Water and Sediment Dynamics in Sikkim's Teesta Basin: Climate, Land Use, Floods, and Future Challenges

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Abstract

The Teesta River in Sikkim, fed by snowfields, glaciers, rainfall, and water bodies, is central to the state's water, agriculture, and hydropower. Yet it also poses recurring challenges in the form of soil erosion and frequent floods that damage property and claim human lives. Two recent scientific studies have provided new insights into how climate (rainfall, temperature, snow/glacier melt) and land cover (forests, agriculture, built-up land) together shape river flows and sediment movement in the Teesta Basin. Rainfall remains the dominant driver of both water and sediment yield, but baseflow and snow/glacier melt provide essential stability across seasons. Land cover change especially deforestation and urban expansion exacerbates soil erosion and flood risks. This article synthesizes key findings, underlining implications for agriculture, hydropower, and disaster management, and argues for urgent conservation and adaptive planning in the fragile Himalayan environment.

Keywords: water & sediment dynamics, climate change, land use change, flood, Teesta River.

1. Introduction

The Himalayas are often described as the "water towers of Asia", releasing freshwater through rainfall, snow, and glacier melt to sustain some of the largest river systems on Earth (Immerzeel et al., 2010). For Sikkim, the Teesta River Basin is a lifeline, providing water for agriculture, drinking, and hydropower, while shaping the landscapes and livelihoods of the region.

At the same time, the Teesta is also a source of risk. Frequent floods, triggered by intense rainfall, cloudbursts, or glacial lake outburst floods (GLOFs), have caused devastating losses in recent years, including the 2023 - 2024 (SSDMA, 2023) flood disaster that destroyed infrastructure, hydropower projects, and claimed many lives. Such disasters highlight the fragility of the Eastern Himalayas, where climate variability and human activity interact in complex ways (Tiwari & Joshi, 2012).

Large portions of the upper Teesta Basin are covered by snow and glaciers, making snow and glacier melt an important contributor to river flow, alongside rainfall and groundwater (baseflow). These multiple sources create a unique hydrological balance that regulates water availability across seasons (Lutz et al., 2014). However, the steep terrain and fragile soils make the basin prone to erosion, particularly during the monsoon, when rainfall intensity peaks. Sediment transported downstream reduces farm productivity, clogs hydropower reservoirs, and increases flood risks (Singh et al., 2016).

Fig. 1 Damage Caused by the Teesta Flash Floods in 23–24

Scientific studies have sought to disentangle the drivers of water yield (river discharge from a basin) and sediment yield (soil loss carried by rivers). Recent work in the Teesta Basin has quantified the significance of climate and basin parameters across spatio-temporal scales, showing that rainfall dominates both water and sediment yield, while baseflow and glacier melt provide critical stability (Lepcha et al., 2022). Another study highlighted that land cover changes, especially deforestation and urbanization, significantly increase erosion and flood risks, interacting with climate change to magnify impacts (Lepcha et al., 2024). Together, these studies underline the urgency of addressing both natural and human drivers in Himalayan River management. The extent of damage caused by the Teesta flash floods in 2023–24 is shown in Figure 1.

2. Water yield and its drivers

2.1 Rainfall: The key factor

Studies confirm that rainfall is the single largest driver of water yield. Daily rainfall variations directly translate into spikes in river discharge, often causing flash floods. At the annual scale, higher rainfall years bring more water but also greater risks of erosion and sedimentation.

2.2 Baseflow: sustaining rivers in dry months

Groundwater contribution, or baseflow, plays a stabilizing role. In non-monsoon periods, when rainfall is scarce, baseflow keeps rivers flowing, ensuring water availability for households, irrigation, and ecosystems. Its role is often underestimated but is vital for year-round water security.

2.3 Snow and Glacier Melt: The high-altitude reservoirs

Large areas of Sikkim are snow-covered or glaciated. Meltwater from these sources contributes significantly to summer and lean-season flow, buffering against water scarcity. With glaciers retreating due to rising temperatures, this buffer may decline in future, raising concerns about long-term river stability.

2.4 Temperature and seasonal patterns

Temperature affects both snowmelt and evapotranspiration. Minimum temperatures favor snow accumulation, while maximum temperatures drive melting. Seasonal differences are clear: rainfall dominates in monsoon, while baseflow and meltwater dominate in non-monsoon.

3. Sediment yield and erosion dynamics

3.1 Rainfall-driven erosion

Rainfall also governs sediment yield, with intense monsoon showers dislodging soil and triggering landslides. Sediment yield peaks during July–September, coinciding with the flood season.

3.2 Slopes, soil fragility, and hotspots

The basin's steep slopes and fragile soils make it erosion-prone. Certain sub-basins with shallow soils and sparse vegetation emerge as erosion hotspots, contributing disproportionately to sediment yield.

3.3 Land cover matters

The second study highlights the strong role of land cover change. Forests, by binding soil and reducing runoff speed, reduce erosion. When forests are cleared for roads, settlements, or agriculture, erosion intensifies. Built-up areas increase impermeable surfaces, raising flood peaks. Thus, climate and land cover changes together exacerbate erosion risks.

3.4 Floods and human costs

Floods are a recurring reality in Sikkim. Beyond erosion, sediment-laden floodwaters devastate infrastructure, farmland, and homes. The human costs, loss of lives, displacement, trauma, are immense. Recovery often takes years, and repeated events erode not just soils but also livelihoods and community resilience.

4. IMPLICATIONS FOR SIKKIM

4.1 Agriculture

Soil erosion reduces fertility, affecting crop yields. Traditional practices like terracing and agroforestry remain crucial, but must be reinforced with modern soil conservation techniques. Climate-resilient farming is essential for food security.

4.2 Hydropower development

Sedimentation is a major challenge for hydropower. Reservoirs silt up, turbines wear down, and project lifespans shorten. Land cover management in upstream catchments can reduce sediment inflow and prolong hydropower viability.

4.3 Water security

Rainfall provides sudden pulses of water, but baseflow and glacier melt provide stability. With climate change threatening glaciers and rainfall patterns becoming erratic, securing groundwater recharge and protecting snow-fed catchments is vital.

4.4 Disaster and flood management

The combined impact of heavy rainfall, fragile geology, and land cover change has increased flood frequency. Cloudbursts and glacial lake outburst floods (GLOFs) add new risks. Investing in early warning systems, floodplain zoning, and community preparedness is urgently needed.

4.5 Climate change adaptation

Climate change will likely bring more intense rainfall and faster glacier retreat. Without proper adaptation, this could mean more floods in the short term and water scarcity in the long term. Integrating forest restoration, slope stabilization, and careful infrastructure planning into adaptation strategies is critical.

5. Broader significance

- The combined findings of the two studies offer important lessons:
- Rainfall remains the dominant driver of both water and sediment yield.
- Snow and glacier melt, along with baseflow, are crucial for seasonal stability.
- Land cover change, especially deforestation and urban expansion magnifies erosion and flood risks.
- The interaction of climate change and land use change creates a double burden for Himalayan rivers.

For policymakers, farmers, and communities, the message is clear: conserving forests, protecting slopes, and planning development carefully are essential for water and soil security.

6. Conclusion

The Teesta Basin embodies the contradictions of the Himalayas: abundant water, yet frequent scarcity; fertile soils, yet rapid erosion; life-giving rivers, yet deadly floods. Rainfall, baseflow, and snow and glacier melt together sustain its flow, while slopes, soils, and land cover dictate how much sediment is carried downstream. Climate change and land cover change are reshaping this balance, making floods more destructive and water supplies less predictable. The tragic loss of lives and property in recent flood events underscores the urgency of action. Managing the Teesta requires more than engineering, it requires watershed conservation, climate adaptation, and community resilience. By protecting forests, conserving soil, and respecting the fragility of glaciers and slopes, Sikkim can safeguard its rivers for generations to come.

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