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Topic of Research: Impact of Climate Change on Natural Resources and Livelihood in South Sikkim

FINDINGS

This thesis presents a holistic understanding of how long-term climate variability has reshaped natural resources and livelihoods in South Sikkim between 1991 and 2022. The multi-variable climate analysis shows a clear warming trend with Tmax and Tmin increasing at +0.026°C/year and +0.022°C/year respectively. This warming is consistent with elevation-dependent warming trends reported across the Himalayan region as highlighted by the Intergovernmental Panel on Climate Change. Although total annual rainfall has not changed substantially, its seasonal behavior has shifted noticeably. Rainfall is now more concentrated during the pre- and post-monsoon periods while the core monsoon months show stagnation or a slight decline. At the same time, rising humidity, declining wind speed and reduced solar irradiance further indicate shifts in regional atmospheric conditions.

Assessments of natural resources using NDVI and NDWI reveal clear signs of stress. Dense vegetation has steadily declined across all seasons with pre-monsoon dense forest decreasing from 17,101 ha (22.7%) in 1991 to 14,481 ha (19.2%) in 2022. In contrast, sparse vegetation and bare soil have expanded, suggesting increasing degradation and surface exposure. Water and snow-covered areas have also declined significantly falling from 4,415 ha (6.0%) to 3,163 ha (4.0%). Temperature anomalies exceeded +2°C after 2000, reinforcing the warming trend. NDVI shows strong positive relationships with rainfall ($r = 0.726$ during monsoon; $r = 0.723$ annually), indicating that vegetation productivity remains closely linked to precipitation. NDWI, in contrast exhibits strong negative correlations with precipitation ($r = -0.704$) and temperature ($r = -0.364$). Soil moisture indices (SSW, RZW, PSM) show a rebound after 2005 and display very strong correlations with monsoon rainfall, each exceeding $r = 0.950$, highlighting the dominant influence of rainfall on soil moisture dynamics.

Land degradation modeling further indicates increasing susceptibility to landslides and soil erosion. Among the machine learning models, Stacking performed best with accuracy reaching up to 91% for Very High susceptibility under the RCP 8.5 Phase II scenario. Soil erosion estimates using the Revised Universal Soil Loss Equation show a sharp rise in erosivity, increasing from 1999.96 MJ mm ha^{-1} h^{-1} yr^{-1} in Phase I to 3899.2 MJ mm ha^{-1} h^{-1} yr^{-1} in Phase III. Under RCP 8.5, Very High erosion areas expanded to 10.92% in Phase III. The overlap of landslide and erosion zones indicates an increasing concentration of degraded areas, particularly in the western uplands and southern slopes.

Livelihood analysis identifies agriculture as the most affected sector with more than 54% of households shifting to short-duration or climate-resilient crops. Water scarcity, declining forest resources, livestock stress and increasing disease incidence further heighten vulnerability. Tourism is also affected, with 62% reporting climate-related disruptions. The study applies the Livelihood Vulnerability Index (LVI) and the LVI-IPCC framework to assess vulnerability in South Sikkim. The LVI is 0.348, indicating a moderate level of vulnerability. However, the LVI-IPCC value of 0.093 points to deeper structural issues. Exposure is relatively high (0.534), reflecting the increasing frequency and intensity of climatic events while sensitivity (0.360) remains notable due to the strong dependence on climate-sensitive sectors. In contrast, adaptive capacity is lower (0.274) mainly because of limited institutional support and restricted access to resources. In conclusion, these findings suggest that South Sikkim is experiencing increasing environmental stress alongside growing socio-economic vulnerability. Addressing these interconnected challenges will require more integrated and locally grounded adaptation strategies that strengthen both ecological resilience and livelihood security.