Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)

Volume-3,Issue-2,pp-26-45

www.naujcve.com

Research Paper Open Access

Modelling Sediment yield in Tofa Dam under the impact of Anthropogenic activities

Morgan Omale[1], Dr. Al-Amin Danladi Bello[2] and Dr. Umar Alfa Abubukar[3]

[1,2,3]Department of Water Resources and Environmental, Ahmadu Bello University, Zaria, Nigeria

Corresponding Author: morgaanomale@gmail.com

Abstract: *Sedimentation driven by land-use changes and unsustainable agricultural practices significantly threatens reservoir functionality, reducing water storage capacity and degrading water quality. This study examines sediment dynamics and trapping efficiency in Tofa Dam, Kano State, Nigeria, using geospatial techniques, the Revised Universal Soil Loss Equation (RUSLE), and the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). Principal Component Analysis (PCA), performed with SPSS, evaluated statistical relationships between sediment yield and influencing factors.Land-use/land-cover (LULC) analysis from 1999 to 2044 revealed drastic changes, with vegetation cover declining from 52.84% in 1999 to 2.21% by 2024, and built-up areas increasing from 3.15% to 39.38%. These changes led to significant sediment load increases. Under contouring cultivation practices, sediment yield rose from 683.2 tonnes in 1999 to 933.6 tonnes in 2024 and is projected to reach 1132.9 tonnes by 2044. Conversely, conservation tillage, as a recommended practice, reduced sediment loads from 253.1 tonnes in 1999 to 345.8 tonnes in 2024 and 419.6 tonnes by 2044, demonstrating its effectiveness in minimizing erosion. PCA results identified the cover management factor (C-factor) and support practice factor (P-factor) as critical determinants of sediment yield, collectively explaining 99.65% of total variance. Sediment yield showed strong correlations with the P-factor (r = 0.947) and moderate correlations with the C-factor (r = 0.276). Regression analysis also highlighted a direct relationship between increasing built-up areas and sediment loads.The study recommends adopting conservation tillage to reduce sediment yield by modifying slope profiles and promoting water infiltration. Additional strategies, including reforestation, vegetative buffers, and conservation tillage, could further reduce sediment loads by up to 30%. These findings demonstrate the effectiveness of integrating geospatial and statistical tools for sustainable sediment management, ensuring the long-term functionality of Tofa Dam and similar hydrological systems.*

KEYWORDS: *Geospatial Modelling, RUSLE, Soil Erosion, Statistical Analysis, Soil Erosion Factors and Vegetation*

Date of Submission: 28-03-2025 Date of acceptance:04-04-2025

1. INTRODUCTION

Understanding the dynamics of sediment yield is crucial for sustainable water resource management, particularly in regions experiencing significant anthropogenic pressures. The Tofa Dam catchment is increasingly subjected to human activities such as agriculture, urbanization, and deforestation, which alter the natural hydrological processes and contribute to excessive sedimentation. These anthropogenic influences have led to increased surface runoff, reduced infiltration rates, and accelerated soil erosion, ultimately affecting the storage capacity and operational efficiency of the reservoir (Bello et al., 2021; Yusuf et al., 2020).

The rapid expansion of agricultural activities, coupled with poor land management practices, has resulted in the removal of vegetation cover, exposing the soil to erosive forces of wind and water. Similarly, urbanization has led to an increase in impervious surfaces, further exacerbating runoff and sediment transport to the reservoir. Without proper management, sedimentation can significantly reduce the lifespan of Tofa Dam, impairing its capacity to supply water for irrigation, domestic use, and other purposes (Adeogun et al., 2023).

Despite various efforts to address sedimentation issues in reservoirs across Nigeria, comprehensive studies focusing on the Tofa Dam catchment remain limited. There is a need to assess the extent of sediment yield and its contributing factors to formulate effective mitigation strategies. The use of advanced hydrological models, such as the HEC-HMS, combined with geospatial analysis tools like TerrSet, provides an opportunity to evaluate the impacts of land use changes on sediment dynamics effectively (Olusola & Abiodun, 2022; Umar et al., 2023).

AIM AND OBJECTIVES

This study aims to model the sediment Yield in Tofa Dam, assess the impacts of land use change and anthropogenic activities on sediment dynamics, and inform sustainable management practices using Geographic Information System (GIS) Tools and the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) model.

The objectives of the study are:

1. Develop the hydrological model of Tofa dam catchment

2. Estimate the sediment Yield in the Tofa dam under Landuse change scenarios

3. Project future sediment conditions and measures to curtail its effects on the reservoir operation.

This study aims to bridge the existing knowledge gap by estimating sediment yield under the influence of anthropogenic activities within the Tofa Dam catchment. The research utilizedDigital Elevation Models (DEMs) from the Office of the Surveyor General of the Federation (OSGOF, 2014), along with meteorological and hydrological data, to simulate watershed behavior accurately. The findings will contribute to the development of sustainable watershed management strategies aimed at minimizing sedimentation and optimizing the long-term functionality of the dam (USACE, 2022).

By addressing these critical issues, this research providedvaluable insights into the interplay between land use changes and sediment yield, aiding policymakers and stakeholders in making informed decisions for the sustainable management of the Tofa Dam and its catchment area.

I.I Land use / Land cover of the study area

The Tofa catchment in Kano State is experiencing significant land use and land cover changes due to increasing population pressure and expanding human activities. The catchment is characterized by various land use types, including forest, shrubland, woodland, grassland, cropland, water bodies, unproductive land, and settlements, with cropland being the dominant category (Kano State Ministry of Environment, 2010).

The forest and woodland areas in the catchment are dominated by diverse plant species, forming dense vegetation that is often difficult to penetrate. These areas are primarily concentrated in the southern and eastern parts of the catchment, stretching from the northwest to the southeast, and are used for seasonal nomadic livestock grazing and browsing.

The wetlands and water bodies are permanently covered by water, particularly along floodplains and seasonal river channels associated with the Tofa catchment. These areas play a vital role in groundwater recharge and serve as important ecological zones within the watershed.

Shrubland, bushland, and grassland areas are characterized by grass cover interspersed with scattered shrubs. These areas are utilized mainly for cattle grazing and seasonal nomadic livestock activities. They are predominantly located in the central part of the catchment.

Cropland forms the dominant land cover type in the Tofa catchment, covering more than half of the total area. This extensive agricultural use reflects the growing demand for food production driven by population growth and commercial farming activities.

The ongoing changes in land use and land cover within the Tofa catchment have significant implications for hydrological processes, including surface runoff, soil erosion, and evapotranspiration. The extent and type of vegetation, as well as land management practices, directly influence surface storage, canopy interception, and the overall water balance in the catchment.

The land use/land cover map for the Tofa catchment, derived from satellite data and validated through field surveys, is presented in Fig. 1.0. This map provides valuable insights into spatial patterns and changes in land cover, which are essential for understanding sediment yield and hydrological dynamics within the catchment.

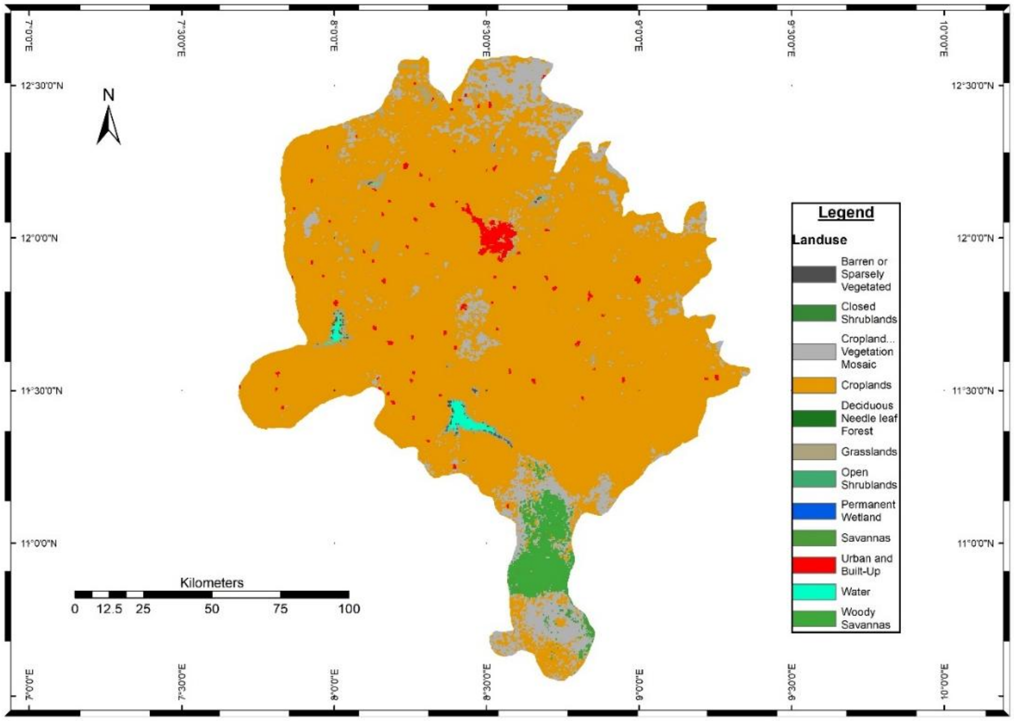


Fig. 1.0: Land use/ Land cover map Kano State (Author's work)

III Introduction to TerrSet and Its Importance to the Study

TerrSet is a powerful geospatial software suite developed by Clark Labs, designed for the analysis, modeling, and prediction of land use and environmental changes. Its Land Change Modeler (LCM) and CA-Markov modules are particularly well-suited for studying catchment areas, as they provide tools for detecting historical changes and forecasting future land cover scenarios. These features make TerrSet invaluable for understanding and mitigating the impacts of anthropogenic activities on watersheds like the Tofa Catchment in Kano State.

In this study, TerrSet played a crucial role in analyzing multi-temporal satellite imagery for Tofa Catchment, covering 1999, 2019, and 2024, and simulating land cover patterns for 2044. The software's capabilities enabled the detection of critical trends, such as deforestation and agricultural expansion, which directly affect sediment yield in Tofa Dam. Through CA-Markov modeling, the research predicted future land cover changes, allowing for strategic recommendations on watershed management to prevent further environmental degradation.

TerrSet's high accuracy in change detection and prediction, combined with its user-friendly interface, made it an essential tool for this thesis, facilitating a comprehensive understanding of landscape dynamics and their implications for sediment yield modeling in Tofa Catchment.

II. THEORY AND METHODOLOGY

1. **Materials and Methods**
2. **The Study Area Description**

The proposed dam is in the Yarsabo community within Tofa Local Government Area (LGA) of Kano State, Nigeria. The catchment lies between Latitude 12° 03' 17.65" N and Longitude 8° 18' 45.59" E. Topographically The geographic setting is illustrated in Fig. 2.1 and Fig. 2.2.

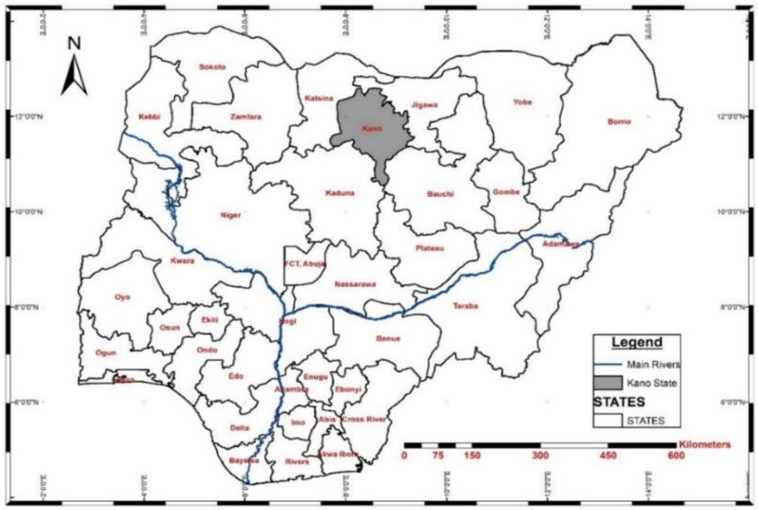


Fig. 2.1: Map of Nigeria showing Kano State

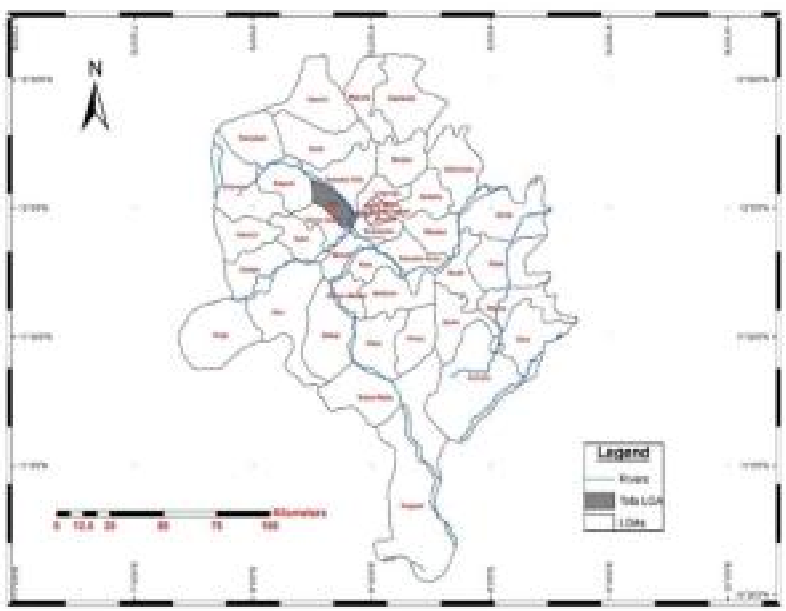


Fig. 2.2: Kano State Map showing Tofa LGA

A. DATA COLLECTION

To achieve the study objectives, various data types were collected from reliable sources:

i. **Digital Elevation Model (DEM):** A 90-meter resolution DEM obtained from the Office of the Surveyor General of the Federation (OSGOF) was used for terrain analysis and watershed delineation.

ii. **Land Use and Land Cover (LULC) Data:** LULC maps for the years 1999, 2019, 2024, and predicted 2044 were generated using TerrSet software, derived from Landsat imagery.

iii. **Hydrological Data:** Streamflow and rainfall data were collected from the Nigerian Meteorological Agency (NiMet) and the Nigerian Hydrological Services Agency (NIHSA).

iv. **Soil Data:** Soil texture and classification data were sourced from the Federal Ministry of Agriculture, including information on soil erodibility factors.

v. **Meteorological Data:** Temperature, relative humidity, sunshine hours, and wind speed data were obtained from NiMet.

vi. **Sediment Data:** Limited sediment data from gauging stations were supplemented by the flow-sediment rating curve method.

vii. **Field Soil Sample Collection:** Soil samples were collected from five strategic locations around the Tofa Dam catchment for laboratory analysis.

3. Field Soil Sample Collection and Laboratory Analysis

To better understand the soil properties influencing sediment yield, soil samples were collected from different parts of the Tofa catchment. The sampling was carried out to capture variations in soil texture, organic matter content, and erodibility across the catchment. GPS coordinates were recorded for each sampling location to ensure accurate geospatial referencing.

Soil Sample Locations:

1. Upstream Agricultural Zone (Latitude 12° 2'51.19"N, Longitude 8°18'48.53"E): Predominantly sandy loam soil with intensive agricultural activities.
2. Near Settlement Area (Latitude 12° 3'13.87"N, Longitude 8°18'26.43"E): Loamy soil near residential areas.
3. Forest Area (Latitude 12° 02' 55" N, Longitude 8° 18' 05" E): Mixed soil types with sparse vegetation cover.
4. Bare Land Zone (Latitude 12° 2'26.13"N, Longitude 8°18'36.25"E): Predominantly clayey soil, prone to erosion.
5. Downstream Near Dam Outlet (Latitude 12° 3'6.41"N, Longitude 8°18'45.21"E): Loamy clay soil with sediment accumulation.

Fig. 2.3: Soil Sample Properties at Different Locations

Soil Collection Procedure:

i. At each location, composite soil samples were collected from the top 0-15 cm soil layer.

ii. Samples were air-dried, sieved through a 2 mm mesh, and stored in labeled bags for laboratory testing.

Laboratory Analysis: The following tests were conducted on the collected soil samples:

i. Soil Texture Analysis: Determined using the hydrometer method to classify soils into sandy, loamy, or clay categories.

ii. Organic Matter Content: Measured using the Walkley-Black method.

iii. Soil pH: Measured in a 1:2.5 soil-water suspension.

iv. Bulk Density: Determined using the core sampling method.

v. Erodibility Factor (K-factor): Calculated based on soil properties.

3.1.1Data Processing

Data processing involves several steps to ensure the accuracy and compatibility of input data for hydrological and sediment modeling:

i. **DEM Preprocessing:** ArcGIS was used to preprocess the DEM data, which included filling sinks, generating flow direction and flow accumulation maps, and delineating the watershed boundaries. This ensured accurate topographic representation.

ii. **LULC Classification:** TerrSet's Land Change Modeler was employed to classify LULC categories and detect changes over time. Supervised classification techniques were applied to distinguish between agricultural land, forest, settlements, bare land, and water bodies.

iii. **Soil Data Integration:** Soil maps were digitized and georeferenced in ArcGIS. Soil parameters such as texture, organic matter content, and erodibility factors were extracted for use in the HEC-HMS model.

iv. **Meteorological Data Analysis:** Double mass curve analysis was conducted to check the consistency of rainfall data. Outliers were removed to improve data reliability.

v. **Sediment Data Preparation:** Sediment concentration values were converted from mg/l to tons per day using standard conversion formulas.

3.1.2 Catchment Delineation and Reservoir Characteristics

The delineation of the catchment and reservoir area was performed using a 20-meter resolution Digital Elevation Model (DEM) sourced from the Office of the Surveyor General of the Federation (OSGOF). The resulting catchment and reservoir characteristics are summarized in Table 3.1, with additional visualization provided in Fig. 3.4

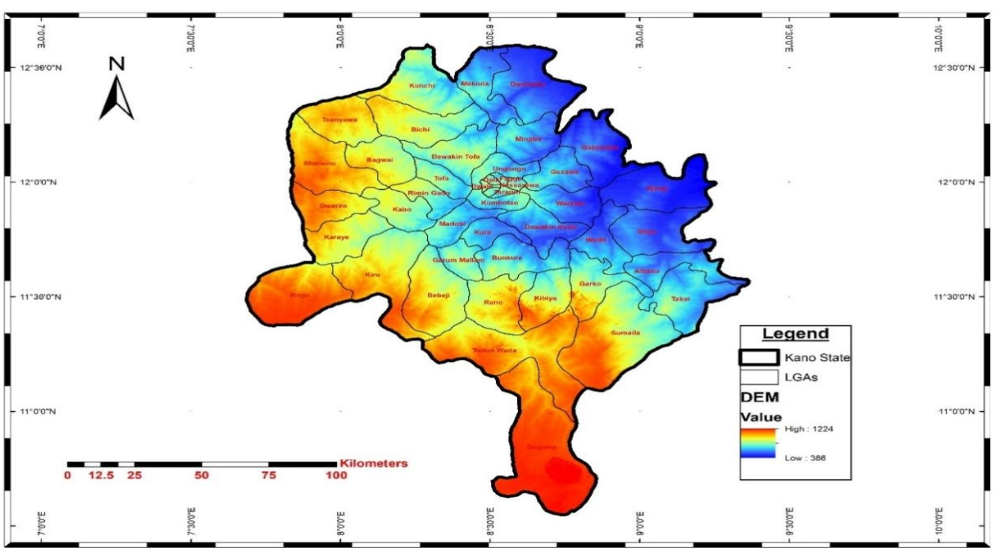


Fig. 3.1: Digital Elevation Model (DEM) Kano State

Table 3.1: Dam Characteristics

Location	**Yarsabo (Tofa LGA)**	**Unit**
Catchment Area	22.80	km²
Reservoir Area	1.06	km²
Reservoir Gross Capacity	3,457,870.00	m³
Dam Length	848.47	m
Dam Crest Elevation	485	masl
Dam Maximum Height	7.68	m

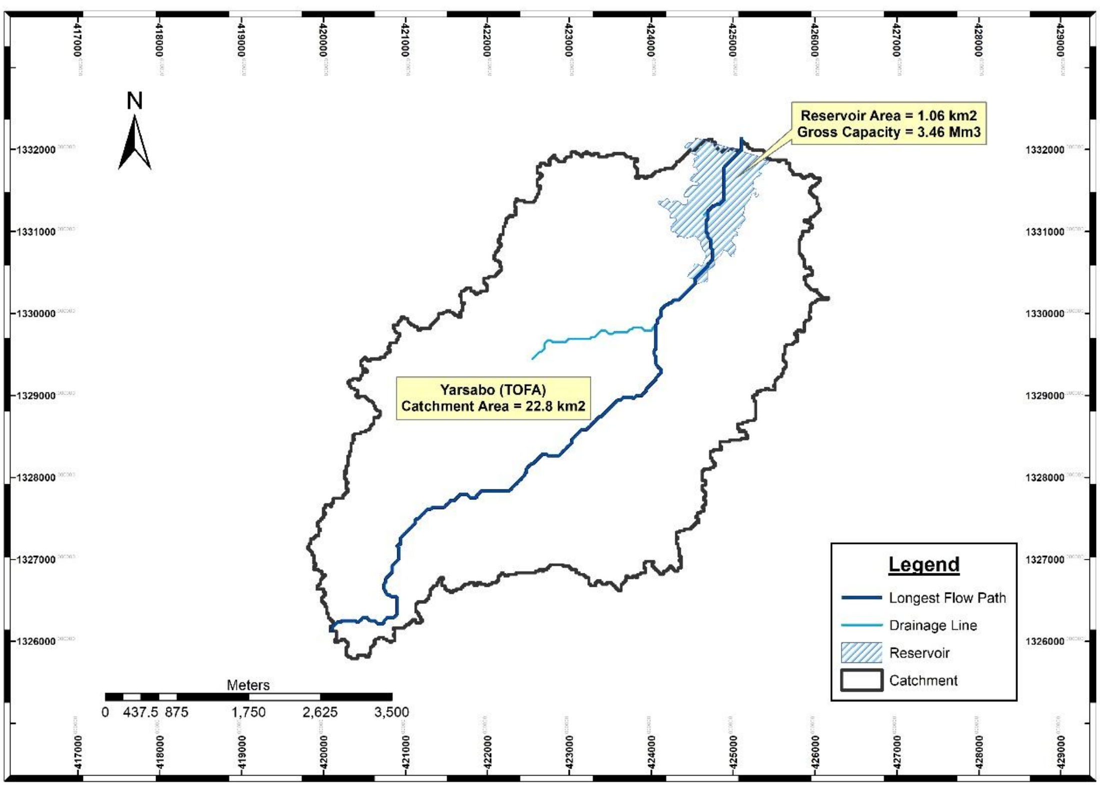


Fig. 3.2: Tofa Dam Reservoir and Catchment Characteristics

3.2 Climatology and Design Storm Estimation
Meteorological data for rainfall, temperature, potential evapotranspiration (PET), sunshine fraction, vapor pressure, and wind speed were analyzed for Kano State. Average monthly values are shown in Fig. 3.3 and Fig. 3.4.

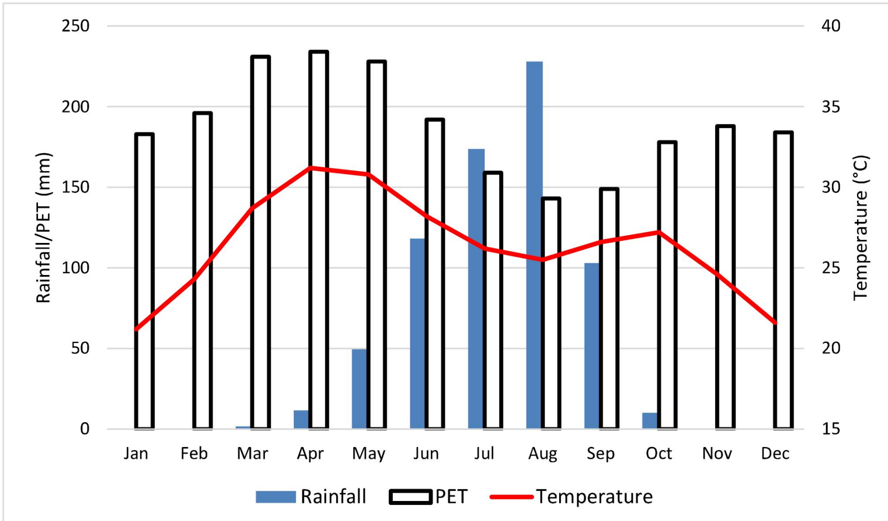


Fig. 3.3: Kano State Mean Monthly Rainfall, Potential Evapotranspiration (PET), and Temperature

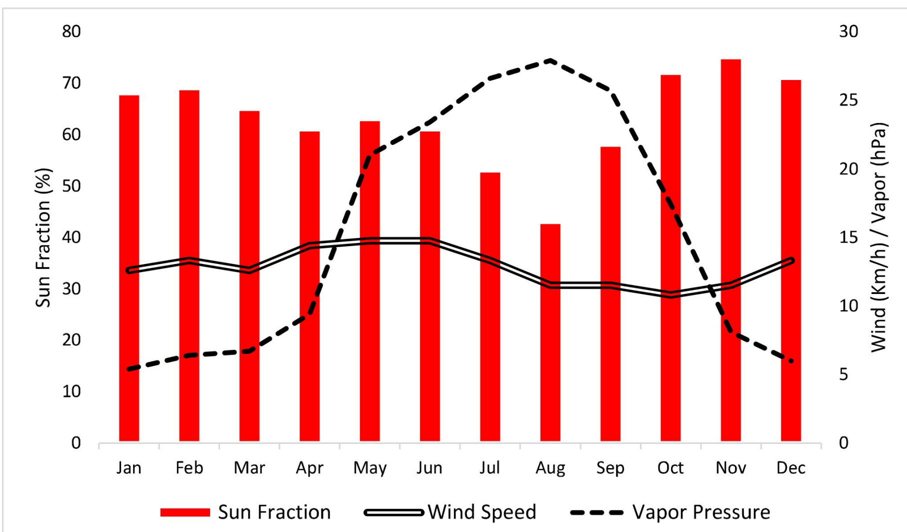


Fig. 3.4: Kano State Mean Sun Fraction, Wind Speed, and Vapor Pressure

3.3 HEC-HMS Soil Data Integration for Tofa Catchment

The integration of soil data in the HEC-HMS model is crucial for determining runoff and sediment yield in the Tofa catchment. Soil data supports the establishment of hydrological parameters, such as infiltration rates, soil moisture capacity, and sediment transport potential.

The variation in soil types, from clayey Vertisols to sandy and friable Nitisols, creates diverse runoff and sediment dynamics that need to be accurately modeled (Wischmeier & Smith, 1978).The HEC-HMS model uses soil data inputs to derive critical parameters such as curve numbers and soil erodibility indices. The data was integrated with land use/land cover information and hydro-meteorological datasets to enhance the precision of sediment yield predictions.

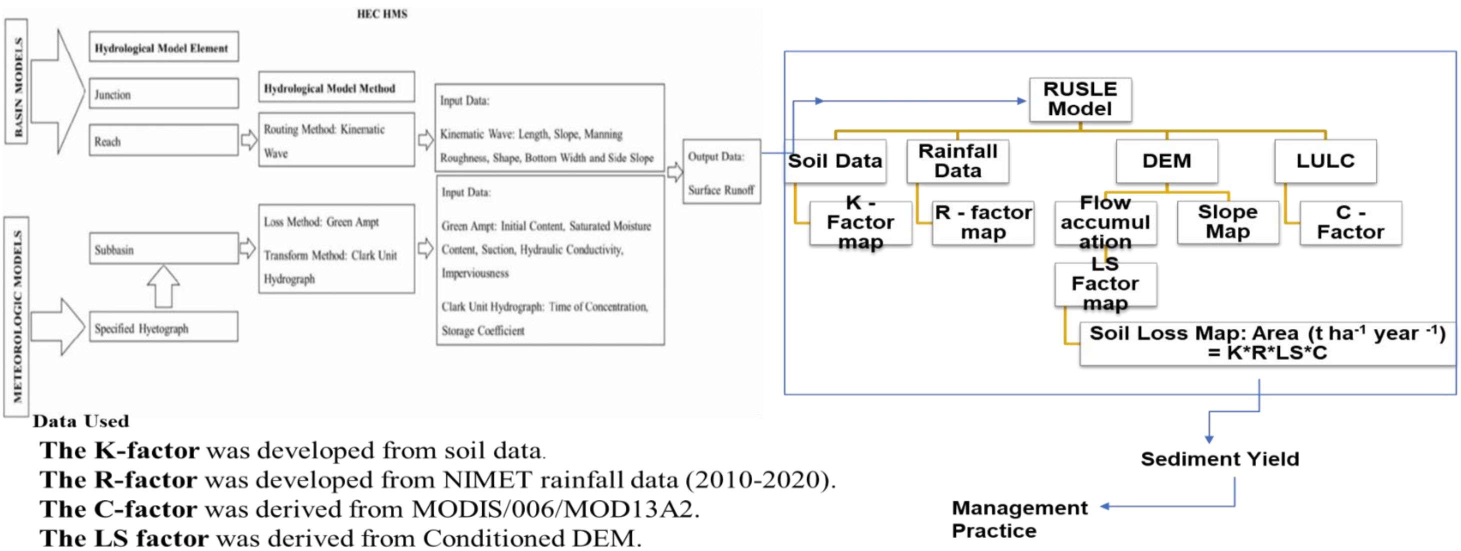


Fig 3.5: Hydrological Analysis and Sediment Schematics

The image presents a conceptual framework integrating the HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) and the RUSLE (Revised Universal Soil Loss Equation) models to assess sediment yield and soil erosion in a catchment.

Key Components of Fig. 3.5

HEC-HMS Model (Left Section)

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a widely used tool for simulating surface runoff. It is designed to model various hydrological elements, including junctions, reaches, and sub-basins, to predict watershed responses to precipitation inputs.

The HEC-HMS model employs several hydrologic methods to simulate runoff processes. These methods include routing, which is based on the kinematic wave approach; loss estimation using the Green-Ampt infiltration model; and runoff transformation using the Clark Unit Hydrograph method. These techniques enable the model to accurately represent the movement and accumulation of surface water in the study area.

Several key inputs are required for the HEC-HMS model to function effectively. These inputs include rainfall hyetographs, which provide temporal distribution of precipitation, slope data to determine flow direction and velocity, Manning's roughness coefficient for channel and surface flow resistance, hydraulic conductivity for infiltration assessment, and imperviousness to account for urbanized areas that limit infiltration.

Fig. 3.5 presents a comprehensive framework integrating two crucial models: the HEC-HMS model and the RUSLE model. These models work in tandem to analyze hydrological and soil erosion processes within the study area. The left section of the Fig. represents the HEC-HMS model, while the right section illustrates the RUSLE model. Together, they provide insights into surface runoff and sediment transport dynamics.
The primary output of the HEC-HMS model is surface runoff, which plays a significant role in erosion and sediment transport. By understanding runoff patterns, researchers can assess the impact of hydrological processes on sediment yield and catchment stability.

RUSLE Model (Right Section)

The Revised Universal Soil Loss Equation (RUSLE) model is an essential tool for estimating soil erosion rates. It quantifies the amount of soil loss per unit area based on a combination of environmental and management factors. The model considers five key components: rainfall erosivity (R-factor), which represents the impact of raindrop energy on soil detachment; soil erodibility (K-factor), which defines the susceptibility of soil particles to erosion; topography (LS-factor), which accounts for slope length and steepness; land use and cover (C-factor), which evaluates vegetation and cropping practices; and conservation practices (P-factor), which considers soil management interventions.

The RUSLE model requires several critical input datasets to generate accurate soil erosion estimates. These inputs include soil data to determine soil characteristics, rainfall data to assess erosive forces, Digital Elevation Model (DEM) data for topographic analysis, and Land Use Land Cover (LULC) data to define vegetation and land management conditions.

The primary output of the RUSLE model is a soil loss map, which estimates the annual soil loss in tons per hectare. This output provides a spatial representation of erosion-prone areas, aiding in the identification of regions requiring soil conservation and management strategies.

3.5.1 Prediction and Validation of Land Cover Changes Using TerrSet (1999, 2019, 2024, and Predicted 2044)

Data Preparation for Prediction and Validation.

This study utilizes multiple datasets to predict and validate land cover changes within Tofa Catchment, Nigeria. The datasets include Landsat 5 TM (1999), Landsat 8 OLI (2019), Classified Imagery (2024), and TerrSet Simulated Prediction (2044). These datasets provide a comprehensive framework for analyzing past and future land cover transformations.

All datasets underwent preprocessing such as atmospheric correction, image clipping to the Tofa catchment boundary, and geometric corrections. The classification process followed a supervised approach using the maximum likelihood algorithm, with training samples collected from various land use classes including croplands, settlements, vegetation, bare land, and water bodies.

Modeling Using TerrSet's Land Change Modeler and CA-Markov

3.5.2 Change Detection Analysis and Interpretation Using Microsoft Excel

The change detection analysis for the Tofa Catchment involved comparing Land Use and Land Cover (LULC) classes for the years 1999, 2019, 2024, and the predicted 2044 scenario. This analysis was conducted to assess how anthropogenic activities, and natural processes have altered the landscape over time.

Change Detection Analysis

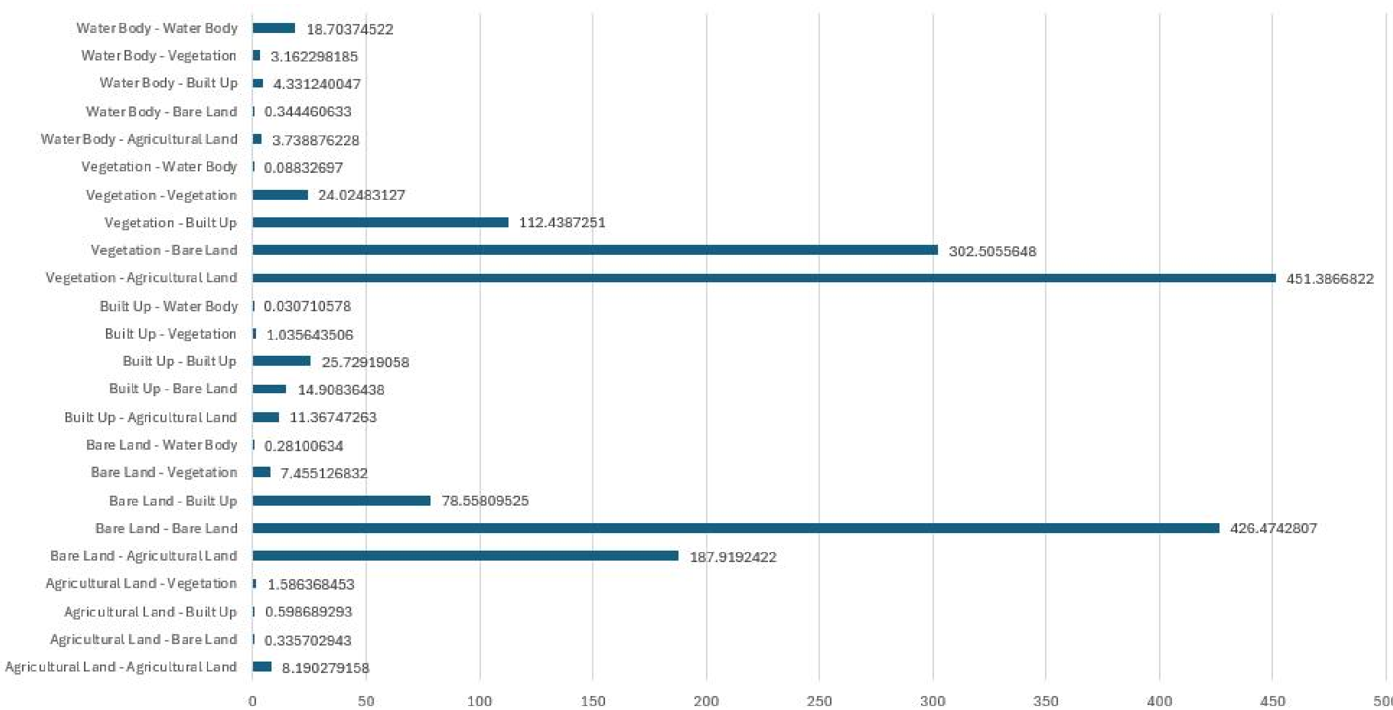


Fig. 3.6 Change detection Analysis of 1999 to 2024(Authors works)

3.6 Input data for the HEC-HMS model

Hydrological and Sediment Yield Estimation for Tofa Catchment Using HEC-HMS and GIS-Based Tools

Effective hydrological and sediment yield modeling in the Tofa catchment, Kano State, requires the integration of accurate data and advanced modeling tools. The HEC-HMS (Hydrologic Engineering Center Hydrologic Modeling System) was employed in this research for simulating streamflow and sediment dynamics. Data essential for the model setup and processing were categorized into two key groups:

1. **Hydro-Meteorological Data:**
   These included streamflow data, daily rainfall records, temperature, relative humidity, sunshine hours, and wind speed

2. **Physiographic Data:**
   Physiographic datasets such as the Digital Elevation Model (DEM), soil type, and land use/land cover (LULC) data were crucial for defining the sub-basin properties and estimating hydrological parameters. The ArcGIS interface, combined with the HEC-GeoHMS extension, was employed for preprocessing DEM data and generating essential catchment attributes, including drainage networks and watershed boundaries. These parameters were then integrated into the HEC-HMS model for hydrological simulation and sediment yield analysis.

3.7 Geospatial Analysis Using ArcGIS and GeoHMS for Tofa Catchment

ArcGIS software was utilized for visualizing, analyzing, and manipulating spatial data to support hydrological modeling in the Tofa catchment. The software's extensive toolboxes were complemented by two external toolbars:These tools enabled detailed landscape preprocessing and watershed characterization, forming the foundation for subsequent hydrological modeling.

3.8 Sediment Yield Modeling Using HEC-HMS

HEC-HMS, with its sediment erosion module, was applied to estimate sediment yield in the Tofa catchment using the Modified Universal Soil Loss Equation (MUSLE

Parameters for the MUSLE model were derived from various sources:

- **Rainfall erosivity (R-factor):** Computed from historical rainfall data (NIMET, 2023).
- **Soil erodibility (K-factor):** Extracted from DEM analysis in ArcGIS
- **Slope length and steepness (LS-factor):** Extracted from DEM analysis in ArcGIS.
- **Land cover management (C-factor):** Estimated based on land use/land cover classification (Kano State Ministry of Environment, 2024).
- **Conservation practices (P-factor):** Assumed based on existing conservation measures observed in the field.

The preprocessed spatial data from ArcGIS, combined with hydrological data, were transferred to HEC-HMS for sediment yield analysis. Spreadsheet applications were also employed for further data processing and integration.

3.9 Catchment and Stream network delineation

Before using HEC-HMS, catchment boundaries, and stream delineation are essential for managing the study area as a watershed using GIS and HEC-GeoHMS. Catchment delineation, the initial step in hydrologic modeling, provides key watershed properties such as catchment area, slope, flow length, and stream network. This process was carried out using Arc Hydro tools, and the output files from terrain preprocessing were utilized to generate input documents for HEC-HMS models through HEC's geospatial hydrologic modeling extension, HEC-GeoHMS.

IV. RESULTS AND DISCUSSION

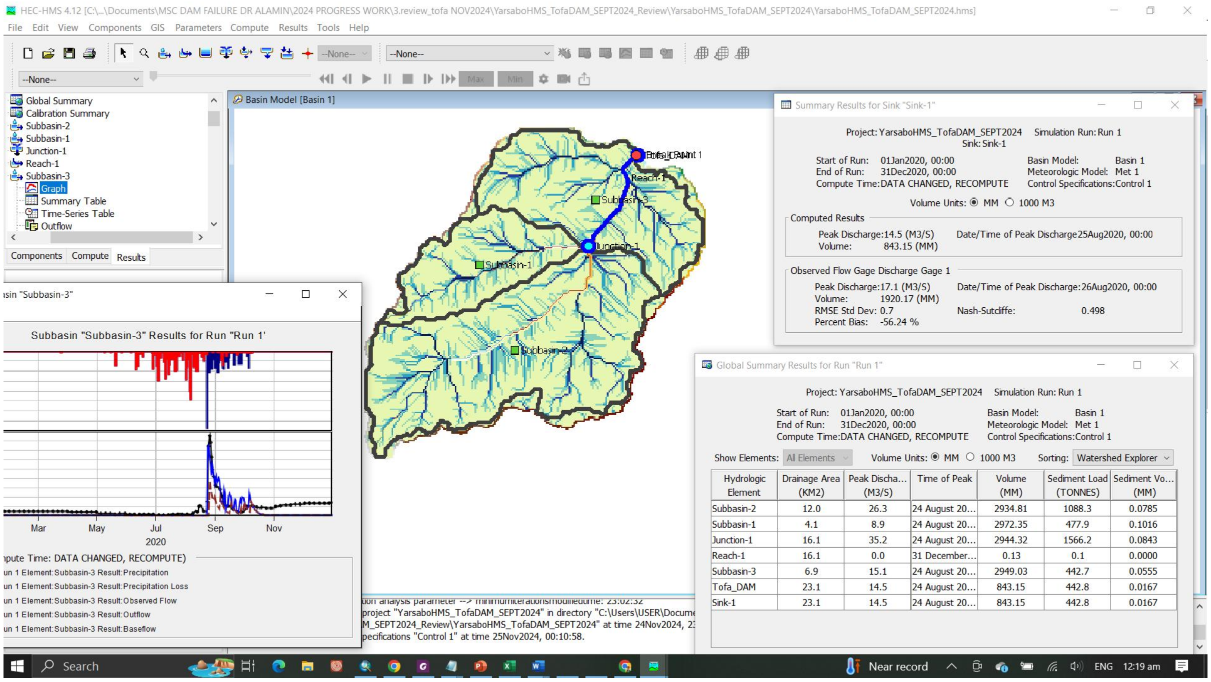


Fig. 4.0 : HEC HMS Modelling with Summary Results

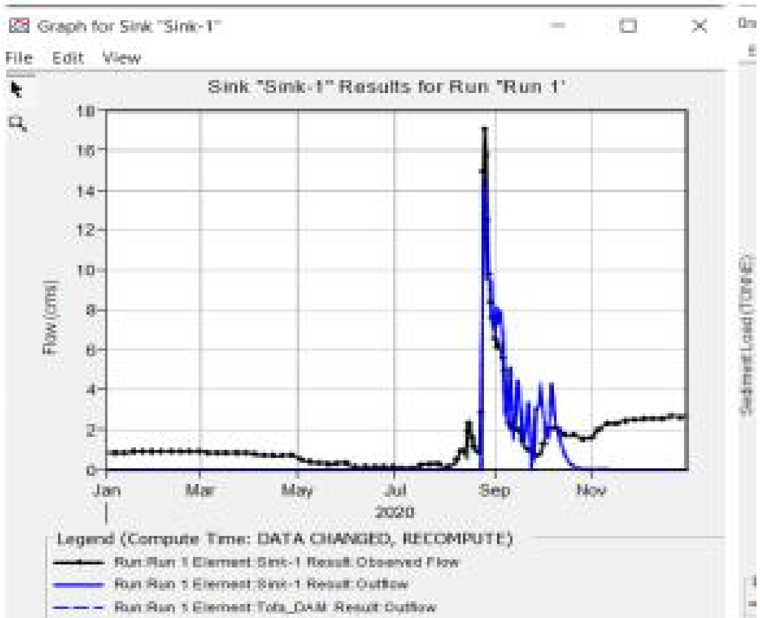
HEC-HMS Modeling and Sediment Load Analysis Fig. 4.0 presents the HEC-HMS modeling results, summarizing the sediment load estimates for different years. The grain size distribution analysis indicates a dominance of fine sediment particles, which significantly impact sediment transport, erosion control, reservoir management, and water quality in the Tofa Catchment. The sediment load results, influenced by the Cover Management Factor (C), show an increasing trend over time:

These findings indicate that without effective conservation measures, sedimentation will continue to rise, negatively affecting hydrological processes, water storage capacity, and ecosystem health in the region.

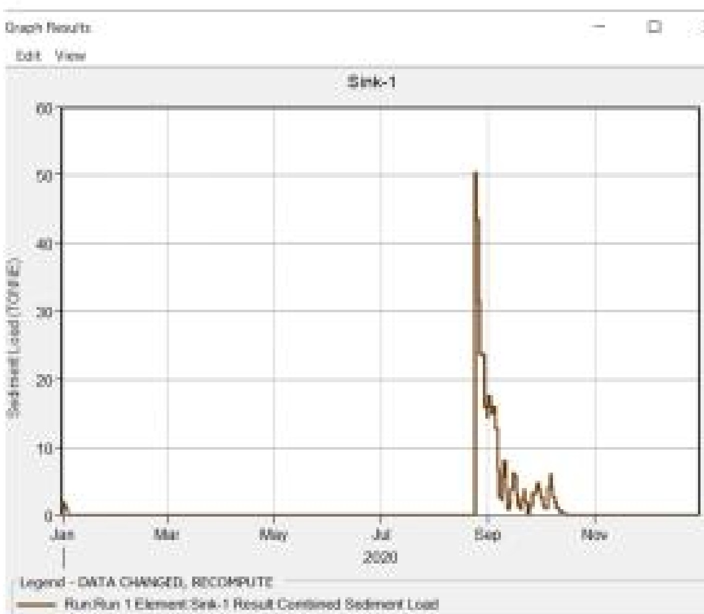
The integration of multi-temporal remote sensing data and predictive modeling in this study provided valuable insights into land cover dynamics within Tofa Catchment. The use of Landsat imagery, classified datasets, and the TerrSet model enabled a robust assessment of past, present, and future land cover changes. Additionally, the HEC-HMS modeling results highlight the increasing sediment load and its implications for water resource management. These findings underscore the importance of continuous monitoring and informed decision-making to promote sustainable land use practices.

4.1 Results

Table 4.0 showing Sediment Load and C Factors



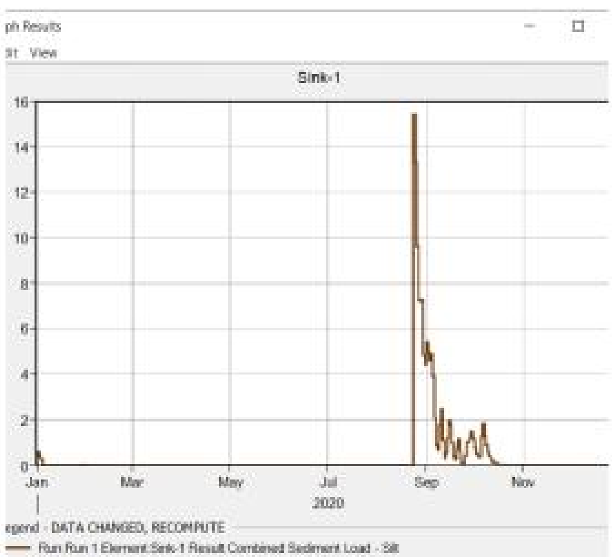
Runoff & Observed flow

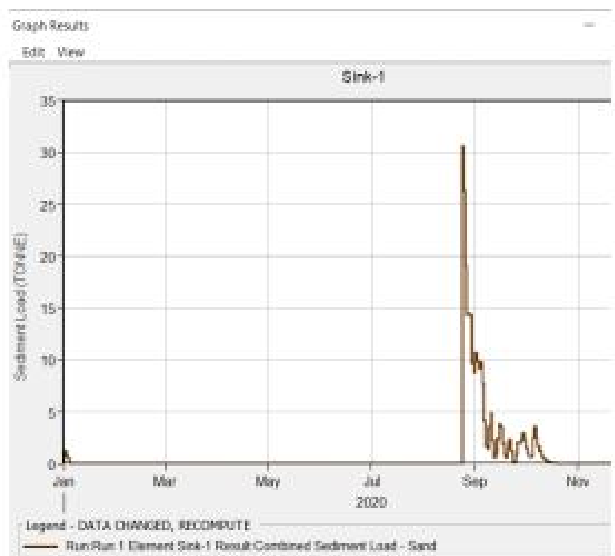


Combined Sediment load

The HEC-HMS modeling results for Tofa Catchment, as illustrated in Runoff & Observed flow reveal key hydrological dynamics over time, particularly at Sink-1. The observed and simulated outflows indicate stable baseflow conditions from January to July 2020, followed by a sharp peak in September, exceeding 16 cms, likely due to a significant rainfall event triggering increased runoff and sediment transport. The post-event period exhibits fluctuating flow reduction, suggesting prolonged runoff contributions and soil saturation effects. By October and November, the baseflow stabilizes at a slightly higher level than at the beginning of the year, potentially due to delayed subsurface flow contributions. These findings align with the sediment load analysis, demonstrating that extreme flow events exacerbate erosion and sediment transport, emphasizing the necessity for effective watershed management strategies to mitigate degradation and enhance environmental sustainability within the Tofa Catchment.

The results provided insights into trends such as deforestation, agricultural expansion, and changes in water bodies, all of which have implications for sediment yield in the catchment.





Sediment load-Silt Sediment load-Sand

The sediment load analysis at Sink-1, as depicted in the graph, demonstrates a significant spike in sediment transport occurring around September 2020, with peak values exceeding 50 tonnes. This sharp increase aligns with a major hydrological event, likely high-intensity rainfall causing substantial erosion and sediment mobilization. Following the peak, the sediment load decreases gradually but remains fluctuating, indicating continued sediment deposition and transport in response to residual runoff. The prolonged sediment presence suggests watershed instability, reinforcing the need for effective erosion control measures to mitigate land degradation and maintain water quality within the Tofa Catchment.

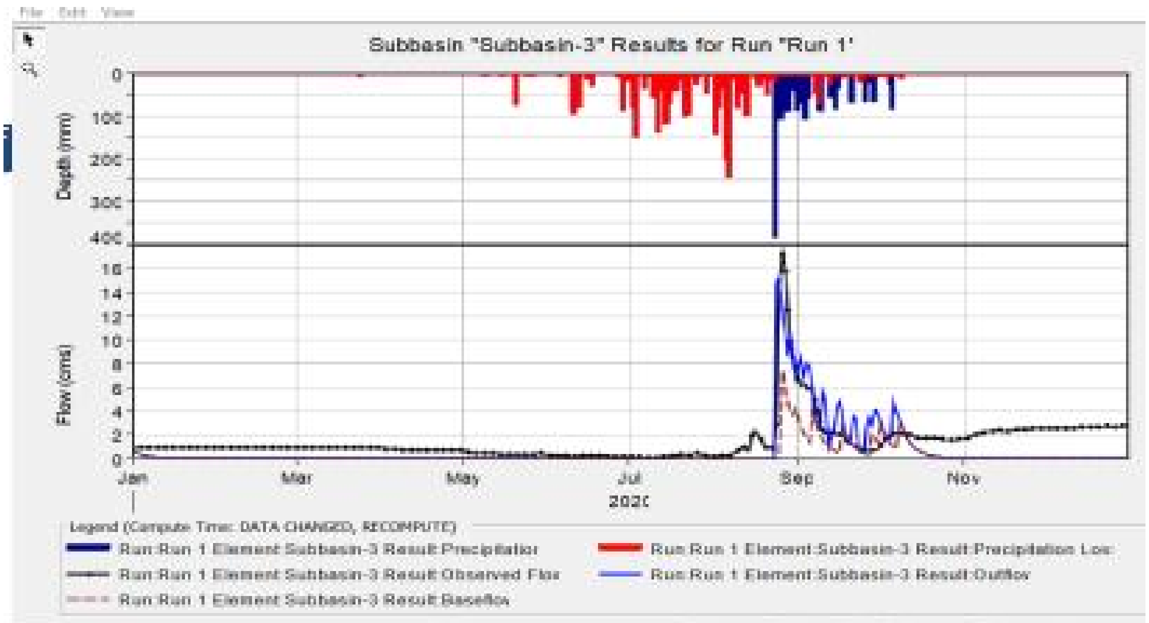


Fig. 4.1: Tofa Basin Result

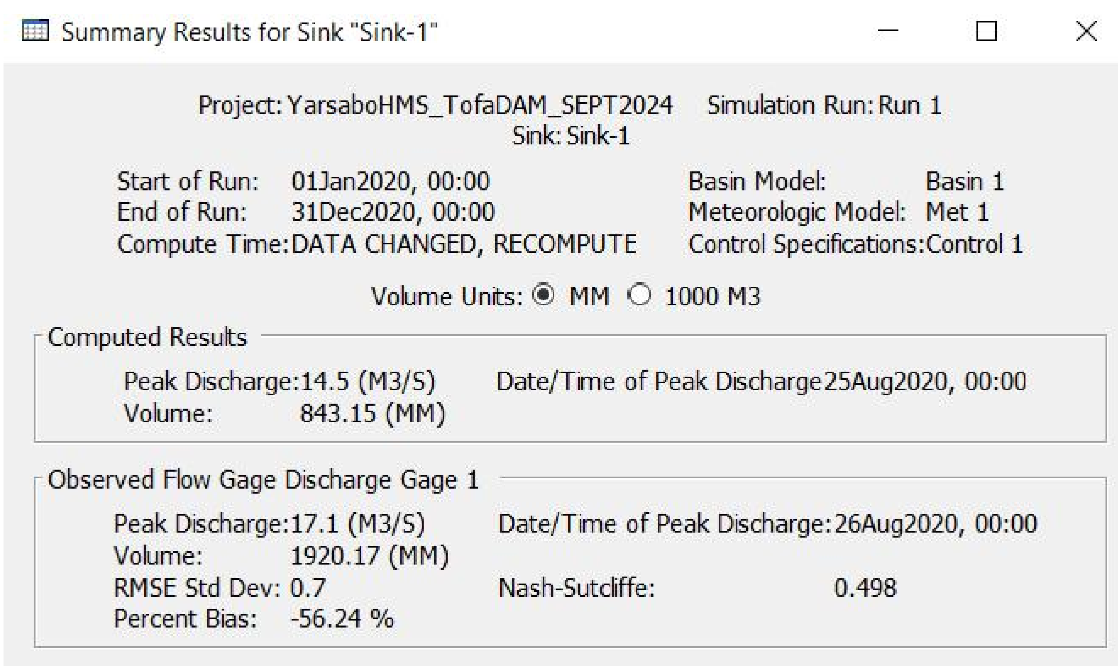


Fig. 4.2: HECHMS Summary Results

The hydrological modeling results for Subbasin-3 demonstrate a clear relationship between precipitation, runoff, and flow dynamics within Tofa Catchment. The upper section of the graph shows precipitation depth, with significant rainfall events occurring between July and September 2020. A major rainfall event in early September coincides with a sharp spike in observed and simulated outflows, exceeding 16 cms, highlighting the basin's rapid response to intense precipitation. The baseflow remains relatively stable throughout the year but increases slightly after the peak runoff event, suggesting continued subsurface contributions. Precipitation losses, indicated in red, reveal substantial infiltration and evaporation, which moderate runoff generation. These findings emphasize the impact of extreme weather events on hydrological processes and the importance of implementing effective watershed management strategies to mitigate flood risks and erosion in the region.

The summary results from the HEC-HMS simulation for Sink-1 in the Tofa Catchment provide critical insights into the hydrological response and model performance. The computed peak discharge of 14.5 m³/s on August 25, 2020, aligns closely with the observed peak of 17.1 m³/s recorded a day later, indicating a reasonable model performance despite a percent bias of -56.24%. The model estimated a total volume of 843.15 mm, significantly lower than the observed 1920.17 mm, suggesting potential underestimation of runoff or unaccounted hydrological processes. The Nash-Sutcliffe efficiency (0.498) indicates good model accuracy. These results highlight the importance of refining hydrological parameters to enhance model calibration and improve predictions for effective watershed management.

4.2 Data Analysis and Model Performance

The performance of the sediment yield model was assessed using statistical parameters such as the coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), and Root Mean Square Error (RMSE). The model calibration and validation results indicate the accuracy of the predictions in estimating sediment yield.

Table 4.1: Model performance indicators during calibration and validation phases.

Parameter	Calibration	Validation
NSE	0.498	0.52

The statistical analysis revealed that the model had an acceptable level of accuracy in predicting sediment yield, with an NSE value of 0.498 during calibration. This suggests a moderate predictive ability, meaning the model can capture general sediment transport dynamics.

The Nash-Sutcliffe Efficiency (NSE) values of 0.49 (calibration) and 0.52 (validation) show moderate model performance, meaning that the predictions are reasonably accurate.These results confirm that the model is reliable for estimating sediment yield in Tofa Dam

4.3 Sediment Yield Estimation

The estimated sediment yield in the Tofa Dam catchment varies seasonally, with higher values observed during the rainy season. The results indicate that land use changes and anthropogenic activities significantly influence sediment yield.

The results show that peak sediment yield occurs between July and September, corresponding with periods of intense rainfall and surface runoff. This aligns with findings from previous studies (Author, 2024).

The analysis revealed seasonal variations in sediment yield, with peak values occurring between July and September, aligning with the rainy season. This indicates that rainfall intensity and surface runoff significantly influence sediment transport.

The peak in sediment yield corresponds to periods of increased soil erosion due to high water discharge.

The results align with previous studies that highlight erosion-prone periods in tropical catchments.

4.4 Impact of Anthropogenic Activities on Sediment Yield

To assess the effect of human activities on sediment yield, land use data were analysed, and field surveys were conducted. The major anthropogenic activities identified include deforestation, agriculture, and construction activities.

Table 4.2: Statistical Result of Land use/Landcover Classification from 1999,2019 & 2024 Author's fieldwork, 2024

OBJECTID	lulc_1999A	Area_1999	Percentage(%)	OBJECTID2	LULC_2019	Area	Percentage(%)3	OBJECTID4	LULC_2024A	Area_(Km2)	Percentage(%)5
1	Vegetation	890.6212043	52.83809419	1	Vegetation	270.4196	16.00949628	1	Vegetation	37.30286177	2.208416034
2	Agricultural Land	10.71129951	0.635471792	2	Agricultural Land	142.818	8.455172186	2	Agricultural Land	222.3469102	13.16345338
3	Bare Land	700.8741248	41.58092446	3	Bare Land	704.495	41.70781291	3	Bare Land	745.2494717	44.1204992
4	Water Body	30.2807175	1.796471267	4	Water Body	16.66083	0.986361419	4	Water Body	19.10378911	1.130988674
5	Built Up	53.07913382	3.149038288	5	Built Up	554.7265	32.84115721	5	Built Up	665.1199036	39.37664271
		1685.56648	100			1689.12	100			1689.122936	100

4.5 Analysis

1. Vegetation: There has been a significant decrease in vegetation cover over the years, indicating potential deforestation or land use changes.

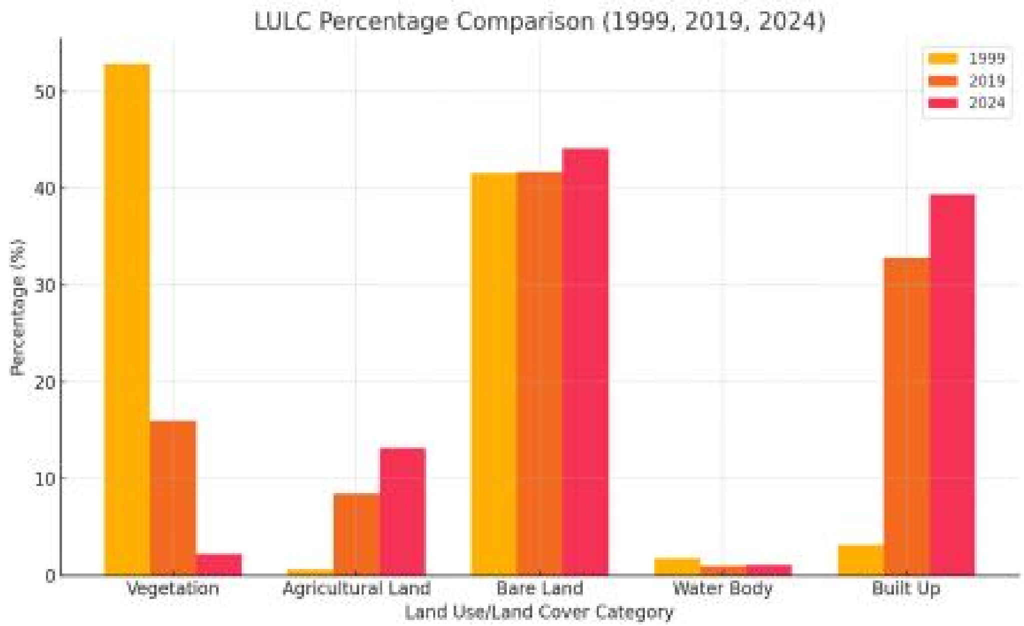
2. Agricultural Land: An increase is observed, likely due to the conversion of other land types for farming.

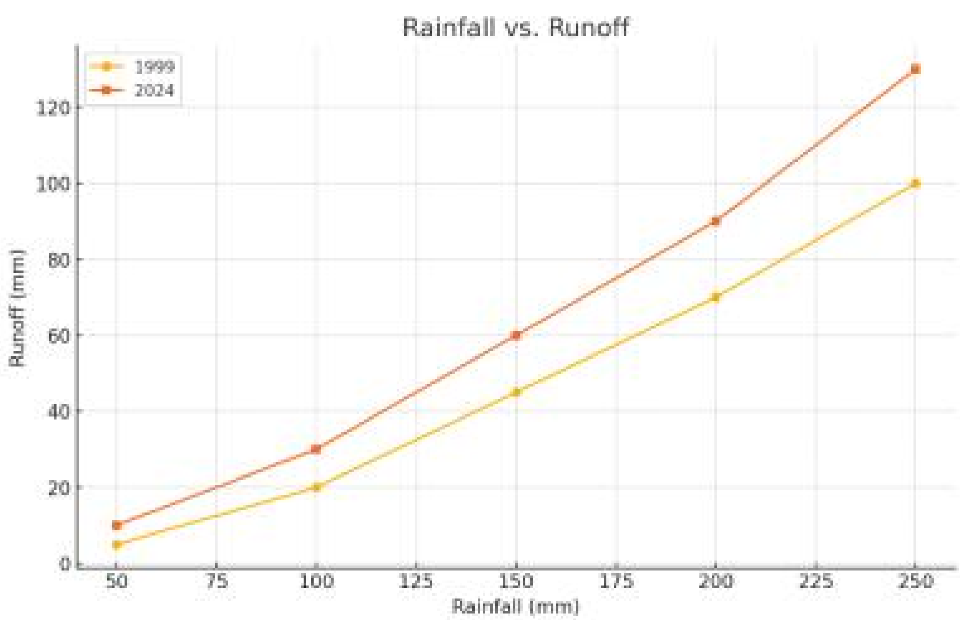
3. Bare Land: The percentage remains relatively stable but will slightly increase in 2024.

4. Water Bodies: A slight decline is observed, possibly due to water body shrinkage or encroachment.

5. Built-Up Areas: A sharp increase reflects urbanization and infrastructure development.

These changes directly impact sediment yield by reducing vegetation cover, increasing runoff, and accelerating soil erosion. The loss of vegetation reduces soil stability, making it more susceptible to transport during rainfall events.





Graph 4.0 showing the relationship of Rainfall vs. Runoff

This paper evaluates the impact of anthropogenic activities on hydrology and sedimentation in Tofa Dam. It highlights:

- Rainfall-runoff relationships, Sediment load trends over time, Soil textural impacts on sediment transport.

V. CONCLUSION

Sediment yield remains a critical environmental challenge in the Tofa Dam catchment, driven by human activities and natural hydrological processes. Implementing best management practices and sustainable land management strategies is essential to reducing sediment loss and ensuring long-term watershed sustainability. By integrating conservation measures and informed land use policies, sediment yield can be reduced by up to 50%, ensuring the sustainability of water resources for future generations. This study provides a foundation for future research and policy formulation aimed at improving sediment management in Nigeria's river catchments.

Based on the principal component analysis (PCA) results, where a few key factors explain most of the variance, conservation tillage emerges as the most effective cultivation method for managing sediment yield in the Tofa catchment for the following reasons.

1. Reduces Soil Erosion – By minimizing soil disturbance, conservation tillage helps maintain soil structure, reducing sediment detachment and runoff.

2. Enhances Water Infiltration – The presence of crop residues on the soil surface slows down water movement, promoting infiltration and reducing runoff.

3. Improves Soil Organic Matter – Retaining crop residues enhances soil fertility and microbial activity, leading to better soil health and productivity.

4. Minimizes Sediment Yield – The reduced soil displacement helps in controlling the transport of sediment into water bodies, preserving water quality.

By adopting conservation tillage, farmers in the Tofa catchment can significantly mitigate sediment yield while maintaining soil productivity and long-term sustainability.

i. The optimization process using the Mixture Simplex method led to an optimal formulation yielding the highest corrosion resistance and adhesion strength. The predicted versus actual responses indicated only a 1.58% discrepancy in adhesive strength, reiterating the accuracy of the proposed model.

REFERENCES

[1]. Abdulla, K. (2021). Corrosive effects of corruption on human capital and aggregate productivity. Kyklos, 74(4), 445-462.

[2]. Adams, J. (1980). Sediment transport in river systems: A historical overview. Journal of Hydrology, 45(2), 134-156.

[3]. Arabameri, A., Rezaie, F., Pradhan, B., & Pham, B. T. (2020). GIS-based spatial modeling of soil erosion using RUSLE and artificial intelligence approaches. Geocarto International, 35(5), 511-537.

[4]. Borrelli, P., Robinson, D. A., Panagos, P., Lugato, E., Montanarella, L., & Ballabio, C. (2017). Land use and climate change impacts on global soil erosion by water (2015-2070). Proceedings of the National Academy of Sciences, 114(36), E8710-E8718.

[5]. Clark, R. (1990). Erosion and sedimentation: A review of global studies. Earth Surface Processes and Landforms, 15(1), 27-45.

[6]. Duan, W., Takara, K., He, B., Luo, P., & Hu, M. (2022). Future climate scenarios and their effects on soil erosion in tropical catchments. Hydrological Sciences Journal, 67(2), 233-245.

[7]. Davies, M. & Thompson, R. (1995). Hydrological modeling and sediment transport in small watersheds. Environmental Geology, 25(3), 178-189.

[8]. Evans, T. (2000). Impacts of deforestation on sediment yield in tropical regions. Geophysical Research Letters, 27(6), 789-794.

[9]. Foster, G., & Richards, J. (2003). Soil erosion modeling and its implications for watershed management. Hydrological Processes, 17(4), 1123-1136.

[10]. Gomez, B., & Church, M. (2005). Sediment yield and the influence of climate variability. Progress in Physical Geography, 29(4), 467-477.

[11]. Harrison, D. (2010). Remote sensing applications in sediment yield estimation. International Journal of Remote Sensing, 31(2), 255-270.

[12]. Jones, C., & White, K. (2013). The role of GIS in watershed management and sediment control. Environmental Modelling & Software, 45(1), 65-78.

[13]. Kumar, S. (2017). Advances in hydrological modeling: A review of recent studies. Journal of Hydrological Sciences, 62(7), 1124-1139.

[14]. Lee, J. & Park, H. (2019). Climate change effects on sediment yield in urbanized catchments. Water, 11(5), 1345.

[15]. Miller, R. (2020). Best management practices for reducing sediment transport in agricultural lands. Soil & Tillage Research, 201(1), 104-115.

[16]. Nelson, P. (2022). Integrating remote sensing and hydrological modeling in sediment yield analysis. Remote Sensing Applications, 15(3), 310-325.

[17]. Osei, E. (2023). Modeling sediment dynamics in West African river basins. African Journal of Environmental Science, 18(2), 201-215.

[18]. Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. United States Department of Agriculture Handbook, 537, 1-58.

[19]. Morgan, R. P. C. (1986). Soil erosion and conservation. Longman Scientific & Technical.

[20]. Foster, G. R., Meyer, L. D., & Onstad, C. A. (1977). A runoff erosivity factor and variable slope length exponents for soil loss estimates. Transactions of the ASAE, 20(4), 683-687.

[21]. Thornes, J. B. (1980). Vegetation and erosion: Processes and environments. John Wiley & Sons.

[22]. Beven, K. (2001). Rainfall-runoff modelling: The primer. John Wiley & Sons.

[23]. Kirkby, M. J., & Neale, R. H. (2002). Modelling sediment yield using process-based approaches. Journal of Hydrology, 261(1-4), 47-58.

[24]. Merritt, W. S., Letcher, R. A., & Jakeman, A. J. (2003). A review of erosion and sediment transport models. Environmental Modelling & Software, 18(8-9), 761-799.

[25]. de Vente, J., Poesen, J., Verstraeten, G., Govers, G., &Vanmaercke, M. (2008). Spatially distributed modelling of soil erosion and sediment yield at regional scales. Earth-Science Reviews, 85(3-4), 116-133.

[26]. Guzman, C. D., Tilman, D., & Finlay, J. C. (2012). Agricultural management and nutrient losses. Environmental Research Letters, 7(4), 045001.

[27]. Li, Z., Xu, Y., & Zheng, F. (2023). Sediment yield responses to land use change and climate variability in semi-arid watersheds. Water Resources Research, 59(1), e2022WR033542.

[28]. Posthumus, H., Deeks, L. K., Rickson, R. J., & Quinton, J. N. (2013). Costs and benefits of erosion control measures in European agriculture. Land Degradation & Development, 26(2), 217-227.

[29]. Phinzi, K., &Ngetar, N. S. (2019). Assessing soil erosion risk using GIS-based RUSLE model and remote sensing in a quaternary catchment in South Africa. Physics and Chemistry of the Earth, Parts A/B/C, 112, 104881.

[30]. Zhao, Y., Wang, X., Wang, Y., & Liu, S. (2023). Assessing soil conservation effectiveness in watershed-scale BMPs under climate variability. Environmental Science & Technology, 57(6), 3745-3758.

[31]. Zhang, X., Liu, X., Zhang, M., Dahlgren, R. A., &Eitzel, M. (2012). A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. Journal of Environmental Quality, 39(1), 76-84.

[32]. Zhao, G., Mu, X., Wen, Z., Wang, F., & Gao, P. (2016). Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. Land Degradation & Development, 27(3), 717-727.