ADDA Lab

Network Coverage Analysis

SIMULATING CELL TOWER REACH USING VIEWSHED MODELING TECHNIQUE

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Overview, Objective, and Skills

Overview: Prior to the advent of computer mapping and GIS, contour lines created from surveyed elevation points (called as benchmarks) were used almost exclusively to represent elevation. The ability to fully visualize the landscape based on contours required considerable familiarity and experience that were beyond most everyone save for those who worked with topographic maps on a regular basis. Moreover, deriving even the most direct information from contours – ground slope or aspect, for example – was tedious at best. Geographic information systems provide a variety of ways to visualize the landscape more effectively than conventional contour lines, and they offer a rich variety tools for terrain analysis.

Scenario: As an experienced GIS Analyst, you won the contract from TNM to carry out a cellular network coverage analysis to provide updated information on where their coverage is good and where it is lacking. As an end product, you are required to submit a map showing cell coverage areas and location of cell towers.

Learning Objective: In this exercise, Q-GIS is used to explore techniques for deriving terrain visibility models from elevation data. Although the problem presented here involves elevation data, the principles and procedures can be applied to any conceptual three-dimensional surface from atmospheric pressure to migration potential.

Skills Introduced and Practiced: You will learn to use spatial analysis techniques including spatial selection and viewshed analysis tools. You will also practice skills involving adding and importing various dataset, downloading data from various sources, stitching, and clipping raster dataset, and visualizing the outcomes using appropriate symbology.

Submit: 1) Make a good cartographic map of your results, and 2) Your answers to the questions presented, and 3) your reflections.

Plugins used: QuickMapServices, SRTM Downloader (optional), and **Visibility Analysis**

1. From Start Menu, open **QGIS Desktop with GRASS**
2. If you don't have this plugin already, search for and install **QuickMapServices.** After successful installation, click on menu **Web → QuickMapServices → Settings**

On the settings window, click on "**More Services**" tab and then click on "Get Contributed Pack". This will install a lot of other basemap layers including Google Earth Satellite and Terrain views that is very useful in showing the topography of the area.

3. If you don't have this plugin already, search for and install **SRTM Downloader** plugin (this is an optional plugin for this exercise as you are given the data needed for the analysis, so no need to download it using SRTM Downloader plugin)
4. Search for an install **Visibility Analysis** plugin. When installed, this will add necessary tools for viewshed analysis to your **Processing Toolbox** area.

Data Used: Cell tower location data used in this project was downloaded from https://opencellid.org (cell data for any country can be downloaded from this source)

There are different types of cell towers – CDMA, GSM, UMTS, LET, 5G etc., For this activity, we will use data pre-downloaded for Malawi and use it. Our purpose here is to understand how GIS can help solving real world problems through a variety of analytical techniques. Keeping in mind this goal and limited time that we have, we will make a lot of generalizations regarding the effective range and quality of cell phone signal from the towers. Generally, the effective range of cell towers depend on many factors, including frequency and intensity (power) of signal, height of the tower where antenna is fixed, the directionality of the antenna, texture and ruggedness of the landscape (buildings, trees, hills and mountains), and weather conditions.

For the GSM network, the absolute maximum range for signal is 35 km. We also must keep in mind that there must be enough overlap between cells to effectively *handover* signal from one tower to another as the user travels in and out of cells. So, we will assume that on a flat terrain, we can read a 35 km effective range whereas on a terrain with lots of high building or with a rugged topography, the effective range can only be 5 to 10 km. LTE towers have much shorter range compared to GSM whereas 5G cell towers have even shorter range than LTE. All these depend on the wavelength used for transmitting and receiving signals, number of simultaneous users expected, and the bandwidth necessary. The cell tower data attributes are explained below (source: http://wiki.opencellid.org/)

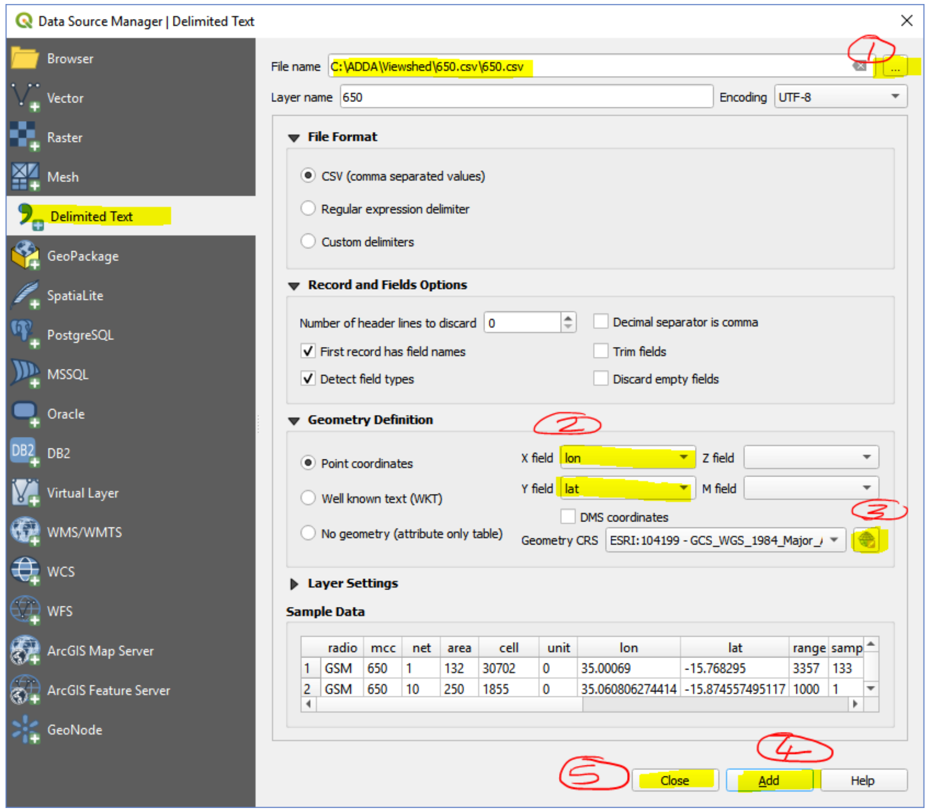
Parameter	Description
Radio	The generation of broadband cellular network technology (eg. LTE, GSM)
MCC	Mobile country code. This info is publicly shared by International Telecommunication Union (link)
MNC	Mobile network code. This info is publicly shared by International Telecommunication Union (link)
LAC/TAC/NID	Location Area Code
CID	This is a unique number used to identify each Base transceiver station or sector of BTS
Longitude	Longitude, is a geographic coordinate that specifies the east-west position of a point on the Earth's surface
Longitude	Latitude is a geographic coordinate that specifies the north–south position of a point on the Earth's surface.
Range	Approximate area within which the cell could be. (In meters)
Samples	Number of measures processed to get a particular data point
Changeable=1	The location is determined by processing samples
Changeable=0	The location is directly obtained from the telecom firm
Created	When a particular cell was first added to database (UNIX timestamp)
Updated	When a particular cell was last seen (UNIX timestamp)
AverageSignal	To get the positions of cells, OpenCelliD processes measurements from data contributors. Each measurement includes GPS location of device + Scanned cell identifier (MCC-MNC-LAC-CID) + Other device properties (Signal strength). In this process, signal strength of the device is averaged. Most 'averageSignal' values are 0 because OpenCelliD simply didn't receive signal strength values.

Part I - Data Download and Import

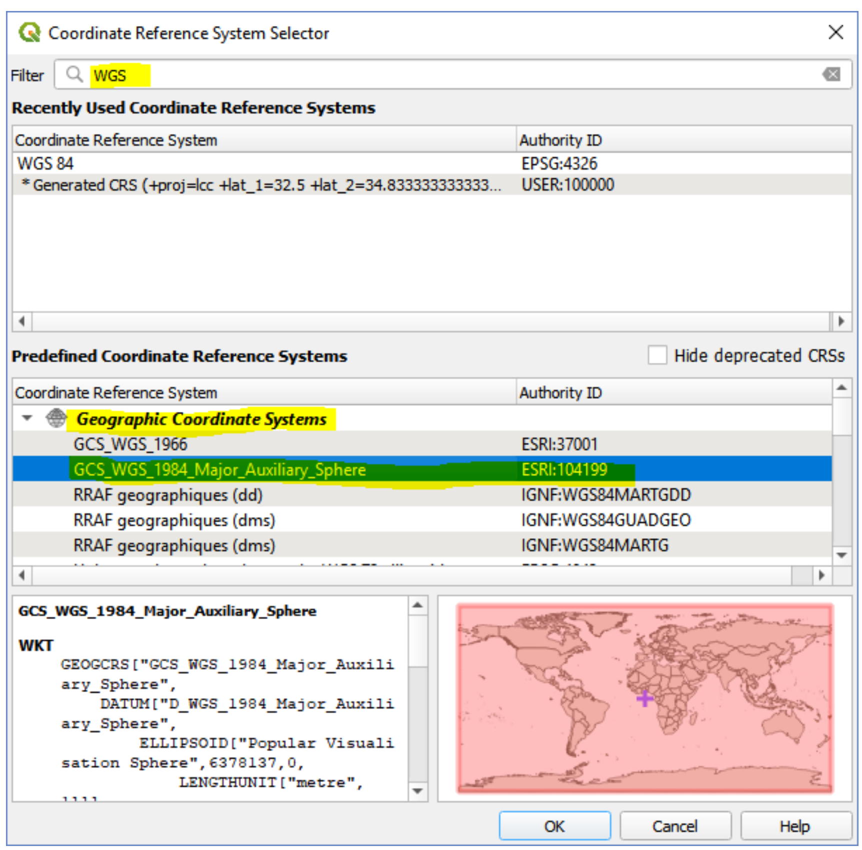
Download the data provided on Moodle in zip file format (**LabData.zip**) and extract the contents into a new lab folder.

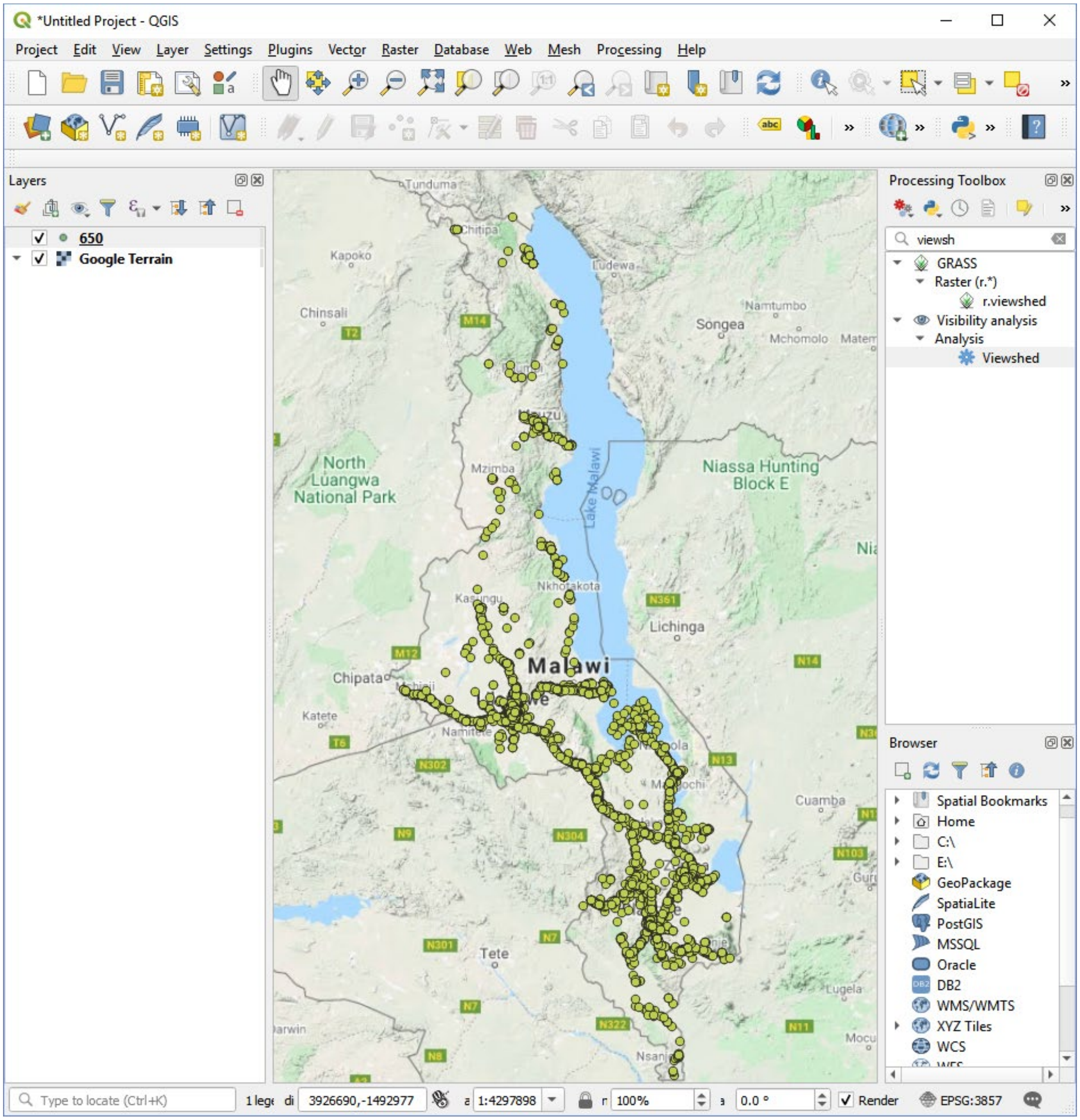
On QGIS window, Click on menu **Web → QuickMapServices → Google → Google Terrain**

We will now add the CSV (Comma Separated Values) file to our QGIS project. Click Layer → Add Layer → Add Delimited Text Layer



1. When the Data Source Manager window opens, click on Open File button and navigate to where you have saved your **Malawi_CellTowers.csv** file on your computer.
2. Make sure to match latitude and longitude values to the right X and Y fields.
3. We need to assign projection information for the point locations. Latitude and Longitude values were mostly acquired using handheld GPS units. The GPS projection setting are required to assign the proper geometry to the file before importing. We know from the source that the GPS was using GCS_WGS_1984 (a type of un-projected, geographic coordinate system with WGS_1984 as the reference datum surface), so we will assign it. Click on the button next to Geometry CRS field. In the resulting **Coordinate Reference System Selector** window, type WGS to filter all projects with the followed by selecting **GSC_WGS_1984_Major_Auxillary_Sphere** (**ESRI:104199**) as the coordinate system. Click OK to get out of this window.
4. Click **Add** on the Data Source Manager window. If the projection information was assigned properly, you should see all the cell towers get mapped and identified as points and displayed. Now explore the displayed data. Remember that the points are just being displayed directly from the CSV file. We must export the displayed data to a GIS compatible file format to be able to do further analysis. We will export this to a GIS compatible format after we study and understand the data.





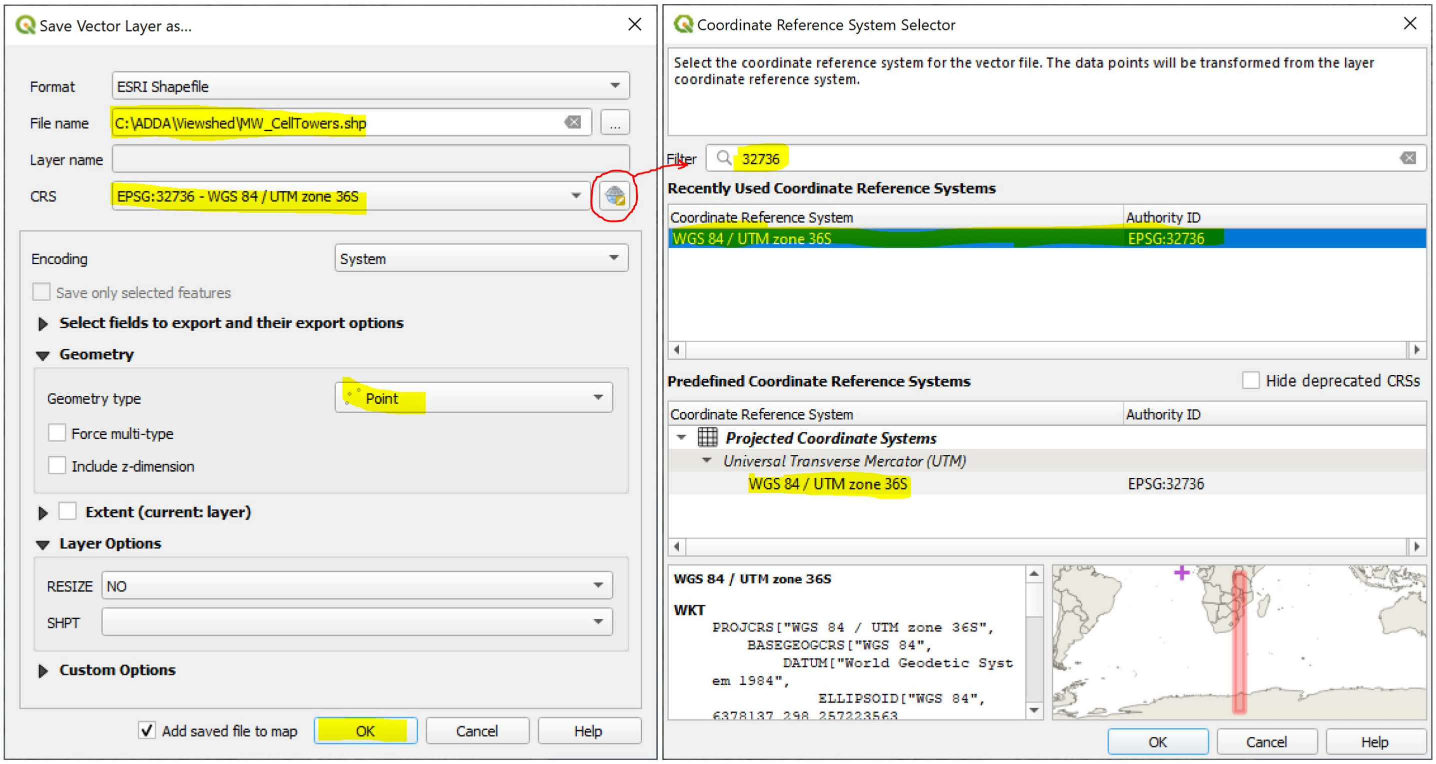
Study the data as represented on the map and discuss these with one of your friends in class.

a) What is your first thought about the distribution of different kinds of cell towers that is displayed on the map?
b) Do you see any specific patterns or association with respect to the location of cell towers?
c) Where are higher concentration of cell towers located generally? Can you come up with a list of possible reasons for those?
d) Zoom in to some urban areas and study where the towers are located. Do you have any specific question about the validity and quality of the location data? Why?
e) Do you feel comfortable with the process of importing a CSV (or other similar types) file into GIS for further use?

5. To save this point data as a permanent GIS data, we must export the data - **Right-Click** on the Malawi_CellTowers layer and select **Export → Save Features As…**
6. Now, in the new window, make sure to select the output file **Format (ESRI Shapefile), provide a file name** (click on the button with three dots next to it) and select a new **Projected Coordinate System** under **CRS.**
   a. **Selecting new projection for the layer being Exported**: To do any kind of spatial analysis with your data, your data should have a proper projected coordinate system. Since the CSV was displayed using a Geographic

coordinate system, we have to now assign a new projected coordinate system. This time, we will pick **Universal Transverse Mercator (UTM)** as the projection. UTM requires you specifying a zone number where your study area falls. For Malawi, it is **Zone 36 South**, so we will pick **WGS 84 / UTM Zone 36S** (you can search for this by typing the number **32736** or **UTM 36S** in the **Filter** box on top). Under Geometry, select **Point**. Then Click Ok.

7. Click OK to export the layer as new ESRI Shape File. It should add the file to your project in addition to saving the new file on your designated folder.

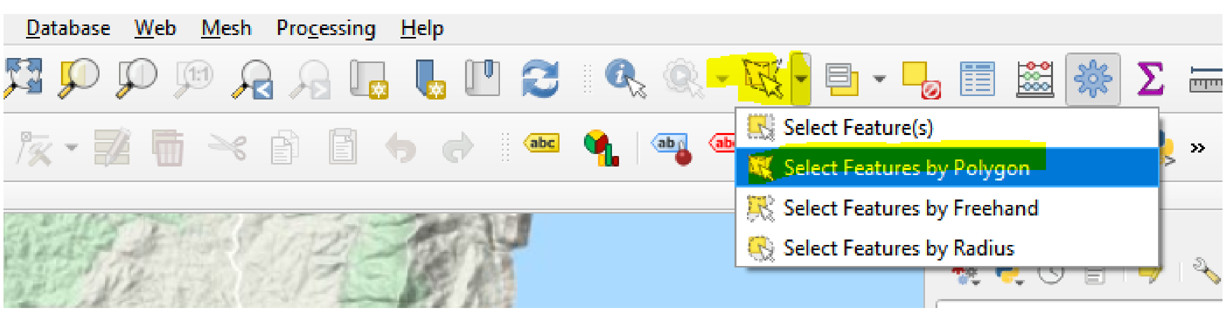


Part II - Data Extraction

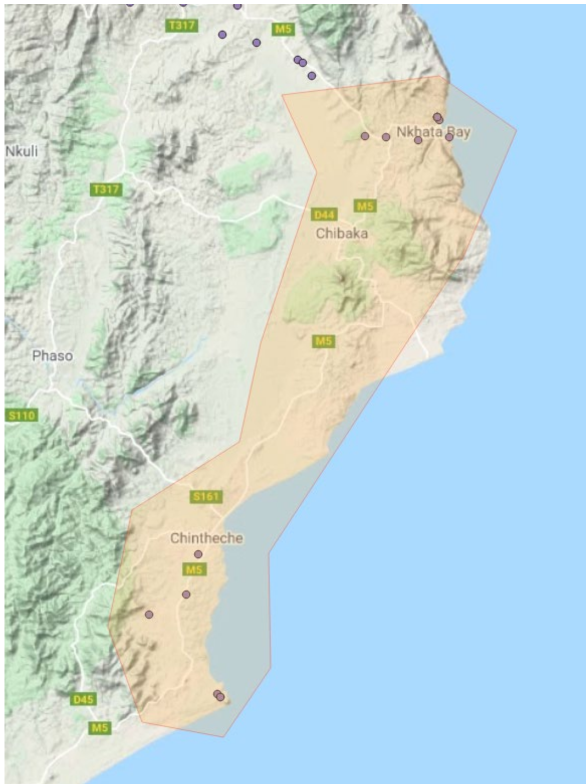
In this section, you will learn how to select a sub-set of a larger dataset for further analysis. You will create a sub-set of cell tower points from the whole country list.

First, for the purpose of this exercise, we will run the viewshed modeling for a small number of cell towers located along the northern part of Lake Malawi's shore, in between Nkhata Bay and Chintenche. Our goal here is to analyze the coverage of cellular network in the given area.

1. Click on the **Select Features** button and look for **Select Features by Polygon** option.



2. When the mouse curser changes to digitizing mode, click and create a polygon that covers all the cell towers in Nkhata Bay and Chintenche area. When done creating the polygon, **right click** to complete digitization. Result should look like in the image below. All selected cell towers will be highlighted.



3. Now, **right click** on the Malawi Cell Tower layer and select **Export → Save Selected Features As…**and in the File Save As window, give **Chintenche_Towers** as the output file name, and make sure it is **ESRI Shapefile** format.

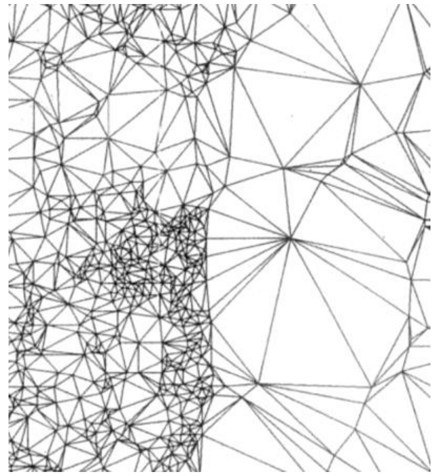
Part III – Background on Elevation Models:

All representations of terrain are derived ultimately from a series of control points for which are known geographical location (X and Y) and elevation (Z). Conventional topographic maps are constructed by interpolating isolines – hypothetical lines of equal elevation – from this series of control points. Isolines that represent elevation are known more specifically as contour lines. While geographic information systems certainly have the ability to interpolate discrete contour lines, they also accommodate representations of terrain that are effectively continuous. Like contours, however, these continuous models also are derived from a series of discrete control points. Although there are a number of different methods for constructing elevation surfaces from X-Y-Z points, most elevation models are constructed using either of two particular techniques: inverse distance weighting (IDW) and triangulated irregular network (TIN).

The IDW (inverse distance weighting) method produces a grid or raster elevation model in which the value of each grid cell or pixel is an elevation. In constructing this raster model, a grid is superimposed over the control points, and then the elevation of each grid cell or pixel is interpolated in turn based on the nearest N control points. In some software, the user specifies the number of control points (N) to be used in the interpolation, while in other packages, the number of points is determined internally. In either case, control points closer to the grid cell or pixel in question have greater weight in effecting the value of that pixel, while more distant control points have less weight. Specifically, the IDW algorithm is:

$$E = \frac{\sum_{i=0}^{n} \frac{e_i}{d_i^b}}{\sum_{i=0}^{n} \frac{1}{d_i^b}}$$

E is the elevation of the pixel in question; e_i is the elevation of the j^{th} control point; d_i is the Euclidean distance from the pixel in question to control point i; N is the number of control points; and b is a weighting exponent that controls the effect of distance. Values of b are usually set between 1 and 2. When b=1, the effect of distance decreases linearly, whereas for b=2, the effect diminishes as the square of distance. Most simply, as values of the exponent b increase, proportionally greater weight is given to closer control points



The IDW (inverse distance weighting) method is especially appropriate when control points are more or less uniformly distributed across the area, but when the points are irregularly spaced, the TIN (triangulated irregular network) may produce a more accurate model.

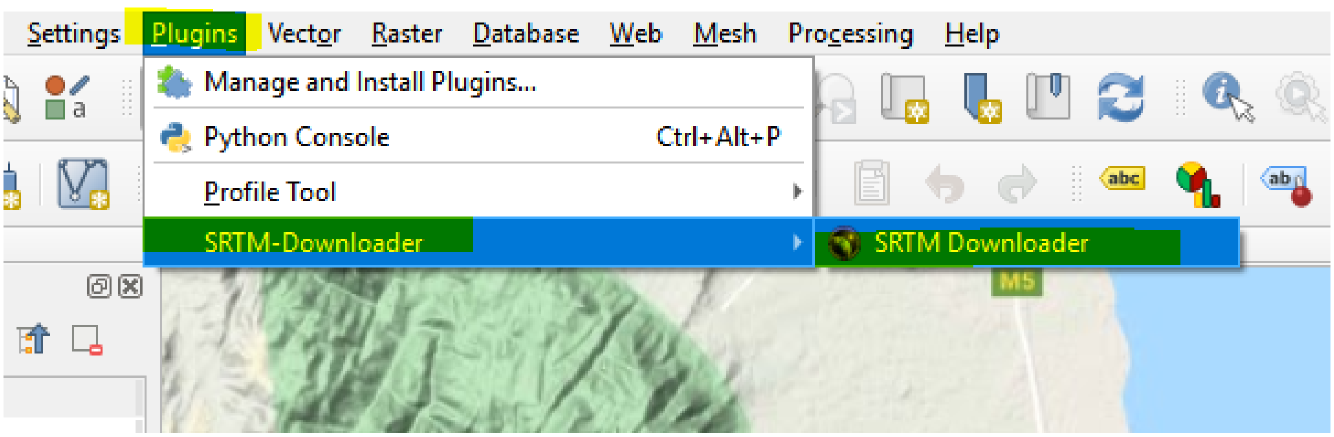
As the name implies, a TIN (triangulated irregular network) is constructed by using the control points to construct a set of continuously connected triangles as illustrated at left below. Because the slope and aspect of any triangular facet can be calculated from the control points that define the triangle, each triangle can be conceptualized as a three- dimensional. Known as Delauney Triangulation, the most common algorithm for determining how to build triangles searches for the three contiguous points that fit within the smallest radius.

Elevation models are often displayed with a so-called *spectral* ramp that ranges from red or orange for high values through blues for low elevations, but some monochromatic color ramps – ramps comprised of different shades of a single hue or color – also can be effective.

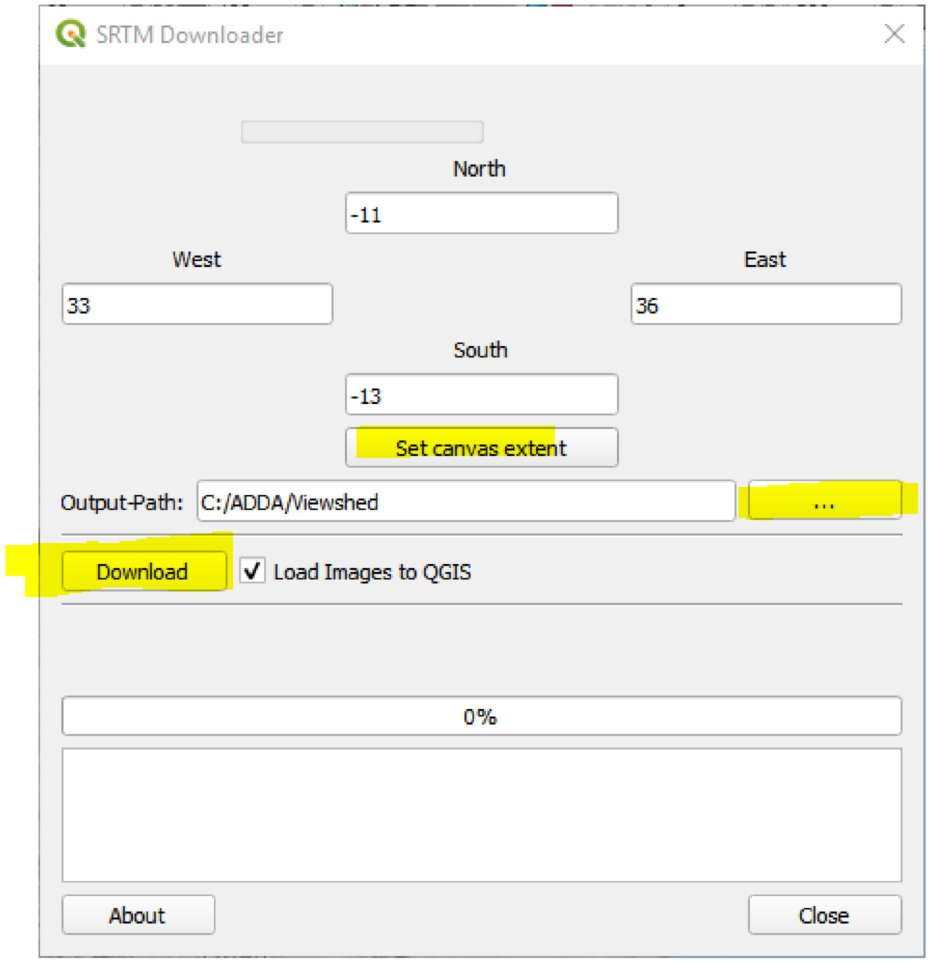
<u>Part IV: Downloading and Extracting DEM Data</u> (Skip this section and proceed to Part V, since you are given the data needed on Moodle. Use the instructions here if you want to download your own data for a different location)

For this lab, we are going to use a new plugin (**SRTM Downloader plugin**) that is available within QGIS to download the tiles necessary DEM tiles for the study area. This dataset can also be downloaded directly from the USGS website. Note that you do have to create a login on USGS or NASA websites to be able to download the available dataset for free.

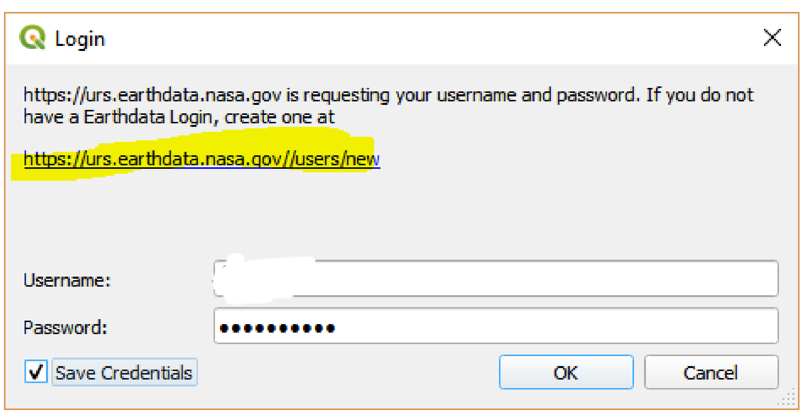
1. Click **Plugins → SRTM-Downloader → SRTM Downloader** option from the menu



2. The plugin window opens with few options. First, we need to know the boundaries of the study area. You can enter the coordinates in either Latitude / Longitude (degrees) or in UTM coordinates. For this exercise, use the following lat-long values. Alternately, you can also make sure you have zoomed in to appropriate level so that all of the study area is visible and then under **SRTM Downloader**, click **Set Canvas Extent** as the option. The program will automatically fetch the coordinates for the top, bottom, left, and right boundaries of the map under view. You can also manually adjust these if necessary.



3. When you click **Download**, you will notice a pop-up window asking you to sign into your account to be able to download the data. Click the link to create a new user profile and get a login. Once successfully created your account and verified it through email, you can then enter the login and password here. Click **OK** when done.

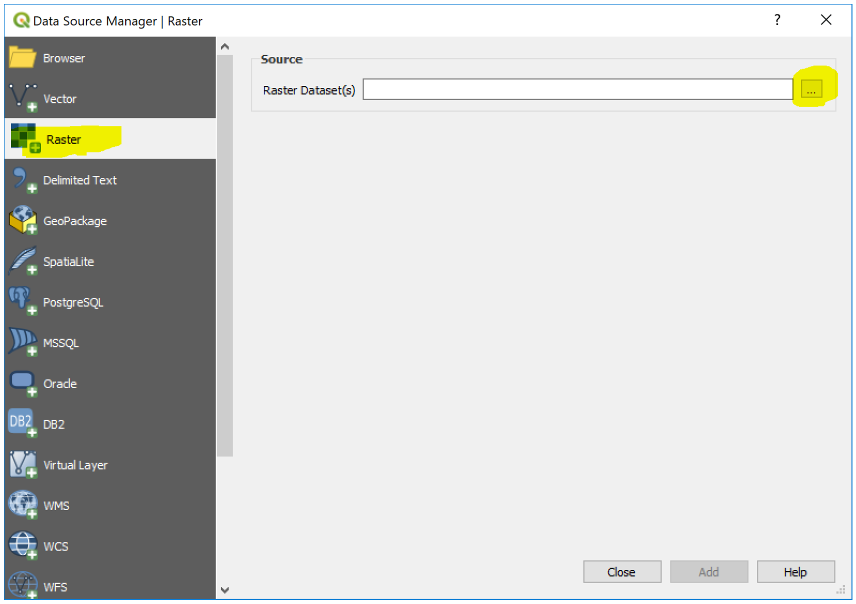


Program will automatically check the extent and download the tiles that are necessary for the study area. Sometimes you may have to manually adjust the latitude and longitude extents to get the coverage. When the program downloads, it will automatically add to your project (unless you unchecked the **Load Images to QGIS** box next to **Download** button.

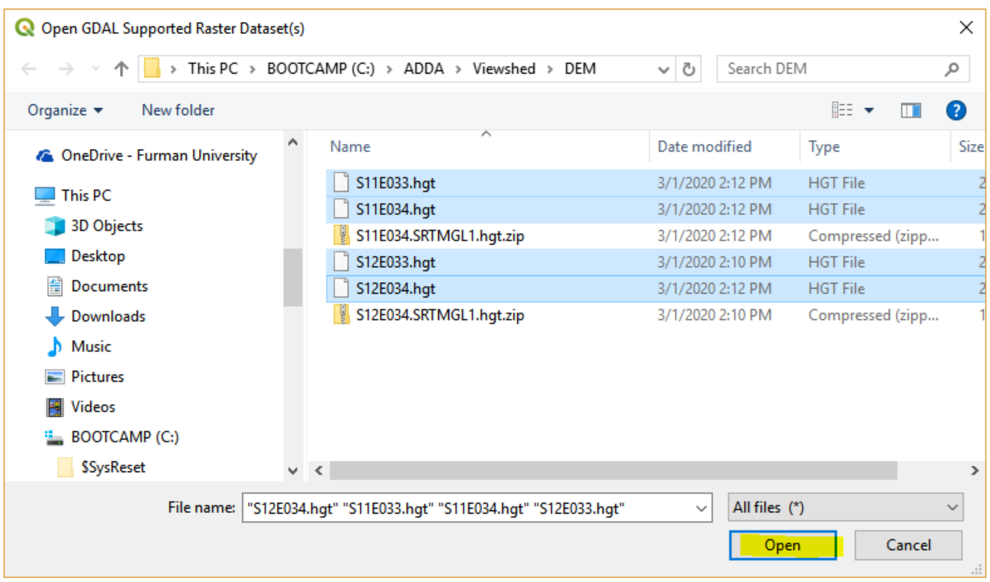
Now that the raster DEM dataset tiles are downloaded and added to your layers on QGIS, you can view it to confirm it covers your study area. It should be a gray shaded layer. Each pixel value corresponds to the average elevation over the area representing the pixel. Often you will have more than one tile to get the coverage necessary. You will have to stitch them together to create a seamless dataset for further analysis. The following section will tell you how you stitch the raster tiles together.

Part V - DEM Mosaic Creation and Re-projection:

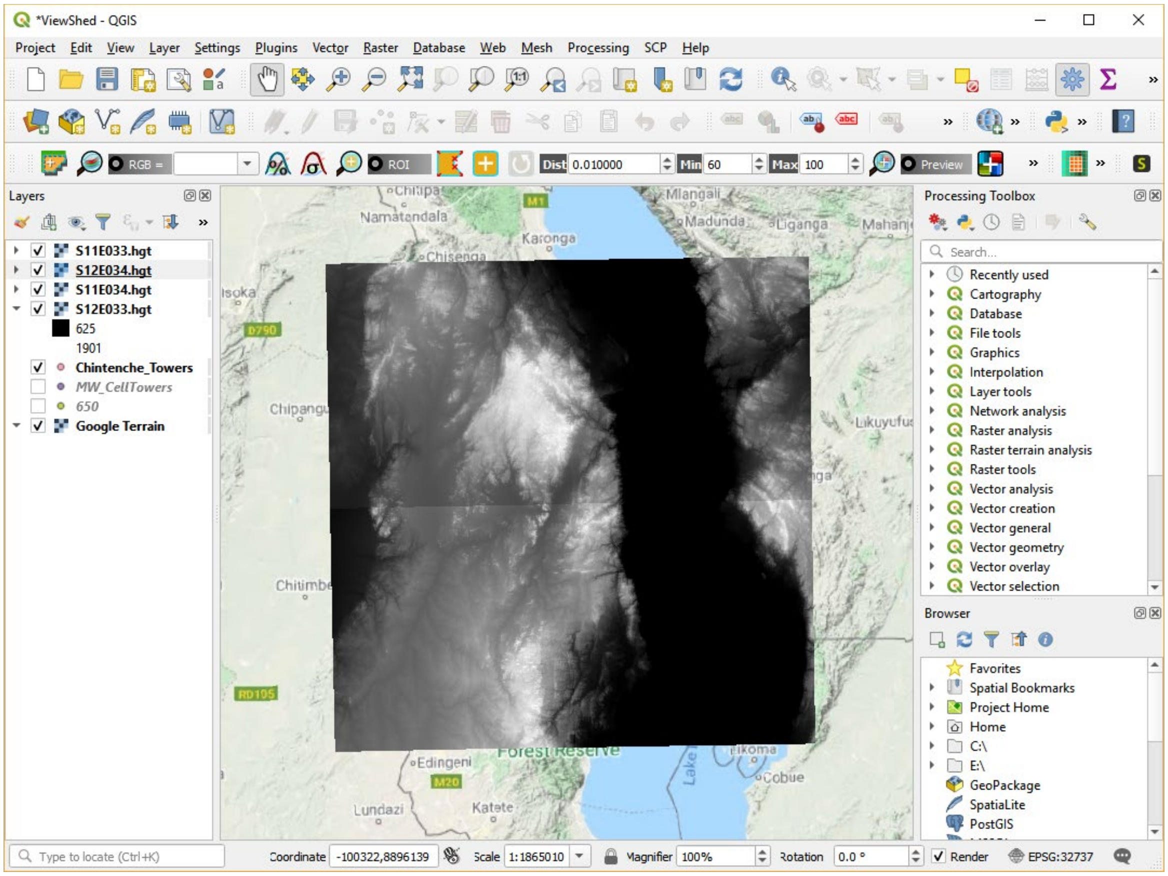
1. Add the four DEM tiles in your lab folder. From QGIS **Menu**, select **Layer → Add Layer → Add Raster Layer**



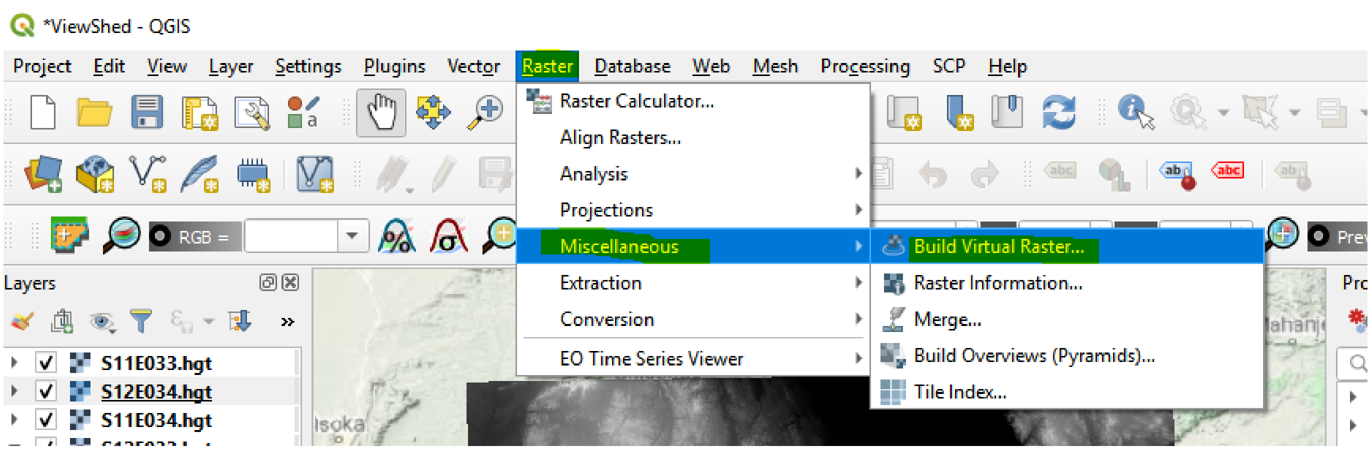
2. Navigate to the lab folder where you have extracted and saved your DEM data for the project.



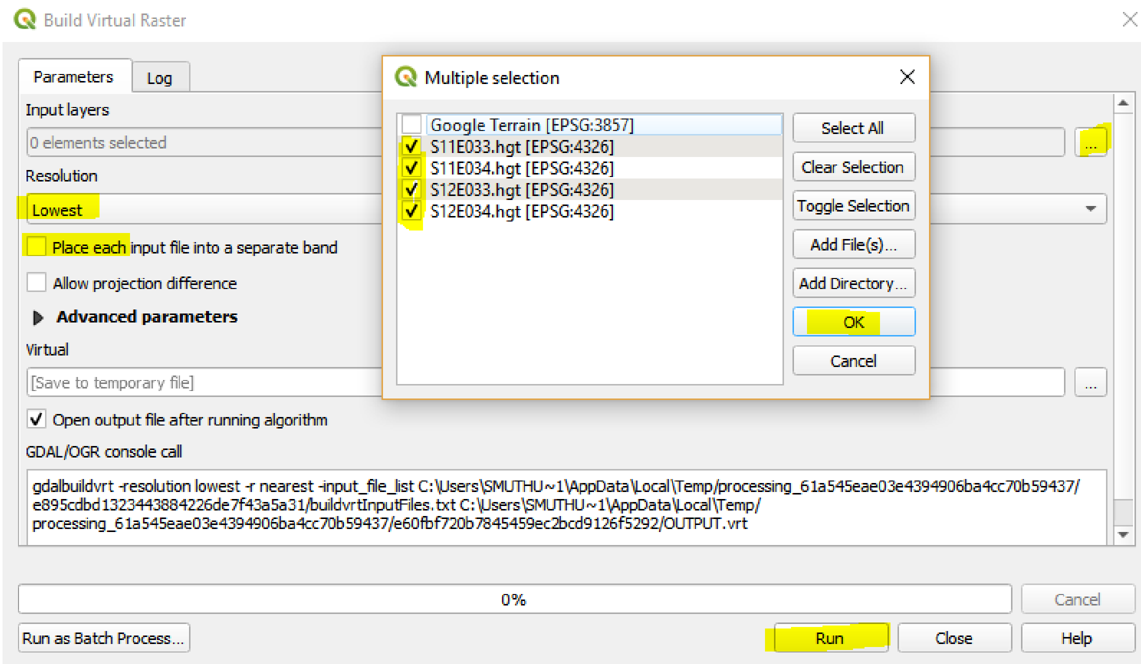
3. Select the DEM tiles and click **OPEN**
4. Click **Add** in the **Data Source Manager** window. When the data is added to the project window, you can close the Data Source Manager window.
5. From **Project Menu**, click **Save**.
6. The tile boundaries are clearly visible because the gray coloring is done based on highest and lowest elevation values observed within each tile. We will fix it when we combine the tiles to create one single DEM file.
7. Right click on one of the DEM layers and click Properties. In the **Layer Properties** window, click on **Source** tab. You will notice the projection is set to **WGS 84 (EPSG:4326)**, which means it is displayed using Latitude-Longitude, which is one of the standard geographic coordinate systems. It is not ideal since we want to be able to make measurements in units such as meters or kilometers, and not angular measurements in decimal degrees.



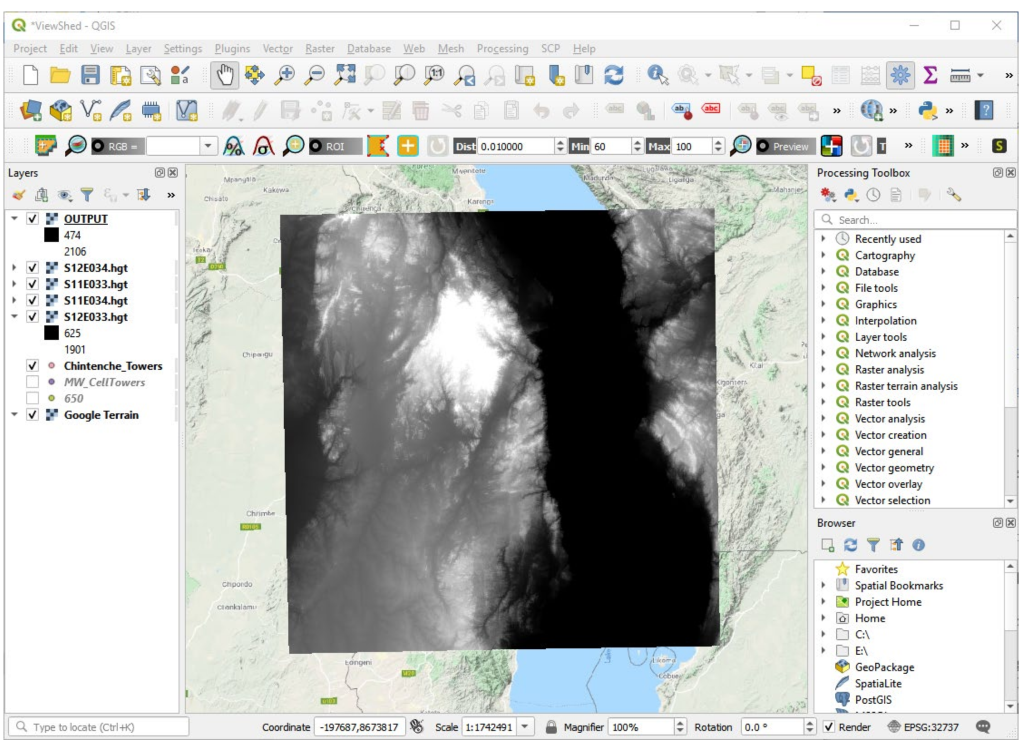
8. We will first create a **virtual mosaic,** which is a way of stitching the DEM tiles together to create one seamless DEM file. After creating a mosaic file, we will have to re-project the data from ***geographic coordinate system (lat-long)*** to a ***projected coordinate system***.
9. From the Menu, click **Raster → Miscellaneous → Build Virtual Raster**



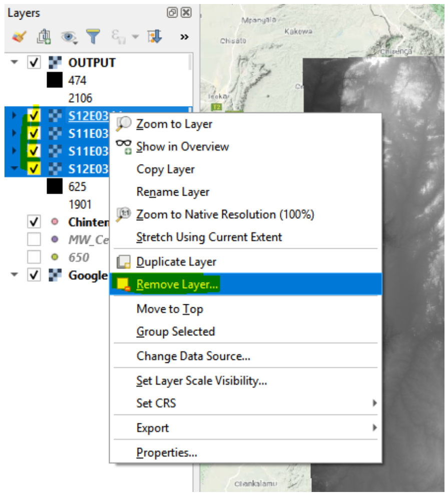
10. Build Virtual Raster window opens



11. On the Build Virtual Raster window, under **Input** Layers, click folder icon at the end to select and add all input raster tiles.
12. We Under **Resolution**, select **Lowest** resolution. In this case, it is irrelevant but if your tiles have different resolution, then you should always pick lowest. You can resample a higher resolution pixel and create a lower resolution pixel, but the opposite is not good.
13. Disable **Place each input file into a separate band** option (also called as **Layer Stack**) since we are stitching all layers to create one single layer. Layer stack will be useful if you are combining different wavelength bands of a satellite data into one single file.
14. We will let the program save the output file to a temporary folder (default), so you do not need to change it for this step.
15. Click **Run** to build the virtual raster
16. The algorithm runs in the background and produces the output, which is automatically added to the project window.



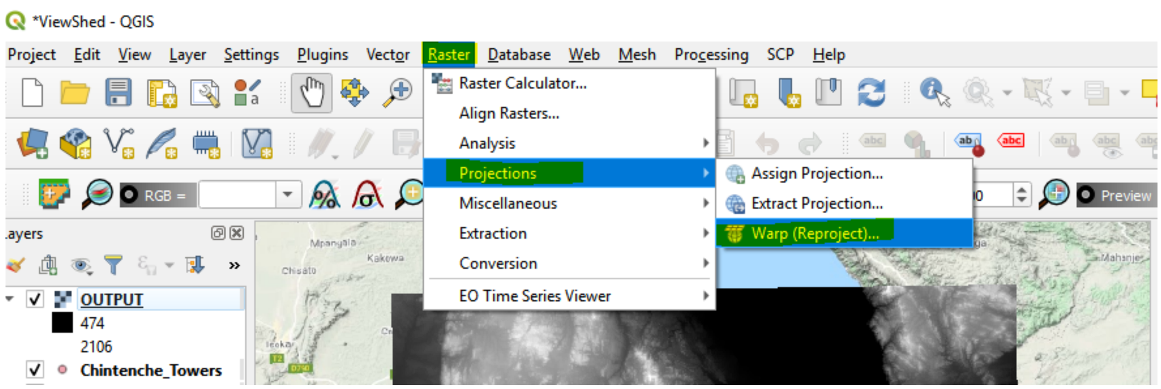
17. Since we have a single file showing all the tiles together, we can remove the individual tiles from the project area by right clicking and selecting Remove. Remember, we are note deleting them permanently from the computer. They are just bring removed from our project window.



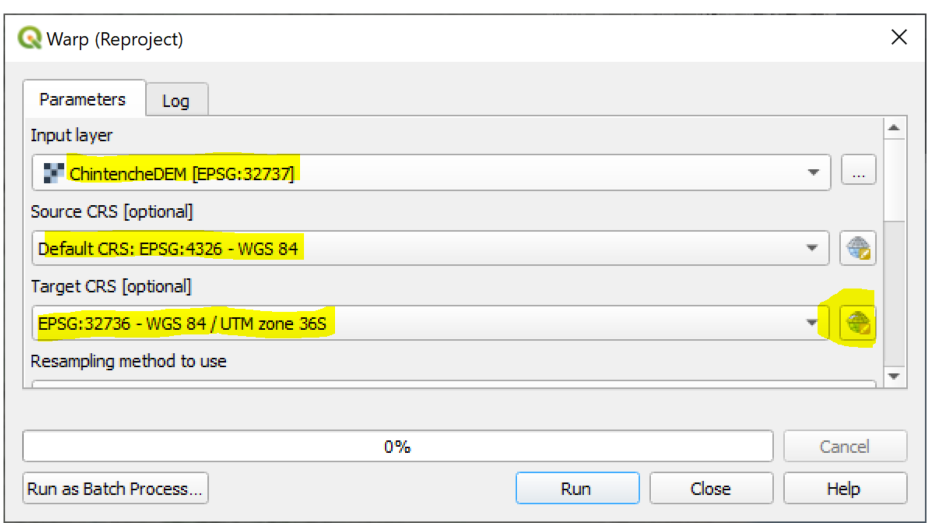
18. Next, we will re-project the virtual tiled layer so that we can use it for watershed delineation.

Re-projecting the Data

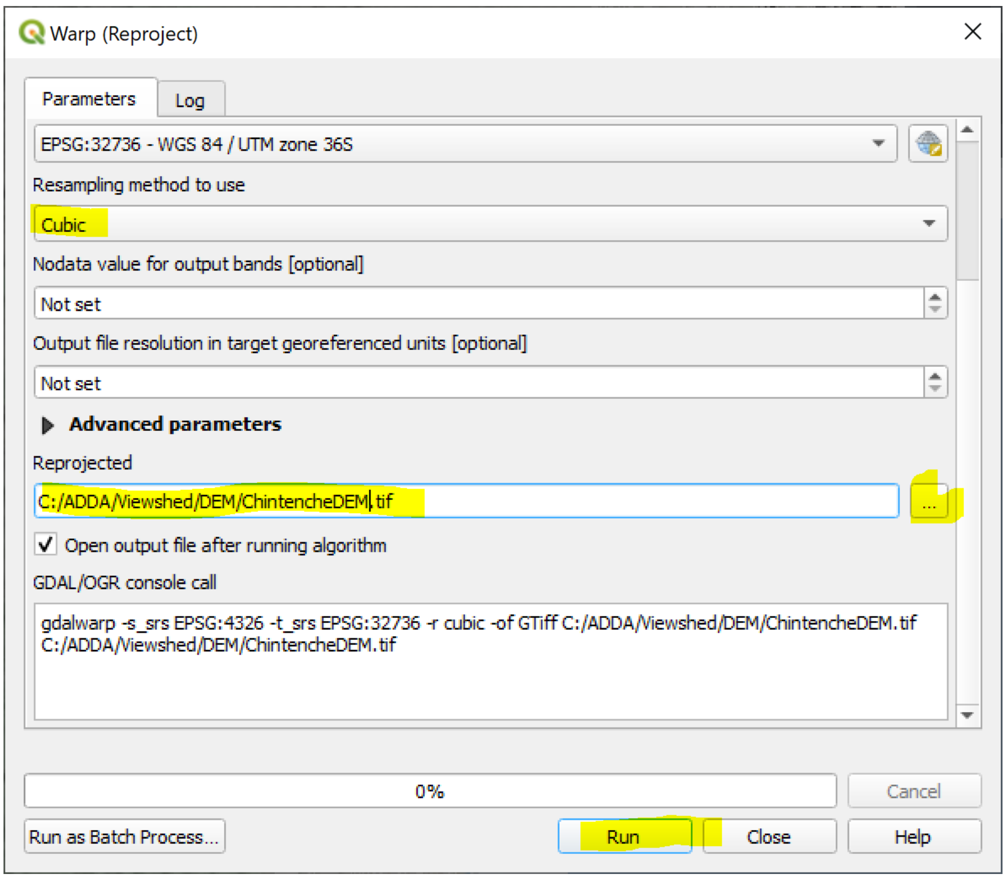
1. From the menu, click **Raster → Projections → Warp (reproject)**



2. The Raster **Projection box (Wrap)** will open.
3. Under Input layer, pick the virtual mosaic that was just created.
4. Source CRS should be automatically selected - in this case to be EPSG:4326 – WGS 84
5. Under Target CRS, click on the small globe icon (coordinate reference selector located to the right of the box.



6. A new window to help define the new projection and coordinate system opens.
7. Type **32736** under **Filter** box. This is the reference number for UTM projection for this part of South Africa (This number can be identified from http://spatialreference.org).
8. It should bring the correct information for the UTM projection for this part of South Africa. Select **WGS 84 / UTM Zone 36S**
9. Under **Resampling Method to Use**, select **Cubic.** For any raster data that represents a spatially continuous variable, such as Elevation in this case, **Cubic** convolution or **bilinear interpolation** method is more appropriate because the resulting data will be smoother without too many artifacts. Remember that all resampling procedures result in creation of new file and it modifies the original dataset. You should learn more about the implications of this for your specific use case.
10. Under **Reprojected** option, enter the output file name **ChintencheDEM.tif** (make sure to select Tif file format under **Save As Type**) under your project folder.



11. Click **Run** button to complete projection. Re-projected data will be added to your project when completed.
12. Now we can remove the virtual DEM mosaic (**OUTPUT** under the list of layers**)** we created earlier by right clicking the layer name and selecting **Remove**
13. Save your project now (Click **Project → Save**)

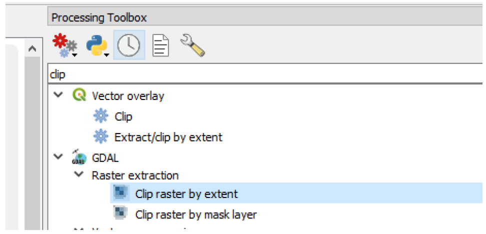
Part VI - Clip the DEM for the Study Area:

Viewshed analysis is a time-consuming algorithm that could take a lot of time if your input data contains too many points or if your DEM covers much larger area than necessary. It is wise to clip your DEM data to represent only the area of interest, considering the distance range that is of interest. Keeping the input file area to just what you need will expedite the time to process. In the next step, you will clip the data to a smaller extent.

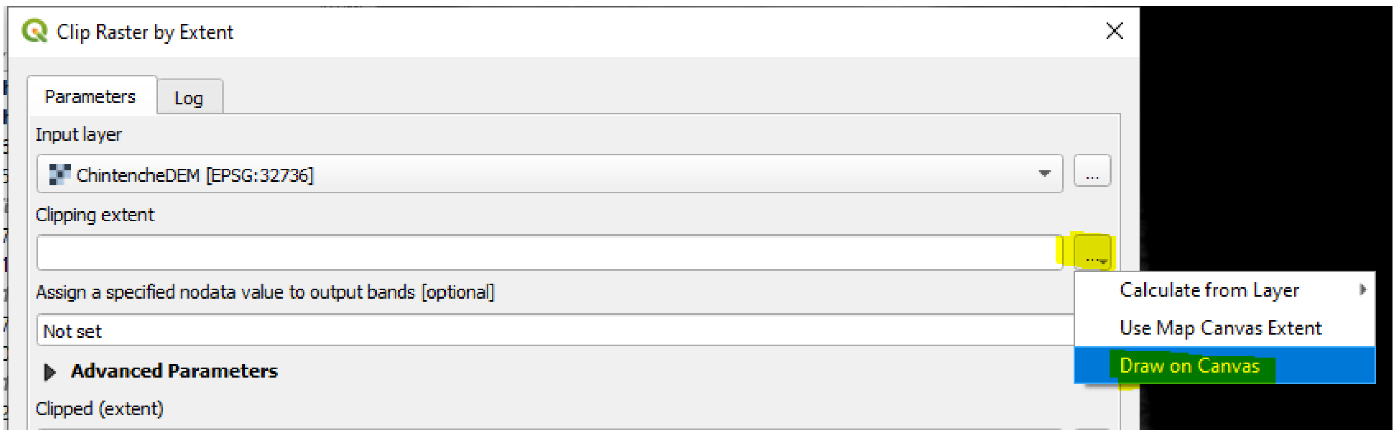
1. Before we start clipping the dataset, we have to make sure the QGIS Project coordinate system are set to be same as the data we are using, which should be **WGS 84 / UTM Zone 36S.** Check the right bottom corner of QGIS window and look for EPSG number. It should be set to **EPSG:32736**. This is important because the tools that are used to

extract coordinates for clipping would use the coordinate system specified for the QGIS project. If it is different from your data project, then clip function would not succeed.

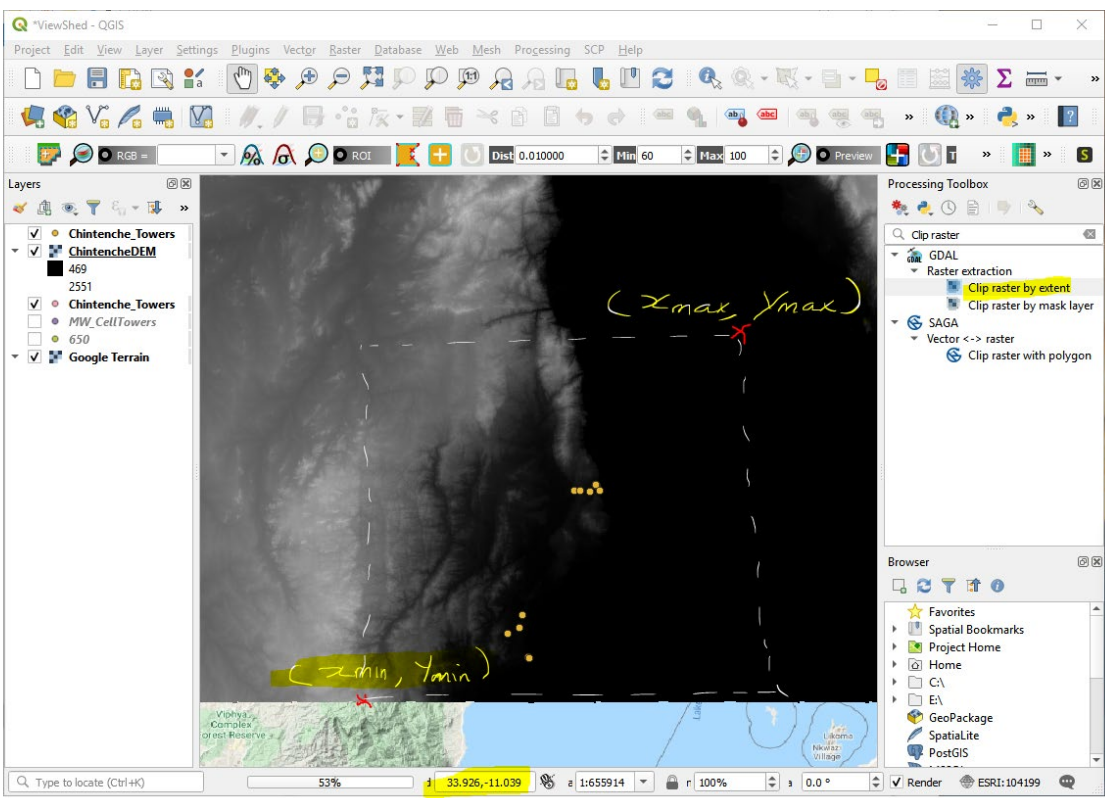
2. Under **Processing Toolbox** panel, search for **Clip Raster by Extent** tool



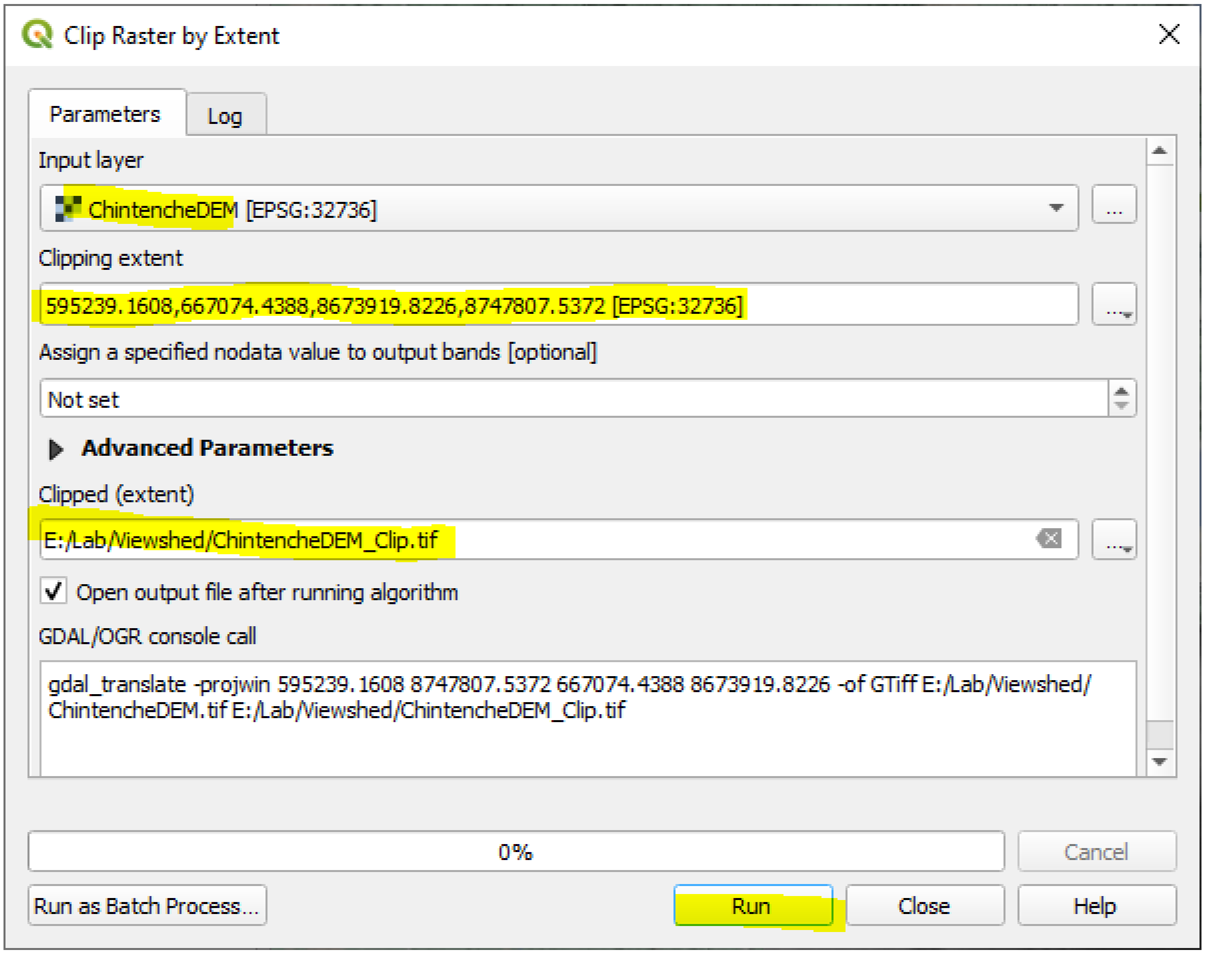
3. For the input layer, select your reprojected layer. For clipping extent, click on the button next to the field and select **Draw on** Canvas as the method to select clipping extent.



Click the area shown by the dotted line in the following diagram.



4. Under **Clipped (Extent)** option, select the output file button and choose **File Save As.** Then name your file **ChintencheDEMClip** and make sure it is saved as a **tif** file in your project folder.



5. Click **Run**. The extracted DEM file will be displayed on your screen on top of your larger DEM. Now, you can remove the virtual DEM that covers larger area from your project. Save project! We will use this dataset in our next lab.

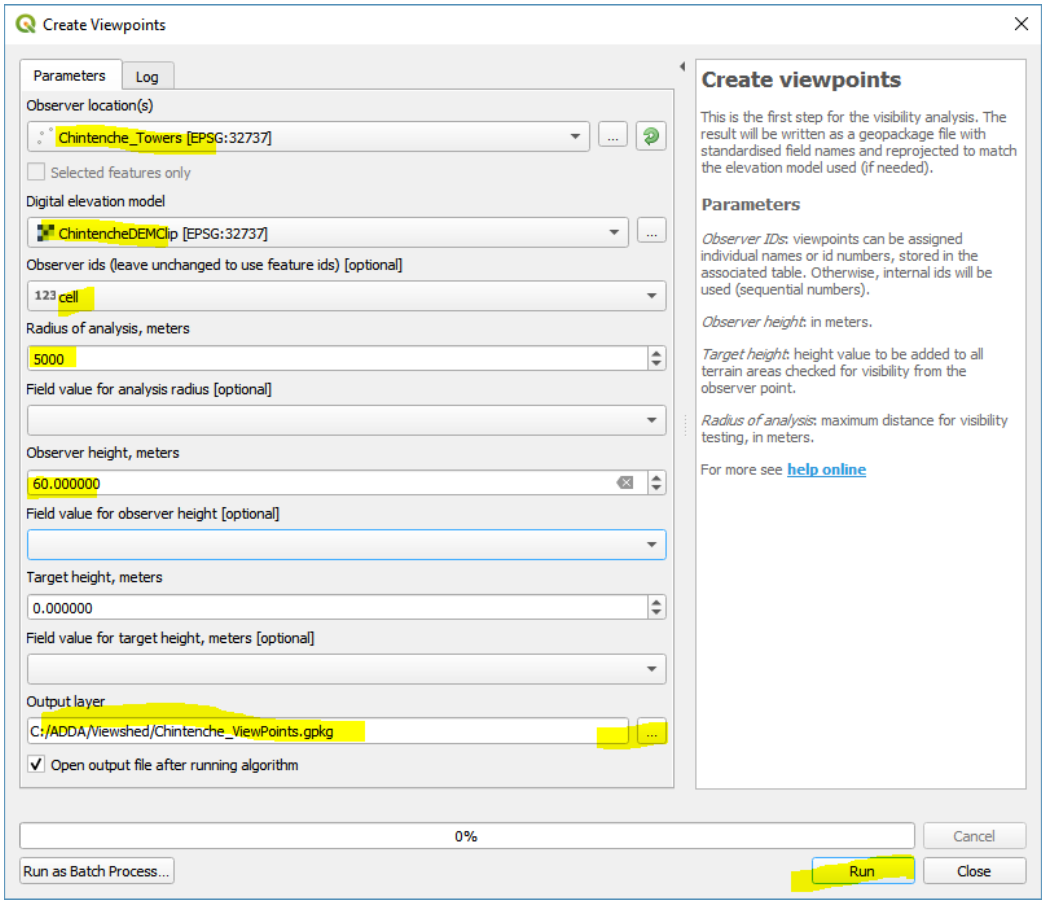
Part VII - Viewshed Analysis

Viewshed analysis constructs a raster image to show what is and is not visible from a specified point or a set of points. Because viewshed analysis is based on a line of sight, the reciprocal also holds. That is, if a location is visible from a particular point, it follows that the point is visible from that location. The objective of this exercise is to determine the areas with strong cell signal from multiple towers to the area where signal doesn't reach the cell subscriber from even a single cell tower. If the locations of the cell towers themselves are used as the points for the analysis, then the result will show how far the cell tower can reach what is visible from that set of points or, in other words, the areas that will be covered by cell tower signal. Remember that we are making a lot of assumptions and estimates here.

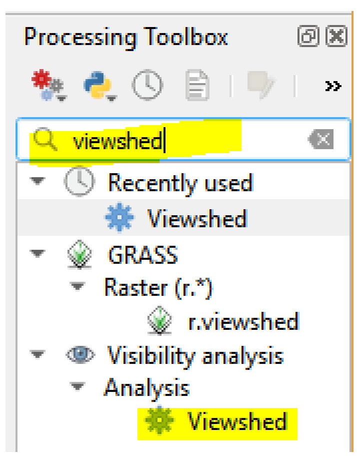
We now have a clipped DEM data representing the terrain, and a shape file containing the cell towers for the study area. Our next step is to prepare the cell towers and make them compatible with the data analysis methods.

1. To prepare the tower data, we will use a tool called "Create Viewpoints" under **Processing Toolbox → Visibility Analysis → Create Viewpoints** option.
2. In the window that opens, select the Chintenche towers that was created earlier, select the clipped DEM file that we created earlier, set 5000 meters (5 kilometers) as the radius of analysis, and the cell towers height is set at 60 m (200 feet).
    a. In reality, cell towers are all different. It is easy to take into account those differences and create a more accurate representation. If you have specific height and range information for each of these cell towers, you could include those values as part of the attribute table in the original file. If such is the case, you can leave the radius and observer height fields blank and pick the field that contains the values under **Field Value for Analysis Radius**, and **Field Value for Target Height**.

3. Make sure to assign a file name for the output file and clearly indicate which folder it should be saved under.

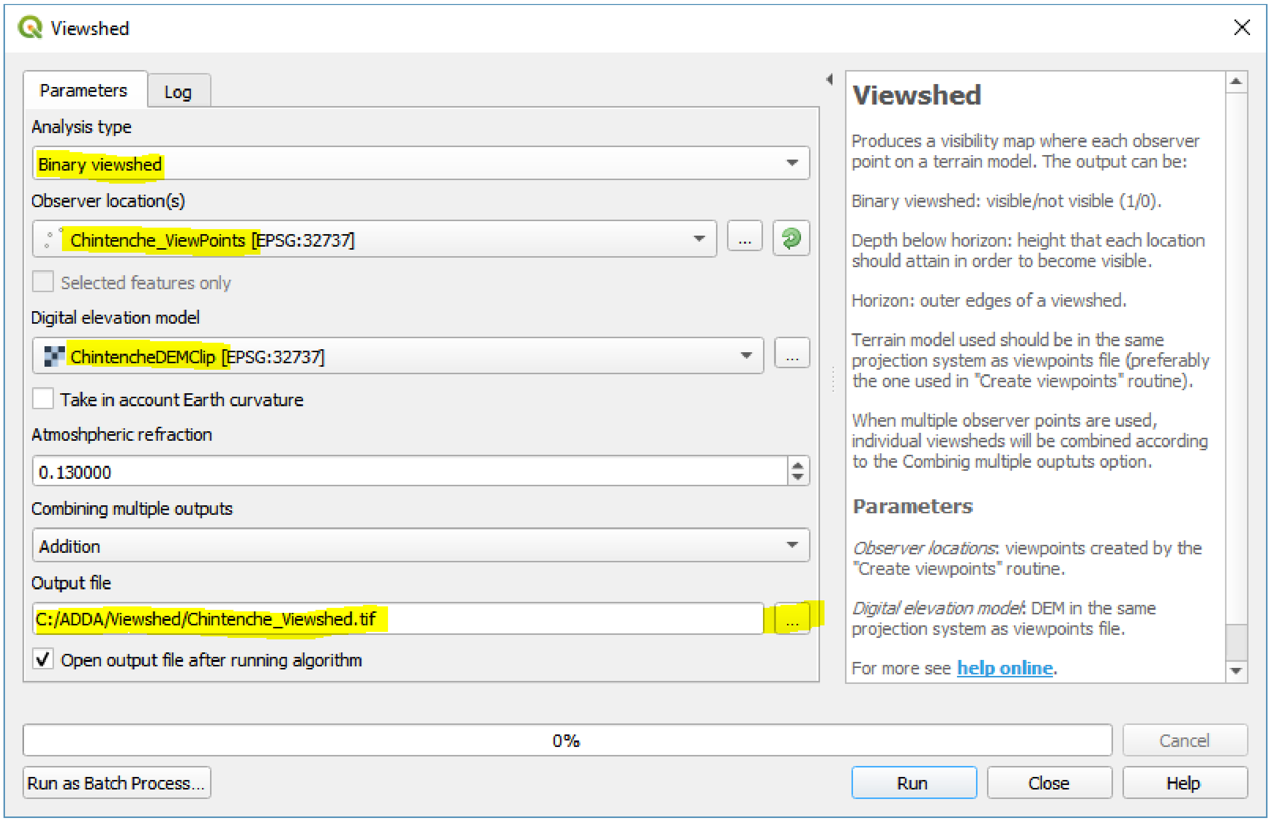


4. If the process is completed successfully, you should see a new layer with the name Chintenche_Viewpoints added to the project. <u>Note that this is not an ESRI shape file</u>. It is saved by the algorithm in the form of a **geopackage**, which is compatible with many GIS software.
5. Open the attribute table for this new file and see how it is different from our original cell tower data attribute.
6. Next, we will run the **Viewshed** analysis. Under **Processing Toolbox,** search for **Viewshed**.



7. Under Viewshed window, select **Binary Viewshed** as the analysis type. Areas that have direct line of sight with cell tower will be given 1 and all other areas will be given 0.
8. Select the **Observer Locations,** which should be the geopackage file that was created; Digital Elevation Model, which should be the Clipped DEM file; and select **Addition** under **Combining Multiple Outputs** option. This means, when multiple towers are visible from one location, those pixels values will tell you how many towers are visible by adding the number of towers.

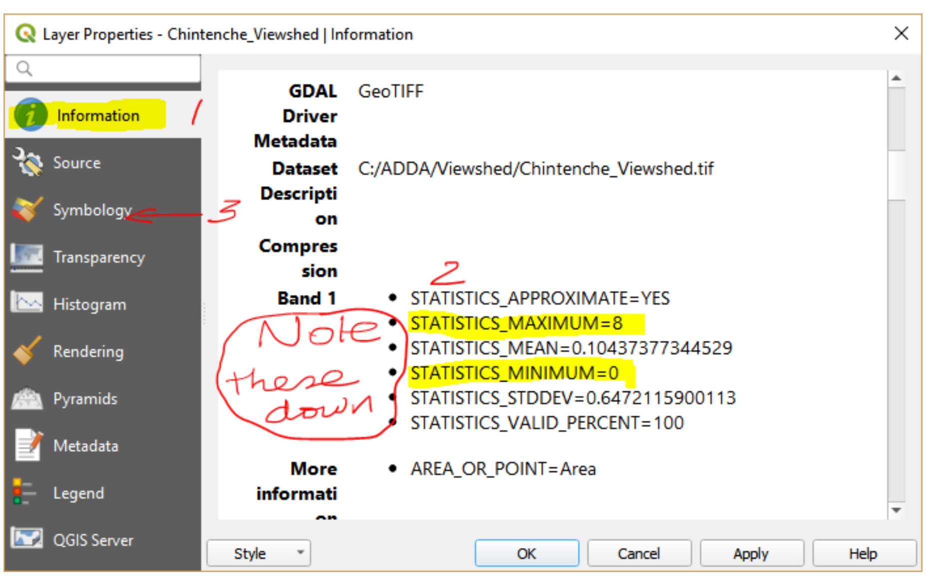
9. Make sure to provide a name and location for the output file. This is the file we really need for making maps or visual representations.
10. Click **Run.** If the process completed successfully, you will see the output showing the range of visibility by location. Study the output and make note of the patterns in area with visibility vs non-visibility.



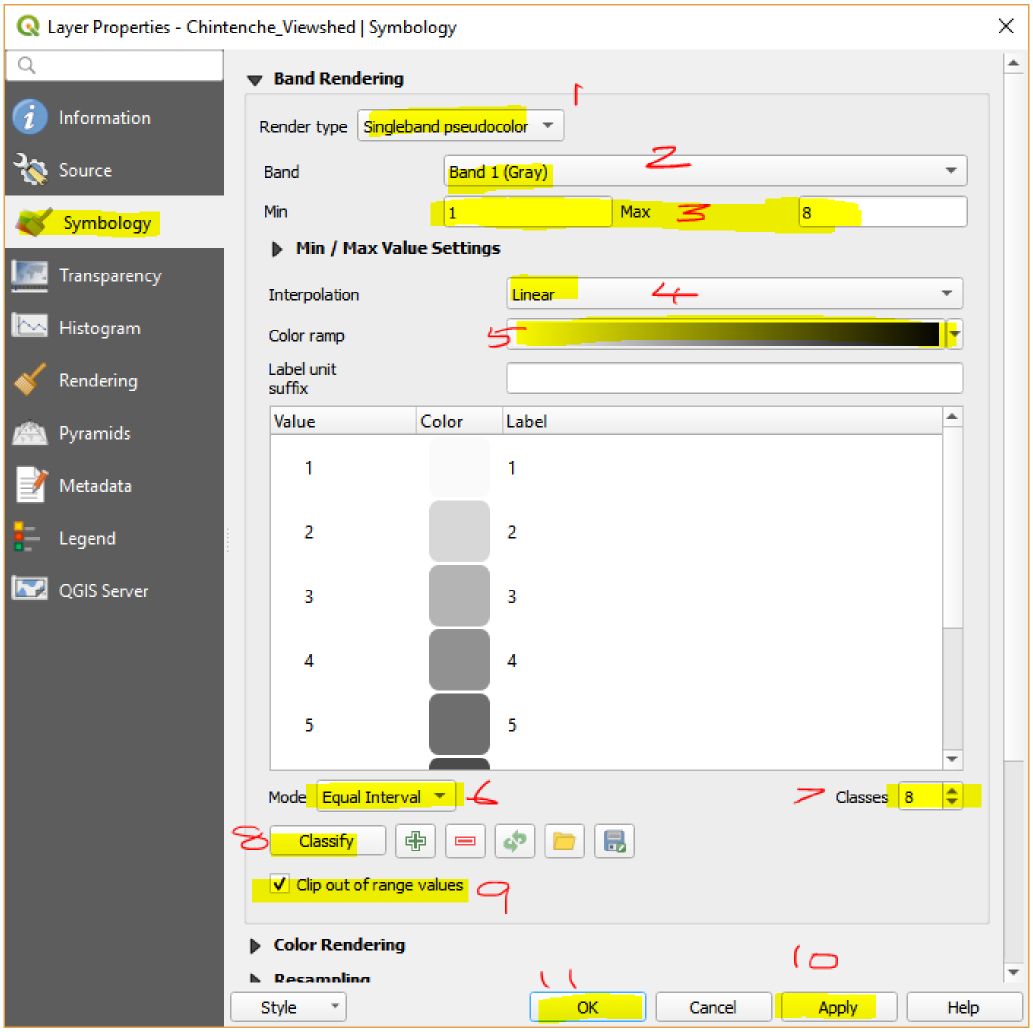
Part Viii - Symbolizing the Output and Preparation for Map Making:

Visibility analysis results in gray scale by themselves are not attractive to include in a report or presentation. We need to make it look nice and put the location in the context. This means, we should change how it is represented and use proper symbology for cell tower locations also.

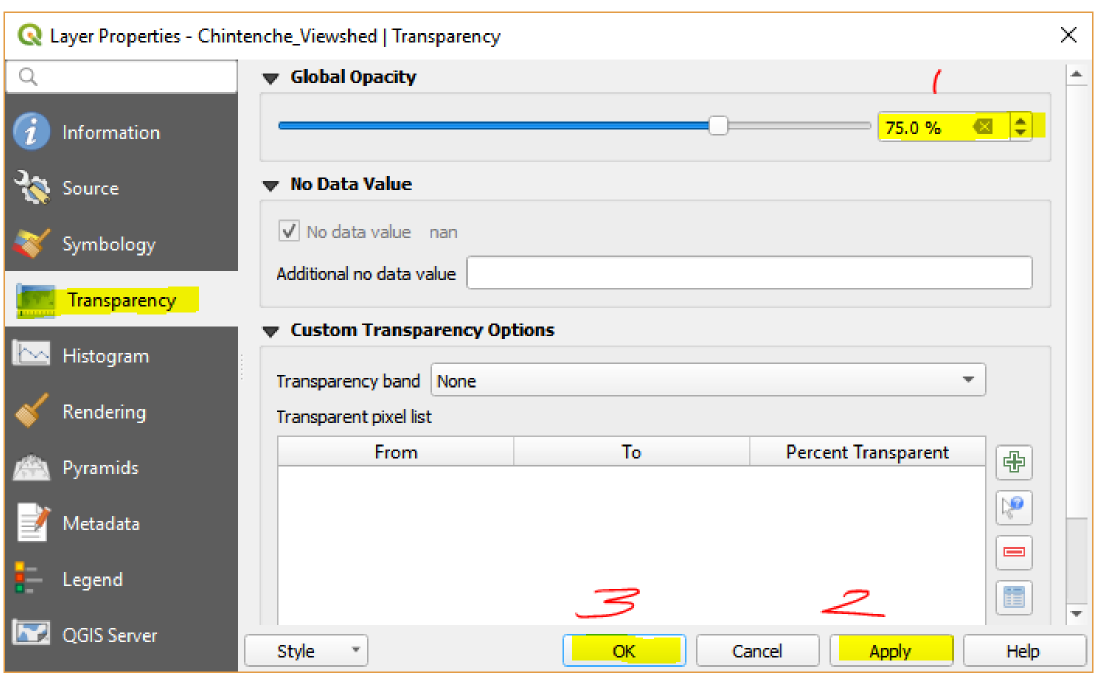
1. **Right-click** on the viewshed result file under your **Layers**. Select **Properties** link.
2. In the **Layer Properties** window, look under **Information**. Basic statistics of the results layer is displayed – you might have to scroll down to get to this. Note down the minimum and maximum numbers here.



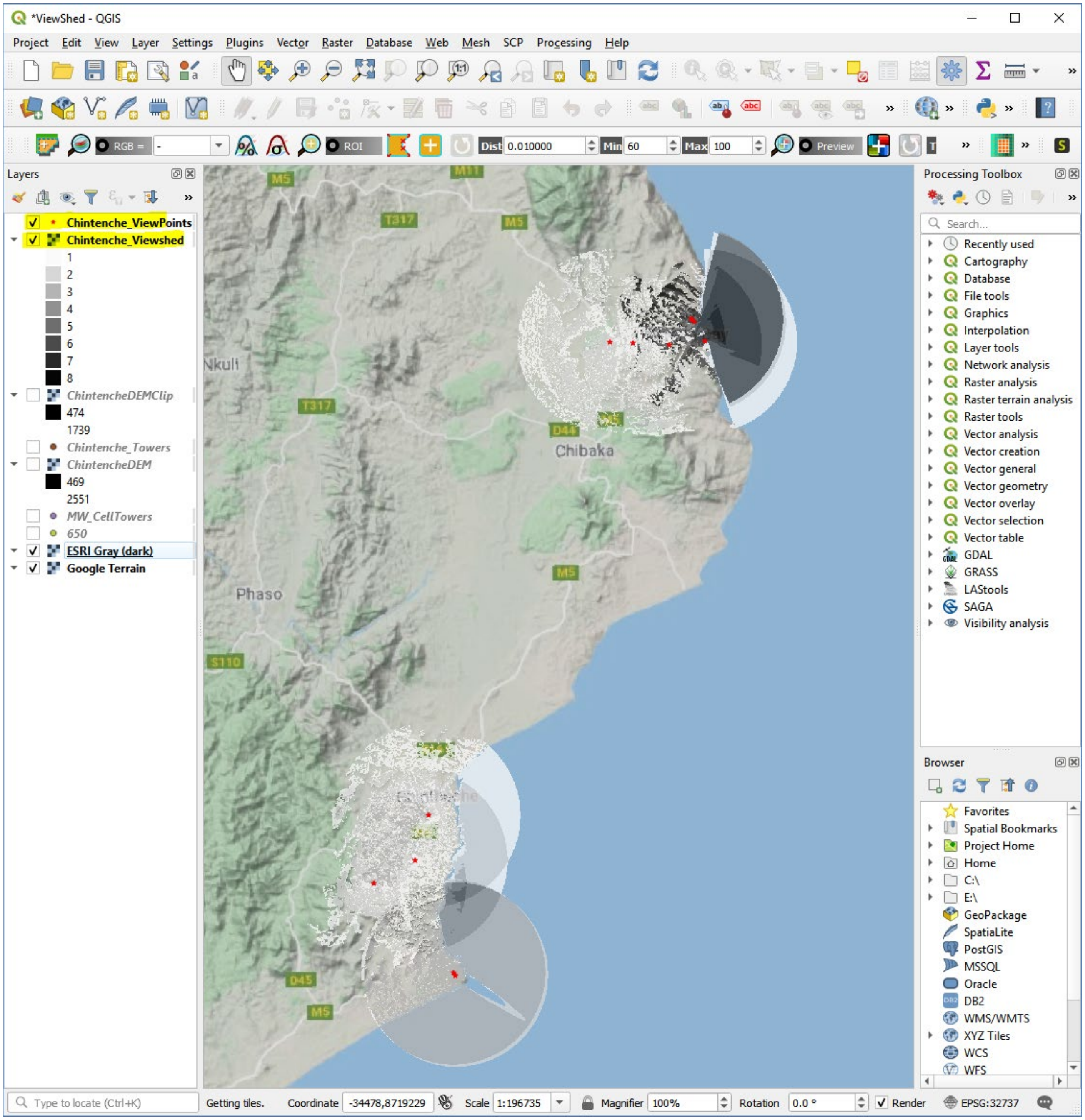
3. Click on **Symbology** tab and make the following changes (shown in the image in sequence). Under #3, enter 1 for minimum and what ever value you had under **maximum** under layer properties information.



4. Click on **Transparency** tab. Change transparency to 75%. Click **Apply** and if you are happy with it, click **OK.** You can make changes to level of transparency as needed.



5. The final image should look something similar to what is shown in the image below.



Zoom close to the two towns and observe how the cell signal reception (as indicated by higher number or darker gray) varies across the town. In Chintenche (northern town), what makes some of the highest number of tower reception happens east of the town, over water?

6. Make a final map of the results using your map making skills. Remember to include all the map elements including title, scale, north arrow, legend, your name and data, and a brief description.
7. Write a couple of paragraphs of reflection on your experience learning the new skills through this lab. What were your expectations when you started and did the lab meet your expectations? Can you think of an application for this analysis method in a different setting?

Congratulations! You just completed your very first viewshed analysis.