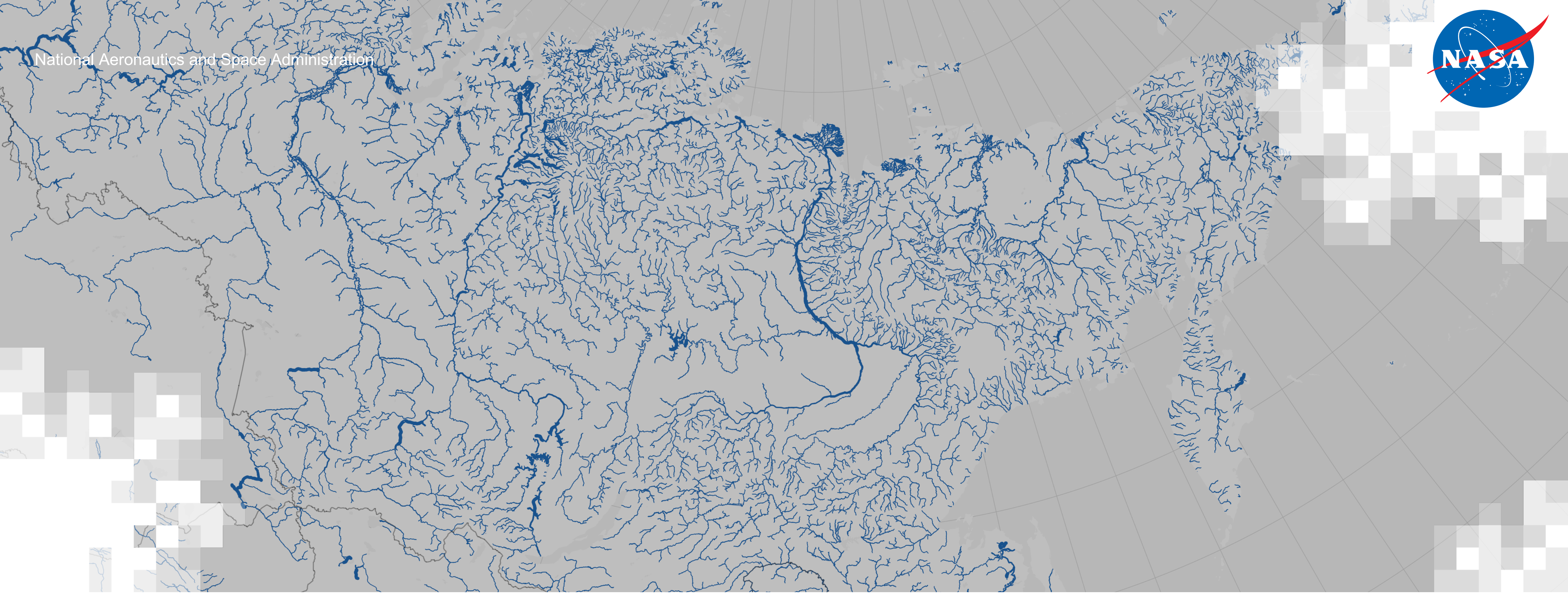
National Aeronautics and Space Administration



Exercise 3: Using Earth Observations to Monitor Water Budgets for River Basin Management II

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Exercise 3

- This exercise will focus on using GLDAS 2.1 water components downloaded in Session 1 to estimate the water budget components for the Limpopo River Basin.

Glossary

Evapotranspiration = ET

Precipitation = PR

Runoff = RO

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 from GLDAS 2.1

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

Requirements

- GLDAS 2.1 monthly water component data from Session 1 for 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 three-part exercise based on GLDAS data analysis using QGIS:

Part 1: Convert units of all water budget components to mm/month

Part 2: Estimate seasonal water budget components

Part-3: Compare dry and wet season water budget components for the Limpopo River Basin and selected sub-basins

- **Questions based on this exercise will be included in Homework 3.**

Part 1: Convert units of all water budget components to mm/month

- Load the Limpopo River Basin shapefile and GLDAS water budget components to a QGIS project.
- Change units of Precipitation (PR), Evapotranspiration (ET), Runoff (RO), and Terrestrial Water Storage (TWS) data.

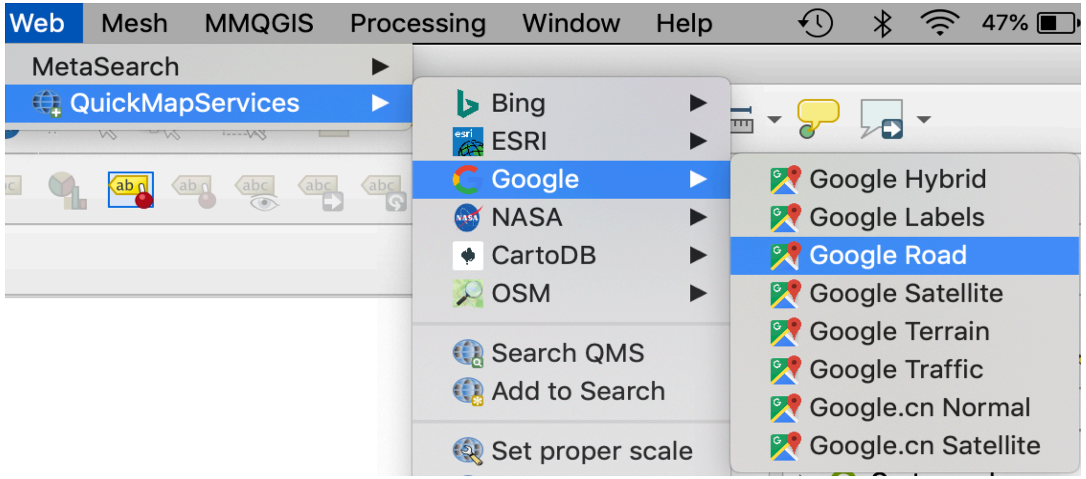
For Monthly Data:

- PR and ET are in kg m^{-2} s^{-1} per second.
  - Need to multiply by 3600 (s/hr) * 24(hr/day) * (# of days in month)
- RO is in kg m^{-2} accumulated over 3-hour interval.
  - Need to multiply by 8 (3hr/day) * (# of days in month)
- TWS is in mm.$month^{-1}$ and needs no unit conversion.

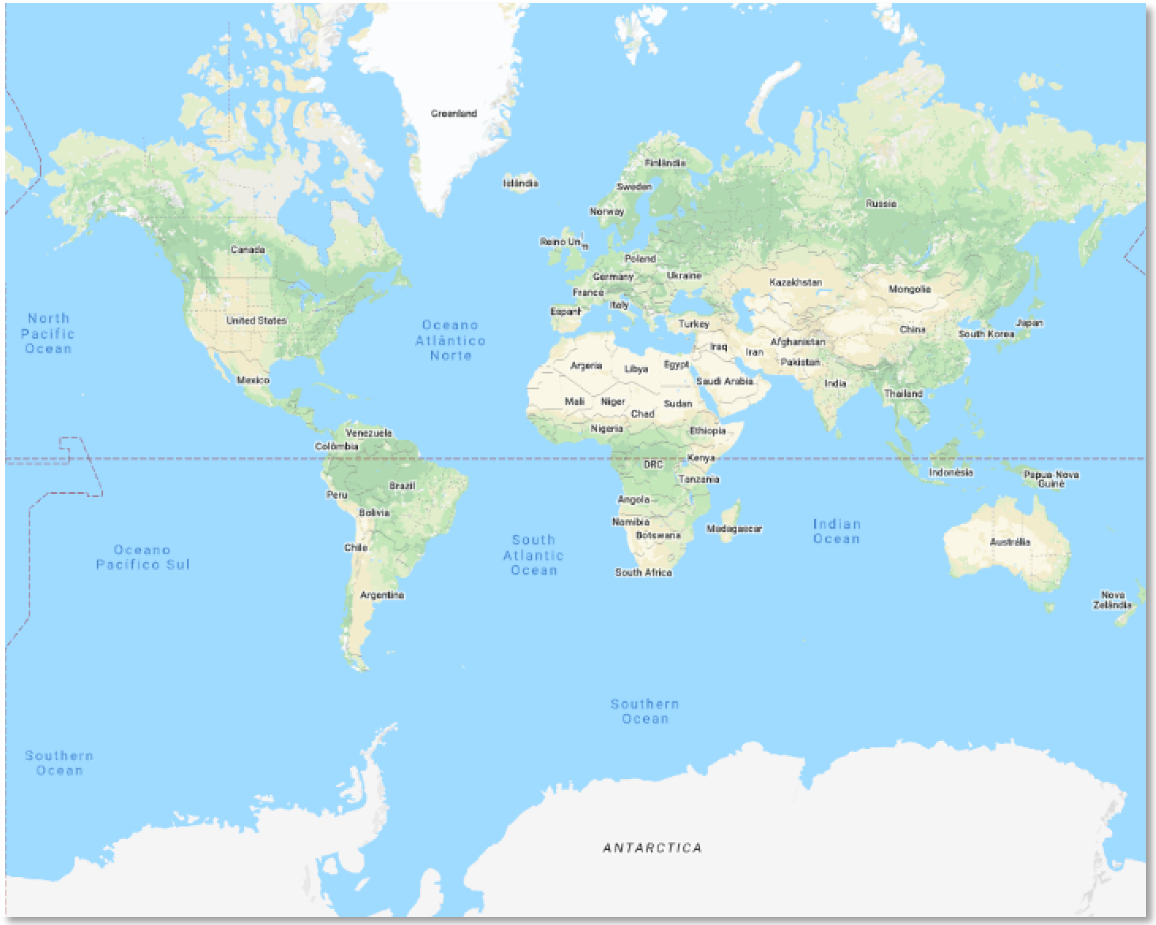
https://hydro1.gesdisc.eosdis.nasa.gov/data/GLDAS/GLDAS_NOAH025_3H.2.1/doc/README_GLDAS2.pdf

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**



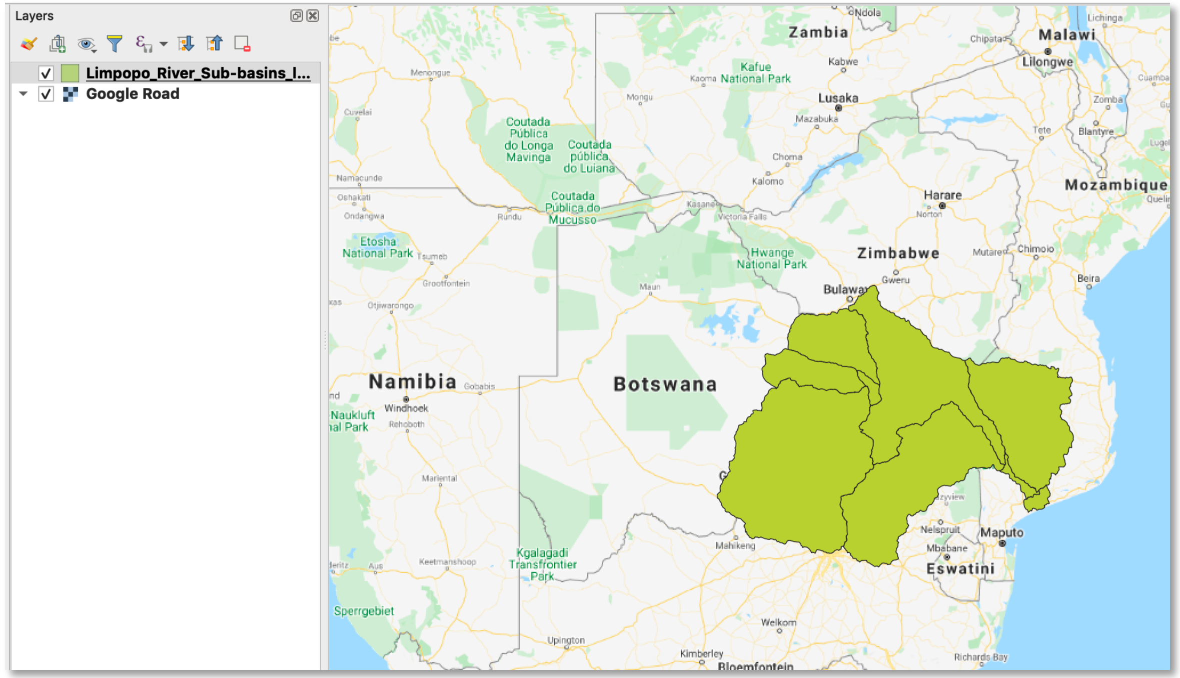
Base Map in QGIS Window



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.

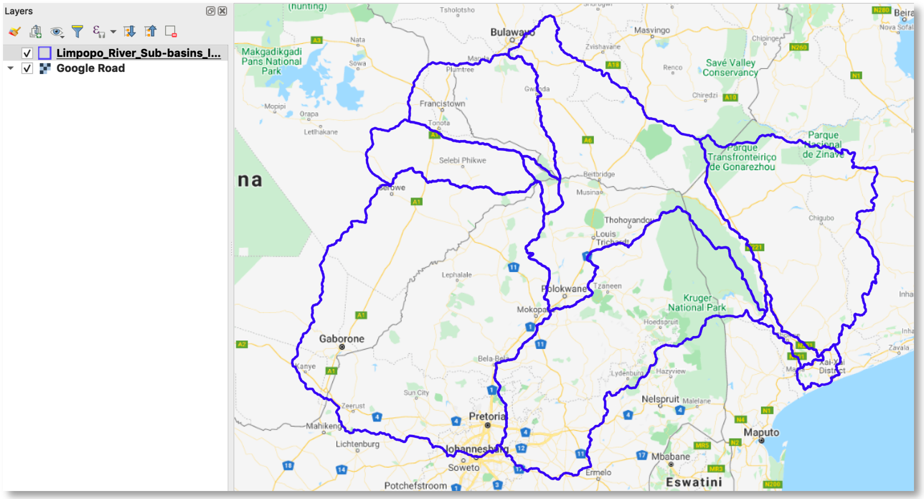
4. You will see the shapefile added to the project. Use the top menu bar and select the "Zoom In" tool to zoom into the shapefile and the pan tool to pan around the map.



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



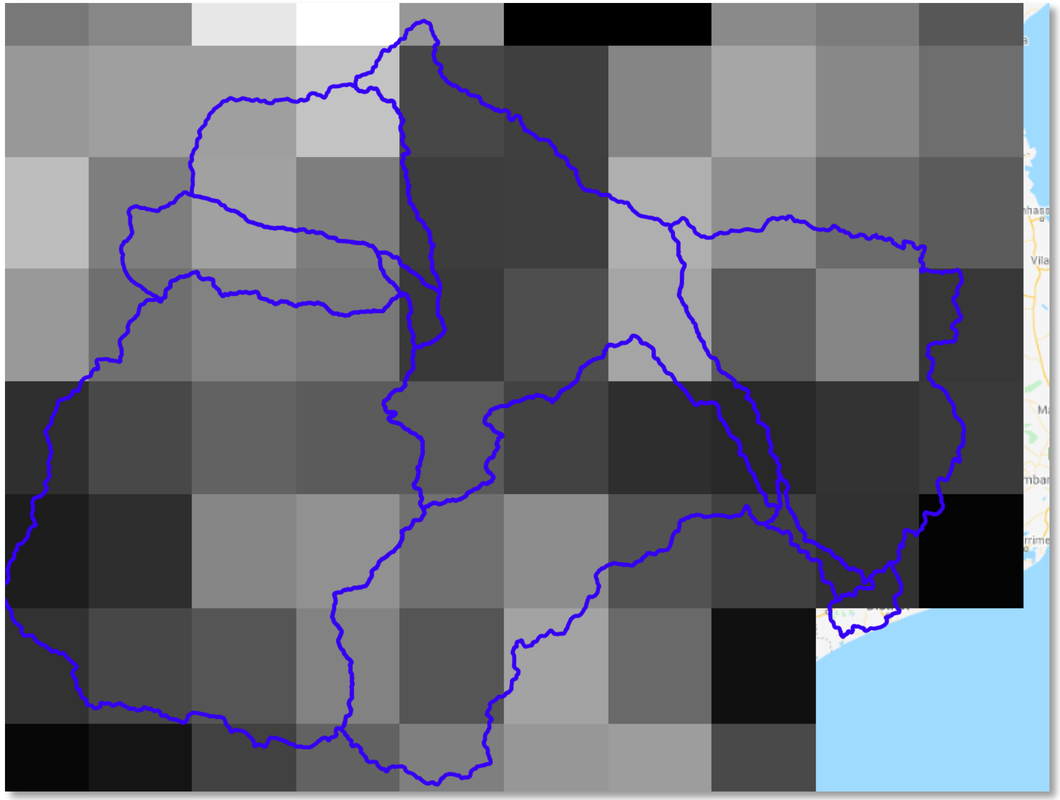
Part 1: Add GLDAS Precipitation and Evapotranspiration Rasters

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

11. Navigate to the GLDAS data downloaded in Session 1.

12. Select the precipitation and evapotranspiration data files for December (2018), January, February (2019), and June, July, August (2019). Click **Open** and then click **Add** to add the files to your Layers panel.

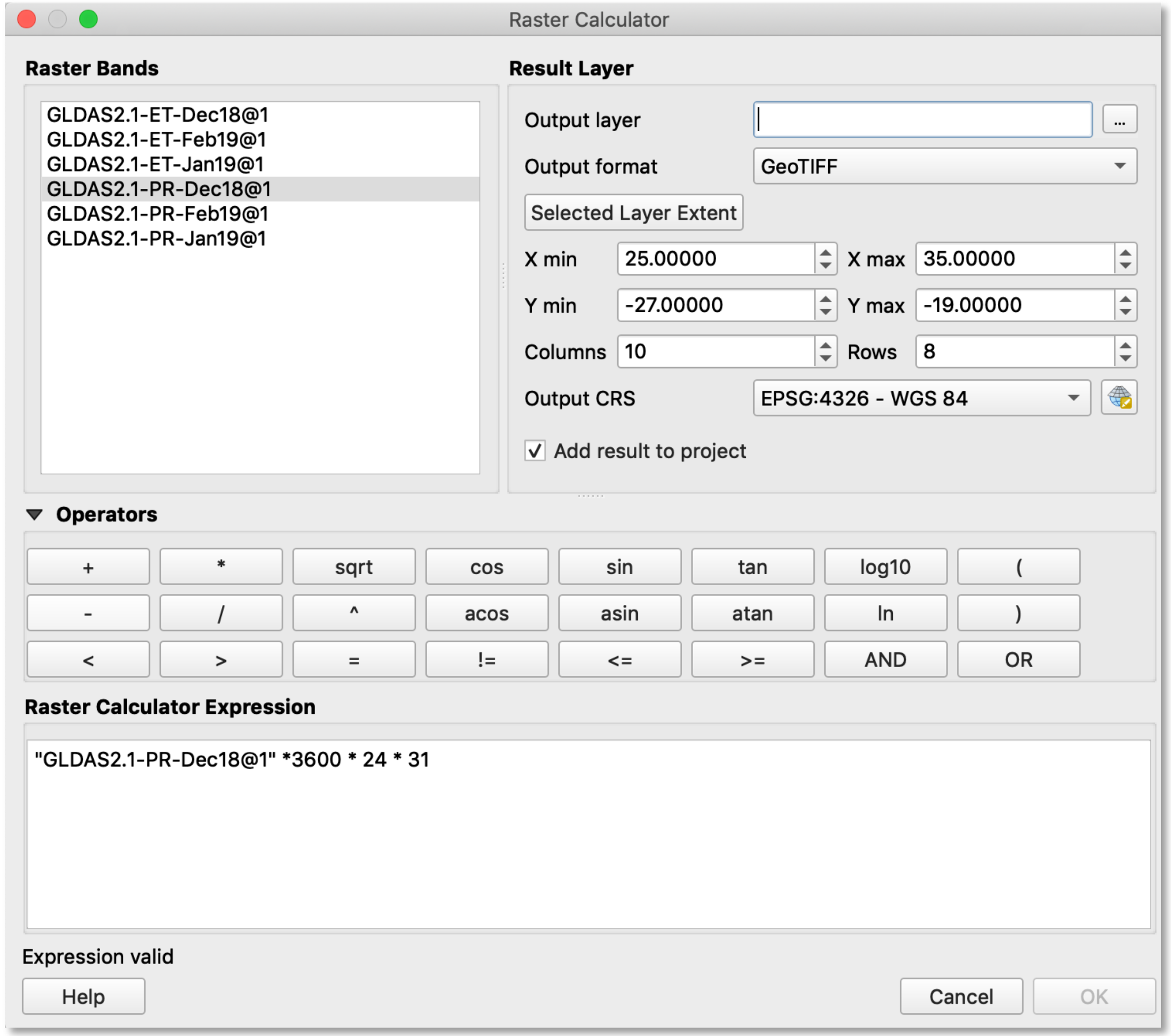
    *You may need to drag your river basin shapefile to the top of the layers panel after adding the raster files.



Part 1: Convert Precipitation and Evapotranspiration to mm/month

13. On the top menu bar go to **Raster → Raster Calculator**.
14. In the Raster Bands window you will see the list of all the PR and ET rasters for which units must be converted to $mm.month^{-1}$ from $kg\ m^{-2}\ s^{-1}$.
15. By clicking on the **Operators** and raster enter the following in the **Raster Calculator Expression:**
GLDAS2.1_PR_Dec18@1 * 3600 * 24 * 31

    (Note: 31 for number of days in December, other months will differ)



Part 1: Convert Precipitation and Evapotranspiration to mm/month

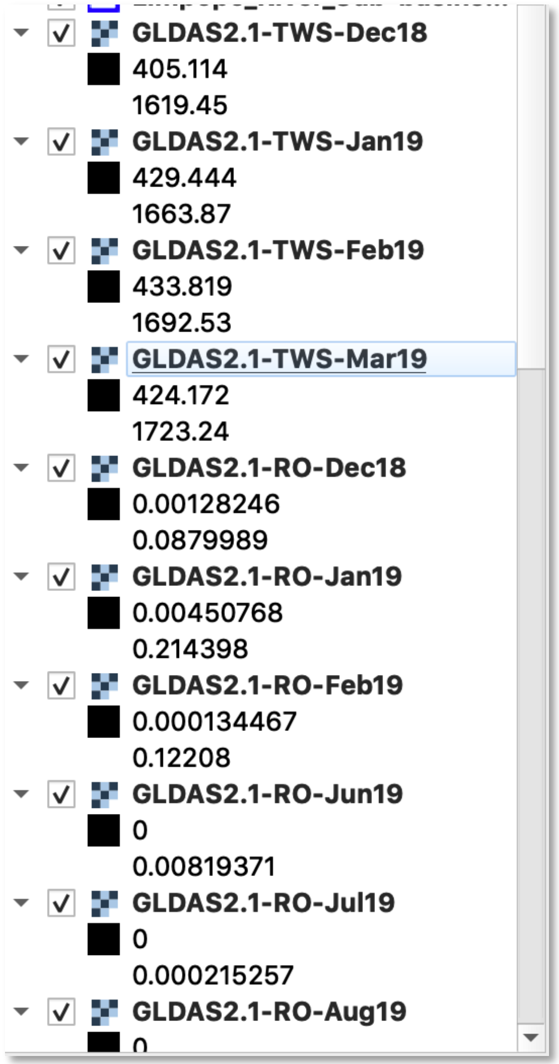
16. In the **Output layer** window choose the location to save the resulting raster and enter the raster name (we will use PR_Dec18) and click **Save**.
17. Make sure **Add result to project** is checked and click **OK**.
18. You will get the raster PR_Dec18 with precipitation values in mm/month.

Part 1: Convert Precipitation and Evapotranspiration to mm/month

19. Repeat Steps 13 to 18 for all the **PR rasters** using 31 days for January, July, and August, 30 days for June, and 28 days for February in Step 15 (e.g. PR_Dec18, PR_Jan19, PR_Feb19, PR_Jun19, etc.).
20. Repeat steps 13 to 18 for all the **ET rasters**, naming the output file names ET_Dec18, ET_Jan19, etc.
21. You may remove the original rasters GLDAS2.1_PR-* and GLDAS2.1_ET-*.

Part 1: Add Total Water Storage (TWS) and Runoff Data

22. Follow Steps 10-12 and add rasters for TWS data for December 2018 (e.g. GLDAS2.1_TWS_Dec18), January, February, March (2019) and June, July, August, September (2019).
    - The TWS data are in mm/month, **no unit change required**.
23. Repeat Steps 10-12 and add Runoff for December 2018 (e.g. GLDAS2.1_RO_Dec18), January, February (2019) and June, July, August (2019).
    - Baseflow Runoff is negligible and can be ignored.



Part 1: Convert Runoff to mm/month

24. Go to **Raster → Raster Calculator**.

25. By clicking on the **Operators** and raster, enter the following in the

    Raster Calculator Expression:

    GLDAS2.1_RO_Dec18@1 * 8 * 31

- The runoff data are accumulated over 3 hours and 31 for the number of days in December (28 days in February, 30 days in June, etc.).

26. In the **Output layer** window choose the location to save the resulting raster and enter the raster name (we will use **RO_Dec18**) and click **Save**.

27. Click **OK** to get the RO raster data in mm/month.

Part 1: Convert Runoff to mm/month

28. Repeat Steps 24-27 for all the Runoff rasters using 31 days for January, July, and August, 30 days for June, and 28 days for February in Step 31.
29. You may remove the original rasters GLDAS2.1_RO-*.

Part 2: Estimate Seasonal Water Budget Components

- Calculate wet and dry season water budget components:
  - Wet Season: December, January, February
  - Dry Season: June, July, August

- Wet Season [PR - ET]:

  (PR_Dec18 + PR_Jan19 + PR_Feb19) – (ET_Dec18 + ET_Jan19 + ET_Feb19)
- Wet Season Runoff:

  (RO_Dec18 + RO_Jan19 + RO_Feb19)
- Wet Season Change in TWS:

  (TWS_Jan19 - TWS_Dec18) + (TWS_Feb19 - TWS_Jan19) + (TWS_Mar19 - TWS_Feb19)

  = TWS_Mar19 - TWS_Dec18

Part 2: Estimate Seasonal Water Budget Components

- Dry Season (PR - ET):

  (PR_Jun19 + PR_Jul19 + PR_Aug19) – (ET_Jun19 + ET_Jul19 + ET_Aug19)
- Dry Season Runoff:

  (RO_Jun19 + RO_Jul19 + RO_Aug19)
- Dry Season Change in TWS:

  (TWS_Jul19 - TWS_Jun19) + (TWS_Aug19 - TWS_Jul19) + (TWS_Sep19 - TWS_Aug19)

  = TWS_Sep19 - TWS_Jun19

Part 2: Find Seasonal PR-ET and RO

1. Go to **Raster → Raster Calculator** and choose the wet season (December, January, February) PR and ET and use the following formula to find seasonal PR minus ET:

(PR_Dec18@1 + PR_Jan19@1 + PR_Feb19@1) – (ET_Dec18@1 + ET_Jan19@1 + ET_Feb19@1)

2. Choose the **Output layer** name to be **PR_ET_Wet19** and click **OK**.

Part 2: Find Seasonal PR-ET and RO

3. Repeat Steps 1 & 2 for the dry season (Jun, July, August) as:

   (PR_Jun19@1 + PR_Jul19@1+ PR_Aug@1) - (ET_Jun19@1 + ET_Jul19@1+ ET_Aug19@1)

- Save the resulting raster as **PR_ET_Dry19**.

4. Repeat Steps 1-3 to get wet and dry season RO as:

   RO_Dec18@1 + RO_Jan19@1 + RO_Feb19@1

   and

   RO_Jun19@1 + RO_Jul19@1 + RO_Aug19@1

- Save the resulting rasters as **RO_Wet19** and **RO_Dry19**.

Part 2: Find Seasonal Change in TWS

5. Using the **Raster Calculator**, find TWS change for wet and dry seasons as:

   (GLDAS2.1_TWS_Mar19@1) - (GLDAS2.1_TWS_Dec18@1)

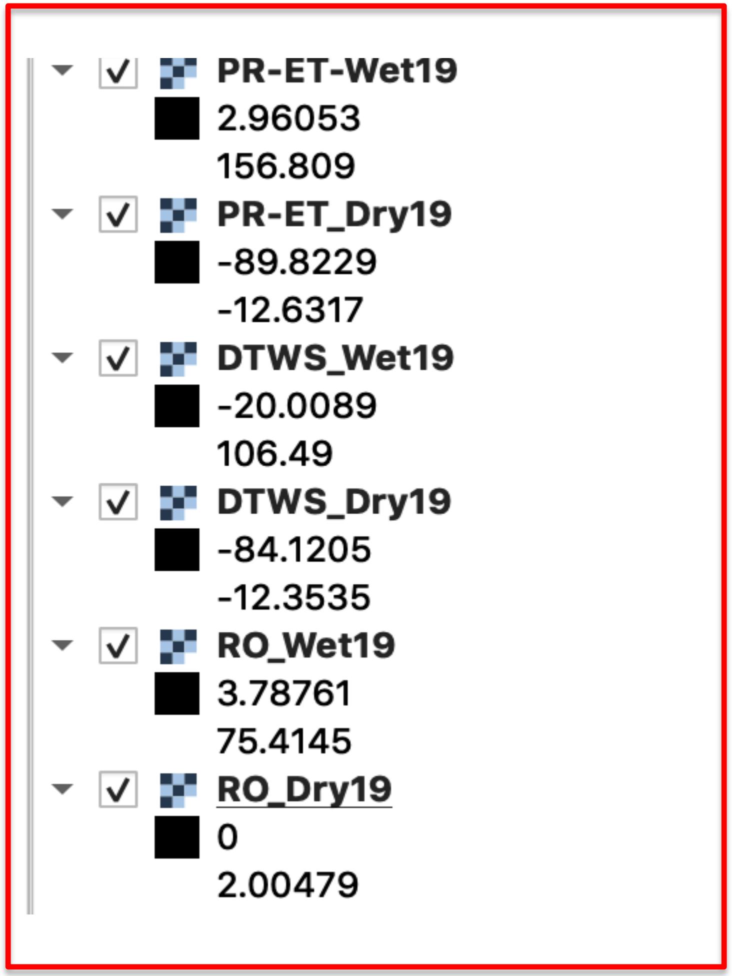
   and

   (GLDAS2.1_TWS_Sep19@1) - (GLDAS2.1_TWS_Jun19@1)

- Choose the **Output layer** names to be:

  DTWS_Wet19 and **DTWS_Dry19**

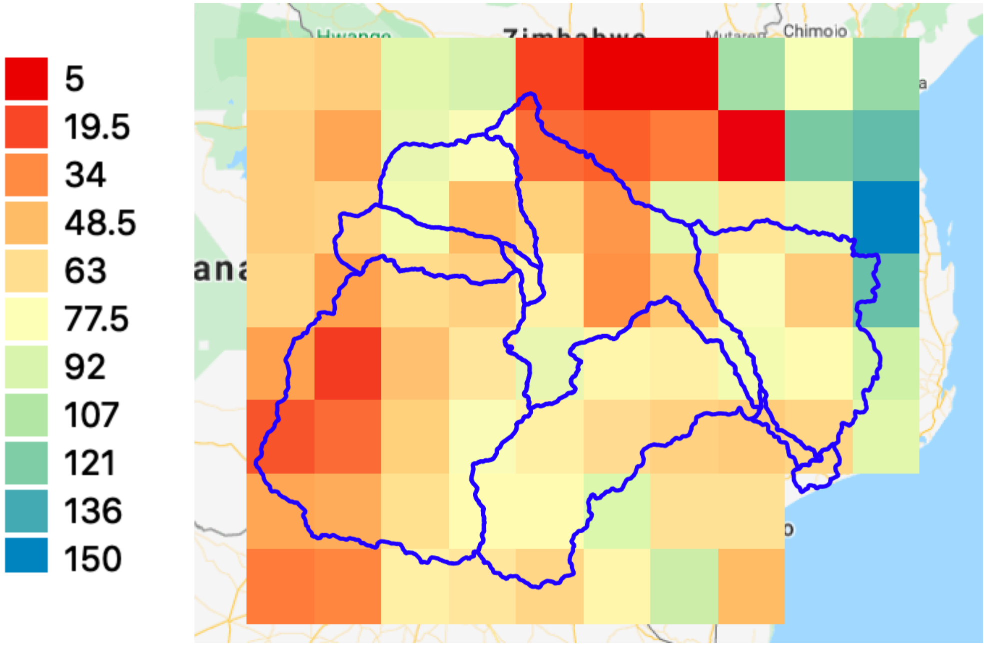
6. You will have 3 wet and 3 dry season raster files.



Part 2: Examine Seasonal Water Budget Components (PR-ET)

7. Right click on the layer PR_ET_Wet19 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 **5** and **150** respectively.
   - Below the color display, change the **Mode** to **Equal Interval** and **Classes** to **11** and click **OK**.

PR-ET_Wet19



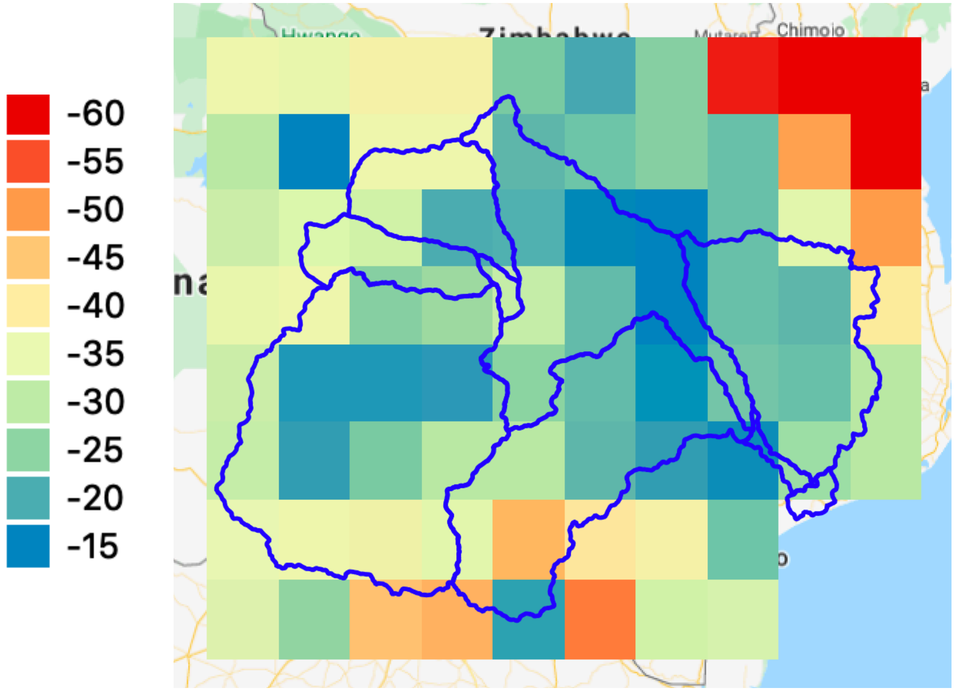
mm

Part 2: Examine Seasonal Water Budget Components (PR-ET)

8. Repeat Step 7 for PR_ET_Dry19 raster with **min** and **max** values set to **-60** and **-15**, and **Equal Interval → Classes** to **10**.

9. Examine how the Precipitation minus Evapotranspiration changes between the wet and dry seasons.

PR-ET_Dry19



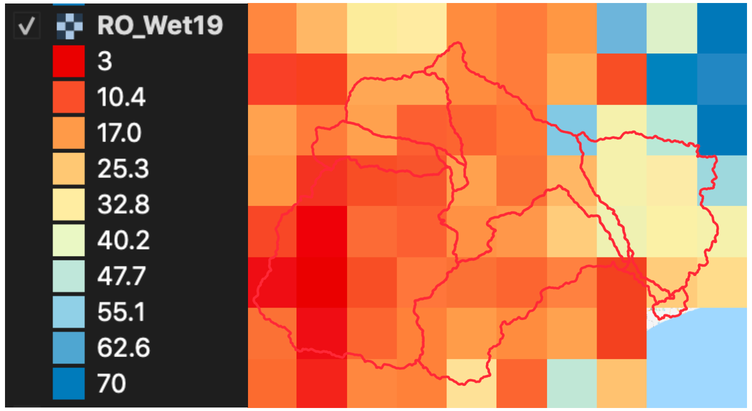
mm

Part 2: Examine Seasonal Water Budget Components (RO)

10. Repeat Step 7 for RO_Wet19 raster with **min** and **max** values set to **3** and **70**, and **Equal Interval → Classes** to **10**.

11. Repeat Step 7 for RO_Dry19 raster with **min** and **max** values set to **0** and **2**, and **Equal Interval → Classes** to **8**.

RO_Wet19

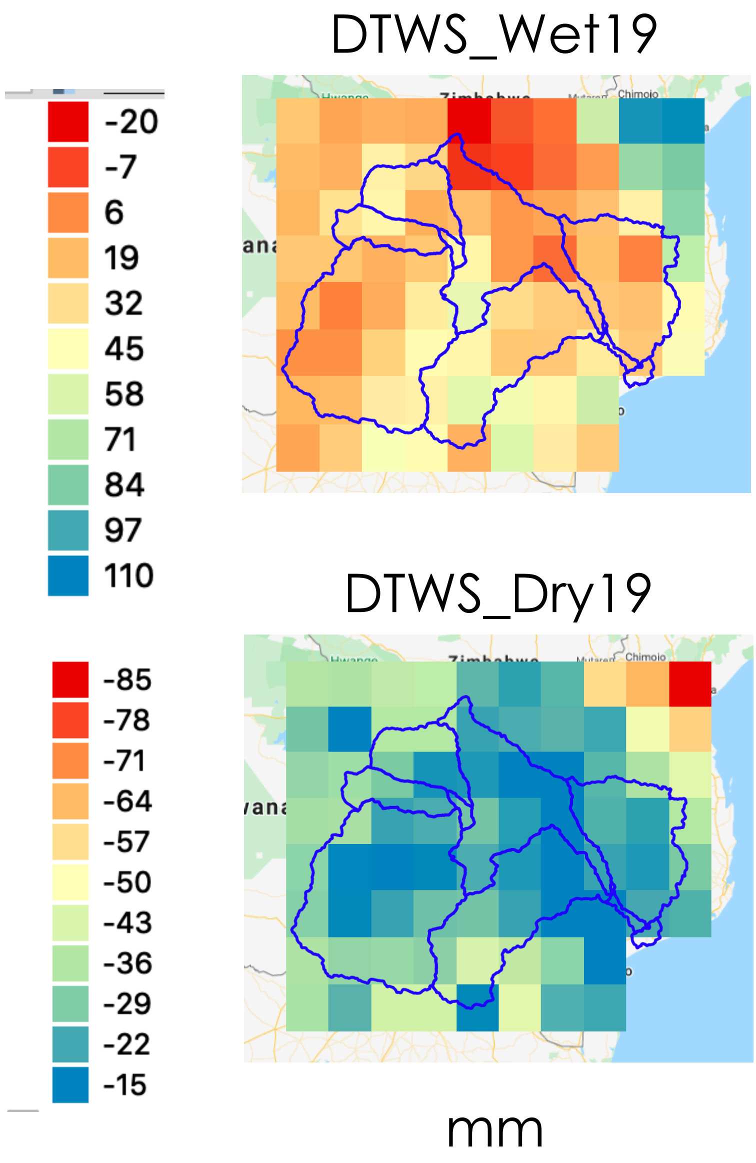


RO_Dry19

mm

Part 2: Examine Seasonal Water Budget Components (RO)

12. Repeat Step 7 for DTWS_Wet19 raster with **min** and **max** values set to **-20** and **110**, and **Equal Interval →** **Classes** to **11**.
13. Repeat Step 7 for DTWS_Dry19 raster with **min** and **max** values set to **-85** and **-15, and Equal Interval →** **Classes** to **11**.
14. Examine seasonal differences in the Runoff and DTWS.

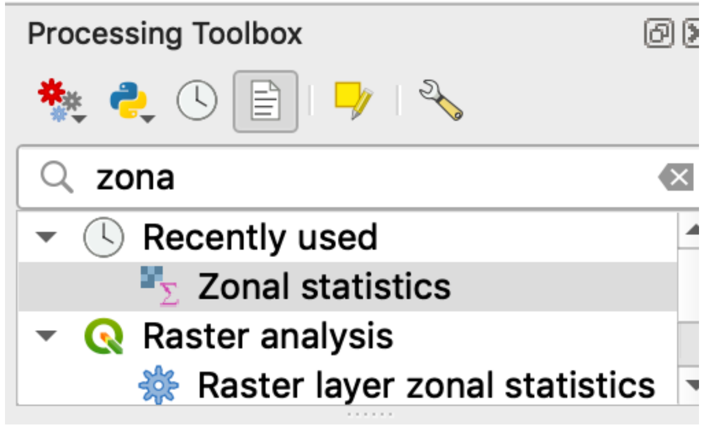


Part 3: Compare Dry and Wet Season Water Budget Components for the Limpopo Basin and Selected Sub-basins

- Use QGIS **Zonal Statistics** to get the total seasonal water amount over the Limpopo sub-basins.
- Use the shapefile **Attributes/Calculator** to get the area of the sub-basins.
- Estimate total water amount over the basin using Excel.

Part 3: Seasonal Water Amount Estimation

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 **PR_ET_Wet19**.
   - For **Vector layer containing zones** make sure that **Limpopo_River_Sub-basins_lev04** is selected.
   - Enter an **Output column prefix = PEW**.
   - In **Statistics to calculate** select **Count** and **Mean** and click **OK**, then **Run**.



Part 3: Seasonal Water Amount Estimation

4. Repeat Step 3 for PR_ET_Dry19, DTWS_Wet19, DTWS_Dry19, RO_Wet19, and RO_Dry19, but include only **Mean** in the **Statistic to calculate**.
   - Suggest Output column prefix to be **PED**, T**WSW**, T**WSD**, **ROW**, **ROD** 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.

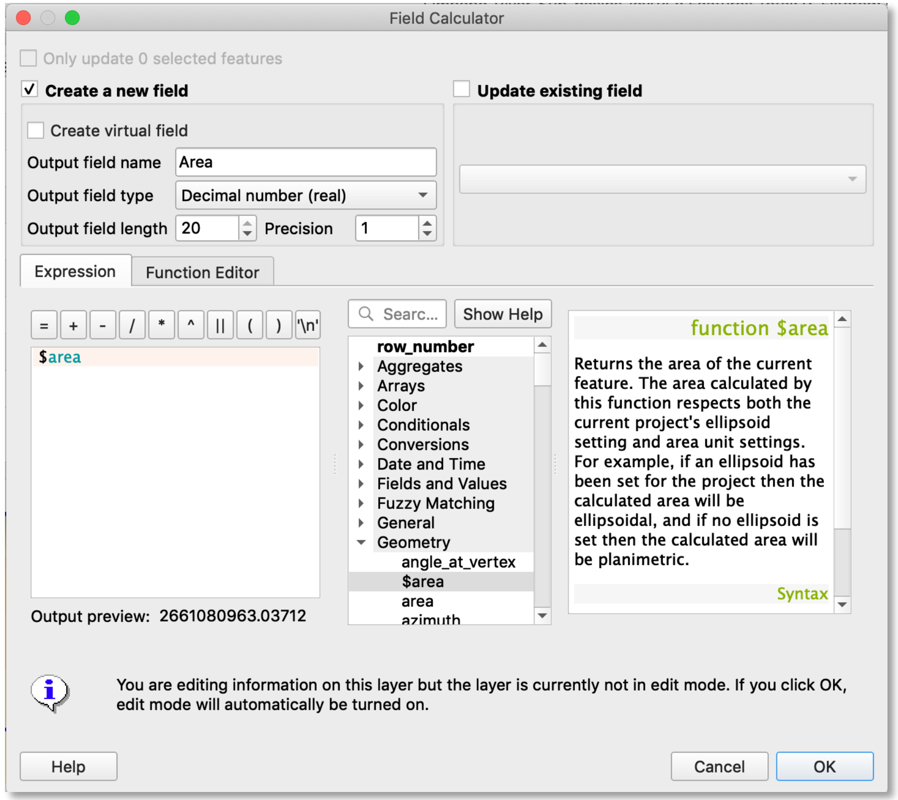
Zonal Statistics in the Attribute Table

PEWcount	PEWmean	PEDmean	TWSWmean	TWSDmean	ROWmean	RODmean
13.00000000...	51.73971528...	-26.9052897...	23.57042987...	-24.2495727...	10.09673481...	0.000258657...
8.00000000...	56.47977876...	-22.5430061...	18.35472869...	-19.7693405...	19.36087036...	0.069132083...
0.215342964...	60.15416629...	-23.6149939...	29.67289202...	-18.4029800...	20.36278143...	0.144661419...
0.139966261...	60.3754234...	-28.0143184...	24.72973632...	-22.2406311...	26.86031341...	0.207351878...
1.699643937...	63.2573898...	-29.1836791...	28.84135346...	-26.6968544...	14.35189717...	0.003956167...
0.224210953...	67.66315487...	-30.0297581...	36.49635921...	-26.1992208...	17.85832081...	0.00598442...
4.00000000...	67.872811317...	-27.10717344...	18.34967041...	-21.30381011...	32.9266052...	0.68040243...
5.00000000...	71.88395080...	-29.4158039...	35.26763916...	-25.0346801...	18.15540828...	0.004364671...
4.00000000...	74.34418201...	-31.3141098...	31.82112884...	-30.1350097...	18.30066251...	0.014108975...

Part 3: 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.



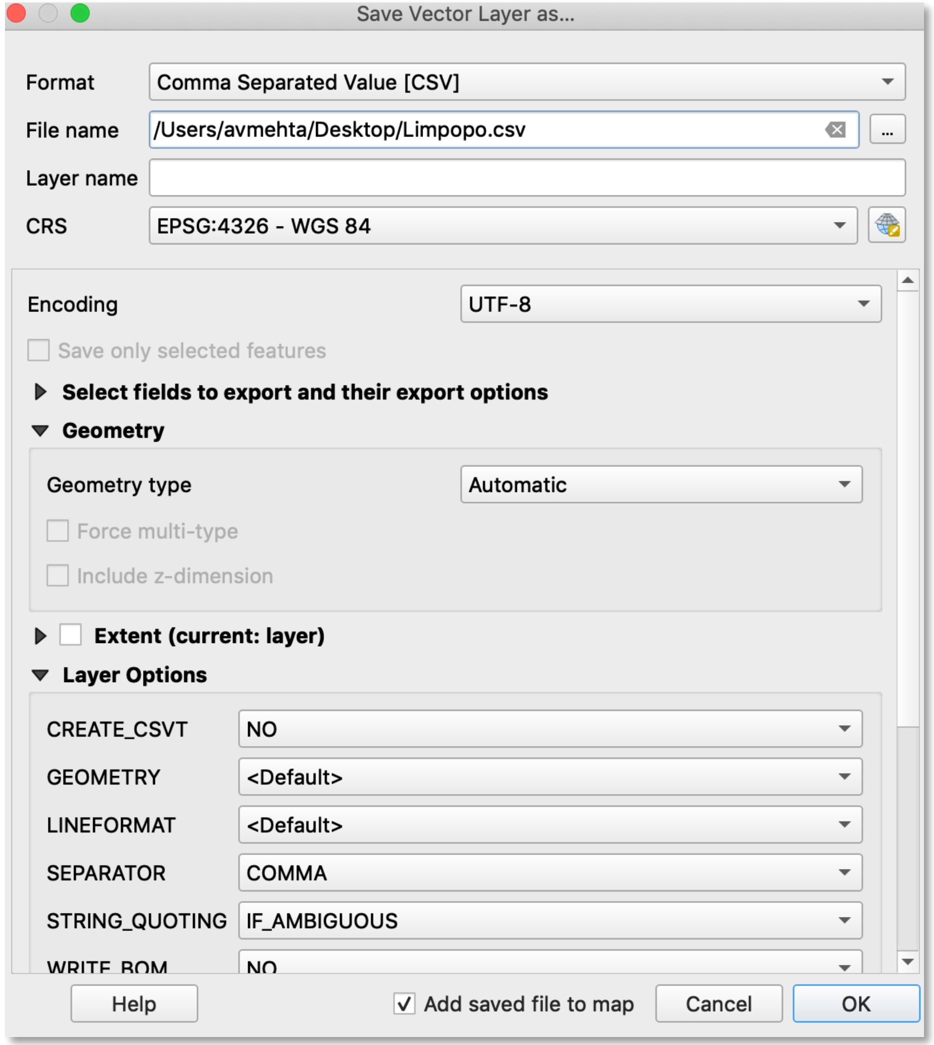
Part 3: Examine Seasonal Water Budget Components

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_GLDAS.csv).
- Click **OK**.



Part 3: Examine Seasonal Water Budget Components

8. Open the CSV file (Limpopo_GLDAS.csv) in Excel or Open Office Spreadsheet.
9. Select a column to the right of the Area column.
10. Enter the following function in the first cell underneath the column heading:
    PEWmean (O2) * the first cell under Area (U2) * 0.001:

    = O2 * U2 * 0.001

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

Part 3: 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 PEWmean from mm to m^3.
12. Repeat steps 9-11 for PEDmean, TWSWmean, TWSDmean, and ROWmean, multiplying each top value of the column by Area * 0.001 (e.g. P2 * U2 * 0.001) and then drag down.

PEWmean	PEDmean	TWSWmean	TWSDmean	ROWmean	RODmean	Area			
60.3754234	-28.014318	24.7297363	-22.240631	26.8603134	0.20735188	2661080963		160663889.9	-74548369.56
67.8728113	-27.107173	18.3496704	-21.30381	32.9266052	0.68040244	6.4387E+10		4370109510	-1745342710
60.1541663	-23.614994	29.672892	-18.40298	20.3627814	0.14466142	2417663382		145432525.1	-57093106.08
71.8839508	-29.415804	35.2676392	-25.03468	18.1554083	0.00436467	8.1309E+10		5844788959	-2391760108
56.4797788	-22.543006	18.3547287	-19.769341	19.3608704	0.06913208	7.7022E+10		4350203623	-1736314647
67.6631549	-30.029758	36.4963592	-26.199221	17.8583208	0.00598442	2558704860		173130043.2	-76837288.16
74.344182	-31.31411	31.8211288	-30.13501	18.3006625	0.01410898	2.8987E+10		2155035561	-907710843.8
51.7397153	-26.90529	23.5704299	-24.249573	10.0967348	0.00025866	1.3281E+11		6871709361	-3573373573
63.2573898	-29.183679	28.8413535	-26.696854	14.3518972	0.00395617	1.9447E+10		1230150983	-567527868.3

Part 3: 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(W2:W10)**, replacing the column identifier (e.g. W, X, Y, etc.) with the correct identifier corresponding to your spreadsheet.
15. Repeat step 14 for each converted column to determine the totals for the entire basin.

PEWmean	PEDmean	TWSWmean	TWSDmean	ROWmean	RODmean	Area			
60.3754234	-28.014318	24.7297363	-22.240631	26.8603134	0.20735188	2661080963		160663889.9	-74548369.56
67.8728113	-27.107173	18.3496704	-21.30381	32.9266052	0.68040244	6.4387E+10		4370109510	-1745342710
60.1541663	-23.614994	29.672892	-18.40298	20.3627814	0.14466142	2417663382		145432525.1	-57093106.08
71.8839508	-29.415804	35.2676392	-25.03468	18.1554083	0.00436467	8.1309E+10		5844788959	-2391760108
56.4797788	-22.543006	18.3547287	-19.769341	19.3608704	0.06913208	7.7022E+10		4350203623	-1736314647
67.6631549	-30.029758	36.4963592	-26.199221	17.8583208	0.00598442	2558704860		173130043.2	-76837288.16
74.344182	-31.31411	31.8211289	-30.13501	18.3006625	0.01410898	2.8987E+10		2155035561	-907710843.8
51.7397153	-26.90529	23.5704299	-24.249573	10.0967348	0.00025866	1.33E+11		6871709361	-3573373573
63.2573898	-29.183679	28.8413535	-26.696854	14.3518972	0.00395617	1.9447E+10		1230150983	-567527868.3
							SUM	25301224455	-11130508514

Part 3: 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 **=W11 * 10^-9**, replacing the column identifier (e.g. W, X, Y, 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.

PEWmean	PEDmean	TWSWmean	TWSDmean	ROWmean	RODmean	Area			
60.3754234	-28.014318	24.7297363	-22.240631	26.8603134	0.20735188	2661080963		160663889.9	-74548369.56
67.8728113	-27.107173	18.3496704	-21.30381	32.9266052	0.68040244	6.4387E+10		4370109510	-1745342710
60.1541663	-23.614994	29.672892	-18.40298	20.3627814	0.14466142	2417663382		145432525.1	-57093106.08
71.8839508	-29.415804	35.2676392	-25.03468	18.1554083	0.00436467	8.1309E+10		5844788959	-2391760108
56.4797788	-22.543006	18.3547287	-19.769341	19.3608704	0.06913208	7.7022E+10		4350203623	-1736314647
67.6631549	-30.029758	36.4963592	-26.199221	17.8583208	0.00598442	2558704860		173130043.2	-76837288.16
74.344182	-31.31411	31.8211289	-30.13501	18.3006625	0.01410898	2.8987E+10		2155035561	-907710843.8
51.7397153	-26.90529	23.5704299	-24.249573	10.0967348	0.00025866	1.33E+11		6871709361	-3573373573
63.2573898	-29.183679	28.8413535	-26.696854	14.3518972	0.00395617	1.9447E+10		1230150983	-567527868.3
							SUM	25301224455	-11130508514
							BILLIONS m3	25.30122446	-11.13050851

Part 3: 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 GLDAS data.
- Questions based on this exercise will be included in Homework #3.