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Hydrogeology of the Tambacounda Watershed

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Abstract: The Tambacounda watershed, located in eastern Senegal (West Africa), constitutes one of the major hydrological units draining toward the Gambia River system. Covering a total area of approximately 42,364 km², the watershed presents a complex geomorphological framework shaped by millions of years of geological history, tectonic inheritance, and intense tropical weathering. This article provides a comprehensive analysis of the geomorphology of the Tambacounda watershed, examining its structural geology, relief classification, drainage network, weathering processes, soil formation, and their implications for hydrological modeling and land resource management. Elevation ranges from -12 m in river valley floors to 330 m in the northeastern highlands, with a dominant west-to-east gradient reflecting the transition from the flat Senegalese interior plains toward the Fouta Djallon foothills.

Keywords: *Watershed, Tambacounda, Hdrogeology, SRTM 30m, RCP4.5, RCP4.8, SWAT Modelling.*

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I. GEOGRAPHICAL AND GEOLOGICAL SETTING

➢ *Location and Regional Context*

The Tambacounda watershed is situated in the eastern part of Senegal, between approximately 12°N and 14°N latitude and 12°W and 14°W longitude. It forms part of the broader Gambia River basin, one of the most important transboundary river systems of West Africa. The Gambia River originates from the Fouta Djallon plateau in northern Guinea and flows westward across Senegal for approximately 1,120 km before emptying into the Atlantic Ocean.

The region lies at a critical transition zone between two major geological domains: (1) the ancient Precambrian basement exposed in the east, and (2) the Mesozoic-Cenozoic sedimentary sequences of the Senegal-Mauritania Basin extending to the west. This duality fundamentally controls the topographic gradient, soil types, drainage patterns, and groundwater behavior observed across the watershed.

➢ *Tectonic and Geological Framework*

The geology of eastern Senegal is dominated by Precambrian formations belonging to the West African Craton, specifically the Birimian greenstone belts and associated granite intrusions. These formations are part of the Kedougou-Kenieba inlier, a major geological unit exposed across the Senegal-Mali border region.

The Birimian formations consist of volcano-sedimentary schists, greywackes, and metavolcanic rocks affected by syn-, late-, and post-tectonic granite intrusions. These ancient rocks, dating back approximately 2.1 billion years, form the resistant geological substrate of the northeastern highlands visible in the relief map as the dark blue elevation class (113-330 m).

The Continental Terminal formation (Miocene age) overlies the basement in large portions of the watershed. This formation, composed of heterometric sands and argillaceous sandstones, forms the flat to gently undulating plateaus of the western and central zones (elevation 42-85 m). It represents the dominant geological unit across the low-lying orange-colored terrain visible in the SRTM relief map.

Quaternary alluvial deposits occur along the major river valleys, particularly in the Gambia and Mamacounda floodplains. These unconsolidated sediments, composed of sands, silts, clays, and gravels, correspond to the lowest elevation class (-12 to 42 m) displayed in dark brown on the relief map.

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Table 1 Tectonic and Geological Framework

Geological Formation	Age	Rock Type	Elevation Zone
Birimian / Precambrian Basement	~2.1 Ga	Schist, greywacke, granite	113-330 m (blue)
Continental Terminal	Miocene	Sands, argillaceous sandstone	42-85 m (orange/green)
Quaternary Alluvium	PleistoceneHolocene	Sand, silt, clay, gravel	-12 to 42 m (brown)

II. RELIEF AND TOPOGRAPHIC ANALYSIS

➢ *Elevation Zones and Their Significance*

Based on the SRTM 30m Digital Elevation Model, the Tambacounda watershed can be divided into five distinct elevation zones, each with specific geomorphological and hydrological characteristics:

- *Zone 1: River Valleys and Floodplains (-12 to 42 m)*

This lowest elevation class corresponds to the active river valleys of the Gambia River, the Mamacounda River, and their tributaries. The visible dark brown dendritic pattern on the relief map directly traces this zone. The negative elevation values (-12 m) likely reflect SRTM data artifacts associated with dense riparian vegetation canopy or areas of active floodplain sedimentation. These zones are subject to seasonal flooding during the rainy season (JulyOctober), forming temporary wetlands of ecological and agricultural importance.

- *Zone 2: Low Alluvial Plains and Interior Plateaus (42-63 m)*

The dominant land surface of the western portion of the watershed, this orange-colored zone covers large expanses of flat to gently undulating terrain developed on Continental Terminal sediments. The landscape is characterized by a tabular morphology, locally incised by river valleys. Agricultural activity is concentrated in this zone due to favorable topography and relatively accessible soils. Groundwater recharge is significant given the low slopes and high infiltration potential.

- *Zone 3: Transitional Slopes and Intermediate Plateaus (63-85 m)*

Occupying the central portion of the watershed, this green zone represents the transition between the low sedimentary plains and the crystalline basement highlands. Moderate slopes generate intermediate runoff velocities, making this zone important for HRU (Hydrological Response Unit) differentiation in SWAT-based models. Vegetation cover is typically dominated by Sudanian savanna woodlands, transitioning toward denser formations eastward.

- *Zone 4: Northeastern Highlands (85-113 m)*

The teal/cyan zone marks the approach to the crystalline basement outcrops. Higher slopes and more resistant rock substrates lead to thinner, stonier soils, faster runoff, and greater erosion potential. This zone acts as a secondary water tower, generating significant discharge that feeds into the main river tributaries during rainfall events.

- *Zone 5: Eastern Crystalline Peaks (113-330 m)*

The highest elevations, concentrated in the northeastern corner of the watershed, correspond to Precambrian basement exposures. With elevations reaching up to 330 m, these highlands represent the headwater recharge zones of the Gambia and Mamacounda river systems. The steep slopes, thin regolith cover, and high runoff coefficients make this zone particularly sensitive to land degradation and climate variability.

➢ *West-to-East Topographic Gradient*

The most striking feature of the Tambacounda watershed relief is its clear west-to-east elevation gradient. This gradient reflects the fundamental geological transition from the sedimentary Senegal Basin in the west to the Precambrian crystalline basement in the east. Hydrologically, this gradient dictates that water flows generally from east to west, with the watershed outlet located in the lower southwestern sector.

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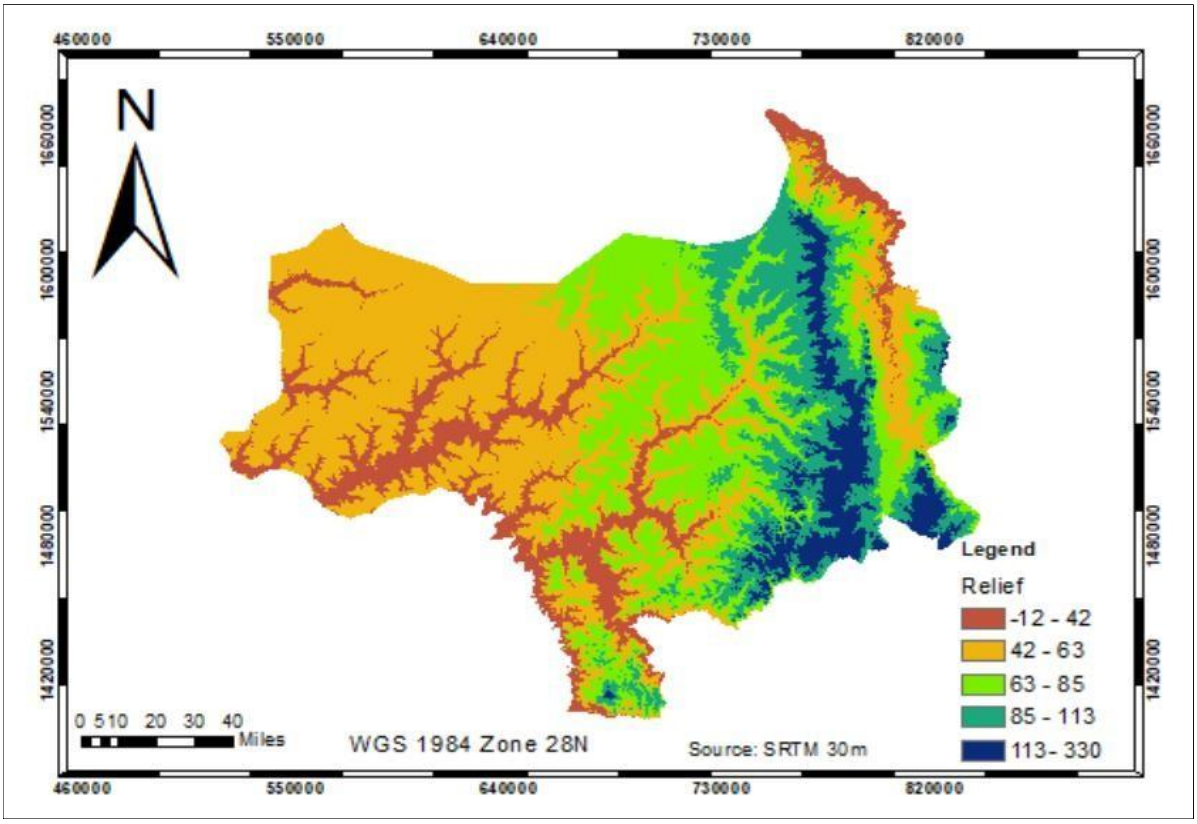

Fig 1 The Topographic Relief of Tambacounda Basin HydroSHEDS / SRTM 30m: NASA Shuttle Radar Topography Mission. USGS EarthExplorer.

III. DRAINAGE NETWORK AND FLUVIAL GEOMORPHOLOGY

➢ *The Dendritic Drainage Pattern*

The Tambacounda watershed exhibits a well-developed dendritic drainage pattern, clearly visible as a branching tree-like network of brown (low-elevation) channels on the SRTM relief map. Dendritic patterns develop in geologically homogeneous terrain where rock resistance is relatively uniform, allowing water to erode channels freely in any direction following the slope gradient.

This pattern is characteristic of the flat to gently undulating Continental Terminal surfaces that underlie much of the watershed. The high density of tributary channels, especially in the western plateau zone, indicates low substrate permeability, high surface runoff generation, and longterm fluvial incision into the plateau surface.

➢ *The Main River System*

Two principal river systems dominate the drainage network:

The Gambia River serves as the main trunk channel and principal water collector. Originating from the Fouta Djallon plateau in Guinea at elevations exceeding 900 m, it enters the Tambacounda watershed from the east and flows in a broadly westward direction. The river has carved a pronounced valley into the Continental Terminal sediments, forming the main 'trunk' of the dendritic tree visible in the SRTM data.

The Mamacounda River is the most important tributary within the watershed, draining a substantial portion of the central and southern zones. Its dendritic sub-network feeds into the Gambia system, and its valleys play an important role in the regional water and sediment budget. The Mamacounda is of direct practical relevance to water resource management in the Tambacounda administrative region.

Table 2 Stream Order and Fluvial Hierarchy

Stream Order	Description	Visible Feature	Hydrological Role
1st order	Fingertip seasonal streams	Smallest brown tips	Rainy-season runoff initiation
2nd-3rd order	Small-medium tributaries	Branch-level channels	Sediment transport
4th order	Mamacounda tributaries	Large branch network	Sub-basin collector
5th order	Mamacounda River	Major branch	Regional flow aggregation
6th+ order	Gambia River	Main trunk channel	Watershed outlet and export

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IV. WEATHERING, SOILS AND LATERAL PROCESSES

➢ *Lateritization and Ferruginous Crusts*

One of the most significant geomorphological processes operating in the Tambacounda region is deep chemical weathering leading to lateritization. Under the warm, seasonally humid climate of eastern Senegal (average annual rainfall 800-1000 mm, concentrated in 4-5 months), intense tropical weathering has produced thick lateritic weathering profiles across the Continental Terminal surfaces.

Lateritic crusts (cuirasses) cap many of the plateau surfaces, forming resistant hardpan layers that strongly influence surface hydrology. Where intact, these crusts generate rapid overland flow with minimal infiltration. Where broken or absent, deeper infiltration occurs. The spatial distribution of lateritic surfaces is therefore a key control on the Curve Number (CN2) values used in SWAT hydrological modeling of the watershed.

➢ *Soil Types and Their Geomorphological Context*

Soil distribution across the Tambacounda watershed closely mirrors the geomorphological zonation described above:

- Valley floors: Hydromorphic soils (gleysols, fluvisols), seasonally waterlogged, rich in organic matter from riparian vegetation
- Low plateaus (42-63 m): Ferruginous tropical soils (lixisols/luvisols) on Continental Terminal sediments, moderately deep
- Transition zones (63-85 m): Increasingly shallow ferruginous soils with laterite fragments
- Highlands (85-330 m): Lithosols and leptosols on Precambrian basement outcrops, very thin and stony

V. CLIMATE-GEOMORPHOLOGY INTERACTIONS

➢ *Seasonal Dynamics*

The geomorphological processes in the Tambacounda watershed are strongly controlled by the alternation between a dry season (November-May) and a rainy season (June-October) characteristic of the Sudano-Sahelian climate. During the rainy season, intense rainfall events (frequently exceeding 50 mm/day) trigger rapid overland flow, gully erosion in degraded areas, and temporary flooding of valley floors.

The dry season, conversely, is characterized by desiccation, wind erosion of exposed surfaces, and shrinkage of river channels to residual pools in the main Gambia and Mamacounda valleys.

➢ *Implications of Climate Change (RCP4.5 / RCP8.5)*

Under projected climate scenarios for 2030-2060, geomorphological processes in the watershed are expected to intensify:

- Increased rainfall intensity (more extreme events) will accelerate sheet erosion and gully formation on low-permeability lateritic surfaces
- Extended dry seasons will increase wind erosion and soil desiccation in degraded zones
- Higher peak flows will increase lateral bank erosion along the Gambia and Mamacounda rivers
- Reduced baseflows during the dry season will contract riparian vegetation zones, exposing floodplain soils to degradation

VI. HYDROLOGICAL MODELING IMPLICATIONS (QSWAT)

➢ *DEM-Derived Parameters*

The SRTM 30m DEM analyzed in this article provides the foundational topographic input for QSWAT/SWAT+ hydrological modeling of the Tambacounda watershed. The key parameters derived from this DEM include:

Table 3 DEM-Derived Parameters

SWAT Parameter	Geomorphological Basis	Expected Range
CN2 (Curve Number)	Soil type + slope + land use	65-85 (lateritic surfaces)
SLSUBBSN (slope length)	Sub-basin topographic gradient	50-200 m
SURLAG (surface lag)	Drainage density, channel slope	1-4 days
HRU slope class	DEM slope reclassification	0-5%, 5-15%, >15%
TLAPS (temperature lapse)	Elevation gradient E-W	~0.5°C/100m
Channel geometry	Valley width / bankfull depth	Derived from DEM + field

➢ *Sub-Basin Delineation*

The dendritic drainage network and the clear topographic gradient facilitate reliable sub-basin delineation within QSWAT. The principal sub-basins expected from DEM-based delineation include the upper Gambia sub-basin (eastern highlands), the Mamacounda sub-basin (central zone), and several smaller plateau sub-basins in the western sector. The alignment of the DEMderived drainage network with the known Gambia and Mamacounda river channels constitutes a critical quality validation step for the modeling workflow.

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VII. GEOMORPHOLOGICAL HAZARDS

➢ *Erosion Risk*

The combination of intense seasonal rainfall, sloping terrain in the eastern highlands, degraded vegetation cover, and low-permeability lateritic soils creates significant soil erosion hazards across parts of the Tambacounda watershed. Gully erosion is particularly active in areas where the protective lateritic crust has been broken by agricultural practices or overgrazing, exposing softer underlying materials to concentrated overland flow.

➢ *Flood Risk*

Recent research using multi-criteria GIS approaches (FIGUSED model) has shown that approximately 40% of the Tambacounda study area is classified as high flood risk, concentrated in low-lying zones near the main drainage axes. The Gambia and Mamacounda river valleys, corresponding to the brown elevation class on the DEM, are the zones of greatest flood exposure for agricultural perimeters and rural communities.

➢ *Land Degradation*

Decades of population pressure, overgrazing, charcoal production, and expanding rain-fed agriculture have accelerated land degradation processes across the watershed. This degradation modifies geomorphological dynamics by reducing vegetation interception, increasing runoff coefficients, and accelerating soil erosion — all of which feed back into altered hydrological behavior that SWAT modeling must capture through updated LULC layers.

VIII. CONCLUSION

The Tambacounda watershed presents a geomorphologically rich and hydrologically complex landscape shaped by the interplay of ancient Precambrian basement geology, Cenozoic sedimentary deposition, intense tropical weathering, and dynamic fluvial processes. Its clear west-to-east topographic gradient, well-developed dendritic drainage network, and five-class elevation zonation provide a robust structural framework for understanding water movement, erosion dynamics, and land surface behavior across the basin.

For hydrological modeling purposes, the SRTM 30m DEM captures the essential relief features — particularly the Gambia and Mamacounda river networks, the lateritic plateau surfaces, and the northeastern crystalline highlands — with sufficient resolution to support reliable QSWAT sub-basin delineation, slope classification, and HRU definition. Integration of this geomorphological understanding with multi-temporal LULC analysis, soil data, and climatic projections constitutes the methodological foundation for a comprehensive water resource assessment of the Tambacounda region under current and future climate conditions.

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