ISSN: 3048-9938, Volume- 3, Issue- 1, January - March 2026

Assessing The Impact of Climate Change on Snow Characteristics and Glacier Area Change in the Subansiri Basin: A Review

Bipul Saikia[1*] & Dr. Jyotishmoy Bora[2]

[1]Research Scholar, Department of Geography, Bhattadev University, Bajali Pathsala, Assam

[2]Associate Professor, Department of Geography, Bhattadev University, Bajali Pathsala, Assam

Abstract:

Recent studies on snow and glacier area change in the Subansiri Basin, a sub-basin of the Brahmaputra Basin in the Eastern Himalayas, have focused on changes in snow cover and characteristics of glaciers. The Subansiri basin is one of the larger north bank tributaries of the Brahmaputra river system and hence has a significant contribution to the river discharge in the downstream reaches. Researchers have analyzed important changes, such as Accumulation area, debris cover, Glaciered & Snow field, non-glaciated area, including earlier snowmelt, decreased glacier coverage, reduced seasonal snow, and higher snowlines, using remote sensing and GIS techniques. Land use land cover (LULC) change detection of an area is also important, as this is an indicator of climate change. LULC has various categories to recognize vegetation transformation over a time period. The transformation of the vegetation classes and human settlement in upper catchment areas is investigated by the Land Use Land Cover as well. These changes directly affect the accumulation area of the glacier, water security, ecosystem resilience, and vegetation. The changer of glacier area has also impacted landslide, glacier rock flow simulation, and multi-hazard modelling. The results highlight the required of continuous monitoring, improved modeling, and adaptive new management techniques to handle the growing problems resulting from climate change in the Subansiri basin.

Keyword: Climate Change, Snow Cover, Remote Sensing, Hydrology, Subansiri Basin

Introduction:

The Subansiri Basin is a major tributary of the Brahmaputra River and an important boundary watershed in the Eastern Himalayas. The river starts in the Great Himalayan Range at around 5,340 meters above sea level and flows through a wide range of elevations before joining the Brahmaputra. Its water flow depends on both monsoon rains and snowmelt, which makes the basin very sensitive to climate change.

This review looks at how snow cover and glacier characteristics in the Subansiri Basin have changed due to global climate change. Recent research points to rising temperatures as the main cause. From 1901 to 2017, the average annual temperature in the basin increased by about 0.77°C, with the fastest warming after 1992. This warming has led to faster snowmelt, higher

*Corresponding Author Email: saikiabipul22@gmail.com
Published: 16 February 2026
DOI: https://doi.org/10.70558/COSMOS.2026.v3.i1.25440
Copyright © 2026 The Author(s). This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

snowlines, and more sublimation losses (Barman, S. 2016, and Murtem, R. et al., 2023). MODIS satellite data shows a clear drop in snow cover for most months except January. Compared to other Himalayan basins, the Subansiri Basin has less snow cover, with only 12 to 28% of its area affected seasonally. The biggest decreases in snow cover happen in April, July, and October, which are also the months with rising temperatures (Hasson, S. et al., 2020). Hydrological modeling using the SNOWMOD model shows that stream flow is very sensitive to climate change. Snowmelt runoff is expected to increase by about 5% with a 1°C temperature rise and by about 12% with a 2°C rise. The basin's water flow comes from about 11 to 16% snowmelt, 58 to 62% rainfall, and 25 to 27% base flow (Shukla, A. et al., 2020).

The basin has experienced significant glacier changes. The total glacier area dropped from 75.06 km^2 (52 glaciers) in 2013 to 67.85 km^2 (52 glaciers) in 2022, which means an annual retreat rate of 1.01%. During this time, the average snow line altitude increased by 22 ± 60 meters (Space Applications Centre, ISRO 2016). The Subansiri Basin has distinct seasonal snow patterns shaped by winter westerly and summer monsoons. Snow begins to build up in early December and lasts until February, with some melting also happening in winter. Unlike the Western Himalayas, the Subansiri region shows little change in winter snow cover area (Sharma, S., and Jain, S. K. 2016). Most snow accumulates during the monsoon season from June to September, which brings about 75% of the yearly precipitation. Winter snow buildup is limited, mainly because of high sublimation losses. Melting starts early in spring, and the snow cover lasts for a shorter time than in higher elevation basins (Borgaonkar, H et al., 2015).

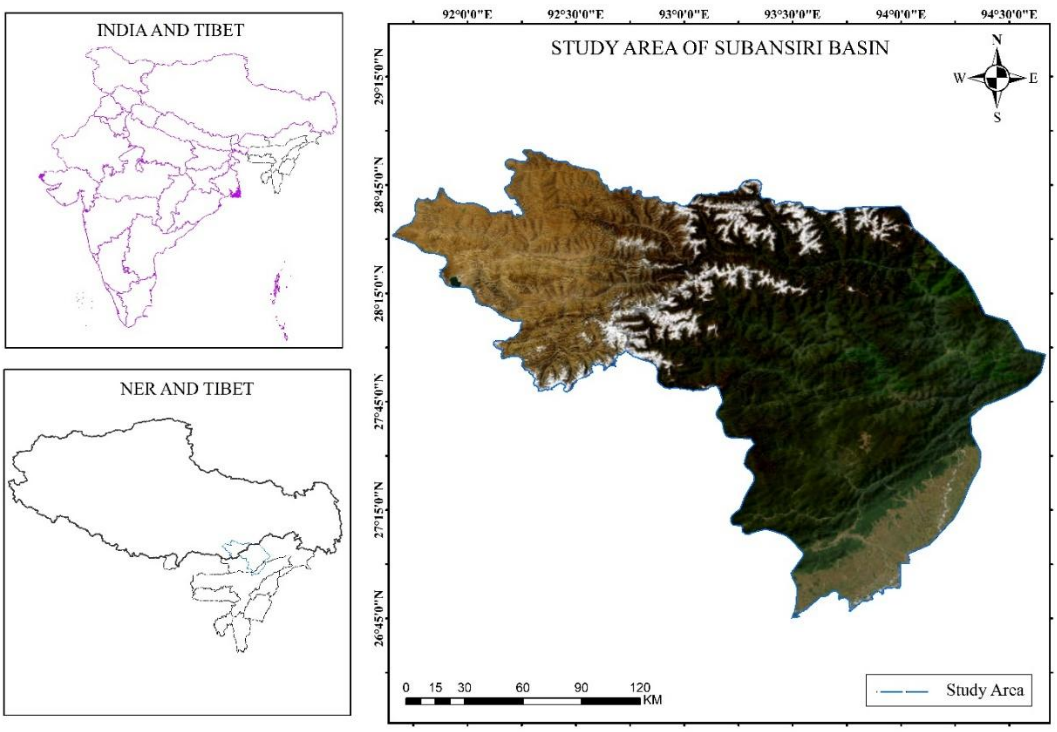

Figure 1: study area map of Subansiri Basin

Methodological Approaches and Remote Sensing Applications

The Subansiri Basin covers a massive catchment area marked by steep topographic variation, with elevations ranging from about 80 to over 9300 Meters in the foothills to over 25345 km^2

at its source. Spanning nearly 32,483 square kilometers, the basin experiences diverse climatic conditions shaped by the South Asian monsoon and high altitude continental influences. Its upper reaches hold extensive snow and glacier-covered zones, which play a key role in sustaining river discharge through seasonal snowmelt. Satellite remote sensing using Sentinel II, LISS IV (Linear Imaging Self Scanning Sensor IV), MODIS (Moderate Resolution Imaging Spectroradiometer), and Google Earth data has proven highly effective for tracking snow cover changes in the Subansiri Basin. The Normalized Difference Snow Index (NDSI) provides reliable snow cover mapping at resolutions of 10 meters, 5.6 meters, and 500 meters, enabling detailed analysis of both spatial and temporal variations. Recent studies rely heavily on satellite data for snow monitoring, with MODIS products (MOD10A1 and MOD10A1) at 500-meter resolution serving as the primary source for large-scale analysis. The NDSI, based on the contrast between visible and shortwave infrared reflectance, remains the standard technique, where values above 0.4 typically indicate snow presence (Azam, M. F., et al., 2024; Lupker, M. et al., 2017; Pfeffer, W. T., 2014; and Barman, S. 2016). Snow cover products generated at 5 to 10 day intervals show consistent seasonal patterns in the Subansiri Basin, though cloud cover during the monsoon causes some data gaps. Combining multiple satellite datasets with ground observations has improved the reliability of snow cover monitoring and trend analysis (Dharpure, J. K., et al., 2020).

The use of distributed snowmelt runoff models, such as SNOWMOD and the Spatially Distributed Snowmelt Runoff Model (SDSRM), has improved the understanding of snow hydrology interactions in the Subansiri Basin. These models apply elevation-dependent parameterization, incorporating temperature lapse rates, degree day factors, and recession coefficients tailored to Himalayan conditions (Cook, K. H. et al., 2022, and Usha, K. H. et al., 2022). Calibration methods that combine limited ground observations with remote sensing data have shown good results in data-scarce regions like the Subansiri Basin. By integrating snow cover information with meteorological inputs, these approaches offer a useful framework for evaluating how climate change affects hydrological systems (Sharma, A. et al., 2024).

Literature Review:

Rising temperatures lower snow albedo by accelerating snow metamorphism and through the deposition of light-absorbing particles. Research shows that aerosol-driven snow darkening can raise snowpack temperature by about 1.47°C and reduce snow cover fraction by 10.6%. Across the Himalayas, a consistent upward shift in snowline altitude has been observed, with regional trends ranging from +8.2 to +14.4 m per year in different valleys. Warmer conditions, combined with strong winds and low humidity, have also intensified sublimation losses during winter (Sasaki, O. et al., 2025, and Sci Tech Daily 2024).

Climate projections for the Subansiri Basin suggest notable shifts in rainfall patterns. For the period 2011 to 2040, models project statistically significant increases in annual precipitation, ranging from about 1.8% under RCP2.6 to nearly 11% under RCP8.5. The basin is expected to experience higher rainfall intensity alongside fewer rainy days in its lower reaches, with a trend toward more frequent extreme precipitation events (Yang, T. C. et al., 2017)

Climate change projections indicate that stream flow could rise by up to 6% under a +2°C warming scenario combined with a 10% increase in precipitation, while declines of up to 11% are possible under a +1°C warming with a 10% reduction in precipitation. Research across the Himalayan region highlights major shifts in snowmelt timing, with melt occurring more than 20 days earlier in many areas. Rising temperatures are shortening the melt season, an effect most evident in regions that usually experience longer melt durations. Earlier snowmelt is also leading to earlier peak river discharge. Seasonal delineation of snow characteristics and snow-covered areas remains essential for accurate assessment (Shivam, G. et al., 2017, Mishra, V. et al., 2017, Ghosh, S. et al. 2022, Bahadur, B. and Wahid, S. M. 2021, Dharpure, J. K. et al., 2021, and Crane, R. G. and Anderson, M. R. 1984).

Shifts in snow characteristics directly affect water security in the Subansiri Basin. Reduced snow storage and earlier melt can lead to water scarcity during the pre-monsoon months when agricultural demand is at its peak. A decline in snow cover also weakens the basin's ability to regulate flow, raising the risk of floods during the monsoon and shortages in the dry season (Barman, S. 2020).

The Subansiri Basin holds significant hydropower potential, but changing snow dynamics present serious challenges. Altered snowmelt timing and declining snow storage threaten the reliability and consistency of power generation. Earlier and more rapid snowmelt may compress energy production into shorter windows, complicating grid stability and increasing the demand for effective energy storage solutions (Sci Tech Daily 2024, Shivam, G. et al., 2018, and Barman, S. 2020). The shifting snow regime in the Subansiri Basin poses major challenges for water resources planning and management. Earlier snowmelt and reduced snow storage later in the season demand adaptive strategies to safeguard water security for downstream communities and ecosystems (Dharpure, J. K. et al., 2021). Effective management will require integrating the increasing variability of snowmelt contributions, along with the heightened risks of both floods and droughts driven by changing temperature and precipitation patterns. Building climate-resilient infrastructure and storage systems is essential to address these evolving hydrological conditions (Yang, T. C. et al. 2017). Changes in snow characteristics directly influence ecosystem functioning and biodiversity in the Subansiri Basin. Variations in snow cover duration and depth affect vegetation cycles, soil moisture availability, and the habitats of species that depend on specific snow conditions (Crane, R. G. and Anderson, M. R. 1984). As snow lines shift upward and persistence decreases at lower elevations, ecosystem connectivity and species migration are increasingly disrupted. To safeguard long-term resilience, conservation strategies need to integrate climate change projections into their planning and management (Lupker, M. et al., 2017).

Research Gaps:

Despite progress in remote sensing and modeling, large knowledge gaps remain in understanding snow processes in the Subansiri Basin. The lack of ground-based observations, especially at higher elevations, limits both model validation and process-level insights. Expanding monitoring networks with automated weather stations, snow depth sensors, and ablation measurements would strengthen calibration and validation efforts. Using emerging remote sensing tools such as synthetic aperture radar and high-resolution optical imagery could also improve spatial and temporal detail in snow monitoring.

A deeper understanding of snow climate interactions in the basin requires focused process studies on energy balance components, wind redistribution, and snow vegetation interactions, all of which gain importance under a changing climate. Advanced modeling approaches that apply machine learning and ensemble climate projections could provide more reliable assessments of future conditions. Building coupled models that integrate snow dynamics with vegetation and permafrost processes would further support system-level understanding.

Results and Discussion:

According to research, the Subansiri Basin's annual and seasonal temperatures have clearly increased over the last few decades. Precipitation patterns have increased with the increasing of temperature at lower elevations; therefore, in these regions, more rainfall occurs rather than snowfall. At lower elevation glaciers, areas are mostly exposed, and with the help of remote sensing data, the snow cover area, runoff, and the decrease in the accumulation area of the glacier can be determined. Through satellite, it is clearly observed that glacier areas are gradually reducing and fragmenting into smaller pieces, with noticeable losses in the ablation zones. Variability in winter precipitation and rising temperatures are closely related to these changes.

The results suggest that the Subansiri basin is already being impacted by the increased of snowmelt and glacier decrease. Future predication indicates potential drops in dry season flow as glacier storage continues to decline, even though increased of meltwater has momentarily increased river discharge during the pre-monsoon and early summer months. In order to better assess and manage the sustainability of water resources in the Subansiri Basin in the future under ongoing climate change, the review emphasizes the significance of high-resolution climate datasets, integrated modeling frameworks, and sustained glacier monitoring using advanced remote sensing.

Conclusion:

The Subansiri Basin highlights the complex challenges Himalayan watersheds face under climate change. Although the basin has less seasonal snow cover than many other Himalayan regions, changes in snow dynamics have serious consequences for water resources, ecosystems, and downstream communities. Evidence shows that climate change is altering snow accumulation, melt timing, and overall water storage. Rising temperatures are the main factor accelerating snowmelt, with projected increases of 5% to 12% under moderate warming scenarios. Still, uncertainties remain due to the interaction of shifting precipitation patterns, rising temperatures, and elevation-dependent processes.

The upward shift of snow lines advancing more than 7 meters per year, along with declining snow water equivalent, points to major changes in the basin's hydrological balance. These trends call for proactive adaptation strategies that address both short-term variability and long-term water availability.

Future research should strengthen process-level understanding, expand monitoring systems, and develop integrated modeling frameworks to support adaptive management. The Subansiri Basin is a key case study for transitional snow regimes, offering lessons for managing watersheds across the Eastern Himalayas.

Adaptation strategies must be comprehensive, combining scientific insight with local engagement. Priorities include building water storage infrastructure to offset reduced natural snow reserves, deploying snow and flood monitoring systems through satellite data and hydrological models, exploring supplementary water sources such as groundwater and rainwater harvesting, and conserving or restoring watershed forests and wetlands to improve water retention. Ensuring sustainable water resources will depend on close collaboration among researchers, policymakers, and local communities (Cook, K. H., et al., 2022).

Key research priorities include high-resolution spatial analysis using advanced satellite data, deeper investigation of snow physics processes such as sublimation and energy balance, and integrated studies connecting snow changes with glacier dynamics and ecosystem responses. There is also a need for detailed assessments of how climate change affects local communities and economic activities. Evidence shows that the Subansiri Basin is experiencing rapid cryospheric changes, posing risks to water security and socioeconomic stability. Sustained monitoring, targeted research, and proactive adaptation planning are critical for safeguarding water resources and supporting sustainable development in this Himalayan basin (Sasaki, O. et al., 2025).

In the Subansiri Basin, located in the lower Himalayan belt of northeastern India, climate change has brought substantial changes to snow characteristics and snow-covered areas. Climate change is driving significant changes in snow cover and dynamics in the Subansiri Basin, with clear ecological and hydrological impacts. Rising temperatures have accelerated snowmelt and reduced snow-covered areas, leading to higher stream flow during melt periods. For each 1°C to 2°C rise in temperature, snowmelt runoff has increased by roughly 2.5% to 5%, while glacier area has been shrinking at about 1.01% per year in recent decades.

These changes, largely linked to global climate warming, heighten the risks of downstream flooding and unstable water resources. Current monitoring and modeling highlight that without timely action, both the hydrological balance and cryospheric stability of the basin will remain under threat. This underscores the need for sustained observation and adaptive water management strategies to reduce future risks.

Reference:

1. Barman, S. (2016). Change in Snow Cover Area and Flow Scenario of the Brahmaputra and Subansiri Basins Due to Climate Change. [Doctoral dissertation, Indian Institute of Technology Guwahati]. Gyan IIT Guwahati.
2. Murtem, R., Mandal, S., Nunchhani, V., Megozeno, Bandyopadhyay, A., & Bhadra, A. (2023). Temporal variation in glacier surface area and glacial lakes in glaciated river basins of Arunachal Pradesh. *Journal of Water and Climate Change*, *15*(1), 50–74. https://doi.org/10.2166/wcc.2023.368
3. Hasson, S. U., Böhner, J., Lucarini, V., Saeed, F., & Schleussner, C.-F. (2020). High-resolution gridded dataset of temperature and precipitation for the Himalayan region (1951–2015). Earth System Science Data, 12(3), 1245–1267.

4. Shukla, A., Garg, S., Mehta, M., Kumar, V., & Shukla, U. K. (2020). Temporal inventory of glaciers in the Suru sub-basin, western Himalaya: impacts of regional climate variability. *Earth System Science Data*, *12*(2), 1245–1265. https://doi.org/10.5194/essd-12-1245-2020

5. Space Applications Centre, ISRO. (2016). Atlas of Snow Cover over Brahmaputra Basin 2015-16.

6. Sharma, S., & Jain, S. K. (2016). Assessment of climate change impacts on hydrology of Brahmaputra basin using a semi-distributed model. Global NEST Journal, 18(4), 798-810.

7. Borgaonkar, H., Pant, G., Alexander, C., Vose, L., R, Carter, T., Hulme, M., Crossley, J., Malyshev, S., New, M., Schlesinger, M., Tuomenvirta, H., Yu-Xu, C., Dye, D., Hall, D., Riggs, G., Singh, P., Jain, S., Singh, P., Salomonson, V. (2015). Impact of climate change on the runoff regime of an Eastern Himalayan river basin. Global NEST Journal, 17(2), 323–333. https://doi.org/10.30955/gnj.001554

8. Azam, M. F., et al. (2024). Temporal variation in glacier surface area and glacier lakes in the upper Brahmaputra River Basin from 1990 to 2018. Journal of Water and Climate Change, 15(1), 50–64.

9. Lupker, M., Lavé, J., France-Lanord, C., Christl, M., Bourlès, D., Carcaillet, J., Maden, C., Wieler, R., Rahman, M., Bezbaruah, D., & Xiaohan, L. (2017). 10 Be systematics in the Tsangpo-Brahmaputra catchment: the cosmogenic nuclide legacy of the eastern Himalayan syntaxis. *Earth Surface Dynamics*, *5*(3), 429–449. https://doi.org/10.5194/esurf-5-429-2017

10. Pfeffer, W. T., Arendt, A. A., Bliss, A., Bolch, T., Cogley, J. G., Gardner, A. S., Hagen, J., Hock, R., Kaser, G., Kienholz, C., Miles, E. S., Moholdt, G., Mölg, N., Paul, F., Radić, V., Rastner, P., Raup, B. H., Rich, J., & Sharp, M. J. (2014). The Randolph Glacier Inventory: a globally complete inventory of glaciers. *Journal of Glaciology*, *60*(221), 537–552. https://doi.org/10.3189/2014jog13j176

11. Dharpure, J. K., Patel, A., Goswami, A., Kulkarni, A. V., & Snehmani. (2020). Spatiotemporal snow cover characterization and its linkage with climate change over the Chenab river basin, western Himalayas. *GIScience & Remote Sensing*, *57*(7), 882–906. https://doi.org/10.1080/15481603.2020.1821150

12. Cook, K. H., et al. (2022). Enhanced warming and melting of the Himalayas caused by a shift in snow–albedo feedback from clouds. Water Resources Research, 57(3), e2021WR030140.

13. Usha, K. H., Nair, V. S., & Babu, S. S. (2022). Effects of Aerosol–Induced Snow Albedo feedback on the seasonal snowmelt over the Himalayan region. *Water Resources Research*, *58*(2). https://doi.org/10.1029/2021wr030140

14. Sharma, A., et al. (2024). Evaluating snow cover changes and hydrological impacts in the Eastern Himalaya, India: A remote sensing and modeling approach. EGU sphere.

15. Sasaki, O., Miles, E. S., Pellicciotti, F., Sakai, A., & Fujita, K. (2025). Contrasting patterns of change in snowline altitude across five Himalayan catchments. The Cryosphere, 19(11), 5283–5298. https://doi.org/10.5194/tc-19-5283-2025

16. Sci Tech Daily. (2024). New Satellite Data Uncovers a Stunning Shift in Himalayan Snowlines.

17. Yang, T. C., et al. (2017). Seasonal changes of snow cover area and runoff in the upper Brahmaputra River basin. Malaysian Journal of Medical and Biological Research, 4(2), 89–99.

18. Shivam, G., Goyal, M. K., & Sarma, A. K. (2018). Index-Based Study of Future Precipitation Changes over Subansiri River Catchment under Changing Climate. Journal of Environmental Informatics. https://doi.org/10.3808/jei.201700376

19. Gardelle, J., Berthier, E., Arnaud, Y., & Kaab, A. (2017). Area and mass changes of Himalayan glaciers: A review. The Cryosphere, 11, 2329-2344.

20. Mishra, V., Oinam, B., & Jain, S. K. (2017). Climate change impact on the snow hydrology and hydropower production in the Himalayan region. Journal of Hydrology, 549, 123-142.

21. Ghosh, S., et al. (2022). Spatiotemporal study of snow cover and snowmelt in the Himalayan region. Annales Geophysicae, 40(1), 67–82.

22. Bahadur, B., & Wahid, S. M. (2021). Hydrological impacts of snow retreat in the Himalayan cryosphere. Hydrological Sciences Journal, 66(6), 985–998.

23. Dharpure, J. K., Goswami, A., Patel, A., Kulkarni, A. V., & Snehmani. (2021). Assessment of snow cover variability and its sensitivity to hydrometeorological factors in the Karakoram and Himalayan region. Hydrological Sciences Journal, 66(15), 2198–2215. https://doi.org/10.1080/02626667.2021.1985125

24. Crane, R. G., & Anderson, M. R. (1984). Satellite discrimination of snow/cloud surfaces. International Journal of Remote Sensing, 5(1), 213–223. https://doi.org/10.1080/01431168408948799

25. Barman, S. (2020). Snow Cover and Flow Scenario Analysis in Brahmaputra Basin. Indian Institute of Technology Roorkee Conference Paper.