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Evaluating the Role of Hydro-climatic Drivers in Shaping Suspended Sediment Dynamics across Sub-Arctic Riverine System: A Case Study of Tana River Deltaic Estuary

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1. INTRODUCTION

The Arctic flow regimes have become vulnerable to the ongoing climate change-induced Arctic Warming, which is referred to as Arctic Amplification (Rantanen et al. 2022). Consequently, Arctic Amplification has impacted the riverine water flow, significantly affected stream networks, and critically impacted the large river deltaic estuaries. Nutrients. Across the Arctic, a 2 °C rise in air temperature can lead to a 30% increase in sediment flux, while a 20% increase in river runoff can result in a 10% increase in sediment load (Syvitski 2002). It has induced permafrost thaw across the Arctic catchments, mobilizing sediment particles and associated nutrients. Due to Arctic amplification, since 1990, Scandinavia has experienced a warming trend, primarily due to winter warming; it was unusually warm even during the 20th century's first half (Dankers 2002). Temperature rise in the Scandinavian Arctic significantly impacted the hydrological cycle as higher water vapour concentrations in the atmosphere could have led to increased precipitation, particularly from the northern mid-latitudes to the high latitudes. In addition, precipitation in Finnish Lapland has increased significantly since 1879 (Lee et al. 2000). Previous research on northern Scandinavia indicated that the rise in extreme precipitation events in recent decades reduced soil storage capacity, triggered extreme soil erosion events, and contributed to sediment availability and mobilization across flow regimes. Thus, the significance of permafrost thaw impacting hydrological processes is recognized widely (Vihma et al. 2019); however, the hydrological processes operating in Arctic River deltaic estuaries have been mainly overlooked due to the challenges and associated costs associated with assessing the water-sediment processes (Chalov et al. 2023).

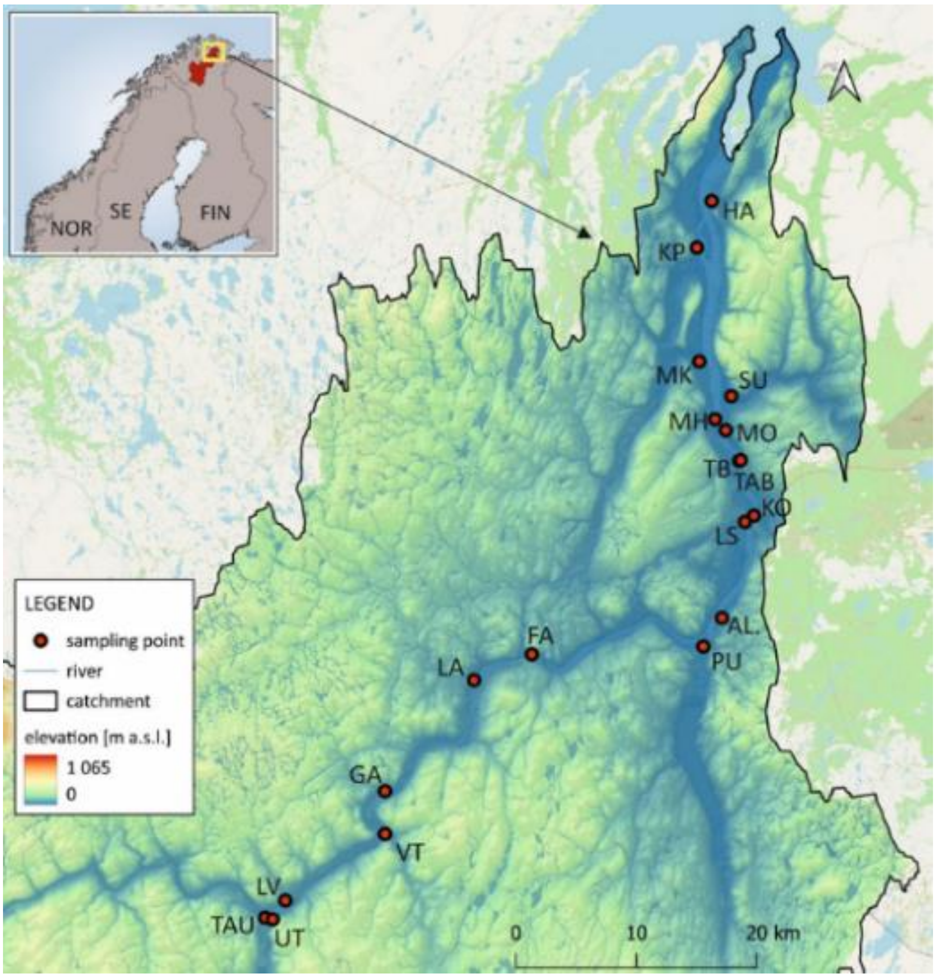

Fig. 1. Study area selected for the projected with sampling points selected for the field investigation across the Tana River estuary.

Considering the complexities of hydrological monitoring, our study is based on the Finnish-Norwegian river basin of Tana (also known as Tenojoki in Finnish), located in the circumpolar subarctic zone (between 68°N and 70°N). This study involves a meticulous investigation of the seasonal dynamics of the Suspended Sediment Concentration (SSC) across the estuarine catchment of the Tana River (Fig. 1).

2. SUMMARY OF METHODS AND RESULTS

The Tana River, being the formal boundary between Norway and Finland spanning over 338 km, is one of the largest and unexploited river deltaic estuaries of Scandinavia. The unique flow regime of Tana features low discharge (21 m^3s^{-1}) between December and mid-May when the basin is ice-covered, which can occur as early as October. Following that, the Peak discharge range (1,000–2,000 m^3s^{-1}) occurs from late May until June when the temperature is >10 °C during the spring freshet post-ice-breakup from late May to June. To begin the research approach has prioritized in-situ SSC sampling conducted across the tributaries (indicated in Fig. 1, as acronyms) of Tana's estuarine section (Utsjoki, Levessejhoka, Pulmankijarvi Kulpukanjoki, Álletjohka, Korselva, Vestjoki, Mohkkevajohka, Harrijoki, and Maskijoki) during the peak flow events after ice breakup and consequent spring freshet (end of May 2024 and 2025), alongside observations from lower flow summer conditions (e.g. in August). The field-based SSC measurements establish a baseline for comprehending the Tana flow regime's rapid response to the dominant impact of ice-breakup.

Field data depicted significantly higher SSC values during May 2024; for instance, Tana River's tributary Maskijoki exhibited SSC values ranging between 41.87–114.4 mg/L, whereas in August measurements for the same tributary recorded markedly lower SSC range of 0–5.8 mg/L (Fig. 2).

This pronounced seasonality in SSC can be directly linked with the intense spring runoff, reflecting the sharp increase in discharge patterns during the freshet flood period (as shown in Fig. 3 – Flow Hydrography of Tana).

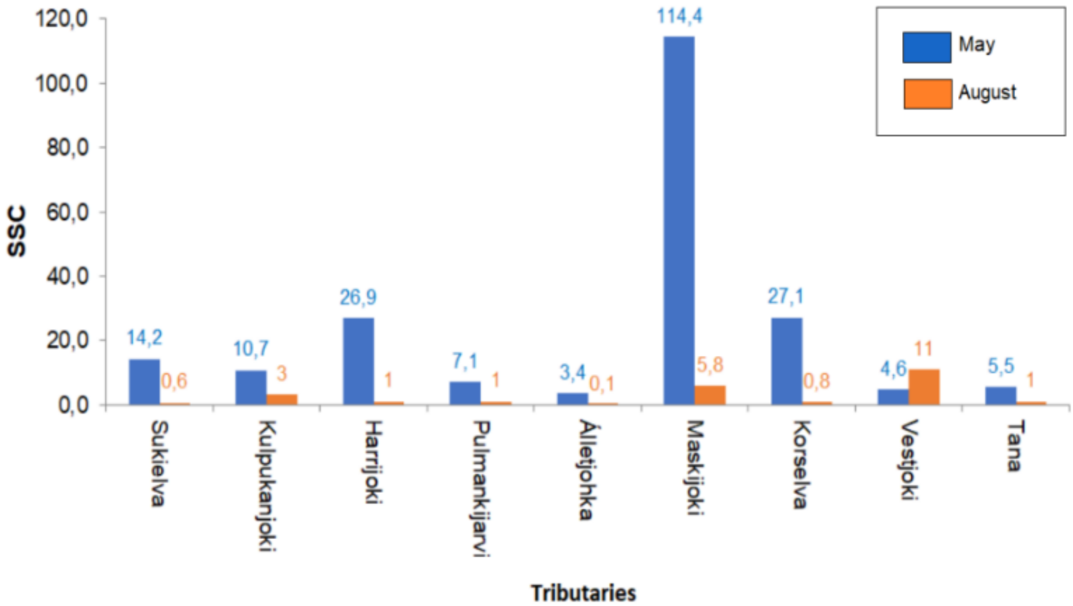

Fig. 2. Estimated SSC in 2024 via in-situ sampling undertaken across Tana and its tributaries.

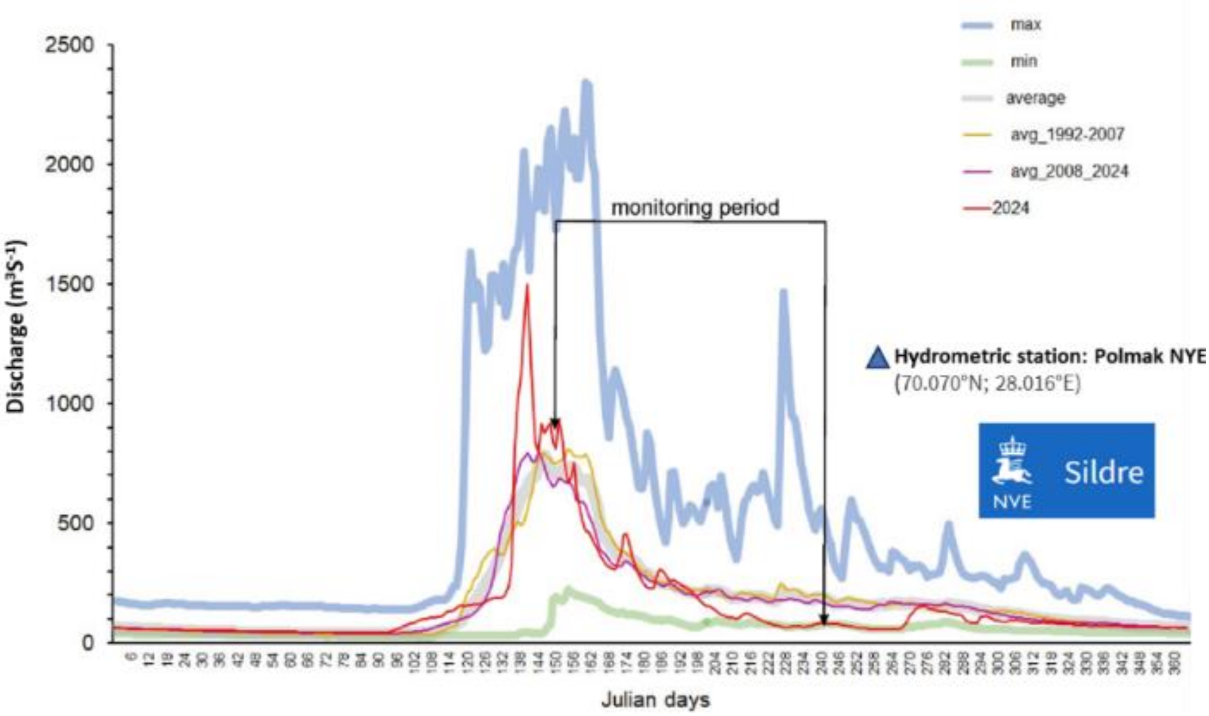

Fig. 3. Flow Hydrograph: Tana River, 1992–2024, recorded at Polmak NYE, Norway (Raw data source: https://sildre.nve.no/map).

The second part of the research involves leveraging the robust in-situ SSC dataset to develop and validate satellite data-based SSC estimations via optical remote sensing data using Sentinel-2 MSI. Therefore, this integrated approach of field data data-to-satellite data-based SSC patterns across the Tana River Estuary and its tributary network overcoming the limitations of solely point-based measurements.

3. CONCLUSIONS

Our two years monitoring covered more than 20 locations spanning a route of approximately 100 km, enabling the effective characterization of SSC patterns across the entire Tana River Estuary. Our research tends to establish that ice breakup and spring freshet are the dominant drivers influencing the duration and level of sediment flux and concentration in the Tana River Estuary, which is profoundly influencing its morpho-dynamics, channel stability, and the overall sediment budget. Our observations in May 2024 and 2025 shows that the specific climatic conditions of the Arctic, the ice cover, are an important factor modulating the flow of water and sediments between the Tana River and its tributaries. At the same time, each of the tributaries is characterized by individual features, hence the dates of the SSC peak differ.

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