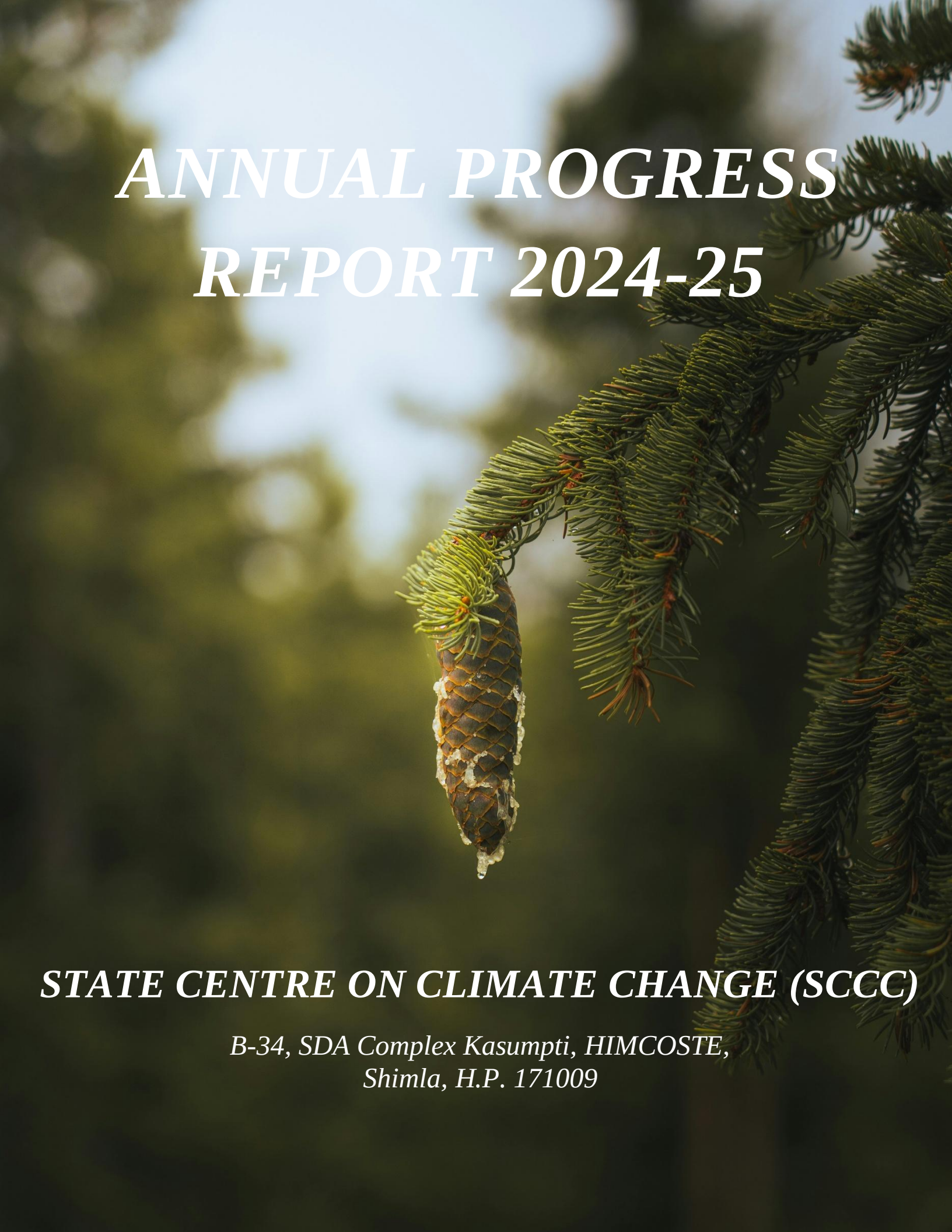




ANNUAL PROGRESS REPORT 2024-25

STATE CENTRE ON CLIMATE CHANGE (SCCC)

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INTRODUCTION

CLIMATE CHANGE

Climate change is no longer a distant or uncertain threat—it is a scientifically established and observable reality. The Intergovernmental Panel on Climate Change (IPCC) affirms with high confidence that human activity is the dominant driver of global warming, affecting the atmosphere, oceans, and land systems. The past decade has likely been the hottest in the last 125,000 years, and carbon dioxide levels are now at their highest in over two million years. Oceans have absorbed the vast majority of excess heat, while the Earth continues to lose trillions of tons of ice annually.

Air pollution presents a paradox, simultaneously harming human health while slightly masking the true extent of warming by reflecting sunlight. Advances in climate science have also made it possible to directly attribute the increased frequency and intensity of extreme weather events to anthropogenic climate change. If emissions were halted today, some warming effects could gradually reverse, but others—such as sea level rise—would persist for centuries. The impacts are already tangible: productivity losses due to extreme heat, ecosystem disruptions, and expanding uninhabitable zones threaten billions of lives and livelihoods. Without urgent action, the economic costs of inaction will far outweigh those of mitigation. These facts underscore the need for immediate, science-based responses to secure a livable future for both people and the planet.

STATE CENTRE ON CLIMATE CHANGE



Himachal Pradesh's fragile Himalayan ecosystem and dependence on climate-sensitive agriculture make it highly vulnerable to climate change impacts such as landslides, erratic rainfall, and temperature rise. A dedicated Climate Change Centre is essential for localized data collection, impact assessment, disaster risk management, and providing scientific guidance to policymakers. This enables effective climate adaptation strategies, safeguards livelihoods, and supports sustainable development in the region.

Under the headship of the Himachal Pradesh Council for Science, Technology & Environment; Department of Environment, Science, Technology & Climate Change, Himachal Pradesh, the "State Centre on Climate Change" was founded as a continuation to the "Shimla Declaration" in order to facilitate the alignment of the State's initiatives with those of the Indian government.

In order to implement the mandate of the National Action Plan on Climate Change and National Missions in the State of Himachal and to study the impact of climate change on the Himalayan Eco-System and combat its effects through implementation of mountain specific adaptation plans, the centre was notified vide notification no. STE-B(15)-1/2010 dated 9th September, 2011 with the following objectives: -

1. To coordinate with different universities, research institutions, government departments, NGOs etc. to pursue theme based specific research on climate change in the Himalayan Region and also to evolve and implement mitigation and adaptation plans.
2. To act as a repository of climate change related information in the State of Himachal Pradesh.
3. To generate awareness amongst various stakeholders for undertaking appropriate measures in combating the impact of climate change etc.

For over a decade, the Centre has played a vital role in mapping and monitoring glaciers and snow cover across Himachal Pradesh. This ongoing work is crucial for understanding changes in the cryosphere, assessing water resource availability, and predicting the impacts of climate change on the region's hydrology and downstream communities.

Additionally, the Centre has been actively engaged in comprehensive studies in disaster management, agriculture, and horticulture. These multidisciplinary efforts contribute to a better understanding of climate impacts, enhance resilience, and inform sustainable development policies in the state.

SNOW & GLACIERS STUDIES

The Western Himalayan state of Himachal Pradesh is home to a large number of glaciers and significant amounts of snow, which act as vital freshwater supplies for the area and people downstream. These cryospheric components support agriculture and biodiversity, control river flows, and affect local climate patterns.

The stability and extent of the state's glaciers and snow cover, however, are seriously threatened by climate change. Water availability is being impacted, the likelihood of glacial lake outburst floods (GLOFs) is rising, and traditional livelihoods are being disrupted due to the rapid retreat of glaciers, decreased snow accumulation, and changed melt patterns.

In order to produce precise, localized data, the State Centre on Climate Change has made the systematic mapping and monitoring of glaciers and snow cover a top priority. In order to facilitate prompt effect assessments, risk assessments, and well-informed policy development for climate adaptation and catastrophe risk reduction in Himachal Pradesh, reports produced by these studies are routinely distributed to line departments. Key initiatives and activities were completed by centre during 2024-25 is as follows:

1. CRYOSPHERE, SCIENCE & APPLICATION PROGRAM (CAP)

The study, supported by SAC-ISRO, Ahmedabad, employs multi-resolution satellite imagery to systematically map snow and glacier cover in the Himachal Himalayas. In the current financial year, glacier mapping was successfully completed for the Chenab and Satluj basins using 2020 LISS-III satellite data. A total of 492 glaciers were identified in the Beas basin, 196 in the Chenab, 274 in the Ravi, 1,674 in the Satluj, and 34 in the Uhl sub-basin.

This research holds critical significance as it enhances understanding of the extent, distribution, and dynamics of Himalayan glaciers—vital freshwater sources for millions across northern India. In the face of escalating threats from glacial lake outburst floods (GLOFs), erratic meltwater flows, and shrinking glaciers, such precise mapping is a key pillar for effective disaster risk reduction, water resource management, and climate impact assessment. The insights generated not only inform scientific inquiry but also directly support evidence-based policymaking and long-term climate resilience planning in the region.

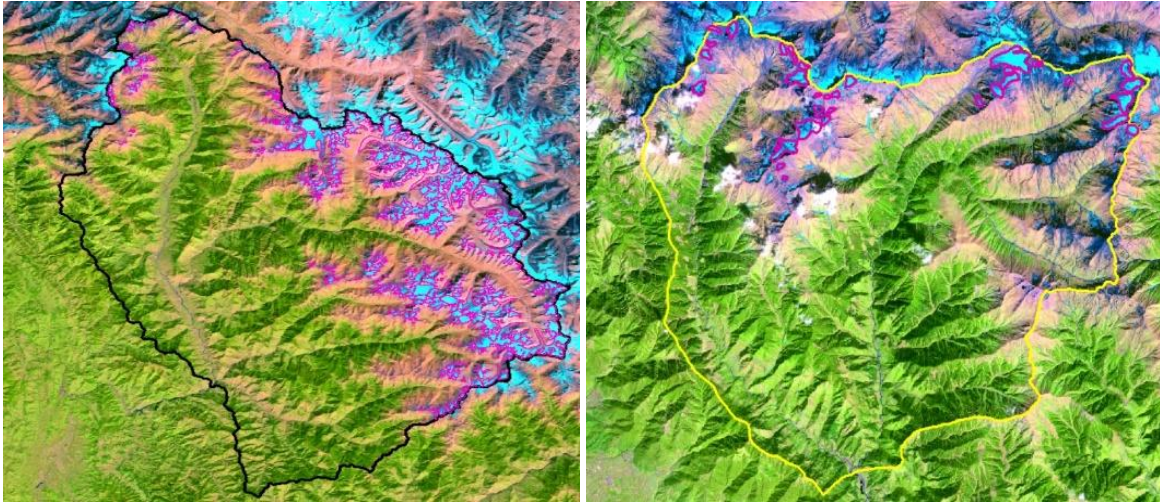


Figure 1 Mapping of glaciers in (a- left) Beas basin and (b-right) Uhl Sub basin using LISS-III satellite images during 2020

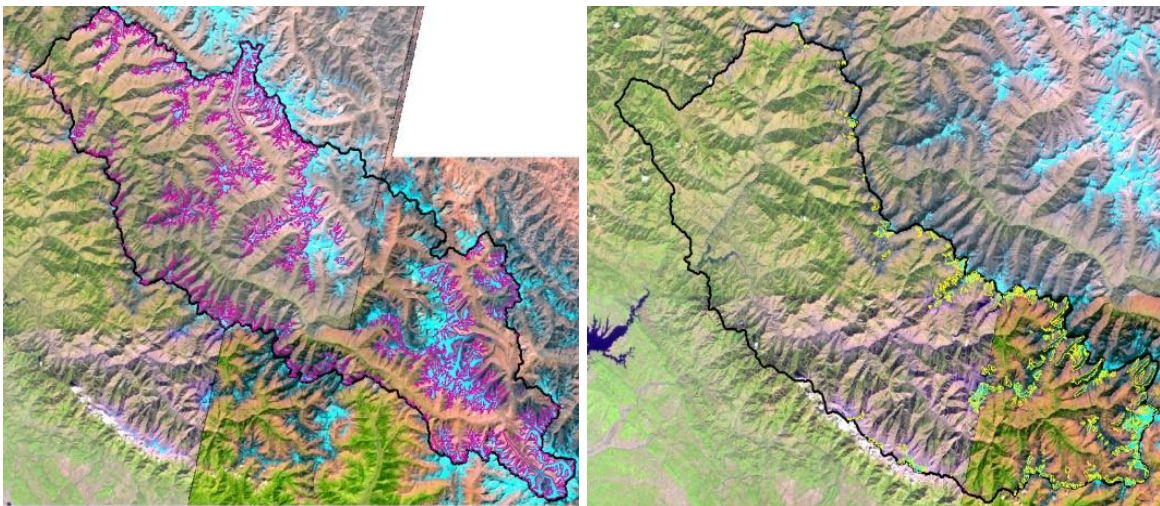


Figure 2 Mapping of glaciers in Chenab basin (a- left) and (b-right) Ravi basin using LISS-III satellite images during 2020

2. ASSESSMENT OF SPATIAL DISTRIBUTION OF SEASONAL SNOW COVER DURING THE YEAR 2023-24 IN HIMACHAL PRADESH USING AWIFS SATELLITE DATA



Climate change poses a major threat to mountain ecosystems, particularly the Himalayas, which support 51 million people dependent on hill agriculture. In Himachal Pradesh, glacial retreat, reduced snow cover, and increasing incidents of Glacial Lake Outburst Floods (GLOFs) are critical concerns, threatening water security, hydropower, agriculture, and infrastructure.

The state receives significant winter snowfall, essential for sustaining major rivers like the Chenab, Beas, and Satluj. An assessment of seasonal snow cover using AWiFS satellite data for the winter of 2023–24 (October–April) showed a 13% overall decline in snow-covered area compared to 2022–23. Most river basins showed negative trends during October–January, except the Satluj and Ravi, which showed slight increases in snow cover. February–April showed some recovery. Temperature analysis (2018–2023) indicated a slight increasing trend in maximum and minimum temperatures during the October–January period. Mean temperatures ranged from 18.65°C (Keylong) to 32.63°C (Chamba), with minimums as low as –10.35°C (Keylong).

METHODOLOGY

NORMALIZED DIFFERENCE SNOW INDEX (NDSI)

Normalized Difference Snow Index (NDSI) utilize the normalized ratio of green and SWIR and was used as an automated approach for snow mapping addressing the shadow and cloud problems in snow bound areas. Normalized Difference Snow Index was calculated using the ratio of green wavelength (band 2) and SWIR (band 5) of AWiFS sensor:

$$\text{NORMALISED DIFFERENTIAL SNOW INDEX (NDSI)} = (\text{BAND2} - \text{BAND5}) / (\text{BAND2} + \text{BAND5}) \quad \text{Q.1}$$

To estimate NDSI, digital numbers (DN) were converted into top-of-atmosphere reflectance. This involves conversion of DNs into the radiance values, known as sensor calibration, and then

reflectance was estimated. The various parameters (e.g., maximum and minimum radiances, mean solar exo-atmospheric spectral irradiances in the satellite sensor bands, satellite data acquisition time, solar declination, solar zenith and solar azimuth angles and mean Earth–Sun distance) were used to estimate reflectance (Markham and Barker, 1987; Srinivasulu and Kulkarni, 2004). Sensitivity analysis has shown that a NDSI value of 0.4 can be taken as a threshold to differentiate between snow and non-snow pixels. Exo-atmospheric reflectance of bands 2 and 5 of the AWiFS sensor was used to compute the NDSI, and no atmospheric correction has been applied at present. Field investigations suggest that NDSI values are independent of illumination conditions, i.e., snow/non-snow pixels can be identified under different slopes and orientations, even under mountain shadow region (Kulkarni et al., 2006).

RESULTS

One of the Himalayas' most important resources is snow. For hydrological and climatological reasons, it is crucial to track changes in snowfall over time. The winter precipitation in the Chenab, Beas, Ravi, and Satluj basins in Himachal Pradesh was mapped using AWIFS satellite data with a spatial resolution of 56 meters from October 2023 to April 2024, taking into account the current trend of winter snowfall in the state. A decreasing trend has been observed compared to past three 5 years. The findings highlight the urgent need for climate-resilient planning and water resource management in Himachal Pradesh.

Table 1 Area under snow in Himachal Pradesh

Basin-wise Snow Cover in H.P (Km ²)			
Basin	2022-2023	2023-2024	Difference in area (%)
Chenab	7049.67	5964.70	-15.39
Beas	2174.88	2008.59	-7.65
Ravi	1886.29	1699.67	-9.89
Satluj	8868.27	7764.41	-12.45
Total	19979.11	17437.37	12.72

Table 2 Total area under snow in Himachal Pradesh

Year	2022-23 Area in Km ²	2023-2024 Area in Km ²	% Change
Total Area	19979.11	17437.37	-12.72

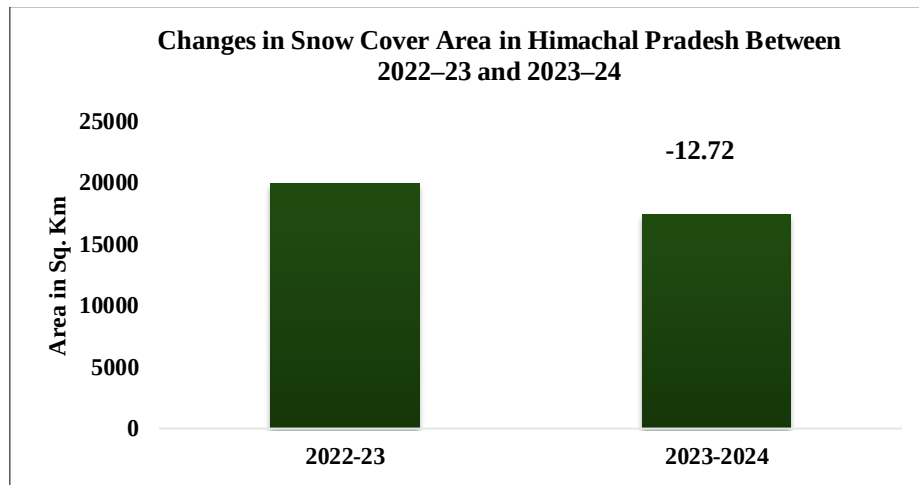


Figure 3 Total area under snow in Himachal Pradesh

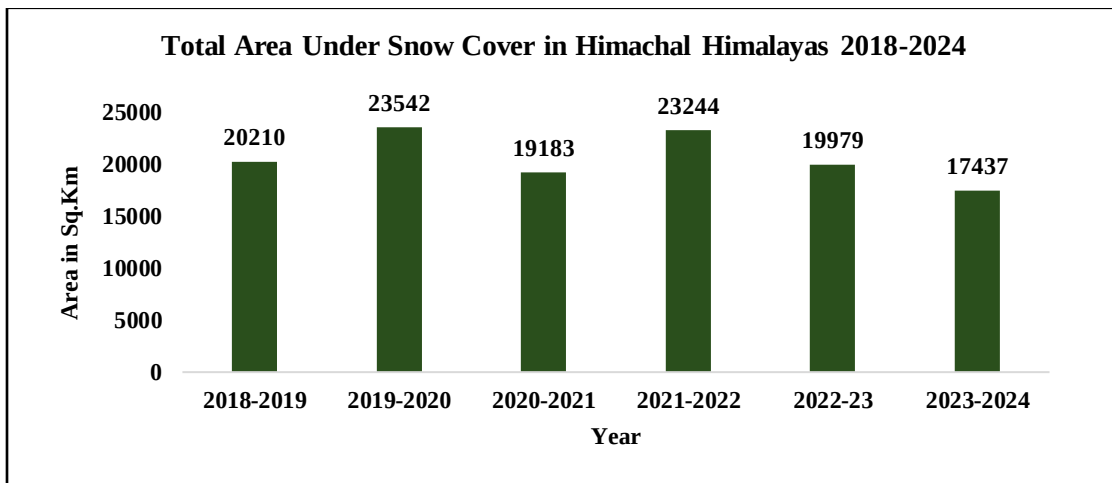


Figure 4 Total area under snow in Himachal Himalaya from 2018 to 2024

The observed decrease in Himachal Pradesh's snow cover area between 2022–2023 and 2023–2024 suggests a substantial change in the local weather. Rising winter temperatures, changed

precipitation patterns, and an increase in the frequency of extreme weather events—all effects of ongoing climate change—may be to blame for this decline. In addition to affecting downstream areas' access to water, the declining amount of snow cover also jeopardizes the ecological equilibrium and conventional farming practices that rely on snowmelt. To lessen the long-term effects of this trend on the Himalayan region's agriculture, hydrology, and biodiversity, integrated climate adaption methods and ongoing monitoring are crucial.

3. SATELLITE INTEGRATED LANDSLIDE ASSESSMENT AND ALERT SYSTEM (SILAAS)

Himachal Pradesh is vulnerable to landslides and other natural disasters because of its hilly and mountainous landscape. Large portions of the state's territory are always under danger because to the state's remarkable rise in landslide incidents in recent years. This susceptibility is caused by its rough terrain, drastic weather patterns, and increasing human activity, which can have disastrous effects like fatalities, destruction of infrastructure and property, lost connectivity, and environmental deterioration. Landslides are mostly caused by the monsoon season, especially in the Himalayan region, with its heavy and protracted rainfall. Among the technological innovations that are essential to effective disaster mitigation is the creation of an extensive landslide inventory.

- In order to map post-monsoon landslides in 2023 and build a state-wide landslide database, the current study was conducted in Himachal Pradesh. The National Remote Sensing Centre (NRSC) created the Field Landslide Inventory Mapping (FLIM) software was used in the study. Landslide inventory was prepared manually using high-resolution LISS IV satellite images from 2022 and 2023 (5.8 m spatial resolution).
- Heavy rains during the 2023 monsoon caused extensive damage throughout the state. 32 flash floods and 163 significant landslides were caused by three periods of exceptionally heavy rainfall, which occurred from July 8–11, August 14–15, and August 22–23. In order to create a thorough inventory, 13569 landslides were mapped as a result of the anthropogenic activities and protracted, intense precipitation events.
- Severe Human and Infrastructure Loss: There was extensive destruction in Himachal Pradesh as a result of the 2023 monsoon-caused landslides, especially in the districts of Mandi, Shimla, and Kullu. On August 14, 2023, a huge landslide near the Shiv Temple in

Summerhill, Shimla, killed 20 people, making it one of the most tragic events. Thousands of homes in the impacted areas were either totally destroyed or severely damaged. Roads, bridges, and agricultural land were among the critical infrastructures severely damaged; numerous bridges were washed away, preventing communication and impeding rescue efforts.

- Four field surveys were carried out over 12 districts of Himachal Pradesh in order to verify the satellite-based mapping. Out of the 290 FLIM points obtained from these field trips, 286 were confirmed by NRSC. Duplication at identical positions resulted in the exclusion of four points.
- Kangra (4027 landslides), Mandi (2169), Solan (1930), and Chamba (1666) were the districts most affected, according to the district-by-district research. Conversely, the areas with the fewest landslides were Lahaul and Spiti (31), Kinnaur (65), and Una (98). The detailed table depicting number of landslides in Himachal Pradesh is at table 3.

Table 3 District wise distribution of landslide mapped for 2023 post monsoon of Himachal Pradesh

S. No.	District Name	Number of landslides
1.	Bilaspur	442
2.	Chamba	534
3.	Hamirpur	1666
4.	Kangra	4027
5.	Kinnaur	65
6.	Kullu	729
7.	Lahaul and Spiti	31
8.	Mandi	2169
9.	Shimla	483
10.	Sirmour	1395
11.	Solan	1930
12.	Una	98



Figure 5 Landslide at Shiv Mandir, Summerhill, in Shimla district, Himachal Pradesh



Figure 6 A Flash flood at Thunag Market in Mandi district, Himachal Pradesh



Figure 7 Landslides in Nigulsari, Kinnaur district, Himachal Pradesh



Figure 8 Footpath landslide at Himland, Shimla, district Shimla, Himachal Pradesh



Figure 9 Landslide at Kanlog, Shimla, district Shimla, Himachal Pradesh



Figure 10 Landslide at Kanlog (near Rajvir Motors), Shimla, district Shimla, Himachal Pradesh



Figure 11 Landslide at Kotropi, Mandi district, Himachal Pradesh (landslide on NH-154, active since 2017, reactivates annually during monsoon)

In order to better understand the scope, distribution, and recurrent nature of landslide events—particularly in the wake of extreme monsoon-induced disasters like those that occurred in 2023—the State Centre on Climate Change has mapped all landslides using visual interpretation technique based on satellite imagery (LISS IV) in Himachal Pradesh and carried out extensive ground truthing through 286 FLIM points to strengthen the above data. Such proactive efforts are essential for disaster preparedness and risk reduction, enabling more accurate hazard zonation, early warning systems, and informed land-use planning. Additionally, this data-driven approach supports long-term climate resilience strategies, encourages scientific decision-making, and enhances the ability of local and state authorities to safeguard people, infrastructure, and ecosystems in the face of growing climate variability.

This work lays the foundation for better disaster preparedness and response in Himachal Pradesh by making a significant contribution to the SILAAS project's development of a Regional Landslide Early Warning System (LEWS).

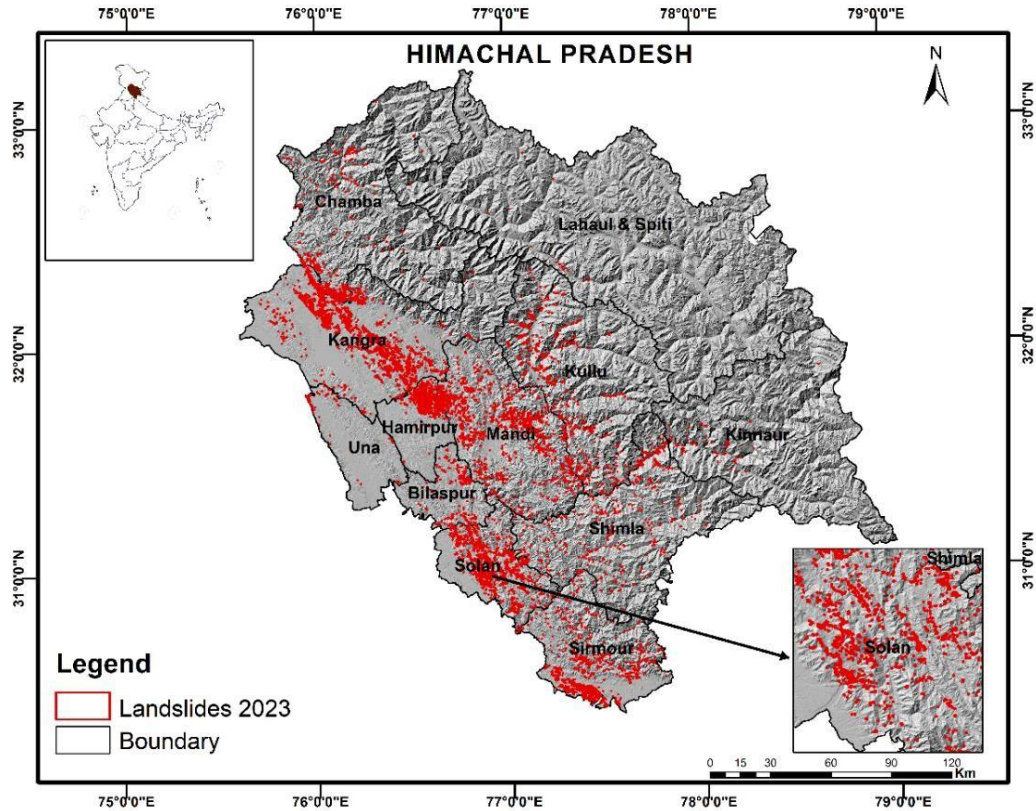


Figure 12 Landslide Inventory map of Himachal Pradesh

4. IMPACT OF CLIMATE CHANGE IN WATER FLOW PATTERN OF SATLUJ CATCHMNET (SJVNL) JOINT STUDY WITH IISC BAGALORE

This study, undertaken in collaboration with IISc Bangalore at the request of SJVNL, aims to assess the impact of climate change on the water flow patterns within the Satluj catchment. As part of this initiative, significant progress has been made in glacier monitoring across the basin.

A comprehensive glacier inventory was developed using a combination of satellite datasets, including LANDSAT 04, LANDSAT 05, LANDSAT 08, LISS III and high-resolution LISS-IV imagery. The study area spans from the glacier origins in the Tibetan Himalayan region to downstream reaches of the Satluj Basin. Glacier boundaries were delineated for multiple time periods to enable a temporal comparison of glacier extent and retreat patterns. Notably, glacier inventories for the years 2000, 2011, and 2020 were completed using LANDSAT 07, LANDSAT 08, and LISS III imagery, respectively. This has facilitated a detailed assessment of changes in

glacier extent over the past two decades, forming a critical component in understanding climate-induced hydrological variations in the basin.

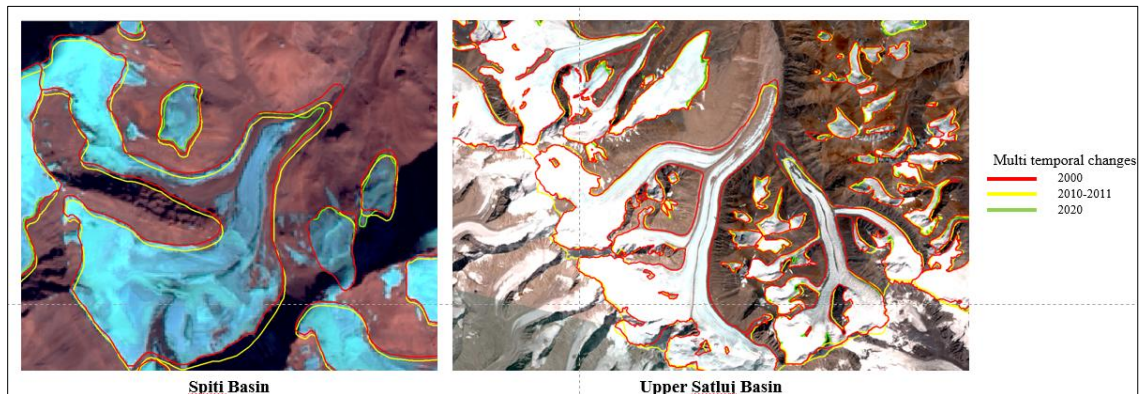


Figure 13 Multi temporal variations in Spiti and Upper Satluj basins

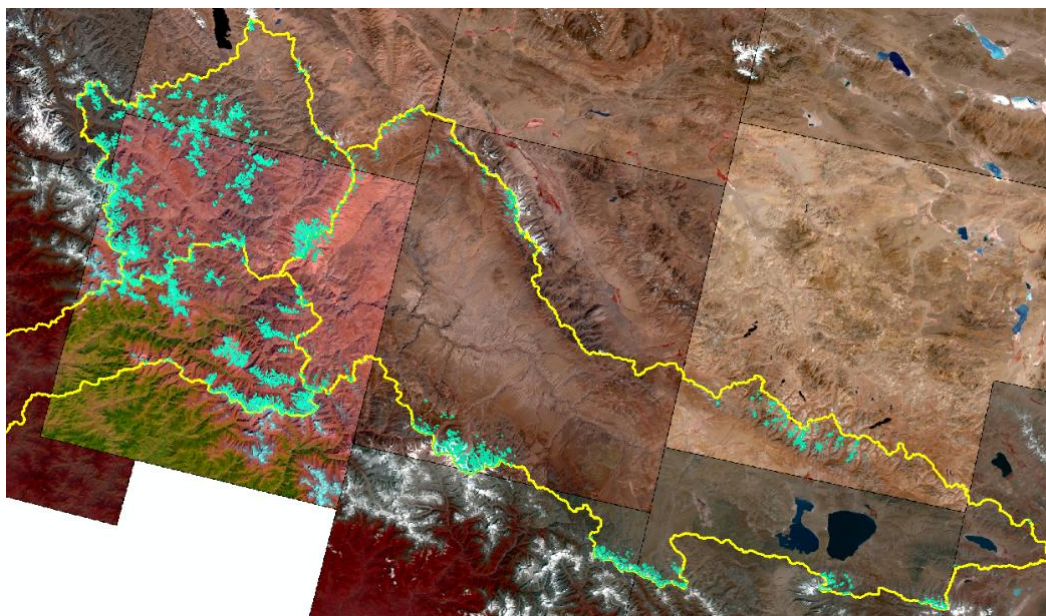


Figure 14 Spatial overview of Satluj basin

The glacier monitoring work in the Satluj Basin is crucial for understanding the impacts of climate change on regional water resources. The study reveals significant glacial retreat between 2000 and 2020, indicating reduced long-term water availability from snow and ice melt. These findings are vital for planning hydropower operations, managing seasonal water flows, and strengthening climate adaptation strategies. The use of multi-temporal satellite data ensures accurate, science-based insights to support sustainable water resource management and disaster risk reduction in the Western Himalayas.

DISASTER MANAGEMENT STUDIES

In Himachal Pradesh, whose susceptibility is increased by the fragile Himalayan environment and heavily inhabited river valleys, monitoring glacial lakes is the first line of defense against climate-induced calamities. Climate change-induced accelerated glacier melt has increased the risk of Glacial Lake Outburst Floods (GLOFs), which can seriously jeopardize infrastructure, power plants, and downstream communities. These unexpected floods have the potential to cause catastrophic death tolls and financial losses. As a result, proactive integration into the state's disaster management framework, early warning systems, risk mapping, and ongoing monitoring to detect potentially dangerous glacial lakes (PDGLs) are crucial for safeguarding human life, vital infrastructure, and long-term climate resilience. The Centre has carried out several studies and shared the findings with the concerned line departments. Here are some of the key studies undertaken during the financial year 2024–25:

5. MONITORING OF PARECHHU LAKE

Parechhu Lake is a shallow geomorphic depression located in the Spiti sub-division of Lahaul & Spiti District. Formed by the Parechhu River, it joins the Spiti river on its left bank near Sumdo. The presence of the Sumdo-Kaurik Fault and the region's inherently unstable geology frequently trigger landslides, which block the downstream river channel and lead to water accumulation in the depression. Owing to its history of destructive events, the lake has been continuously monitored during the ablation season (April to September) since 2001. In 2024, regular observations were conducted, and findings related to water spread were submitted to both the government and Satluj Jal Vidyut Nigam Limited (SJVN).

OBSERVATIONS

Based on the analysis of IRS-R2-L3-97-48, 24th July 2024, high resolution satellite data having spatial resolution of 5.8 m, the following observations are made:

- ✓ A water body situated in a topographic depression of braided channel. The water appears to be contained within the boundaries outlined in red, likely due to glacial meltwater, precipitation, or both. The lake seems relatively stable but surrounded by sediment-laden inflows.

- ✓ Water enters from the western side via a braided channel system, indicating high sediment load and variable flow paths. This pattern is common in glacial or snow-fed rivers that transport a significant amount of silt and sand.
- ✓ The inflow and outflow seem to be comparatively normal as on 24th July 2024.
- ✓ There is a visible outflow on the eastern side, showing that the lake is not completely dammed.

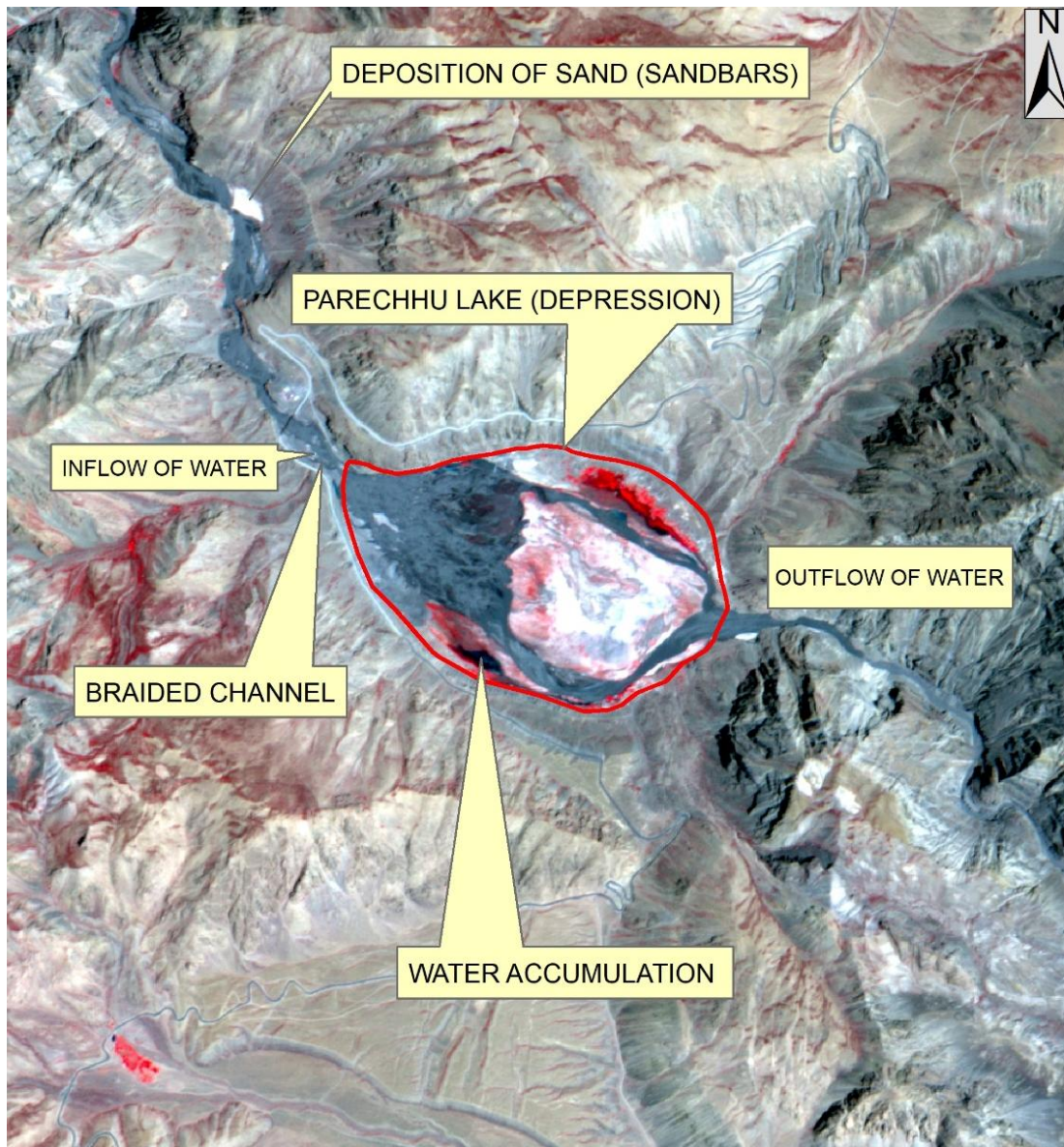


Figure 15 Satellite view of Parechhu Lake through IRS RS2 LISS-III 96-48 24th July 2024

- ✓ The braided nature of the inflowing channel suggests active sediment transport and variable discharge. This indicates seasonal flow changes, possibly driven by glacial melt in summer.
- ✓ Deposition of sand have formed along the channel, especially north of the lake. These are created when the river loses energy and deposits sediment- a sign of reduced flow velocity or spreading of water flow over a wider area.
- ✓ A mid-channel bar is visible inside the lake itself, which indicates ongoing deposition within the water body and it may dam when water inflow will increase. This is a sign of sediment build-up, which could change the lake's depth and flow dynamics over time.
- ✓ Noticeable accumulation in the southern part of the lake, likely due to lower elevation or basin topography. This suggests possible localized flooding or pooling due to slow drainage.
- ✓ As such based on the satellite data interpretation for the month from 24th July 2024, there does not seem to be any threat from the Parechhu lake have been observed. The lake needs regular monitoring as the ablation process is still undergoing and also needs the landslide monitoring in order to assess any further changes in the river flow/ blockade etc.

6. MONITORING OF GLACIAL LAKES AND WATER BODIES IN SATLUJ CATCHMENT USING REMOTE SENSING AND GIS TECHNIQUES DURING 2024

The Glacial lakes/ wetlands in Satluj River basin is the subject of the study, which follows it from its source close to Mansarovar Lake and Rakas Tal in the Tibetan Plateau (about 4,500 meters above sea level) to the Bhakra Gorge in Himachal Pradesh. The study area is divided into three sub-basins i.e., Spiti, Lower Satluj, and Upper Satluj in Tibet that make up the basin, which is a significant tributary of the Indus River.

The Satluj travels 620 miles across the untamed Himalayas, which are abundant in glacial resources and snow. This makes it ideal for investigations based on remote sensing, especially since a lot of the basin is inaccessible. The significance of the basin for hydropower is highlighted by the Nathpa-Jhakri Hydro-Electric Project (NJHEP), a significant run-of-river project in the area.

To monitor glacial lakes and water bodies, satellite images from AWiFS, LISS III, and LISS IV sensors onboard IRS-RS2 and RS2A were utilized during 2024. These data enabled effective

observation and mapping of high-altitude glacial features that are otherwise difficult to access. Remote sensing has thus proven essential for hydrological monitoring and climate-related assessments in this ecologically sensitive and strategically important Himalayan basin.

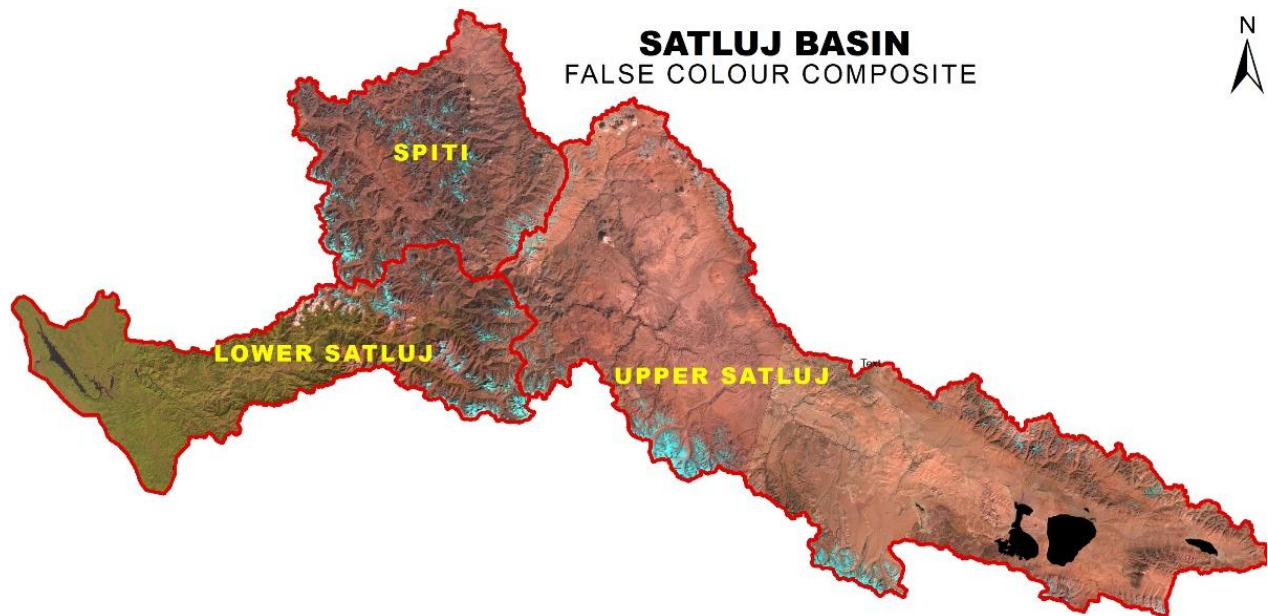


Figure 16 False color composite map showing sub basins of the Satluj river basin

METHODOLOGY

Satellite imagery covering the Satluj basin during the period from April to November 2023 was systematically analyzed. Cloud-free and snow free data from the AWiFS sensor for the year 2024 were utilized for temporal monitoring of lake dynamics. In addition, high-resolution imagery acquired from LISS-III and LISS-IV sensors onboard IRS-RS2 and RS2-A satellites was procured to facilitate detailed spatial assessments. The AWiFS data, with a spatial resolution of 56 meters, enabled the identification and delineation of all water bodies on monthly basis, irrespective of their areal extent. The mapped lake extents for 2024 were subsequently compared with those derived from AWiFS high resolution data for the year 2023 to assess interannual variations.

High-resolution satellite imagery from LISS-III and LISS-IV sensors was employed to accurately delineate water bodies across the Satluj catchment. The LISS-III sensor, with a spatial resolution of 23.5 meters, was used to map medium and large-sized water bodies, while the LISS-IV sensor, offering a finer resolution of 5.8 meters, enabled the identification and mapping

of smaller and scattered water bodies, particularly in upper catchment and mountainous areas where such features are often missed by coarser-resolution datasets.

The satellite imagery was processed using standard techniques such as visual interpretation, image classification, and spectral water indices like the Normalized Difference Water Index (NDWI) to enhance the detection of surface water features. This high-resolution mapping has contributed to the development of an updated inventory of lakes and reservoirs, which is critical for understanding changes in surface water availability, glacial melt contribution, and potential risks related to flooding or glacial lake outburst floods (GLOFs).

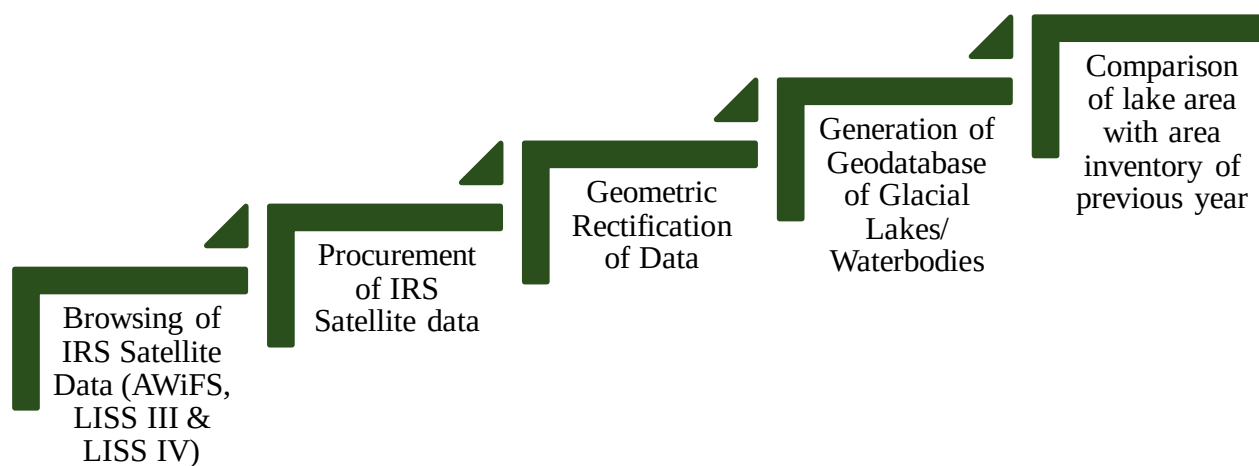


Figure 17 Flow chart methodology

INVENTORY OF LAKES BASED ON AWIFS SATELLITE DATA

The seasonal and temporal variations in lake formation and visibility in the Satluj basin during 2024 were analyzed using AWiFS satellite data with a spatial resolution of 56 meters. This assessment also includes a comparative analysis with multiple preceding years to highlight interannual changes.

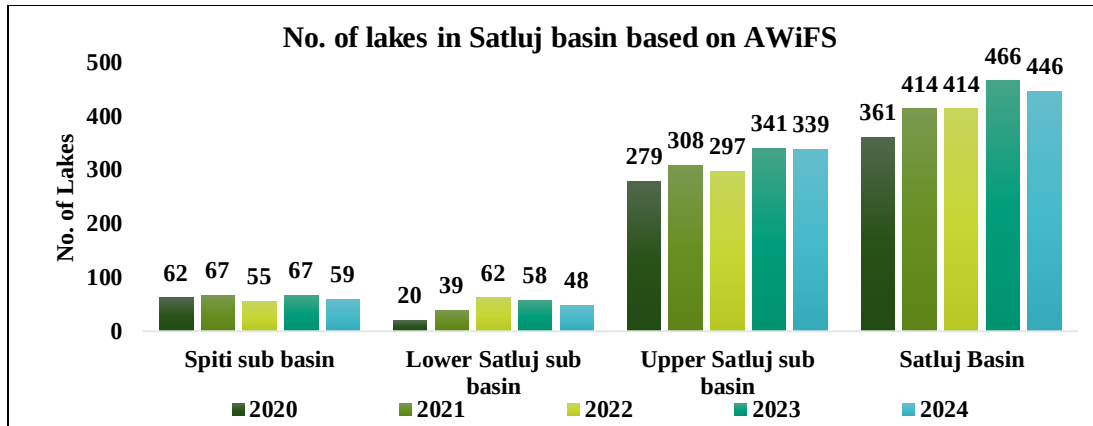


Figure 18 Number of lakes in Satluj basin based on AWiFS satellite data from 2020 to 2024

The number of lakes in the Satluj basin has shown a notable increasing trend over the period from 2020 to 2024. In 2020, a total of 361 lakes were identified, which steadily rose to 466 by 2023, indicating a significant expansion in surface water bodies over these years. However, a slight decline was observed in 2024, with the number of lakes decreasing to 446. This fluctuation may be attributed to seasonal variations, glacial melt patterns, or changes in precipitation and temperature regimes, highlighting the dynamic nature of hydrological features in the region (figure 18). A comparative analysis spanning from 2014 to 2024 reveals an overall increasing trend in the number of lakes within the region, as illustrated in Figure 19.

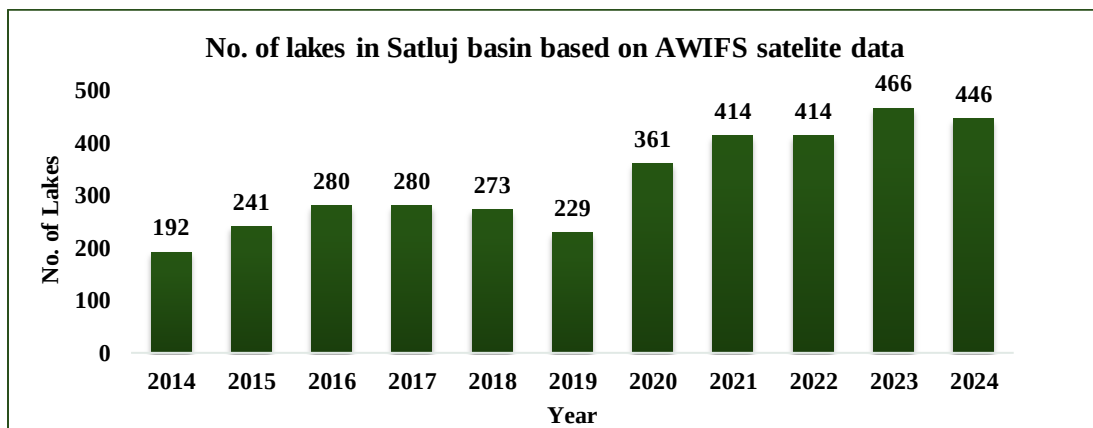


Figure 19 Number of lakes in Satluj basin based on AWiFS satellite data from 2014 to 2024

INVENTORY OF LAKES BASED ON LISS-III SATELLITE DATA

The number of lakes in the Satluj basin has shown dynamic variation from 2020 to 2024, with the overall count peaking in 2023. Upper Satluj consistently recorded the highest number of

lakes, indicating it as a critical zone for hydrological monitoring. While some sub-basins like Lower Satluj showed increasing trends initially, all regions experienced a slight decline in 2024 (figure 20).

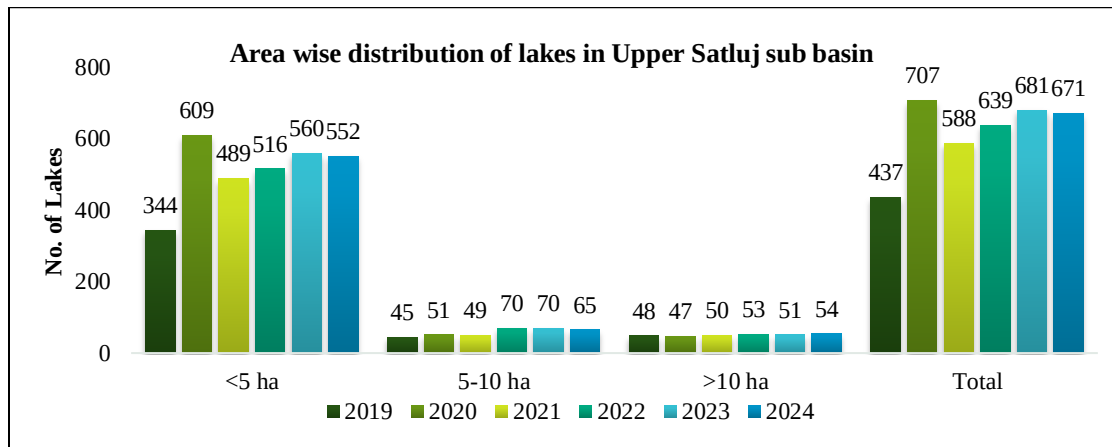


Figure 20 Area wise distribution of lakes in Upper Satluj sub basin based on LISS-III satellite data from 2020 to 2024

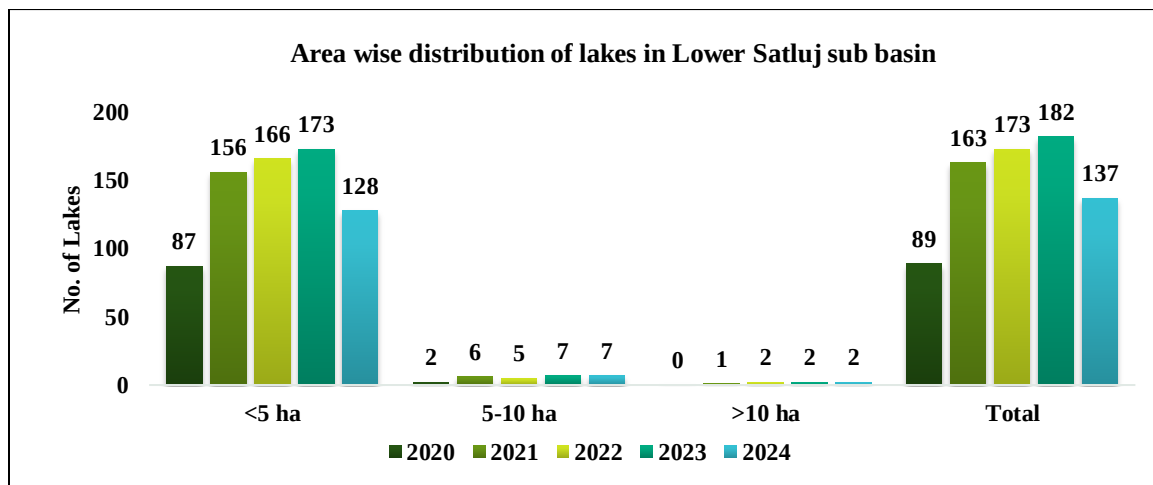


Figure 21 Area wise distribution of lakes in Lower Satluj sub basin based on LISS-III satellite data from 2020 to 2024

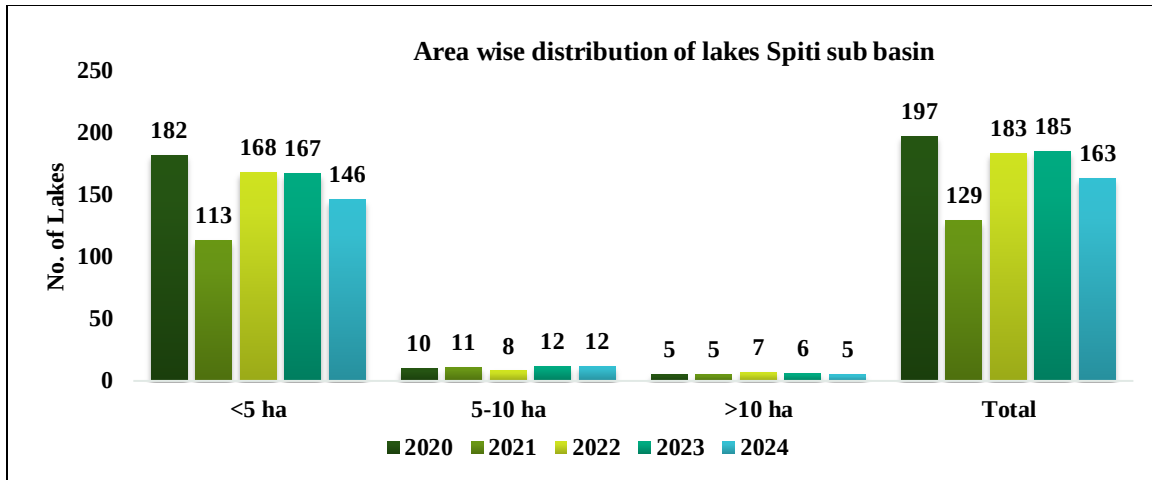


Figure 22 Area wise distribution of lakes in Spiti sub basin based on LISS-III satellite data from 2020 to 2024

The graph shows a significant rise in the number of lakes (<5 ha) in the Lower Satluj sub basin from 2020 to 2023, with a peak of 173 lakes in 2023, followed by a decline in 2024. Medium (5–10 ha) and large lakes (>10 ha) remained minimal and nearly unchanged. The total lake counts also followed this trend, peaking in 2023 (182 lakes) and dropping in 2024 (137 lakes) at figure 21. The number of lakes in the Spiti sub basin (<5 ha) showed significant fluctuation from 2020 to 2024, peaking in 2020 (182 lakes) and dipping in 2021 (113 lakes), followed by a modest rebound before another drop in 2024 (146 lakes). Medium (5–10 ha) and large lakes (>10 ha) remained relatively stable and low in number throughout the period. The total lake count mirrored these trends, with a high of 197 in 2020 and a low of 129 in 2021 (figure 22).

These results collectively point to high hydro-climatic sensitivity of the region and reinforce the need for ongoing observation and modelling of glacier-fed lakes. The dynamic behavior of these lakes serves as an indicator of climate change impacts and supports proactive planning for risk mitigation, water resource management, and climate resilience in Himalayan River basins.

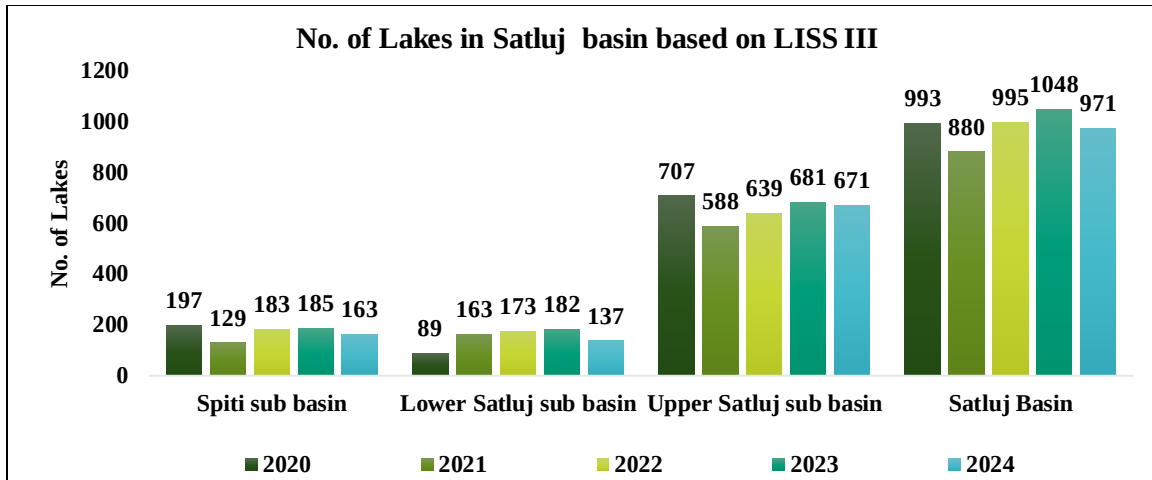


Figure 23 Number of lakes in Satluj basin based on LISS-III Satellite data from 2020 to 2024

The number of lakes in the Satluj basin has shown dynamic variation from 2020 to 2024, with the overall count peaking in 2023 (1048 lakes). Upper Satluj sub basin consistently recorded the highest number of lakes, indicating it as a critical zone for hydrological monitoring. While some sub basins like Lower Satluj showed increasing trends initially, all regions experienced a slight decline in 2024. These fluctuations highlight the need for continuous glacier and lake monitoring to assess climate-induced hydrological changes and potential risks like glacial lake outburst floods (GLOFs) (figure 23).

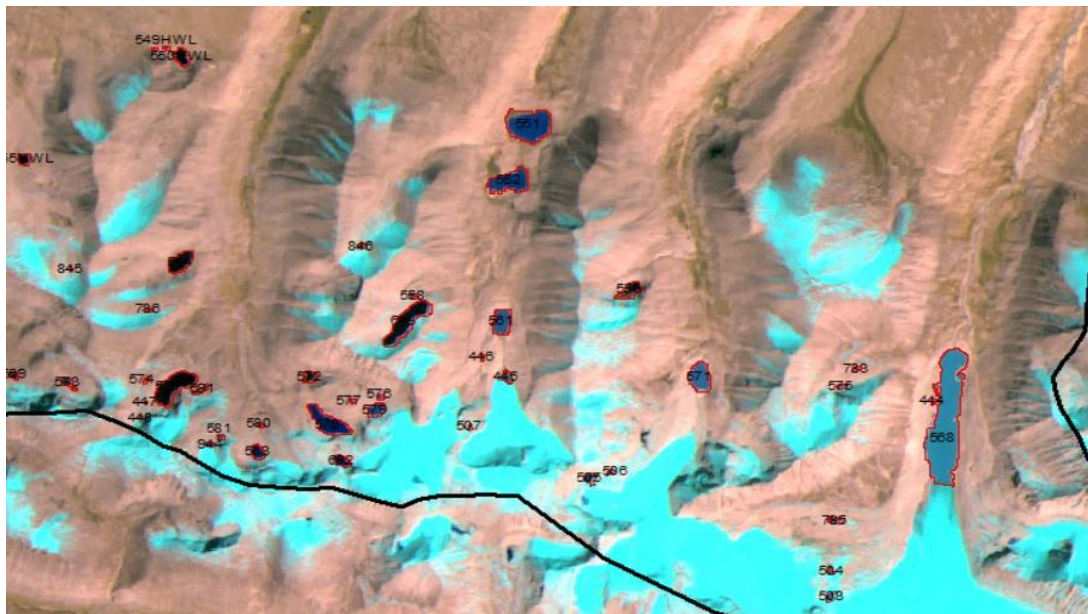


Figure 24 Glacial lakes in Upper Satluj sub basin based on LISS-III Satellite image

INVENTORY OF LAKES BASED ON LISS-IV SATELLITE DATA

High-resolution LISS-IV satellite data, which offers a spatial resolution of 5.8 meters, was used to create an inventory of lakes in the Satluj Basin. Small and medium-sized water bodies, which are frequently overlooked in coarser-resolution datasets, can be precisely delineated and mapped thanks to this greater resolution. Lake detection, mapping, and classification according to size, elevation zones, and spatial distribution were the main objectives of the analysis.

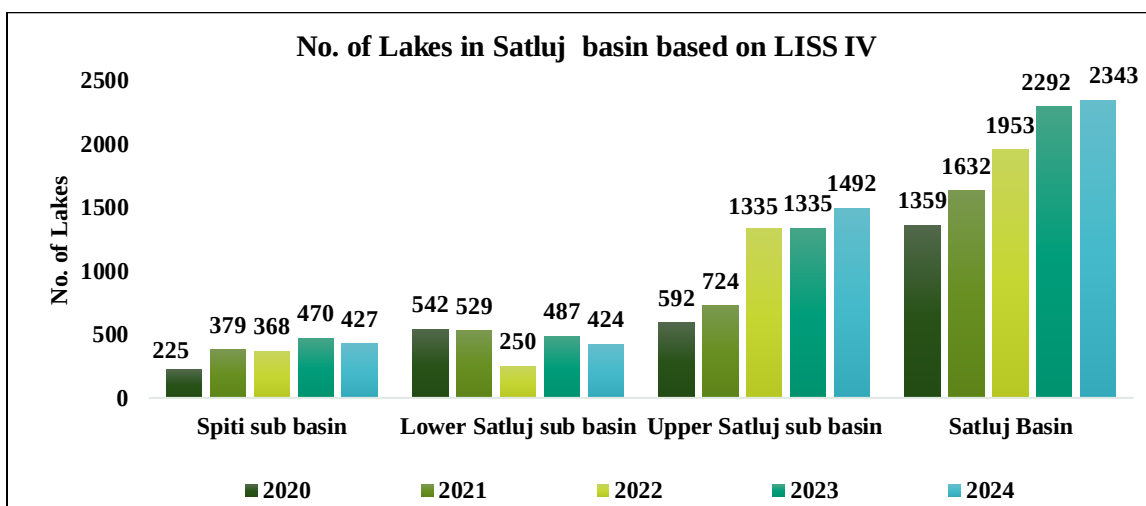


Figure 25 Number of lakes in Satluj basin based on LISS-IV Satellite data from 2020 to 2024

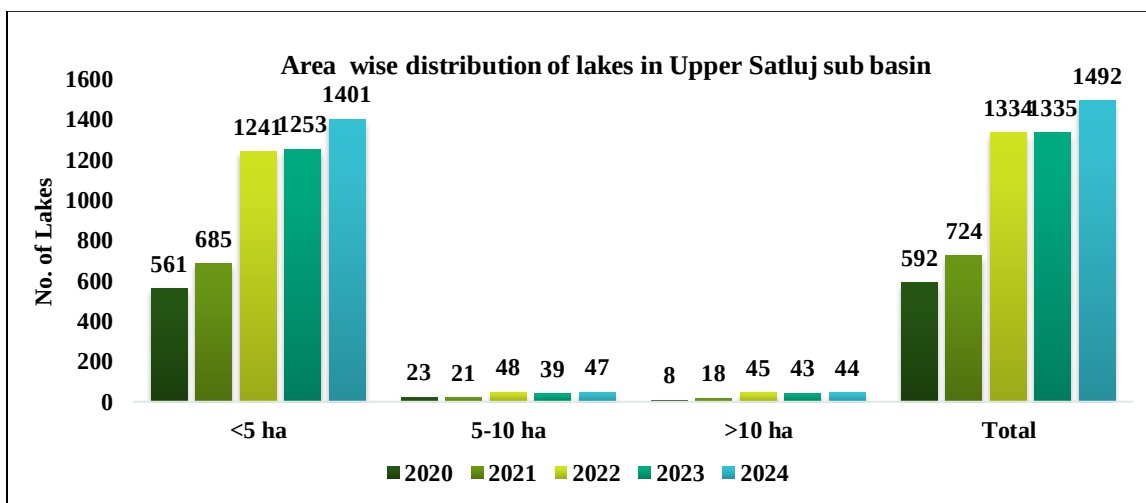


Figure 26 Area wise distribution of lakes in Upper Satluj sub basin based on LISS-IV satellite data

A thorough geographical evaluation was made possible by the LISS-IV imagery, which showed both seasonal and permanent lakes in the basin's several physiographic zones. Using visual interpretation techniques, geodatabase of lakes was generated and categorized (on the basis of areal extent and sub basins). The lake inventory is an important starting point for monitoring the effects of climate change, understanding hydrological dynamics, and developing disaster risk reduction plans. Regular updates using LISS-IV and other high-resolution datasets will be necessary to capture continuous changes in the distribution and characteristics of lakes.

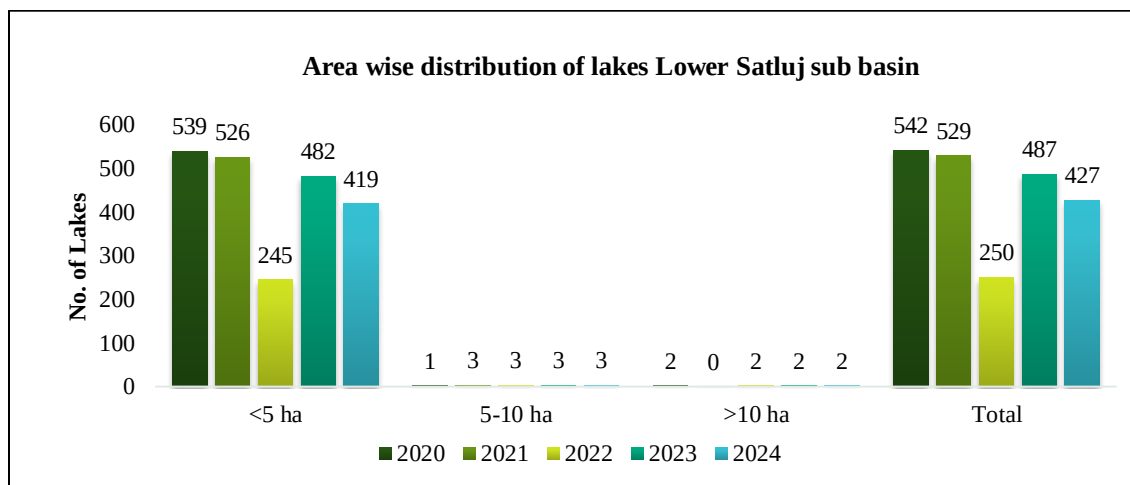


Figure 27 Area wise distribution of lakes in Lower Satluj sub basin based on LISS-IV satellite data

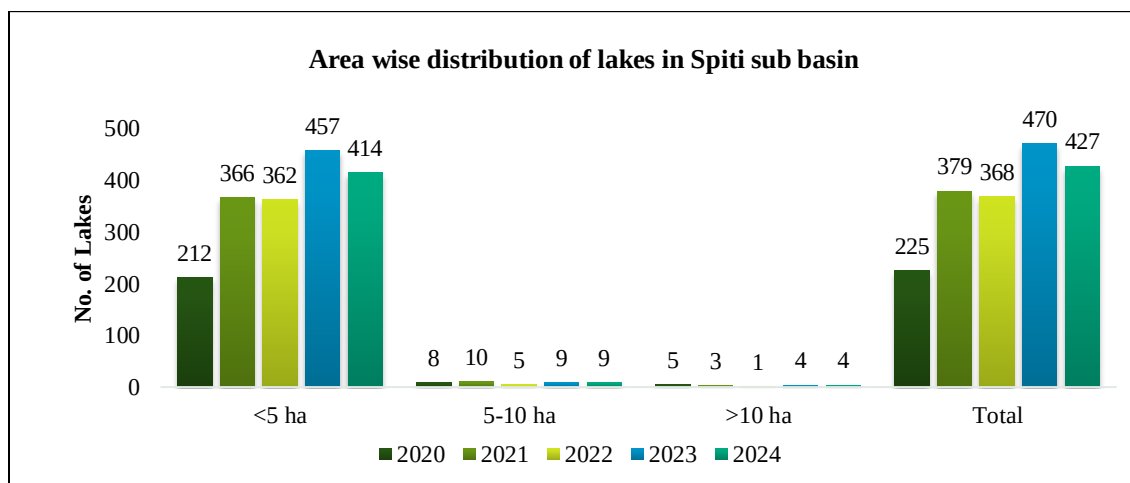


Figure 28 Area wise distribution of lakes in Spiti sub basin based on LISS-IV satellite data

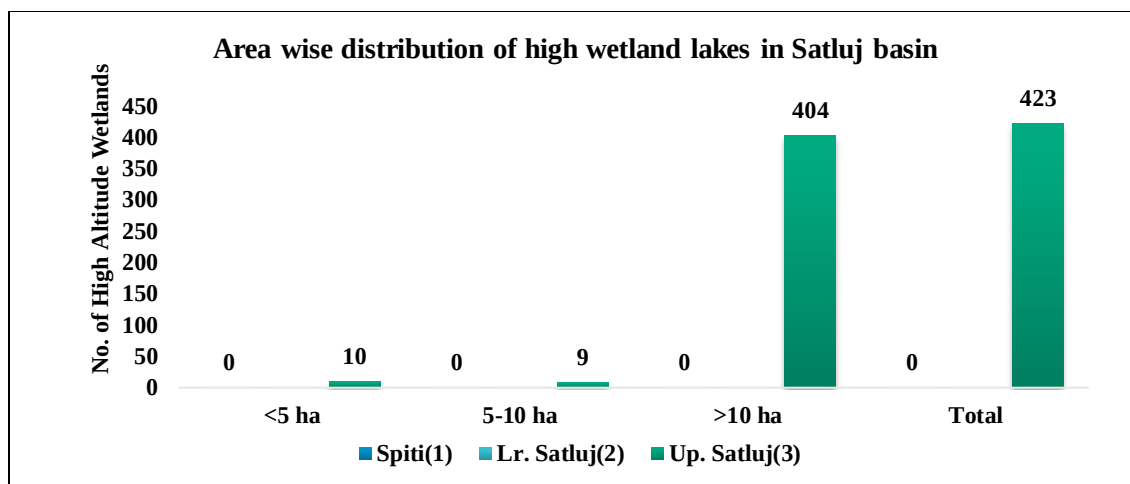


Figure 29 Area wise distribution of High-Altitude wetland lakes in Satluj Basin based on LISS-IV satellite data

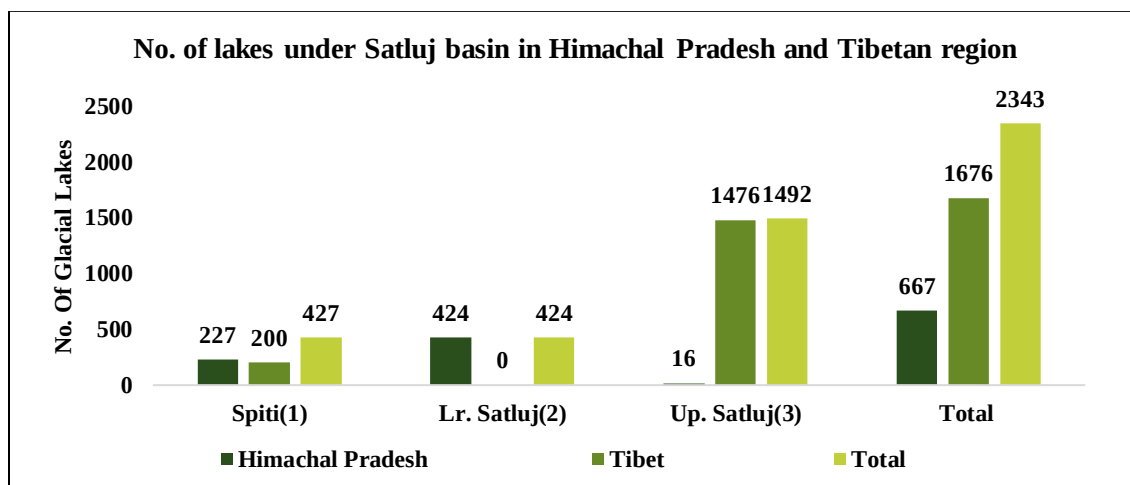


Figure 30 Number of lakes under Satluj basin based on LISS-IV satellite data in Himachal Pradesh and Tibetan region



Figure 31 High altitude lake in Upper Satluj sub basin

SIGNIFICANCE

The continuous monitoring of lakes in the Satluj basin by the State Centre on Climate Change holds critical significance for Himachal Pradesh's climate resilience planning. The changing number and distribution of high-altitude lakes, as revealed through multi-year satellite imagery, serve as important indicators of glacial retreat and snowmelt—key consequences of climate change in the Himalayan region. These observations not only enhance our understanding of hydrological shifts but also play a pivotal role in identifying potential risks of glacial lake outburst floods (GLOFs), which pose a serious threat to downstream communities and infrastructure. The data generated through this study aids in water resource planning, disaster risk reduction, and informs adaptive strategies. Importantly, the Centre regularly shares these findings with relevant line departments, strengthening inter-agency coordination and preparedness across the state.

7. MONITORING OF GLACIAL LAKE OUTBURSTS IN DIFFERENT BASINS VIZ., CHENAB, BEAS, RAVI AND SATLUJ DURING 2022

Glacial lakes, which are frequently found near the edges of ice sheets and glaciers, are profoundly impacted by the existence of glaciers (Fitzsimons and Howarth, 2018). Glacial lake outbursts, is the sudden withdrawal of water from a glacier lake triggers catastrophic floods. Because of their inherent instability, GLOFs can form on, inside, beneath, or near glaciers (Kehew et al., 2013). Roughly 3 million-hectare Himalayan region's glaciers are rapidly retreating, losing mass, which leads to the emergence of glacial lakes and ultimately floods. The structures and communities downstream are critically susceptible to damage from the glacier lake eruptions. A variety of postglacial alterations to the environment, such as shifts in water management, fragility of land slopes, seismic trembling, magnetic fields, and plant change, have made these lakes significant ecological records. Glacier Lake outbursts have resulted in extensive geomorphological alterations with particular landscape and have contributed to the biggest flood catastrophes in history.

The impacts of climate change are evident and severe. Extreme weather events, including wildfires, droughts, floods, and heatwaves, are becoming more frequent and intense. Melting glaciers and ice caps are driving sea-level rise, threatening coastal regions. The potential adverse effects of climate change will only intensify with further warming. Immediate and effective mitigation and adaptation measures are crucial to limiting the magnitude and rate of climate change and its associated hazards. Without decisive action, the risks to humanity and the planet will continue to grow.

However, the fragile and geologically young Himalayas are highly susceptible to climate change. The region experiences a warming trend of 0.15–0.60°C per decade, significantly exceeding the global average warming rate of 0.74°C per century (Ahmed et al., 2021). This warming has led to profound glaciological changes, including the formation of hazardous glacial lakes that threaten downstream communities and infrastructure.

Several studies have documented the retreat of Himalayan glaciers. For example, Ravindra et al. (2024), Romshoo (2023), Kulkarni et al. (2021b), and others have discussed the ongoing

changes. According to Patel et al. (2021), over the past two decades, four glacier basins—Chandra, Bhaga, Miyar, and Parvati—have experienced significant mass loss (0.2 km² per year) and glacier segmentation in certain areas due to climate change. In Himalayas, glaciers that result in lakes are losing ice at a significantly faster than others, accounting for up to 32% of the region's overall ice loss after 2000, as reported by King et al. (2019).

Glacier mapping through remote sensing is very successful because of the significant variations in snow and ice reflectance across the visible (VIS), near-infrared (NIR), and shortwave infrared (SWIR) portions of the spectrum. Kaab et al. (2014) described several methods for mapping and monitoring glaciers using space-based spectral data. The use of satellite data to estimate glacier contours has grown in popularity. Knowing the accuracy of glacier outlines is crucial, especially since they serve as the foundation for assessing change (Paul et al., 2017).

OBJECTIVE

To develop an updated inventory of glacial lakes in the Chandra, Bhaga, Miyar, Ravi, Jiwa and Parbati sub-basins for the year 2022, utilizing remote sensing and geospatial techniques to analyze changes in their characteristics and spatial distribution.

METHODOLOGY

Moraine-dammed glacial lakes (potential GLOFs) were identified throughout the **Chenab, Beas, Ravi, and Satluj river basins** using Landsat (30 m) and LISS III (23.5 m) satellite data collected between August and October 2022. The Satluj basin was specifically examined from its starting point at Mansarovar Lake in the Tibetan Himalayas. To represent the water spread area of each lake, lake boundaries were digitized in ArcGIS and then distinct IDs were assigned. The region's glacial lake monitoring and risk assessment are based on this mapped data. Figure 12 is showing all the basins and sub-basins mapped during 2022. The graph at figure 20 depicts area wise distribution of lakes from 2016 to 2022.

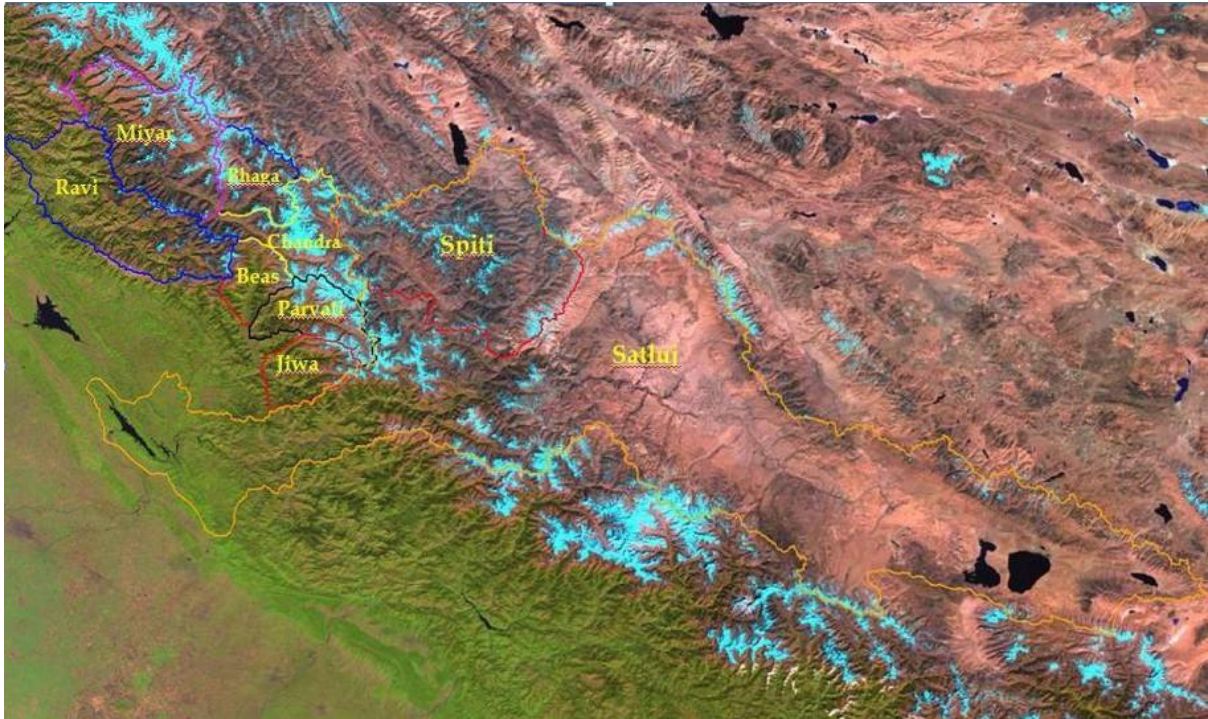


Figure 32 Different sub basins in Himachal Pradesh

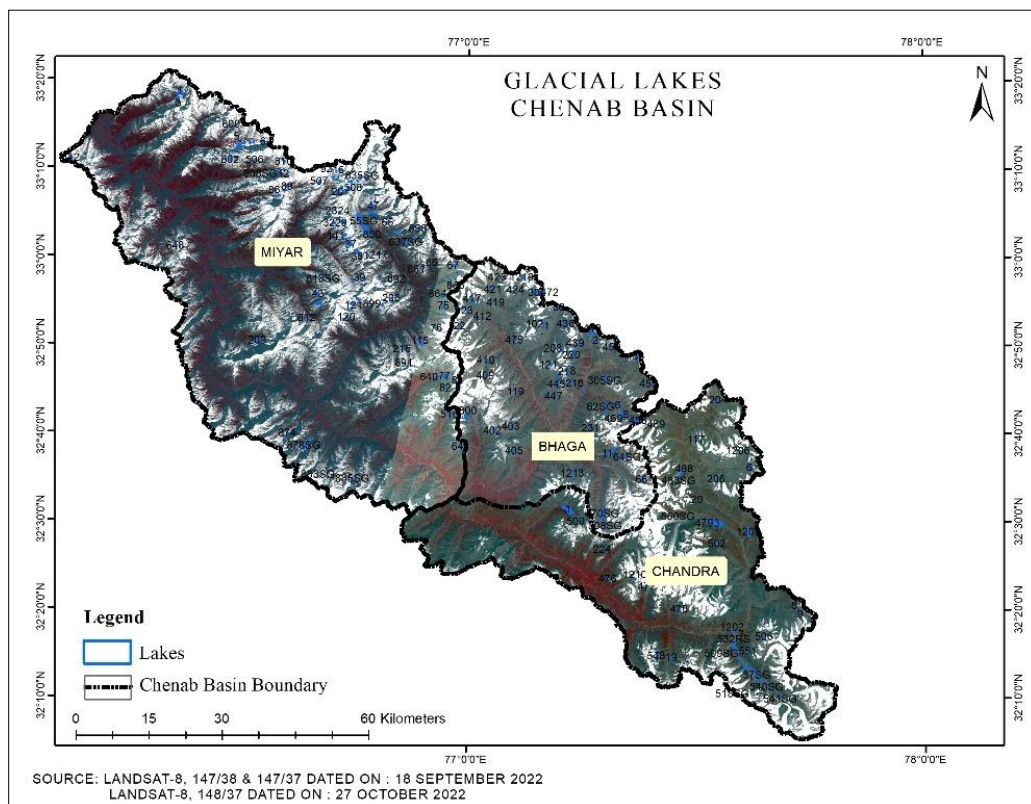


Figure 33 Glacial lakes in Chenab basin (Miyar, Bhaga, Chandra sub basins) during 2022

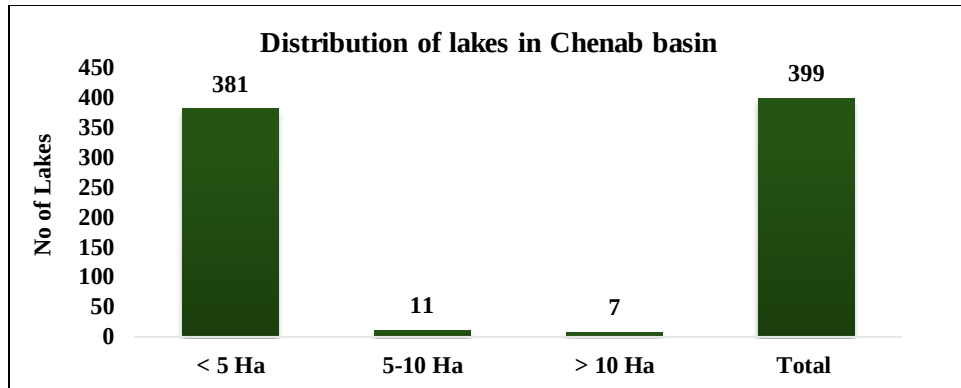


Figure 34 Area wise distribution of lakes in Chenab basin during 2022

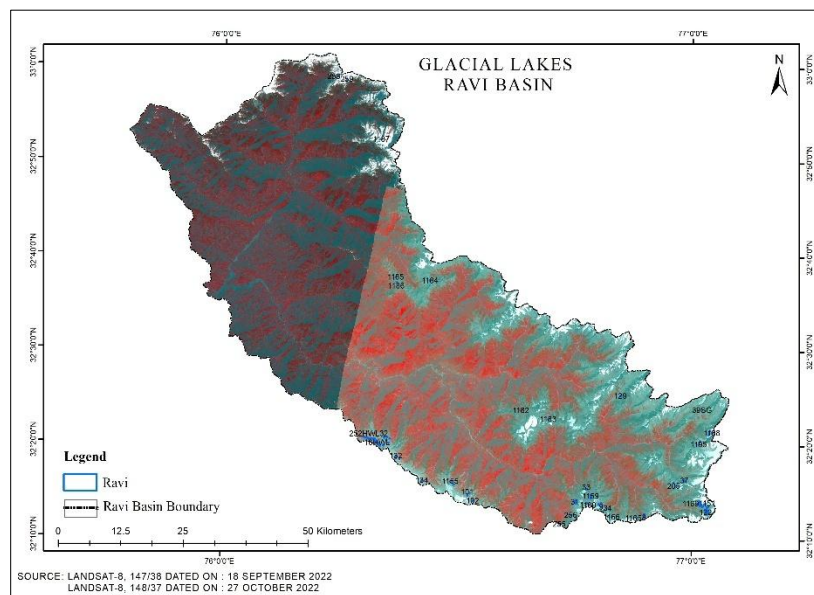


Figure 35 Glacial lakes in Ravi basin during 2022

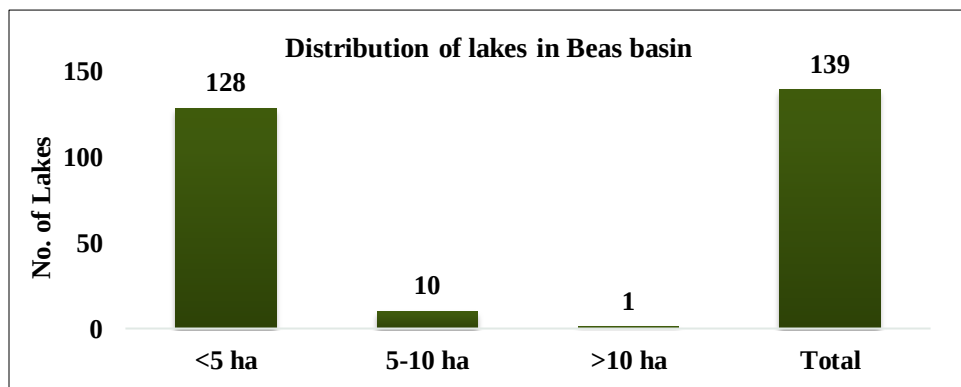


Figure 36 Area wise distribution of lakes in Beas basin during 2022

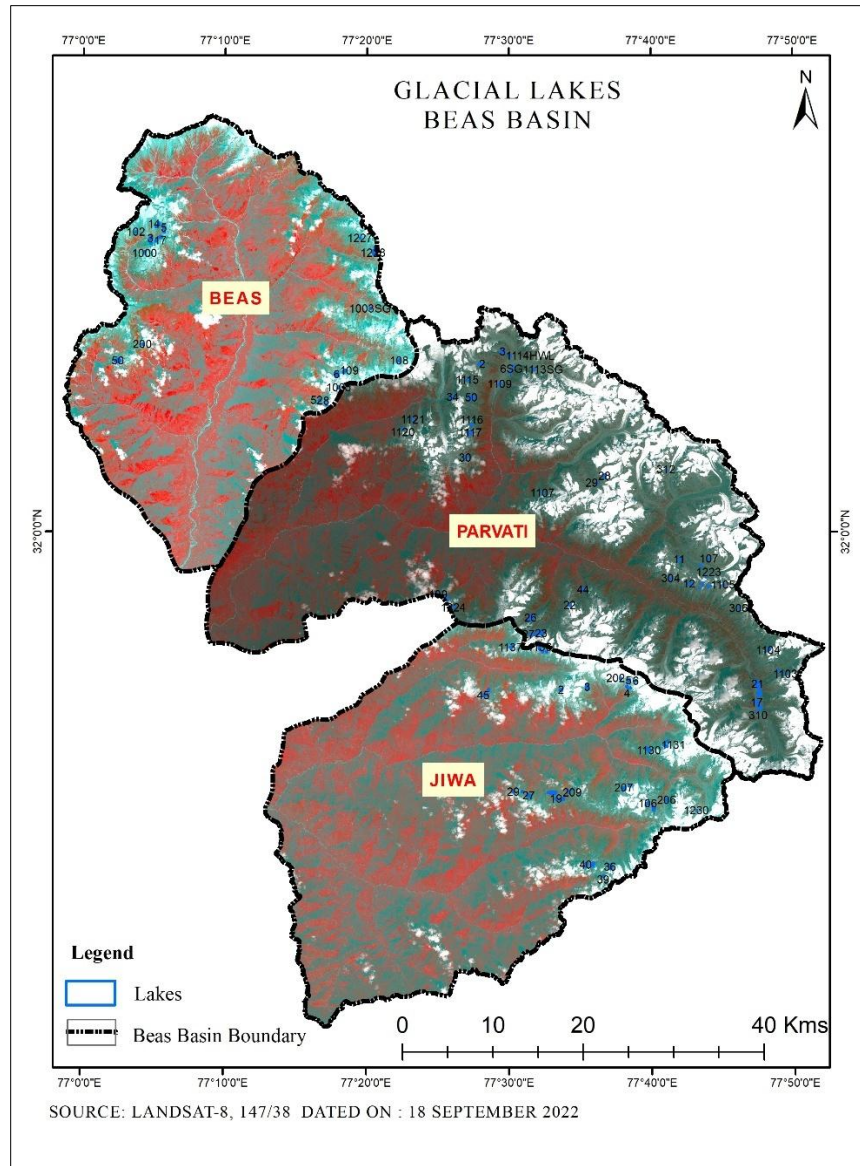


Figure 37 Glacial lakes in Beas basin and Parvati & Jiwa sub basin during 2022

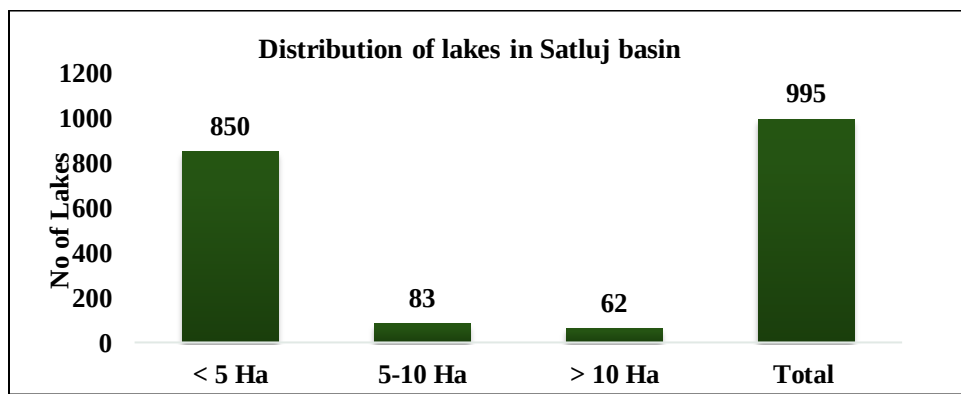


Figure 38 Area wise distribution of lakes in Satluj basin during 2022

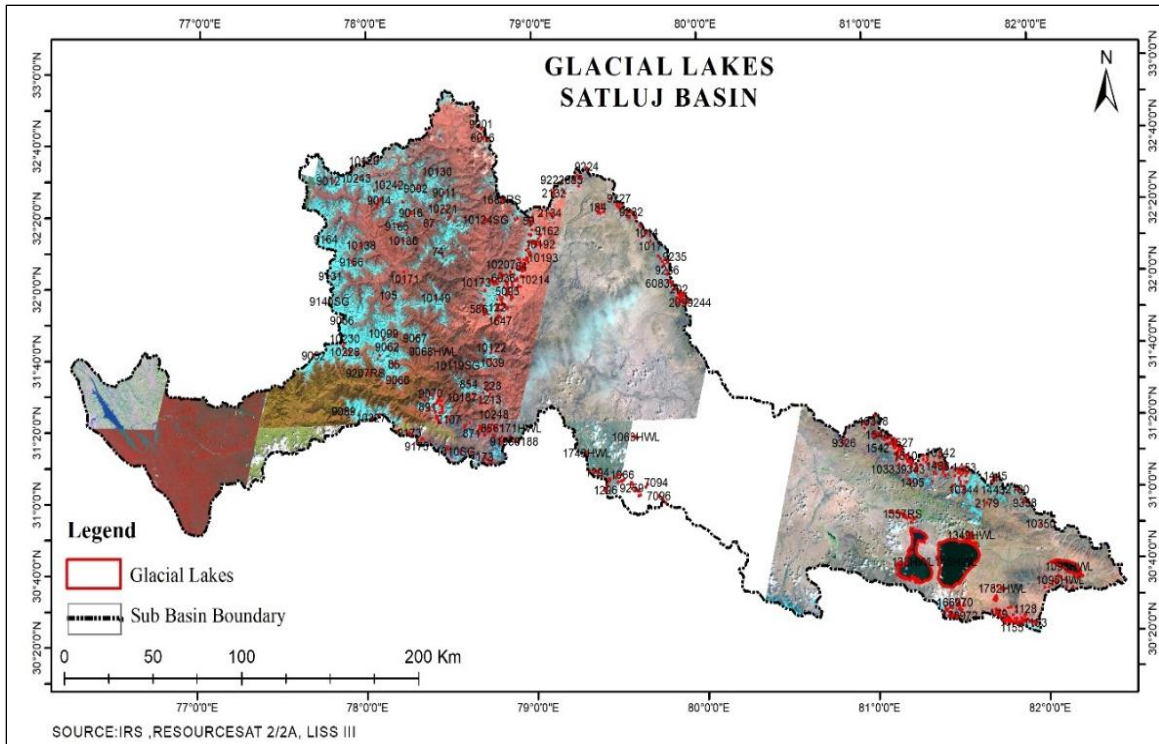


Figure 39 Glacial lakes in Satluj basin during 2022

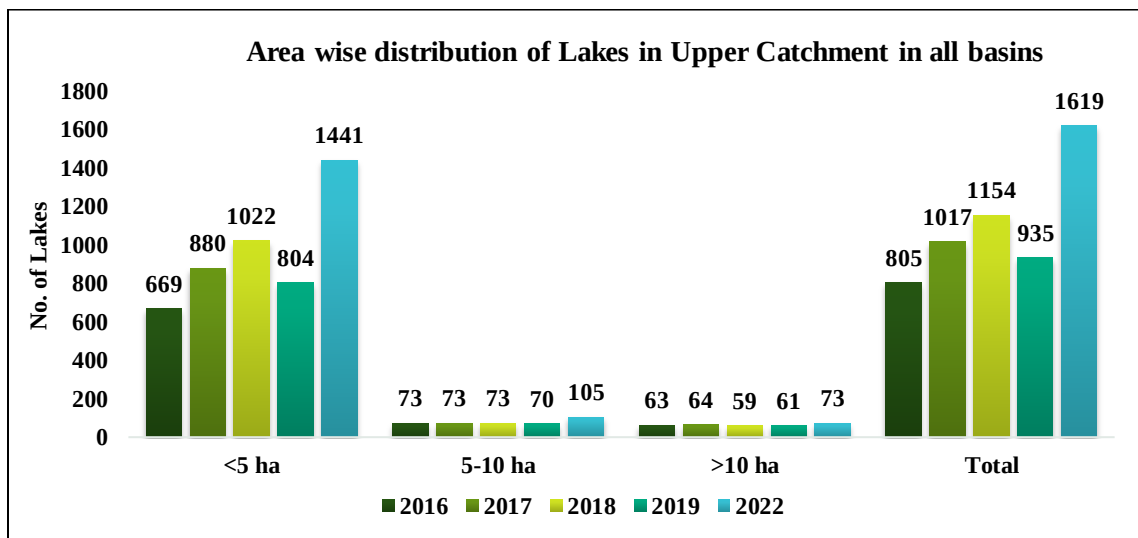


Figure 40 Distribution of lakes in upper catchment in all basins (Chenab, Beas, Ravi and Satluj basin) from 2016 to 2022

The figure 40 reveals a notable increase in the total number of lakes in the upper catchment areas across all basins from 2016 to 2022. The most significant rise is observed in small lakes (<5 ha),

which surged from 669 in 2016 to 1441 in 2022, indicating heightened glacier and snowmelt activity.

- **Small lakes (<5 ha):** These dominate the lake population and show the sharpest growth, highlighting increasing fragmentation or new formation of meltwater lakes due to glacial retreat.
- **Medium lakes (5–10 ha):** Remained relatively stable, with a slight uptick in 2022 (105 lakes), suggesting limited new formation or transformation of small lakes into this category.
- **Large lakes (>10 ha):** Numbers stayed mostly stable, indicating fewer large water bodies are forming or being sustained.

The total lake count rose from 805 in 2016 to 1619 in 2022, doubling in just six years, which is a clear indicator of significant cryospheric changes. This trend underscores the urgency of continuous monitoring, particularly for disaster risk management, water resource planning, and assessing climate change impacts in Himalayan headwaters.

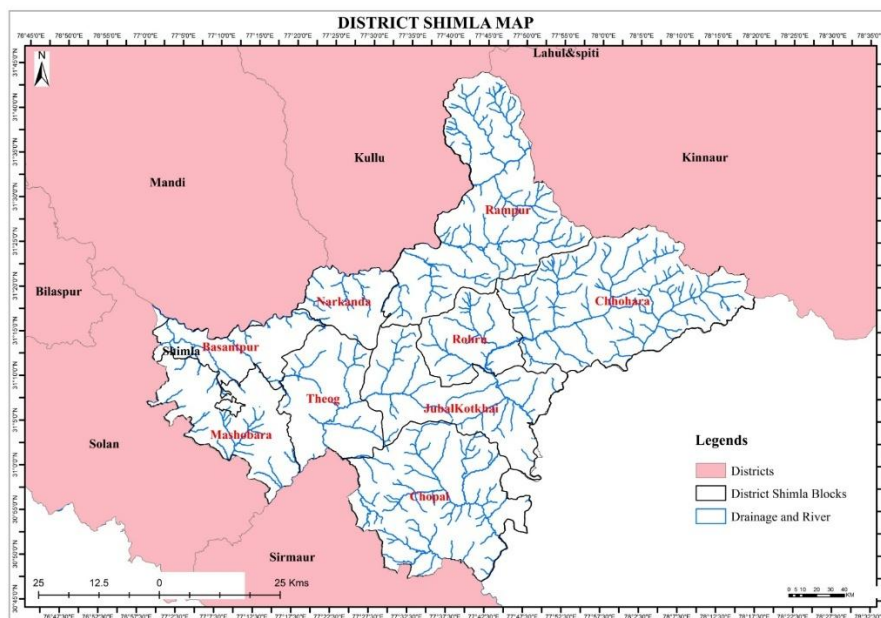
AGRICULTURE AND HORTICULTURE SECTOR

8. IMPACT OF CLIMATE VARIABILITY ON HORTICULTURE CROPS IN SHIMLA DISTRICT, HIMACHAL PRDAESH

Concern over climate change has spread throughout the globe, and the Shimla district of Himachal Pradesh is one very susceptible part with horticultural significance. Administratively, Shimla is the capital of Himachal Pradesh. The district comprises of 10 development blocks viz., Mashobra, Theog, Narkanda, Rampur, Jubbal-Kotkhai, Rohru, Chhohara, Chopal, Nankhari and Basantpur.

GEOGRAPHICAL OVERVIEW

The Shimla district, situated in the southern Himalayan mountains, the Shimla area offers a rocky terrain with hills, slender valleys, and majestic mountain ranges. The district's elevation ranges from 987 to 4,500 meters (3,238 to 14,764 feet) and northeastern regions have higher elevations, while southwestern regions have lower elevation.



Source: Himachal Pradesh Remote Sensing Cell

Figure 41 Geographical map of Shimla district, Himachal Pradesh

The landscape is intricately drained by tributaries of the Satluj, Yamuna, Pabbar, and Tons rivers. Spanning an area of 5131 sq km, district lies between latitudes 30°45' and 31°44' North and longitudes 77°0' and 78°19' East. The district shares its borders with Mandi and Kullu to the north, Kinnaur to the east, Uttarakhand to the southeast, Solan to the southwest, and Sirmaur to the south.

CIMATIC CHARACTERISTICS

Shimla district experiences four well defined seasons: winter (October to March), summer (March to June), monsoon (June to September), and Post-monsoon (October to November). The region features a subtropical in the valleys and tends to be temperate climate at the mountain, characterized by chilly, brisk winters and pleasantly warm summers. Shimla experiences an average yearly maximum temperature of 18.4°C and a minimum of 10.2°C. On May 27, 2010, the district's hottest temperature ever recorded was 32.4°F (90.3°F). The annual rainfall in the district is about 1415mm, whereas highest average monthly rainfall occurs in July. Figure 2 shows the temporal changes in the maximum and minimum temperatures between 1969 and 2024. On the other hand, figure 3 shows a graph of the rainfall variance over time.

HORTICULTURAL PRACTICES

Horticulture is a key pillar of Himachal Pradesh's economy, with major crops including apple, apricot, mango, orange, pear, plum, peach, and galgal. Crop zoning is influenced by elevation—apples thrive in higher altitudes (e.g., Jubbal, Kotkhair, Rohru), while stone fruits suit lower areas (e.g., Theog, Mashobra). Although traditionally rainfed and reliant on organic practices, Shimla's horticulture is transitioning to modern methods like clonal rootstocks, high-density planting, IPM, and mechanized tools, improving yields and reducing losses. Farmers increasingly use water-efficient practices like drip irrigation and farm ponds, and soil management includes mulching and composting. The government supports this sector through schemes such as MIDH, RKVY, and SMAM. Horticulture now spans 2.37 lakh hectares (up from 792 ha in 1950–51) and contributes 22% to the agricultural output value, worth ₹4,461.59 crores in 2023–24. Climate variability is challenging traditional systems, prompting a gradual shift to resilient practices like micro-irrigation and crop diversification.

METHODOLOGY

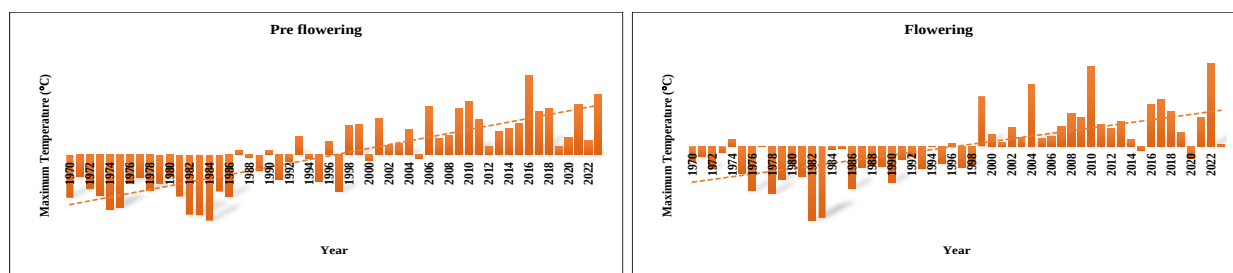
To ascertain the impact of changes in climatic variables on horticulture in the pre-flowering, flowering, and fruit setting phenological stages, the study employs three distinct statistical measures: a trend analysis based on the Mann Kendall Test, the Standardized Anomaly Index (SAI), and the Multivariate Linear Regression Analysis.

RESULTS

A comprehensive study was conducted in the Shimla district to evaluate the impact of climate variability on the phenological stages—pre-flowering, flowering, and fruit setting—of key horticultural crops over the period 1972 to 2023.

The Standardized Anomaly Index (SAI) was used to evaluate trends and inter-annual variability in maximum, minimum, diurnal temperatures and rainfall throughout three crucial phenological stages of key horticultural crops: pre-flowering, flowering, and fruit setting. Three temporal datasets—1970–2023, 1990–2023, and 2001–2023—that represent the availability and cultivation span of several fruit crops in the area were used for the analysis.

- ✓ In Shimla district, analysis of temperature trends across pre-flowering, flowering, and fruit setting stages from 1970–2023 shows a significant rise in maximum, minimum, and diurnal temperatures, especially during the pre-flowering stage. Rainfall trends remained largely insignificant, except for a decline during 1990–2023. The most recent period (2001–2023) showed no significant trends, indicating possible short-term variability. These results underline the impact of long-term warming on crop phenology, consistent with previous studies (figure 42 to 45).



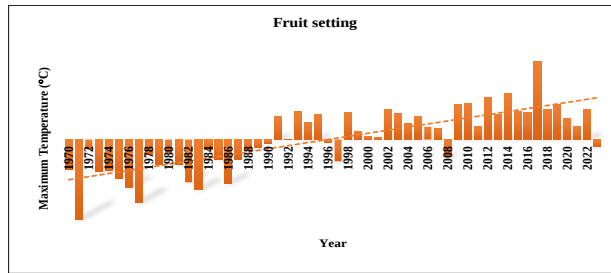


Figure 42 Standardized Anomaly Index (SAI) graphs of maximum temperature (three phenological stages i.e., Pre-flowering, Flowering and Fruit setting) from 1970 to 2023 in Shimla district, Himachal Pradesh

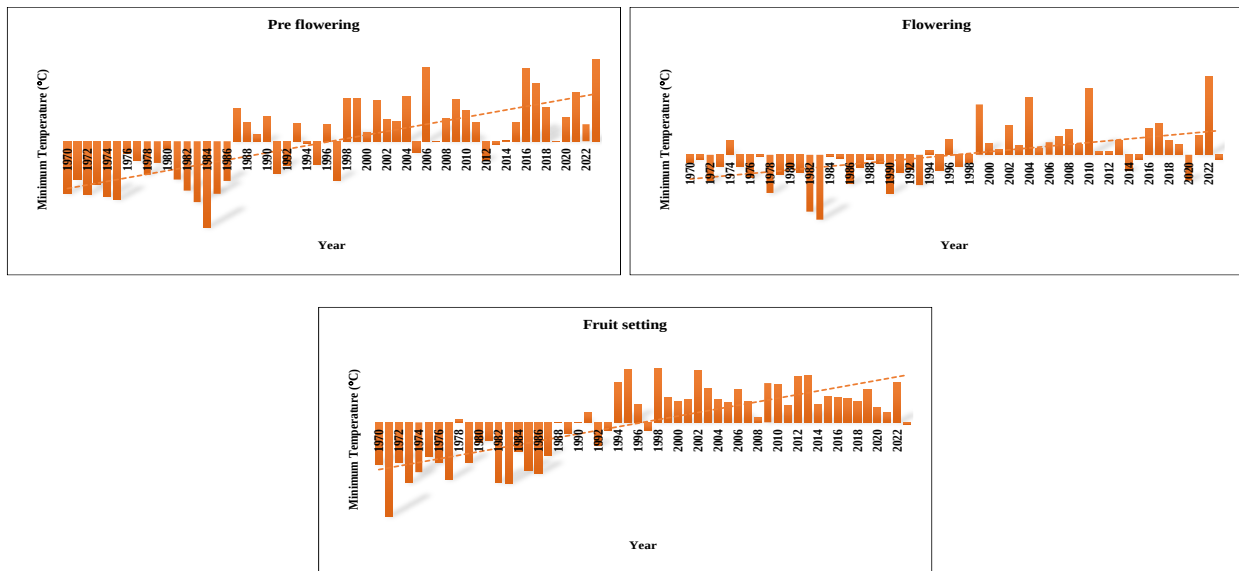
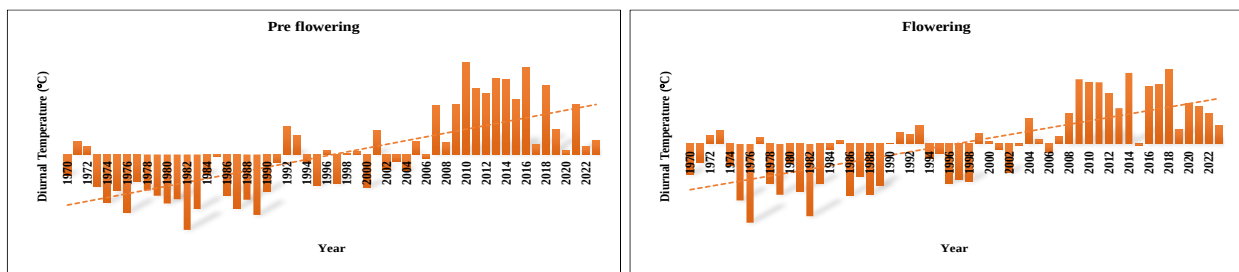


Figure 43 Standardized Anomaly Index (SAI) graphs for minimum temperature (three phenological stages i.e., Pre-flowering, Flowering and Fruit setting) from 1970 to 2023 in Shimla district, Himachal Pradesh



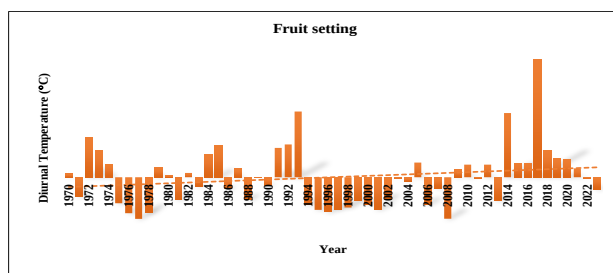


Figure 44 Standardized Anomaly Index (SAI) for diurnal temperatures rainfall (three phenological stages i.e., Pre-flowering, Flowering and Fruit setting) Graphs of Apple from 1970 to 2023 in Shimla district, Himachal Pradesh

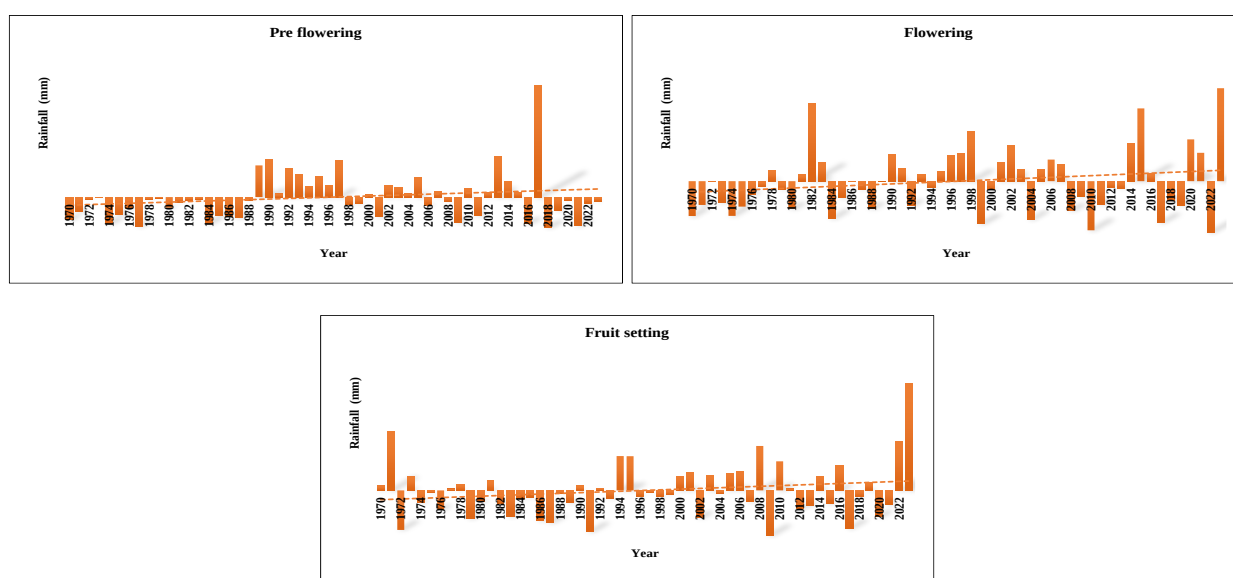


Figure 45 Standardized Anomaly Index (SAI) graphs of rainfall (three phenological stages i.e., Pre-flowering, Flowering and Fruit setting) for Apple from 1970 to 2023 in Shimla district, Himachal Pradesh

- ✓ Secondary data on acreage and production from 1972 to 2023 spanning a variety of fruit crops grown in the area were used to analyze the productivity of horticulture crops in Shimla district. To evaluate long-term trends throughout three time periods—1970–2023, 1990–2023, and 2001–2023) that corresponded to data availability for various crop collections, productivity (yield per hectare) was calculated.

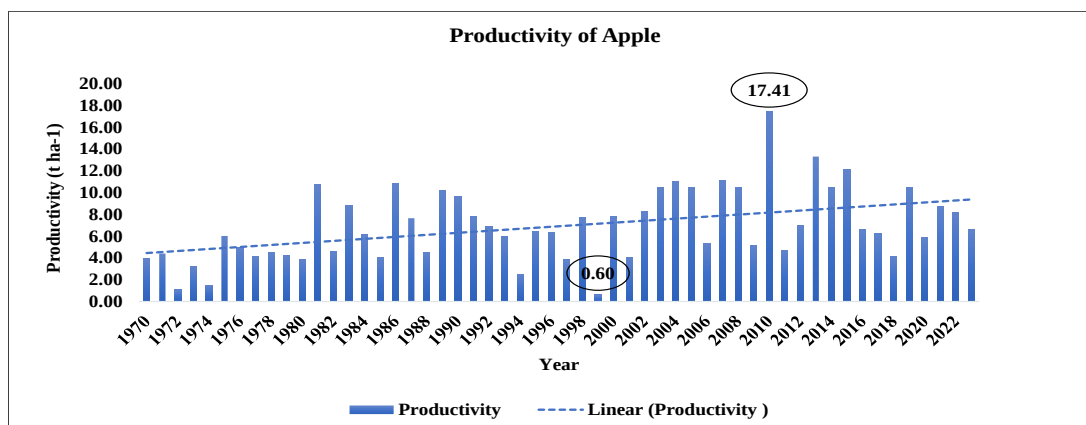
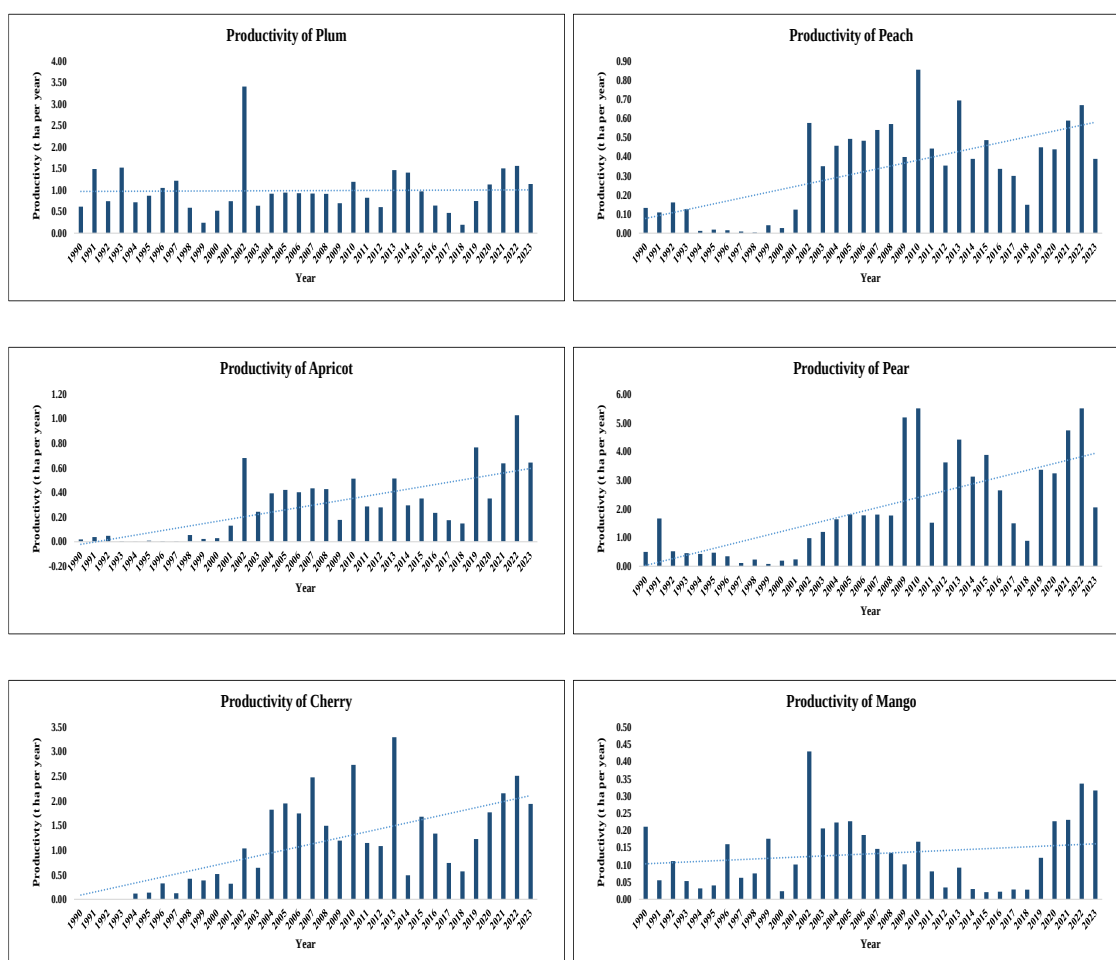


Figure 46 Productivity graph of apple from 1970 to 2023 in Shimla district, Himachal Pradesh



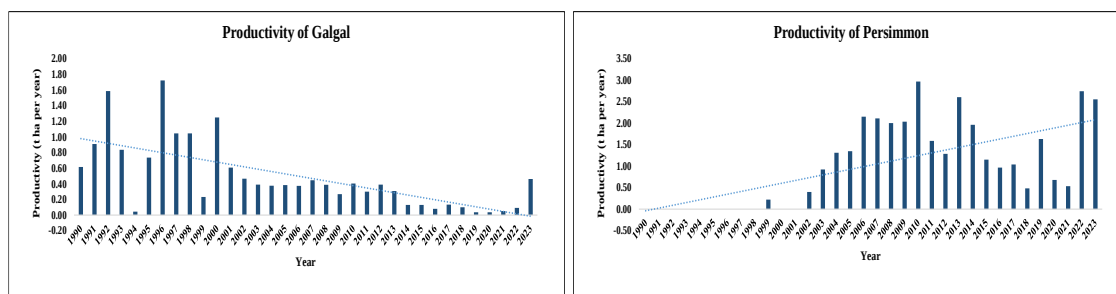


Figure 47 Productivity graphs of plum, peach, apricot, pear, cherry, mango, galgal and persimmon from 1990-2023 in Shimla district, Himachal Pradesh

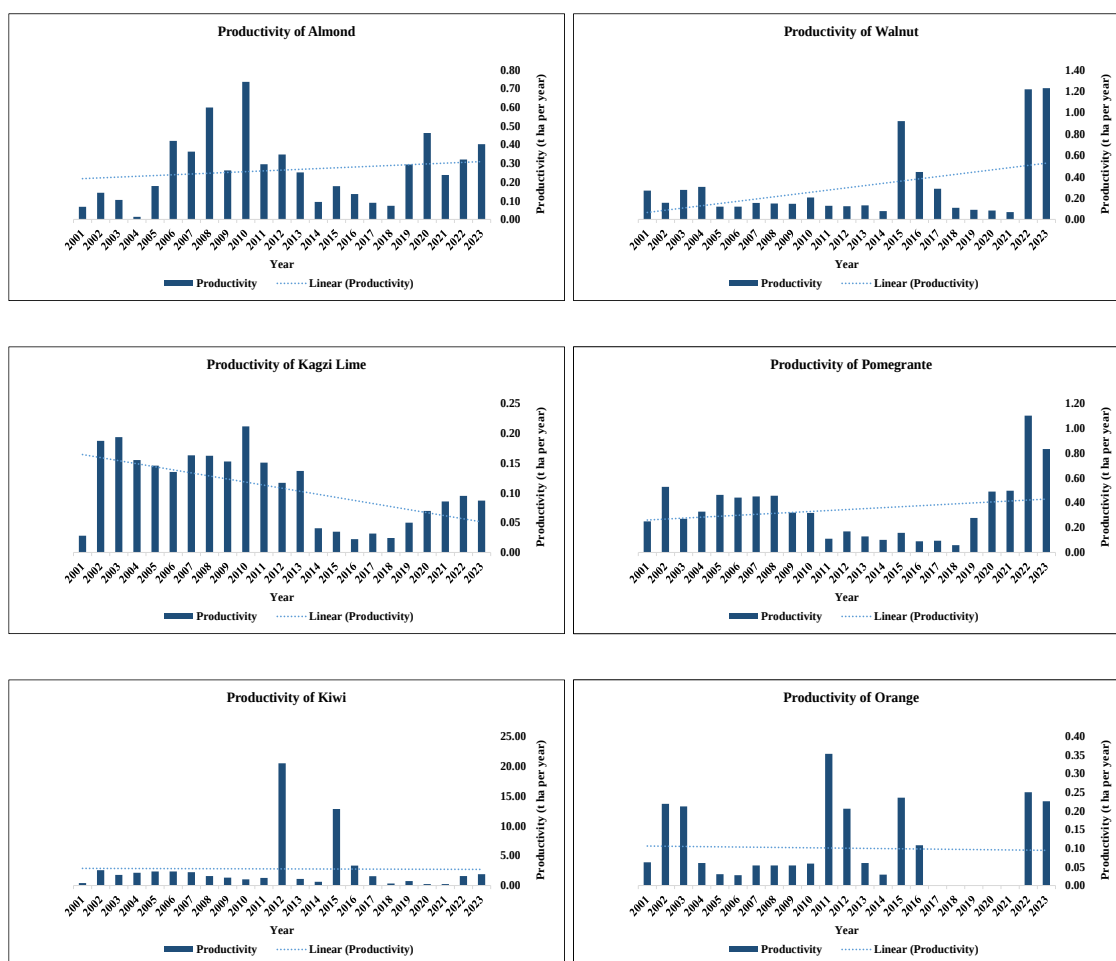


Figure 48 Productivity graphs of almond, walnut, kagzi lime, pomegranate, kiwi and orange from 2001-2023 in Shimla district, Himachal Pradesh

- ✓ Over the past 53 years, Shimla district's apple cultivation area, production, and productivity have shown a parallel and consistent increase (figure 46). As noted by Arundhati and Bhagat

(2021), the shift to low-chilling cultivars has helped sustain and even enhance yields, making apple cultivation viable despite rising temperatures.

- ✓ From 2001 onward, plum cultivation area declined and then stabilized, while production fluctuated and productivity followed a linear upward trend with a sharp increase in 2002. Peach area slightly increased until 2000, followed by irregular patterns; productivity improved overall but remained negligible in the earlier years. Apricot cultivation stayed stable, while both production and productivity showed a steady rise (figure 47).
- ✓ Pear cultivation expanded after 2001, with corresponding increases in production and productivity. Cherry cultivation area rose sharply from 2011, accompanied by fluctuating but generally increasing production and rising productivity. Mango cultivation increased, though production was inconsistent; productivity declined until 2018, then rebounded from 2019 onward. Galgal cultivation remained largely unchanged, but experienced declining production and a sharp drop in productivity. Persimmon cultivation extended, with consistent production growth and increasing productivity from 2002, likely due to new plantations (figure 47).
- ✓ Among crops studied from 2001 to 2023: almond area declined, production was erratic, but productivity showed a slight upward trend. Walnut cultivation and production increased modestly, along with productivity. Kagzi lime area increased, but production declined, leading to reduced overall productivity. Pomegranate showed an overall rise in area, production, and productivity (figure 48).
- ✓ In contrast, despite extensive cultivation, kiwi and orange production remained low and erratic. Both crops exhibited stable but low productivity throughout the study period, highlighting challenges in adapting these crops to local conditions (figure 48).

STATISTICAL SIGNIFICANCE OF TEMPERATURE AND RAINFALL VARIATIONS

In Shimla district, Mann-Kendall analysis across three phenological stages—pre-flowering, flowering, and fruit setting—revealed a highly significant rise in both average maximum and minimum temperatures from 1970–2023. Maximum temperatures increased by 0.053°C, 0.045°C, and 0.047°C, while minimum temperatures rose by 0.045°C, 0.032°C, and 0.032°C, respectively. Diurnal temperature also showed a significant increase in the pre-flowering

(0.045°C) and flowering (0.048°C) stages, but not during the fruit setting stage. Rainfall trends were statistically insignificant during this period.

From 1990–2023, the pre-flowering stage continued to show significant warming across maximum, minimum, and diurnal temperatures, while rainfall declined significantly at a rate of - 0.031 mm/year. The flowering and fruit setting stages during this period also recorded notable increases in maximum and diurnal temperatures. However, the third time frame (2001–2023) did not show any statistically significant trends. These findings align with Arundhati and Bhagat (2021), who also reported a consistent warming trend in Shimla district.

STATISTICAL SIGNIFICANCE OF PRODUCTIVITY VARIATIONS

Mann-Kendall analysis of crop productivity in Shimla district revealed significant temporal trends based on available area and production data. Apple productivity showed a statistically significant increase of 0.088 t/ha/year, aligning with previous findings by Arundhati and Bhagat (2021), who also reported a rise in apple cultivation and output. Between 1990 and 2023, peach, apricot, pear, cherry, and persimmon exhibited a highly significant increase in productivity, while galgal showed a highly significant decline. Plum and mango recorded a non-significant upward trend. From 2001 to 2023, kagzi lime and kiwi experienced significant declines in productivity, while almond and orange showed a non-significant increase. Walnut and pomegranate, on the other hand, recorded a non-significant decline.

CLIMATE AND CROP CORRELATION

A correlation study in Shimla district assessed the relationship between climatic variables and temperate fruit productivity across phenological stages and time frames.

- For **apples** (1972–2023), no significant association was found between temperature variables and productivity during any phenological stage. However, pre-flowering rainfall showed a statistically significant but weak positive correlation, suggesting other contributing factors to rising productivity over time.

- During 1990–2023, **plum** productivity showed no significant climatic correlation in pre-flowering and fruit setting stages, but rainfall during flowering had a statistically significant moderate positive correlation, accounting for 14.9% of variability.
- In the case of **peach**, the pre-flowering stage showed no significant correlations, though climatic factors explained 7.3% of productivity variability. During flowering, maximum and diurnal temperatures showed statistically significant relationships—maximum temperature had a weak positive correlation, while diurnal temperature had a moderate positive correlation, accounting for 22.4% variability. In the fruit setting stage, only diurnal temperature had a significant but weak positive correlation, explaining 12.6% of the variability. Overall, the findings highlight the varying influence of climatic factors on fruit productivity, depending on crop type, stage, and time frame.
- **Apricot** showed significant positive correlations during pre-flowering with maximum, minimum, and diurnal temperatures, accounting for 18.8% variability. Flowering and fruit setting stages were influenced mainly by diurnal and maximum temperatures, respectively, with moderate correlations and up to 23.4% variability.
- **Pear** productivity was significantly influenced by diurnal temperature across all stages, especially during flowering and fruit setting, contributing up to 25% variability.
- **Cherry** showed moderate positive correlations with temperature variables during pre-flowering and flowering, but no significant relationships during fruit setting. Climatic variability had its highest impact (19.3%) during the flowering stage.
- **Mango** was negatively impacted by diurnal and maximum temperatures. Significant moderate negative correlations were observed across all three stages, especially in fruit setting, where climatic variability explained 18.8% of the changes.
- **Galgol** did not show any statistically significant relationships across all stages, despite a highly significant decline in productivity.
- **Persimmon** exhibited consistent significant positive correlations with temperature variables during pre-flowering and flowering. Rainfall during fruit setting also showed a significant positive correlation, with the flowering stage showing the highest climatic influence (47.9%).

- Among crops with shorter data spans (2001–2023), **almond** and **kagzi lime** showed no or minimal associations, with kagzi lime showing a negative correlation with minimum temperature during pre-flowering.
- **Walnut** showed significant positive and negative correlations with maximum and diurnal temperatures during flowering and with rainfall during fruit setting, with notable climate-driven variability (up to 33.2%).
- **Pomegranate** was strongly affected by minimum and diurnal temperatures during all phenological stages, showing moderate negative correlations and high climatic variability contributions—especially during flowering (42%).
- **Kiwi** exhibited one significant positive relationship during the fruit setting stage with maximum temperature.
- **Orange** showed significant correlations only during flowering, where maximum and minimum temperatures were positively correlated, and rainfall negatively correlated with productivity. No other stages showed notable associations.

Overall, temperature—particularly diurnal—was found to be a key driver of productivity variation across most crops and stages, with rainfall playing a secondary but sometimes significant role. Crops like persimmon and pomegranate showed strong sensitivity to climatic changes, while others like galgal and almond were relatively unaffected.

CONCLUSION

- **Rising Temperatures:** A significant increase in maximum, minimum, and diurnal temperatures have been observed, particularly since 1972. The pre-flowering and flowering stages were notably affected by rising maximum and minimum temperatures, while the fruit-setting stage also showed a marked increase in both parameters.
- **Erratic Rainfall Patterns:** Annual and seasonal rainfall exhibited increased variability, with frequent deviations from normal monsoon trends. Rainfall during all three phenological stages was found to be statistically insignificant, suggesting a limited role in supporting crop development during critical growth phases.
- **Decline in Snowfall and Chilling Hours:** A pronounced decline in snowfall, especially at elevations below 2,000 meters, was noted. The delayed onset of snowfall has resulted in

reduced chilling hours, which are vital for the successful flowering and fruiting of temperate fruit crops such as apple and pear.

- **Rise in Extreme Weather Events:** Since 2000, the region has experienced an uptick in extreme weather events such as hailstorms, untimely frost, intense rainfall, and landslides, adversely impacting crop health and productivity.
- **Shifting Cropping Patterns:** Traditional cropping calendars have been disrupted, and climatic suitability zones have shifted. Apple cultivation is gradually moving to higher altitudes, while lower elevations report a decline in both yield and fruit quality due to suboptimal chilling and rising temperatures.

POLICY RECOMMENDATIONS

Promoting climate-resilient crop varieties, revising crop zoning according to altitude and climatic trends, and enhancing water management through rainwater collecting are important policy strategies to lessen the impact of climate variability on horticulture in Shimla district. Climate-resilient horticulture also requires the establishment of early warning systems, improved crop insurance, improved training of farmers in adaptation methods, and the tracking of chilling hours and snowfall.

9. PUBLICATION

Bharti, H. Panatu, A., Sharma, P., Randhawa, S. S., Dhiman, S. & Rana, R. S. (2024). Impact of climatic variations in the horticulture sector, Kinnaur, Himachal Pradesh, India. *Mausam*, 75, 2, 313-326. <https://doi.org/10.54302/mausam.v75i2.827>

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