

Development of a Hydrological Model for Automation of Watershed Analysis

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SUMMARY

Hydrological analysis is very essential in design of bridges, dams, culverts and other hydrological structures. Watershed is one of the important analysis that facilitate the determination of the size of catchment area of a hydrological feature. Development of fast computers, availability of remote sensing data, engineering techniques, algorithms and the need to automate certain tasks that previously required intelligence humans serve as a motivation factor for the automation of hydrological analysis. This study aimed at developing a model for the automatic delineation of watershed area from Shuttle Radar Topographical Mission (SRTM) digital elevation. This was achieved through the analysis of the tasks required to delineate the watershed, data curation, modelling/coding and model deployment. The software used were anaconda version 3.8. The libraries utilized were numerical python (numpy), matplotlib, geopandas, pysheds and npleaflet. The data required by the model are digital elevation and the spatial coordinate of spill way, outlets etc. The model can detect and correct depressions of the digital elevation, create flow direction and finally generate watershed within a reasonable time. The model was deployed using Docker technology. Analysis of watersheds of the upstream of Jibia dam were used as a case study to analyse and validate the model. The result of the validation proved the model was efficient.

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1. INTRODUCTION

A watershed is a contributory area through which water flows across the land and drains into a major river, stream, river, lake, or ocean (Rughunath, 2006). The watershed boundary follows the highest ridgeline around the stream channels and meet at the lowest point of the land where water flows out of the mouth of the waterway (Edwards, *et al.*, 2015). Watershed has many applications in the field of engineering, environmental management, hydrology, town planning, agriculture and water resources etc (Anning and Flynn, 2014).

Watershed can be used for the analysis of Basin area, curve number, length of the flow paths, slope of the flow paths, watershed slope, topographic index, lag time, drainage pattern and order DEP, (2021). These applications are a pre-requisite in the design of water infrastructures such dam, reservoir, bridges and culverts. Watershed is also important for the implementing water quality protection policy and restoration actions to protect the downstream from the negative impacts of human activities in the upstream (Rughunath, 2006).

Process of watershed analysis started with the acquiring digital elevation of the area of interest, detection and filling/resolving of the image sinks and peaks, creating flow direction and delineation of the river basin area or watershed.

Current development of fast, powerful and high storage computers and availability of data set of engineering techniques and algorithm together with the need to automate certain tasks that previously required human intelligence as stated by Gardner in his top ten artificial intelligence key trends are the major motivation for this research and the model development (Wolf, 2020).

Before, watershed delineation requires high technical user who can read topographic map, scan the map, georeferenced it and identify ridges, valley, major river and contour line to delineate watershed. This process is associated with time/storage consuming and difficult. Nowadays, with the user's digital elevation, coordinates (in both geographic or projected reference) of the spill-way, watershed can be delineated with a few lines of codes in Jupyter-python.

This paper aimed at the automation of the process of watershed delineation using pysheds and python. This was achieved through design of the model. Coding using python and pysheds, deployment and testing. The Shuttle Radar Topography Mission (SRTM) Digital elevation was aimed at mapping the Earth's land surface in three dimensions, which was achieved during 11-22 February 2000. Successfully collected data were further available in form of grid data files and called Digital Elevation Models (DEMs) with an accuracy of 1-arc second (30 meters, DEM30). Hence, this project will contribute a lot in the development of hydrology.

Pysheds is an open-source library designed to help with processing of digital elevation models (DEMs), particularly for hydrologic analysis. Pysheds performs many of the basic hydrologic functions offered by commercial software such as ArcGIS, including catchment delineation and accumulation computation. It can delineate a flow direction grid of ~10 million cells in less than 5 seconds. Flow accumulation for a grid of 36 million cells can be computed in about

~~15 seconds. These methods can be readily automated and incorporated into web services: for~~

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for instance, a web mapping service like leaflets could use pysheds to generate contributing areas for locations of interest on the fly (ESIP, 2017)

Docker is an open platform for developing, shipping, and running applications. Docker enables you to separate your applications from your infrastructure so you can deliver software quickly. With Docker, you can manage your infrastructure in the same ways you manage your applications. A Dockerfile is a text document that contains all the commands a user could call on the command line to assemble an image. An image is a read-only template with instructions for creating a Docker container. You might create your own images or you might only use those created by others and published in a registry. A container is a runnable instance of an image. You can create, start, stop, move, or delete a container using the Docker API or CLI. You can connect a container to one or more networks, attach storage to it, or even create a new image based on its current state (Docker hub, 2020).

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Software used and the application

- i. Anaconda python 3.8 was utilized for coding
- ii. Pysheds library provided the required geospatial tools
- iii. Numerical python(numpy) was used for array analysis of values
- iv. Matplotlib was used for plotting the outcome of the geospatial analysis
- v. Geopandas was used for depicting the geospatial figures
- vi. Docker for deployment of the model
- vii. Notepad for creating a dockerfile

2.1.2 Data used

- i. SRTM Digital elevation
- ii. Coordinates of the pour-point or outlet
- iii. Threshold value

2.2 Method

2.2.1 Design of model

This analysis requires the digital elevation topography to be hydrologically correct (i.e free from sinks and peaks) to enable water travel from upward to downward elevation (pour-point, spillway or outlets) with only the force of gravity as a driven force. As usual digital elevation comes with sinks and peaks as a result of differences in platform altitude and interpretations of the heights. It is because of this; the model was design to handle these issues before the hydrological analysis. As follows, the model was design to;

- a. Detect the depressions in the form of sinks
- b. Fill the depressions or the sinks
- c. Detect the flats or peaks
- d. Resolve the flats or peaks
- e. Create the flow direction and
- f. Delineate the catchment using coordinates of the pour-point and threshold value.

2.3 Modelling

The modelling or coding started with the installation of pysheds, Fiona, geopandas, pyproj on the anaconda python and update pysheds to the latest edition. The python libraries required for the coding such numerical python, pysheds, geopandas and matplotlib were imported in to a Jupyter workspace.

The modelling continues with the opening of the raster, detecting and filling or resolving raster depressions, creating the flow direction, delineating catchment and plotting the result after each process and #tag was used to indicate comment or explanation as below:

```

#Import modules
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.colors as colors
import geopandas as gpd
from pysheds.grid import Grid

#Instantiate a grid from a DEM raster
grid = Grid.from_raster('../Digital_elevation.tif',data_name='raw_dem')

#plot the raw DEM data
def plotFigure(data, label, cmap='Blues'):
    plt.figure(figsize=(6,5))
    plt.imshow(data, extent=grid.extent)
    plt.colorbar(label=label)
    plt.grid()
    elevDem=grid.raw_dem[:-1,:-1]
    plotFigure (elevDem, 'Elevation (m)')

# Detect depressions
depressions = grid.detect_depressions('raw_dem')

# Plot depressions
plt.imshow(depressions)

# Fill depressions
grid.fill_depressions(data='raw_dem', out_name='corrected_dem')

# Test result
depressions = grid.detect_depressions('corrected_dem')
plt.imshow(depressions)

# Detect flats
flats = grid.detect_flats('corrected_dem')
# Plot flats
plt.imshow(flats)
grid.resolve_flats(data='corrected_dem', out_name='resolve_dem')
plt.imshow(grid.resolve_dem[:-1,:-1])

# Create a flow direction grid
#N NE E SE S SW W NW
dirmap = (0, 1, 2, 3, 4, 5, 6, 7, 8)
grid.flowdir(data='resolve_dem', out_name='flow_direction', dirmap=dirmap)
plotFigure(grid, 'Flow Direction', 'viridis')

```

```

# Specify discharge point
x, y = 311436.105, 1435698.022

# Delineate the catchment
grid.catchment(data='flow_direction', x=x, y=y, dirmap=dirmap, out_name='watershed',
               recursionlimit=15000, xytype='label', nodata_out=0)

# Clip the bounding box to the catchment
grid.clip_to('watershed')-

# Get a view of the watershed
demView = grid.view('watershed', nodata=np.nan)
plotFigure(demView, 'Elevation')

#export selected raster
grid.to_raster (demView, './catchment_WGS84.tif')

# Define the stream network
grid.accumulation(data='catch', dirmap=dirmap, pad_inplace=False, out_name='acc')
accView = grid.view('acc', nodata=np.nan)
plotFigure(accView, "Cell Number", 'PuRd')

streams = grid.extract_river_network('catch', 'acc', threshold=200,
dirmap=dirmap)streams["features"][1:2]
(sources: ESIP,2017)

```

2.4 Deployment

At the deployment stage dockerfile (which is the instruction given to the docker to create an image) was created with windows power shell with parameters such as python 3.8 as base image, python code, directory, python libraries used as parameters pysheds, matplotlib and numpy as dependencies and CMD as executables as follows:

```

FROM python:3
WORKDIR /usr/src/app
COPY dem
COPY hydro.py.
RUN pip install pysheds geopandas matplotlib numpy .
CMD ["python", "hydro.py"]

```

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command
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Docker build. -t "hydro".

The built images can be checked by docker images.

Finally, the container (which is the running instance of the image) was created with a command docker run -ti "hydro"

2.5 Model testing

The model was finally tested with the digital elevation of Jibia dam region and coordinate of the spill-way to analyse the watershed of the upstream of the dam.

3. RESULTS AND DISCUSSION

Figure 1-7 is the results of the reading raster data, detection of sinks and peaks, the result of resolving raster depressions, flow-direction, catchment delineation and the stream-network extraction using pysheds in anaconda and python libraries. Python and pysheds has the ability to carry out analysis perform by ArcGIS (commercial) with additional capabilities such as detection, filling and resolving sinks and peaks respectively. This model is now containerized by docker technology for sharing with everyone. The model can process digital elevation raster with high speed and accuracy as revealed by this research. The result of this analysis can be opened and read in both ArcGIS, QGIS etc.

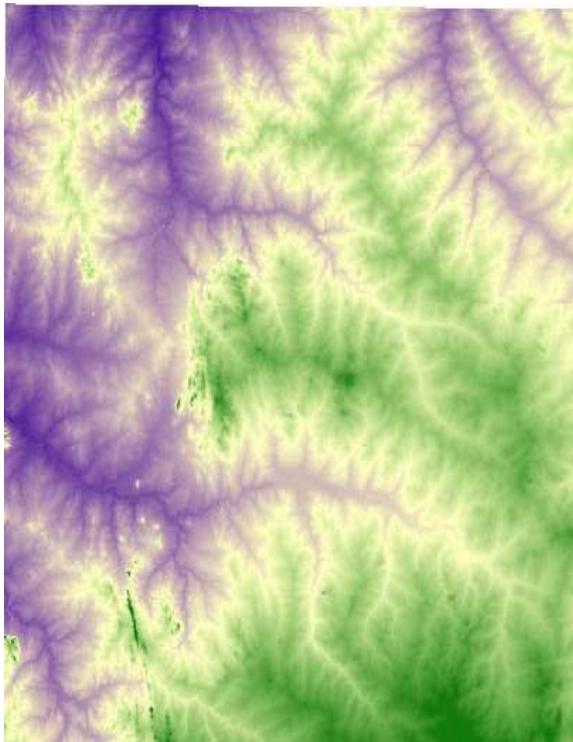


Figure 1 Raw digital elevation



Figure 2 Detected depressions(sinks)

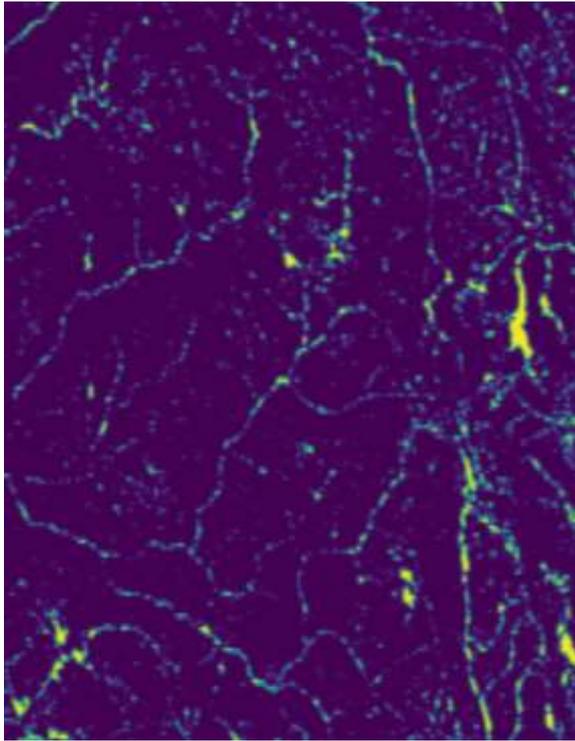


Figure 3 Detected flats(peaks)

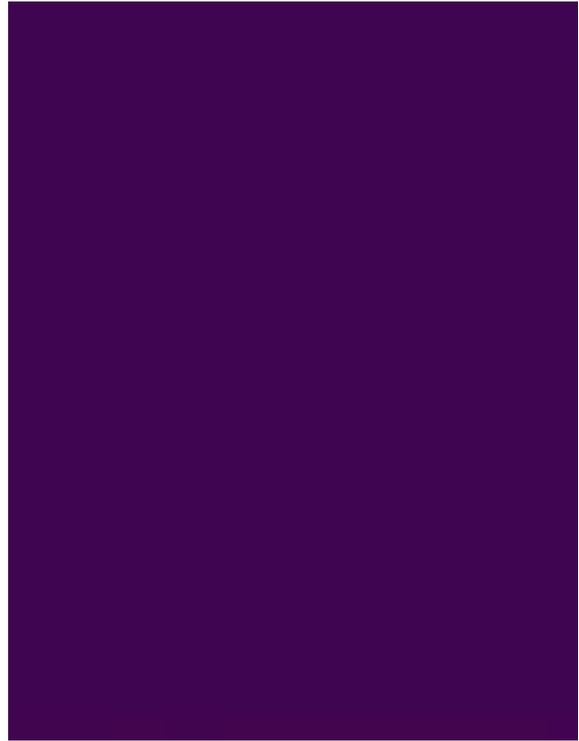


Figure 4 Corrected digital elevation

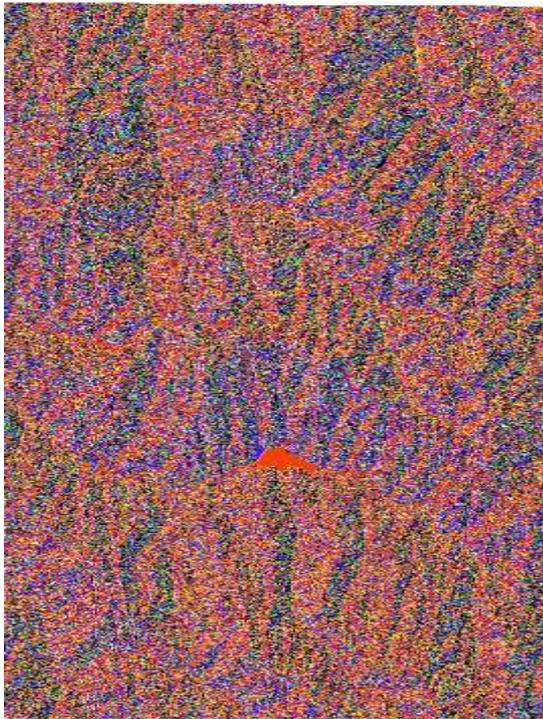


Figure 5 Flow direction

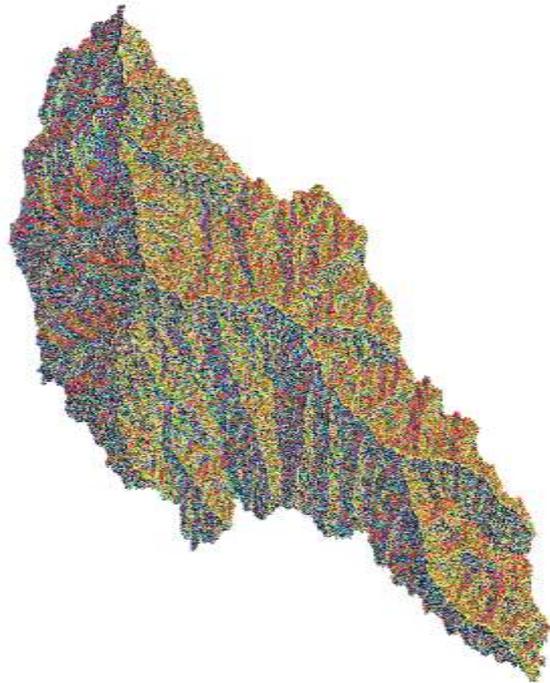


Figure 6 Watershed(catchment)

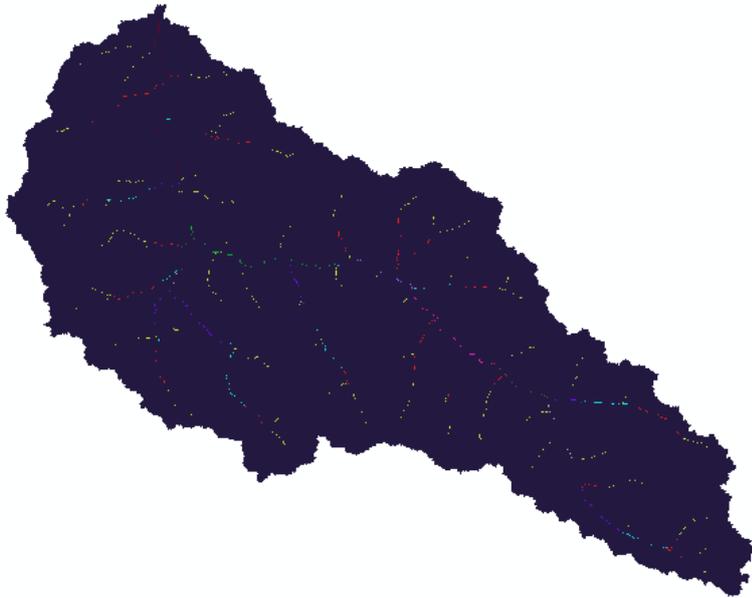


Figure 7 Stream network

4. CONCLUSIONS

This study automated the processes of watershed delineation and stream network extraction through design of model, coding, deployment and testing of the model. The data utilized for testing of the model were the digital elevation of some parts of Katsina State, coordinates of the outlets and the threshold value of the area. Pysheds library in anaconda python was used for the modelling and extraction. Docker technology was utilized containerize the model for sharing. The outcome of the study were the catchment area of the dam and stream network of the upstream basin. Testing of the model shows, the model can recognize all the type of digital elevation data with any coordinate reference system and extract flow direction and stream network in 10 and 15 seconds. The study laid the foundation for continuous development of model for combination of watershed, elevation and land-use land-cover data. Its therefore recommended that, this model should be package as software plugins.

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BIOGRAPHICAL NOTES

Hassan Musa

Hassan Musa is a Lecturer in the Department of Quantity Surveying, Hassan Usman Katsina Polytechnic Katsina State Nigeria, he specialized in GIS, Remote Sensing, Hydrological Analyses and Engineering Surveying. He obtained B.Tech. Land Surveying from Abubakar Tafawa Balewa University Bauchi and MSc. Geomatics the Ahmadu Bello University, Zaria, Nigeria and currently enrolled for PhD. Geomatics. Surveyor Musa is Registered as a Surveyor with the Surveyors Council of Nigeria and a member of some professional bodies including the Nigerian Institution of Surveyors (NIS), FIG Young Surveyors Network (YSN), Nigeria, National Association of Surveying & Geoinformatics Lecturers (NASGL), Northern Surveyors Forum (NSF), amongst others. He has attended and fully participated at numerous national and international Conferences including IAYG Mapping Horizons and GIS competition, 2020 and has numerous local and international publications to his credit.

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Adamu Bala, is a Lecturer in the Department of Geomatics at the Ahmadu Bello University, Zaria, Nigeria, where he specializes in Geo-Information Science, Remote Sensing, Mining Surveying and Professional Practice. He obtained B.Eng. & MSc. Geomatics; PGDE; PGD Mining Engineering and currently enrolled for PhD. Geomatics. He had previously worked with Kabir & Associates Limited, Katsina and Nigerian Institute of Mining and Geosciences, Jos as Surveyor/GIS Analyst and Geoscientist respectively for cumulative 7 years, before joining Academia in 2018. Surveyor Bala is Registered/Licensed as a Surveyor with the Surveyors Council of Nigeria and a member of some professional bodies including the Pan African Scientific Research Council, Nigerian Institution of Surveyors (NIS), FIG Young Surveyors Network (YSN), Nigeria, National Association of Surveying & Geoinformatics Lecturers (NASGL), Northern Surveyors Forum (NSF), amongst others. He has attended and fully participated at numerous national and international Conferences including FIG Working Week, 2013 in Abuja; and has numerous local and international publications to his credit.

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