply the sum by 10^{-9} to calculate billions of cubic meters.
17. In the cell under the sum, enter the function **=T11 * 10^-9**, replacing the column identifier (e.g. U, V, W, etc.) with the correct identifier corresponding to your spreadsheet.
18. Move the cursor to the bottom right of the calculated cell, left-click and drag right to autofill all calculations for each column.

Part 2: Examine Seasonal Water Budget Components

Approximate water budget for each season can be obtained by:

PR-ET-DTWS for each season

19. For the wet season, calculate PRW-ETW (precipitation - evapotranspiration) by entering (=T12-V12) in a blank cell.
20. Repeat Step 19 for the dry season to calculate PRD-ETD by entering (=U12-W12).
21. Similarly, calculate PRW-ETW-DTWS and PRD-ETD-DTWD. The residual numbers can be interpreted as approximate seasonal discharge in the basin.

Part 2: Examine Seasonal Water Budget Components

- This completes the exercise examining seasonal water budget components for the dry and wet periods in the Limpopo River Basin using remote sensing data.
- Questions based on this exercise will be included in Homework #2.