

Original Research Article

**DELINEATION OF RIVER WATERSHED AND STREAM NETWORK
USING ILWIS 3.7.1 ACADEMIC**

ABSTRACT

The delineation of watersheds can be carried out manually using topographic maps but these maps are mostly outdated and scarce for most parts of Nigeria and may be of different scales for large watersheds that require several sheets of the map.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 remote sensing and GIS technologies and comparing the shape and pattern with the one previously delineated manually using topographic maps and areal photographs. The 90m 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 10640km² while it was 9600km² 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 10244km². The differences in the watershed area could be due to the effect of input data or inability of some topographic details to be captured for the estimation using traditional delineation. The study showed similarity in shape and pattern however for both watersheds and stream networks delineated using the two methods. The study shows the capability of the ILWIS DEM hydro-processing tools for watershed and stream network delineation and recommends its use.

KEY WORDS: Watershed delineation, Stream network, GIS, Remote Sensing, DEM, topographic map

INTRODUCTION

Watershed modelling is an ideal application for GIS which allows the simulation of hydrologic processes in a more holistic approach manner, compared to many other models (Poyer, 2010 ; Tripathi and Gosain, 2013). A key component of watershed modelling is the watershed area that contributes flow to the point of interest (Poyer, 2010). 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', (Mays, 2005).

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 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 (Al-Muqdadi and Merkel, 2012). Digital Elevation Models (DEM) and Geographic Information System (GIS) softwares are tools that can be used for the quick 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. Daniel et al (2010) in their paper buttress 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.

Al-Muqdadi and Merkel (2011) also demonstrated the use of Digital Terrain Model and GIS techniques in delineating watersheds in flat and arid terrains of western Iraq desert. 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.

Sitanggang and Ismail (2010) demonstrated the use of standard Digital Elevation Model for watershed delineation in ArcGIS 9.1 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 map 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 (Al-Muqdadi and Merkel, 2010), there is the need to check the accuracy and effectiveness of this alternative because the areas and perimeters of watersheds are used in many hydrological analyses.

This study is aimed at delineating the River Dep watershed boundary and stream network using ILWIS 3.7.1 ACADEMIC and comparing the shape and pattern with the one previously delineated manually in 1980 using topographic maps and areal photographs.

ILWIS 3.7.1 HYDROPROCESSING TOOLS

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 Geographic Information System are mainly based on Digital Elevation Models. These are grids of elevation that store the same type of information as contour lines but with a different data structure. Most of the GIS softwares carry out watershed delineations by considering the following basic steps as extracted from the ILWIS 3.7.1 HEPL Menu:

77 Fill Sinks Operation: This is used to clean up the DEM before the carrying out the Flow
78 Direction Operation. Sinks are areas where water flows into and not out because all surrounding
79 pixels are higher in elevation. Flow directions cannot be defined for cells within a terrain
80 depression therefore DEMs have to be filled first. The Fill Sinks Operation removes:

- 81 • depressions that consist of a single pixel
- 82 • depressions that consist of multiple pixels

83 Flow Direction Operation: This operation uses the output map of the Fill Sinks Operation. It
84 indicates the pixel, out of the eight neighboring pixels, in a block of 3 by 3 pixels, towards which
85 water will flow naturally. That is the flow direction is calculated for every central pixel of input
86 blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8
87 neighbours.

88 Flow Accumulation Operation: This operation comes after the Flow Direction Operation. It
89 performs a cumulative count of the number of pixels that naturally drain into outlets. This
90 operation represents the amount of water that would flow into each cell assuming all the water
91 became runoff and there was no interception, evapotranspiration or loss to groundwater. Flow
92 Accumulation grid contains a running total of all cells contributing to a given cell. The operation
93 can be used to find the drainage pattern of a terrain.

94 Drainage Network Extraction: This operation extracts a basic drainage network, with input from
95 the Flow Accumulation Operation. The output raster map will show the basic drainage as pixels
96 with value True, while other pixels have value False.

97 A user sets a user-defined:

- a threshold value, i.e. a value for the minimum number of pixels that are supposed to drain into a pixel to let this pixel remain as a drainage in the output map; the larger the value chosen, the fewer drainages will remain in the output map;

- a threshold raster map that contains variable threshold values. A threshold map can for instance be based on geological units, on height values, or on an internal relief map, etc.

Drainage Network Ordering: This operation examines all drainage lines in the drainage network map from the Drainage Network Extraction Operation, finds the nodes where two or more streams meet, and assigns a unique ID to each stream in between these nodes, as well as to the streams that only have a single node. An attribute table is also created where information on the drainage network can be obtained.

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 and therefore requires as input the raster maps from the Drainage Network Ordering Operation and the Flow Direction Operation. As output a raster map, a polygon map and an attribute table are produced which all use the ID domain of the input Drainage network ordering map.

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 stream outlets within a catchment; all adjacent catchments that drain into such outlets will be merged,
- by simply specifying a Strahler or Shreve ordering value: all adjacent catchments that have this Strahler or Shreve order value (or a lower value) and which drain into a common catchment will be merged.

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

122

123 METHODOLOGY

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

125 Data Used: 90-meter Shuttle Radar Terrain Mission Digital Elevation Model (SRTM DEM) of
126 the study area.

127 The Digital Elevation Model (DEM) of the study area which lies between latitudes 8°00'00"N to
128 9°30'00"N and longitudes 8°20'00"E to 9°30'00"E, is shown in Figure 3.1 below.

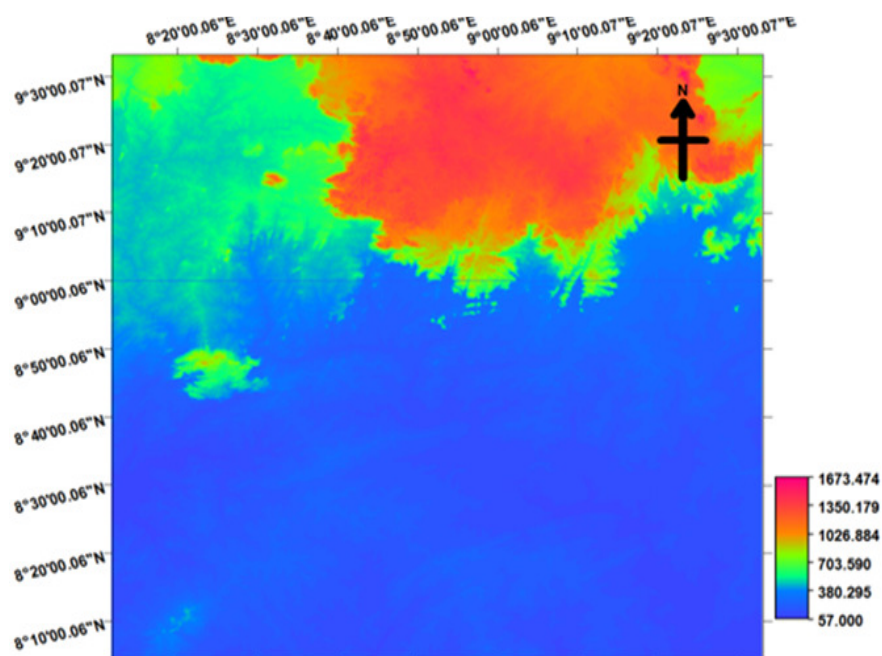


Figure 3.1: Digital Elevation Model Covering The Study Area

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130 The DEM hydro-processing Raster Operations in ILWIS 3.3 Academic were used to identify the
131 watershed by:

- 132 i. Identifying and filling sinks in the DEM using the Fill Sinks operation.
- 133 ii. Calculating and creating the flow direction map with new filled DEM using the Flow
134 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.

The following processes were used to subset the watershed of the Dep River Basin from the raster map obtained from the Catchment Merge operation:

- i. The map from the previous operation was polygonized to show all the catchments created.
- ii. The watershed of interest was manually digitized using the create segment map operation and also using a domain identifier.
- 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.

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

161 The digitally delineated and manually delineated watershed and stream network were
162 superimposed and compared.

163

164 RESULTS AND DISCUSSION

165 Figure 2 shows the map produced from the Catchment Merge operation. The digitized,
166 polygonized and rasterized Dep River catchment boundary is shown in Figure 3.
167 From the attribute table produced from this process, the total catchment area for the Dep River
168 watershed was 10640km². The delineated catchment was seen to be pear-shaped at the top and
169 narrowing down at the bottom portion towards its confluence with River Benue and similar to
170 the watershed manually delineated.

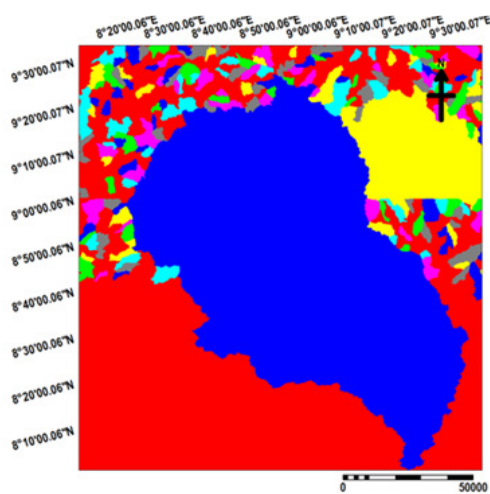


Figure 2: Map of the Delineated Catchments

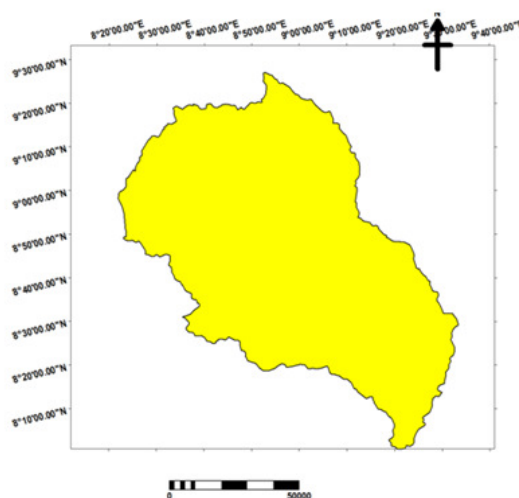


Figure 3: Digitized Dep River Watershed

172 The drainage network which was subset to the shape of the catchment boundary using map
173 calculation is shown in Figure 4, this gives an indication of the stream network within the Dep

174 River basin. The digitized stream network and watershed boundary for the Dep River watershed
175 is shown in Figure 5.

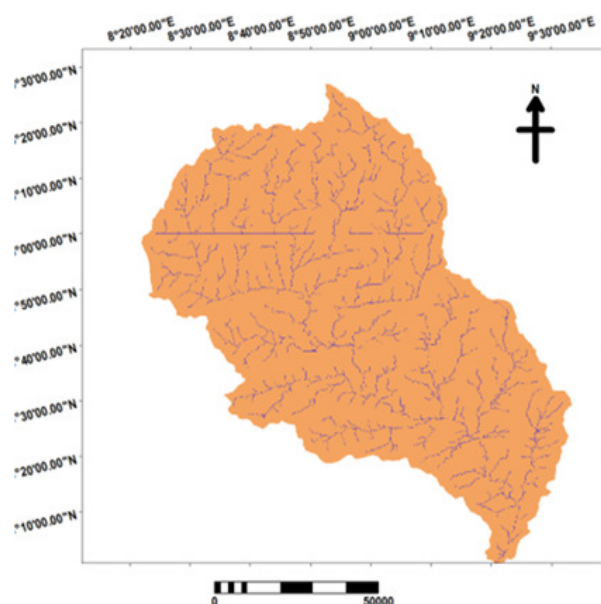


Figure 4: Subset Drainage Network Map of River Dep Watershed



Figure 5: Digitized Stream Network of River Dep Watershed

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177 The GIS delineated stream network and watershed boundary for the Dep River Basin follows the
178 same pattern as the one delineated manually by Comprehensive Engineering Consultants in 1980
179 and given in its Final Report submitted to Lower Benue River Basin Development Authority,
180 Nigeria. The two maps are observed to be identical when compared as shown in Figure 6.

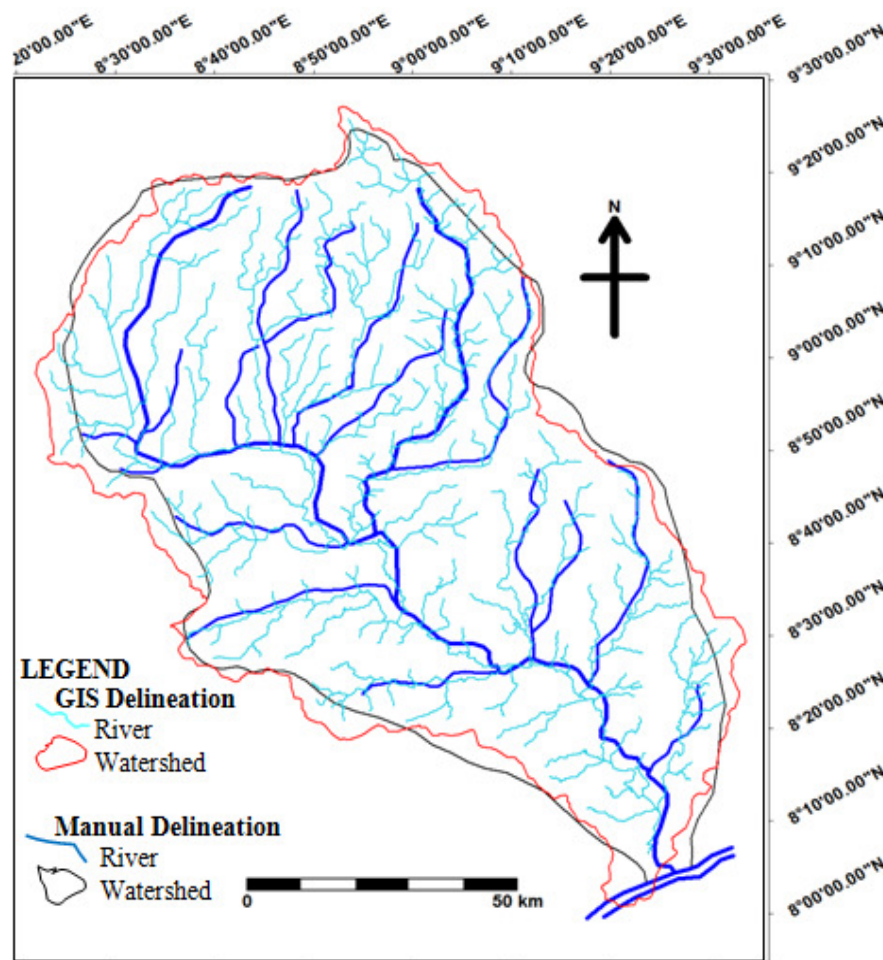


Figure 6: Watersheds and Stream Networks Overlaid for Comparison

The total catchment area obtained for the GIS delineated watershed was 10640km² while it was 9600km² 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 10244km². 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. These differences can also be attributed to changes caused by rain resulting in erosion or deposition of parts of the catchment boundary.

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.

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 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 GIS as useful tools for hydrological processing and analyses. The differences in the values of the watershed area using the two methods do not reduce the effectiveness of the GIS method as an acceptable alternative to the manual method which could still produce differences from two individuals carrying out the same task.

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.

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