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Analysis of Spatial Data for Hydrological Modelling of Tiga Dam Watershed, Kano, Nigeria

***[1]Ibrahim Yakubu Abubakar, [1]Haruna Garba and [2]Abbas Usman**

[1]Department Of Civil Engineering, Nigerian Defence Academy, Kaduna State, Nigeria.
[2]Department Civil Engineering, Nuhu Bamalli Polytechnic, Zaria, Kaduna State, Nigeria.

*Corresponding authors' email: iyabubakar779@gmail.com

ABSTRACT
Hydrological modelling depends on reliable spatial datasets that represent watershed terrain, land use/land cover (LULC), soil and drainage characteristics. This study analyzed and prepared spatial datasets for subsequent hydrological modelling of a selected 116.46 km² portion of the Tiga Dam watershed, Kano State, Nigeria, using Geographic Information System (GIS) and remote sensing techniques. A 30 m Shuttle Radar Topography Mission (SRTM) Digital Elevation Model was processed in ArcGIS to derive elevation, slope, flow direction, flow accumulation, drainage networks, and the watershed boundary. Sentinel-2 imagery with 10 m spatial resolution was classified using the Maximum Likelihood supervised classifier into vegetation, agricultural land, built-up area and water body classes. The resulting LULC distribution comprised agricultural land (75.19 km²; 64.56%), vegetation (25.41 km²; 21.82%), water body (13.32 km²; 11.44%), and built-up area (2.54 km²; 2.18%). Accuracy assessment based on 69 validation samples produced 88% overall accuracy and a Kappa coefficient of 0.84. Soil information obtained from OpenLandMap was classified into Hydrologic Soil Groups A–D, while DEM-derived flow characteristics were used to delineate the watershed and its drainage/sub-basin structure. All datasets were spatially harmonized through projection, clipping and resampling. The resulting terrain, LULC, soil and drainage layers provide a documented spatial basis for subsequent watershed and Hydrological Response Unit development. No rainfall–runoff simulation, SWAT calibration or validation was conducted. Therefore, the findings represent spatial characterization and preprocessing outputs not direct hydrological model predictions.

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INTRODUCTION

Water resources management in semi-arid regions requires a comprehensive understanding of watershed characteristics and hydrological processes. The Tiga Dam watershed, located within the Kano River Basin of northern Nigeria, is a vital source of irrigation water, domestic supply, and flood regulation. However, increasing population growth, agricultural expansion, and land-use changes have altered the watershed's physical characteristics, influencing runoff generation, sediment transport, and overall hydrological response. Accurate characterization of these changes is therefore essential for effective watershed management and hydrological modelling (Umar, 2019; Li et al., 2018; Foley et al., 2005). Recent advances in Geographic Information Systems (GIS), Remote Sensing (RS), and Digital Elevation Models (DEMs) have significantly improved the ability to analyze watershed terrain and environmental characteristics. These technologies facilitate the extraction and integration of critical spatial datasets, including elevation, slope, drainage networks, land use/land cover (LULC), and soil properties, which serve as fundamental inputs for hydrological models such as the Soil and Water Assessment Tool (SWAT) thereby improving the accuracy and reliability of watershed characterization and simulation (Arnold et al., 2012; Dile et al., 2017; Tuo et al., 2021). The integration of raster and vector datasets within a GIS environment enables detailed assessment of watershed processes and supports evidence-based water resources planning. Spatial dataset analysis involves the acquisition, preprocessing, analysis, and validation of geographically referenced data to understand environmental patterns and hydrological behavior. According to Campbell & Wynne (2011), a satellite imagery requires radiometric and atmospheric corrections to enhance classification accuracy. In watershed studies, DEMs are commonly used to derive topographic parameters such as slope, flow direction, and flow accumulation, while satellite imagery provides information on land cover dynamics. These datasets are subsequently processed through projection harmonization, resampling, and clipping to ensure spatial consistency and analytical reliability (Burrough et al., 2015; Wilson & gallant, 2000; Taborton, 1997). The resulting spatial layers form the basis for watershed delineation and the generation of Hydrological Response Units (HRUs) required for SWAT simulations. Hydrological models provide a framework for understanding watershed processes and supporting sustainable management of soil and water resources. Among the available models, SWAT has gained widespread acceptance due to its capability to simulate complex hydrological processes at watershed scale while accounting for spatial heterogeneity through HRUs (Gassman et al., 2007). The model's compatibility with GIS and its ability to utilize globally available spatial datasets make it particularly suitable for watershed assessments in data-scarce regions. Although hydrological modelling has been applied in the wider Hadejia–Jama'are–Komadugu–Yobe system, the spatial-data requirements of the selected Tiga Dam portion remain insufficiently documented despite the importance of the River Basin to agricultural production and water supply in Kano. Ejieji et al. (2016), for instance, applied SWAT to stream-flow prediction in the Hadejia–Jama'are–Komadugu–

Yobe River Basin and calibrated and validated the model using observed stream-flow, adopted a 90m DEM resolution, the resolution introduced spatial uncertainty, making it harder for their model to accurately capture localized runoff and drainage patterns. However, Balarabe et al (2025), analyzed satellite-derived land cover shifts around the Tiga Dam, documenting a steady decline in natural shrub-land/vegetation alongside expanding cropland, which reflect ongoing land-use transformation and increasing agricultural land coverage within the region. The study did not address the terrain generalization and lack of spatial datasets cross-validation. Babaremu (2024), also applied GIS terrain pre-processing and ArcSWAT modeling to semi-arid savanna catchments in Northern Nigeria, confirming that high-resolution DEMs (30m SRTM) effectively capture slope-driven hydrologic response units. These studies demonstrate that hydrological modeling and LULC studies were established in the wider basin. Therefore, a more specific gap concerns the need for a clearly documented and internally consistent spatial-data framework for a selected portion of the Tiga Dam area. In particular, the present work brings together DEM-derived terrain and drainage characteristics, Sentinel-2 LULC classification, soil information and GIS-based spatial harmonization within a single workflow. The contribution is therefore methodological and spatial, it also provides a documented geospatial characterization and preprocessing framework that can support subsequent SWAT watershed and HRU development.

Table 1: Summary of Related Studies and Identified Gaps

Author / Year/Topic	Study Area	Methodology	Research Gap
Balarabe et al. (2025)/Impact of LULU changes on flood risk	Tiga Dam Watershed	GIS & Remote Sensing	Did not focus on preparation of spatial datasets specifically required for SWAT hydrological Modelling
Mohammed et al. (2021)/Rainfall-Rainoff Modelling	Challawa & Jakara Rivers	DEM & HEC-HMS	Soil and LULC not integrated for HRUs
Ejieji et al. (2016)/Stream-flow Prediction	Hadejia–Jama’are–Komadugu–Yobe system	SWAT Modelling, 90m DEM resolution	The resolution introduced spatial uncertainty, making it harder for their model to accurately capture localized runoff and drainage patterns

Scope

This study covered a selected portion of the broader Tiga Dam watershed in the semi-arid Sudan Savanna of northern Nigeria, particularly the area surrounding the Tiga Dam water body. GIS and remote sensing were used to characterize terrain, LULC, soil and drainage and prepare spatial inputs for subsequent hydrological modelling.

MATERIALS AND METHODS

Study Area

The study was conducted in the semi-arid Sudan Savanna of northern Nigeria within the Kano River Basin and the wider Hadejia–Jama’are–Komadugu–Yobe system. Tiga Dam, constructed in 1974, covers about 178 km² and has a maximum capacity of 2,000,000,000 m³. Its water supports the Kano irrigation scheme, water treatment facilities and a potential hydropower plant. The present study focuses on spatial preprocessing within the selected portion of the wider watershed.

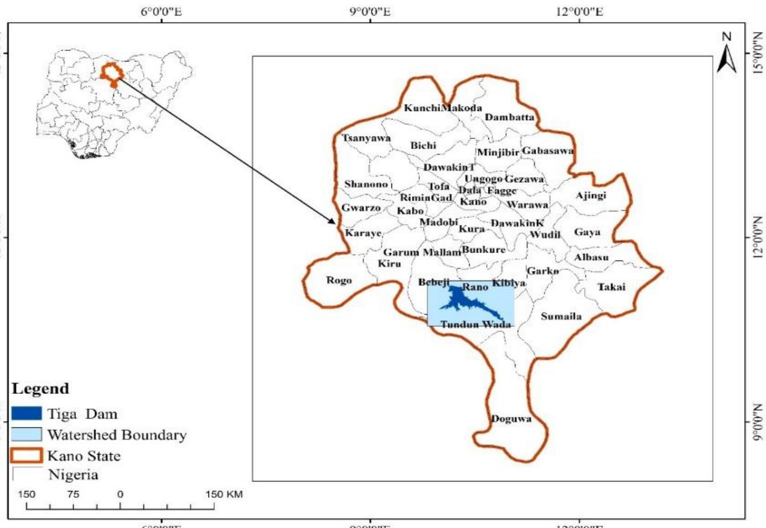

Figure 1: Map of the study area

Materials

A Digital Elevation Model (DEM) of 30m was the primary terrain dataset for deriving elevation, slope, flow direction and drainage networks. It was projected to WGS 84 / UTM Zone 32N and clipped to the study watershed to maintain spatial consistency and limit processing to the area of interest. Sentinel-2 imagery was used for LULC analysis, while soil data were obtained from a global soil database. Datasets were imported into the GIS environment and resampled where necessary to support consistent overlay and subsequent hydrological applications.

Table 2: Data Sources

Dataset	Description	Source
Digital Elevation Model (DEM)	30 m resolution elevation data	Shuttle Radar Topography Mission (SRTM)
Satellite Imagery	10m Copernicus image for LULC classification	Sentinel-2
Soil Data	Soil and infiltration analysis	OpenLandMap
Ancillary Data	Dam outlet location map	Google earth pro

Software Used

All spatial analyses were carried out using ArcGIS map with the Spatial Analyst extension enabled. The hydrological analysis tools embedded in ArcGIS were used for terrain processing, drainage extraction, and watershed delineation. Supervised classification image for the land use land cover (LULC) and the soil characteristics was analyzed in the ArcGIS interface.

Methods

DEM Preprocessing

A Digital Elevation Model (DEM) represents the vertical height of the Earth's surface and serves as the fundamental dataset for terrain and hydrological analysis. In this study, the DEM was used as the primary input because surface water movement is largely controlled by differences in elevation, with water naturally flowing from higher areas to lower areas. It therefore provided the basis for analysing terrain, flow and watershed characteristics.

The SRTM DEM was imported into ArcGIS, projected to WGS 84 / UTM Zone 32N and clipped to the watershed boundary. This ensured spatial consistency, reduced redundant data and restricted analysis to the study area.

To enhance the reliability of hydrological analysis, surface depressions and sinks present in the DEM were removed using the Fill tool in the Spatial Analyst Hydrology toolbox. These depressions, if left uncorrected, can interrupt natural flow paths and produce unrealistic results in flow direction and flow accumulation analyses. The filling process ensured a continuous terrain surface, allowing water to flow uninterrupted across the landscape in a manner that closely represents natural hydrological conditions.

The resulting elevation map provides critical information on the spatial distribution of high and low terrain within the watershed. These elevation differences determine the direction of water flow, influence the speed at which runoff travels across the land surface, and control areas of water accumulation. Consequently, the DEM-derived elevation analysis forms the foundation for subsequent slope analysis, drainage network extraction, and watershed delineation carried out in this study.

Elevation Analysis

Elevation analysis was conducted to examine the vertical variation of the land surface within the Tiga Dam watershed. Elevation refers to the height of the land above mean sea level and is a fundamental terrain parameter that influences hydrological processes such as the direction, velocity, and accumulation of surface runoff. Variations in elevation determine how water moves across the landscape, making elevation analysis essential for understanding watershed behaviour.

In this study, elevation information was visualized using contour lines generated from the filled Digital Elevation Model (DEM). Contour lines are lines that connect points of equal elevation and provide a clear representation of how terrain height changes across space. By transforming the DEM into a contour map, subtle and pronounced variations in land surface height were effectively displayed, allowing for a detailed interpretation of the watershed's topographic structure.

The contour map reveals important information about the terrain characteristics of the Tiga Dam watershed. Areas where contour lines are closely spaced indicate steep terrain, reflecting rapid changes in elevation over short distances. In contrast, widely spaced contour lines represent gentle slopes or relatively flat areas where elevation changes gradually.

This elevation analysis provided a foundational understanding of the watershed's topography and supported subsequent analyses, including slope assessment, drainage network extraction, and watershed delineation. The contour-based elevation map therefore plays a critical role in explaining the spatial organization of terrain features and their influence on hydrological processes within the Tiga Dam watershed.

Slope Analysis

Slope analysis was carried out to evaluate the steepness of the terrain within the Tiga Dam watershed, as slope is a key factor influencing surface runoff, erosion processes, and drainage behaviour. Slope was derived from the filled Digital Elevation Model (DEM) using the Slope tool in the ArcGIS Spatial Analyst Surface toolbox. The slope values were computed in degrees to provide a standardized and easily interpretable measure of terrain steepness across the watershed.

The generated slope values were further classified into categories representing gentle, moderate, and steep terrain in order to simplify interpretation and support hydrological assessment. These categories help to distinguish areas with differing hydrological responses, as terrain steepness directly affects how quickly water flows over the land surface. Steeper slopes tend to generate faster runoff with limited opportunity for water to infiltrate into the soil, while gentler slopes promote slower movement of water and greater infiltration capacity.

The slope map provides valuable insight into areas that are more susceptible to soil erosion, particularly where steep slopes coincide with sparse vegetation or disturbed land cover. In addition, slope plays a critical role in shaping drainage patterns by controlling flow velocity and influencing the formation of stream channels. As a result, slope information is an essential input for hydrological modelling, where it is used to estimate runoff rates, erosion risk, and flow routing within the watershed. The slope analysis therefore contributes significantly to understanding the terrain-driven hydrological behaviour of the Tiga Dam watershed and supports subsequent watershed modelling efforts.

Land Use / Land Cover (LULC) Classification

Sentinel-2 satellite images were used to map how the land is being used. The image was processed in ArcGIS to classify land use and land cover within the watershed. Before classification, the images were radio-metrically corrected to remove noise and atmospheric haze. The image was then composite to natural color to obtain a clear image and clipped to the watershed boundary. Representative training samples were digitized for major land cover classes identified, including:

i. Vegetation
ii. Agricultural land
iii. Built-up areas
iv. Water bodies

A Supervised Classification was performed using the Maximum Likelihood classifier. Post-classification processing was conducted to remove noise and improve classification accuracy. Area statistics were computed to quantify the spatial distribution of each land cover class.

LULC Accuracy Assessment

Four LULC classes were identified in the study area: vegetation, agricultural land, built-up area, and water body. Representative training samples were selected for each class through visual interpretation of the Sentinel-2 imagery. The training samples were selected from relatively homogeneous areas that clearly represented the spectral characteristics of the respective land-cover classes. The initial training dataset consisted of 245 sample points, comprising 96 vegetation points, 67 agricultural-land points, 35 built-up points, and 47 water-body points. The training dataset was divided using a 70:30 training-validation split, with approximately 70% of the samples used to train the Maximum Likelihood classifier and the remaining portion reserved for validation.

Following classification, an independent accuracy assessment was undertaken to evaluate the reliability of the resulting LULC map. A total of 69 reference/validation samples were assessed, of which 61 were correctly classified, giving an overall accuracy of approximately 88%. The Kappa coefficient was 0.84, indicating a high level of agreement between the classified map and the reference data.

The Kappa coefficient is used to evaluate the accuracy of how well a pixel-based classified image performed as compared to the reference data. It measures the level of agreement between the classified map and the reference data beyond chance agreement.

$$P_o = \frac{\sum_{i=1}^{n} D_i}{N}$$

Where

$$P_e = \frac{\sum_{i=1}^{n}(R_i \times C_i)}{N^2}$$

$D_i =$ represents the number of correctly classified samples for class i(diagonal elements of the error matrix),

R_i and C_i denote the row and column totals for class i, respectively,

N is the total number of validation samples, and n is the number of land use and land cover classes

A Kappa value of 1 indicates perfect agreement between the classified map and reference data, whereas a value of 0 indicates agreement equivalent to random chance. The overall accuracy generally measures the accuracy of a classified image, however, does not tell us whether errors are evenly distributed for all classes. We don't know which classes were well or poorly mapped, that is where the producer and the consumer accuracy come in, these two explain which classes were correctly classified and the errors generated. Overall Accuracy $(OA) = \frac{\sum_{i=1}^{n} D_i}{N} \times 100$

Where:

i. D_i= number of correctly classified samples for class i
ii. N= total number of validation samples
iii. n= number of land use and land cover classes

Overall Accuracy is expressed as a percentage, with higher values indicating better classification performance.

Producer's Accuracy indicates how well a particular land cover class has been classified from the perspective of the reference data.

Producer's Accuracy $(PA) = \frac{D_i}{R_i} \times 100$

Where:

i. D_i= number of correctly classified samples for class i
ii. R_i= total number of reference samples for class i

Producer's Accuracy is expressed as a percentage, with higher values indicating better classification performance for that land cover class.

User's Accuracy measures the probability that a pixel or sample classified into a particular land use or land cover class on the map represents that class on the ground.

User's Accuracy $(UA) = \frac{D_i}{C_i} \times 100$ Where:

i. D_i= number of correctly classified samples for class i
ii. C_i= total number of samples classified into class i

User's Accuracy is expressed as a percentage, with higher values indicating greater reliability of the mapped land cover class.

Soil Property Analysis

Soil texture data from OpenLandMap were clipped to the watershed and projected to WGS 84 / UTM Zone 32N in ArcGIS. Soil properties were interpreted using Hydrologic Soil Groups (HSG A–D), representing differences in infiltration capacity and runoff potential.

All four HSG classes occurred within the study portion. Groups A and B represent high to moderate infiltration capacity, whereas Groups C and D have lower infiltration and greater runoff potential, with implications for erosion and localized flooding.

HSG classification was based on soil infiltration capacity, which affects runoff, groundwater recharge, erosion and flood risk. For raster analysis, Groups A–D were coded as Classes 0–3, respectively.

HSG A (Class 0) has very high infiltration capacity and is commonly associated with sandy or gravelly soils. It generally produces low surface runoff and high relative infiltration.

HSG B (Class 1) has moderate infiltration capacity and is commonly associated with loamy soils. It produces moderate runoff and provides reasonable water-storage capacity.

HSG C (Class 2) has low infiltration capacity, often associated with clay loams. Restricted water movement increases surface runoff, erosion potential and localized flooding risk.

HSG D (Class 3) has very low infiltration capacity and poor drainage, commonly associated with heavy clays, shallow soils or hardpan layers. It therefore has the highest surface-runoff and flooding potential.

The HSG map captures spatial variation in infiltration capacity and provides a useful basis for interpreting differences in runoff potential, flood risk and land-use planning for future hydrological modelling.

Delineation of the Tiga Dam Watershed and Sub-Basins

The delineation of the study area and its sub-basins was carried out to define the hydrological extent and to understand how surface runoff is spatially organized within the watershed. Watershed delineation is a critical step in hydrological studies because it identifies the land area that contributes runoff to a specific outlet, in this case, the Tiga Dam.

Pour Point Identification

The outlet point of the Tiga Dam was identified using existing dam infrastructure maps in combination with high-resolution satellite imagery to ensure positional accuracy. A single pour point was digitized at the dam outlet location, representing the point where water exits the watershed. To improve the accuracy of watershed delineation, the Snap Pour Point tool was applied to adjust the digitized point to the nearest cell with the highest flow accumulation. This step ensured that the pour point was correctly aligned with the main drainage channel, thereby preventing errors that could arise from slight misplacement of the outlet point during digitization.

Watershed Delineation

Following pour point identification, the watershed was delineated using the Watershed tool within the ArcGIS Spatial Analyst Hydrology toolbox. This process utilized the previously generated flow direction raster together with the snapped pour point to define the area contributing surface runoff to the Tiga Dam outlet. The output of this process was a raster representing the watershed extent. To facilitate mapping, spatial analysis, and integration with other vector datasets, the watershed raster was subsequently converted to a polygon using the Raster to Polygon tool. The resulting watershed boundary clearly defines the hydrological limits of the Tiga Dam catchment area.

Sub-Basin Delineation

The sub-basins within the delineated Tiga Dam catchment were derived using the Basin tool in the ArcGIS Spatial Analyst Hydrology toolbox. The tool used the D8 flow-direction raster generated from the filled 30 m SRTM DEM to identify internally draining basin units associated with the drainage structure. The resulting basin raster was converted to polygon format for mapping and spatial analysis. The derived sub-basins provide spatial units for subsequent watershed characterization and future Hydrological Response Unit (HRU) development.

Dataset Integration and HRU Relevance

The final stage of the methodology involved preparing spatial input datasets for hydrological modeling applications. Terrain-derived layers, including slope, drainage network, and watershed boundary, was combined with land use and soil maps to create model-ready inputs. These datasets provide the spatial parameters required for subsequent simulation of hydrological processes such as runoff, infiltration, and streamflow within the Tiga Dam watershed.
However, prior to their integration, the LULC, soil, and slope datasets were processed to ensure that they corresponded spatially to the same watershed boundary and coordinate reference system. The datasets were then overlaid to identify spatially homogeneous combinations of land cover, soil characteristics, and terrain slope. These combinations provide the spatial basis for defining HRUs within the watershed and its sub-basins.
For intance, an area characterized by vegetation, a relatively permeable soil group, and gentle slope would be expected to have greater infiltration and lower surface runoff than an area characterized by Agricultural land, a low-infiltration soil group, and steep slope**.** Similarly, built-up areas were distinguished because their relatively impervious surfaces can generate rapid surface runoff. Thus, the integration of LULC, soil, and slope enables areas with different expected hydrological responses to be represented separately in the modelling framework.
The resulting spatial layers therefore provide the necessary spatial information for representing differences in surface runoff, infiltration, soil-water behaviour, evapotranspiration, and terrain-controlled flow processes within the watershed. These inputs were subsequently intended to support the spatial parameterization required for SWAT hydrological modelling

RESULTS AND DISCUSSION

Elevation Characteristics

The elevation pattern reflects the variation in terrain height across the watershed and provides the fundamental topographic control on surface-water movement. Higher-elevation areas generally form the upper parts of the watershed, where runoff originates and begins to move downslope, while lower-elevation areas tend to receive and accumulate water from surrounding terrain. The elevation gradient therefore influences the direction and concentration of runoff and provides the topographic basis for flow-direction, flow-accumulation, drainage-network, and watershed-delineation analyses. The contour pattern further indicates that closely spaced contours represent areas of rapid elevation change, whereas widely spaced contours represent relatively gentle terrain.
The processed 30-m SRTM DEM showed elevations ranging from 458 to 677 m above mean sea level, with a reported mean elevation of 567.5 m and an elevation range of 219 m. The higher terrain occurs toward the upper portions of the mapped study area, while lower elevations occur toward drainage convergence and the dam-side portion of the area.
Elevation establishes the topographic framework for subsequent terrain analysis. In combination with the DEM-derived flow-direction and flow-accumulation layers, it helps explain the spatial organization of drainage pathways and supports watershed and sub-basin delineation.

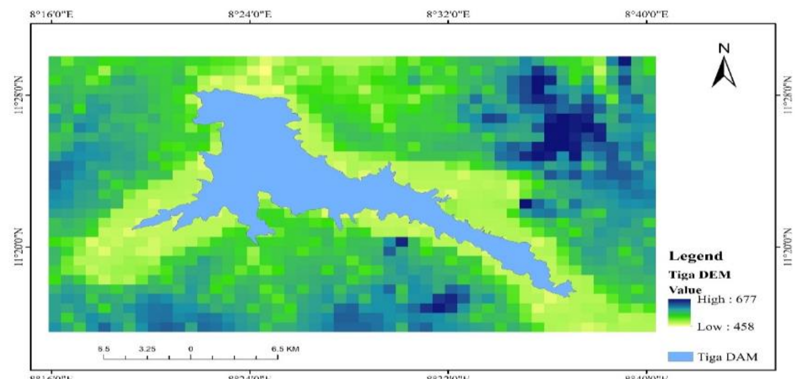

Figure 2: Digital elevation of the study area

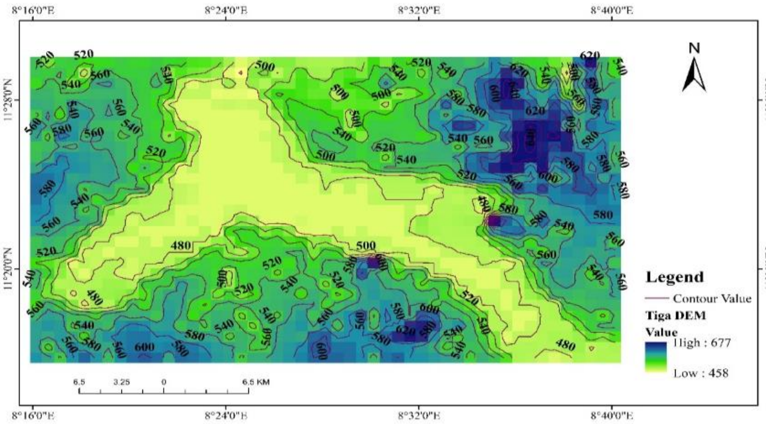

Figure 3: Elevation (Contour) Map of Tiga Dam Watershed

Table 3: Elevation Statistics of the Tiga Dam Watershed

Parameter	Value
Minimum Elevation	458 m
Maximum Elevation	677 m
Mean Elevation	567.5 m
Elevation Range	219 m

Slope Characteristics
Slope determines the degree of terrain steepness and has a direct influence on the movement of surface water. Steeper areas are likely to produce faster surface runoff because water moves downslope more rapidly, thereby reducing the time available for infiltration. Such areas may also have greater erosion potential, particularly where steep slopes occur together with sparse vegetation or disturbed land. In contrast, gentler slopes tend to slow surface-water movement and provide greater opportunity for infiltration and temporary water retention. Thus, the spatial distribution of slope helps explain differences in runoff response and drainage behaviour across the watershed.

Topographically, the region is dominated by a low-gradient terrain that favours low flow velocities, enhanced rainfall infiltration, and localized surface storage. High-gradient zones accelerate overland flow, suppress infiltration, and heighten erosion vulnerability, making slope an important spatial factor for representing runoff generation and flow routing in subsequent hydrological modelling.

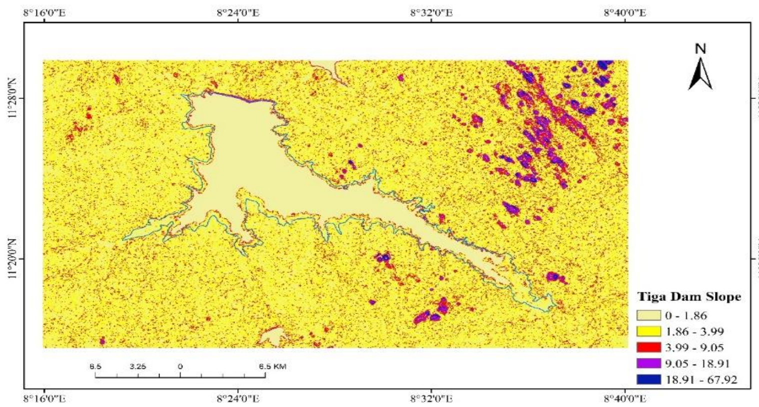

Figure 4: Slope Map of Tiga Dam Watershed

DEM and Slope comparative analysis
Terrain analysis of the Tiga Dam watershed revealed a mean elevation gradient ranging from 458 m to 677 m above mean sea level. The slope distribution is predominantly gentle with localized steep slopes occupying minor portions of the upper catchment boundaries. This topographic structure aligns with typical baseline geomorphology reported across the upper Hadejia-Jama'are catchment, where gentle lowlands dominate the basin floor. Hydro-logically, this indicates that surface flow velocity is attenuated across the broad plains, making local soil hydraulic conductivity and land cover the primary regulators of runoff rates rather than steep slope gradients.

Land Use/Land Cover Characteristics
The spatial distribution of LULC indicates differences in surface characteristics that can influence rainfall partitioning, infiltration, evapotranspiration, and runoff generation. Vegetated areas generally provide greater surface interception and roughness and can promote infiltration while reducing the speed of overland flow. Bare or sparsely covered areas provide less interception and surface protection and may therefore have greater runoff and erosion potential, depending on the underlying soil and surface condition. Built-up areas generally have more impervious surfaces, which can reduce infiltration and increase the rate at which rainfall becomes surface runoff. Water bodies represent existing

surface-water storage and therefore contribute differently to the watershed hydrological response than terrestrial land-cover classes. The LULC map was derived from Sentinel-2 imagery using four classes: vegetation, bare land/agricultural land, built-up areas, and water bodies.

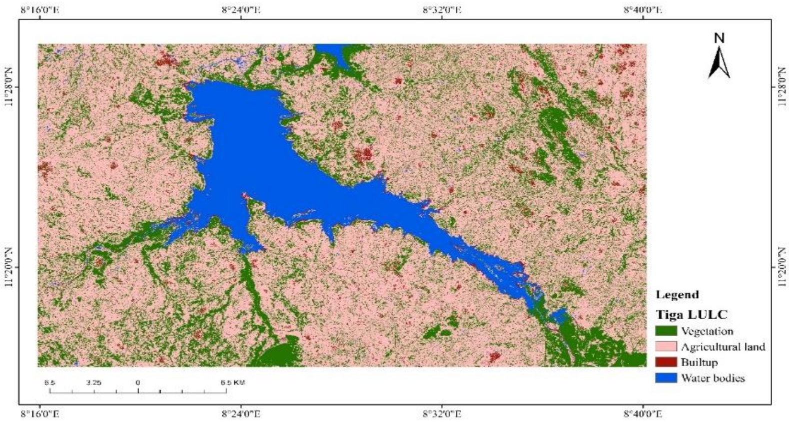

Figure 5: Land Use/Land Cover Map of Tiga Dam Watershed

Table 4: Land Use/Land Cover Distribution

Class	Area (km²)	Percentage (%)
Vegetation	25.41	21.82
Agricultural Land	75.19	64.56
Built-up Area	2.54	2.18
Water Body	13.32	11.44

Table 5: ***LULC Classification Accuracy Result***

Class	Correctly Classified	Total Reference Samples	Producer Accuracy (%)	User Accuracy (%)
Vegetation	24	26	92.3	92.3
Agricultural land	16	18	88.9	84.2
Built-up	9	10	90.0	75.0
Water-body	12	15	80.0	100.0
Total	61	69	88.4% (≈88%)	_____

Overall accuracy = 88%
Kappa Coefficient = 0.84
The classification Accuracy assessment indicates strong performance of the Maximum likelihood. A total of 69 validation samples were used, of which 61 were correctly classified. Producer's Accuracy indicates that most classes were well detected, particularly vegetation (92.3%), Agricultural land shows a slight directional bias toward over-mapping by (4.7%), though water body showed little omission (80%). User's Accuracy shows that water body was highly reliable (100%), while built-up had moderate commission error (75%).
The Kappa coefficient of 0.84 indicates strong agreement between the classified map and the reference data beyond chance agreement, confirming the robustness of the classification.
The classification achieved an overall accuracy of 88%, indicating that 88% of validation samples were correctly classified.

Comparative Analysis of Land Cover Distribution

Supervised classification showed that Agricultural Land is the dominant land cover class (64.56%), followed by Vegetation (21.82%), Water Bodies (11.44%), and Built-up areas (2.18%). The dominance of agricultural land cover reflects documented land transformation trends across Sudan-savanna catchments in Northern Nigeria. Driven by intensive smallholder farming and large-scale schemes such as the Kano River Irrigation Scheme (KRIS), native savanna woodland has been systematically cleared for rain-fed and irrigated cropland. The relatively high proportion of agricultural land is consistent with findings from comparable Lake Chad Basin tributaries, where previous studies have associated agricultural land conversion with changes in runoff and sediment delivery.

Soil Characteristics

The soil analysis identified the presence of all four Hydrologic Soil Groups (HSG A–D) within the watershed. HSG A and B soils, characterized by high to moderate infiltration capacity, were observed across substantial portions of the watershed, indicating favorable conditions for relative infiltration potential. In contrast, HSG C and D soils exhibited lower infiltration rates and greater runoff potential, making them more susceptible to erosion and localized flooding.
The spatial variability of soil properties highlights the importance of incorporating soil information into hydrological modelling, as infiltration and runoff processes differ significantly among soil groups.
The figure below shows the Hydrologic Soil Group base on infiltration potential.

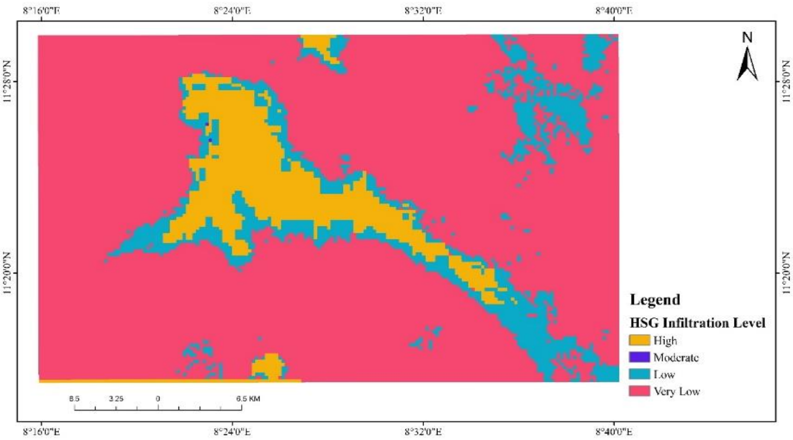

Figure 6: Hydrologic Soil Map of Tiga Dam Watershed

Comparative Analysis of Soil Infiltration and Runoff Potential

Soil characterization indicated the presence of all four Hydrologic Soil Groups (HSGs), but with a spatial dominance of Group D (Very Low Infiltration) across the vast interior, contrasted by Group A (High Infiltration) concentrated along the reservoir boundaries. The predominance of HSG D soils indicates an inherently low infiltration capacity and high runoff potential across the catchment. This outcome agrees with regional soil studies in the Sudan savanna, where clay-rich and crusted topsoils impede deep percolation. Consequently, when intense convective rainfall events occur over the watershed, the combination of low-infiltration HSG D soils and extensive agricultural land cover accelerates overland flow generation into the Tiga Dam reservoir.

Flow Accumulation and Drainage

The flow-accumulation pattern identifies locations where runoff from surrounding areas converges. Areas with high flow-accumulation values represent preferential pathways for concentrated surface-water movement and correspond to major drainage channels within the watershed. Hydrologically, these areas are important because they collect runoff generated from upslope contributing areas and convey it toward downstream locations and ultimately the Tiga Dam outlet. The flow-accumulation pattern was therefore useful not only for interpreting drainage behaviour but also for extracting the drainage network and correctly positioning the dam outlet during watershed delineation.

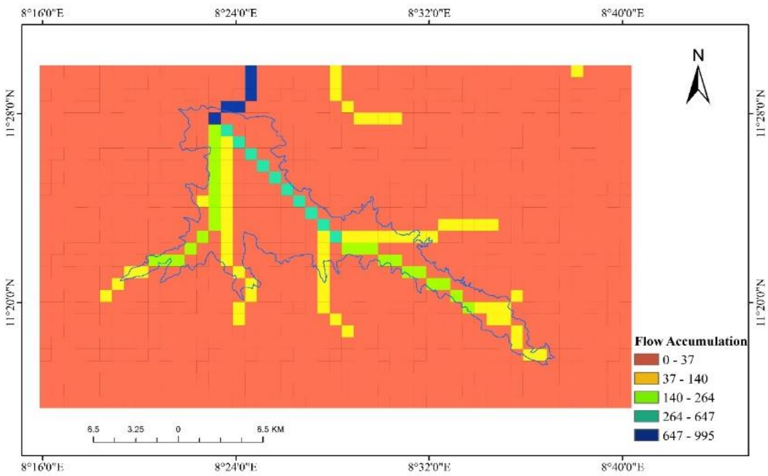

Figure 7: Flow Accumulation Map

The flow accumulation map (Figure 7) illustrates the spatial distribution of upslope contributing area within the Tiga Dam watershed based on the processed Digital Elevation Model (DEM). Cells with low accumulation values represent upland areas where runoff originates, whereas cells with high accumulation values indicate locations where flow from numerous upstream converges to form stream channels.

Flow accumulation is an essential input for hydrological modelling because it facilitates stream network extraction, watershed delineation, and identification of runoff concentration zones. These parameters provide spatial inputs that can support subsequent estimation of streamflow and sediment-related responses in distributed hydrological models.

Sub-Basin Delineation

The subdivision of the watershed into sub-basins allows for more detailed spatial analysis of hydrological processes, supports distributed hydrological modeling, and enhances understanding of how different areas within the watershed contribute to overall runoff and streamflow dynamics. The resulting sub-basin map provides a structured framework for future modeling applications and watershed management planning.

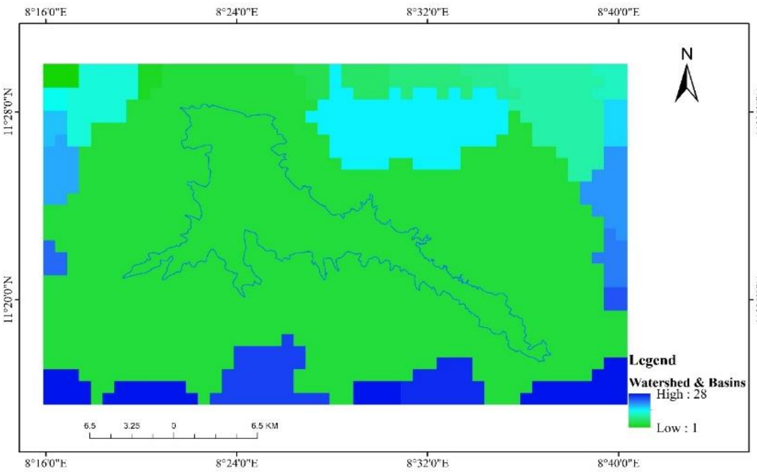

Figure 8: Tiga Dam Watershed and Sub-Basins

Figure 8 presents the delineated Tiga Dam watershed together with the sub-basin boundaries generated from the hydrological analysis of the DEM. The watershed boundary defines the entire contributing catchment draining into the Tiga Dam reservoir, while the sub-divisions provides a more detailed representation of spatial variability within the basins. The delineated sub-basins exhibit varying sizes and drainage characteristics, reflecting differences in terrain, slope, land use, and drainage density across the watershed. These subdivisions are particularly important because hydrological processes such as infiltrations, runoff generations, evapotranspiration and sediment transport are rarely uniform throughout an entire watershed. Dividing the basin into sub-basins enables these spatial differences to be represented more accurately during hydrological simulations.

The generated watershed boundary corresponds well with the natural drainage pattern derived from the DEM, indicating that the terrain processing and outlet definition were successfully implemented. The delineated drainage system, demonstrate a dendritic drainage pattern, which is typical of watersheds developed on relatively homogeneous geological formations and gently sloping terrain. Such drainage characteristics suggest that runoff is efficiently collected through interconnected stream channel before discharging into the reservoir.

Furthermore, the delineated sub-basins provide the spatial framework required for Hydrological Response Unit (HRU) generation within the SWAT model. By integrating sub-basins with land use, soil, and slope datasets, the resulting HRUs will allow distributed simulation of watershed hydrological processes, thereby improving the accuracy and reliability of runoff and water balance predictions.

Limitations

This study acknowledges several methodological and data-driven limitations that should be considered when interpreting the spatial outputs and their subsequent integration into SWAT hydrological modeling. Primary among these are resolution disparities and classification uncertainties; integrating 10 m Sentinel-2 LULC imagery with a 30 m SRTM DEM introduces spatial generalization that may obscure fine-scale terrain heterogeneity, micro-drainage pathways, and small land-cover patches. Furthermore, despite achieving strong overall classification performance (88% accuracy; Kappa = 0.84), spectral confusion remains evident in lower class-specific metrics—such as built-up user's accuracy (75%) and water-body producer's accuracy (80%). Temporal constraints also dictate that the LULC layer reflects a static snapshot, which may not capture seasonal or long-term fluctuations in vegetation cover, agricultural cycles, and surface water extent that dynamically influence infiltration, evapotranspiration, and runoff generation.

Additional uncertainties stem from cumulative processing errors and DEM-based watershed delineation mechanics. Standard raster operations, including image preprocessing, training-sample selection, spatial re-projection, and resampling, inherently introduce minor positional and spectral artifacts. Similarly, while snapping the Tiga Dam outlet to a high-accumulation cell optimizes network alignment, automated delineation remains highly sensitive to DEM resolution, artifact filling, and threshold selection. Consequently, minor variations in drainage structure or catchment boundaries could arise under alternative spatial inputs or processing parameters. Nevertheless, these limitations do not undermine the validity of the study; the spatial datasets capture the predominant terrain, soil, and land-cover dynamics of the Tiga Dam watershed effectively, providing a robust, systematically derived baseline for future SWAT modelling development and parameterization.

CONCLUSION

This study successfully analyzed and prepared the key spatial datasets required for hydrological modelling of the Tiga Dam watershed using Geographic Information System (GIS) and remote sensing techniques. Terrain, land use/land cover (LULC), soil characteristics, and hydrological features were integrated to develop a comprehensive geospatial database suitable for watershed-scale hydrological applications.

Terrain analysis based on the 30 m SRTM Digital Elevation Model revealed that the watershed exhibits moderate topographic variability, with elevations ranging from 458 m to 677 m above mean sea level. The predominance of nearly flat and gently sloping terrain indicates favorable conditions for infiltration and agricultural activities, although localized steeper areas may contribute to increased runoff and erosion risk.

Land use/land cover analysis derived from Sentinel-2 imagery showed that agricultural land is the dominant land cover type, accounting for 64.56% of the watershed area, followed by vegetation (21.82%), water bodies (11.44%), and built-up areas (2.18%). The classification achieved an overall accuracy of 88% and a Kappa coefficient of 0.84, indicating strong agreement and reliability for hydrological modelling purposes. Soil analysis identified the presence of all Hydrologic Soil Groups (A–D), reflecting spatial variability in infiltration and runoff generation potential across the watershed. While relative infiltration potential and areas characterized by low-infiltration soil groups may contribute disproportionately to surface runoff and localized flood susceptibility.

The hydrological analysis successfully delineated the Tiga Dam watershed, drainage network, and contributing sub-basins. The resulting spatial datasets provide essential inputs for Hydrological Response Unit (HRU) development and subsequent hydrological simulations using models such as the Soil and Water Assessment Tool (SWAT).

Overall, the study demonstrates that the integration of GIS, remote sensing, and spatial analysis techniques provides an effective framework for watershed characterization and spatial database development. The generated datasets constitute a reliable foundation for future hydrological modelling, watershed management planning, and sustainable water resources management within the Tiga Dam watershed.

Conflict of Interest Statement

The Author declares that there are no conflicts of interest regarding the publication of this paper. The research was conducted independently as part of an Academic Postgraduate study. Financial support was provided through the Petroleum Technology Development Fund (PTDF) Local Postgraduate Scholarship. However, the sponsor had no role in the study design, data collection, analysis, interpretation of results, manuscript preparation or the decision to publish the findings.

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