A summary tutorial on open Source GIS-based Lake Basin Delineation Procedure

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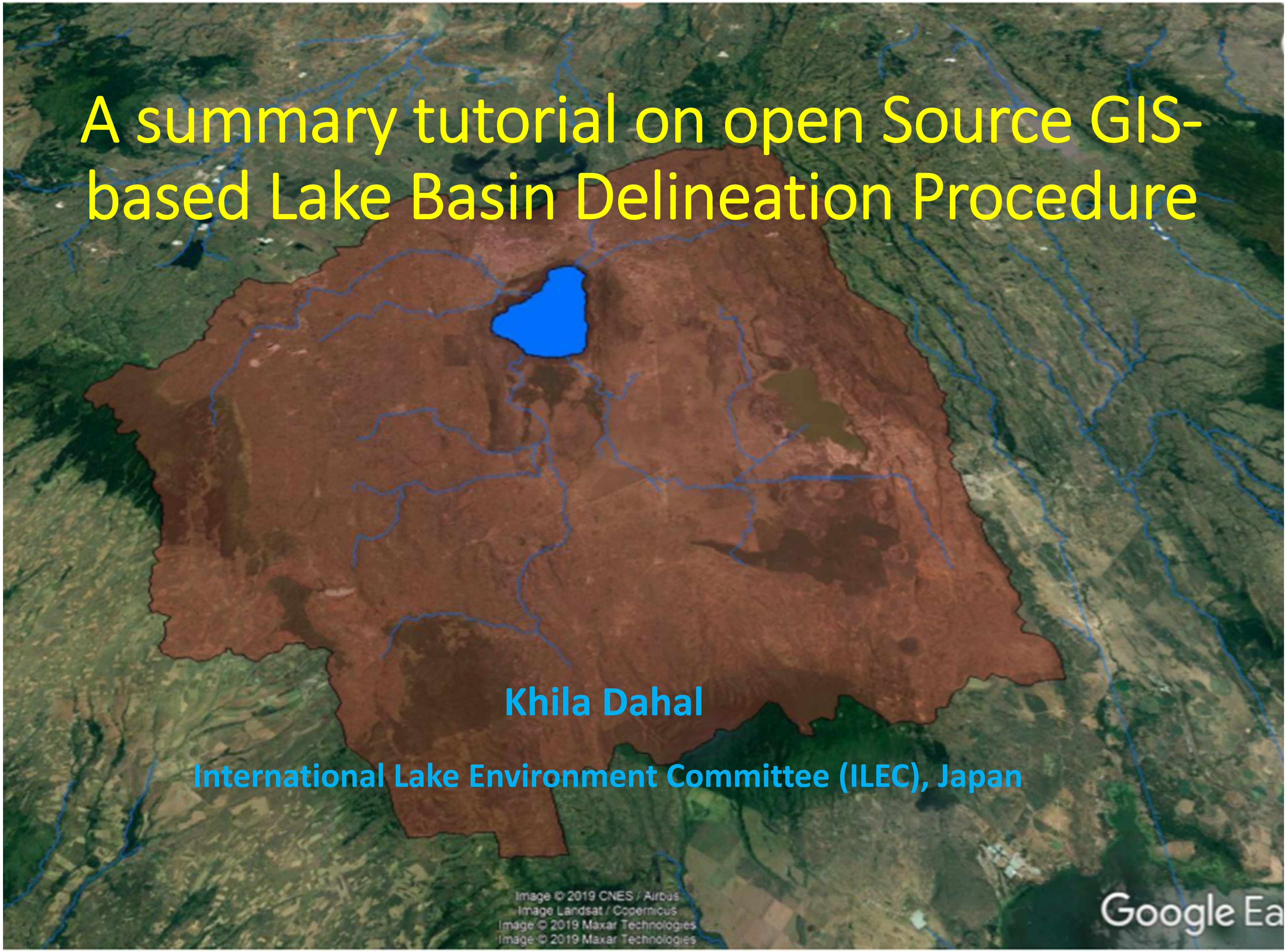


1. Introduction

Determination of an accurate areal extent of a lake's watershed is important for making any threat assessment, designing a management plan, conducting a basin-wide hydrological study, or making resource evaluation, thus making the basin delineation a very first and a vital step in that direction.

The purpose of this document is to describe and illustrate a detailed <u>GIS-based procedure (Figure 1)</u> to delineate a lake drainage basin using digital elevation model (DEM) data in a <u>freely available open source GIS</u> platform.

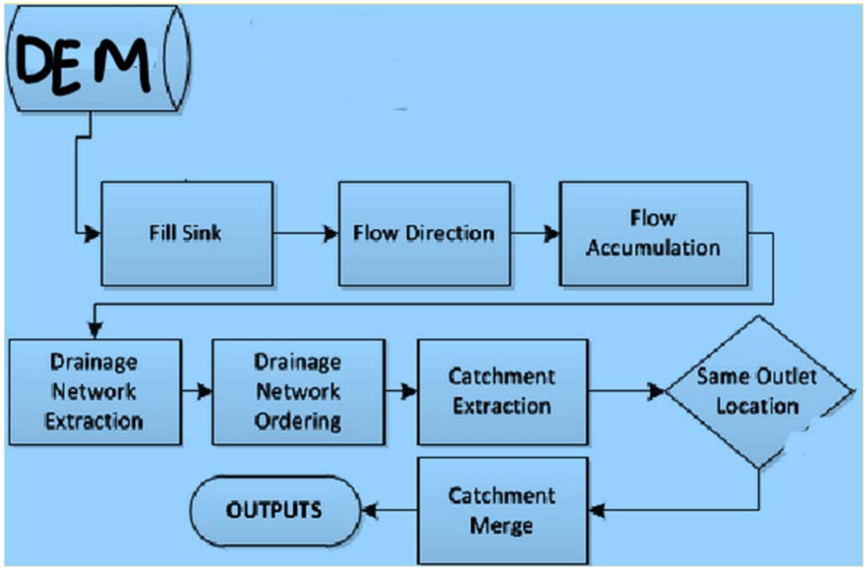


Figure 1: A generic lake/river basin delineation workflow (adapted from Anornu et al. 2012)

Introduction

Open source GIS software (unlike the proprietary counterparts such as ESRI's ArcGIS) and their source codes are freely available for public use (i.e. are free to download, modify and use as needed).

There are multiple open source GIS platforms to choose. QGIS, GRASS, SAGA, GeoDa, DIVA-GIS and gVSIG are some commonly used open source Desktop GIS packages (Figure 2).

Figure 2: Examples of some open source Desktop GIS packages available on the web

Introduction

As each of these GIS packages have been developed with specific objectives, they have their own strengths and are more appropriate for certain purposes.

However, QGIS is comparatively more comprehensive, user-friendly, highly reliable (i.e. not buggy), faster in geo(processing), full of ample documentation, and with one of the largest GIS user-communities.

Moreover, it allows for the widest range of geoprocessing operations, consumes all GIS data types, comes with the most regular and timely updates, is treasured with an ever-growing number of native as well as user-developed plugins, and integrates external packages such as GRASS, GDAL and SAGA, thereby adding to the repository of available tools and operations.

Therefore, we will use QGIS to generate basin boundaries and stream networks in this tutorial.

Introduction

Required software: QGIS. It should be downloaded and installed in your machine. Version 3.14.15 is preferred for this tutorial purpose. But the latest is also OK.

Required Data: Lake (optional) and **elevation** data. Both datasets to be downloaded from the web.

NOTE: This tutorial accompanies two corresponding versions: a text tutorial (i.e. a pdf file) and a video tutorial, both on the ILEC website. This summary tutorial should be complemented by these detailed versions as needed.

2. Methodology

I. Creating a workspace to save initially obtained and output datasets.

Before starting to download the data, create a folder and subfolders. E.g. Lake and Elevation subfolders within the Basin_delineation folder in Documents (Figure 3). You can refer to Step 1.1.1 from the text tutorial or the corresponding part of the video tutorial for detail.

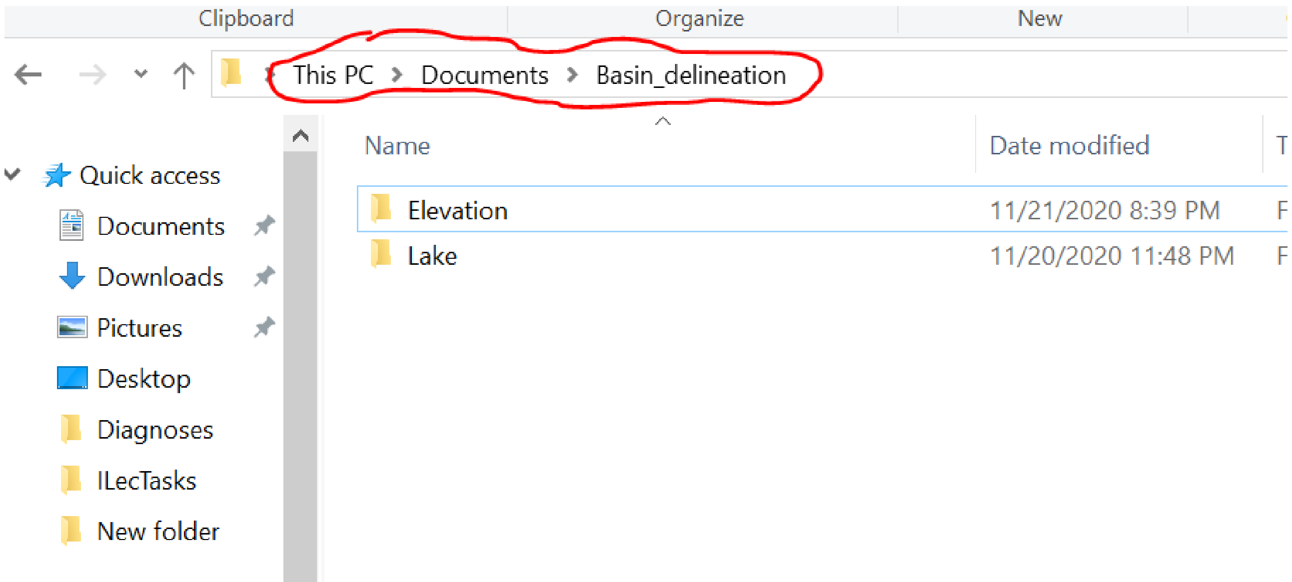


Figure 3: File explorer window showing the workspace named Basin_delineation

II. Choosing the lake of interest: For illustration purpose, Lake Volta, a West African Lake is selected (Figure 4). Downloading lake data is OPTIONAL as we use a basemap to locate the lake. But, if you are interested, you can download from GLWD website. Refer to steps 1.1.2 – 1.1.4 from the text tutorial for detail.

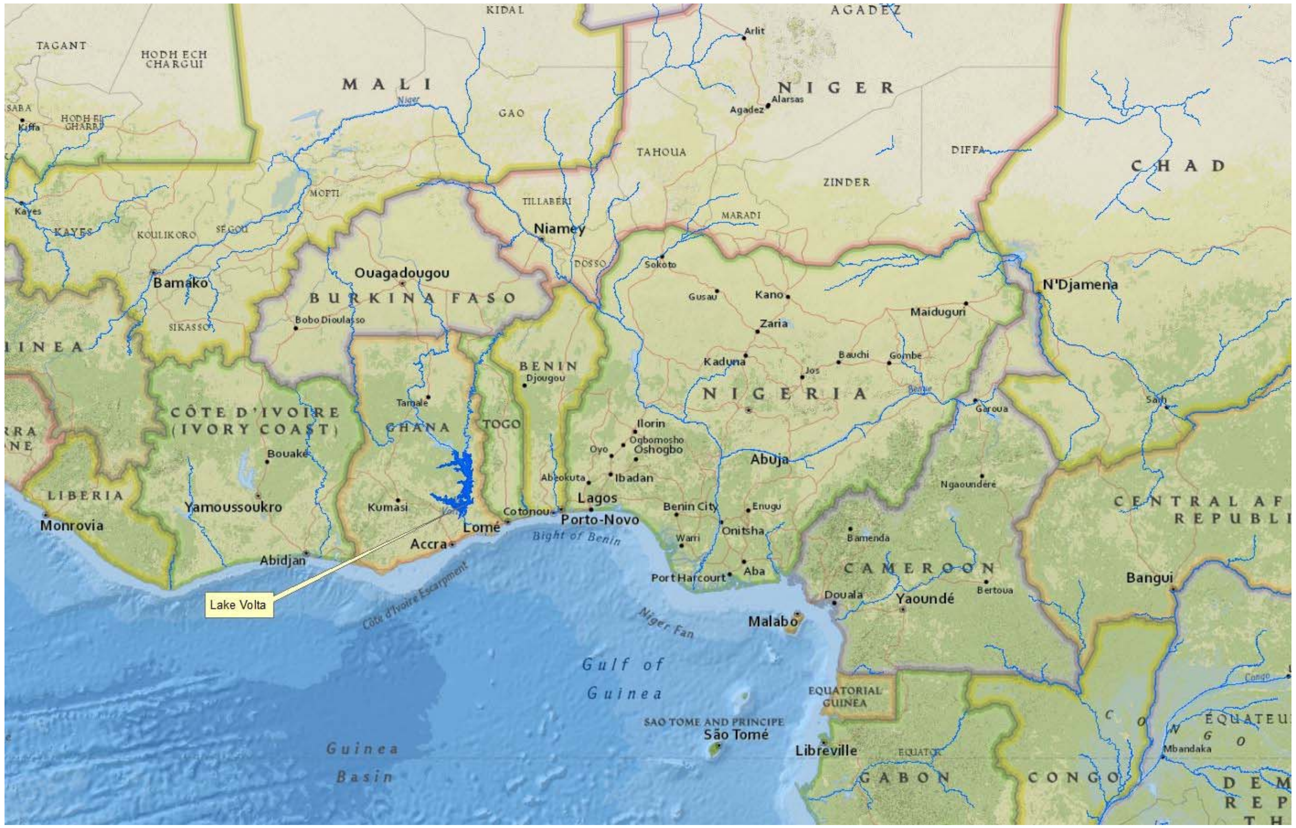


Figure 4: Location of Lake Volta over a basemap

III. Getting a DEM of the Lake Volta basin area.

There are different web and other sources of elevation data. But here, we download from USGS's Earth Explorer website. Go to the Earth Explorer webpage > log in > select the tentative basin area (Figure 5)) > select an appropriate elevation dataset (e.g. GMTED2010) > click Results tab. This outputs four DEM tiles.

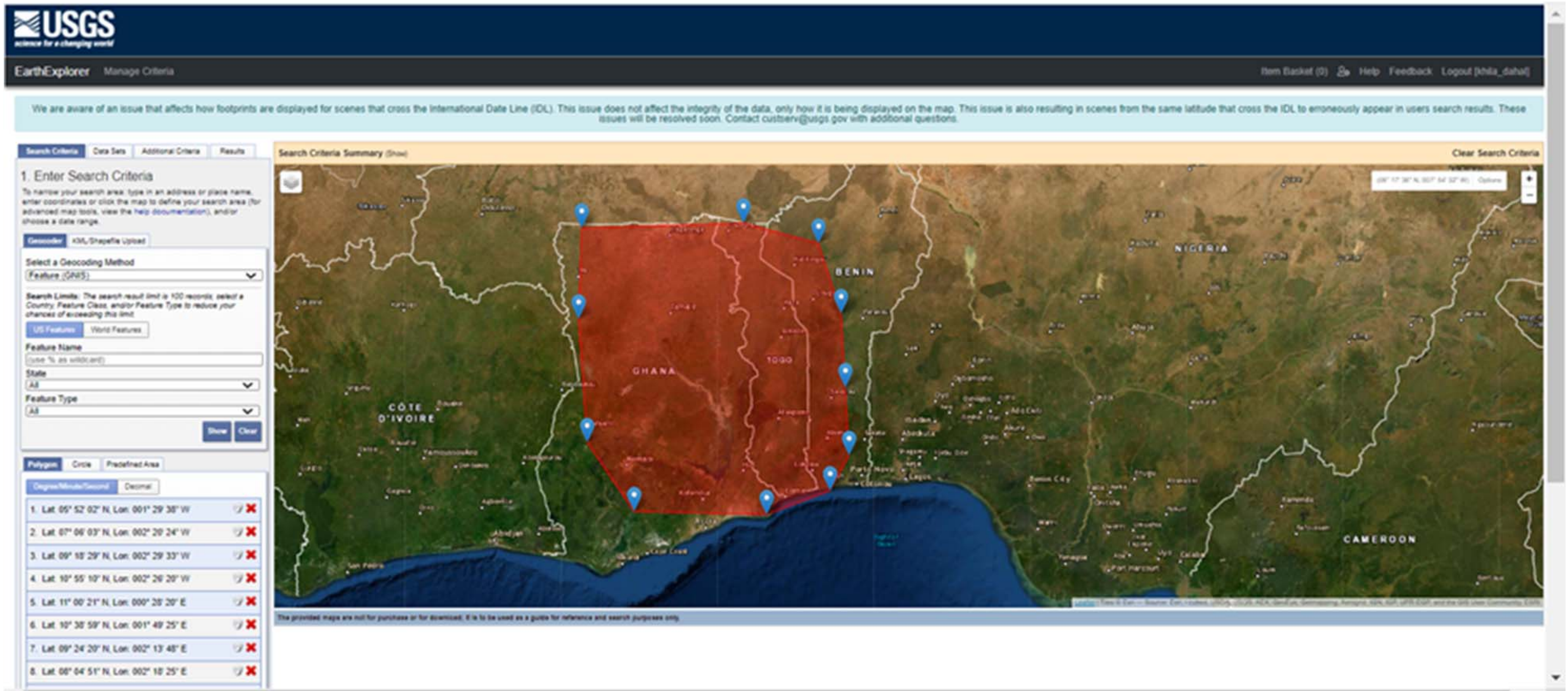


Figure 5: Tentative drainage area for Lake Volta

Download the four DEM tiles (shown on the left side of Figure 6) one by one and save them in your workspace (e.g. ‘Elevation’ folder). For convenience of processing select the coarsest option (watch the corresponding video tutorial for details if needed). Then, unzip the data-files.

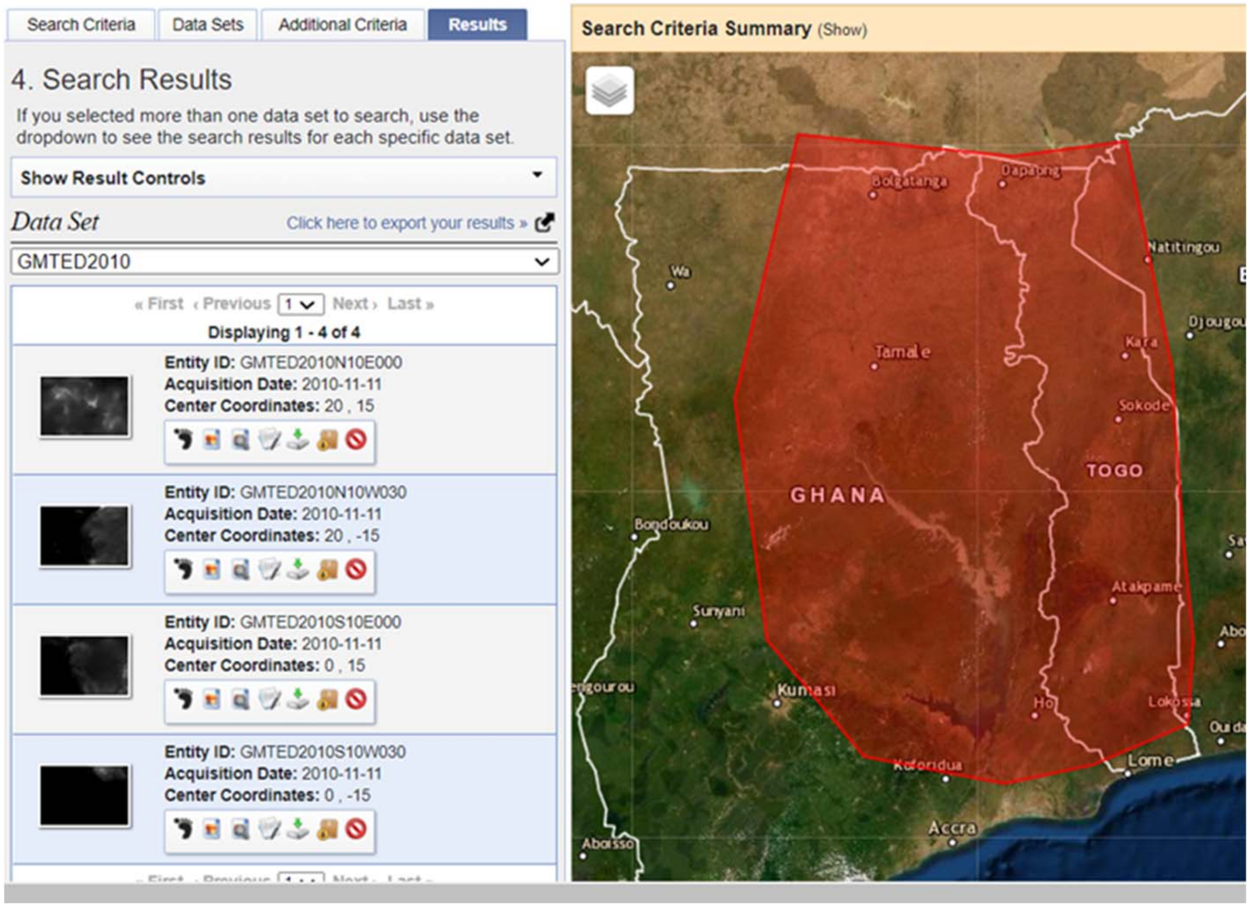


Figure 6: The four selected elevation tiles/rasters for the Volta basin area

IV. Adding the elevation data on QGIS desktop interface

Open QGIS > add the four zipped DEM surfaces one by one (but remember to select ‘Mean’ layers in case of GMTED2010, and look at the video if needed). The QGIS interface should look something like Figure 7. Save the project (i.e. the QGIS file) in your workspace. It’s a good habit to click Save button time to time.

This task is analogous to Step#2.2.1 from the accompanying text tutorial.

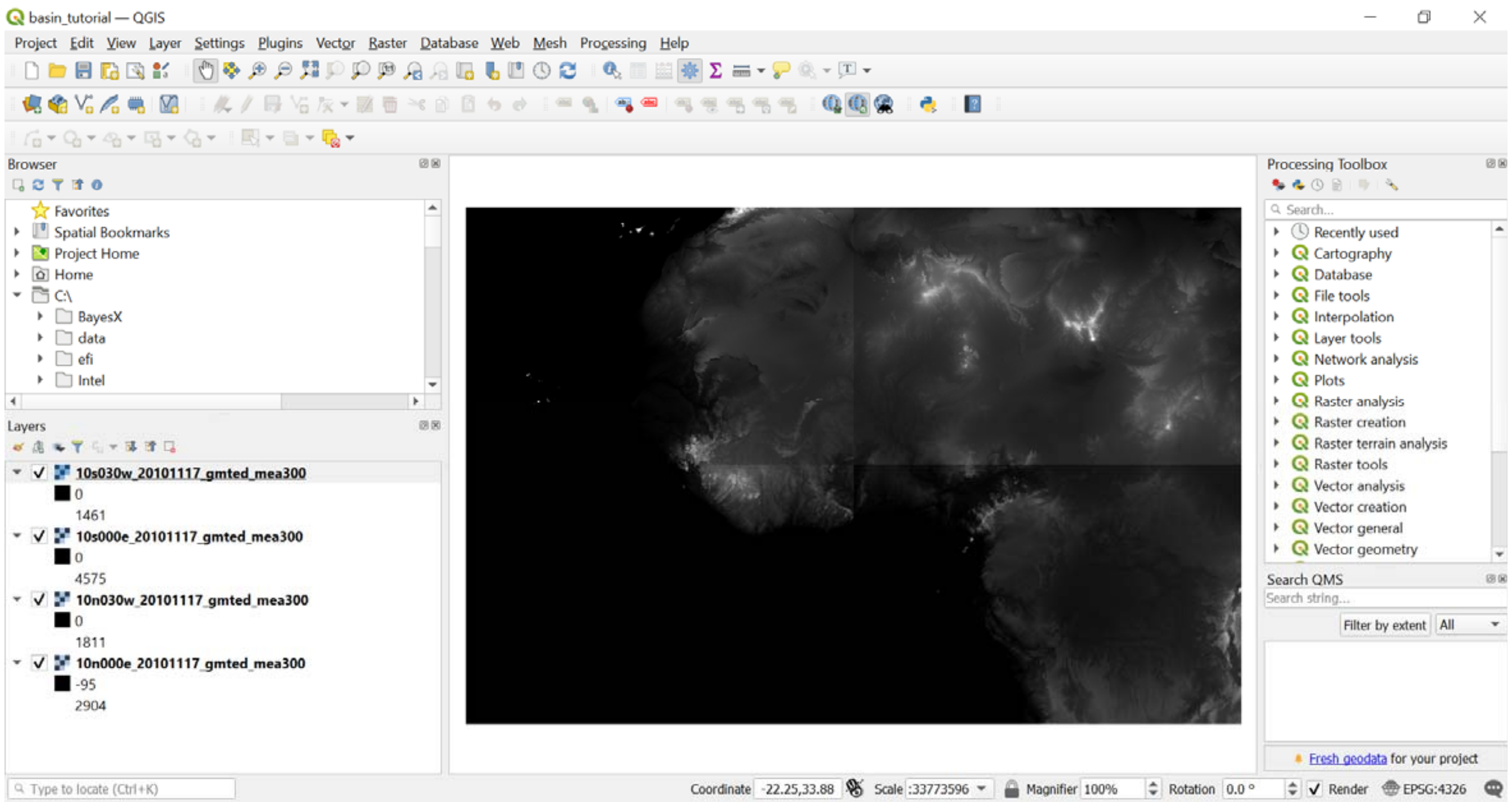


Figure 7: The QGIS screen with the four layers/tiles added

V. Merging the four DEM tiles into one raster surface

Mosaic or merge the four rasters by using Merge tool, which you can open by clicking Raster from the Menu bar > Miscellaneous > Merge. Select the four rasters as the input layers, save the output into your workspace, and run the tool by leaving other parameter values as default. This, results in a single raster covering the whole area (Figure 8)

This task is analogous to Step#2.2.3 from the accompanying text tutorial.

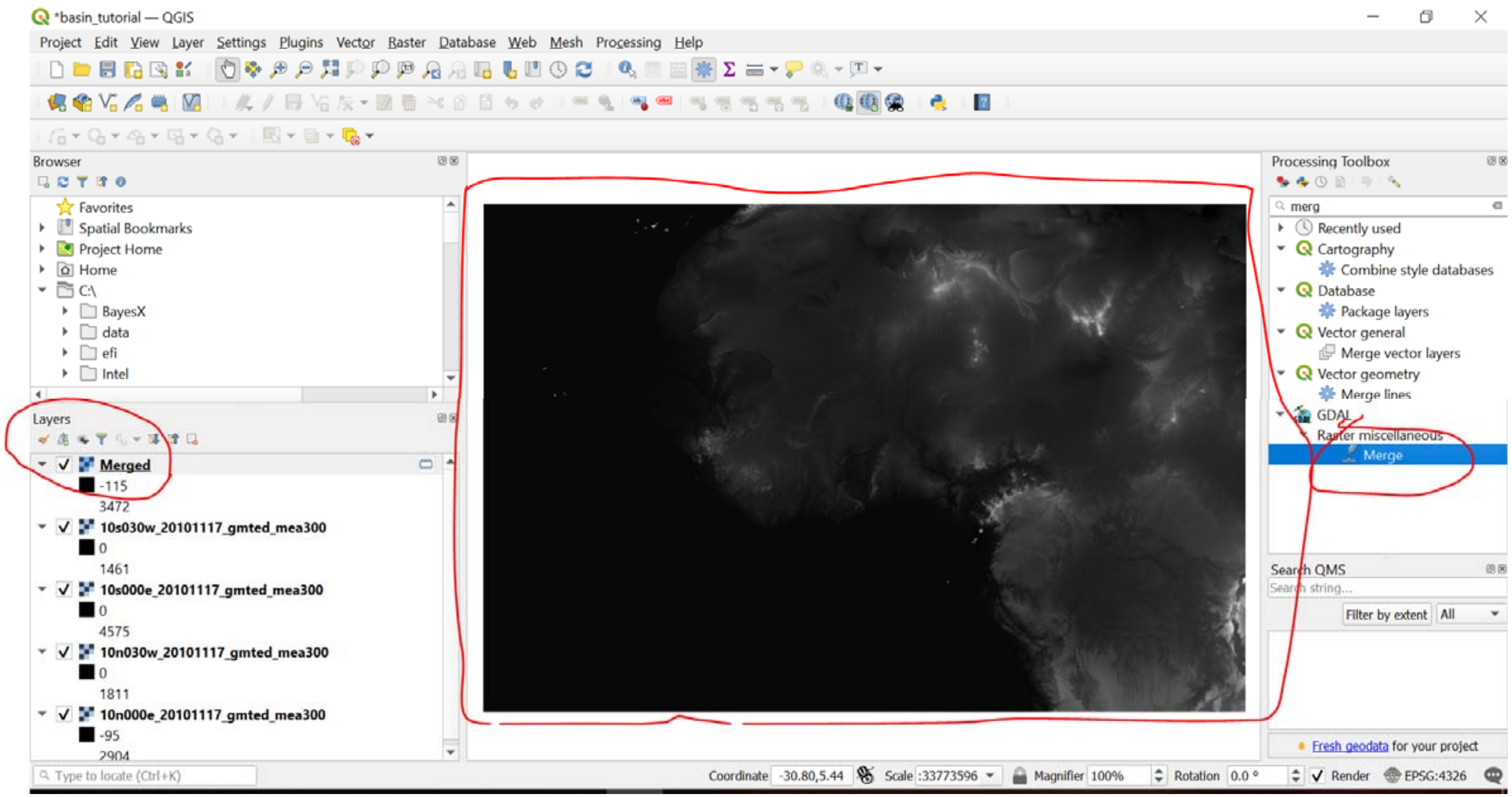


Figure 8: The merged DEM on the QGIS canvas

VI. Downsizing the merged DEM (optional)

For convenience of processing in upcoming steps, downsize the mosaicked raster to cover only the Volta basin area. Click Raster > Extraction > Clip Raster by Extent. Then draw a rectangle on Canvas to cover the tentative area. Save the output in your folder and Run. The result should look similar to Figure 9.

This task is analogous to Step#2.2.4 from the accompanying text tutorial.

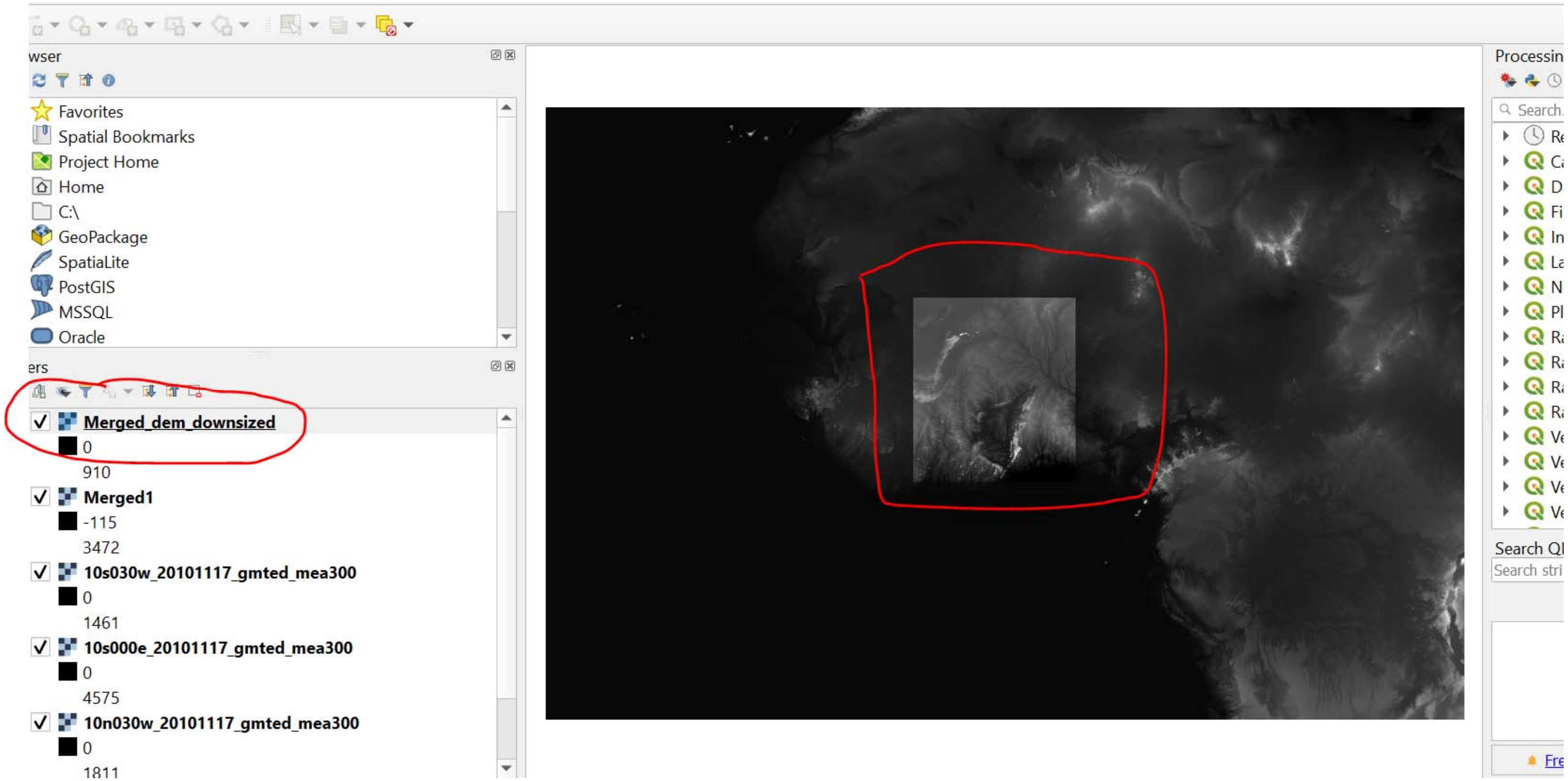


Figure 9: Clipping of the merged DEM to cover a smaller area

A NOTE:

If you are working for your own lake of interest (i.e. not Volta) and already have a DEM of the area obtained from local sources or other web sources, then you can skip the **steps II – VI** (i.e. previous 5 slides). Just open QGIS and add the DEM. Then, start running different Hydrology and Channels tools (operations) in a sequence as described in the upcoming slides.

BY THE WAY:

As QGIS integrates other GIS packages such as GDAL, GRASS and SAGA as toolboxes (Figure 10), we can access the hydrology tools such as Fill Sink and Flow Direction from each of these internally linked packages.

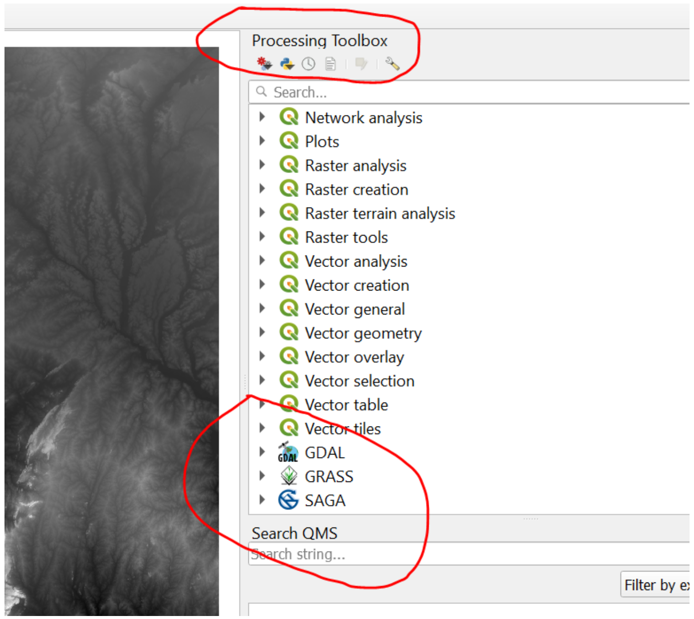


Figure 10: Toolboxes in QGIS

However, in this tutorial, we will use the tools under SAGA toolbox simply because SAGA has an edge in terrain analyses and spatial statistics. SAGA has a more sophisticated array of Hydrology and Channels tools with comparatively more accurate algorithms and their smooth (bugless) implementation.

VII. Hydrologically correcting the DEM

For the hydrology tools such as Flow Direction to run correctly, the input DEM should be free of anomalous sinks. These sinks should be filled, making the DEM surface smooth for the flow of water. So, run the Fill Sinks tool (any version) from SAGA's Terrain Analysis - Hydrology toolbox by inputting the clipped DEM (Figure 10a). The resultant DEM looks pretty much same as the input DEM (Figure 10b), but now is hydrologically conditioned. Refer to Step#2.2.7 from the text tutorial for detail.

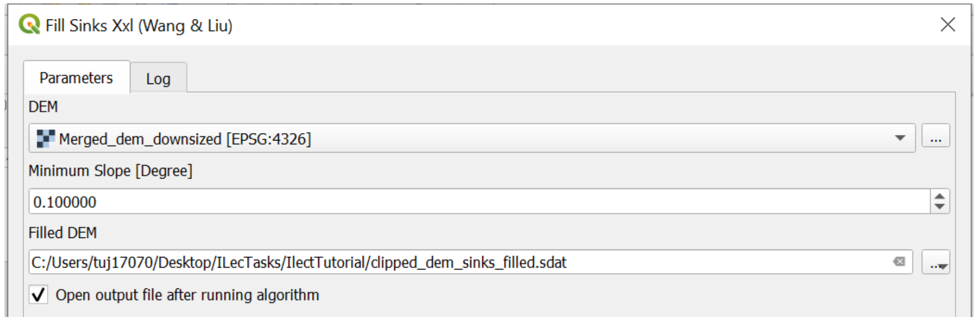


Figure 10a: Fill Sinks dialog box with the parameter values

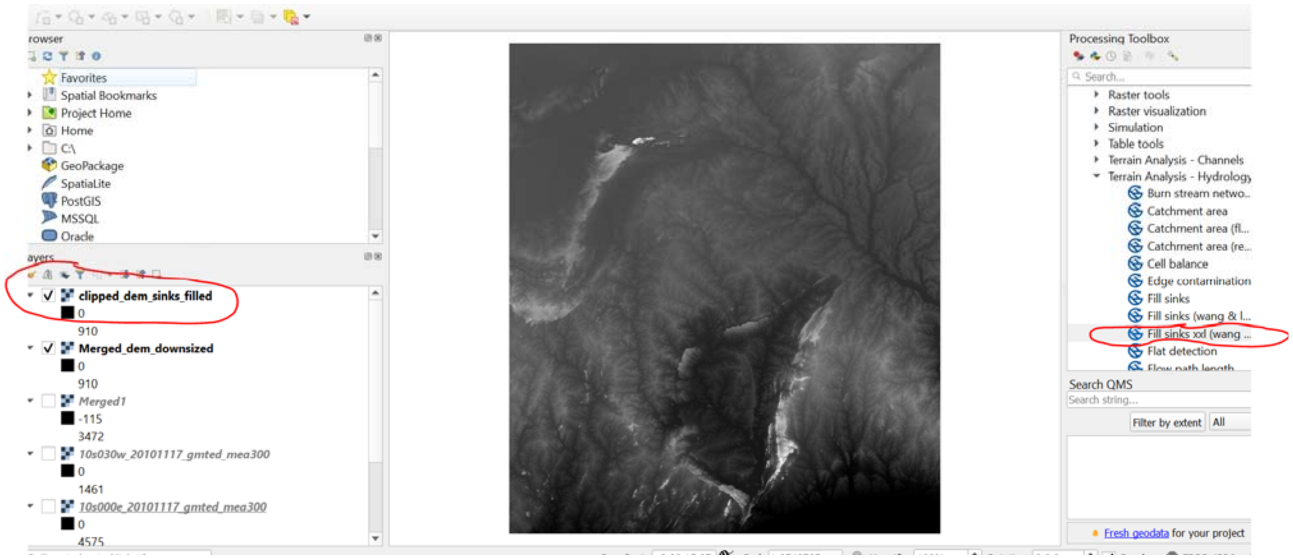


Figure 10b: Result of the Fill Sinks operation

VIII. Generating a flow accumulation or Strahler order surface

As the objective is to capture the whole area that drains through a single outlet or a pour point (i.e. a drainage basin by definition), the sinks-filled DEM should be converted into a flow accumulation surface or a Strahler stream order surface, which helps identify the pour point (a cell or pixel).

There are multiple tools available in SAGA for this purpose, but open the 'Channel network and drainage basins' tool from the 'Terrain Analysis – Channels' toolbox of SAGA package. Save Strahler orders and Channels. Complete the parameters as shown in Figure 11. Then, click Run.

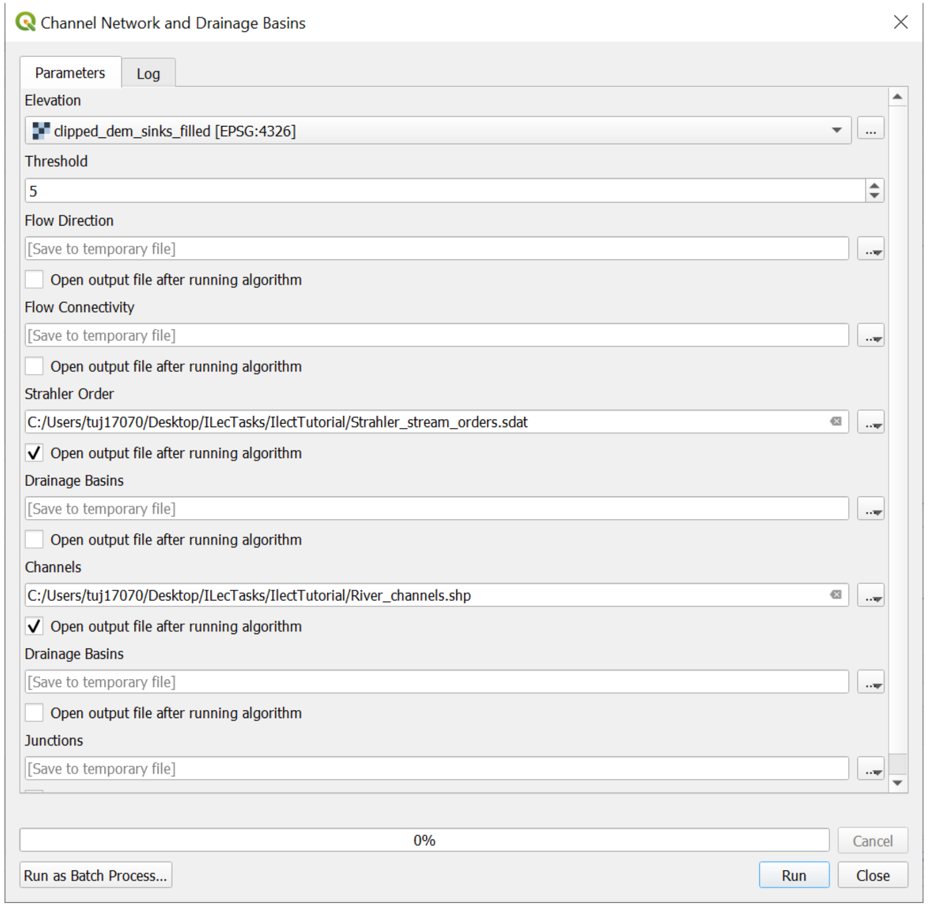


Figure 11: The tool window with all the necessary parameter values completed

The tool results

The running of 'Channel network and drainage basins' tool results in two output layers: a) a raster surface showing the stream orders based on flow accumulation values (Figure 12a), and b) a vector layer (i.e. a Shapefile) of stream networks for the area (Figure 12b).

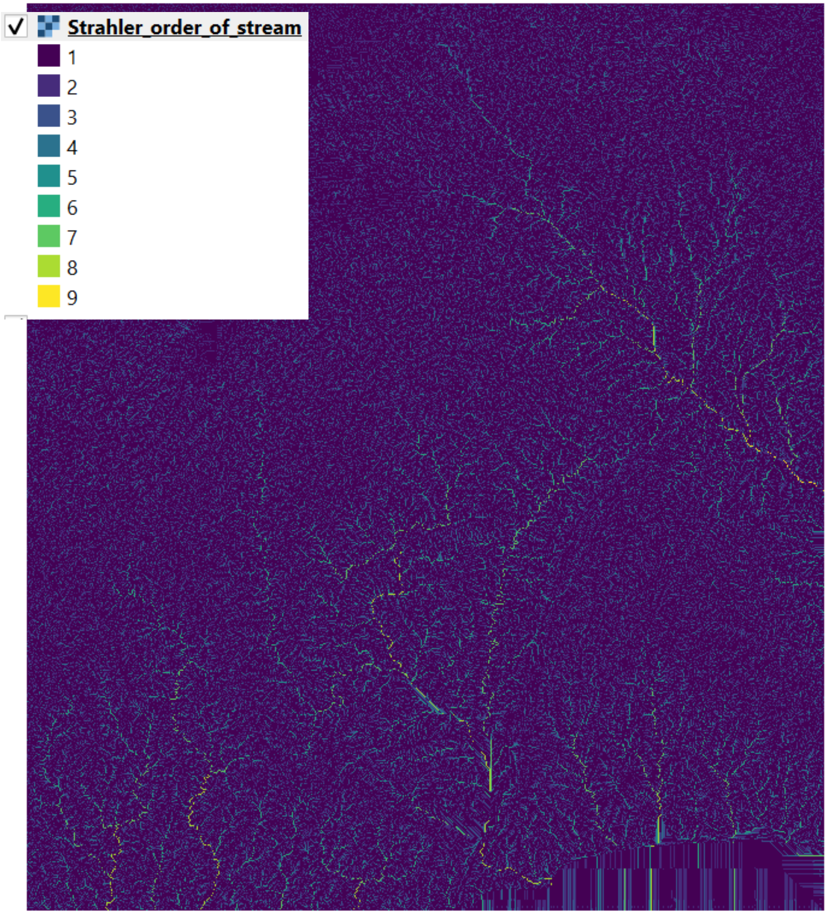


Figure 12a: Stream orders 1 through 9

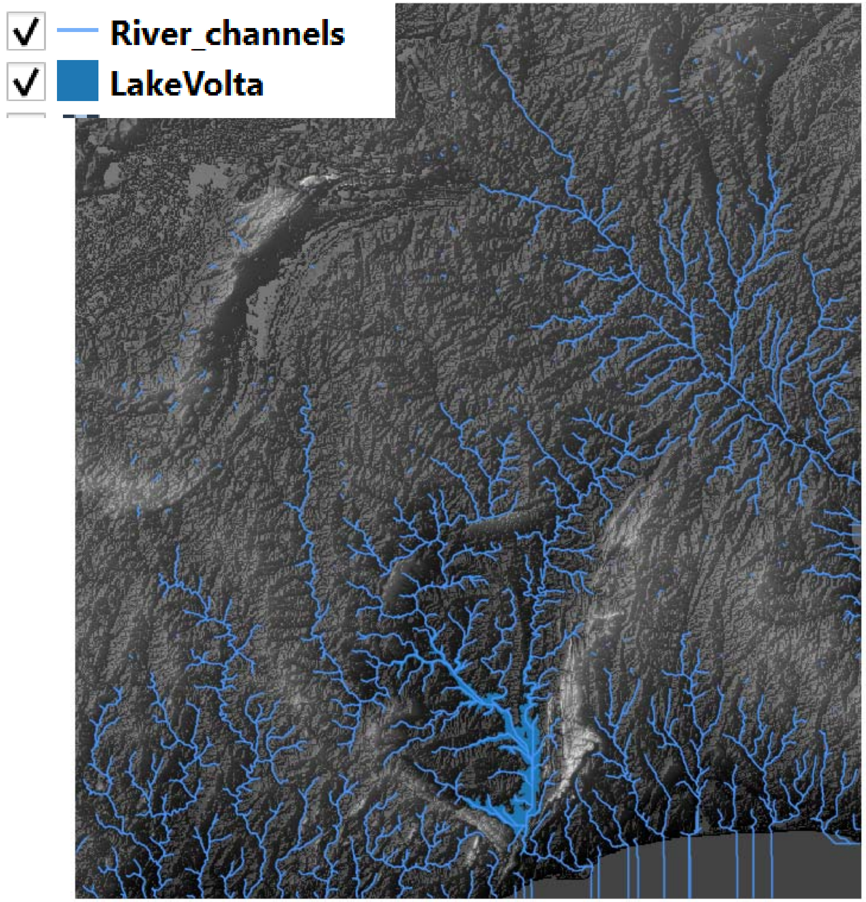


Figure 12b: Channels derived from the DEM

IX. Pinpointing the pour point

As the overall objective is to generate the basin boundary, we want to run a basin generation tool and it is called ‘Upslope area’ in SAGA package. The main parameter in this tool is the location (i.e. X,Y coordinates) of the lake outlet or the pour point. Therefore, before running the Upslope area tool, we need to capture the X,Y position of pour point that falls exactly on the stream path or on the high accumulation pixel of the Strahler order layer.

Add a basemap by clicking Web > Quick Map Services. (Refer to Step#2.2.9 from the text tutorial if needed.) Then, zoom to the outlet area of Lake Volta. Identify the outlet (i.e. the dam or bridge at the end of the lake). Zoom further (as needed) and pinpoint the single pixel on the stream path on the Strahler order layer. Right click on that pixel, copy the coordinate values and save in a word document such as Note Pad. These XY values should be used in the next step. **Positional accuracy of this point determines the quality (extent) of the watershed to be generated**. Refer to the video demonstration if confused.

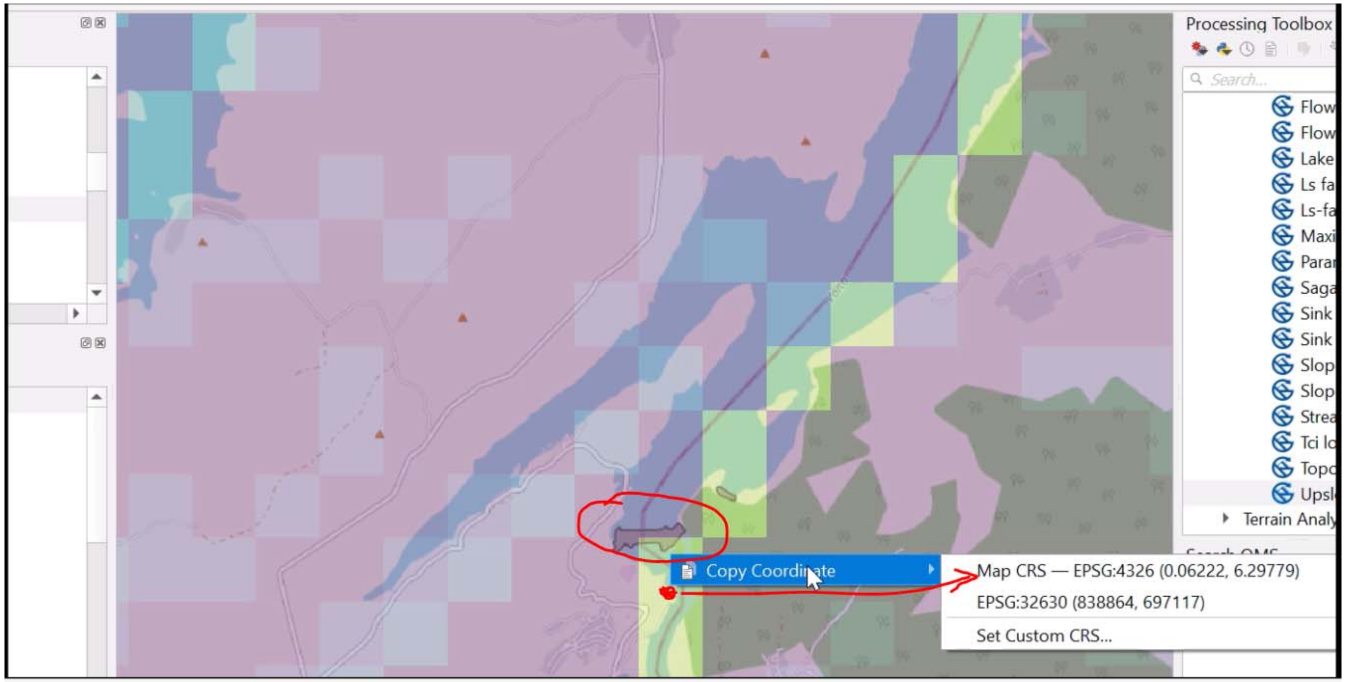
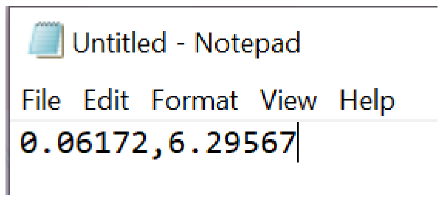


Figure 13: Identifying the pour point’s location and capturing the XY values to save on Notepad



X. Generating the watershed (basin)

As said in the previous slide, now we are ready to run the 'Upslope area' tool. Click SAGA > Terrain Analysis – Hydrology > Upslope area. The resultant tool window should be completed as shown in Figure 14a. Click Run. The output layer looks like Figure 14b, where the white area is the drainage basin of Lake Volta.

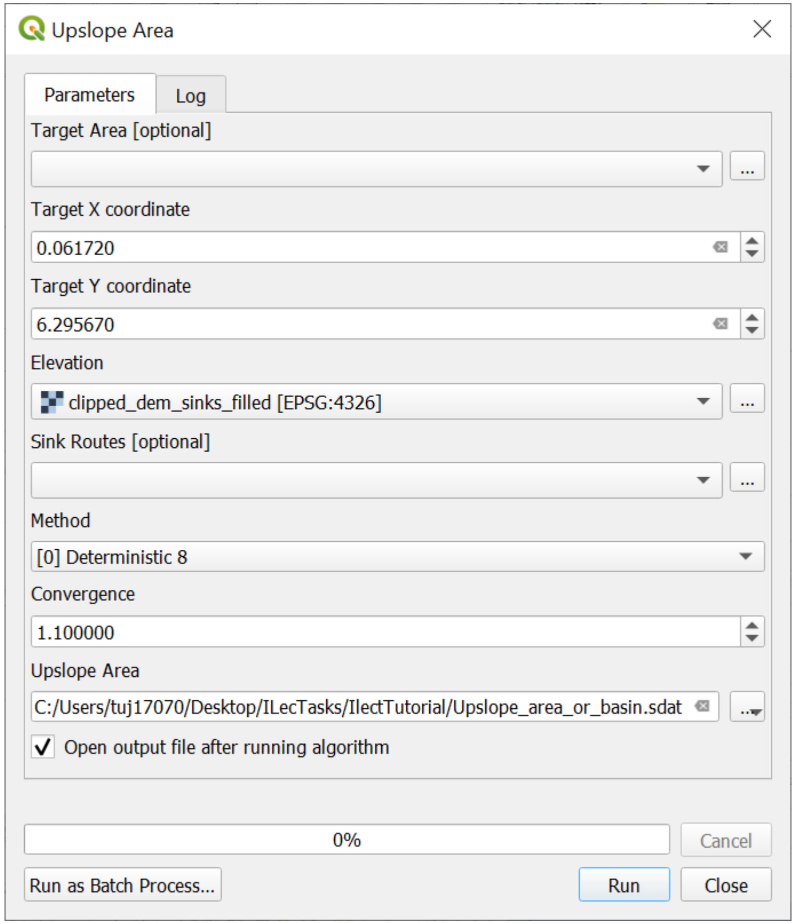
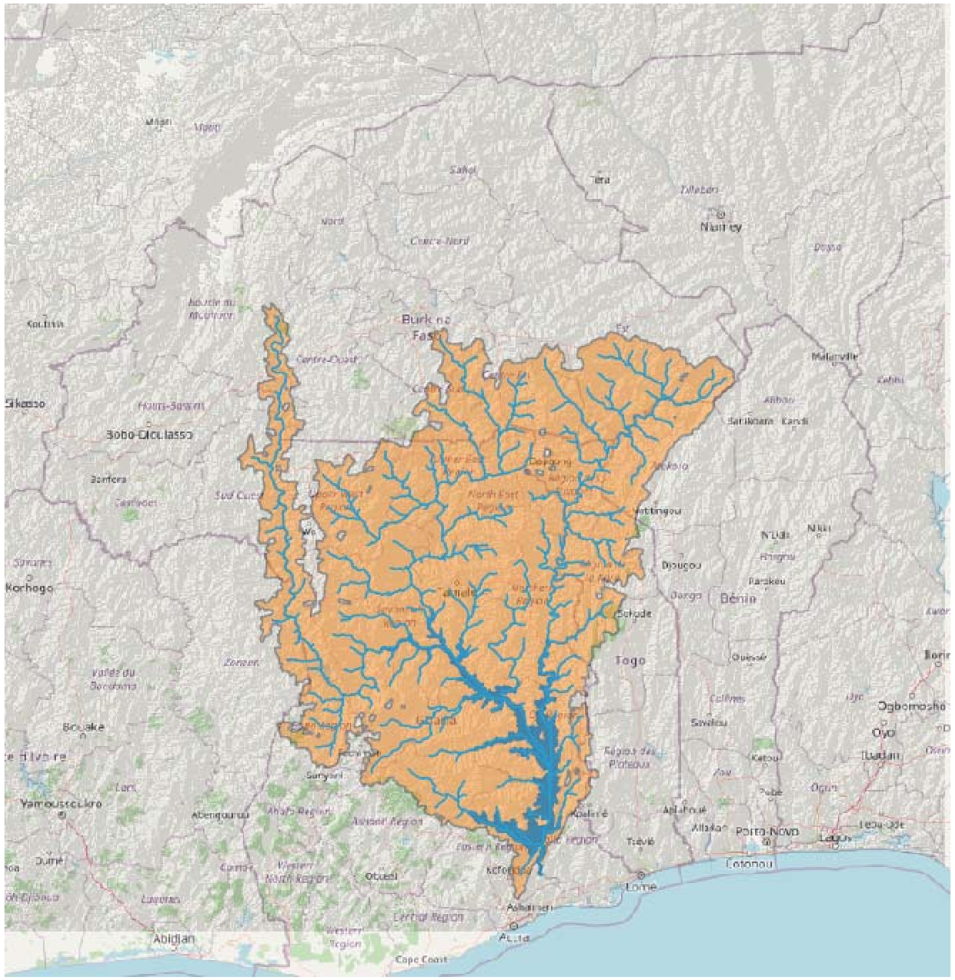


Figure 14a: 'Upslope area' tool window

Figure 14b: Result of 'Upslope area' tool

XI. Visualization of the basin and stream network

The upslope area layer thus created can be vectorized (i.e. conversion to vector layer). Only the basin polygon from the layer can be selected and saved as a new layer. The stream network can be clipped by this basin boundary. And finally, they can be visualized over the base-map by using appropriate color scheme, transparency, hollowness etc. as shown in Figure 15.



Refer to the text/video tutorial for 'How' part on this.

Figure 15: Map of Volta Basin with the lake and stream network overlaid on a basemap

3. Conclusion

Result quality

The quality (specifically the positional accuracy) of GIS outputs is very important because they are often used as a decision-support tool.

In case of lake basin delineation, the accuracy of the generated boundary depends on multiple factors including the quality and resolution of the DEM, and the algorithms of the tools.

Therefore, it is always a good idea to make an assessment of our GIS outputs. Figure 16 presents a visual comparison of the Volta basin created by using different datasets and software.

Figure 16: Volta basin map a) created as part of this tutorial, b) generated in ArcMap using SRTM elevation data, and c) authored by Ndehedehe et al. (2017).

Conclusion

This Tutorial provides just the basics

This tutorial just scratches the surface on drainage basin delineation by presenting a basic and generic GIS-based procedure.

There are other relevant steps and tools as well that are worth exploring to achieve specialized goals.

Individual needs and issues may require additional effort on the part of the learners to do some internet ‘searching’ and some individual ‘troubleshooting’.

4. References

Ndehedehe, C., Awange, J., Kuhn, M., Agutu, N., and Yoichi, F. 2017. Analysis of hydrological variability over the Volta river basin using in-situ data and satellite observations. Journal of Hydrology: Regional Studies, Volume 12, Pages 88-110

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Rast, W., Nakamura, M., Dahal, K., and Lin, H., 2016. Transboundary Lakes and Reservoirs: Status and Future Trends. Transboundary Waters Assessment Programme (TWAP), UNEP office, Nairobi, Kenya. http://geftwap.org/water-systems/lake-reservoir-basins