

Google Map Based Morphodynamics Analysis of Selected Reaches of the Teesta River

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Abstract

Understanding spatial and temporal variability of river morphodynamics is essential for sustainable river management, particularly in highly dynamic alluvial rivers. The present study investigates zone-wise morphodynamic behavior of a 6.42 km reach of the Teesta River using multi-temporal Google Earth Pro imagery and secondary hydrological data. The study reach was divided into three zones based on changes in plane form characteristics and channel behavior. Zone-wise analyses of river width, longitudinal slope, stream power, specific stream power, bank migration, and erosion–deposition dynamics were carried out for the periods 2011–2016, 2016–2021, and 2021–2025. Bank line positions were manually digitized to quantify lateral migration, while erosion and deposition areas were delineated using polygon overlay techniques. Stream power and specific stream power were estimated using representative discharge values and zone-wise slope and width measurements. Results indicate pronounced spatial variability in morphodynamic processes along the study reach. Zone 2 exhibits the highest stream power and bank migration rates, corresponding to dominant erosion, whereas Zone 3 shows relatively lower energy conditions with localized deposition. Temporal analysis reveals increasing bank instability in recent years, particularly in the middle reach. The study demonstrates the effectiveness of Google Earth Pro as a low-cost tool for river morphodynamic assessment and provides valuable insights for riverbank management and planning in braided river systems.

Keywords: Teesta River, River Morphodynamics, Bank Migration, Stream Power, Erosion–Deposition, Google Earth Pro.

1. Introduction

Rivers are dynamic geomorphic systems that continuously modify their planform, cross-sectional geometry, and longitudinal profile in response to variations in water discharge, sediment supply, and boundary conditions. These morphodynamic adjustments control critical processes such as bank erosion, channel migration, bar formation, and floodplain development. Understanding river morphodynamics is therefore essential for effective river management, flood hazard mitigation, infrastructure planning, and sustainable utilization of floodplain areas, particularly in large alluvial river systems.

In the Himalayan foreland region of India, rivers draining the Himalayas are characterized by high sediment loads, braided channel patterns, rapid lateral migration, and frequent avulsion. The Teesta River, a major tributary of the Brahmaputra River, exemplifies such highly dynamic behavior. Originating in the eastern Himalayas, the Teesta River undergoes significant morphological transformations after entering the alluvial plains, resulting in severe bank erosion, loss of agricultural land, displacement of settlements, and damage to critical infrastructure. These issues are particularly pronounced in the lower reaches of the river, where channel instability poses persistent socio-economic and environmental challenges.

Previous studies on the Teesta River have largely focused on hydrological characteristics, sediment transport, and large-scale channel pattern changes. However, detailed reach-scale investigations integrating longitudinal slope variability, river width variation, stream power estimation, temporal bank migration, and erosion–deposition dynamics remain limited. Moreover, the potential of freely available high-resolution satellite imagery and tools such as Google Earth Pro for systematic, zone-wise morphodynamic analysis has not been fully explored, despite their increasing reliability and accessibility for geomorphological research.

In this context, the present study aims to conduct a comprehensive geospatial analysis of river morphodynamics along a selected reach of the Teesta River using multi-temporal satellite imagery and Google Earth Pro. The specific objectives of the study are to:

1. Delineate the study reach into distinct geomorphic zones based on channel characteristics.
2. Analyze zone-wise longitudinal slope variability using elevation profile data.
3. Estimate zone-wise average river width and examine spatial width variation along the reach.
4. Compute zone-wise stream power and specific stream power using representative discharge values.
5. Quantify temporal river bank migration and identify erosion-prone and deposition-prone zones.
6. Assess zone-wise land loss (erosion) and land gain (deposition) over the study period.

2. Literature Review

Braided rivers are highly dynamic fluvial systems characterized by multiple channels separated by bars and islands. These rivers commonly occur in regions with high sediment supply, variable discharge, and erodible banks. The morphology and evolution of braided rivers are strongly influenced by the balance between water discharge, sediment load, and channel slope. According to Bagnold (1966), stream power plays a critical role in controlling sediment transport and channel morphology in alluvial rivers [1]. Higher stream power increases the river's ability to erode banks and transport sediment downstream.

Several researchers have investigated the morphodynamic behavior of braided rivers in the Himalayan foreland. Ashmore (1991) explained that braided channel patterns develop where sediment supply exceeds the transport capacity of the river, leading to the formation of mid-channel bars and multiple flow paths [2]. Similarly Knighton (1998) further emphasized that variations in channel slope, discharge, and sediment characteristics strongly influence river planform and channel stability [3].

Remote sensing techniques have become an effective tool for analyzing river morphodynamics. Hooke (2003) demonstrated that satellite imagery can be used to identify bank erosion, channel migration, and sediment deposition patterns over time [4]. With the availability of high-resolution satellite imagery, tools such as Google Earth Pro allow detailed monitoring of river channel changes and bank migration processes.

In Himalayan rivers such as the Teesta and Brahmaputra, rapid lateral migration and severe bank erosion are common due to high sediment load and monsoonal discharge variability. Therefore, understanding spatial variations in stream power, channel width, and bank migration is essential for river management and floodplain planning.

3. Study Area and Data

The present study focuses on a selected 6.42 km long reach of the Teesta River located in the alluvial plains downstream of the Himalayan foothills. The study reach extends from an upstream point at Chainage 0.00 km to a downstream point at Chainage 6.42 km. Geographically, the reach lies downstream of Teesta National Highway Bridge within the Jalpaiguri district of West Bengal, India, and is characterized by a wide, braided channel with multiple sand bars and actively migrating banks.

Based on observable changes in channel pattern, width, and slope, the study reach was divided into three geomorphic zones. Zone 1 extends from Chainage 0.00 km to 2.30 km, Zone 2 from 2.30 km to 4.80 km, and Zone 3 from 4.80 km to 6.42 km. This zonation facilitates a comparative assessment of morphodynamic behavior along the river course.

The primary datasets used in this study include high-resolution satellite images available in Google Earth Pro for multiple years (2011, 2016, 2021, and 2025). These images were used for bankline digitization, river width measurement, and erosion–deposition analysis. Longitudinal elevation data were extracted using the “Show Elevation Profile” tool along the digitized river centerline. Discharge data were obtained from published secondary sources and converted into SI units for consistency in hydraulic calculations.

4. Methodology

4.1 River Zonation and Centerline Digitization

The river centerline was digitized along the mid-channel using **Google Earth Pro** to extract longitudinal elevation data and establish chainage reference points. Zone boundaries were marked based on observable geomorphic changes and distance along the river. In braided reaches of the Teesta River, multiple flow channels are present. For the present study, analysis was restricted to the dominant main channel, as it conveys the majority of discharge and controls river morphology, erosion, and stream power. Minor anabranches and seasonal channels were excluded to maintain consistency in zone-wise comparison.

Zone–1: Upper / High-Energy Confined Reach

Chainage: 0 – ~2.3 km. The longitudinal elevation profile shows noticeable undulations and relatively higher slope compared to downstream reaches. The channel is relatively straight to mildly sinuous with limited bar development. The channel remains comparatively narrow and confined. This reach is dominated by erosion and sediment transport due to higher stream energy. Zone-1 represents an upstream, high-energy confined reach dominated by erosional and transport processes.

Zone–2: Transitional / Adjustment Reach

Chainage: ~2.3 – ~4.8 km. The elevation profile becomes nearly flat, indicating a significant reduction in slope. The channel exhibits transitional behavior from straight to mildly sinuous. Emergence of mid-channel and point bars is observed along with a gradual increase in channel width. Both sediment transport and deposition processes are active, indicating channel adjustment. Zone-2 represents a transitional reach where the river adjusts its geometry in response to reduced slope and changing sediment dynamics.

Zone–3: Downstream / Floodplain Depositional Reach

Chainage: ~4.8 – 6.42 km. This reach is characterized by very low slope with minor elevation fluctuations. The channel becomes more sinuous and locally braided with well-developed mid-channel and lateral bars. The channel is wide with significant floodplain interaction. Deposition and lateral migration dominate, making this reach flood-prone. Zone-3 represents a downstream floodplain reach dominated by depositional processes and lateral channel movement.

4.2 Longitudinal Slope Analysis

A longitudinal elevation profile was generated along the digitized centerline using Google Earth Pro. Average slope for each zone was calculated using the relationship:

$$\text{Average Slope} = \frac{\Delta \text{Elevation}}{\text{Length of Zone}}$$

where Δ Elevation represents the difference between upstream and downstream elevations of each zone.

4.3 Zone-wise River Width Measurement

River width was measured as bank-to-bank distance using the ruler tool in Google Earth Pro. Multiple cross-sections perpendicular to the flow direction were drawn within each zone, and the average width was computed for each zone.

4.4 Stream Power and Specific Stream Power Estimation

Stream power (Ω) was estimated using the standard equation:

$$\Omega = \rho g Q S$$

$$\omega = \frac{\Omega}{\text{Average Width (B) of the Channel}}$$

Where ρ is the density of water, g is acceleration due to gravity, Q is discharge, and S is channel slope. Specific stream power (ω) was calculated by dividing stream power by average channel width.

4.5 Bank Migration Analysis

Left bank lines were digitized for the years 2011, 2016, 2021, and 2025. Bank migration distances were measured at fixed locations within each zone, and average migration rates were computed for successive time intervals.

4.6 Land Loss and Land Gain Analysis

Erosion (land loss) and deposition (land gain) areas were calculated by overlaying bank lines from successive years and measuring polygon areas corresponding to eroded and deposited regions within each zone.

5. Source of Discharge Data

Discharge data for the Teesta River were obtained from published secondary sources. The original discharge values were reported in **cusecs (ft³/s)**. For consistency with SI units used in river engineering analysis, all values were converted to **cumecs (m³/s)**.

5.1 Unit Conversion Used

1 cusec = 0.02832 cumec

5.2 Period of Data Used

The discharge characteristics correspond to the period between **1970 and 1999**, observed at the **Dalia gauging station** on the Teesta River.

5.3 Peak and Mean Discharge Values (Converted)

Description	Original Value (cusec)	Converted value (cumec)
Average monsoon discharge (Jun–Sep)	1800	50.98
Average dry season discharge	200	5.66
Lowest flow (February)	160	4.53
Minimum monsoon discharge (1979)	71.73	2.03
Maximum discharge (1999)	1825.86	51.72
Maximum dry season discharge	158.49	4.49
Minimum dry season discharge	5.36	0.15

5.4 Justification for Using Secondary Data

The use of secondary discharge data is justified due to the absence of direct field measurements, time and resource constraints of the mini project, and the reliability of published hydrological studies. Converted SI-unit discharge values are suitable for zone-wise river width analysis, stream power estimation, and future hydraulic modeling.

6. Results

6.1 Longitudinal Slope Variation

The longitudinal profile indicates an overall downstream reduction in elevation from approximately 111 m to 97 m above mean sea level, indicating an overall elevation fall of about 14 m along the reach with overall slope 0.00218. Zone 1 exhibits the highest average slope, followed by Zone 2, while Zone 3 shows the lowest slope, reflecting decreasing stream energy downstream.

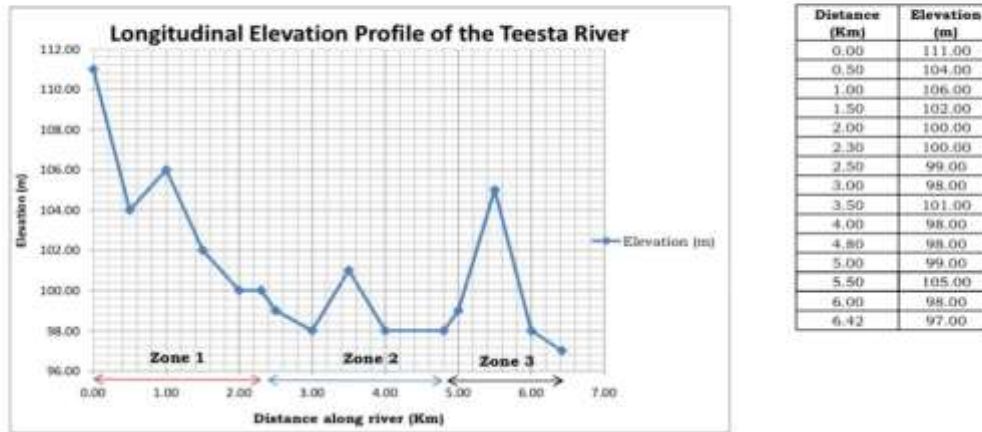


Figure 1: Longitudinal elevation profile of the Teesta River showing variation of bed elevation along the study reach and division into three morphodynamics zones (Zone 1: Upstream high-energy reach, Zone 2: Transition reach, Zone 3: Downstream depositional reach)

Zone-1: Upstream / High-Energy Reach

Chainage: 0 – 2.3 km. Length: 2.3 km (2300 m). Upstream elevation is 111 m; downstream elevation is 100 m. Elevation = 11 m. Average slope = $11 / 2300 = 0.0048$ (0.48%). This zone exhibits the highest slope and is dominated by erosion and sediment transport processes.

Zone-2: Transitional / Adjustment Reach

Chainage: 2.3 – 4.8 km. Length: 2.5 km (2500 m). Upstream elevation 100.00 m; downstream elevation is 98.00 m. Elevation = 2 m. Average slope = $2 / 2500 = 0.0008$ (0.08%). This zone represents a transitional reach with both sediment transport and deposition.

Zone-3: Downstream / Floodplain Reach

Chainage: 4.8 – 6.42 km. Length: 1.62 km (1620 m). Upstream elevation is 98.00 m; downstream elevation is 97.00 m. DElevation = 1 m. Average slope = $1 / 1620 = 0.0006$ (0.06%). This zone has the lowest slope and is dominated by depositional processes and lateral migration.

Comparison of Zone Wise Slopes:

Zone	Length (Km)	Elevation Drop (m)	Average Slope
Zone-1	2.3	11	0.0048
Zone-2	2.5	2	0.0008
Zone-3	1.62	1	0.0006

6.2 Influence of Slope on River Behavior:

The progressive downstream reduction in slope strongly controls river behavior along the study reach. The higher slope in Zone-1 results in higher flow velocity and dominant erosion. Zone-2 exhibits reduced slope leading to channel adjustment and partial deposition. Zone-3, characterized by very low slope, promotes deposition, bar formation, floodplain interaction, and lateral migration of the channel.

6.3 Zone-wise River Width Variation

Zone 2 records the highest average river width, indicating a highly braided and laterally unstable channel. Zone 1 remains relatively confined, whereas Zone 3 shows moderate width reduction, suggesting partial stabilization.

The river width was measured as bank-to-bank distance using the Ruler (Line) tool in Google Earth Pro. Multiple cross-sections were drawn perpendicular to the river flow direction in each zone and the average width for each zone was computed.

Zone-wise Average River Width

Zone-1: 1756 m

Zone-2: 2088 m

Zone-3: 1912 m

6.4 Stream Power Characteristics

Zone 1 exhibits the highest stream power due to steeper slope, while Zone 2 shows elevated specific stream power associated with wider channel and active lateral erosion. Zone 3 records comparatively lower energy conditions.

Formula Used for Stream Power

$$P = \rho g Q S$$

$$P = \rho g / B$$

Input Data

Discharge (Q) = 50.98 m³/s

Density of water = 1000 kg/m³

Gravity = 9.81 m/s²

Zone-wise Parameters

Zone-1: S = 0.0048, Width = 1756 m

Zone-2: S = 0.0008, Width = 2088 m

Zone-3: S = 0.0006, Width = 1912 m

Zone-wise Stream Power Calculations

Zone-1

$$P = 1000 \times 9.81 \times 50.98 \times 0.0048 = 2401 \text{ W}$$

$$P = 2401 / 1756 = 1.37 \text{ W/m}$$

Zone-2

$$P = 1000 \times 9.81 \times 50.98 \times 0.0008 = 400 \text{ W}$$

$$P = 400 / 2088 = 0.19 \text{ W/m}$$

Zone-3

$$\square = 1000 \times 9.81 \times 50.98 \times 0.0006 = 300 \text{ W}$$

$$\square = 300 / 1912 = 0.16 \text{ W/m}$$

6.5 Engineering Implications

Stream power decreases downstream, explaining erosion upstream and deposition downstream.

6.6 Bank Migration and Erosion–Deposition Patterns

Classification Criteria for Bank Migration:

Bank migration intensity was classified based on the average lateral shift observed during each 5-year interval: **Low Migration:** < 25 m – Relatively stable bank conditions **Moderate Migration:** 25–75 m – Active but controlled lateral movement, **High Migration:** 75–150 m Significant erosion and channel instability **Very High Migration:** > 150 m – Severe bank erosion and channel shifting.

Zone	Period	Average Migration (m)	Migration Class	Dominant Process
Zone 1	2011-16	96.00	High	Active Erosion
Zone 1	2016-21	55.60	Moderate	Reduced Erosion
Zone 1	2021-25	53.80	Moderate	Reduced Erosion
Zone 2	2011-16	119.00	High	Severe bank Erosion
Zone 2	2016-21	202.20	Very High	Extreme Instability
Zone 2	2021-25	61.60	Moderate	Channel Adjustment
Zone 3	2011-16	48.60	Moderate	Local Erosion
Zone 3	2016-21	11.40	Low	Stable bank
Zone 3	2021-25	34.60	Moderate	Renewed adjustment

Key Observations

Zone 2 exhibits the highest bank migration, confirming it as the most erosion-prone and unstable reach. Maximum migration occurred during 2016–2021, possibly linked to high-magnitude flood events. Zone 1 shows a declining migration trend, indicating gradual bank stabilization. Zone 3 remains comparatively stable, with only localized and episodic bank shifts. The spatial variation in migration reflects the influence of channel slope, width, and stream power.

6.7 Land Loss and Land Gain Analysis

Land loss (erosion) and land gain (deposition) were quantified zone-wise using bankline polygons digitized from multi-temporal Google Earth Pro imagery (2011, 2016, 2021, and 2025). Area calculations were performed for each 5-year interval.

Classification Criteria

Net land change was classified based on the difference between land gain and land loss:

- Net change > 0: Deposition-dominated
- Net change < 0: Erosion-dominated
- |Net change| < 10,000 m²: Stable / Minor change

Zone	Period	Land Loss (m ²)	Land Gain (m ²)	Nature
Zone 1	2011-16	213022	2309	Severe Erosion
Zone 2	2016-21	19823	122994	Deposition Dominated
Zone 3	2021-25	104222	33	High Erosion
Zone 1	2011-16	7780	416488	Strong Deposition
Zone 2	2016-21	608228	2155	Extreme Erosion

Zone 3	2021-25	111307	14696	High Erosion
Zone 1	2011-16	28835	479	Moderate Erosion
Zone 2	2016-21	6795	23167	Moderate Deposition
Zone 3	2021-25	31973	40997	Net Deposition

Key Observations

- Zone 2 experienced the highest land loss during 2016–2021, indicating extreme channel instability.
- Deposition dominated Zone 2 during 2011–2016, reflecting bar formation and channel shifting.
- Zone 1 shows alternating erosion and deposition, indicating an adjustment reach.
- Zone 3 exhibits comparatively stable behavior with localized deposition in recent years.

7. Morphodynamics Interpretation

7.1 Morphodynamic Interpretation of the Study Reach

The zone-wise analysis of slope, channel width, and stream power provides important insights into the morphodynamic behavior of the Teesta River along the study reach.

Zone-1 represents an upstream high-energy reach characterized by relatively steep channel slope and comparatively confined channel width. The higher slope results in increased stream power and flow velocity, promoting active erosion and sediment transport. As a result, this reach is dominated by erosional processes with limited bar development.

Zone-2 represents a transitional adjustment reach where channel slope decreases and channel width increases significantly. The reduction in slope reduces flow energy, while the wider channel promotes lateral instability and bar formation. The presence of mid-channel bars and high bank migration rates indicates that this reach experiences active channel adjustment and morphological instability. The highest bank migration values observed in this zone confirm that Zone-2 is the most dynamic segment of the study reach.

Zone-3 represents a downstream floodplain reach characterized by very low channel slope and relatively wider floodplain interaction. In this reach, stream power decreases significantly, resulting in reduced transport capacity and increased sediment deposition. As a result, deposition processes dominate and the channel exhibits moderate lateral migration with localized bar formation.

Overall, the downstream reduction in channel slope leads to a gradual decrease in stream power, which explains the transition from erosion-dominated processes in the upstream reach to deposition-dominated processes in the downstream reach.

8. Implications for River Management

The results of the present study have important implications for river management and floodplain planning in the Teesta River basin. The identification of Zone-2 as the most morphodynamically unstable reach indicates that this segment of the river is highly susceptible to bank erosion and channel migration. Therefore, priority attention should be given to this reach for riverbank protection measures and continuous monitoring.

The analysis also demonstrates the usefulness of multi-temporal satellite imagery for monitoring river channel changes. Regular monitoring using satellite data can help identify erosion-prone zones and support early planning of river training measures.

In addition, the study highlights the importance of considering channel slope, stream power, and bank migration patterns while planning infrastructure such as bridges, embankments, and flood protection structures along the river. Understanding these morphodynamic processes can significantly improve river management strategies and reduce flood-related risks in vulnerable floodplain regions.

9. Conclusions

This study presents a comprehensive zone-wise morphodynamic assessment of a selected reach of the Teesta River using multi-temporal satellite imagery and secondary hydrological data. The integration of river width variation, longitudinal slope, stream power, bank migration, and land loss-gain analysis provides a holistic understanding of channel behavior.

The results highlight significant spatial heterogeneity along the study reach. Zone 2 emerges as the most morphodynamically active segment, characterized by higher stream power, greater bank migration distances, and dominant erosion. Zone 1 shows moderate instability with alternating erosion and deposition, while Zone 3 exhibits comparatively stable behavior with localized depositional features. Temporal analysis indicates that erosion processes have intensified in recent years, suggesting increasing channel instability.

The present study highlights the effectiveness of integrating remote sensing tools with basic hydraulic parameters for understanding river morphodynamics in data-scarce regions. The use of freely available satellite imagery and geospatial techniques provides a practical and cost-effective approach for monitoring river channel instability and bank erosion in large alluvial rivers. Such reach-scale morphodynamic assessments can support better river management, floodplain planning, and identification of erosion-prone zones requiring priority intervention.

10. Limitations of the Study

10.1 Limitations and Uncertainty

Although the study provides useful insights into the morphodynamic behavior of the Teesta River, certain limitations should be acknowledged. The analysis is based primarily on satellite imagery obtained from Google Earth Pro, and therefore the accuracy of elevation and positional measurements may be affected by the resolution of the available imagery. In addition, bankline digitization was performed manually, which may introduce minor positional errors.

The discharge data used in the stream power calculations were obtained from secondary sources rather than direct field measurements. Seasonal variations in discharge and sediment load were also not explicitly considered in the analysis. Future studies incorporating detailed field measurements, hydraulic modeling, and higher-resolution remote sensing data could further improve the accuracy and reliability of morphodynamic assessments.



Figure 2: Longitudinal profile and planform of the selected Teesta River reach showing elevation variation, channel alignment, and zonation into three morphodynamic reaches (Zone 1, Zone 2, Zone 3) based on slope characteristics.



Figure 3: Temporal variation of left bank line positions of the Teesta River for the years 2011, 2016, 2021, and 2025, showing lateral channel migration and zone-wise bank erosion patterns along the study reach. Source: Google Earth Pro (Imagery: 2011, 2016, 2021, 2025)



Figure 4: Study area location map of the selected Teesta River reach showing the centerline alignment, chainage from 0.00 km to 6.42 km, and key reference points including starting and ending locations used for morphodynamic analysis.

Source: Google Earth Pro (2025)

Note: Red indicates erosion-prone areas, while green indicates zones of sediment deposition.



Figure 5: Zone division map of the selected Teesta River reach showing classification into three morphodynamic zones (Zone 1, Zone 2, and Zone 3) based on variations in channel geometry, slope, and geomorphic characteristics.

Source: Google Earth Pro (2025)

Note: Red indicates erosion-prone areas, while green indicates zones of sediment deposition.



Figure 6: Spatial distribution of erosion (bank retreat) and deposition (bar formation) zones along the Teesta River reach derived from overlay analysis of bank line positions between 2011 and 2016.

Source: Google Earth Pro (Imagery: 2011 & 2016)

Note: Red indicates erosion-prone areas, while green indicates zones of sediment deposition.



Figure 7: Spatial distribution of erosion (bank retreat) and deposition (sediment accumulation) zones along the Teesta River reach derived from overlay analysis of bankline positions between 2016 and 2021.

Source: Google Earth Pro (Imagery: 2016 & 2021)

Note: Red indicates erosion-prone areas, while green indicates zones of sediment deposition.



Figure 8: Spatial distribution of erosion (bank retreat) and deposition (sediment accumulation) zones along the Teesta River reach derived from overlay analysis of bankline positions between 2021 and 2025.

Source: Google Earth Pro (Imagery: 2021 & 2025)

Note: Red indicates erosion-prone areas, while green indicates zones of sediment deposition.



Figure 9: Overall spatial distribution of erosion (bank retreat) and deposition (sediment accumulation) zones along the Teesta River reach based on multi-temporal overlay analysis (2011–2025). The figure presents the overall spatial distribution of erosion and deposition zones along the selected reach of the Teesta River based on multi-temporal

analysis. In the figure, erosion zones are represented in red, while deposition zones are shown in green. Erosion is predominantly observed along Zone 2, indicating severe bank retreat and channel instability, whereas deposition is limited and occurs in localized patches in low-velocity regions.

11. References

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