National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Topographic maps

November 2025

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Topographic maps of Godavari River Basin

National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

www.nrcd.nic.in

Centres for Godavari River Basin Management Studies (cGodavari)

The Centres for Godavari River Basin Management Studies (cGodavari) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by CSIR-NEERI and IIT Hyderabad, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCD). cGodavari is committed to restoring and conserving the Godavari River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.cGodavari.org

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by CSIR-NEERI (Lead Institute) and IIT Hyderabad (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It is submitted to the National River Conservation Directorate (NRCD) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

Disclaimer

This report is a preliminary version prepared as part of the ongoing Condition Assessment and Management Plan (CAMP) project. The analyses, interpretations and data presented in the report are subject to further validation and revision. Certain datasets or assessments may contain provisional or incomplete information, which will be updated and refined in the final version of the report after comprehensive review and verification.

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Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

Centres for the Godavari River Basin
Management and Studies (cGodavari)
CSIR-NEERI, IIT Hyderabad

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Abbreviations and Acronyms

Term	Acronym	Term	Acronym
Digital Elevation Model	DEM	Soil and Water Assessment Tool	SWAT
Forest and Buildings Removed Digital Elevation Model	FABDEM	Hydrologic Engineering Center – Hydrologic Modeling System	HEC-HMS
Shuttle Radar Topography Mission	SRTM	Natural Resources Conservation Service – Curve Number Method	NRCS-CN
Geographic Information System	GIS	Revised Universal Soil Loss Equation	RUSLE
Universal Transverse Mercator	UTM	Unit Stream Power Erosion and Deposition Model	USPED
World Geodetic System 1984	WGS 84	Integrated Watershed Management Programme	IWMP
Root Mean Square Error	RMSE	National Rural Livelihood Mission	NRLM
National Bureau of Soil Survey and Land Use Planning	NBSS & LUP	State Disaster Management Authority	SDMA
Geospatial Data Abstraction Library	GDAL	National Disaster Management Authority	NDMA
Deterministic Eight-Node Flow Direction Algorithm	D8	Indian Meteorological Department	IMD
Survey of India	SOI	Public Works Department	PWD
Digital Elevation Model Hillshade Visualization	DEM-Hillshade	National Highways Authority of India	NHAI
Curve Number	CN	Krishi Vigyan Kendra	KVK
Land Use / Land Cover	LULC	Geospatial Decision Support System	GDSS
Machine Learning (if mentioned in future work)	ML	Mean Sea Level	MSL
Three-Dimensional (context: hillshade visualization)	3D		

1. Introduction

India’s vast and diverse landscapes are deeply influenced by its extensive river systems, which originate from the Himalayas and traverse the peninsular plateaus before merging with the seas through broad coastal plains. These rivers not only sculpt the terrain but also shape ecological diversity, agricultural productivity, and cultural heritage across the subcontinent. Among these, the Godavari River, often referred to as the Dakshina Ganga or Ganga of the South, holds exceptional geographical and topographical significance. It is India’s second-longest river and the largest in peninsular India, forming one of the most complex and dynamic drainage basins in the country.

Originating from Trimbakeshwar in the Western Ghats of Maharashtra at an elevation of approximately 1,067 meters above mean sea level (MSL), the Godavari River flows eastward for about 1,465 kilometers, eventually debouching into the Bay of Bengal through an extensive deltaic system in Andhra Pradesh. The Godavari Basin, spreading over 312,812 square kilometers and covering parts of Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, Odisha, Madhya Pradesh, and Karnataka, represents nearly 10% of India’s total geographical area (3,287,263 sq.km). Geographically, the basin extends between 73°24′E to 83°04′E longitudes and 16°19′N to 22°34′N latitudes, encompassing a remarkable diversity of physiographic conditions.

Topographically, the Godavari Basin exhibits a distinct west-to-east gradient, from the rocky escarpments of the Western Ghats through the gently undulating Deccan Plateau to the flat coastal plains of the delta. This continuous decline in elevation, ranging from over 1,500 meters in the source region to sea level at the coast, creates pronounced relief contrasts and defines the basin’s three major physiographic divisions: the Upper Basin (Western Ghats Region), the Middle Basin (Deccan Plateau), and the Lower Basin (Eastern Coastal Plain). The upper basin is characterized by steep slopes, narrow valleys, and deeply incised terrain formed over resistant basaltic formations of the Deccan Traps. This zone displays high local relief and serves as the principal region of orographic influence and runoff generation. The middle basin transitions into a gently undulating plateau with moderate slopes and broad interfluves, dominated by well-developed drainage networks and stable land surfaces. The lower basin forms the deltaic plains and alluvial tracts near the Bay of Bengal, characterized by very gentle gradients, extensive floodplains, and depositional landforms.

Geologically, the basin spans multiple structural provinces, from the basaltic Deccan Traps and crystalline Gondwana formations in the upper and middle reaches to recent alluvial deposits in the lower deltaic zone. These lithological and structural variations significantly influence the basin’s elevation distribution, slope configuration, and contour spacing, reflecting a long history of tectonic stability interspersed with erosional and depositional adjustments.

The physiography and terrain configuration of the Godavari Basin form the fundamental framework for understanding its landscape processes. Detailed topographical analysis reveals how elevation, slope, and aspect govern the spatial differentiation of terrain features, drainage alignment, and regional landform patterns. Such understanding is essential for accurate representation of the basin's morphology and for identifying terrain-controlled zones that influence surface stability, erosion susceptibility, and development potential.

This study presents a comprehensive topographical mapping and terrain characterization of the Godavari River Basin using advanced Digital Elevation Models (DEMs) and Geographic Information System (GIS) techniques. The Forest and Buildings Removed Copernicus DEM (FABDEM), at a 30-meter resolution, has been employed as the principal dataset to capture accurate elevation information devoid of vegetation and anthropogenic height biases. Through systematic derivation of contours, slope, and aspect maps, the study provides a detailed spatial understanding of the basin's relief (BR) characteristics and physiographic zonation. By focusing exclusively on topographical parameters, this report aims to establish a reliable physical framework that supports future geomorphological, hydrological, and land management studies. The resulting maps and terrain statistics serve as a foundational reference for regional planning, environmental assessment, and sustainable resource management across the Godavari Basin.

2. Data sources and methodology

The comprehensive topographical assessment of the Godavari River Basin employs multiple high-quality datasets and advanced analytical methodologies to ensure accurate terrain characterization and reliable spatial analysis (Figure 1). The selection and integration of these data sources reflect current best practices in digital terrain modeling and geospatial analysis.

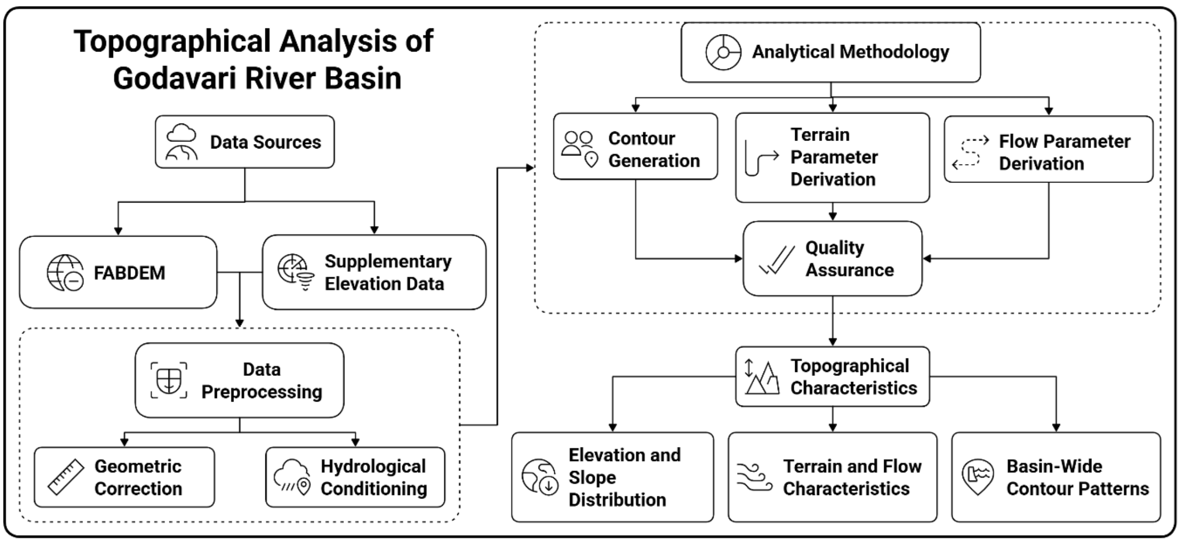

Figure 1 Flow Chart of Methodology used in the Study

2.1 Primary data sources

2.1.1 Forest And Buildings removed Copernicus DEM (FABDEM)

The Forest And Buildings removed Copernicus Digital Elevation Model (FAB DEM) serves as the primary elevation dataset for this comprehensive analysis (Hawker et al. 2022). Available at 1 arc-second grid spacing (approximately 30 meters at the equator) with global coverage, FABDEM represents a significant advancement in digital terrain modeling through its systematic removal of building and forest height biases from the original Copernicus GLO 30 Digital Elevation Model. FABDEM utilizes sophisticated machine learning algorithms to identify and remove vegetation canopy heights and anthropogenic structures, providing a more accurate representation of bare-earth topography. This enhancement is particularly crucial for the Godavari Basin, where extensive forest cover in the Western Ghats and widespread agricultural areas could otherwise introduce substantial errors in elevation measurements and derived terrain parameters. The 30-meter resolution provides optimal balance between spatial detail and computational efficiency for basin-scale analysis, enabling identification of subtle topographical features while maintaining manageable data volumes for comprehensive regional assessment (Farr et al. 2007). The removal of surface obstructions facilitates accurate delineation of drainage networks, precise calculation of slope gradients, and reliable identification of floodplain boundaries.

2.1.2 Supplementary Elevation Data

The Shuttle Radar Topography Mission (SRTM) 30-meter resolution DEM provides complementary elevation data for validation and comparative analysis. SRTM data, acquired through C-band and X-band radar interferometry, offers consistent global coverage with well-documented accuracy characteristics that enable cross-validation of elevation measurements and identification of potential data quality issues.

2.2 Data Preprocessing and Quality Assessment

2.2.1 Geometric Correction and Datum Standardization

All elevation data undergo rigorous geometric correction procedures to ensure consistent spatial referencing throughout the basin. The FABDEM tiles covering the entire Godavari Basin are mosaicked to create a seamless elevation surface, with careful attention to edge matching and elimination of processing artifacts. The data is reprojected to UTM Zone 44N coordinate system (EPSG:32644) to minimize projection distortions and facilitate accurate distance calculations for contour analysis. Elevation values are standardized to the EGM96 geoid model to ensure consistency with Indian Survey datum standards and compatibility with existing topographical mapping products. This standardization is particularly important for contour generation, as small elevation discrepancies can result in significant contour positioning errors that affect subsequent analysis and applications (Singh 1996).

2.2.2 Hydrological Conditioning and Error Correction

Comprehensive data conditioning procedures prepare the elevation surface for accurate contour generation. Hydrological conditioning includes systematic identification and filling of artificial depressions (sinks) that may result from data processing artifacts, using the Planchon- Darboux algorithm to ensure hydrologically consistent elevation surfaces (Jenson and Domingue 1988). Major water bodies including reservoirs and broad river reaches are identified and adjusted to locally consistent levels to prevent stair-step artifacts in contours across water surfaces. This hydro-flattening process utilizes high-resolution imagery from World Imagery Wayback and Survey of India topographic maps to verify water surface elevations and ensure contour continuity across hydrographic features.

2.3 Analytical Methodology

2.3.1 Contour Generation parameters

Based on the analysis of the basin's topographical diversity and following established cartographic standards for regional mapping, a uniform 10-meter contour interval was selected for the comprehensive basin analysis. This interval provides optimal detail for the basin's elevation range while maintaining cartographic clarity and computational efficiency across the diverse terrain conditions present throughout the basin.

Contour generation employs standard isoline extraction algorithms equivalent to GDAL and ArcGIS contouring procedures, with closed-loop retention for hilltops and depressions. The algorithm systematically traces lines of equal elevation across the gridded DEM surface, creating vector contour lines attributed with elevation values and interval classifications. Generated contour lines undergo systematic smoothing procedures using constrained algorithms that eliminate minor irregularities while preserving essential topographical characteristics. The Douglas-Peucker generalization algorithm is applied with tolerance parameters adjusted based on contour interval and local terrain complexity to maintain topographical accuracy while producing cartographically acceptable contour lines (O'Callaghan and Mark 1984).

2.3.2 Terrain Parameter Derivation

From the processed DEM, essential topographical parameters are systematically derived using established algorithms:

Slope Analysis: Slope values were computed using Horn's algorithm, which determines the rate of maximum change in elevation between each cell and its eight surrounding neighbors within a 3×3 moving window. This method produces continuous slope gradients and minimizes sensitivity to local surface noise.

$$Slope = arctan\ arctan\ \sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}$$

Aspect Analysis: Aspect represents the compass direction of maximum slope, providing insights into solar exposure, wind orientation, and erosional processes throughout the basin. Aspect values were derived using standard directional computation based on east-west and north-south elevation gradients:

$$Aspect = arctan2\left(\frac{dz}{dy}, \frac{dz}{dx}\right)$$

2.3.3 Flow Parameter Derivation

To interpret hydrological terrain behavior, flow direction and flow accumulation were derived from the conditioned FABDEM using the D8 algorithm.

Flow Direction: Flow direction assigns each raster cell a downslope path toward one of eight possible directions (N, NE, E, SE, S, SW, W, NW) corresponding to the steepest descent. This step delineates the natural pathways of surface runoff and assists in identifying drainage hierarchies.

Flow Accumulation: Using the computed flow direction grid, the flow accumulation surface was generated to quantify the number of upstream cells draining into each pixel. High accumulation values represent channel networks and sub-basin outlets, whereas low values characterize interfluves and recharge areas. These layers delineate the drainage density and network structure of the basin.

The hillshade model was generated to enhance the visualization of terrain relief and provide a pseudo-3D representation of the basin. Using the standard illumination azimuth of 315° and an altitude angle of 45°, this analysis simulates light and shadow effects over the DEM surface. Hillshade visualization highlights elevation contrasts, slope steepness, and valley morphology, supporting the interpretation of the basin's geomorphic zones and landscape evolution.

2.4 Quality Assurance and Validation

Comprehensive quality assurance procedures ensure reliability and accuracy of derived topographical products. Cross-validation employs multiple elevation datasets to identify and resolve discrepancies. Statistical validation against ground control points and benchmark elevations quantifies accuracy characteristics for different terrain types and physiographic regions. 1) Geometric validation: systematic checks for contour continuity, proper nesting relationships, and absence of self-intersections or impossible crossings. 2) Elevation validation: cross-referencing against Survey of India benchmark elevations and spot heights to verify accuracy within specified tolerances. 3) Topographical validation: comparison with known terrain features, drainage networks, and landmark elevations using high-resolution imagery. Cross-dataset validation employs SRTM 30-meter DEM products to identify areas of significant discrepancy requiring additional investigation. Random transect analysis compares FABDEM-derived contours with alternative elevation source, with discrepancies flagged for local review rather than systematic adjustment to maintain data integrity (Wilson and Gallant 2000).

3. Topographical Characteristics of the Godavari Basin

The Godavari River Basin exhibits remarkable topographical diversity that reflects its geological evolution, tectonic history, and the long-term action of erosional and depositional processes. This diversity creates distinct physiographic environments that significantly influence hydrological behavior, ecological characteristics, and human activities throughout the basin.

3.1 Elevation and Slope Distribution Analysis

3.1.1 Elevation

The Godavari River Basin exhibits substantial topographical variability, reflecting its transition from the steep escarpments of the Western Ghats to the flat coastal plains adjoining the Bay of Bengal (Figure 2). Elevation across the basin ranges from approximately –35 meters (below mean sea level in certain deltaic depressions) to 1,638 meters in the uppermost reaches of the Western Ghats. This broad range underscores the complex relief structure that defines the basin's physiographic diversity.

The elevation statistics, derived from the FABDEM, were classified into 100-meter elevation intervals to quantify areal distribution patterns (Table 1). The resulting elevation-frequency analysis reveals that a majority of the basin lies within 200–600 m above mean sea level (MSL), a range typical of the Deccan Plateau region that dominates the central portion of the basin. Together, these elevation zones account for nearly 69% of the total basin area, representing the gently undulating terrain that characterizes the middle Godavari Basin. The upper basin, confined to elevations exceeding 800 m, constitutes approximately 7% of the total area and includes the rugged, dissected topography of the Western Ghats. These high-relief zones are the principal runoff-generating regions and exhibit steep local gradients. In contrast, the lower basin, below 200 m, occupies roughly 12% of the basin and corresponds to the deltaic and alluvial plains of the lower Godavari, where relief is minimal and surface slopes are extremely gentle (Table 1). The elevation distribution analysis reveals a strongly right-skewed hypsometric pattern, indicating the dominance of mid-elevation terrain and gradual reduction in relief toward the east. This west–east elevation gradient defines the basin's drainage alignment and physiographic zonation.

Table 1: Areal Distribution of Elevation in the Godavari River Basin

ID	Elevation (m)		Area	% of
	Min	Max	(Sq.km)	Total Area
1	0	100	10178.78	3.26
2	100	200	27978.44	8.97
3	200	300	55785.15	17.89
4	300	400	53708.50	17.22

5	400	500	49178.45	15.77
6	500	600	56253.28	18.04
7	600	700	36374.86	11.66
8	700	800	11315.43	3.63
9	800	900	5400.43	1.73
10	900	1000	3126.99	1.00
11	1000	1100	1440.87	0.46
12	1100	1200	682.71	0.22
13	1200	1300	311.95	0.10
14	1300	1400	112.05	0.04
15	1400	1500	32.04	0.01
16	1500	1600	6.34	0.00
17	1600	1638	0.52	0.00

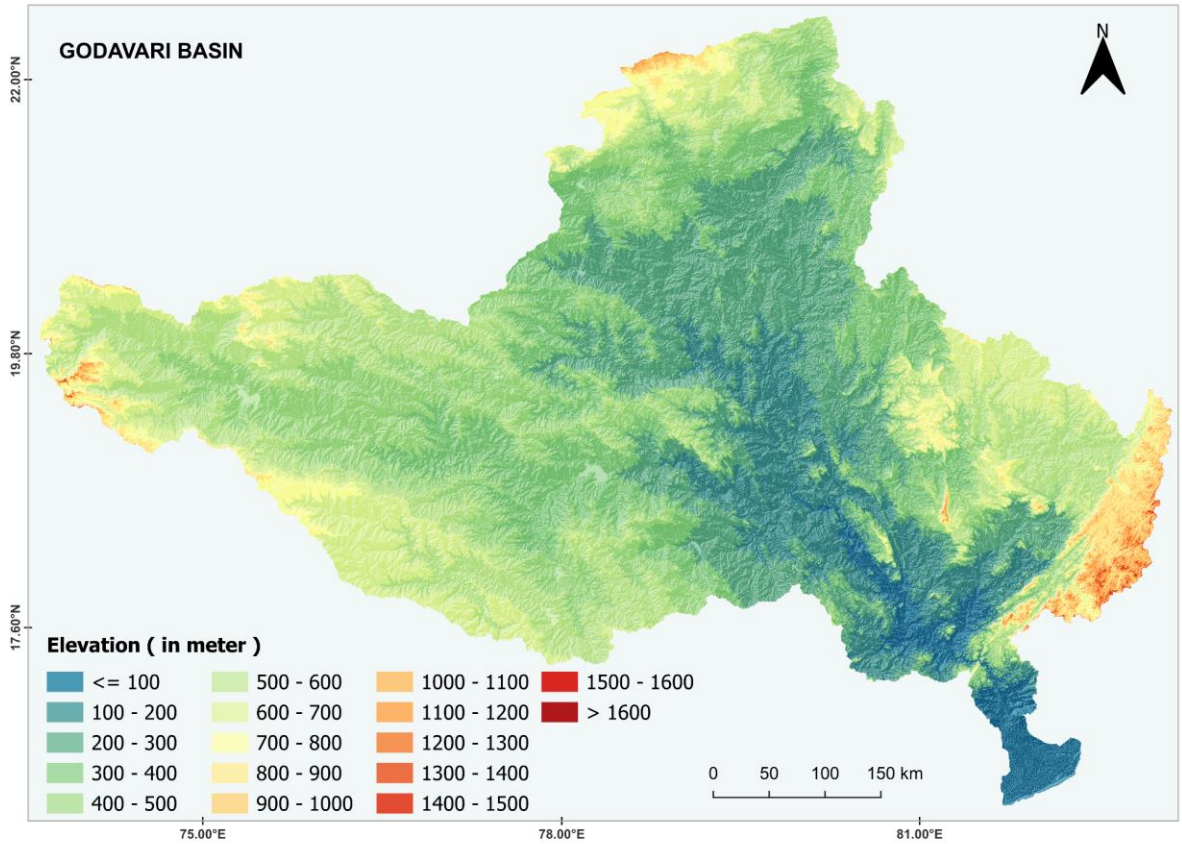

Figure 2 Elevation Map of Godavari Basin

3.1.2 Slope

Slope analysis provides essential insights into the basin's relief intensity, erosional energy, and terrain form. The slope map of the Godavari River Basin was generated from the FABDEM using Horn's algorithm to compute gradients in degrees. The resulting slopes were classified according to the (NBSS&LUP 2015) system and re-grouped into six representative categories (Table 2) to evaluate the distribution of terrain gradients across the basin (Figure 3).

The analysis reveals that slope values within the basin range from nearly level (< 0.4°) in the deltaic and floodplain areas to greater than 4.8° in the rugged escarpments of the Western Ghats. Gentle terrain dominates the basin, with approximately 66.37 % of the total area (slope ≤ 1.7°) exhibiting low-relief conditions. These zones, primarily located in the central plateau and eastern plains, correspond to broad interfluves and depositional surfaces that support intensive agriculture, irrigation development, and settlement expansion. Moderate slopes (1.7–4.8°) cover 17.04 % of the basin and occur mainly along dissected plateau margins and upper valley systems. These areas represent transitional terrain where contour-aligned land-use practices are necessary to minimize erosion. Steeper slopes exceeding 4.8°, occupying 16.59 % of the total area, are concentrated within the Western Ghats and adjoining uplands. These high-gradient zones, although spatially limited, contribute significantly to runoff generation and influence the basin's geomorphic evolution. The combination of steep gradients, resistant lithology, and intense rainfall makes these regions particularly susceptible to soil loss and landslide activity. The overall slope pattern exhibits a progressive decline from west to east, consistent with the longitudinal profile of the river. The predominance of gentle and very gentle slopes toward the lower basin reflects advanced erosional maturity and extensive alluvial deposition. This gradient structure defines the basin's fundamental terrain framework and supports its division into high-energy (Western Ghats), moderate-energy (Deccan Plateau), and low-energy (Coastal Plain) zones.

Table 2: Slope Distribution of the Godavari River Basin

Slope (°) Category	Description	% of Total Area
≤ 0.4	Very gentle / Flat terrain (deltas and valley floors)	17.65
0.4 – 0.6	Gentle slope (lower plains and broad interfluves)	12.93
0.6 – 1.0	Slight undulating surface (central plateau tracts)	20.06
1.0 – 1.7	Gently sloping areas (agro-productive regions)	15.73
1.7 – 4.8	Moderate slopes (valley flanks and dissected plateau)	17.04
> 4.8	Steep to very steep (Western Ghats and escarpments)	16.59

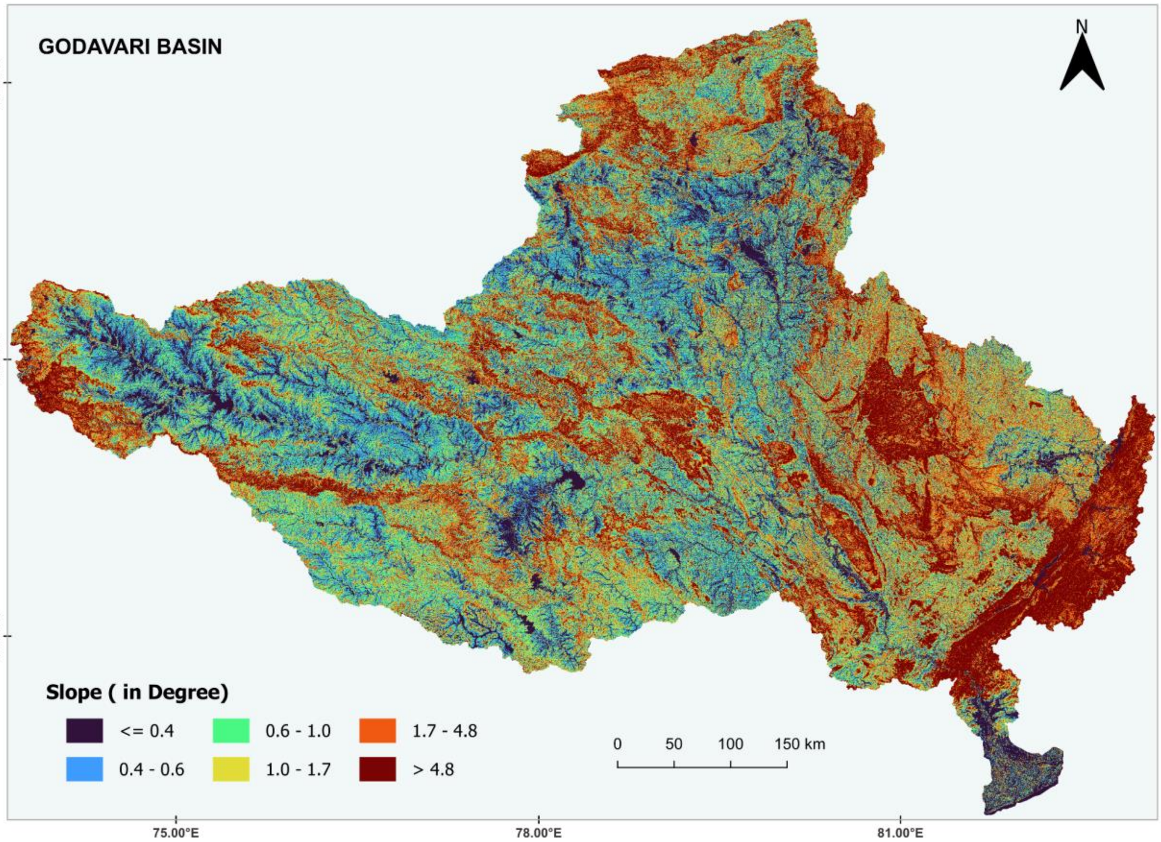

Figure 3 Slope Map of the Godavari Basin

3.2 Terrain and Flow Characteristics Analysis

The terrain configuration of the Godavari River Basin plays a decisive role in governing surface runoff, drainage alignment, and morphological evolution. Using the FABDEM-derived elevation model, various flow-related parameters i.e. flow direction, flow accumulation, aspect, and hillshade were generated to interpret the basin's hydrological behavior and surface morphology.

3.2.1 Flow Direction and Accumulation

Flow direction was derived from the conditioned FABDEM using the D8 algorithm in GIS, assigning flow paths to one of eight cardinal directions (N, NE, E, SE, S, SW, W, NW) based on the steepest descent from each cell. The resultant flow direction map (Figure 4) shows a dominant eastward flow trend, consistent with the basin's regional slope gradient from the Western Ghats to the Bay of Bengal. The western uplands exhibit high drainage density and well-defined sub-basin alignment, while the central plateau displays more diffused and dendritic patterns, reflecting the influence of lithological variability.

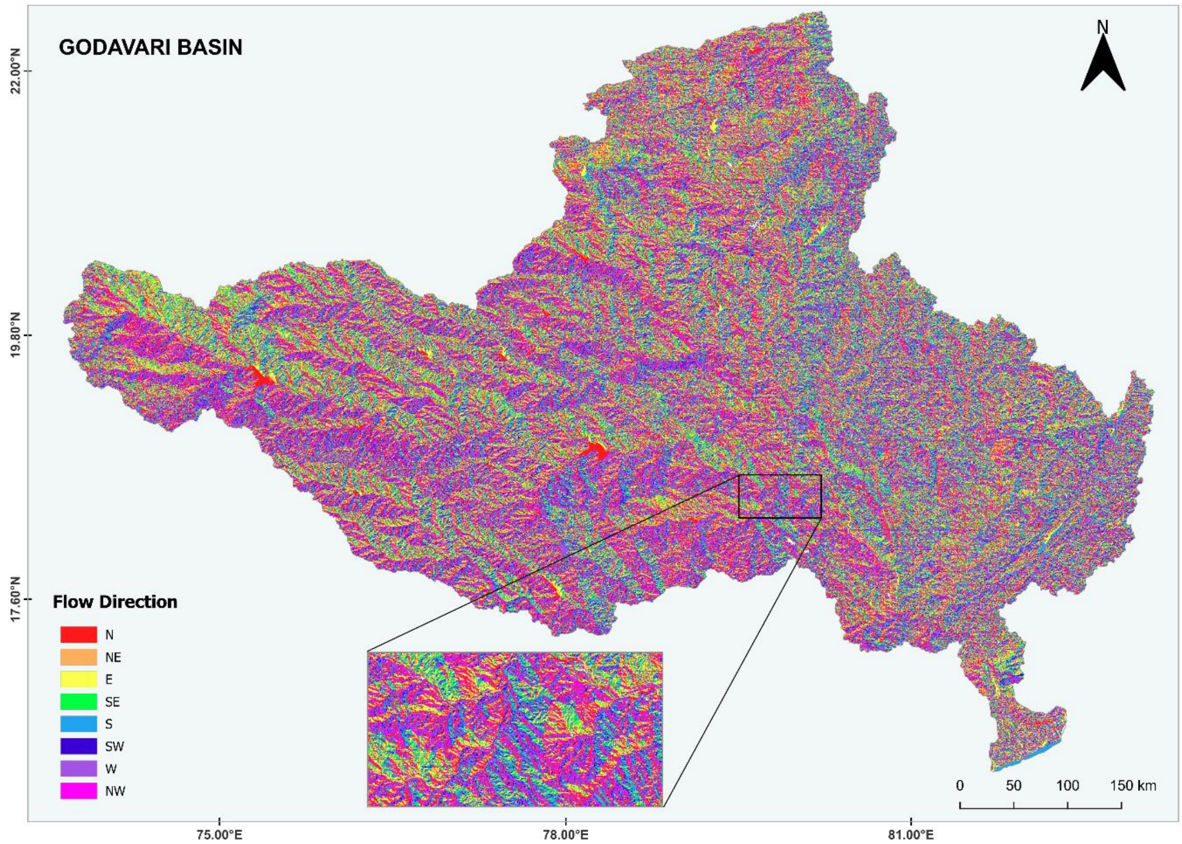

Figure 4 Flow Direction Map of the Godavari River Basin

Flow accumulation analysis (Figure 5) highlights the convergence of runoff in the major channel network, delineating the primary and secondary tributaries of the Godavari system. The high flow accumulation zones (> 850 pixels) correspond to the main river corridors and sub-basin outlets, notably in the Manjira, Pranhita, and Indravati tributary systems. Conversely, areas with low flow accumulation (≤ 10 pixels) dominate the interfluves and plateau surfaces, indicating limited surface runoff and localized infiltration zones. These variations demonstrate the basin's transition from high-energy erosional terrain in the west to low-energy depositional plains in the east.

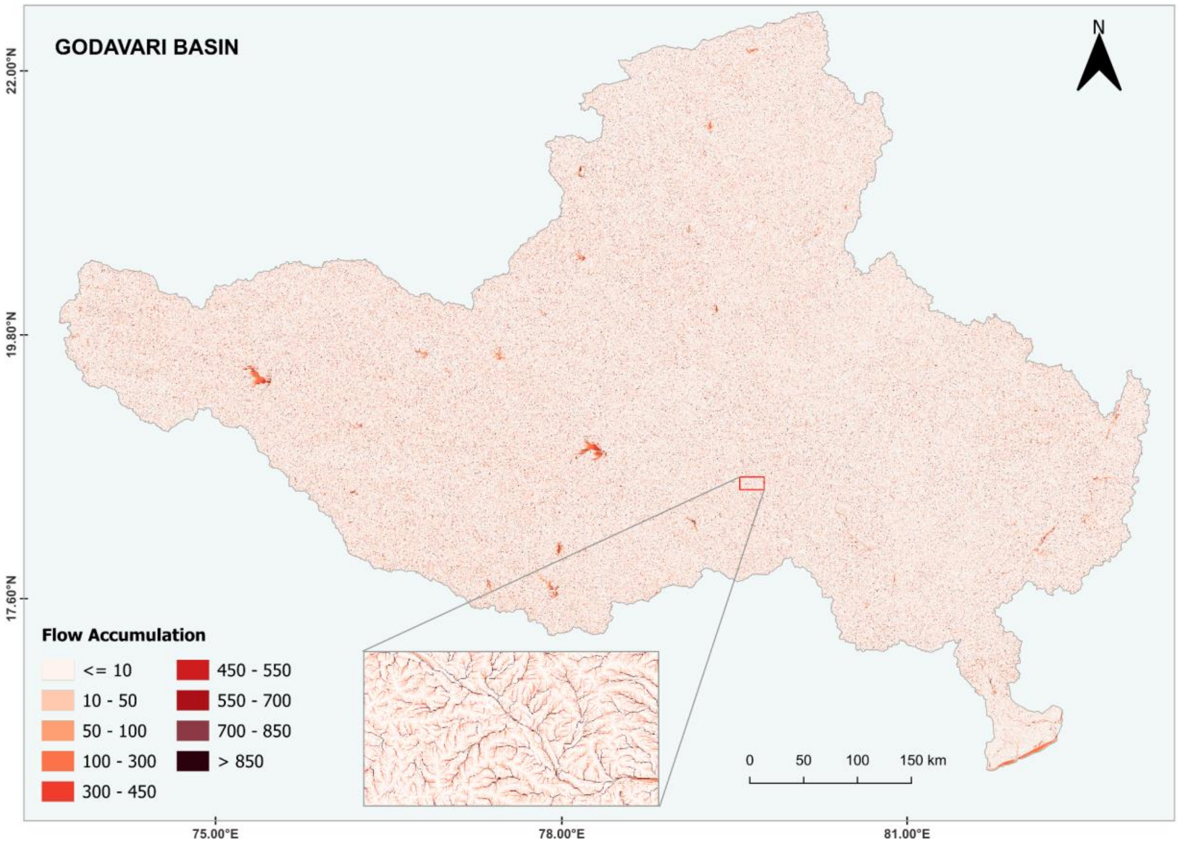

Figure 5 Flow Accumulation Map of the Godavari River Basin

3.2.2 Aspect and Hillshade Analysis

Aspect represents the downslope orientation of the terrain surface, influencing microclimatic conditions, vegetation distribution, and slope stability. The aspect map (Figure 6) classifies the terrain into eight directional categories along with flat areas. The distribution indicates predominantly northeast- and southeast-facing slopes, particularly along the main escarpments and valley flanks of the upper basin. West- and southwest-facing slopes occur extensively in the middle basin, suggesting symmetrical drainage development along the plateau margins. This directional heterogeneity contributes to spatial differences in solar exposure and moisture retention, affecting erosion intensity and soil development. The hillshade provides a three-dimensional visualization of surface relief by simulating illumination from a fixed azimuth. The shading pattern accentuates the basin's rugged topography, clearly distinguishing the Western Ghats highlands, Deccan plateau undulations, and the flat deltaic plains of the lower basin (see Figure 2). Steep escarpments and deep valleys are prominently illuminated, while the smoother plains exhibit minimal relief contrasts. Hillshade visualization thus complements the elevation and slope analyses by enhancing the perception of terrain morphology.

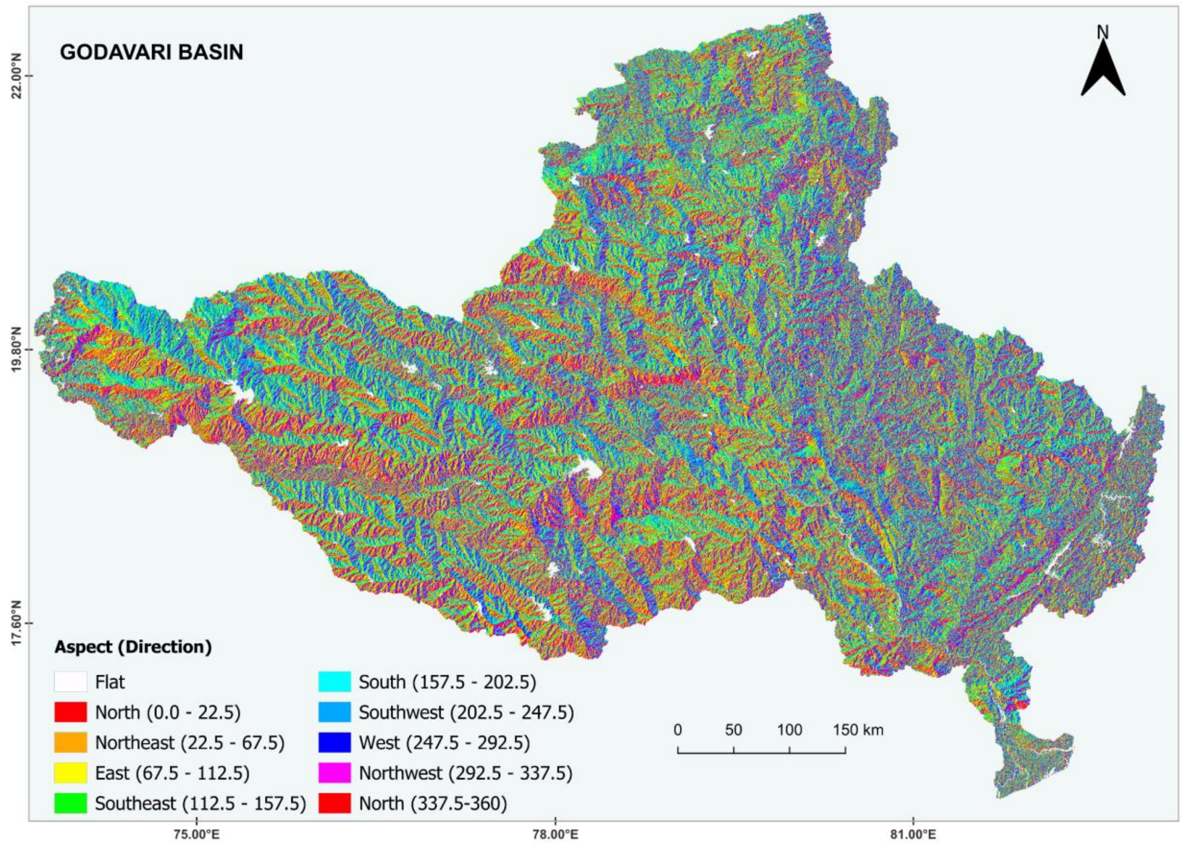

Figure 6 Aspect Map of the Godavari Basin

The flow direction, accumulation, aspect, and hillshade analyses portray the Godavari Basin as a mature, east-draining fluvial system with complex geomorphic zonation. The upper basin (Western Ghats) shows steep gradients, dense drainage, and high relief energy, whereas the middle basin demonstrates gentle to moderate slopes with integrated drainage evolution over the basaltic Deccan Plateau. The lower basin transitions into an expansive depositional plain with low relief and high flow convergence, forming the deltaic region along the Bay of Bengal.

These integrated topographical indicators provide a detailed understanding of surface flow behavior, catchment hierarchy, and geomorphic diversity—offering critical insights for watershed management, erosion modeling, and land-use planning across the Godavari Basin.

3.3 Basin-Wide Contour Patterns

Contour analysis provides a detailed representation of the basin's surface configuration and relief variation. The 10-meter interval contour map (Figure 7) derived from the FABDEM highlights the intricate topographic framework of the Godavari River Basin, capturing both micro- and macro-relief features across its physiographic zones. The contour arrangement distinctly reflects the basin's west–east gradient, which governs the Godavari River's flow from the elevated Western Ghats toward the Bay of Bengal. In the western highlands, the contour lines are densely packed and irregular, indicating steep slopes, sharp ridgelines, and deep valleys. This region represents the rugged escarpments of the Western Ghats, where elevation often exceeds 1000 m and relief energy is at its maximum. Closely spaced contours depict areas of intense dissection and rapid vertical erosion, which serve as the headwaters for numerous tributaries feeding the main river.

Moving eastward, the contours gradually open and smooth out, depicting the Deccan Plateau terrain that forms the middle portion of the basin. Here, contour spacing becomes moderate, representing undulating topography with gentle slopes and broad valley floors. The plateau is characterized by alternating ridges and low-relief plains formed over weathered basaltic surfaces. This physiographic transition marks the shift from erosional to moderately depositional environments, where drainage networks become more organized and less structurally constrained. In the lower basin, the contour lines are widely spaced and nearly parallel, delineating the low-gradient floodplains and deltaic plains near the river's outfall into the Bay of Bengal. Elevations in this region fall below 100 m, and the smooth contour patterns reflect extensive alluvial deposition, meandering river courses, and floodplain expansion. The subdued topography of this zone supports dense agricultural activity and frequent inundation during monsoon flows. A detailed inset (Figure 7) illustrates the contour behavior along a segment of the main Godavari channel. The contour lines exhibit gentle curvature, conforming closely to the meandering river course and valley flanks, effectively delineating the topographic control on fluvial morphology. The river's course follows the lowest elevation paths within the valley troughs, with evenly spaced contours marking gentle valley gradients in the middle reaches. The contour configuration reveals a distinct topographic zonation within the Godavari Basin: 1) High-relief western escarpments: steep gradients, closely spaced contours, high runoff potential. 2) Moderate-relief plateau region: transitional zone with broader contour spacing and controlled slope development. 3) Low-relief eastern plains: gentle contours, depositional surfaces, and near-horizontal gradients. The basin-wide contour patterns show a mature erosional landscape, where elevation and slope decrease progressively from west to east. These patterns not only define the basin's physiographic divisions but also provide critical input for hydrological modeling, slope stability assessment, and terrain-based land use planning.

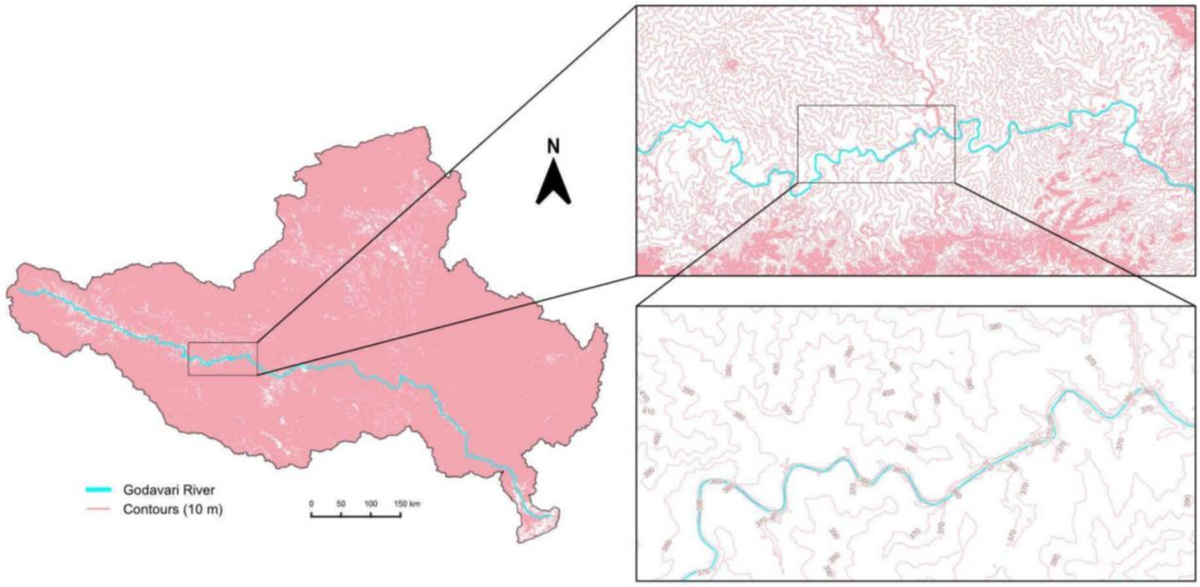

Figure 7 Contour Map of the Godavari River Basin

4. Applications of Topographical Analysis

The comprehensive topographical analysis of the Godavari River Basin provides an essential spatial framework that supports a wide range of scientific, administrative, and developmental activities. The derived terrain parameters i.e. elevation, slope, aspect, contours, flow direction, and flow accumulation, enable a deeper understanding of basin morphology and hydrological behavior. These datasets offer substantial value not only for geomorphological interpretation but also for operational planning across multiple governance sectors. The following subsections outline the major applications of topographical analysis and demonstrate how each application directly benefits specific stakeholder groups.

4.1 Watershed and Drainage Management

Topographical information forms the basis for accurate watershed delineation, drainage network mapping, and understanding runoff pathways. The slope, elevation, and flow accumulation layers allow precise identification of drainage divides, runoff convergence points, and groundwater recharge zones. This application is particularly critical for Water Resources Departments, River Basin Authorities, and Rural Development/Micro-Watershed Missions, who rely on such datasets to plan water harvesting structures, rejuvenate sub-watersheds, and improve overall basin hydrology. The terrain-guided approach ensures more effective placement of check dams, percolation tanks, and recharge interventions.

4.2 Erosion and Sediment Risk Assessment

Slope gradients, contour density, and aspect orientation provide vital information on erosion susceptibility and sediment movement. Steep slopes in the upper basin represent high-erosion zones, while gentler slopes in the lower basin reflect deposition-prone regions. These insights are essential for soil conservation agencies, watershed missions, forestry departments, and agricultural extension centers, enabling them to prioritize erosion-prone areas, promote contour-aligned agriculture, design soil-retention structures, and deploy targeted land management practices. The datasets also support erosion modeling frameworks such as RUSLE, enhancing prediction accuracy.

4.3 Hydrological and Floodplain Modeling

DEM-derived slope and flow direction maps provide critical inputs for hydrological simulations using models such as HEC-HMS, SWAT, and NRCS-CN. Flow accumulation patterns help identify potential floodplain areas, low-lying pockets, and flood routing pathways. These outputs are indispensable for Disaster Management Authorities, Water Resources Departments, and district authorities engaged in flood hazard mapping, flood warning systems, and reservoir operation planning. The ability to recognize inundation-prone areas in the lower Godavari Basin enhances disaster preparedness and response planning.

4.4 Land Use, Urban Development, and Infrastructure Planning

By identifying stable, low-slope terrain, the topographical analysis supports land-use zoning, infrastructure planning, and urban expansion. Contour patterns, slope categories, and hillshade maps help evaluate terrain suitability for roads, industrial corridors, housing layouts, and irrigation canal alignments. This information directly aids Urban Development Authorities, Municipal Corporations, Planning Departments, Public Works Departments, and NHAI in selecting safe, geotechnically stable areas for construction while avoiding steep or erosion-prone terrain. It ensures cost-effective and environmentally sound infrastructure development.

4.5 Environmental and Ecological Applications

Aspect, slope, and elevation influence microclimatic conditions, vegetation density, biodiversity patterns, and habitat suitability. Hillshade outputs also help identify terrain exposure patterns and sensitive hill slopes. These datasets support Forest Departments, Biodiversity Boards, Irrigation–Environment Divisions, and ecological research organizations in mapping priority conservation zones, identifying degraded hill slopes, studying habitat distribution, and designing climate-responsive reforestation programs. The terrain-derived insights aid in preservation of ecological corridors and sensitive upland ecosystems.

4.6 Geomorphological and Terrain Evolution Studies

The detailed terrain modeling provides a clearer understanding of geomorphic processes such as pedimentation, valley evolution, erosional intensity, and depositional characteristics. Researchers, geological agencies, and academic institutions can utilize these datasets for morphometric analysis, landform classification, and paleodrainage interpretation, advancing scientific understanding of the basin’s geomorphic evolution. The contour and slope datasets also help identify tectonic features and terrain anomalies that influence the river’s long-term morphological development.

4.7 Sector-Wise Applications: Integrated Summary

By merging terrain-derived insights with institutional needs, topographical analysis becomes a practical decision-support tool.

- Water Resources & Basin Authorities use slope and flow maps for drainage design, watershed prioritization, and reservoir planning.
- Irrigation Departments utilize elevation and slope datasets for canal alignment, command area optimization, and irrigation infrastructure planning.
- Disaster Management Agencies depend on DEM-based floodplain mapping and slope risk assessment for early warning and mitigation planning.
- Forest and Environment Departments rely on aspect and hillshade patterns to identify eco-sensitive zones and design restoration measures.
- Urban and Regional Planners use contour and slope maps to allocate development areas and prevent construction in hazardous terrain.
- Public Works & Infrastructure Agencies apply terrain intelligence to road siting, embankment design, and slope stabilization engineering.
- Agricultural Departments and KVKs use slope and aspect data to recommend slope-appropriate cropping, soil conservation, and moisture management.
- Research Institutions and Geospatial Analysts leverage the entire suite of terrain parameters for hydrological modeling, geomorphology, and earth system studies.

Through these sector-specific applications, the topographical analysis of the Godavari River Basin becomes an essential, multi-dimensional tool supporting governance, planning, research, and environmental sustainability.

5. Management Implications and Recommendations

The outcomes of the topographical mapping hold significant implications for river basin management, land use policy, and resource planning. Translating these terrain-based insights into practical management strategies can enhance the basin’s resilience and optimize natural resource utilization.

5.1 Terrain-Based Zonation for Land Management

Classify basin areas into high-relief, moderate-relief, and low-relief zones for targeted land management. Restrict deforestation and construction activities in steep slopes (>10°) to prevent landslides and erosion. And, promote soil conservation and agroforestry practices in moderately sloping regions.

5.2 Watershed Prioritization and Erosion Control

Utilize slope and flow accumulation maps to rank sub-watersheds based on erosion susceptibility. Implement check dams, contour bunding, and vegetative barriers in high runoff zones to reduce sediment load. Adopt slope-specific soil conservation techniques for efficient resource use.

5.3 Flood and Drainage Management

Use elevation and contour data to delineate flood-prone plains in the lower basin. Integrate terrain analysis with hydrological modeling for early warning systems and reservoir operation planning. Identify natural depressions for floodwater storage and aquifer recharge.

5.4 Infrastructure and Settlement Planning

Encourage development in areas with gentle slopes and stable terrain, avoiding zones with high relief and erosion risk. Incorporate topographical constraints in road alignment, irrigation canal layout, and urban zoning plans.

5.5 Ecosystem Conservation and Climate Adaptation

Protect steep and forested uplands as ecological buffer zones for hydrological stability. Use aspect and hillshade data to design microclimate-sensitive reforestation and biodiversity corridors. Integrate topographical findings with climate models to anticipate slope failure or sedimentation under extreme rainfall events.

5.6 Capacity Building and Decision Support

Develop a geospatial decision support system (GDSS) combining topographical, climatic, and land use data for dynamic basin management. Encourage institutional data sharing to ensure continuous monitoring and model updating for the Godavari Basin.

These recommendations emphasize the role of topographical understanding in achieving sustainable river basin governance, reducing geomorphic hazards, and enhancing resource resilience under changing climatic and land use conditions.

6. Limitations and Uncertainties

Although this topographical analysis provides a detailed and consistent representation of the Godavari River Basin, several limitations and uncertainties must be acknowledged to ensure balanced interpretation of the results.

1. **Data Resolution Constraints-** The study utilized the FABDEM dataset at a spatial resolution of approximately 30 meters. While adequate for basin-scale mapping, this resolution may not fully capture micro-topographical variations, small channels, or localized relief features, especially in rugged headwater areas and narrow valleys.
2. **Residual Elevation Biases-** Despite the forest and building height corrections applied in FABDEM, residual elevation offsets of ±2–4 meters may persist in densely vegetated or urbanized regions. These residuals can locally influence slope gradient estimation and contour spacing.
3. **Interpolation and Void-Filling Effects-** In areas with radar shadow, data gaps, or low radar coherence, elevation values are interpolated from neighboring cells. Such interpolations

may introduce minor inconsistencies in smooth terrain surfaces, particularly within deltaic plains and broad floodplains.

4. **Datum and Projection Variability-** Although all data were standardized to the EGM96 geoid and UTM Zone 44N projection, subtle discrepancies can arise from transformation differences between global and national vertical datums, introducing minor vertical shifts at regional scales.
5. **Contour Generalization-** The contour-smoothing and generalization algorithms applied to enhance cartographic readability may slightly reduce the expression of sharp or irregular landform features, particularly in high-relief escarpments.
6. **Temporal Limitations-** FABDEM represents a static terrain condition around 2020–2022. Subsequent anthropogenic modifications (e.g., mining, infrastructure, reservoir construction) are not reflected, limiting its use for temporal change detection.
7. **Validation Scope-** Validation was conducted against a limited number of ground benchmarks and comparative DEMs (SRTM, Cartosat-1). While accuracy statistics indicate strong agreement, these datasets share certain error structures, meaning independent high-precision ground surveys could further refine the validation.

Regardless of these limitations, the FABDEM-based analysis provides a reliable representation of basin-scale topography. Future refinement through higher-resolution LiDAR, drone-based photogrammetry, or multi-temporal DEM comparison will further enhance spatial accuracy and the analytical scope of terrain studies within the Godavari River Basin.

7. Conclusion

The topographical mapping of the Godavari River Basin provides a comprehensive and high-resolution understanding of the basin's terrain configuration and geomorphic variability. Through systematic derivation of elevation, slope, aspect, flow direction, flow accumulation, and contour patterns, this report establishes a detailed terrain framework that reflects the basin's distinct west–east physiographic gradient (from the steep escarpments of the Western Ghats to the broad depositional plains of the deltaic region). The elevation and slope analysis shows the majority of the basin lies within the 200–600 m elevation range, characterized by gentle to moderate slopes typical of the Deccan Plateau. In contrast, the upper basin exhibits steep gradients and rugged relief, signifying high runoff potential and erosion susceptibility, while the lower basin transitions into low-lying floodplains shaped by fluvial deposition. Aspect and hillshade evaluations highlight the directional diversity of slopes and illuminate variations in solar exposure, moisture regime, and ecological conditions across the basin. Flow direction and accumulation analyses further delineate the hydrological behavior of the terrain, tracing the natural alignment of drainage networks and identifying key runoff convergence zones. The findings demonstrate that topographical analysis is not merely descriptive but forms the geospatial foundation for multiple applied domains. These include watershed delineation, erosion modeling, floodplain mapping, infrastructure planning, and ecosystem assessment. The terrain-derived indicators directly support hydrological modeling frameworks such as RUSLE, SWAT, and NRCS-CN, improving the accuracy of runoff and sediment estimations. Contour mapping and slope classification provide essential references for terrain stability assessment, land-use zoning, and soil–water conservation planning. From a management perspective, the topographical datasets enable terrain-based zonation for land management, watershed prioritization for erosion control, and flood risk identification in low-lying deltaic regions. The report emphasizes the necessity of integrating topographical insights with climatic, land use, and hydrological datasets to develop robust geospatial decision support systems (GDSS) for sustainable basin management. Despite inherent limitations in DEM resolution and algorithmic assumptions, the FABDEM-based analysis presents a reliable basin-scale representation of terrain conditions. Future work should focus on incorporating higher-resolution LiDAR or drone-derived DEMs, multi-temporal terrain monitoring, and ground validation to refine elevation accuracy and detect dynamic geomorphic changes. This study report provides a detailed topographical framework that enhances the understanding of the Godavari River Basin's geomorphology and hydrological behavior. The outputs serve as a critical reference for scientific research, spatial planning, and environmental management. The basin can move toward a more data-driven, sustainable, and resilient management approach by integrating topographical insights with future modeling efforts and policy frameworks, which is aligned with the objectives of integrated river basin governance in India.

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