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Development of Watershed Delineation Tool Using Open Source Software Technologies

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Abstract: Watershed delineation tool was developed in the Environmental Resource Assessment & Management System (eRAMS) platform using open source software technologies. This tool processes Digital Elevation Model (DEM) and DEM-driven raster data to delineate watersheds using two open source software technologies, TauDEM and GDAL. Users can upload their own DEM or create one using NHDPlusV2, which is provided by default in eRAMS watershed delineation tool. During processing of the DEM, it was found that the flat area was excluded in the stream raster pixels calculated from TauDEM 'Peuker Douglas' module; therefore this module was modified to include stream pixels on flat areas, which had a larger flow accumulation value than the threshold. This threshold was decided as the average of flow accumulation values on Peuker Douglas Stream pixels. To provide users flexibility, three options, Advanced, Basic, and Watershed Extraction, were developed. The Advanced option lets users run every module required for watershed delineation one by one. The basic option allows users to run every module automatically at once without configuring intermediate processes if DEM and outlet points are provided. Watershed extraction module uses NHDPlusV2 flow direction raster to extract watershed rapidly using the outlets and an area of interest. TauDEM modules were used in the Cloud Service Innovation Platform (CSIP), which were called by the eRAMS platform. The tool can be used any place in the continental US.

***Keywords**:* Watershed Delineation; eRAMS; CSIP; GDAL; TauDEM

1. Introduction

Watershed delineation is an important procedure in hydrology and water resources engineering because hydrologic analysis is implemented often for any defined watershed. For example, hydrologic response units (HRU; Leavesley et al., 2002), which are incorporated in Soil and Water Assessment Tool (SWAT; Arnold and Fohrer, 2005), are usually defined for the delineated watershed. Also, watershed area is an input parameter of the rational formula, which is one of the most important methods for estimating peak discharge value. Wurbs and James (2002) defined watershed as the land which contributes runoff to a given site. In the past, watershed area was manually calculated using topographic map and planimeter. The accuracy and reliability of this procedure was not of the highest quality because of the operator's manual measurement. However, the accuracy and reliability of watershed delineation increased dramatically with the application of Geographic Information System (GIS). Digital Elevation Model (DEM) is input data for watershed delineation in GIS environments. Mostly, users have to find, download, process or re-project the DEM for the area of analysis, which is time consuming and tedious. Also, watershed delineation tools provided by commercial GIS software have commercial license restrictions. However, the watershed delineation tool in this research allows users to delineate watersheds on any place on the continental US by providing 30 m resolution DEMs. Also, the tool is built on open source technologies, which frees users and developers from any commercial license restrictions. In addition, it provides useful information for later hydrologic analysis.

2. Overview and Data

The watershed delineation tool was developed in the environmental resources assessment and management system (eRAMS; eRAMS, 2018) platform. Inside eRAMS, the watershed delineation tool calls various services created using the Cloud Service Innovation Platform (CSIP; David et al., 2015). The CSIP services for the watershed delineation tool were created using GDAL (GDAL, n.d.) and Terrain Analysis Using Digital Elevation Model (Taudem; Tarboton, 2014). Taudem consists of executable files, which processes DEMs for various purposes related to watershed delineation. The watershed delineation tool consists of the following modules: Fill Sinks, Flow Direction, Flow Accumulation, Grid Analysis, Stream Network – Modified Peuker Douglas, Outlet Move, Weighted Flow Accumulation Area, Stream Network –

Drop Analysis, Stream Raster – Threshold, Extract Stream and Channel Network, and Gage Watershed. The watershed delineation tool provides three options: Advanced, Basic, and Watershed Extraction. In the Advanced option, the user can run every module in an orderly manner optionally with the user's own data. Basic option allows users to run every procedure at once automatically. Watershed Extraction option allows users to extract the watershed rapidly by incorporating only essential modules from Taudem. The input data for the watershed delineation tool is the NHDplusV2 DEM and flow direction raster (US EPA, 2015), and they are provided by the CSIP service. NHDplusV2 provides National Elevation Dataset (NED), which has 30m resolution. NED is used for earth science research and mapping, and the April 2013 version has an average vertical accuracy of 1.55 meter root mean square error (RMSE) for the conterminous U.S. (Gesch et al., 2014). Because NED provided by NHDplusV2 consists of tiles, the GDAL Virtual format (.vrt) is used by the watershed delineation tool to provide seamless DEM data for the continental U.S.

3. Development and Applications

Taudem was used as the core engine because it supports every procedure required for watershed delineation. In addition, Taudem's open source nature turned out to be useful because the "peukerdouglas" module could be modified to show the stream pixels in flat areas. The data was processed using GDAL (GDAL for raster and OGR for vector) inside the Java programs in the CSIP services. Each service module was developed as follows. Once users define the area of interest, a .vrt file is created using a .csv file with the well known text (WKT) of the bounding box. Then the DEM of interest is clipped using gdalwarp. Figure 1 shows an example DEM. The DEM includes pits, which should be removed to make the DEM hydrologically reasonable (Tarboton, 2014), and this procedure is implemented using the "pitremove" module of Taudem. With the pits-removed DEM, flow direction (Figure 2) is calculated using the "d8flowdir" module, which assumes the number of flow directions is eight. The flow direction raster is used as an inpt raster for flow accumulation, which is implemented using the "aread8" module. Also, with the flow direction raster, grid analysis is implemented in the watershed delineation tool using the "gridnet" module of Taudem. This tool outputs the longest flow path, total flow path and grid network order raster. Grid network order represents the Strahler order number (Strahler, 1952, 1957).

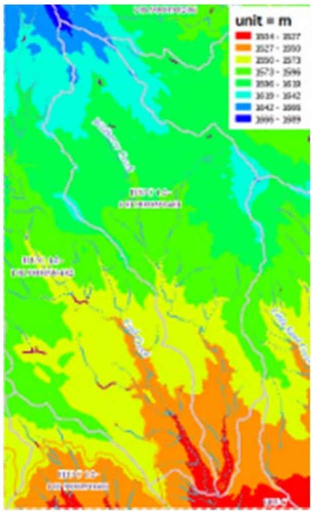

Figure 1. Input DEM

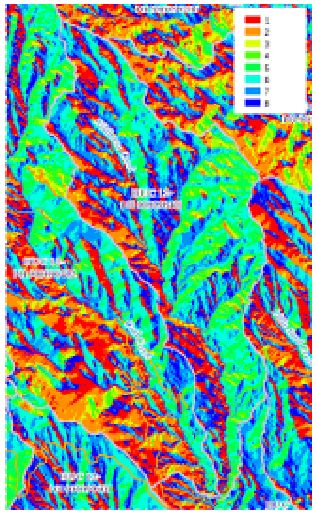

Figure 2. Flow Direction

Figure 3. Moved Outlet

After the flow accumulation raster is created, the stream network is initially approximated by Peucker-Douglas algorithm (Peucker and Douglas, 1975) using the “peukerdouglas” module. The Peucker-Douglas algorithm detects the pixels in the lowest elevation by moving 2 by 2 windows over the input raster and turning off all the pixels except the pixels in the lowest elevation. However, this was found out to turn off pixels in flat areas, which resulted in the under-estimation of stream pixels especially at the downstream area where the stream meets the lake. This caused problems in later steps for moving outlets to stream pixels in the downstream near-lake area since often there were no stream pixels near defined outlets. Also, it affected the overall watershed delineation results by either failing to move outlets to stream pixels or moving outlets to stream pixels too far downstream. Therefore, the original “peukerdouglas” source code was modified to include flat area stream pixels if their flow accumulation value is larger than the average of the flow accumulation value after providing the flow accumulation raster. Figure 4 - 9 shows the updated results made by the modified “peukerdouglas” tool for the examples of Shadow Mountain Lake, CO and Eagle Creek, IN. For the area shown in Figures 4 and 7, the original “peukerdouglas” tool delineated stream as shown in Figures 5 and 8, where stream pixels did not exist in the lake area. The modified “peukerdouglas” tool created stream pixels for the lake area as shown in Figures 6 and 9. This modified “peukerdouglas” tool made the entire watershed delineation procedure more reliable by eliminating the possibility of not having stream pixels in the flat area. The next step is the definition of outlet points’ locations. After the user defines outlet(s) on the map, those outlets are moved to stream pixels using “moveoutletstostrm” module of Taudem as shown in Figure 3 by following the flow direction raster. Then, the number of contributing pixels of stream flowing into each pixel could be calculated with the “aread8” module with weight option (-wg). This raster is called the weighted flow accumulation raster (Figure 10). At this point, the physical boundary of the watershed has been delineated.


Figure 4. Google Map of Shadow Mt. Lake

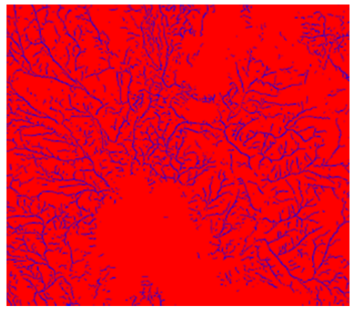
Figure 5. Peuker Douglas Stream

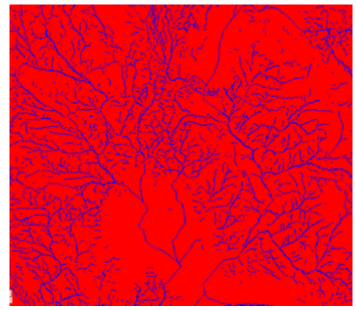
Figure 6. Modified PD stream

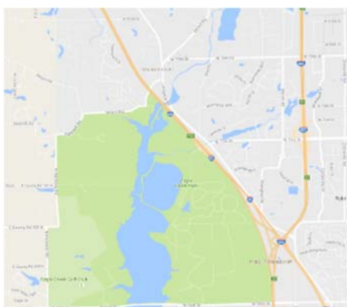
Figure 7. Google Map of Eagle Creek, IN

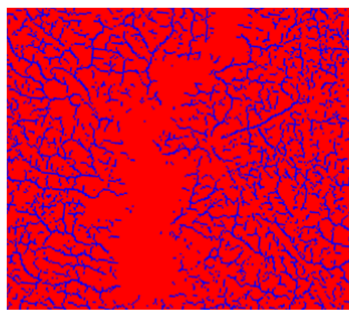
Figure 8. Peuker Douglas stream

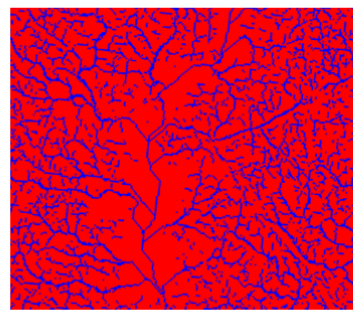
Figure 9. Modified PD Stream

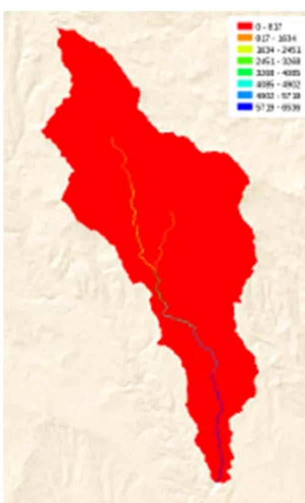
Figure 10. Weighted Flow Accumulation

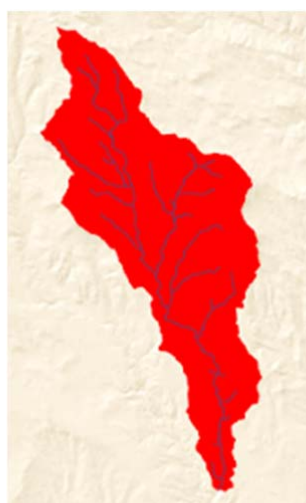
Figure 11. Stream network

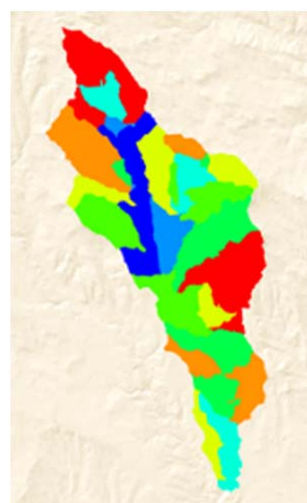
Figure 12. Subwatersheds

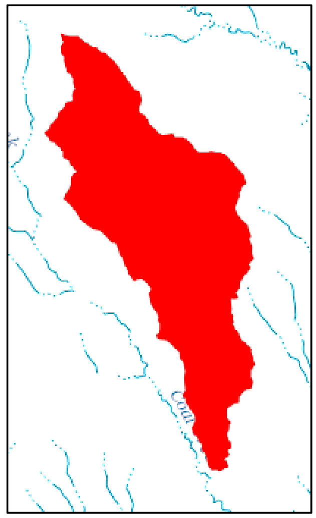

Figure 13. Delineated Watershed Area

Next, drop analysis is implemented using the “dropanalysis” module of Taudem to find the threshold value of weighted flow accumulation raster for rigorous stream raster creation using t-test, which evaluates if the difference between the average drop of the first order stream and higher order streams are significant or not. After finding the minimum threshold, the rigorous stream raster is created using the “threshold” module of Taudem by extracting pixels which have weighted flow accumulation values larger than the threshold found in drop analysis. Next, stream network polyline and sub-watershed polygon vectors are created using the “streamnet” module of Taudem as shown in Figures 11 and 12. For sub-watershed polygons, gdal_polygonize.py is used to convert raster to vector data. Also, the stream network shapefile’s attributes are updated to be consistent with NHDPlusV2’s plusflowlinevaa.dbf format (US EPA, 2015) for future analysis. Finally, a watershed polygon is extracted using the “gagewatershed” module for the drainage area as shown in Figure 13. The Watershed Extraction option uses only essential modules for watershed delineation, which are “moveoutletstostrm” and “gagewatershed” of Taudem. For the area of analysis, the NHD flow direction VRT file is clipped to the bounding box coordinates, which were transformed to EPSG:5070 (NAD1983 Conus Albers, the projection of NHDPlusV2 data). Next, the flow direction values are modified using gdal_calc.py according to Taudem’s standard because NHDPlusV2’s direction standard is different from Taudem’s. Also, the stream VRT is created by extracting pixels less than the threshold (-100m) from NHDPlusV2 HydroDEM. Then the watershed area is delineated using the “gagewatershed” module of Taudem.

4. Conclusion

The watershed delineation tool was created using Taudem, GDAL, CSIP in the eRAMS platform. When comparing delineated watersheds with boundaries of HUC12, HUC10, or even HUC8, it was found that the tool delineated watersheds accurately. Also, the watershed extraction tool provides rapid options for users who don't need any additional information except the delineated watershed boundary. The watershed delineation tool saves users' time and effort to find, download, process, and re-project DEMs by providing and processing DEMs in real-time inside the tool. Also, developing the watershed delineation tool is more convenient (as shown in the case of the modified "peukerdouglas" tool) because it is free from any commercial license restrictions.

5. References

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