

## **Delineation of River Watershed and Stream Network Using ILWIS 3.7.1 Academic**

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### **Authors' contributions**

*This work was carried out in collaboration between both authors. Author RED designed the study, performed the GIS analysis and wrote the first draft of the manuscript. Author IIA managed the literature searches. Both authors read and approved the final manuscript.*

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### **ABSTRACT**

The delineation of watersheds can be carried out manually using topographic maps but these maps are mostly outdated, scarce and incomplete for most parts of Nigeria and may be of different scales for large watersheds that require several sheets of the map. Watershed boundaries need to be delineated accurately because the areas and perimeters of watersheds are used in many hydrological analyses. This study is aimed at delineating the River Dep watershed and stream network using 90m SRTM Digital Elevation Model and Geographic Information Systems technique and comparing the shape and pattern with the one previously delineated manually using topographic maps and areal photographs. The 90 m SRTM Digital Elevation Model used for the study was obtained from the Global Land Facility Cover site and processed in ERDAS Imagine 9.2 before exporting to ILWIS 3.7.1 ACADEMIC. The watershed area obtained from the GIS delineation processes was 10640 km<sup>2</sup> while it was 9600 km<sup>2</sup> from the report of the one delineated by manual methods in 1980. The same 1980 manually delineated watershed when scanned, imported, georeferenced and digitised in ILWIS 3.7.1 gave a watershed area of 10244 km<sup>2</sup>. The differences in the watershed area could be due to the effect of input data or errors from the estimation using

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traditional delineation. The study showed similarity in shape and pattern for both the watersheds and stream networks delineated using the two methods. The study shows the capability of the ILWIS DEM hydro-processing tools used for watershed and stream network delineation using the 90m SRTM Digital Elevation Model and it is recommended that the both can be used with a reasonable level of accuracy.

*Keywords: Watershed; stream network; GIS; remote sensing; DEM; topographic map.*

## 1. INTRODUCTION

Watershed modelling is an ideal application for GIS which allows the simulation of hydrologic processes in a more wholistic manner, compared to many other models [1,2]. A key component of watershed modelling is the watershed area that contributes flow to the point of interest [1]. Each stream or river is bounded by a watershed divide and is defined by the highest elevations surrounding the stream. Watershed, catchment and drainage basin are terms that are used interchangeably to refer to, 'the topographic area that collects and discharges surface streamflow through one outlet' [3].

Watershed delineation is the process of identifying the drainage area of any point on a stream or river network. Topography is usually the main input in determining a river watershed therefore its delineation requires the use of topographic maps which are sometimes not easily available and outdated in most places [4], including Nigeria. They are mostly of different scales when more than one sheet of topographic map is needed to cover the area of interest. Though watersheds can be delineated manually using topographic (contour) maps, it can however prove to be a very tedious and difficult task especially in flat terrains [5]. Digital Elevation Models (DEM) and Geographic Information System (GIS) softwares are tools that can be used for modeling of stream networks [6], delineation of watershed to obtain parameters that are important for management of water volume and quality, soil conservation, flood control, wild life habitat and other hydrological analyses. The accuracy of the result mostly depends on quality and type of DEM and the computer algorithms used. The paper by [7] buttressed the fact that GIS with remote sensing (RS) technologies have played an essential role in supporting both data collection and analysis in the development of watershed modelling capabilities.

The use of Digital Terrain Model and GIS techniques in delineating watersheds in flat and

arid terrains of western Iraq desert was also demonstrated by [5]. Three GIS packages were used (Arc Hydrotools, TNTmips and RiverTools) within two DEMs: the 90m and 30m SRTM in addition to ASTER 30m. The result showed that automated watershed analysis of flat terrains cannot be done without manual evaluation and correction either by using several seeding points or river burning technique.

The use of standard Digital Elevation Model for watershed delineation in ArcGIS 9.1 was also demonstrated by [8] for the Ayer Hiram forest Reserve, Selangor. The DEM was obtained by interpolating a contour map. The automated watershed delineation was carried out, though they pointed out that despite its potential advantages, automated generation of watershed boundaries has several practical challenges. Errors could arise because topographical maps rarely align perfectly, especially in moderate to low-relief terrain resulting in error of different interpretations of watershed flow pathways.

Since GIS is fast becoming a very viable automated alternative for the delineation of watershed boundaries with results that are independent of human decisions [5], there is the need to the check the accuracy and effectiveness of this alternative because the areas and perimeters of watersheds are used in many hydrological analyses.

DEM resolutions for watershed delineation have been tested as shown in the work done by [9]. The Shuttle Radar Topography Mission (SRTM) DEM (90m), Advanced Space-Borne Thermal Emission and Reflection Radiometer (ASTER) DEM (30m), and Land Development Department (LDD) DEM (5m) used for the delineation of characteristics of 144km<sup>2</sup> watershed showed that the watershed sizes and shapes obtained were only slightly different.

The finer the DEM resolution the more the processing time and data storage needs for modelling with no significant difference in the end results [9,10,11], therefore coarser DEM may be

used as opposed to a finer resolution DEM for watershed delineation depending on the watershed size.

Since water flows in the direction of a terrain's steepest downhill slope and drainage divides defined by highest points of the terrain, watershed and stream network delineation in GIS are mainly based on Digital Elevation Models (DEMs). DEMs are grids of elevation that store the same type of information as contour lines but with a different data structure.

This study is aimed at delineating the River Dep watershed boundary and stream network using the 90m SRTM DEM as input data and ILWIS 3.7.1 ACADEMIC and comparing the size and shape with the one previously delineated manually using topographic maps and areal photographs obtained from [12]. This is with a view to assessing the suitability of the 90m DEM for the fast and effective watershed and stream network delineation in ILWIS 3.7.1.

## 1.1 Study Area

The Dep River Basin lies between latitudes 8°00'00"N to 9°20'00"N and longitudes 8°20'00"E

to 9°35'00"E as shown in Fig. 1. It is situated in the South Eastern and South Western parts of Plateau State and North Eastern part of Nasarawa State in North Central Nigeria. The catchment covers an area of over 10,000 km<sup>2</sup>. The upper reaches are very steep at elevations of up to 1300masl while the lower reach is relatively flat at elevations of between 78 – 200 masl.

## 2. METHODOLOGY

Softwares: ILWIS 3.7.1 Academic - GIS analysis software with spatial and attribute data.

Data Used: 90-metre Shuttle Radar Terrain Mission Digital Elevation Model (SRTM DEM) of the study area collected from the Global Land facility Cover website.

The Digital Elevation Model (DEM) of the study area, which is the main input data, is shown in Fig. 2.

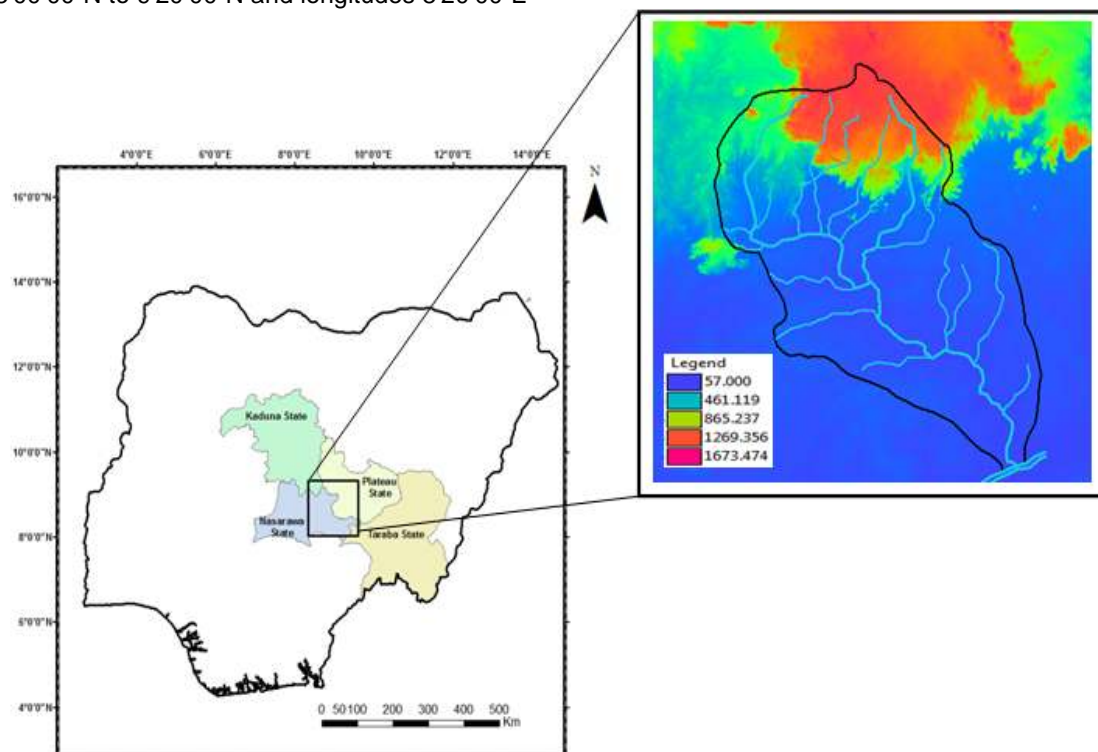


Figure 1: Map of Nigeria Showing the Study Area

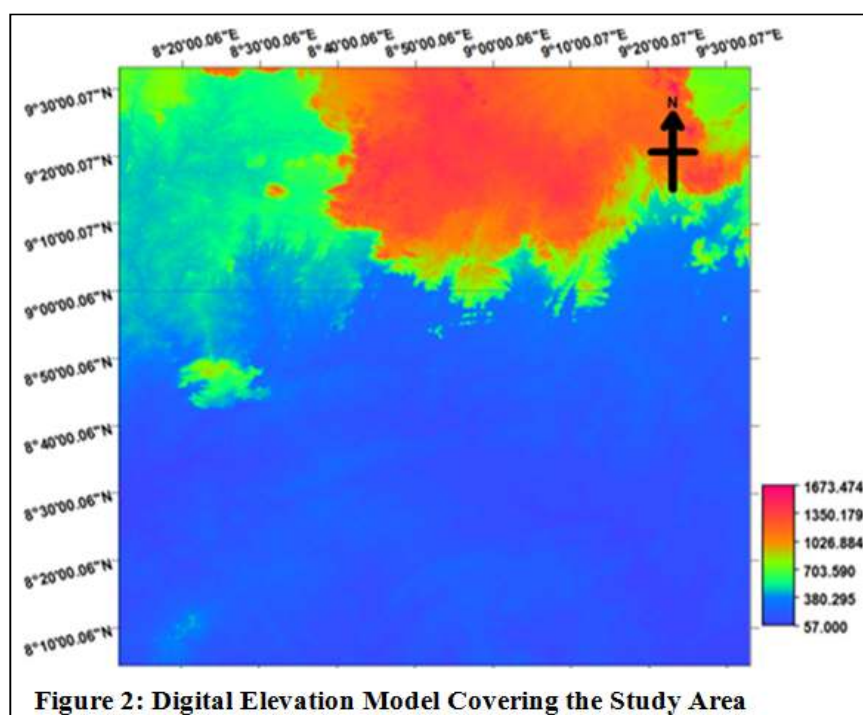


Figure 2: Digital Elevation Model Covering the Study Area

## 2.1 Watershed Delineation in ILWIS 3.7.1

Most of the GIS softwares carry out watershed delineations by considering the following basic steps as extracted from the ILWIS 3.7.1 HELP Menu [13]:

**Fill Sinks Operation:** This is used to clean up the DEM to remove sinks, which are areas where water flows into and not out because all surrounding pixels are higher in elevation.

**Flow Direction Operation:** This operation indicates the pixel, out of the eight neighboring pixels, in a block of 3 by 3 pixels, towards which water will flow naturally.

**Flow Accumulation Operation:** This operation performs a cumulative count of the number of pixels that naturally drain into outlets. It represents the amount of water that would flow into each cell assuming all the water became runoff and there was no interception, evapotranspiration or loss to groundwater. The operation can be used to find the drainage pattern of a terrain.

**Drainage Network Extraction:** This operation extracts a basic drainage network.

**Drainage Network Ordering:** The operation examines all drainage lines in the drainage

network map from the Drainage Network Extraction Operation.

**Catchment Extraction Operation:** This operation constructs catchments for each stream found in the output map of the Drainage Network Ordering Operation. The operation uses a Flow direction map to determine the flow path of each stream.

**Catchment Merge Operation:** The Catchment merge operation merges adjacent catchments found from the Catchment Extraction Operation. Catchments can be merged in two ways:

- By specifying a point map that contains locations of the stream outlets within a catchment
- By simply specifying a Strahler or Shreve ordering value

As output a new catchment raster map, polygon map and attribute table are produced.

The DEM hydro-processing Raster Operations in ILWIS 3.7.1 Academic were used to identify the watershed by:

- Identifying and filling sinks in the DEM using the Fill Sinks operation.

- ii. Calculating and creating the flow direction map with new filled DEM using the Flow Direction operation.
  - iii. Calculating and creating flow accumulation map using the Flow Accumulation operation.
  - iv. Creating stream network map from the flow accumulation grid using the Drainage Network Extraction operation.
  - v. Creating stream order raster from the stream network raster map using Drainage Network Ordering operation. The method of stream ordering used was STRAHLER.
  - vi. Calculating and creating catchment for each of the streams found in the output map of the Drainage Network Ordering operation using the Catchment Extraction operation.
  - vii. Merging adjacent catchments from the catchment extraction operation based on the Drainage Network Ordering using the Catchment Merge operation. A stream order of 5 was used for the processing.
- iii. The segment map was polygonized to produce a polygon map of the delineated watershed.
  - iv. A raster map was created from the polygon map using the polygon to raster operation.
  - v. Map calculation was used to subset the irregular shape of the watershed boundary from the map obtained from the Drainage Network Extraction operation.

## 2.2 Stream Network Delineation in ILWIS

### 3.7.1

The stream network for the Dep River Basin was processed using the create segment map operation where the stream network within the subset watershed boundary was manually digitized.

The GIS and manually delineated watersheds and stream networks were overlaid in the software and compared.

## 3. RESULTS AND DISCUSSION

The map produced from the Catchment Merge operation is shown in Fig. 3. The digitized, polygonized and rasterized Dep River catchment boundary is shown in Fig. 4. From the attribute table produced from this process, the total catchment area for the Dep River watershed was 10640 km<sup>2</sup>. The delineated catchment was seen to be pear-shaped at the top and narrowing down at the bottom portion towards its confluence with River Benue and similar to the watershed manually delineated.

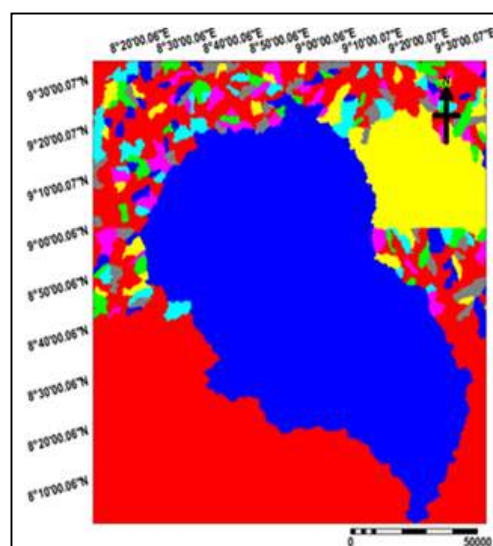


Figure 3: Map of the Delineated Catchments

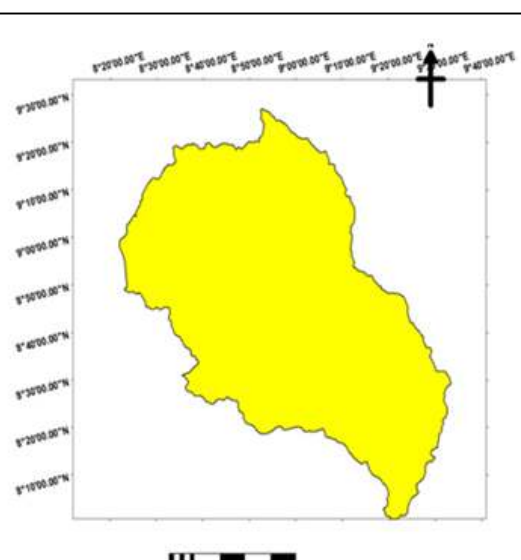


Figure 4: Digitized Dep River Watershed

The drainage network which was subset to the shape of the catchment boundary is shown in Fig. 5, this gives an indication of the stream network within the River Dep Basin. The digitized stream network and watershed boundary for the Dep River watershed is shown in Fig. 6.

The GIS delineated stream network and watershed boundary for the Dep River Basin follows the same pattern as the one delineated manually by Comprehensive Engineering Consultants in 1980 as given in its Final Report submitted to Lower Benue River Basin Development Authority, Nigeria. The two maps are observed to be identical when compared as shown in Fig. 7.

The total catchment area obtained for the GIS delineated watershed was 10640km<sup>2</sup> while it was 9600km<sup>2</sup> for the one delineated by manual methods in 1980, as recorded in the report. The same 1980 manually delineated map when scanned, imported and digitised in ILWIS 3.7.1 gave the total watershed area as 10244km<sup>2</sup>. These differences could be as a result of the effect of input data, which is the 90m SRTM DEM for the GIS delineation, or inability of some topographic details to be captured in estimation using manual delineation as a result of human limitation. This shows there was an underestimation of the catchment area by the manual delineation.

Using the Strahler method for stream network ordering for DEM hydro-processing, the stream order of the river drainage network was estimated to be 5 and a manual estimation of the stream order using the delineated stream network also showed that the stream order is 5. This shows that GIS can effectively capture the real watershed characteristics.

The results obtained from the GIS delineation of the watershed boundary and stream network compared favourably with the one delineated by manual method using topographic map as seen in Fig. 7. The 90m DEM used in delineation was effective in producing results that would not be much different had other finer spatial resolution DEM been used as seen from the work of [9] where 90m, 30m and 5m DEMs were used for watershed delineation and the result showed that there was no significant difference in watershed sizes and shapes. Also, the results of the work by [11] showed that although extremely high resolution data are more readily available now, the use of such data may not necessarily result in better DEMs for hydrologic applications. This suggests that the results obtained are satisfactorily acceptable.

The differences in the values of the watershed area obtained using the two methods do not reduce the effectiveness of the GIS method as an alternative to the manual method which could still produce differences from two individuals carrying out the same task.

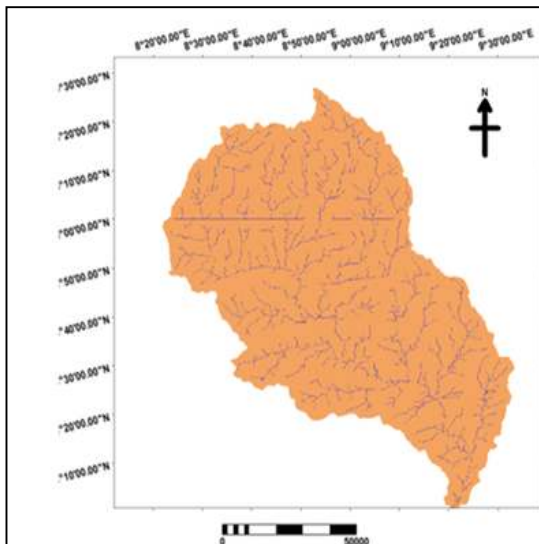


Figure 5: Subset Drainage Network Map of River Dep Watershed



Figure 6: Digitized Stream Network of River Dep Watershed

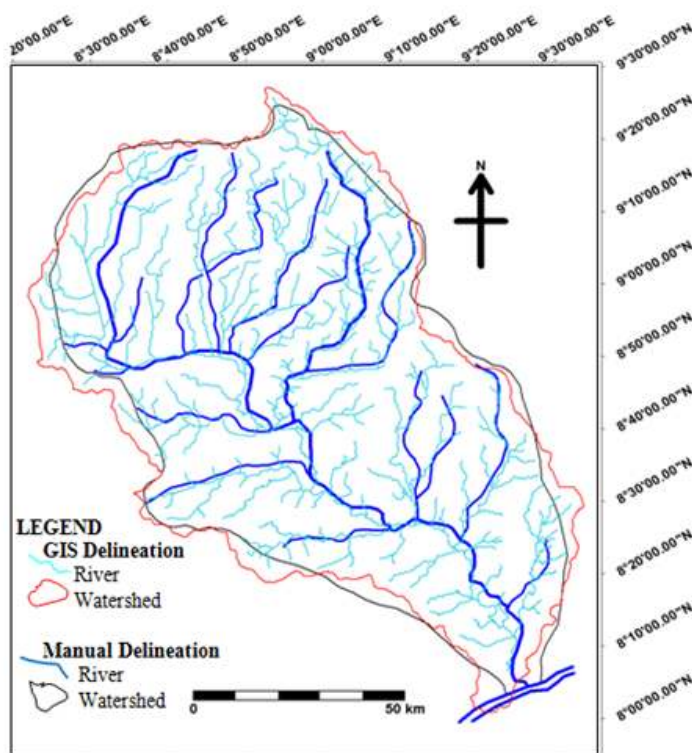


Figure 7: Comparison of GIS Delineated and Manually Delineated Watershed and Stream Network

## 5. CONCLUSION AND RECOMMENDATION

The results showed that the use of ILWIS DEM hydro-processing tools with 90m SRTM DEM produced watershed and stream network similar in shape, size and pattern to the ones delineated by manual method. The good agreement between the results of GIS watershed delineation and the hand delineation using a 90m resolution DEM points to the promising future of the use of remote sensing and GIS as useful data and tools for hydrological processing and analyses. Thus with proper ground truthing and other necessary checks the GIS method can be used for delineation of watersheds and stream networks and estimation of other watershed characteristics. This will help in overcoming the problem of using topographic maps which are mostly unavailable, outdated, scarce, incomplete and of different scales for most parts of Nigeria.

The ILWIS 3.7.1 hydro-processing tools are recommended for use for the delineation of watersheds and stream networks with the 90m or higher resolution DEMs. This is cost effective as both ILWIS 3.7.1, an open source software, and the 90m SRTM DEM can be obtained at no cost.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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