TEMPERATURE CONTROLS ON SEASONAL SNOW VARIABILITY IN THE TUPALANG RIVER BASIN

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ABSTRACT

This study examines whether recent snow variability in the Tupalang River Basin is associated more strongly with temperature or moisture conditions. Daily MODIS snow data for 2001 to 2025 were summarized into annual, spring, winter, and persistent-snow indicators. ERA5-Land, CHIRPS, and TerraClimate supplied temperature, precipitation, maximum snow water equivalent, and runoff-proxy series. Snow-area slopes were negative in all four seasonal definitions, although none was statistically significant. Annual mean temperature increased significantly by 0.041 degrees C per year. Temperature had stronger relationships with snow area than precipitation: the coefficients were -0.6899 for annual conditions, -0.7631 for spring, and -0.7614 for winter. Maximum snow water equivalent was positively related to spring snow area at r equal to 0.6513. The mean elevation of detected spring snow also increased in slope terms and was positively associated with spring temperature. The results show a clear temperature sensitivity in year-to-year snow conditions, but they do not establish a significant long-term decrease in basin-wide snow area. For water planning, the indicators should be combined with measured discharge and station observations before they are used to infer changes in seasonal water supply.

1.Research Aim

The analysis tests which climate variables move most closely with annual and seasonal snow area in the Tupalang River Basin. It also checks whether the twenty-five-year record contains a statistically significant trend in snow extent or spring snow elevation. The focus is climate sensitivity rather than direct runoff prediction.

2 Data and Method

Component	Specification	Reason for inclusion
Snow record	MODIS MOD10A1 daily NDSI, 2001 to 2025	Consistent seasonal time series

Component	Specification	Reason for inclusion
Snow classification	NDSI 30; frequency 0.20; persistent frequency 0.60	Common definition for all years
Climate variables	ERA5-Land temperature; ERA5-Land and CHIRPS precipitation	Thermal and moisture controls
Water-balance variables	TerraClimate maximum SWE and runoff proxy	Indicators of stored snow and potential water response
Trend method	Mann-Kendall test and Sen slope	Direction, magnitude, and significance
Association method	Pearson correlation	Linear co-variation between annual series

Table 1. Analytical design for the climate-sensitivity thesis.

3 Snow and Climate Trends

The winter indicator covered most of the basin on average. Annual and spring means were lower and close to one another, while the persistent-snow criterion isolated a small high-frequency surface. Negative slopes occurred in each series. Because every snow-area p value exceeded 0.05, the direction of change is reported as a tendency rather than a confirmed long-term decline.

Indicator	Mean	Sen slope per year	p value	Statistical result
Annual snow area	1397.85 km2	-6.01 km2	0.3153	Non-significant
Spring snow area	1434.75 km2	-6.26 km2	0.1990	Non-significant
Winter snow area	2182.48 km2	-7.78 km2	0.1682	Non-significant
Persistent snow area	144.10 km2	-1.54 km2	0.5593	Non-significant
Annual mean temperature	4.72 degrees C	+0.041 degrees C	0.0265	Significant increase
Maximum SWE	181.30 mm	-1.59 mm	0.1886	Non-significant

Table 2. Snow and climate trend statistics for 2001 to 2025.

4 Evidence of Climate Sensitivity

The three temperature coefficients were stronger than the precipitation coefficients. Spring temperature explained the clearest seasonal contrast: warmer springs coincided with smaller snow area and a higher detected snow surface. Positive precipitation and SWE coefficients indicate that moisture availability also matters, although those relationships were weaker than the thermal signal.

Climate variable	Snow response	r	p value	Interpretation
Annual temperature	Annual snow area	-0.6899	0.0001	Strong negative association
Spring temperature	Spring snow area	-0.7631	<0.001	Strong negative association
Winter temperature	Winter snow area	-0.7614	<0.001	Strong negative association
CHIRPS precipitation	Annual snow area	+0.4127	0.0403	Moderate positive association
ERA5-Land precipitation	Annual snow area	+0.4341	0.0301	Moderate positive association
Maximum SWE	Spring snow area	+0.6513	0.0006	Positive association
Spring temperature	Mean spring snow elevation	+0.7567	<0.001	Higher snow surface in warmer springs

Table 3. Selected relationships between climate conditions and snow indicators.

5 Implications for Seasonal Water Assessment

The significant warming trend and the seasonal correlations support the use of temperature as an explanatory variable in snow monitoring. They do not demonstrate that annual streamflow has declined. Snow area measures surface extent, whereas discharge also depends on snow depth, melt timing, evapotranspiration, soil and groundwater storage, reservoir regulation, and water withdrawals.

A practical monitoring system should report spring snow area together with its elevation distribution and maximum SWE. Gauge discharge and station meteorology are needed to determine whether years with reduced snow extent also produce lower or earlier flow. Until those observations are available, the runoff values used here should remain labelled as gridded proxies.

6 Conclusion

The Tupalang snow record is temperature-sensitive. Annual warming was significant, and warmer annual, spring, and winter conditions were consistently associated with smaller snow areas. The negative snow trends themselves were not significant over 2001 to 2025. The evidence therefore supports climate-sensitive monitoring but does not yet justify a claim of a confirmed basin-wide loss of seasonal snow or a measured reduction in river discharge.

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