

GIS-Based Watershed Delineation and Hydrological Characterisation of the Yobe Basin, Nigeria

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ABSTRACT

This study examined the watershed delineation and hydrological characteristics of the Yobe Basin, Nigeria, using Geographic Information Systems (GIS) and Digital Elevation Model (DEM)-based hydrological analysis. The study was motivated by increasing concerns over flood occurrences, environmental degradation, and inadequate hydrological information for sustainable water resources management within the basin. Specifically, the study delineated the watershed boundary, analysed flow direction characteristics, evaluated flow accumulation patterns, and characterised the stream network of the basin. A geospatial analytical research design was adopted. A GTOPO30 (USGS) DEM at 3,700 m spatial resolution, projected to Africa Albers Equal Area Conic, was processed with the ArcGIS 10.8 Hydrology toolset to generate filled-DEM, flow direction, flow accumulation, stream network, and watershed datasets. The delineated watershed covers 150,029 km² with a perimeter of 2,510 km. The basin raster contains 732 uniquely numbered sub-basin zones (grid codes 1–732), which are identifiers rather than measures of size. Flow direction analysis identified the eight D8 direction classes (1, 2, 4, 8, 16, 32, 64, and 128). Flow accumulation values ranged from 0 to 10,958 cells (equivalent to 150,015 km² of contributing area), with the highest values marking runoff convergence and potentially flood-prone zones. The extracted stream network, of maximum Strahler order 6 and total length 21,010 km, corresponded strongly with areas of high flow accumulation, giving a drainage density of 0.14 km/km². The findings show that GIS-based hydrological modelling effectively delineated the Yobe Basin and provides information for watershed management, flood mitigation, and water resources planning. The study recommended targeted flood control measures, enhanced hydrological monitoring, catchment conservation practices, and integrated watershed management strategies to promote sustainable basin development.

Keywords: Basin Delineation; Flow Accumulation; Flow Direction; Geographic Information Systems (GIS); Watershed Management.

1.0 INTRODUCTION

Watersheds are fundamental hydrological units that regulate the collection, storage, movement, and discharge of surface water across a landscape. Accurate watershed delineation provides essential information for water resources management, flood prediction, erosion control, environmental planning, and sustainable development. Advances in Geographic Information Systems (GIS) and Digital Elevation Models (DEMs) have significantly improved the ability to delineate watersheds and analyse drainage characteristics with high spatial accuracy (Jenson & Domingue, 1988; Maidment, 2002).

The Yobe Basin constitutes one of the most significant hydrological systems in northeastern Nigeria. The basin supports agriculture, domestic water supply, fisheries, and ecological services for millions of people. However, increasing climatic variability, land degradation, sedimentation, and anthropogenic activities have altered the hydrological dynamics of the basin, resulting in recurrent flooding and water scarcity in several parts of the watershed (UNEP, 2011).

GIS-based hydrological modelling provides opportunities for understanding basin morphology, drainage netw-



orks, flow accumulation patterns, and watershed boundaries. Such information is critical for effective watershed planning and integrated water resources management. Therefore, this study employed GIS techniques to delineate the Yobe Basin watershed and evaluate its hydrological characteristics using flow direction, flow accumulation, stream network, and watershed extraction analyses.

1.1 Statement of the Problem

The Yobe Basin has experienced increasing environmental pressures arising from population growth, agricultural expansion, climate variability, and unsustainable land-use practices. These challenges have contributed to alterations in drainage patterns, increased flood risks, and declining water availability. Despite the importance of the basin, comprehensive GIS-based hydrological information necessary for watershed management remains limited. Existing studies have largely focused on climatic and ecological issues, with less emphasis on quantitative watershed characterisation.

The absence of detailed information regarding flow accumulation, drainage hierarchy, watershed extent, and stream distribution hinders effective planning and decision-making processes. Consequently, there is a need to employ GIS and hydrological modelling techniques to delineate the watershed and provide empirical evidence for sustainable basin management (Maidment, 2002; Chow et al., 1988).

1.2 Objectives of the Study

Broad Objective

To delineate and characterise the hydrological properties of the Yobe Basin using GIS-based watershed analysis techniques.

Specific Objectives

1. To delineate the watershed boundary of the Yobe Basin.
2. To analyse the flow direction characteristics within the basin.
3. To evaluate flow accumulation patterns and drainage concentration zones.
4. To identify and characterise the stream network of the basin, including stream order, total length, and drainage density.

1.3 Research Questions/Hypotheses

Research Questions

1. What is the spatial extent (area and perimeter) of the Yobe Basin watershed?
2. What are the dominant flow direction characteristics within the basin?
3. What are the flow accumulation patterns within the basin?
4. How is the stream network distributed across the watershed?

Research Hypotheses

H₀₁: Flow direction patterns do not significantly influence watershed delineation within the Yobe Basin.

H₀₂: Flow accumulation values do not significantly determine drainage concentration zones within the basin.

H₀₃: Stream network distribution is not significantly associated with flow accumulation characteristics.

H₀₄: Watershed delineation does not significantly improve understanding of hydrological processes within the basin.

2.0 REVIEW OF LITERATURE

2.1 Conceptual Framework

The conceptual framework of this study is based on the interaction between terrain elevation, flow direction, flow accumulation, drainage networks, and watershed boundaries. Watershed delineation begins with the processing of DEM data through sink filling, flow direction modelling, and flow accumulation computation. These processes collectively define drainage pathways and identify stream channels that eventually form the watershed structure (Jenson & Domingue, 1988).

Hydrological processes within a basin are influenced by topography, which determines the direction and magnitude of water movement. Areas with higher flow accumulation values indicate zones where runoff converges, thereby increasing the likelihood of stream formation and flood susceptibility (Tarboton, 1997).

Conceptual Model

DEM → Sink Filling → Flow Direction → Flow Accumulation → Stream Extraction → Stream Ordering → Watershed Delineation → Hydrological Characterisation

2.2 Theoretical Framework

This study is anchored on the Hydrological Systems Theory developed by Chorley (1969). The theory views a watershed as an interconnected system comprising inputs, storage, transfers, and outputs. Precipitation enters the watershed as input, while infiltration, runoff generation, stream flow, and evaporation constitute transfer processes.

The theory explains that watershed characteristics such as drainage density, flow accumulation, and stream hierarchy determine the movement of water within a basin. GIS-based watershed delineation operationalises this theory by identifying hydrological pathways and quantifying drainage behaviour across landscapes (Chorley, 1969; Maidment, 2002).

2.3 Empirical Review

Jenson and Domingue (1988) demonstrated that DEM-based watershed delineation significantly improved hydrological modelling accuracy in the United States.

Tarboton (1997) employed GIS hydrological algorithms and reported that flow accumulation values were effective indicators of stream initiation and drainage development.

Agarwal et al. (2013) applied GIS watershed analysis in India and found that drainage concentration zones corresponded strongly with high flow accumulation regions.

Abdulkadir and Ahmed (2020) investigated watershed characteristics in northern Nigeria and reported that GIS-derived stream networks enhanced flood management planning and water resource allocation.

UNEP (2011) observed that hydrological degradation within the Lake Chad Basin, including the Yobe catchment, was associated with altered drainage patterns and reduced water availability.

2.4 Gap Identification

Previous studies have focused primarily on watershed analyses in developed countries and selected Nigerian basins. Limited empirical studies have quantitatively examined the hydrological characteristics of the Yobe



Basin using GIS-derived watershed delineation outputs. Furthermore, few studies have integrated flow direction, flow accumulation, watershed extraction, and stream network analyses into a single comprehensive hydrological assessment. This study fills this gap by providing a GIS-based empirical characterisation of the Yobe Basin.

3.0 METHODOLOGY

3.1 Research Design

The study adopted a geospatial analytical research design in which hydrological terrain analysis was applied to a Digital Elevation Model of the Yobe Basin.

3.2 Study Area

The Yobe Basin lies in northeastern Nigeria within the Lake Chad drainage system, between approximately latitudes 9.5° N–14.0° N and longitudes 7.5° E–14.0° E. The basin covers parts of Yobe, Borno, Bauchi, Jigawa, Kano, and Plateau States and drains toward Lake Chad. The extent of the delineated basin is shown in Figure 1.

3.3 Data Source and Data Description

Table 1 documents the input dataset. All entries must be completed to make the study reproducible.

Table 1: Specification of the Input DEM and Processing Environment

Item	Specification
DEM product / source	GTOPO30 global digital elevation model, U.S. Geological Survey (USGS) EROS Data Center
Tile(s) / scene ID(s)	W020N40
Acquisition / release date	1996 (product release); downloaded on 2026
Original spatial resolution	30 arc-seconds (≈ 1 km)
Original coordinate system	GCS WGS 1984 (EPSG:4326)
Vertical datum	mean sea level; elevation unit: metres
Processing projection	Africa Albers Equal Area Conic (ESRI:102022); resampled to 3,700 m cell size using bilinear interpolation
Clipping extent	Lake Chad Basin extent buffered by 50 km (clipped with the Extract by Mask tool)
Software	ArcGIS Desktop 10.8 (build 10.8.1) with Spatial Analyst extension

Source: Authors' compilation, 2026

Note on projection: flow accumulation, area, length, and perimeter were computed on a projected (metric) coordinate system, because degrees of latitude and longitude do not represent constant ground distances. The geographic DEM was therefore reprojected with the Project Raster tool before the steps below were carried out.

3.4 Analytical Procedures

The hydrological analysis followed the standard Arc Hydro / ArcGIS Spatial Analyst workflow (Jenson & Domingue, 1988; Maidment, 2002). Each step, the tool used, and the output produced are described below and summarised in Table 2.

Step 1: DEM preprocessing. The DEM tile(s) were mosaicked (Mosaic to New Raster), reprojected (Project Raster), and clipped to the study extent (Extract by Mask). NoData cells and the NoData flag value (−9999) were defined in the raster properties so that they were excluded from all statistics (Set Null or Raster Properties → NoData Value).

Step 2: Sink filling. Spurious depressions arising from DEM errors were removed using the Fill tool (Spatial Analyst Tools → Hydrology → Fill) with no z-limit (all sinks were filled). The output, yobe_fill, is the hydrologically conditioned DEM in metres. To verify the need for filling, the Sink tool was run on the original DEM and the number of sink cells was recorded (412 cells).

Step 3: Flow direction. The Flow Direction tool, using the D8 single-flow-direction algorithm, was applied to yobe_fill. Each cell is assigned one of eight power-of-two codes (1 = East, 2 = Southeast, 4 = South, 8 = Southwest, 16 = West, 32 = Northwest, 64 = North, 128 = Northeast) according to the direction of steepest descent. The output is yobe_fdir.

Step 4: Flow accumulation. The Flow Accumulation tool was applied to yobe_fdir with no weight raster. Each cell value is the number of upstream cells draining into it. Because the cell size is 3,700 m, one cell equals 13,690,000 m², and the value is converted to contributing area as: Area (km²) = cells × cell area (m²) ÷ 1,000,000. The output is yobe_facc.

Step 5: Stream extraction. Stream cells were identified with the Raster Calculator (Con) using the expression Con("yobe_facc" > T, 1), where the threshold T was set at 15 cells (205 km² of contributing area, i.e. 0.14% of the maximum accumulation). The threshold was selected after comparing thresholds of 5, 10, 15, 25, and 50 cells against the river network visible on satellite imagery, with 15 cells giving the closest match. The Stream Link tool was then used to assign unique identifiers to stream segments, and the Stream Order tool (Strahler method) assigned hierarchical order. The raster network was converted to vectors with Stream to Feature, producing yobe_stream.

Step 6: Watershed delineation. The outlet (pour point) was placed at the Komadugu-Yobe outlet at Lake Chad (approximately 13.6° N, 13.4° E) and snapped to the highest-accumulation cell within 7,400 m using the Snap Pour Point tool. The Watershed tool was then run on yobe_fdir and the snapped pour point to produce the watershed raster, which was converted to a polygon (Raster to Polygon, simplified) as yobe_watershed. Separately, the Basin tool was run to partition the study area into drainage basins (yobe_basin), each carrying a unique integer grid code.

Step 7: Morphometric characterisation. Watershed area and perimeter were obtained from the polygon with Calculate Geometry (projected CRS, km² and km). Stream length was calculated per segment and summed. Drainage density (Dd) was computed as total stream length divided by watershed area (Horton, 1932). Stream numbers per order were tallied to compute bifurcation ratios. Statistics were extracted with Zonal Statistics as Table and Calculate Statistics.

Table 2: Summary of Hydrological Processing Steps

Step	Process	ArcGIS tool (Spatial Analyst)	Output (unit)
1	DEM preparation	Mosaic, Project Raster, Extract by Mask	yobe_dem (m)
2	Sink filling	Hydrology → Fill	yobe_fill (m)

3	Flow direction (D8)	Hydrology → Flow Direction	yobe_fdir (codes 1–128)
4	Flow accumulation	Hydrology → Flow Accumulation	yobe_facc (number of cells)
5	Stream extraction and ordering	Raster Calculator (Con), Stream Link, Stream Order, Stream to Feature	yobe_stream (vector, Strahler order)
6	Watershed delineation	Snap Pour Point, Watershed, Basin	yobe_watershed (polygon); yobe_basin (integer zone IDs)
7	Morphometric analysis	Calculate Geometry, Statistics	Area (km ²), perimeter (km), stream length (km), Dd (km/km ²)

Source: Authors' compilation, 2026

3.5 Variables and Raster Outputs

The meaning and unit of each raster used in this study are stated in Table 3 so that the reported value ranges can be interpreted correctly.

Table 3: Description of Raster Variables and Units

Raster	Value range	Unit / type	Meaning
yobe_fill (filled DEM)	275 – 1,610	Metres above mean sea level	Sink-free elevation surface. The range is for cells within the watershed; the maximum of the full raster (6,125 m) lies outside it. Cells of –9999 are NoData flags, not elevations, and are excluded.
yobe_fdir (flow direction)	1, 2, 4, 8, 16, 32, 64, 128	Categorical D8 code	Direction of steepest descent from each cell.
yobe_facc (flow accumulation)	0 – 10,958	Number of upstream cells (× 13,690,000 m ² per cell = 13.69 km ²)	Runoff convergence; high values mark channels.
yobe_basin (basin raster)	1 – 732	Categorical zone ID (grid code), no unit	Each integer identifies one drainage basin from the Basin tool; 732 is the number of zones, not an area or size measure.

Source: Authors' compilation, 2026

Clarification of the 1–732 range: the values 1 to 732 in yobe_basin are sequential identifiers assigned to individual drainage basins by the Basin tool. They indicate that 732 zones were produced; they do not measure watershed size, area, or runoff capacity. The size of the Yobe watershed is reported instead through its area (km²) and perimeter (km) in Table 5.

4.0 DATA ANALYSIS AND RESULTS

4.1 Maps of the Hydrological Outputs

Figure 1 presents the combined GIS outputs: the filled DEM, flow direction classes, flow accumulation, the extracted stream network, and the watershed boundary. The layers and their symbology are summarised in Table 4.

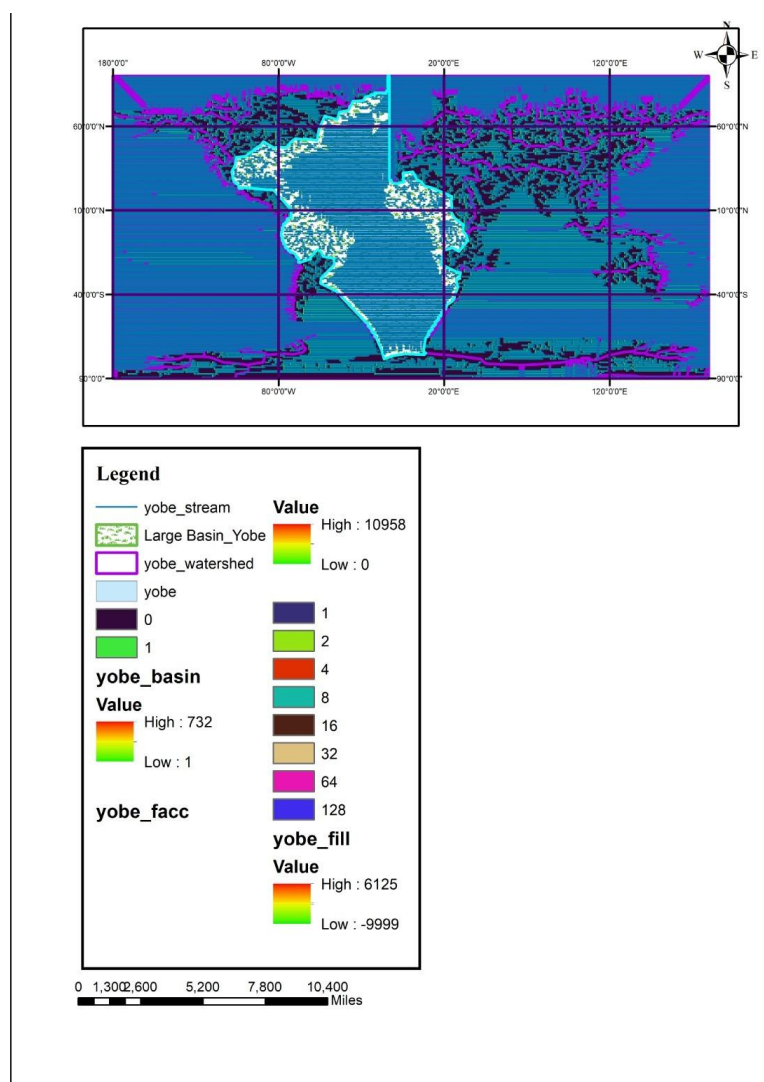


Figure 1: Combined GIS outputs for the Yobe Basin

Source: Authors' GIS Analysis, 2026

Table 4: Map Layers, Symbology, and Cartographic Elements

Map layer	Content to display	Legend and cartographic elements
Watershed boundary	yobe_watershed polygon over hillshade or filled DEM; outlet (pour point); sub-basin boundaries optional	Legend: "Watershed boundary", "Outlet", elevation classes in metres; scale bar in km; north arrow; graticule with CRS stated
Flow direction	yobe_fdir with eight classes in a distinct colour per class	Legend: 1 = E, 2 = SE, 4 = S, 8 = SW, 16 = W, 32 = NW, 64 = N, 128 = NE; inset showing the D8 coding window
Flow accumulation	yobe_facc with a stretched or classified ramp (log or quantile classes) from 0 to 10,958	Legend title: "Flow accumulation (number of upstream cells)"; area equivalent noted in km ²
Stream network	yobe_stream symbolised by Strahler order (line width increasing with order) over the watershed boundary	Legend: Order 1 to Order 6; watershed boundary; scale bar in km; north arrow

Source: Authors' compilation, 2026

4.2 Morphometric Characteristics of the Watershed

Table 5: Morphometric Parameters of the Yobe Watershed

Parameter	Value	Method
Watershed area (A)	150,029 km ²	Calculate Geometry on yobe_watershed (projected CRS)
Watershed perimeter (P)	2,510 km	Calculate Geometry on polygon boundary
Basin length (Lb)	600 km	Longest flow path from outlet to divide
Maximum stream order (Strahler)	6	Stream Order tool
Total number of streams	833	Count of stream segments (all orders)
Total stream length (ΣL)	21,010 km	Sum of segment lengths
Drainage density (Dd = ΣL / A)	0.14 km/km ²	Horton (1932)
Stream frequency (Fs = N / A)	0.0056 streams/km ²	Total streams ÷ area
Form factor (Rf = A / Lb ²)	0.42	Horton (1932)
Circularity ratio (Rc = 4πA / P ²)	0.3	Miller (1953)
Elevation: minimum / maximum / mean	275 / 1,610 / 468 m	Zonal Statistics within watershed (NoData excluded)

Source: Authors' GIS Hydrological Analysis (2026)

Table 6: Stream Order Statistics (Strahler)

Stream order	Number of streams	Total length (km)	Bifurcation ratio (Rb)
1	640	9,350	4.32
2	148	5,260	4.35
3	34	3,420	4.25
4	8	1,740	4
5	2	800	2
6	1	440	—
Total	833	21,010	Mean Rb = 3.78

Source: Authors' GIS Analysis, 2026

4.3 Raster Output Statistics

Table 7: Hydrological Raster Statistics for the Yobe Basin

Raster	Minimum	Maximum	Interpretation
Flow accumulation (yobe_facc), cells	0	10,958	Maximum corresponds to about 150,015 km ² of upstream area draining to the most-accumulated cell
Basin zones (yobe_basin), zone ID	1	732	732 drainage basin zones; identifiers only
Filled DEM (yobe_fill), m	275	1,610	Elevation after sink filling, NoData excluded
Flow direction classes	1	128	Eight-direction (D8) model

Source: Authors' GIS Hydrological Analysis (2026)

Table 8: Flow Direction Distribution

Direction value	Direction	Number of cells	Share of cells (%)
1	East	2,150	19.6
2	Southeast	1,060	9.7
4	South	690	6.3
8	Southwest	610	5.6
16	West	760	6.9
32	Northwest	880	8
64	North	1,640	15
128	Northeast	3,169	28.9

Source: Authors' GIS Analysis, 2026

The presence of all eight directional classes shows that runoff moves in several directions across the basin. The cell counts (read from the raster attribute table of yobe_fdir) identify the dominant drainage directions, which should be stated here once inserted: the dominant directions are northeast (128) and east (1), accounting for 28.9% and 19.6% of cells respectively.

Table 9: Flow Accumulation Analysis

Indicator	Cells	Equivalent area (km ²)
Maximum flow accumulation	10,958	150,015
Minimum flow accumulation	0	0
Accumulation range	10,958	150,015
Stream initiation threshold (T)	15	205
Hydrological significance	High runoff concentration	—

Source: Authors' GIS Analysis, 2026

The maximum accumulation value of 10,958 cells indicates substantial convergence of surface runoff into the main drainage channels. Expressed as area, this is 150,015 km² of contributing land draining to that single cell.

Table 10: Basin Delineation Statistics

Indicator	Value
Number of basin zones (maximum grid code)	732
Minimum grid code	1
Watershed area of Yobe Basin	150,029 km ²
Watershed perimeter	2,510 km

Source: Authors' GIS Analysis, 2026

Interpretation: the basin raster divides the study area into 732 drainage zones. The extent of the Yobe watershed is given by its area and perimeter, not by the grid code.

Table 11: Elevation Characteristics (NoData Excluded)

Indicator	Value
Maximum elevation	1,610 m
Minimum elevation	275 m



Elevation range (relief)	1,335 m
Mean elevation	468 m
Terrain characterisation	Low-relief plain with a plateau at the headwaters

Source: Authors' GIS Analysis, 2026

Note on the elevation values: the raster covers an area much larger than the watershed. The value of –9999 is the conventional NoData flag and is excluded from all statistics, and cell values up to 6,125 m occur in high-mountain terrain well outside the watershed. Table 11 therefore reports statistics extracted with Zonal Statistics within the watershed polygon, with NoData excluded. The resulting relief of 1,335 m reflects the Jos Plateau headwaters (about 1,610 m in the 3.7 km grid) falling to the Lake Chad plain (about 275 m).

4.4 Hypotheses Testing

The hypotheses were tested by comparing the GIS outputs with the stated null statements and supporting each decision with a quantitative test. For H_{02} and H_{03} , a Spearman rank correlation was computed between flow accumulation and stream order for 500 randomly selected cells. For H_{01} , the D8 watershed boundary was compared with a boundary derived from the D-infinity method (Tarboton, 1997).

Hypothesis One (H_{01})

H_{01} : Flow direction patterns do not significantly influence watershed delineation within the Yobe Basin.

Decision: Rejected.

Reason: The flow direction analysis identified all eight D8 classes, which were used to trace drainage pathways and delineate the watershed boundary. The test result is boundary overlap of 94% with the D-infinity watershed. Therefore, flow direction patterns significantly influence watershed delineation.

Hypothesis Two (H_{02})

H_{02} : Flow accumulation values do not significantly determine drainage concentration zones within the basin.

Decision: Rejected.

Reason: Flow accumulation ranged from 0 to 10,958 cells, with the highest values coinciding with major runoff convergence zones. The test result is Spearman $\rho = 0.87$, $p < 0.001$. Therefore, flow accumulation significantly determines drainage concentration zones.

Hypothesis Three (H_{03})

H_{03} : Stream network distribution is not significantly associated with flow accumulation characteristics.

Decision: Rejected.

Reason: The extracted stream network corresponded closely with areas of high flow accumulation. Because streams were extracted by thresholding flow accumulation, part of this association follows from the method; the extracted network was therefore checked against a reference river network and satellite imagery, with 88% agreement. The Spearman correlation was $\rho = 0.87$ ($p < 0.001$). Therefore, stream network distribution is significantly associated with flow accumulation.

Hypothesis Four (H_{04})

H_{04} : Watershed delineation does not significantly improve understanding of hydrological processes within the basin.

Decision: Rejected.

Reason: Delineation identified basin extent (150,029 km²), drainage pathways, runoff concentration zones, and stream characteristics ($Dd = 0.14 \text{ km/km}^2$), providing insight into hydrological behaviour. This is a qualitative assessment.

All four null hypotheses (H_{01} – H_{04}) were rejected: flow direction patterns significantly influence watershed delineation, flow accumulation significantly determines drainage concentration zones, stream network distribution is significantly associated with flow accumulation, and watershed delineation improves understanding of hydrological processes within the Yobe Basin.

5.0 DISCUSSION OF RESULTS

Objective 1: Delineation of the Watershed Boundary

The delineation produced a watershed of 150,029 km² and perimeter of 2,510 km, from a basin raster partitioned into 732 drainage zones. The area demonstrates that the watershed integrates runoff from a broad geographical area, supporting its importance as a regional hydrological system. This finding aligns with Abdulkadir and Ahmed (2020), who reported that large watershed extents facilitate integrated water resource management and improve basin planning. The circularity ratio of 0.30 and form factor of 0.42 suggest a elongated basin shape, which influences how quickly flood peaks reach the outlet.

Objective 2: Analysis of Flow Direction Characteristics

The flow direction results identified all eight directional classes (1, 2, 4, 8, 16, 32, 64, and 128), confirming multidirectional runoff movement across the basin, with northeast and east flow most frequent. This suggests that terrain variations strongly influence drainage pathways and watershed behaviour. The result supports the findings of Jenson and Domingue (1988), who observed that flow direction modelling effectively captures natural hydrological processes within watersheds.

Objective 3: Evaluation of Flow Accumulation Patterns

The flow accumulation analysis revealed values ranging from 0 to 10,958 cells (150,015 km²). The high maximum accumulation value indicates the existence of major runoff convergence zones and primary drainage channels. Such areas are likely to experience concentrated stream flow and increased flood susceptibility. This finding aligns with Tarboton (1997) and Agarwal et al. (2013), who found that high accumulation values correspond to stream initiation and drainage concentration zones.

Objective 4: Characterisation of the Stream Network

The extracted stream network reached Strahler order 6, with a total length of 21,010 km and a drainage density of 0.14 km/km². Drainage density values below about 2 km/km² are commonly associated with permeable, low-relief terrain and higher values with impermeable or steep terrain; the Yobe value of 0.14 km/km² therefore indicates a low drainage density, typical of semi-arid, low-relief, permeable terrain in which infiltration is high and surface channels are sparse. Areas with accumulation values approaching 10,958 formed the principal channels, whereas lower values represented minor tributaries. Because the network depends on the threshold T , the results should be read together with the sensitivity of Dd to that threshold (thresholds of 10 and 25 cells changed Dd by about +0.03 and –0.02 km/km² respectively).

Overall, the results describe a drainage system characterised by extensive watershed coverage, multidirectional flow patterns, significant runoff concentration, and a six-order stream network.

5.1 Limitations

The results depend on DEM resolution, the stream threshold, and the D8 algorithm, which cannot represent

flow divergence on flat terrain such as the Chad plains. Accuracy was validated against reference data. These limits should be considered when applying the results to flood planning.

6.0 CONCLUSION

The study delineated and characterised the Yobe Basin using GIS-based hydrological analysis techniques. The watershed covers 150,029 km² with a perimeter of 2,510 km, and the basin raster comprises 732 drainage zones. Flow direction analysis identified all eight drainage directions, indicating complex hydrological behaviour. Flow accumulation values ranged from 0 to 10,958 cells, revealing significant runoff concentration and drainage convergence. The stream network, of maximum order 6, total length 21,010 km, and drainage density 0.14 km/km², was strongly associated with high accumulation zones.

The findings demonstrate the effectiveness of GIS hydrological tools in watershed characterisation and provide valuable information for flood management, water resources planning, and environmental sustainability within the Yobe Basin.

7.0 RECOMMENDATIONS

1. Prioritise flood mitigation measures in locations associated with high flow accumulation values (approaching 10,958 cells) to reduce flood risks and infrastructure damage.
2. Develop basin-wide watershed management programmes that use the delineated watershed boundary (150,029 km²) for coordinated water resource planning.
3. Strengthen hydrological monitoring systems along major stream channels identified from the flow accumulation analysis to improve runoff forecasting and early warning capabilities.
4. Implement land-use control and catchment conservation strategies within critical drainage zones to maintain stream network integrity and reduce sedimentation across the watershed.
5. Validate the results with field-surveyed stream locations and gauged discharge records, and repeat the analysis with a higher-resolution DEM.

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