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

Geomorphological Mapping
Godavari River Basin

November 2024

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Geomorphological Mapping

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 Mahanadi River Basin Management Studies (cMahanadi)

The Centres for Godavari River Basin Management Studies (cGodavari) are 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 centre 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

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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.

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Centre for the Godavari River Basin
Management Studies (cGodavari)
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Abbreviations and Acronyms

DEM	Digital Elevation Model
FABDEM	Forest and Buildings removed Copernicus DEM
GRD	Ground Range Detected
SAR	Synthetic Aperture Radar
VV	vertical transmit, vertical receive
VH	vertical transmit, horizontal receive
GIS	Geographic Information System
NASA	National Aeronautics and Space Administration
SRTM	Shuttle Radar Topography Mission
NGO	Non-governmental organization
NRCD	National River Conservation Directorate
NRCP	National River Conservation Plan
NMCG	National Mission for Clean Ganga
JRC	Joint Research Centre's
GFPLAIN250m	A global high-resolution dataset of Earth's floodplains

1. Introduction

Geomorphological mapping emerges as a sophisticated scientific discipline that transcends traditional geological research boundaries, offering a comprehensive approach to understanding Earth's complex surface dynamics. This methodology represents an intricate synthesis of spatial analysis, geological interpretation, and advanced technological integration, aimed at unravelling the intricate narratives embedded within landscape morphologies. It captures the nuanced interactions between geological processes, environmental conditions, and temporal transformations.

Active floodplains—areas adjacent to rivers that experience regular flooding, particularly during significant hydrological events—play a vital role in maintaining ecological balance, supporting diverse biological communities, and enhancing soil fertility, which in turn benefits agricultural productivity. Accurately mapping these areas is crucial for mitigating risks associated with flooding and for restoring the natural dynamics of river systems.

This report focuses on the mapping of active floodplains, particularly along the Godavari River, employing satellite data to conduct a first-order assessment of the geomorphological features that influence water flow and sediment transport. Understanding these dynamics is essential not only for preserving the ecological integrity of floodplains but also for informing policies that balance human needs with environmental stewardship. Considering increasing anthropogenic pressures and climate variability, understanding the morphological features and hydrological behaviour of active floodplains is paramount for contemporary water resource management strategies. By accurately delineating these areas, we can better assess their functionality in flood risk mitigation, biodiversity preservation, and agricultural productivity. This study emphasizes the importance of integrating geomorphological knowledge into contemporary hydrological and environmental management strategies to foster resilience against climate variability and promote sustainable land-use practices.

2. Data used

The following data and criteria are used for mapping and verification of the active floodplain and geomorphic changes:

1) FABDEM (Forest and Buildings removed Copernicus) with 30 m resolution

FABDEM (Forest and Buildings removed Copernicus DEM) removes building and tree height biases from the

Copernicus GLO 30 Digital Elevation Model (DEM) (Airbus, 2020). The data is available at 1 arc second grid

spacing (approximately 30 m at the equator) for the globe. The authors use machine learning to remove

buildings and forests from the Copernicus Digital Elevation Model to produce, for the first time, a global map

of elevation with buildings and forests removed at 1 arc second (~30 m) grid spacing. By utilizing this DEM,

we can effectively assess the topography of floodplains, allowing for a more precise understanding of water

flow patterns, sediment deposition, and erosion processes. The removal of forest and building heights enables the identification of subtle geomorphic features and changes over time, facilitating studies on river dynamics, flood risk management, and habitat alterations. Consequently, FABDEM enhances the ability to monitor and model landscape evolution in response to hydrological events, contributing significantly to effective environmental management and planning in flood-prone areas[1].

2) Sentinel-1 Level 1 Ground Range Detected (GRD) with 30 m resolution

Sentinel-1 Level 1 Ground Range Detected (GRD) products are crucial for a variety of applications, particularly in agricultural monitoring and environmental assessment. These products utilize synthetic aperture radar (SAR) technology to provide high-resolution images that are unaffected by cloud cover or lighting conditions, making them ideal for continuous observation. It operates in the C-band of the electromagnetic spectrum, specifically utilizing two polarizations: VV (vertical transmit, vertical receive) and VH (vertical transmit, horizontal receive). The GRD data is processed to correct for geometric distortions, enabling accurate mapping of flood extents and the identification of changes in river morphology, sediment deposition, and erosion patterns. By utilizing the backscatter signals from the radar, researchers can analyse variations in surface roughness and moisture content, which are indicative of floodplain activity. This information is crucial for understanding hydrological processes, managing water resources, and assessing the impact of natural disasters on ecosystems and human settlements. The frequent revisit times of Sentinel-1 satellites further enhance the ability to monitor temporal changes, providing valuable insights into the dynamics of floodplain environments and their response to climatic events[2].

3) Geological Survey of India (GSI) Geomorphology with 250 K resolution

The Geological Survey of India (GSI) provides a geomorphology dataset with a 250 K resolution. This resource, accessible through Bhuvan, is a crucial thematic layer for understanding the landforms and geological features of a region. It is particularly useful for large-scale analysis and provides a foundation for identifying and classifying different geomorphic units, such as floodplains, deltas, and mountainous terrains. The dataset helps in preliminary geomorphic mapping and provides a base layer for more detailed studies, aiding in the interpretation of landform evolution and processes[3].

4) GFPLAIN250m, a global high-resolution dataset of Earth's floodplains

The GFPLAIN250m dataset is a global, high-resolution floodplain dataset with a 250-meter resolution. It provides comprehensive, worldwide coverage of Earth's floodplains, making it a valuable tool for hydrological and geomorphological studies. This dataset is essential for identifying areas prone to flooding, mapping active floodplains, and understanding the extent of fluvial systems. It can be used in conjunction with other datasets to assess flood risk, analyse the geomorphic characteristics of river basins, and inform land-use planning in flood-prone areas[4].

5) Joint Research Centre's Global Surface Water Dataset

The Joint Research Centre's (JRC) Global Surface Water Dataset offers a detailed, high-resolution view of the spatial and temporal distribution of surface water over a 38-year period. Available through Google Earth Engine and for download, this dataset is described in a technical document that provides details on its purpose, bands, and symbology. The data includes layers for mapped products like seasonality, as well as water history layers that track temporal changes at specific locations. These datasets are based on a detailed methodology published in Nature and are valuable for analysing long-term changes in surface water bodies, mapping ephemeral water features, and assessing the influence of climate and human activities on water resources[5].

3. Methodology

The methodology for characterizing and mapping River Styles in the Godavari River builds directly on the principles outlined in the River Styles framework developed by Brierly & Fryirs (2005), and is structured around four technical components shown in Figure 1 that together provide a basis for delineating geomorphologically meaningful reaches and documenting the river's diversity and function.

Active & Passive Floodplain
- Sentinel 1 SAR Data
- Flood Inundation Maps
- Active/ Passive Mapping

Geomorphic Units
- Google Earth Image
- Manual Digitization
- River Island and Channel bars

River Style

Valley Margin
- Google Earth Pro
- Cross Section Analysis

River Margin
- Google Earth Image
- Manual Digitization
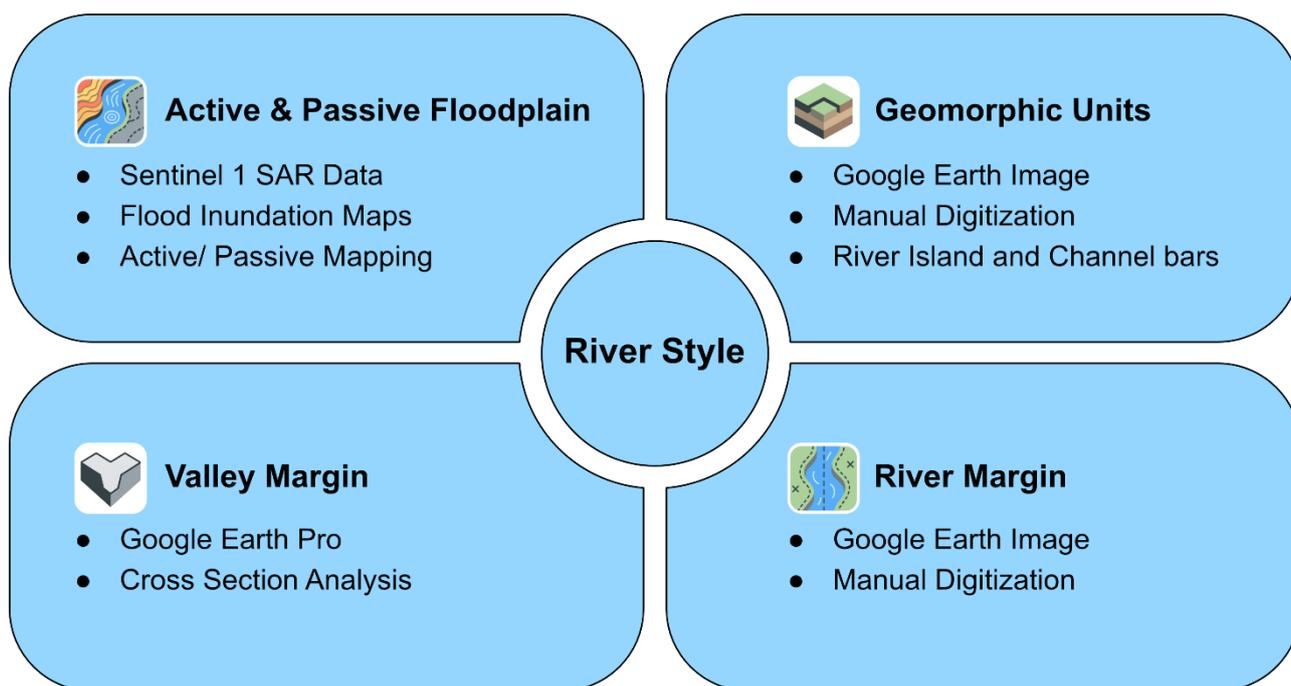
Figure 1 Methodology for River Style of Godavari River

1. Active and Passive Floodplain Delineation: The identification of active and passive floodplain zones is fundamental to understanding flood dynamics and geomorphic connectivity. This is achieved by processing multi-temporal Sentinel-1 SAR data to produce flood inundation maps across several major hydrological events, using change detection algorithms and frequency overlays. Pixels consistently inundated across most events are classified as active floodplain, while areas rarely flooded are designated as passive floodplain. The boundary between active and passive zones is refined by masking permanent water bodies (e.g., JRC Global Surface Water dataset) and removing portions with excessive topographic slope using DEM-derived layers.

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This approach provides a spatial hierarchy of inundation frequency as a primary input to geomorphic mapping, following the nested principles outlined in the River Styles framework.

2. River Margin Analysis: The river margin, defining the immediate interface between channel and floodplain, is manually digitized using high-resolution Google Earth satellite imagery. This includes identifying the contemporary bank lines and lateral channel extents for each reach, enabling precise mapping of the spatial relationships between the river channel and adjacent floodplain units. The process utilizes visual photointerpretation techniques and manual vectorization to ensure that transitions between distinct geomorphic settings are captured at an appropriate scale, in line with the framework's emphasis on accurate reach-level characterization.

3. Valley Margin Delimitation: To objectively determine the valley margin, Google Earth Pro's topographic profiles and cross-section analysis tools are employed. Transects are placed perpendicular to the channel across the AOI, and digital elevation models (e.g., FABDEM) are used to quantify breaks in valley slope, terrace limits, and the presence of geomorphic boundaries such as bedrock or terrace margins. Valley margin assessment reinforces the nested, hierarchical mapping approach and supports the classification of reaches according to their level of lateral confinement and valley setting, as prescribed in the River Styles methodology.

4. Geomorphic Units Mapping: Within each reach, the diversity of geomorphic units is systematically documented using a combination of Google Earth imagery and manual digitization methods. Features such as islands, mid-channel bars, point bars, oxbows, and channel anabranches are mapped and catalogued based on their morphologic character and spatial arrangement. This geomorphic inventory enables a detailed assessment of river style diversity, functioning as a critical component for diagnosing river character and behaviour at both reach and system scales. The mapping of these units supports further analysis of channel type, sediment transport, and river evolution in accordance with the River Styles framework.

4.   Flood Plain

Floodplains are dynamic landscapes shaped by seasonal monsoon floods, which are critical for sustaining agriculture but also pose significant risks to communities. Climate change has intensified the frequency and severity of floods and droughts in the Godavari basin, particularly in sub-basins like Manjra (drought-prone) and Upper Godavari (flood-prone). Floodplain mapping is essential for risk mitigation, sustainable development, and ecological preservation. However, traditional methods often lack consistency at large scales, highlighting the need for standardized datasets like GFPLAIN250m.

GFPLAIN250m is the first global, high-resolution (250 m) floodplain dataset derived from the NASA Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM). It uses a geomorphic algorithm to delineate floodplains based on terrain analysis, identifying low-lying riparian zones shaped by fluvial processes:

- **Methodology**: Combines elevation data with scaling laws to estimate floodplain extents, validated against hydrodynamic models in Europe.
- **Applications**: Supports flood hazard mapping, habitat restoration, and human-flood interaction studies.
- **Accessibility**: Open-source code and datasets are available via GitHub and Figshare.

Limitations:

- Excludes regions with low water availability (e.g., deserts) and relies on SRTM elevation data, which may have vertical errors in densely vegetated or urban areas.

- Does not incorporate hydrodynamic variables like rainfall or river discharge, necessitating complementary models for dynamic flood prediction.

The Sentinel-1 Level 1 Ground Range Detected (GRD) data is used to verify the rivers, water bodies, and floodplains. The synthetic aperture radar (SAR) capabilities of Sentinel-1 allow for consistent data acquisition regardless of weather conditions, enabling me to capture critical information during both day and night. This feature is particularly advantageous during flood events when cloud cover can obstruct optical satellite imagery. Change detection methodologies on GRD data were used to delineate flooded areas and assess water body extent over time. The high spatial resolution facilitated a detailed analysis of land cover changes, which is essential for understanding the dynamics of flood-prone regions and managing water resources effectively.
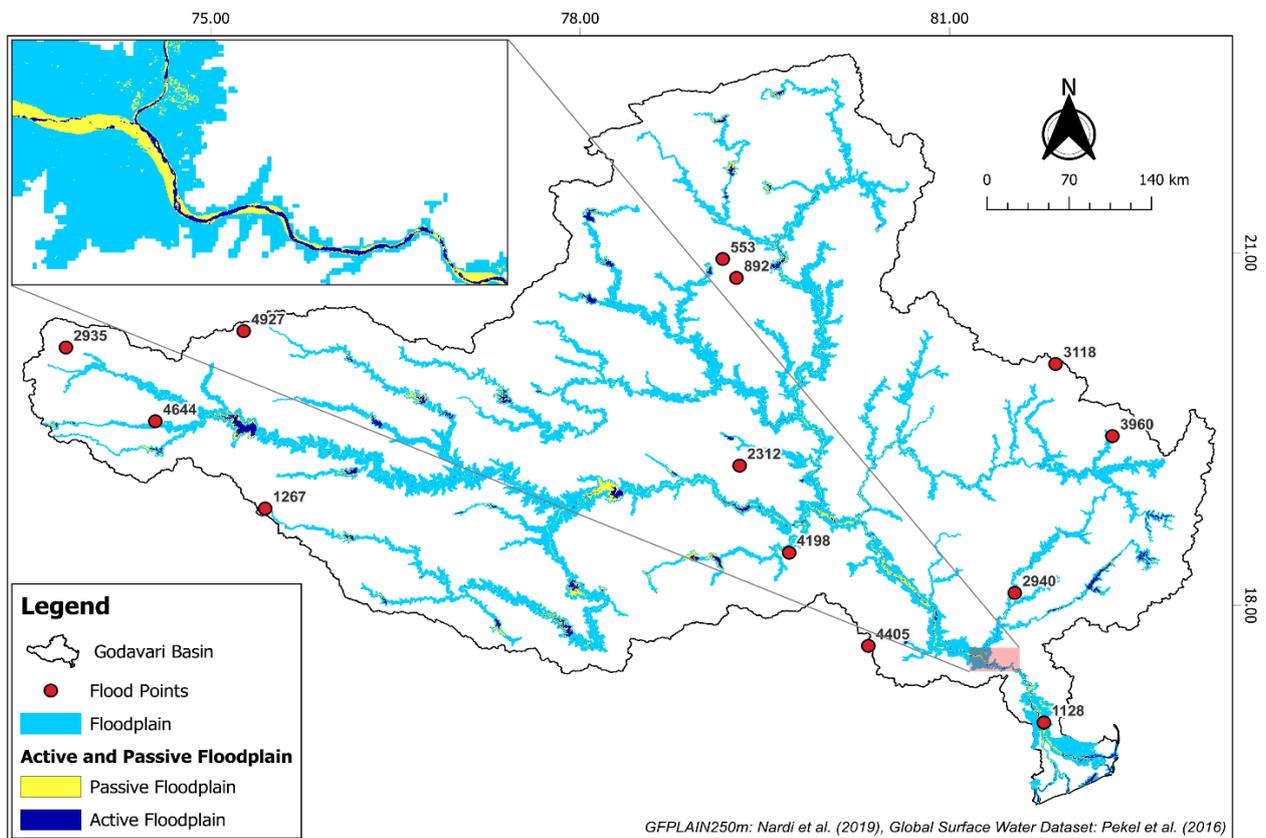
Figure 2 Godavari Basin boundary map showing basin, the river Godavari and the active floodplain

Figure 2 depicts the map illustrates the Godavari Basin, highlighting areas of active and passive floodplains using GFPLAIN250m (Nardi et al., 2019) and the Global Surface Water Dataset (Pekel et al., 2016). Active floodplains are shown in dark blue, while passive floodplains are shown in yellow. The overall floodplain extent is represented in cyan. Red circles mark flood points across the basin, each labelled with identification numbers (e.g., 2935, 4644, 553, 4198). The inset at the top-left provides a zoomed-in view of a river section, showing finer details of the active and passive floodplain delineation.

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Active and Passive Floodplains

The Joint Research Centre's (JRC) Global Surface Water Dataset is a valuable resource for distinguishing between active and passive floodplains. This high-resolution dataset, derived from Landsat satellite imagery, maps the location and temporal distribution of surface water globally from 1984 onwards. By analysing its key layers—such as Water Occurrence, Water Seasonality, and Water Transitions—we can differentiate these two types of floodplain areas:

- Active Floodplain: This corresponds to the areas with high water occurrence and seasonality. These are the areas that are frequently inundated, either seasonally during monsoon events or on a more consistent basis. The JRC dataset identifies these zones by showing a high percentage of water presence over the years, indicating that they are actively part of the river's flood-prone ecosystem.
- Passive Floodplain: These are areas that have a low water occurrence or show a transition from water to non-water. They may have been part of the floodplain historically but are no longer regularly inundated due to human interventions like levee construction, land-use changes, or natural geomorphic processes. The JRC dataset helps identify these areas by revealing a significant decrease in water presence over time.

4.1. Major Flooding Events in the Godavari Basin

Historical and recent floods have caused extensive damage:

- 1986 Flood: Affected 3 million people, destroying crops and infrastructure in Andhra Pradesh.
- 2006 Flood: Inundated 450 villages, displacing 500,000 people and causing $500 million in losses.
- 2020 Flood: Resulted in 1,922 deaths and $7.5 billion in economic losses nationwide, with Godavari's coastal regions severely impacted.

These events highlight the basin's vulnerability to climate extremes and the urgent need for updated floodplain management strategies[6].

GFPLAIN250m is a valuable resource for global and regional floodplain analysis, providing a standardized baseline for comparison across different basins. In the Godavari Basin, this data is particularly useful for identifying areas at elevated risk of flooding, which is crucial for disaster preparedness and informed land-use planning. However, the data does have limitations. The 250-meter resolution might not capture small-scale features that are important to local communities, and elevation data derived from SRTM can have inaccuracies, especially in areas with dense forests or urban development.

To improve the accuracy and utility of GFPLAIN250m, it is essential to address these data gaps and uncertainties. Integrating the data with other sources, such as LiDAR or MERIT DEMs, can help refine elevation data. Additionally, incorporating hydrodynamic models can enable dynamic flood forecasting, providing more real-time and accurate predictions. Ground surveys in high-risk sub-basins, like the Indravati, are also necessary to validate the data and ensure its reliability.

Finally, stakeholder engagement is crucial for the successful implementation of GFPLAIN250m in flood management strategies. By involving local governments, farmers, and NGOs, the floodplain maps can be

tailored to meet specific needs, such as evacuation planning and agricultural zoning. Furthermore, adopting probabilistic flood mapping that considers elevation uncertainties can provide a more comprehensive and reliable assessment of flood risk.

# 5. River valley margin and geomorphic features

River valleys are dynamic and ever-changing landscapes shaped by the continuous processes of erosion and deposition. The river valley margin, also known as the floodplain, is the area adjacent to the river channel that experiences periodic flooding and sediment deposition. This region is characterized by a variety of geomorphic features, which are landforms created by the natural processes of erosion, transportation, and deposition of sediments by the river. These features include meanders, oxbow lakes, levees, and floodplains. Meanders are sinuous curves in the river channel that form due to erosion on the outer bends and deposition on the inner bends. Oxbow lakes are formed when a meander is cut off from the main channel, creating a U-shaped body of water. Levees are natural embankments formed by the accumulation of sediments along the river banks during floods.

Floodplains are flat areas adjacent to the river that are periodically inundated by floodwaters, making them fertile grounds for agriculture. The river valley margin and its geomorphic features play a crucial role in the environment and human activities. They act as natural buffers during floods, enhancing soil fertility for agriculture, supporting biodiversity, improving water quality, providing recreational opportunities, and offering valuable insights for scientific research. Understanding these features is essential for sustainable land use planning, environmental conservation, and mitigating natural hazards.

5.1. Mapping of Valley Margin using FABDEM data

Elevation changes can be effectively identified by classifying the FABDEM data into multiple classes and subsequently assigning a unique colour code to each class. This color-coded representation allows for a visually intuitive understanding of terrain variations, enhancing the ability to discern subtle changes in elevation. For instance, Figure 3 illustrates this process: (a) shows the color-coded FABDEM data, (b) depicts the sections across which profiling has been conducted, and (c) presents the final valley margin of the area. By analysing the FABDEM profiles, particularly focusing on topographic breaks, it is possible to accurately delineate key features such as valley margins.

This approach enables the generation of precise valley margin maps, which are crucial for various applications including hydrological modelling, flood risk assessment, and geomorphological studies. Figure 2 provides a detailed view of the profiles along the selected sections (a-f), highlighting how these profiles contribute to understanding the topography in a more granular manner.
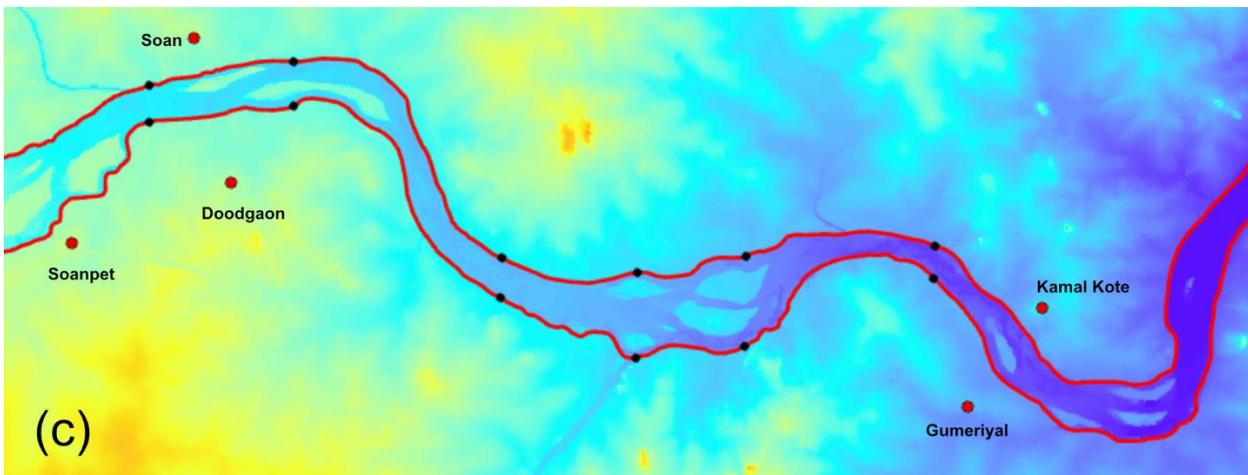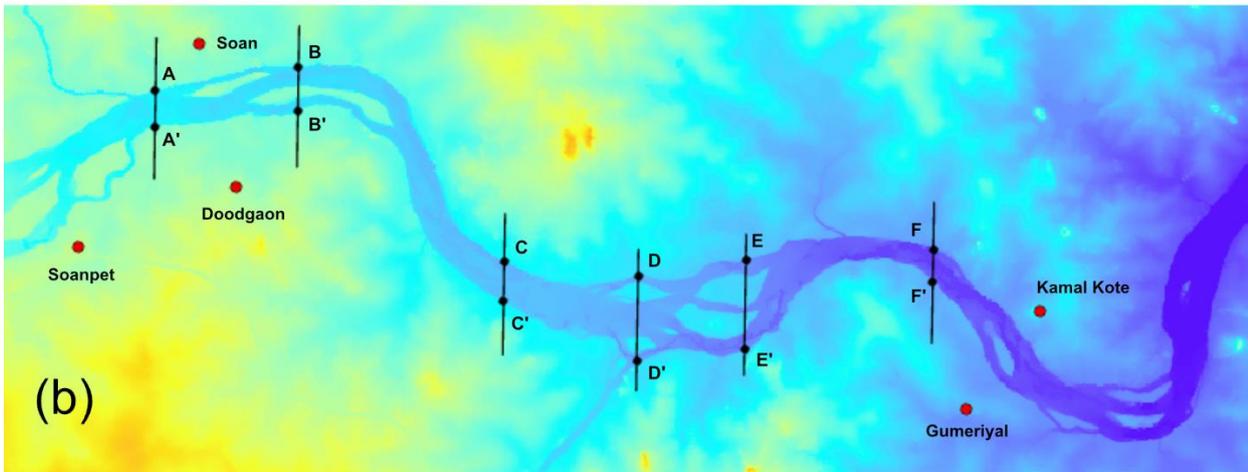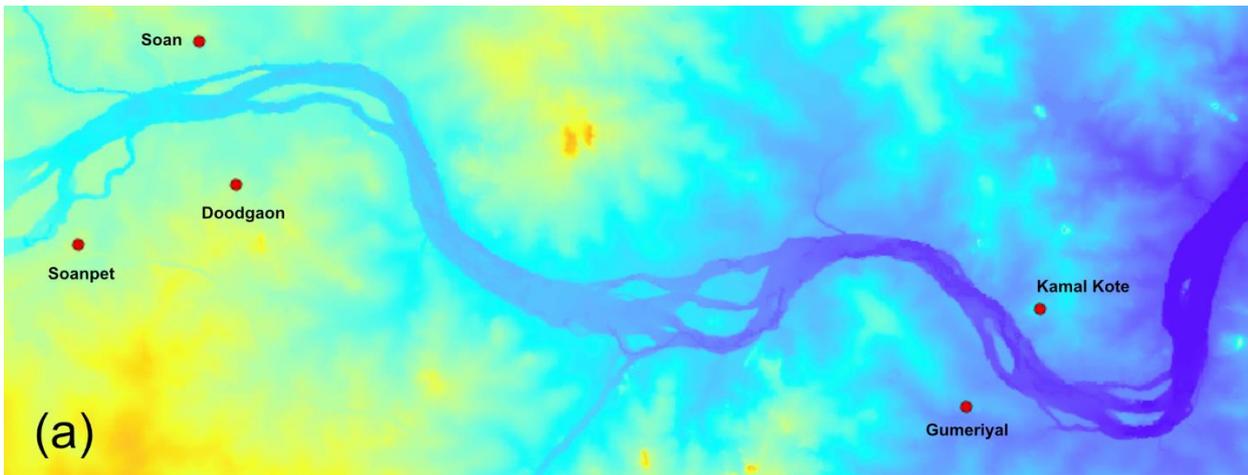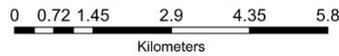
Figure 3 (a) Colour coded FABDEM data, (b) sections across which profiling has been done, (c) final valley margin of the area

(a) Profile along section AA'

(b) Profile along section BB'

(c) Profile along section CC'

(d) Profile along section DD'

(e) Profile along section EE'

(f) Profile along section FF'

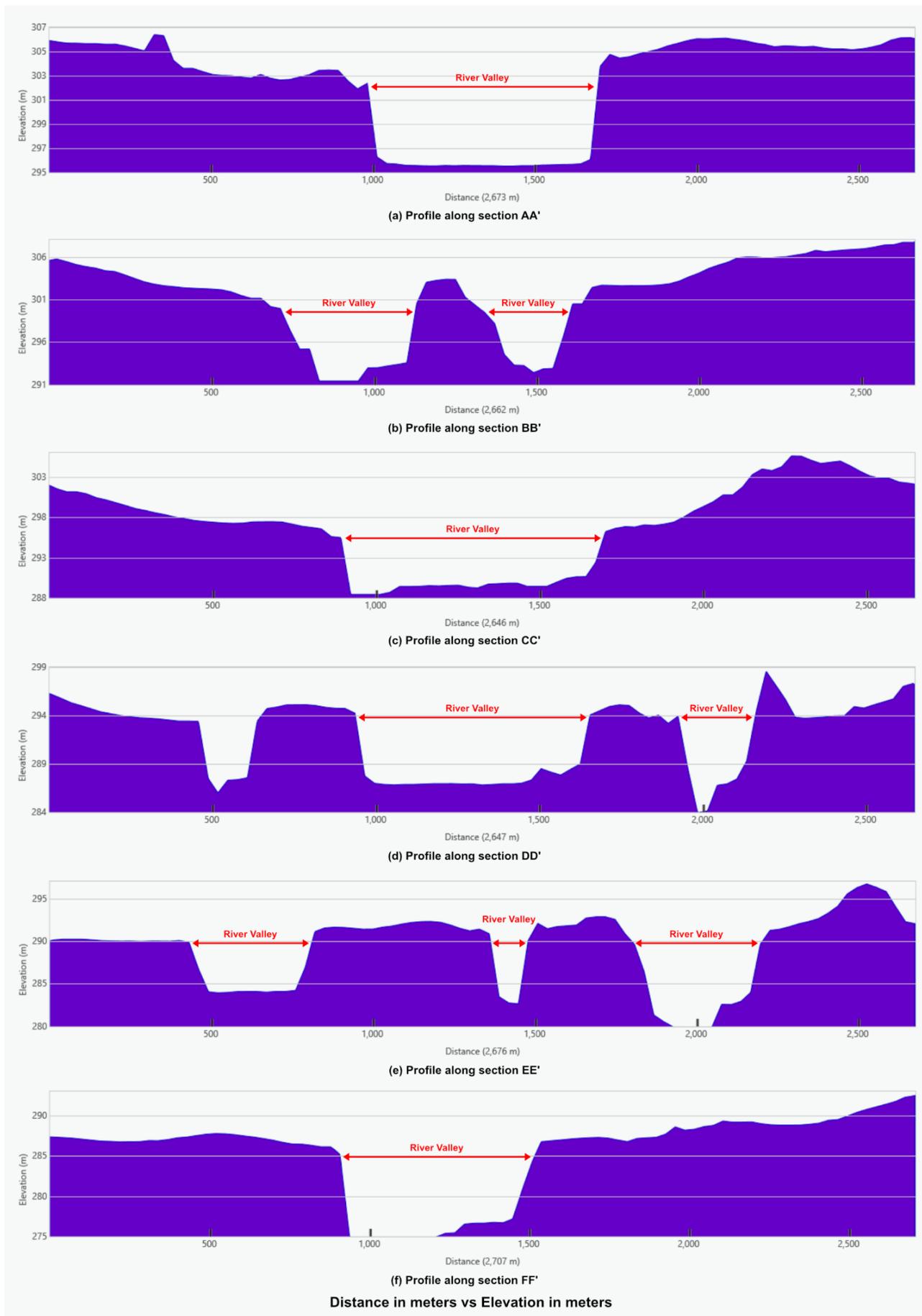Distance in meters vs Elevation in meters

Figure 4 Showing the profiles along the selected sections

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5.2.   Mapping of geomorphic features

The Sentinel-1 and Google Earth images serve as valuable verification tools for the geomorphology data provided by the Bhukosh portal. Colour visualization of Sentinel-1 imagery is a powerful tool for geomorphic classification, as it effectively highlights different land surface properties. This composite, which uses VV and VH polarizations, displays water bodies in shades of blue and black, while land surfaces are rendered in various shades of yellow and green. This distinction is crucial for identifying river channels, lakes, and floodplains. Furthermore, the visualization helps differentiate land cover types by their colour: urban areas appear light green-yellow, vegetated areas are a mustard green, and bare ground is a darker green. These colour variations are invaluable for mapping different geomorphic features, such as human settlements, vegetated riverbanks, and exposed sediment or soil. This capability is particularly beneficial for assessing the accuracy of geomorphic classifications and understanding landscape dynamics over time.

In conjunction with this, Google Earth provides high-resolution satellite imagery that enhances the ability to identify and map geomorphic features. Figure 5 shows the snapshot of Sentinel-1 and Google Earth of the area near Shriram Sagar Dam. By utilizing these two resources, users can cross-reference Bhukosh's geomorphological data with historical and current imagery, ensuring a more robust verification process. This integration not only supports effective environmental monitoring but also aids in resource management and planning efforts, enhancing the utility of the geomorphology data for various stakeholders. The combination of these tools fosters a comprehensive understanding of landform characteristics, addressing potential data gaps and uncertainties inherent in the Bhukosh dataset.

(a)   **(b)**

Figure 5 (a) a snapshot of Sentinel-1, (b) snapshot of the same area in Google Earth

6. Results and Discussions

6.1. Delineation of basin scale Valley margin along the Godavari River

Figure 6 shows distinct variations in its valley margin characteristics as it flows from Gangapur to the Bay of Bengal, covering a total distance of approximately 1,474 kilometres. Table 1 systematically documents the characteristics of ten distinct stretches along the Godavari River, providing detailed measurements and observations for each segment. The river's valley margin demonstrates a general trend of widening as it progresses downstream, though with notable fluctuations. In its upper reaches from Gangapur to Kumbhari, the valley margin is narrow (1103.5 / 18.6 m) over 107.83 km, with bedrock margin control and meandering. Moving downstream to Toka, the valley widens to 2105.8 / 126.7 m over 96.92 km, maintaining bedrock control without a defined meandering pattern. The stretch from Paithan to Manjarath represents a transition to terrace margin control, with the valley widening to 2434.4 / 160.3 m over 142.53 km, developing a meandering pattern with point bar formation. Between Manjarath and Barbadi, covering 156.55 km, the valley margin fluctuates between 1257 / 157.8 m, marking a transition to partly confined conditions with continuous floodplain development. The Barbadi to Panchgudi segment (160.26 km) shows a significant expansion to 4617.5 / 217.6 m with planform control and discontinuous floodplain development. Further downstream, the Soanpet to Bornapalle stretch (63.84 km) transitions to a transitional morphology with sinuous and braided characteristics (3580.4 / 454.4 m) and active sandy islands. The Bornapalle to Murmur segment (52.80 km) narrows slightly to 3876.6 / 485.4 m with moderate confinement and gravel bed material. The Murmur to Waddegudem stretch (350.37 km) represents a major unconfined alluvial plain section, dramatically expanding to 5000 / 395.3 m with braided and meandering characteristics. The Waddegudem to Polavaram segment (68.20 km) shows a distinct narrowing trend (7270.4 / 278.2 m) due to topographical constraints, forming a confined gorge. Finally, as the river approaches its deltaic region from Polavaram to the Bay of Bengal, the valley margin dramatically expands to 6157 / 1127.6 m over 119.87 km, forming an extensive estuarine system with multiple distributaries. This progressive widening pattern corresponds to typical river valley development, where the valley broadens as it transitions from upstream to downstream regions, influenced by factors such as geological constraints, floodplain development, and sediment deposition patterns.
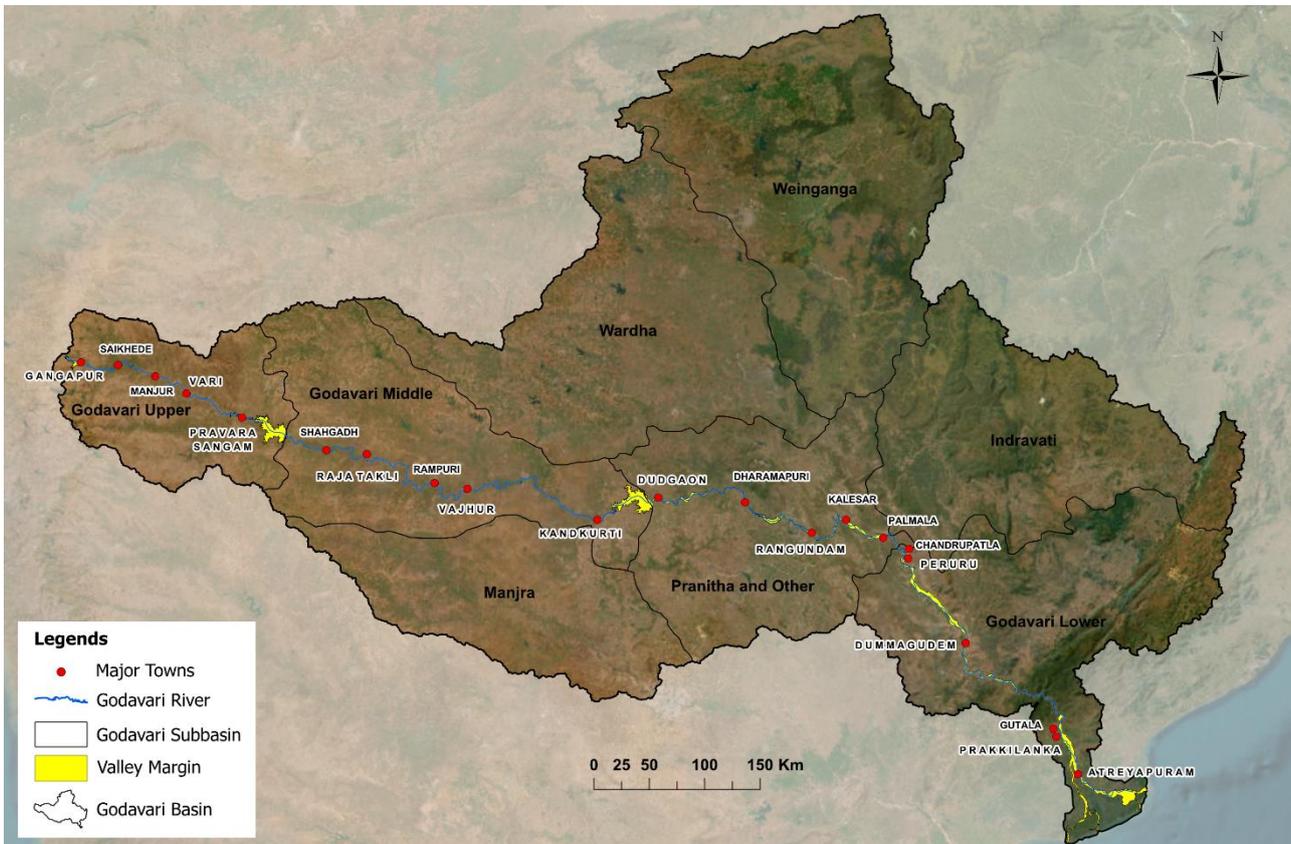

Figure 6 Godavari river valley margin from Gangapur to Bay of Bengal plotted

Table 1 Valley Margin of the Godavari River

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Stretch	Maximum and Minimum width (m)	Length (km)	Major characteristics
Gangapur To Kumbhari	1103.5 / 18.6	107.83	This stretch represents the upstream confined section characterized by bedrock margin control along the channel boundaries. The river maintains a meandering pattern within the constraints imposed by resistant Deccan Trap basalt formations. The presence of bedrock core bars and discontinuous floodplain pockets reflects structural control on channel morphology. Bed material consists of bedrock substrates with boulder-sized clasts, typical of high-energy bedrock-dominated river systems in the Western Ghats region.
Kumbhari To Toka	2105.8 / 126.7	96.92	This stretch maintains bedrock margin control but exhibits wider channel dimensions. The absence of a defined meandering pattern suggests structural constraints that prevent regular planform development. Mid-channel bars form as temporary sediment storage features during variable flow conditions. Discontinuous floodplain development occurs in limited valley expansion zones where bedrock geometry permits sediment accumulation.
Paithan To Manjarath	2434.4 / 160.3	142.53	This stretch transitions from bedrock to terrace margin control, representing a shift in confining mechanisms. The river develops a meandering pattern within terraced valley margins. Point bar formation on meander inner bends indicates active lateral migration processes within the confined setting. The transition to gravel bed material suggests reduced bedrock exposure and increased sediment transport capacity.
Manjarath To Barbadi	1257 / 157.8	156.55	This stretch marks the transition from confined to partly confined conditions. Planform margin control allows meandering development within broader valley constraints. Continuous floodplain development indicates increased lateral adjustment capacity. The transition to sand bed material reflects lower energy conditions and finer sediment supply characteristic of middle reaches.
Barbadi To Panchgudi	4617.5 / 217.6	160.26	This stretch exhibits planform control with expanded channel dimensions. Discontinuous floodplain and alluvial plain development suggest variable valley width and alternating confinement zones. Mid-channel bar formation indicates active bedload transport and temporary sediment storage during variable flow conditions.
Soanpet To Bornapalle	3580.4 / 454.4	63.84	This stretch represents a transitional morphology combining sinuous and braided characteristics. Indicating significant lateral adjustment capacity. Active sandy islands and mid-channel bars reflect dynamic sediment transport processes with frequent reworking during flood events. Alluvial

			floodplain development suggests consistent lateral adjustment and overbank deposition.
Bornapalle To Murmur	3876.6 / 485.4	52.80	This stretch exhibits moderate confinement conditions. The combination of mid-channel bars and point bars indicates complex flow patterns with both central and lateral deposition zones. Gravel bed material suggests higher energy conditions than downstream sand bed systems, indicating competency for coarse sediment transport during flood events.
Murmur To Waddegudem	5000 / 395.3	350.37	This stretch represents the major unconfined alluvial plain section with maximum lateral adjustment freedom. Indicating substantial floodplain development. The combination of braided and meandering characteristics reflects highly dynamic flow conditions with variable sediment transport capacity. Continuous floodplains, point bars, cut banks, and levees indicate active lateral migration and vertical accretion processes. Sand and silt bed composition reflects lower energy conditions typical of large alluvial rivers.
Waddegudem To Polavaram	7270.4 / 278.2	68.20	This stretch represents a confined gorge section with dramatic width variations. The gorge characteristics indicate recent incision through terrace formations, creating steep valley sides and narrow valley floors. Boulder bed material reflects high-energy flow conditions capable of transporting coarse sediment loads. Discontinuous floodplain development is limited to valley expansion zones behind bedrock spurs.
Polavaram To Bay of Bengal	6157 / 1127.6	119.87	The final stretch transitions to deltaic conditions with maximum channel widths reaching 6,157 m. Distributary channel development creates multiple flow paths distributing water and sediment across the coastal plain. Sand bars form as temporary storage features under variable flow and tidal influences. Deltaic deposits indicate the transition from riverine to marine depositional environments with fine-grained sediment accumulation dominating the system.

6.2.   Geomorphic Mapping

This section presents the important geomorphic features in the channel belt and active floodplain along the Godavari River as shown in Figure 7 - 16.

6.2.1.   Gangapur to Kumbhari Stretch

This stretch of the Godavari River is characterized by a highly varied geomorphological landscape dominated by structural and erosional features. A major part of this stretch is occupied by highly dissected plateau formations, with moderately to low dissected hills and valleys flanking the river corridor. The river valley maintains a narrow configuration with limited flood plain development, like mountainous river characteristics.

The floodplain in this stretch is notably restricted in width, indicating the river's incised nature as it cuts through the resistant plateau surfaces. The presence of pediment pediplain complex suggests active erosional processes have shaped the landscape over geological time scales. The geomorphic features are primarily of structural origin, with limited fluvial depositional forms due to the confined valley setting and high-energy flow regime typical of the upper reaches.

6.2.2.   Kumbhari to Toka Stretch

Moving downstream, this stretch exhibits a transitional character between the upper erosional domain and the middle alluvial reaches. The moderately dissected plateau continues to dominate the landscape, but with increased evidence of fluvial activity. The flood plain shows marginal widening compared to the upstream stretch, indicating the beginning of the river's depositional phase.

The valley margins in this stretch are characterized by low dissected hills and valleys, creating a more open valley configuration. The presence of alluvial plain formations, though limited, marks the initial development of depositional landforms. The river channel begins to exhibit characteristics of lateral mobility, though still constrained by the valley margins.

6.2.3.   Paithan to Manjarath Stretch

This stretch represents a significant geomorphological transition zone where the Godavari River begins to develop more pronounced alluvial characteristics. The flood plain becomes notably wider, indicating increased lateral accommodation space and reduced valley confinement. The presence of extensive alluvial plain formations suggests active sediment deposition and channel mobility.

The valley setting in this reach is characterized by a combination of moderately dissected plateau and low dissected hills and valleys, creating a semi-confined valley environment. The pediment pediplain complex continues to influence the broader landscape configuration, while the river corridor shows increased evidence of lateral migration and floodplain development.

6.2.4.   Manjarath to Barbadi Stretch

This stretch exhibits well-developed alluvial characteristics with significantly expanded floodplain formations. The river valley widens, allowing for extensive lateral migration and the development of complex fluvial geomorphic features. The alluvial plain becomes the dominant landform, indicating mature fluvial processes and substantial sediment accommodation space.

The valley margins are characterized by low dissected plateau formations, providing a more open valley configuration. The presence of multiple waterbodies suggests active channel migration, abandoned channel development, and complex floodplain hydrology. This stretch represents the river's transition into its middle alluvial phase with enhanced depositional activity.

6.2.5.   Barbadi to Panchgudi Stretch

The geomorphological character of this stretch is dominated by extensive alluvial plain formations with well-developed floodplain systems. The valley configuration becomes increasingly open, with moderately dissected

hills and valleys providing the valley margins. The river exhibits characteristics of a mature alluvial system with evidence of lateral channel migration and complex floodplain development.

Notable in this stretch is the presence of sea stacks, indicating unique geological formations that influence local river behavior. The pediment pediplain complex continues to shape the broader landscape context, while the immediate river corridor is dominated by active fluvial processes and sediment deposition.

6.2.6. Soanpet to Bornapalle Stretch

This stretch represents a continuation of the mature alluvial phase with extensive flood plain development. The alluvial plain formations dominate the valley floor, indicating sustained sediment deposition and active fluvial processes. The valley setting is characterized by moderately dissected hills and valleys, providing a semi-confined environment that allows for significant lateral channel mobility.

The presence of highly dissected hills and valleys in certain areas suggests local structural control on river behavior, creating zones of varying valley width and floodplain development. The pediment pediplain complex continues to influence the regional geomorphological context.

6.2.7. Bornapalle to Murmur Stretch

This stretch exhibits the most complex geomorphological characteristics within the middle reaches of the Godavari River. The flood plain achieves maximum development, with extensive alluvial plain formations creating a wide valley floor. The valley margins are characterized by a combination of highly dissected hills and valleys and moderately dissected plateau, creating variable valley width and complex floodplain geometry.

The presence of both highly dissected and moderately dissected landforms suggests differential erosional resistance and complex structural controls on river behavior. The river system in this stretch exhibits characteristics of a mature alluvial river with well-developed lateral migration patterns and complex floodplain hydrology.

6.2.8. Murmur to Waddegudem Stretch

This extensive stretch represents the transition toward the lower alluvial reaches of the Godavari River. The alluvial plain formations become increasingly dominant, with expansive flood plain development indicating mature fluvial processes and substantial sediment accommodation space. The valley configuration is characterized by moderately dissected plateau and low dissected hills and valleys, creating a broad, open valley setting.

Notable features in this stretch include bajada formations and piedmont slope developments, indicating the influence of tributary systems and alluvial fan processes. The presence of aeolian plain formations suggests wind-reworking of fluvial sediments, indicating the arid to semi-arid climate conditions in this region.

6.2.9. Waddegudem to Polavaram Stretch

This stretch represents the lower alluvial reach of the Godavari River with well-developed deltaic plain formations. The flood plain achieves maximum width, indicating minimal valley confinement and extensive lateral accommodation space. The alluvial plain dominates the valley floor, with complex channel patterns and extensive floodplain development.

The presence of bajada formations suggests continued influence of tributary alluvial fan systems. The valley margins are characterized by highly dissected plateau and moderately dissected hills and valleys, providing structural control on the overall valley configuration while allowing for extensive floodplain development.

6.2.10. Polavaram to Bay of Bengal Stretch

The final stretch represents the deltaic and coastal zone of the Godavari River system. This reach is characterized by extensive deltaic plain formations, indicating active delta progradation and complex distributary channel systems. The coastal plain formations reflect the influence of marine processes and sea-level variations on river behavior.

The flood plain in this stretch transitions into deltaic and coastal environments, with complex interactions between fluvial, deltaic, and marine processes. The presence of alluvial plain formations continues, but these are increasingly influenced by deltaic sedimentation patterns and tidal processes. This stretch represents the ultimate sediment sink for the Godavari River system, with extensive accommodation space and complex depositional environments.

Geomorphological Synthesis

The geomorphic mapping of the Godavari River reveals a systematic downstream transition from structurally controlled erosional landscapes in the upper reaches to mature alluvial and deltaic systems in the lower reaches. The upstream stretches are characterized by narrow valleys, limited floodplain development, and dominance of dissected plateau landforms. The middle reaches exhibit increasing floodplain development, complex alluvial processes, and semi-confined valley settings. The lower reaches are dominated by extensive alluvial plains, deltaic formations, and minimal valley confinement.

This geomorphological diversity has important implications for river management, flood risk assessment, and ecological restoration initiatives. The variation in valley width and floodplain development across different stretches reflects the complex interplay between structural controls, climatic conditions, and fluvial processes that have shaped the Godavari River system over geological time scales.
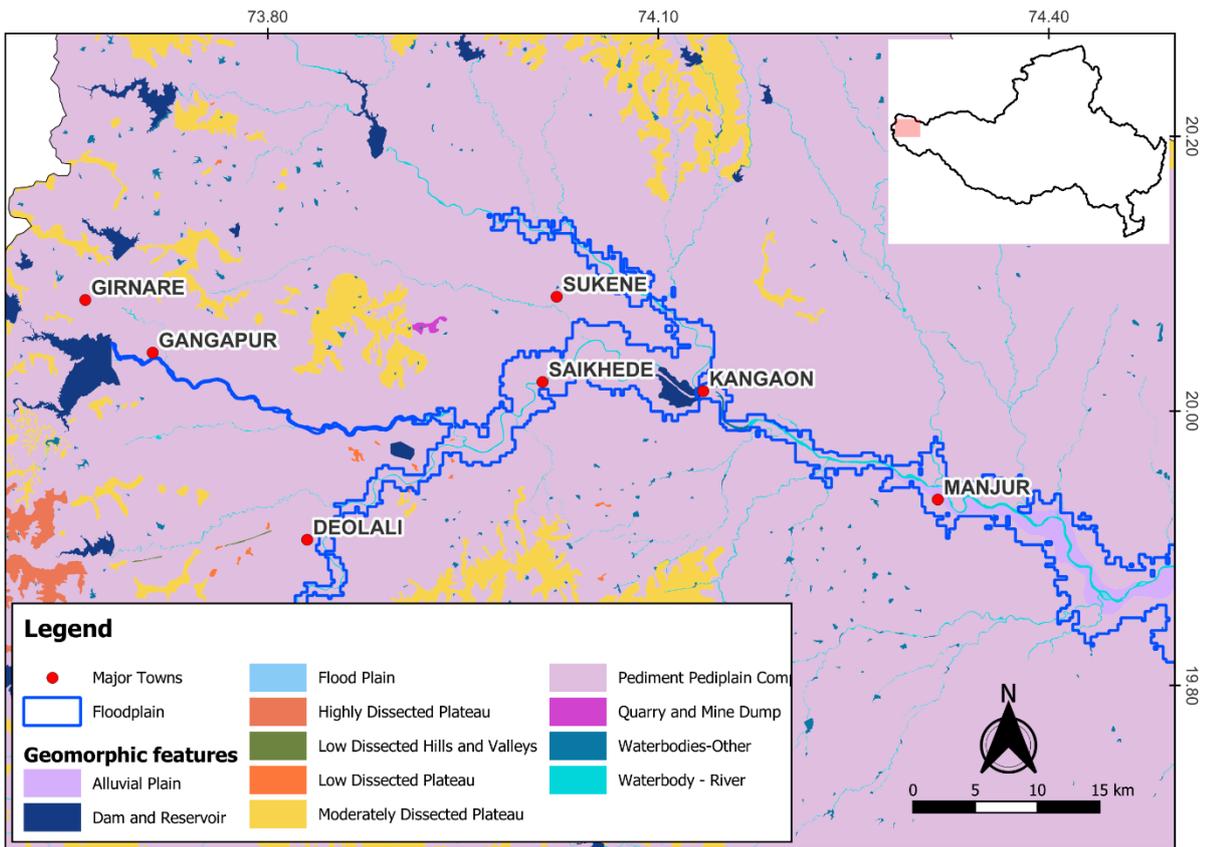
Figure 7 Geomorphic map of the Gangapur to Kumbhari
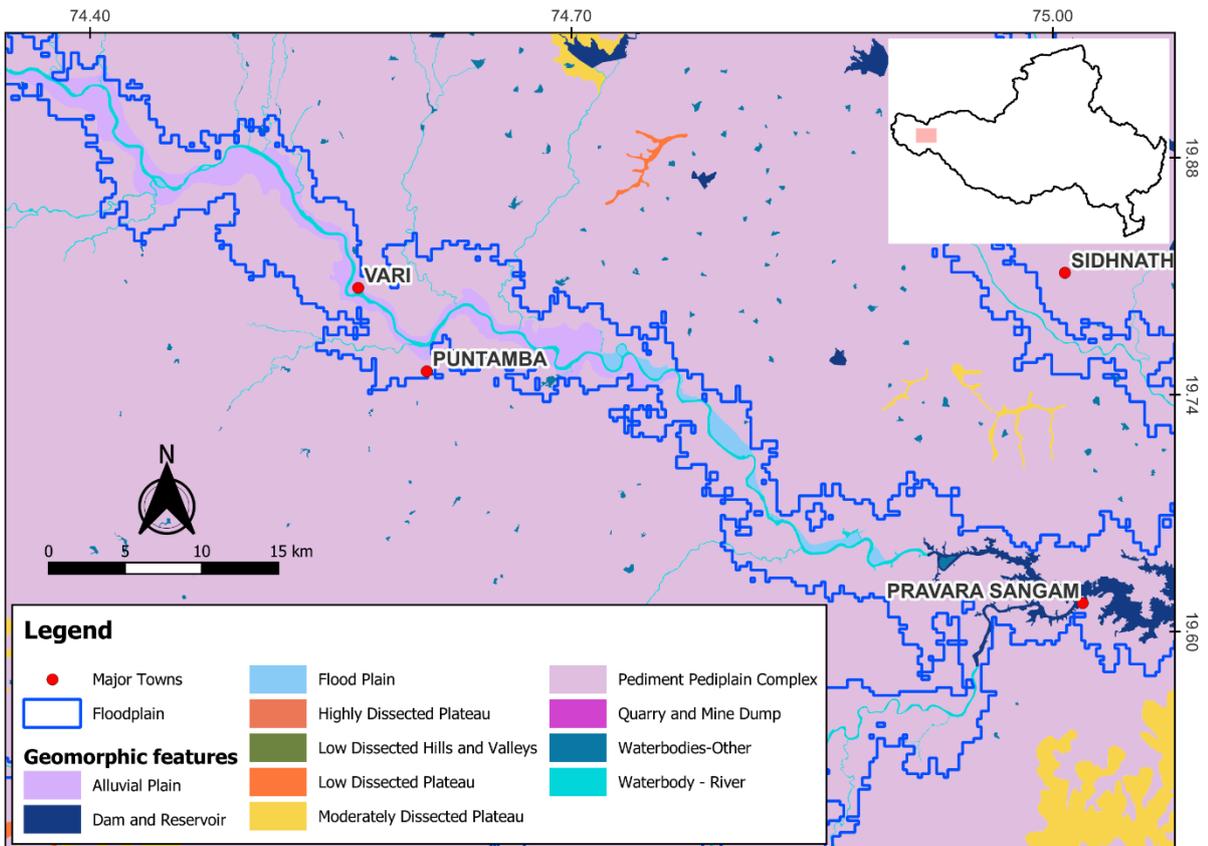

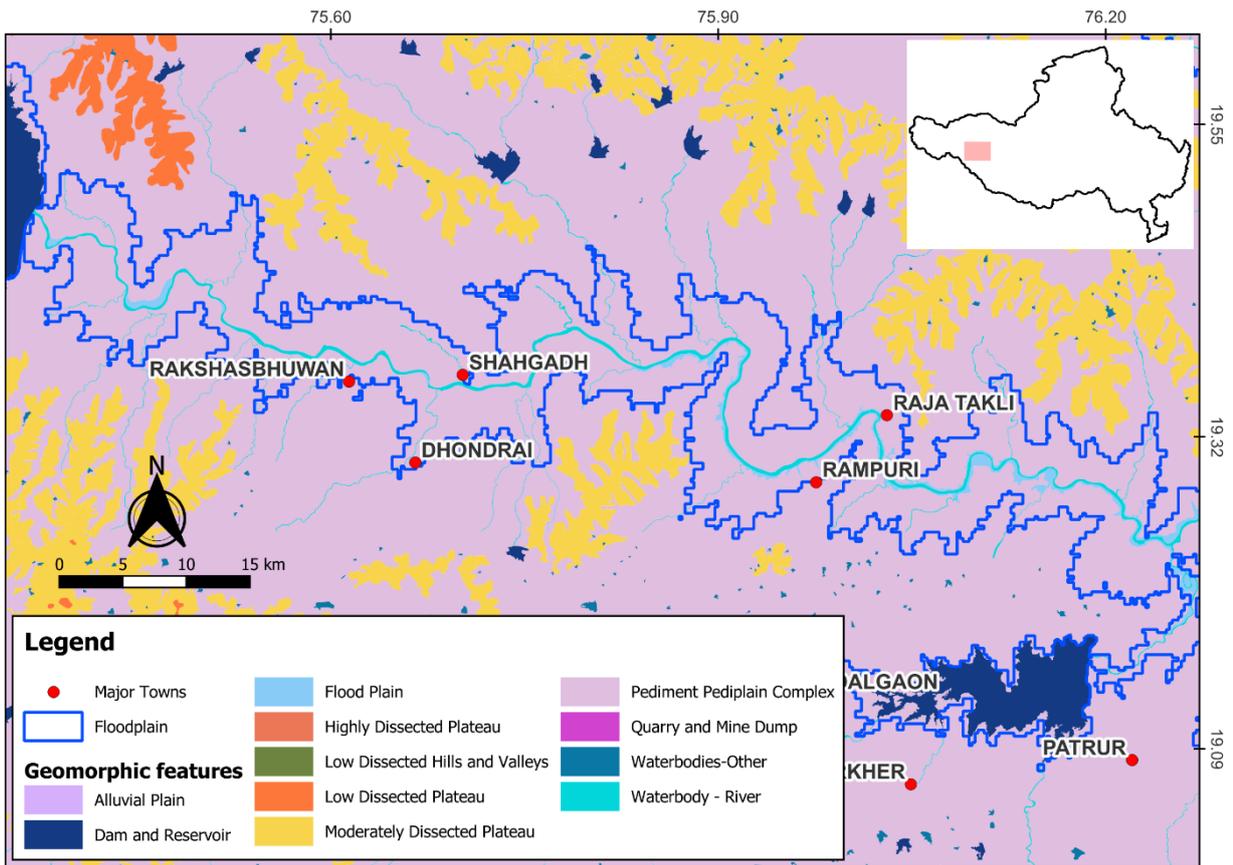Figure 8 Geomorphic map of the Kumbhari to Toka

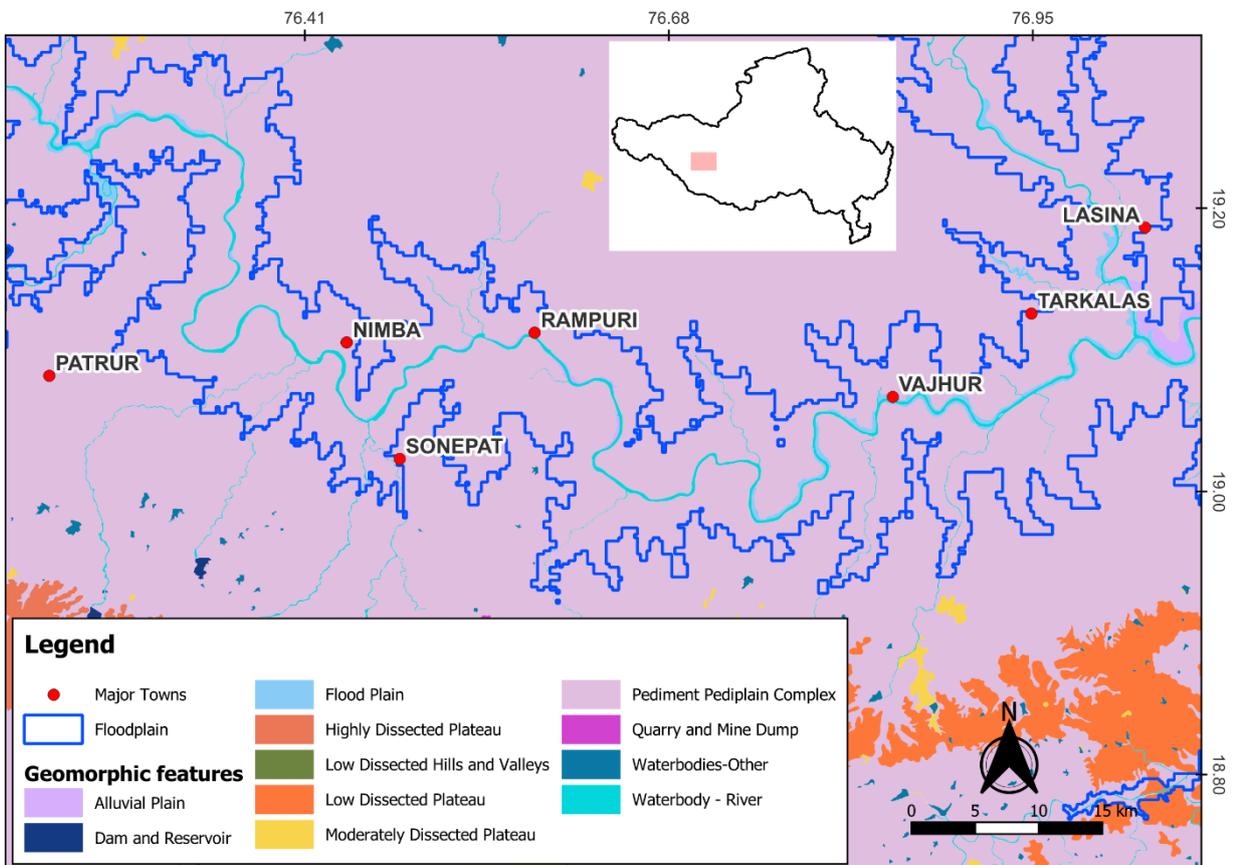Figure 9 Geomorphic map of the Paithan to Manjarath

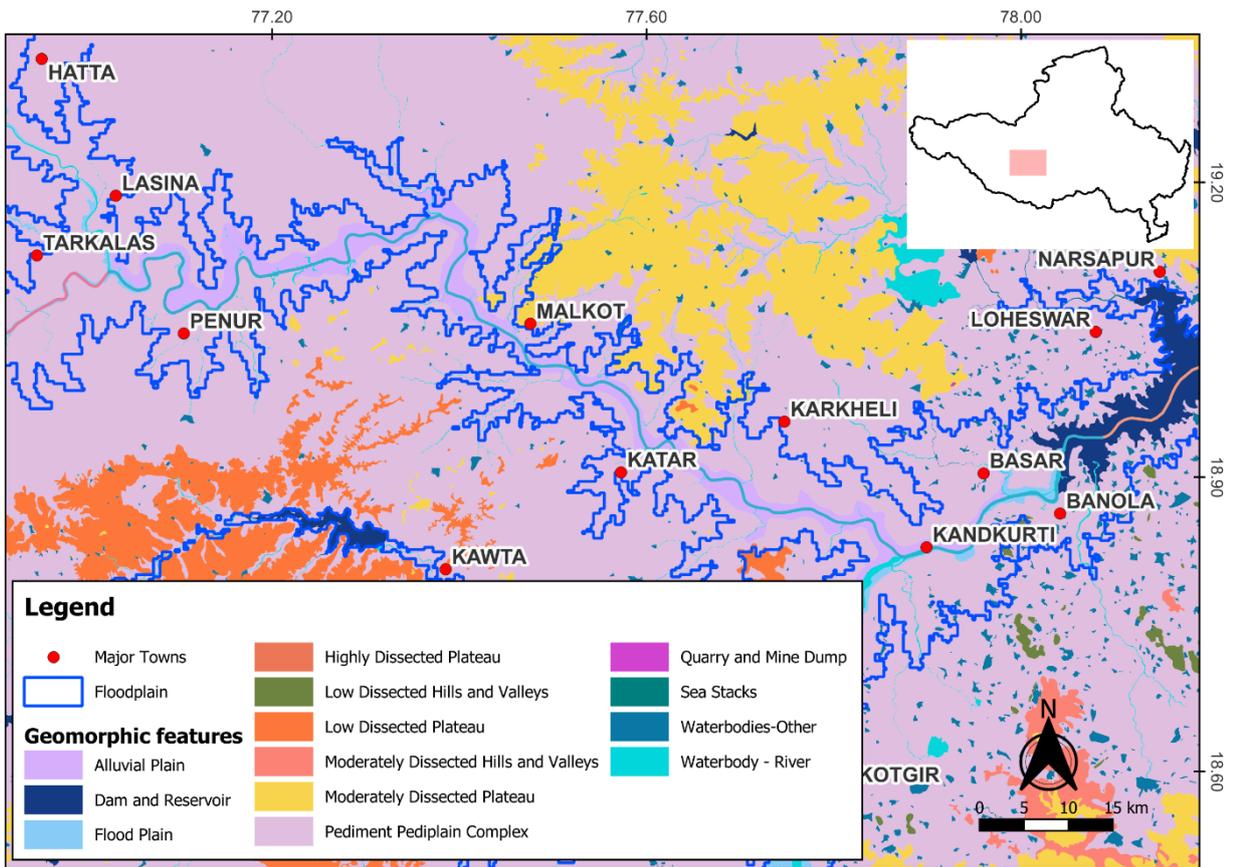Figure 10 Geomorphic map of the Manjarath to Barbadi

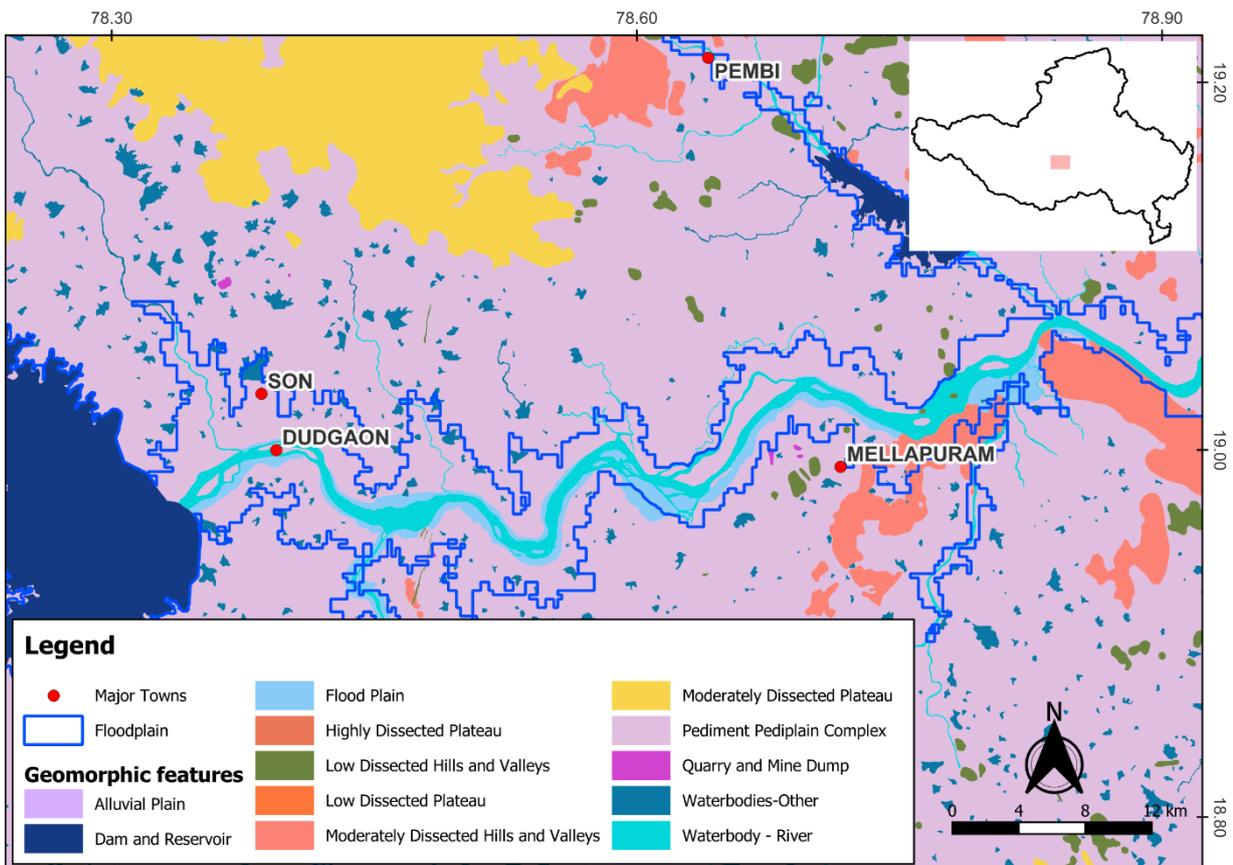Figure 11 Geomorphic map of the Barbadi To Panchgudi

Figure 12 Geomorphic map of the Soanpet to Bornapalle
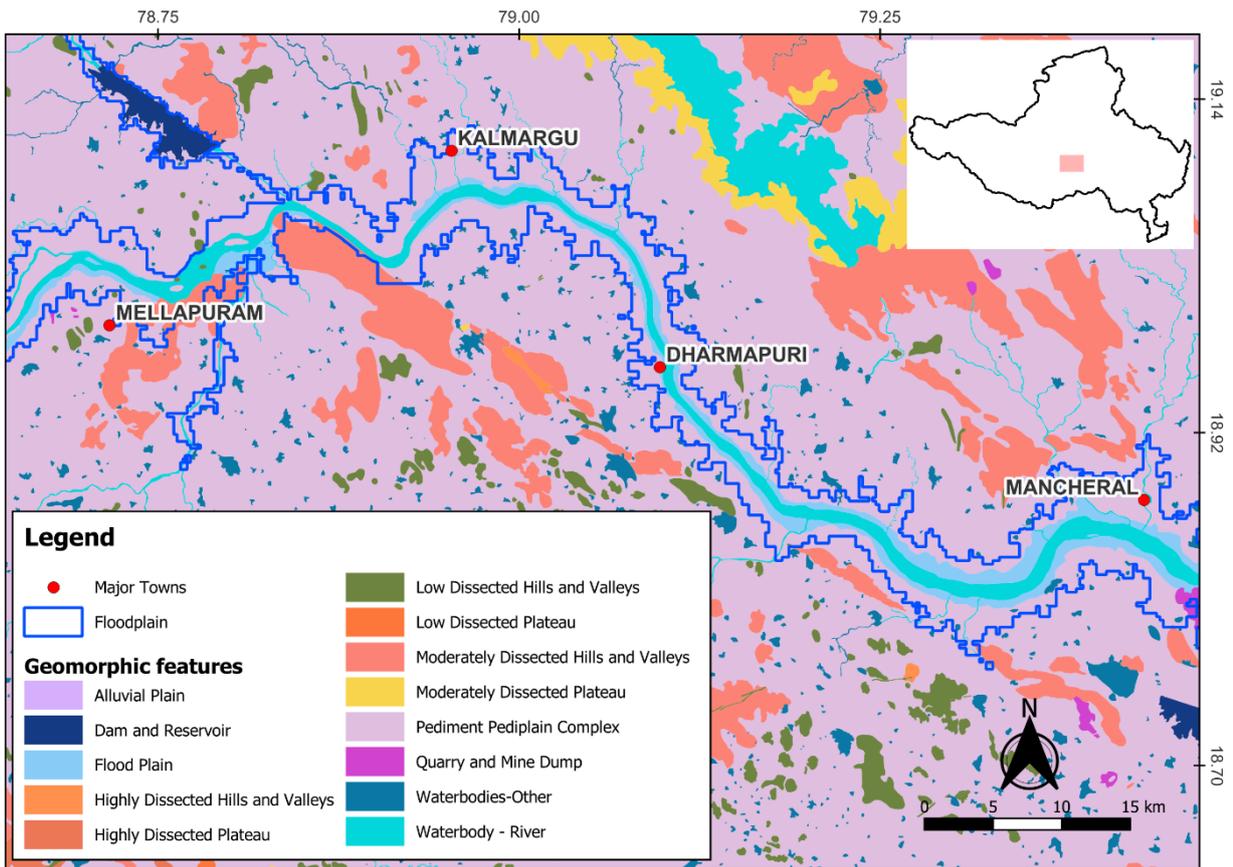
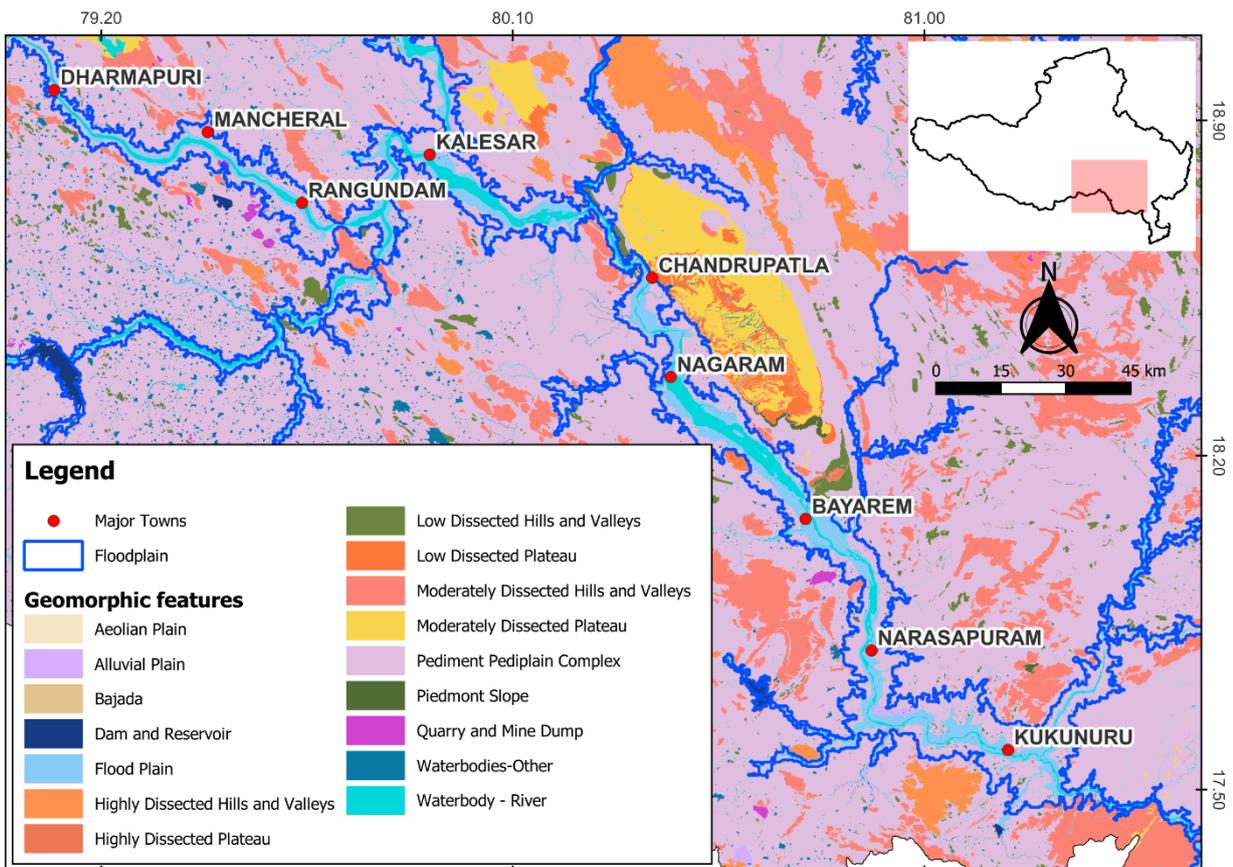Figure 13 Geomorphic map of the Bornapalle to Murmur

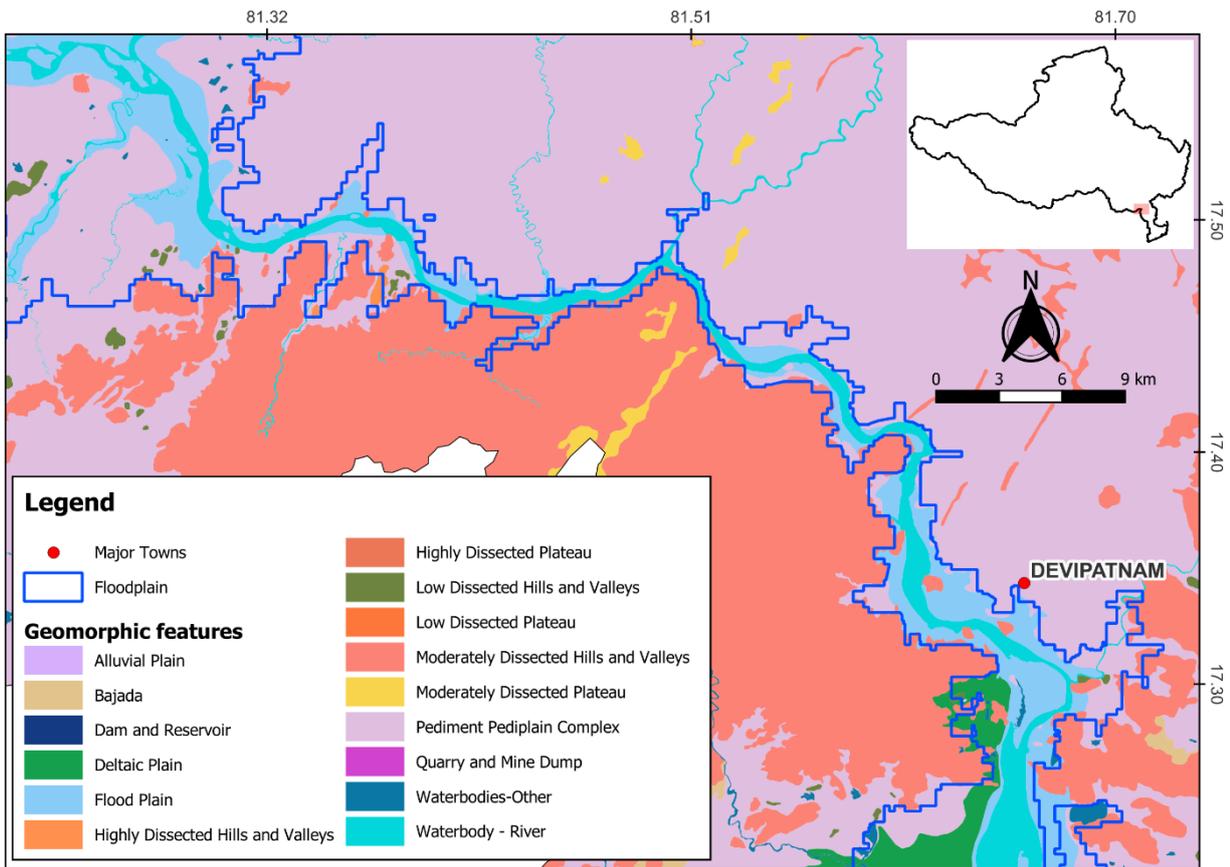Figure 14 Geomorphic map of the Murmur to Waddegudem

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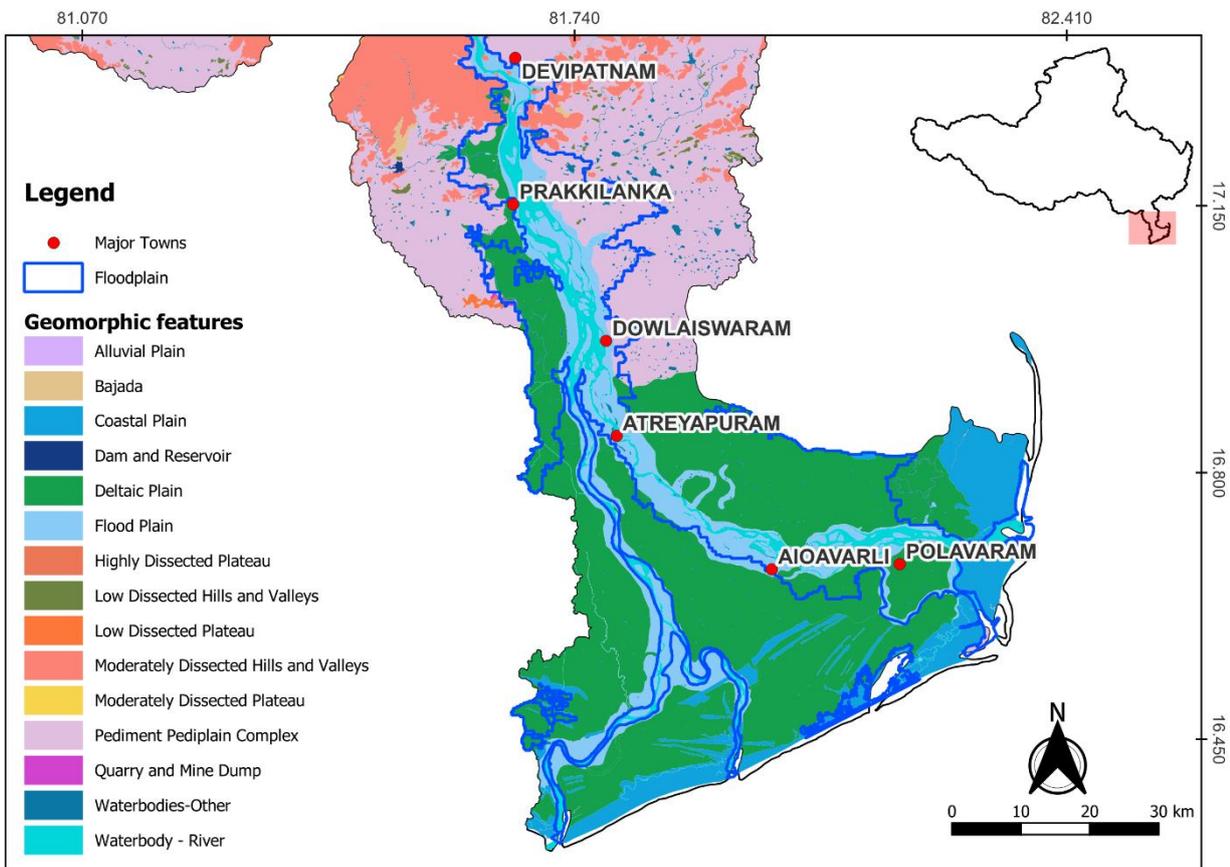Figure 15 Geomorphic map of the Waddegudem to Polavaram

Figure 16 Geomorphic map of the Polavaram to Bay of Bengal

7.   River Style Framework for the Godavari River

Based on the River Styles Framework methodology developed by Brierley and Fryirs, the Figure 17 shows following river style descriptions systematically characterize the diverse geomorphic settings, planform morphologies, and bed material compositions observed along the Godavari River system.
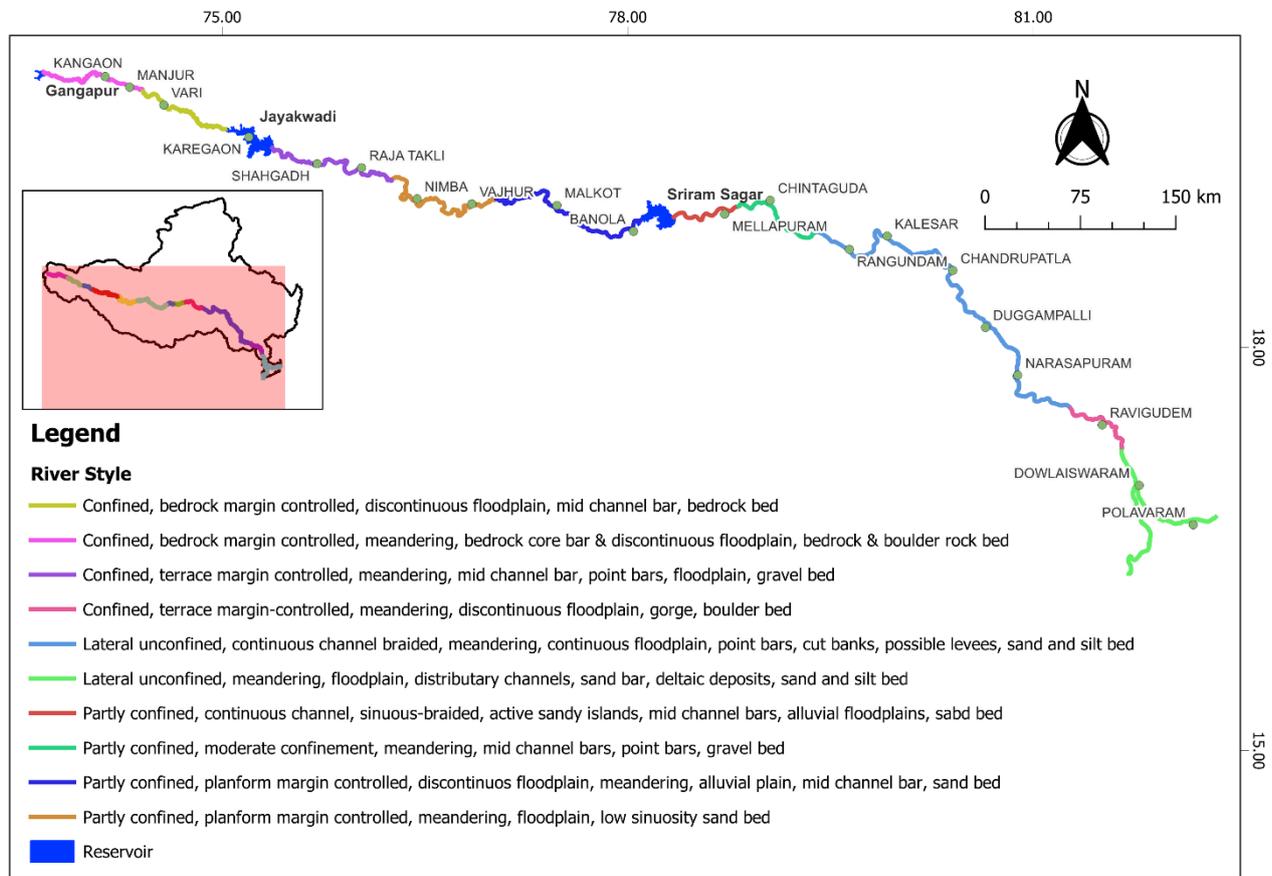

Figure 17 Distribution of River Styles in Godavari River from Gangapur to Bay of Bengal

River Style Classification Framework

The River Styles Framework employs a hierarchical approach to characterize river diversity through five key components: valley setting, degree of lateral confinement, river planform, geomorphic units, and bed material texture. Each river style name follows a structured naming convention that communicates the diagnostic geomorphic attributes of the river reach.

Style 1: Confined, Bedrock Margin Controlled, Meandering, Bedrock Core Bar & Discontinuous Floodplain, Bedrock & Boulder Rock Bed

This river style occurs in narrow valleys where the channel abuts bedrock valley margins along more than 85% of its length. The bedrock-controlled setting constrains lateral channel adjustment, creating a meandering planform that is structurally controlled rather than freely developing. Bedrock core bars form where resistant lithology creates fixed points around which flow is diverted, promoting localized scour and deposition. Discontinuous floodplain pockets develop in valley expansions behind bedrock spurs and at tributary confluences. The bed material composition reflects the local geological setting, dominated by bedrock substrates with boulder-sized clasts derived from mass wasting and weathering processes. This style typically occurs in the upper reaches of the Godavari system where the river cuts through the Western Ghats and Deccan Trap basalts.

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Style 2: Confined, Bedrock Margin Controlled, Discontinuous Floodplain, Mid Channel Bar, Bedrock Bed

This confined river style is characterized by persistent bedrock control along the valley margins, with the channel lacking a consistent meandering pattern due to structural constraints. Mid-channel bars form as temporary sediment accumulations during lower flow stages, typically composed of coarser material that cannot be transported under normal flow conditions. The discontinuous floodplain occurs as isolated pockets where valley geometry permits sediment accumulation. The bedrock bed indicates limited alluvial cover, with flow interacting directly with the underlying geological substrate. This style is common in gorge sections where the Godavari cuts through resistant rock formations.

Style 3: Partly Confined, Terrace Margin Controlled, Meandering, Mid Channel Bar, Point Bars, Floodplain, Gravel Bed

This river style occupies valleys where the channel abuts confining margins along 10-85% of its length. Terrace margins provide intermittent lateral constraint, allowing the development of a meandering planform with associated point bar formation on the inner bends of meanders. Mid-channel bars develop as flow splits around obstacles or during varying discharge conditions. The presence of both point bars and mid-channel bars indicates active sediment transport and deposition processes. Floodplain development occurs where valley geometry permits lateral channel adjustment. The gravel bed material suggests moderate to high-energy flow conditions with competency to transport medium to coarse sediment fractions.

Style 4: Partly Confined, Planform Margin Controlled, Meandering, Floodplain, Low Sinuosity Sand Bed

This style represents a planform-controlled river where channel adjustment is influenced by valley geometry rather than direct margin contact. The meandering pattern develops freely where space permits, but with lower sinuosity values indicating moderate lateral constraint. Continuous floodplain development occurs across the valley floor, reflecting more consistent lateral adjustment capacity compared to margin-controlled systems. The sand bed material indicates lower energy flow conditions and finer sediment supply, typical of middle reaches where transport capacity decreases and deposition become more prevalent.

Style 5: Partly Confined, Planform Margin Controlled, Discontinuous Floodplain, Meandering, Alluvial Plain, Mid Channel Bar, Sand Bed

This style occurs in settings where planform development is constrained by valley geometry and intermittent margin contact. The discontinuous floodplain indicates variable valley width and alternating zones of confinement and expansion. Alluvial plain development suggests broader valley floor areas with significant sediment accumulation. Mid-channel bars form during variable flow conditions, indicating active bedload transport and temporary storage. The sand bed composition reflects moderate energy conditions with fine to medium sediment transport. This style is characteristic of middle reaches where the Godavari transitions from confined mountain valleys to broader plains.

Style 6: Partly Confined, Continuous Channel, Sinuous-Braided, Active Sandy Islands, Mid Channel Bars, Alluvial Floodplains, Sand Bed

This transitional morphology combines elements of both sinuous and braided patterns, indicating variable flow conditions and sediment supply. The continuous channel maintains connectivity while developing multiple flow paths around sandy islands and mid-channel bars. Active sandy islands indicate frequent reworking during flood events, reflecting dynamic sediment transport processes. Alluvial floodplains suggest consistent lateral adjustment capacity and sediment deposition during overbank flows. The sand bed material composition indicates moderate energy conditions suitable for fine to medium sediment transport and storage.

Style 7: Partly Confined, Moderate Confinement, Meandering, Mid Channel Bars, Point Bars, Gravel Bed

This style represents intermediate confinement conditions where channel adjustment is partially constrained but allows meandering development. The combination of mid-channel bars and point bars indicates complex flow patterns with both central and lateral deposition zones. Point bars form on meander inner bends during lateral migration, while mid-channel bars develop from flow separation and sediment sorting processes. The gravel bed material suggests higher energy conditions than sand bed systems, indicating competency for coarse sediment transport during flood events.

Style 8: Lateral Unconfined, Continuous Channel Braided, Meandering, Continuous Floodplain, Point Bars, Cut Banks, Possible Levees, Sand and Silt Bed

This river style occurs where lateral confinement is minimal (less than 10% channel-margin contact), allowing maximum freedom for channel adjustment. The combination of braided and meandering characteristics indicates highly dynamic flow conditions with variable sediment transport capacity. Continuous floodplains extend across the valley floor, reflecting consistent overbank deposition and lateral channel mobility. Point bars and cut banks indicate active lateral migration processes, while levees suggest frequent overbank flooding and vertical accretion. The sand and silt bed material composition reflects lower energy conditions typical of larger alluvial rivers with significant fine sediment loads.

Style 9: Confined, Terrace Margin-Controlled, Meandering, Discontinuous Floodplain, Gorge, Boulder Bed

In this style, the channel is confined by terrace margins rather than bedrock valley walls, representing a different type of lateral constraint. The terraces may be either alluvial or strath terraces that act as confining features, limiting channel adjustment capacity. The meandering planform develops within these constraints, creating a sinuous channel pattern. Gorge characteristics indicate steep valley sides and narrow valley floors typical of incised river systems. The boulder bed material reflects high-energy flow conditions capable of transporting and depositing coarse sediment. Discontinuous floodplains form in valley expansions where terrace geometry permits.

Style 10: Lateral Unconfined, Meandering, Floodplain, Distributary Channels, Sand Bar, Deltaic Deposits, Sand and Silt Bed

This style characterizes the lower reaches approaching deltaic environments where the river system transitions to coastal deposition. The meandering pattern occurs within a broad alluvial plain with minimal lateral constraints. Distributary channels develop as the river approaches base level, creating multiple flow paths that distribute water and sediment across the coastal plain. Sand bars form as temporary sediment storage features during variable flow and tidal conditions. Deltaic deposits indicate the transition from riverine to marine depositional environments, with fine-grained sediment accumulation dominating the system. The sand and silt bed composition reflects low-energy conditions typical of deltaic environments where deposition exceeds erosion.

Geomorphic Process Implications

These river styles reflect the diverse geomorphic processes operating across the Godavari River system, from high-energy bedrock-controlled reaches in the Western Ghats to low-energy deltaic environments at the Bay of Bengal. The systematic variation in confinement, planform, and bed material composition demonstrates the river's adjustment to changing boundary conditions including geology, topography, sediment supply, and discharge variability.

The classification provides a framework for understanding sediment transport dynamics, channel stability, and flood behavior across different reaches of the Godavari system. Each river style exhibits characteristic responses to disturbance and has different implications for river management, habitat provision, and geomorphic evolution.

8. Application

The Godavari floodplain and geomorphology data can significantly benefit various. Here are ten major applications:

Risk Assessment and Management

- **Flood Hazard Mapping**: The GFPLAIN250m dataset supports accurate flood hazard mapping, helping authorities identify high-risk areas and plan for flood events effectively[4].
- **Disaster Management**: The information is crucial for developing disaster response strategies, allowing for better preparedness and mitigation of flood impacts[7].
- **Infrastructure Development**: Engineers can leverage this data to design resilient infrastructure that can withstand flooding, ensuring safety and longevity[7].

Planning and Development

- **Urban Planning**: Urban planners can utilize geomorphological data to design sustainable cities that minimize flood risks and enhance drainage systems[8].
- **Agricultural Planning**: Farmers and agricultural planners can use the data to optimize land use, crop selection, and irrigation practices based on flood risk assessments[4].
- **Policy Formulation**: Policymakers can base their decisions on comprehensive geomorphological analyses to create effective flood management policies[9].

Resource Management and Conservation

- **Water Resource Management**: The data assists in managing water resources efficiently, ensuring sustainable use while mitigating flood risks[8,7].
- **Habitat Restoration**: This data aids in the restoration of natural habitats by providing insights into floodplain dynamics and ecological requirements[4].
- **Environmental Monitoring**: Continuous monitoring of floodplain changes helps in assessing environmental impacts and implementing conservation strategies[4].

Research and Education

- **Research and Education**: The datasets serve as valuable resources for academic institutions and researchers studying geomorphology, hydrology, and environmental science[8,11].

These applications highlight the importance of integrating geospatial data into planning and management processes to enhance resilience against floods in India.

9.   Conclusion

The geomorphological mapping of the Godavari River Basin, conducted through advanced datasets such as FABDEM, Sentinel-1 GRD, Global Surface Water, Geomorphology and Floodplain Datasets, has provided critical insights into the river's dynamic landscape. The study successfully delineated valley margins across six distinct stretches, revealing a downstream widening trend influenced by sediment deposition, structural controls, and floodplain development. Key geomorphic features, including active floodplains, meandering channels, pediment-pediplain complexes, and deltaic systems, were mapped, highlighting the interplay of natural processes and anthropogenic interventions such as dams and reservoirs.

The integration of multi-source remote sensing data enabled precise identification of flood-prone zones, seasonal inundation patterns, and erosional-depositional dynamics. These findings underscore the Godavari Basin's vulnerability to climate extremes, as evidenced by historical flood events, and emphasize the need for updated floodplain management strategies. The GFPLAIN250m dataset proved instrumental in risk assessment, disaster preparedness, and sustainable land-use planning, though limitations in resolution and elevation accuracy call for complementary datasets like LiDAR for localized refinement.

By bridging geospatial analysis with practical applications—from resilient infrastructure design to habitat restoration—this study advocates for the integration of geomorphological insights into policy frameworks. Collaborative stakeholder engagement, probabilistic flood modeling, and continuous monitoring are essential to address evolving environmental challenges. This report serves as a foundational resource for fostering resilience, ecological preservation, and informed decision-making in the Godavari Basin, ensuring the river's sustainability for future generations.

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