A Preliminary investigation report

On

The subsidence happening in the Lindur Village, Lahaul, Lahaul & Spiti, Himachal Pradesh

Submitted to

DC-Lahaul & Spiti

By

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Upon the request of the District Commissioner and Stat/ District Disaster Management Agency (SDMA/ DDMA), an expert team comprising two geologists, Mr. Nitesh Dhiman and Mr. Ankit Singh and two glaciologist Ms. Ipshita Priyadarsini Pradhan and Mr. Kirti Kumar Mahanta from Indian Institute of Technology Mandi, carried out the preliminary investigation about the subsidence happening in the Lindur village, Lahaul & Spiti from 3/11/2023 to 4/11/2023. The team investigated the probable reason that led to the formation of cracks both in the agricultural field and several houses near the banks of Jahmala Nullah that flows next to the village. The findings of this report are primarily based upon the initial preliminary investigation.

1. Location

The Lindur village is located in the Lahaul part of Lahaul and Spiti district of Himachal Pradesh situated at an elevation of around 3328m above the mean sea level. The village is a small hamlet in Lahaul tehsil and it comes under Lindur Panchayat. It is located around 13 Km towards East from district headquarter at Keylong. There is a village road that connects this village with the National Highway which is around 4-5 Km from this village. Jhalmah nala that is fed by the glaciers of the catchment flows near the village and then drains into Chenab River as shown in figure 1. As per 2011 census data, there are 14 families residing in Lindur village that has a total population of 72 of which 37 are males while 35 are females. In Lindur village population of children with age 0-6 is 3 which makes up 4.17 % of total population of village. Average Sex Ratio of Lindur village is 946 which is lower than Himachal Pradesh state average of 972. Child Sex Ratio for the Lindur as per census is 2000, higher than Himachal Pradesh average of 909. Lindur village has a lower literacy rate compared to Himachal Pradesh. In 2011, literacy rate of Lindur village was 69.57 % compared to 82.80 % of Himachal Pradesh. In Lindur Male literacy stands at 77.78 % while female literacy rate is 60.61 %.

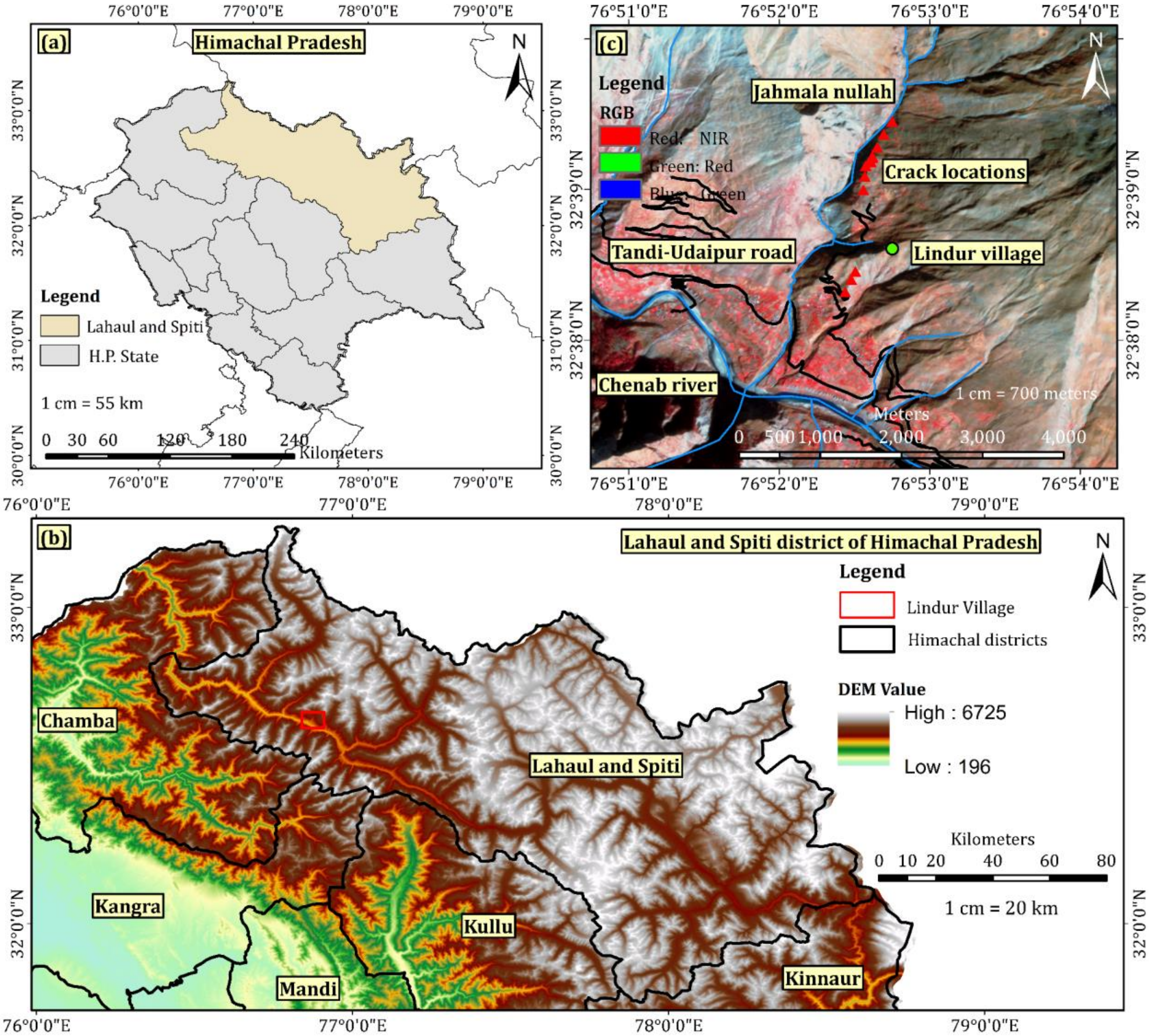

Figure 1: The study area map (a) Himachal Pradesh administrative boundary (b) Elevation map of the Lahaul and Spiti District (c) Satellite image of Lindur village and crack locations

2. General Description

Generally, Lahaul and Spiti region experiences scanty rainfall during the monsoon season. However due to climate change, these areas are now continuously experiencing an increase in the mean annual rainfall. Furthermore, due to significant rise in the mean air temperature, the accumulation of snow is also less in recent years. Thus, the melting of snow from the glaciers is a common occurrence in these regions. One such drainage source that shed its glaciated water in the Chenab river is Jhulammah Nallah originating from the glacier above the Lindur village. The villagers reported heavy precipitation in the Nallah and found numerous cracks in the various houses around the village. Further, several cracks were observed in the agricultural field while several landslides occurred along the banks of Nallah after the 2023 monsoon.

3. Initial Description

Based upon the initial survey done, it was found that the whole area of Lindur village is situated upon a thick debris cover formed by the moving of glaciers below which bedrock of carbonaceous slate and phyllite occurs. Additionally, the glaciers have changed their characteristics from debris covered glaciers to rock glaciers. Glaciers are those geomorphic landforms that hold a significant quantity of ice and a lesser percentage of debris. A debris-covered glacier is formed when the glacier regresses upwards leaving behind a thick layer of debris with some ice beneath. A rock glacier is a further extension of a debris-covered glacier where the percentage of debris dominates, consisting of very few percent of ice. In addition to it, rock glaciers are characterized into two types i.e. active rock glaciers and inactive rock glaciers. The active rock glaciers contain some amount of ice which when melts show some kind of activity while on the other hand, the inactive rock glaciers contain very few amounts of ice thereby showing no such signature of any activity. Based upon the field survey done in the upper reaches of the Lindur village, the rock glaciers seem to be an active one. Upon the interaction, the villagers reported that in the higher reaches of the slope where rock and debris covered glaciers are present, many cracks are visible which have been formed in last 5-8 years (approximate). Further, in the lower reaches i.e. close to the Jhalmah nallah, there were multiple evidence of sinking where the agricultural fields have been washed away and an important buddhist Stupa has also been destroyed. There are cracks all on the agricultural fields and many cracks are also formed in the several houses of which its orientation and measurements were taken in detail by the team described in the forthcoming sections.

4. Geological Context

4.1. Geology

The age of the rock is predominantly of proterozoic age consisting of the Vaikrita group of Chamba formation. The rocks of the areas consist of Carbonaceous slate, phyllite and quartzite. The Vaikrita group of rocks are overlain by a neoproterozoic group consisting of diamictite shale, slate, sandstone and a few limestone. Further, the Vaikrita group of rocks are overlain by Permian groups of rocks consisting of limestone, dolomite and sandstone. The rocks in the area strike towards North-west and dipping towards the north-eastern side.

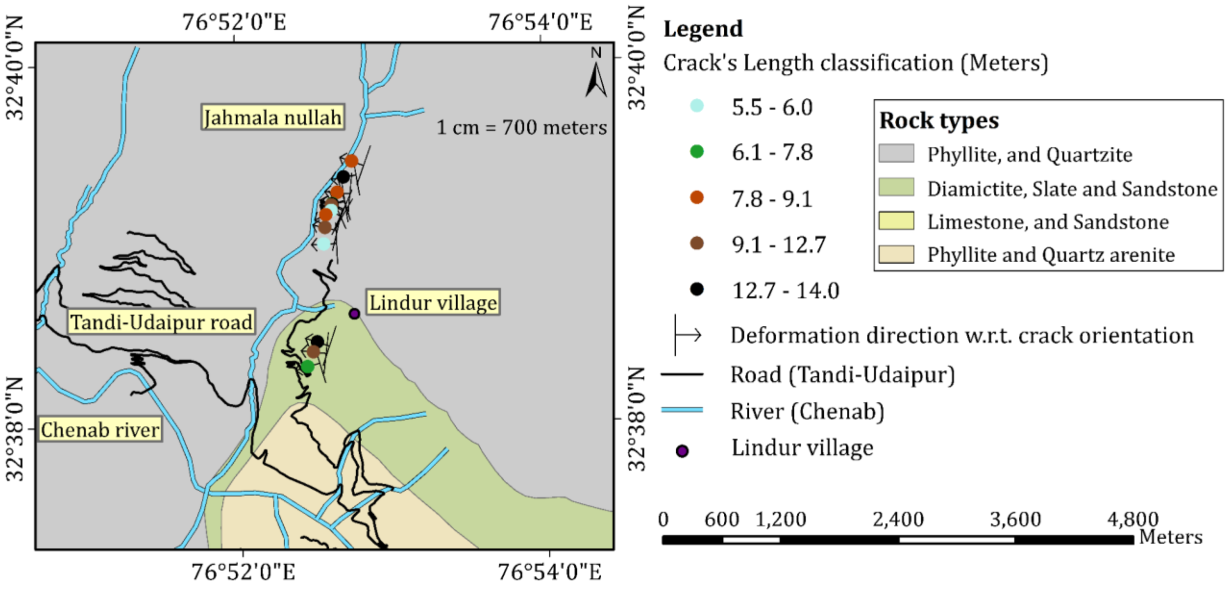

Figure 2 a: Lithological Map of the area representing the cracks and their deformation direction w.r.t crack orientation

The data shows that the orientation of the slopes are facing towards the river. This might be one of the many causes of land subsidence in the area. Further, the cracks were observed in the agricultural fields closer to the bank of the river. Figure 2a shows the overall geology of the area, the deformation direction with respect to cracks orientation and cracks length classification in meters. While figure 2b and c shows the field photograph of the rock types. The figure shows the outcrops of slate beds exposed. Upon investigation and examining outcrops of outcrop, it was observed that the foliation oriented along the direction of slope gradient provides valuable insights into the direction of dipping or the inclination of rock layers. The foliation patterns in the slates are formed due to the alignment of minerals during the metamorphism. The parallel orientation of the outcrop to the dipping direction suggests a consistent geological process that influenced the deposition and subsequent metamorphism of the slate. The alignment of beds with the direction of the slope generates a slip surface indicating a geological setting conducive to mass wasting processes such as subsidence and landslides. The alignment of the rock layers with the slope suggests that gravitational forces, combined with factors like weathering and erosion, are influencing the stability of slopes. Thus, the slip surface, formed along the bedding planes of the slate, becomes a potential failure plane where material can detach and move downslope.

Figure 2b: Outcrops showing the direction of dipping (Rock Type- Slate)

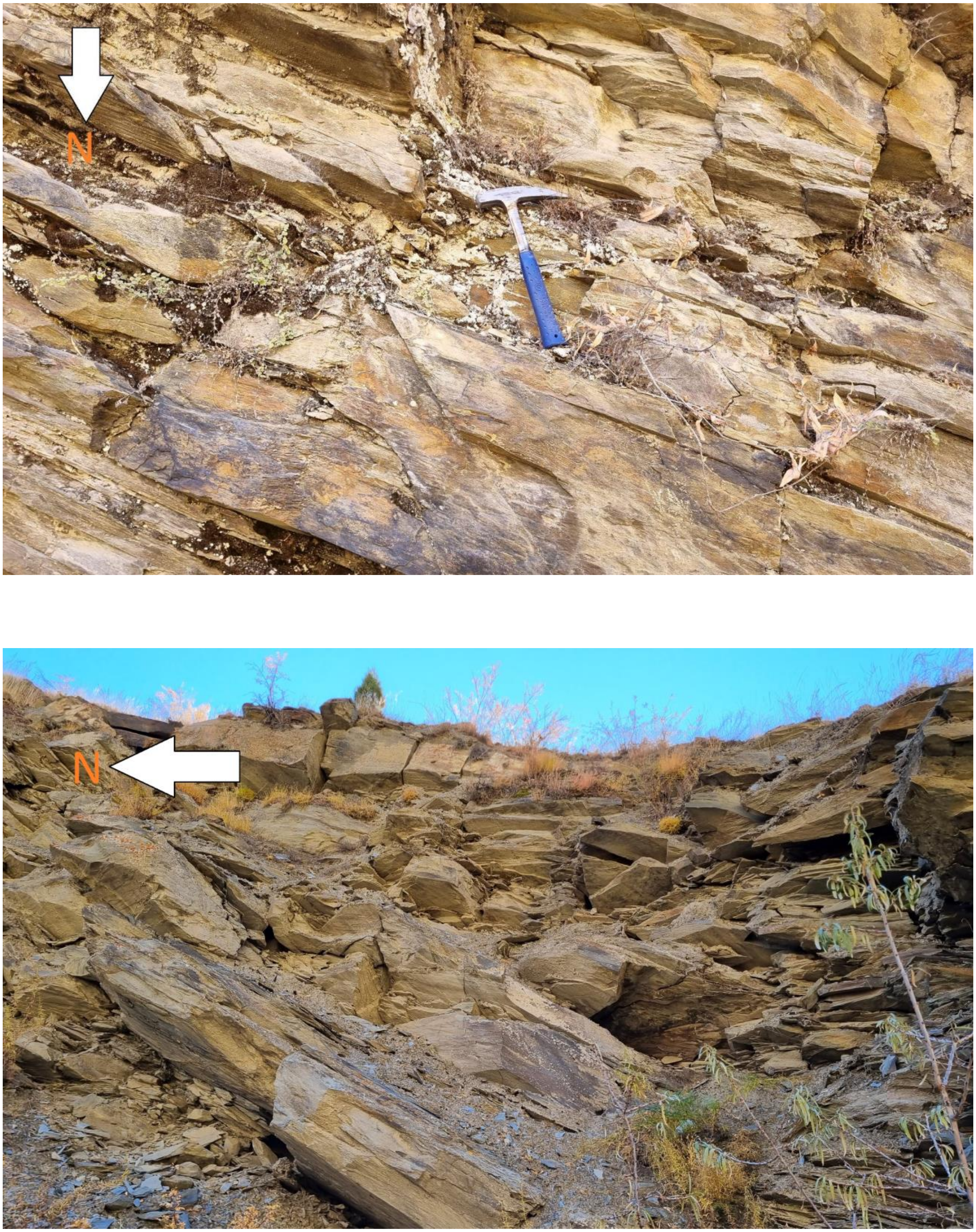

Figure 2c: Outcrops showing the direction of dipping (Rock Type- Slate)

The figure 2c shows the slate beds dipping in the north-east direction. The tip of the hammer shows the direction of beds dipping. 2 set joints are present which is defined as a fracture or crack in a rock mass along which there has been no significant movement parallel to the fracture surfaces. The presence of joints creates zones of weakness within the slate beds which reduces the cohesion and makes the rock susceptible to weathering and erosion. Over time, water infiltration through joints can lead to the expansion and contraction of the rock, further contributing to the breakdown of the slate beds.

The average strike and dip data of the location observed are tabulated below

Serial No	Latitude	Longitude	Trend	Elevation	Rock Type
1	32.6402	76.86933	S35°E/30°-SW	3029m	Slate and Phyllite
2	32.6402	76.86936	S35°E/30°-SW	3029m	Slate and Phyllite
3	32.6402	76.86936	S40°E/30°-SW	3029m	Slate and Phyllite
4	32.64391	76.87129	S30°E/35°-SW	3002m	Carbonaceous slate
5	32.64389	7.687119	S36°E/41°-SW S25°E/35°-SW	3000m	Carbonaceous slate

4.2. Topographical Characteristics

The topographical characteristics of the Lindur village and adjoining areas were obtained from the ALOS-PALSAR Digital Elevation Model of 12.5m spatial resolution. The topographical characteristics were slope and aspect of the study area.

Elevation Map

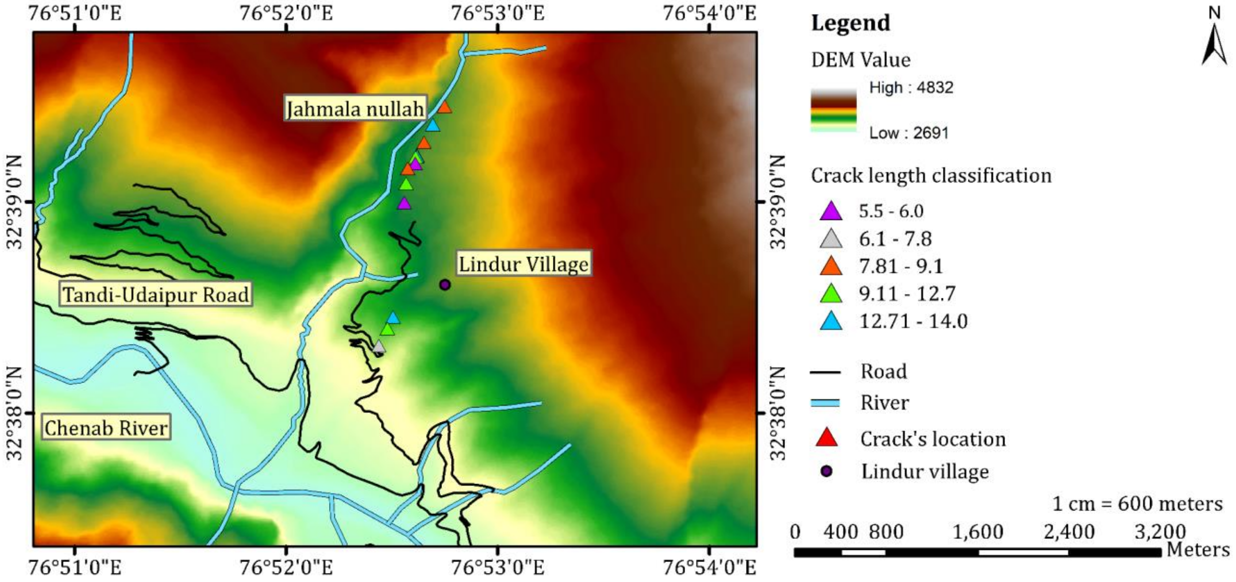

Figure 3a: Elevation map of the study area

Slope Map

The Lindur study area exhibits a diverse range of slope angles from 0 to 80 degrees. This variation in topography is a crucial factor influencing the local landscape and ecological dynamics. The distinct gradient disparity between the northeastern and northwestern slopes is a key observation within the study area.

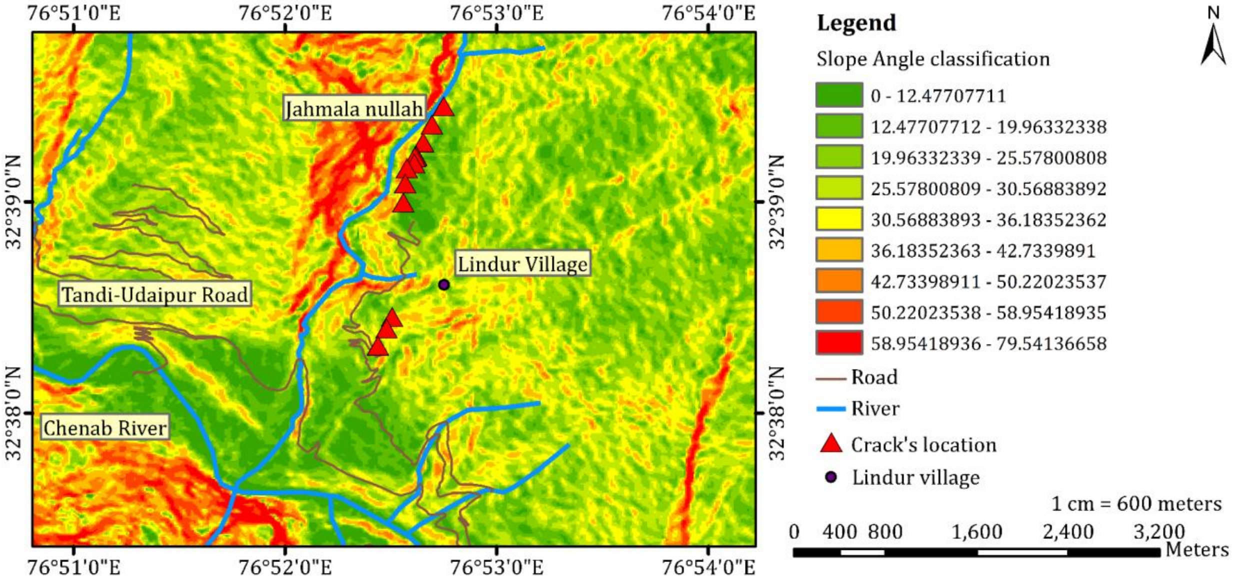

Figure 3b: Slope angle map classification representing the cracks

In the northeastern regions, the slopes generally display lower gradients. Milder slopes in this quadrant indicate a relatively gradual incline, suggesting a more stable terrain. Lower slope angles often facilitate improved water retention, fostering favorable vegetation growth and soil stability conditions. This can have implications for land use, agriculture, and the overall ecological balance in these areas. The slopes are steeply inclined in areas closer to the banks, making them vulnerable to landslides. This condition was observed when a large quantity of water from the Nallah drained, leading to the toe-cutting of the steeper slopes. This slope-cutting resulted in multiple slides along the affected areas in figure 4 a and b.

Figure 4 a: Landslide Scarp along the steeper slopes

Figure 4b: Landslide Scarp along the slopes close to the agricultural fields

Aspect Map

Aspect is the direction of the slope facing from the north direction. An aspect map derived from a Digital Elevation Model (DEM) provides valuable insights into the directional orientation of slopes across a geographic area.

Steeper slopes and mountainous areas often have distinct aspect patterns compared to flatter terrain. It is evident from the map that the steeper slopes along the banks face towards east and southeast directions while the slopes of the terrain's relatively gentle topography have west and southwest aspect directions Figure 5.

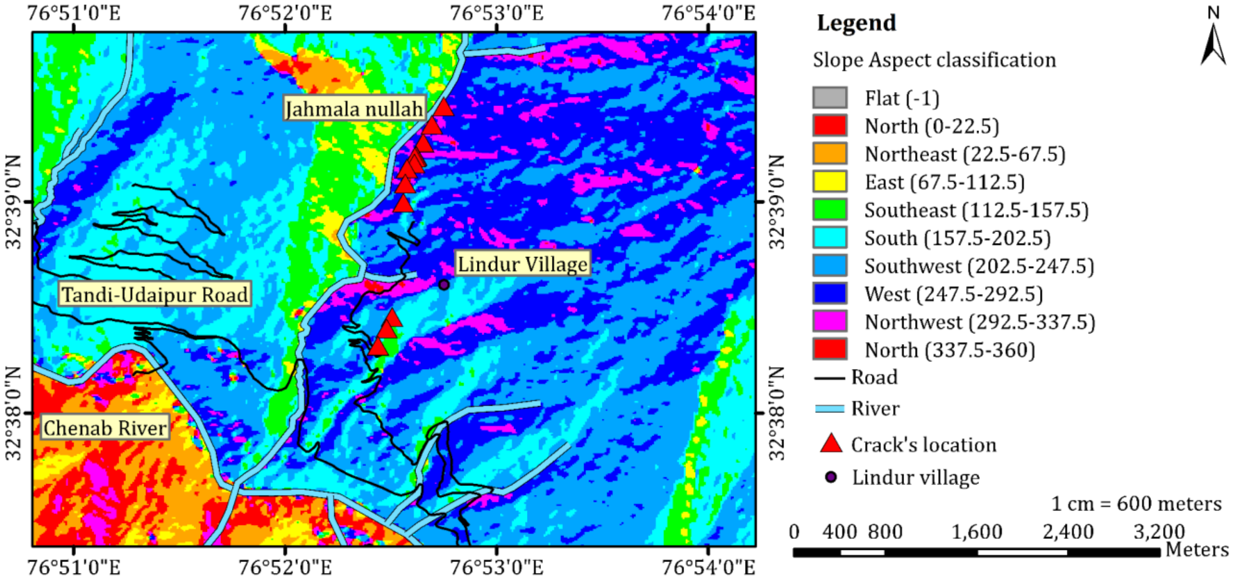

Figure 5: Slope Aspect classification of the area

4.2 Cracks Orientation, Characteristics and Rose Diagram

The cracks developed in the agricultural field close to the drainage were mainly oriented in the north direction, while few of the rocks were in the northeast direction. The data of the cracks are tabulated below

Table 1: Details of the Cracks present in the agricultural field

Sr No.	Latitude	Longitude	Orientation of length	(360 degrees)	Trend of the crack length	Length (m)	Width(m)
1	32.65	76.877	N19°E	19	N-S	8.5	0.26
2	32.65	76.877	N5°E	5	N-S	9.1	0.29
3	32.65	76.87	N10°W	350	N-S	13.8	0.27
4	32.65	76.87	N9°W	351	N-S	11.3	0.15

5	32.65366	76.87697	N17°W	343	N-S	7.8	0.16
6	32.65361	76.87698	N22°E	22	N-S	14	0.19
7	32.65354	76.87688	N24°E	24	N-S	12.4	0.14
8	32.65304	76.87684	N30°E	30	N-S	5.5	0.15
9	32.65265	76.87625	N24°W	336	N-S	8.9	0.21
10	32.64996	76.87598	N3°W	357	N-S	6	0.17
11	32.65147	76.87613	N13°E	13	N-S	11.6	0.12
12	32.64094	76.87509	N18°E	18	N-S	14	0.16
13	32.64003	76.87465	N6°E	6	N-S	12.7	0.15
14	32.63867	76.87398	N17°W	343	N-S	7	0.91

Figure 6: Field Photograph of the cracks observed in the agricultural field

A rose diagram is a graphical representation used in structural geology to analyze the orientation of geological features, such as fractures, faults, or other linear structures. It is a circular histogram that helps geologists visualize the distribution of these features in different directions.

The rose diagram indicates a significant concentration of cracks in the north direction, suggesting a dominant northward orientation. The dominant orientation of the cracks is in the north direction, signifying the deformation of the cracks along the dipping surface. Further, the direction of the cracks represents the regional stress regime in the north direction.

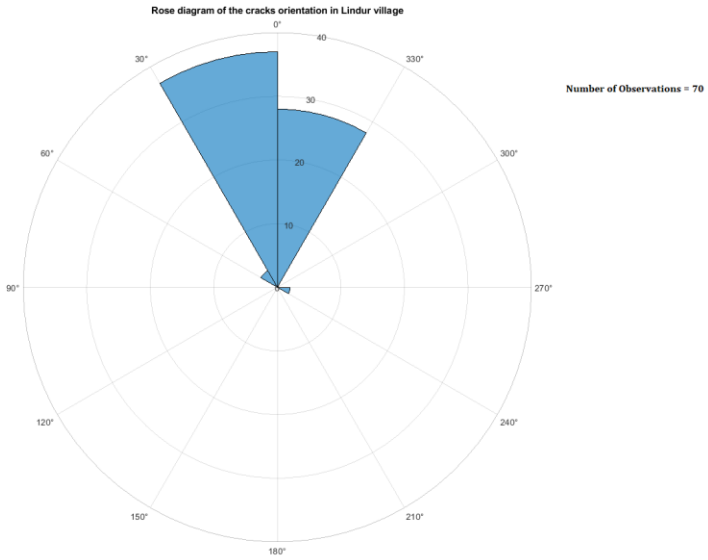

Figure 7: Rose diagram representing the orientation of the cracks in the North direction

5. Glaciological Context:

5.1 Observations and Characteristics of the Crack:

Upon initial inspection, it became evident that the crack extends over a considerable length and varies in width, indicating a complex interplay of geological forces. The crack follows the natural contours along the rooting line of the rock glacier in both elevated and relatively flat terrain. Field measurements suggest that the depth and width of the crack are more prominent in the northern direction compared to the crack present in the southern direction. The details, including width, depth and orientation of the some measured cracks, are given in the table below.

Table 2: Crack present in the upper part of the village (above 3800 m.s.l)

Sl no.	Photos	Width	Depth	Orientation
1		65cm	--	90°EW
2		44cm	130cm	88°EW

3		33cm	142cm	89°EW

The alignment of the cracks in layering curve shape with the probable flow path of rock glaciers is a notable observation, raising questions about the role of these dynamic formations in the crack's development. Additionally, the crack's dimensions and the irregularities observed along its length hint at a dynamic and ongoing geological process.

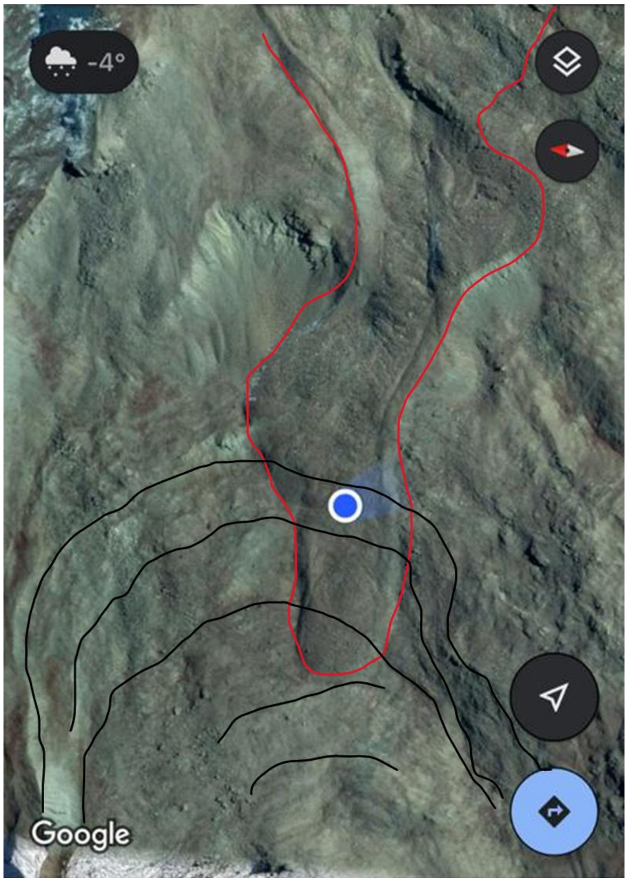

Figure 8: Black colour curved line showing the approximate orientation of the cracks and red color line sowing the outline of the active rock glacier.

5.2 Rock Glacier Influence:

The presence of extensive rock glaciers in the vicinity of the Lindur village may be a potential contributor to the observed crack. Rock glaciers, composed of a mixture of ice and debris, exhibit slow downslope movement influenced by gravity. Many researchers have included rock glaciers as a glacial landform because of their hydrological importance. The ongoing 'rock glacier controversy' centers on their origin, questioning whether it stems from periglacial processes or glacigenic ice contributions, highlighting the blurred boundaries between glacial and periglacial landforms.

Rock glaciers, as creeping permafrost features, can emerge from periglacial mechanisms, such as ground ice forming into talus or moraines, or glacial processes, involving debris-covered glaciers. Consequently, they play a pivotal role in the continuum of the glacial-periglacial landscape.

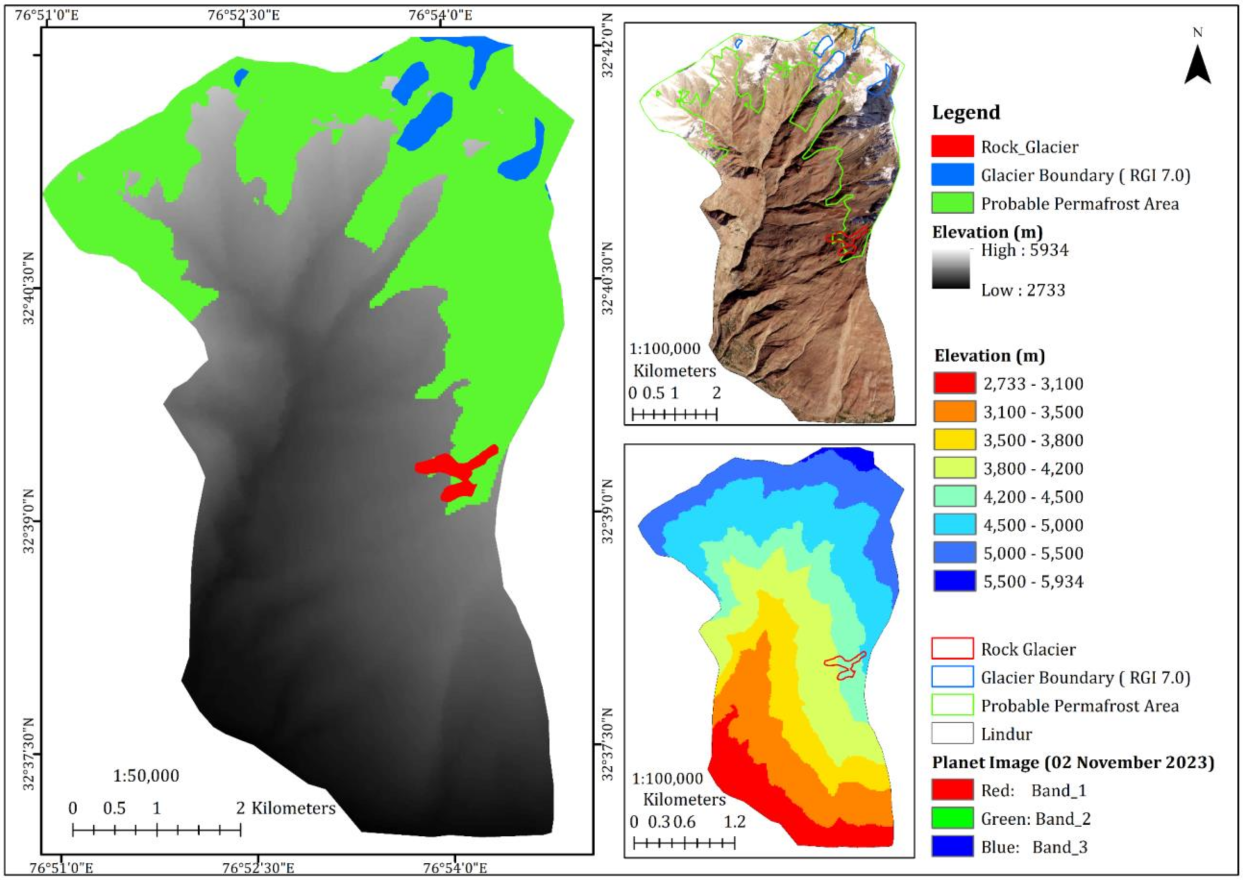

Figure 9: The map shows the probable permafrost area (prepared using the method given by Pradhan and Shukla, 2023), glaciers, and rock glaciers present in the periphery of Lindur village.

In mountainous terrains, distinguishing between debris-covered glaciers, moraine complexes, and rock glaciers proves challenging due to their coexistence. The term 'ice-debris complex' was introduced to describe landforms incorporating elements of debris-covered glaciers transitioning into rock glaciers.

Rock glaciers, formed over time from debris-covered glaciers, represent a transformative process. In contrast, debris-covered glaciers are characterized by a surface mantle of supraglacial debris resulting from various mass movements like rockfall and avalanches. Their formation occurs as debris accumulates in the glacier's ablation zone. Debris-covered glaciers are further categorized based on ice amount and surface debris coverage into semi-debris-covered glaciers (85% ice), fully debris-covered glaciers (65-85% ice), and buried debris-covered glaciers (45-65% ice). As debris-covered glaciers evolve, they gradually transition into rock glaciers, marking a dynamic continuum in the ever-changing mountainous landscape.

Lindur Village's topography indicates that rock glaciers are integral to the local geological makeup. The alignment of the observed crack with the flow path of rock glaciers suggests a potential correlation between the two phenomena. Rock glaciers contribute to ground movement and deformation, exerting pressure on the underlying terrain. As these formations slowly move, they create stress and strain in the surrounding areas. The interaction between rock glaciers and the underlying permafrost layer may be a key factor in the development of the observed crack. The potential coupling of these geological features raises questions about the magnitude and duration of their influence on the crack's formation.

The interplay between permafrost and rock glacier dynamics emerges as a critical factor in the observed crack formation. Rock glaciers, through their slow downslope movement, likely contribute to the deformation of the permafrost layer, exacerbating the stresses on the ground and resulting in surface cracks. The potential for thermal variations in the permafrost layer, induced by climatic changes or other external factors, further complicates the dynamics. As permafrost degrades or experiences temperature-related fluctuations, it may amplify the ground movements initiated by rock glaciers, contributing to the development of observed cracks. The combined influence of these geological features underscores the need for a comprehensive understanding of the interactions occurring beneath the surface.

The presence of the crack poses potential risks to both infrastructure and the stability of the village. Additionally, disruptions in the permafrost layer may influence local hydrology, impacting water drainage patterns and potentially affecting agricultural activities. The potential consequences of the crack underscore the importance of a thorough assessment and proactive measures to mitigate risks.

6. Climatological Observations

Understanding the relationship between climatic conditions and rock glacier deformation and crack formation is critical for forecasting how these features will respond to ongoing climate change. Rock glaciers, which are distinguished by the coexistence of ice and rock, are extremely vulnerable to climatic changes. We analyzed the trend in air temperatures, precipitation patterns, snow accumulation, and their combined effects on crack formation. We used ERA5-Land Daily Aggregated data, which has a spatial resolution of 11 km, and covers the time period from 1950 to the present, to produce time series plots for various climate parameters.

6.1. Trend in Air Temperature

Air temperature is a crucial climatological parameter that affects the thermal regime of rock glaciers. Temperature fluctuations can cause thawing and freezing processes, resulting in thermal expansion and contraction inside the rock mass. High air temperatures can accelerate the melting of ice within rock glaciers, increasing water flow. This increased flow can erode the underlying rock, producing material displacement and changing the topography. Temperature fluctuations can cause thermal contraction and expansion cycles inside the rock mass, thereby triggering subsidence. This stress may cause fractures and fissures, further contributing to the degradation of rock glaciers.

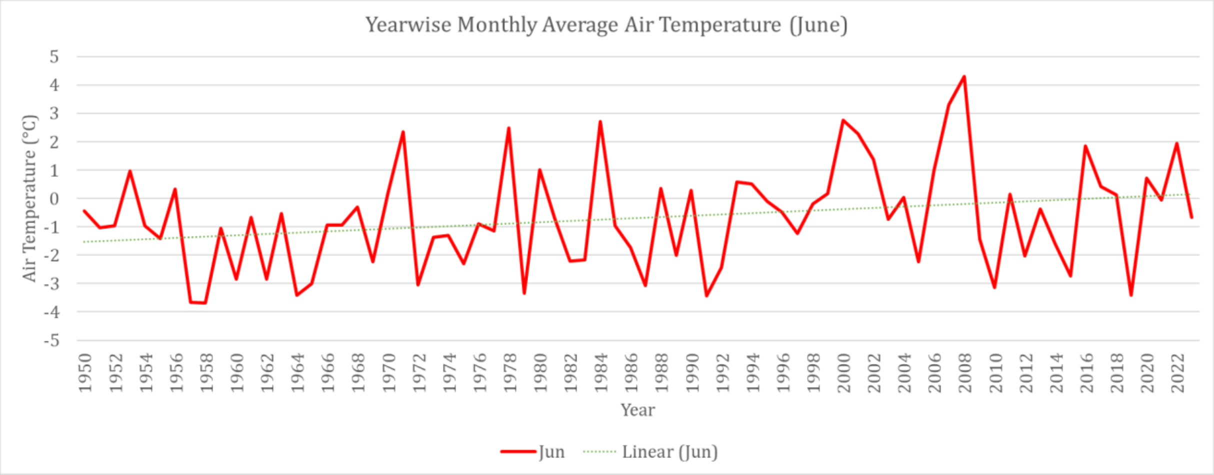

Figure 10: The plot shows the yearwise monthly average air temperature of Lindur for the month of June from 1950 to 2023.

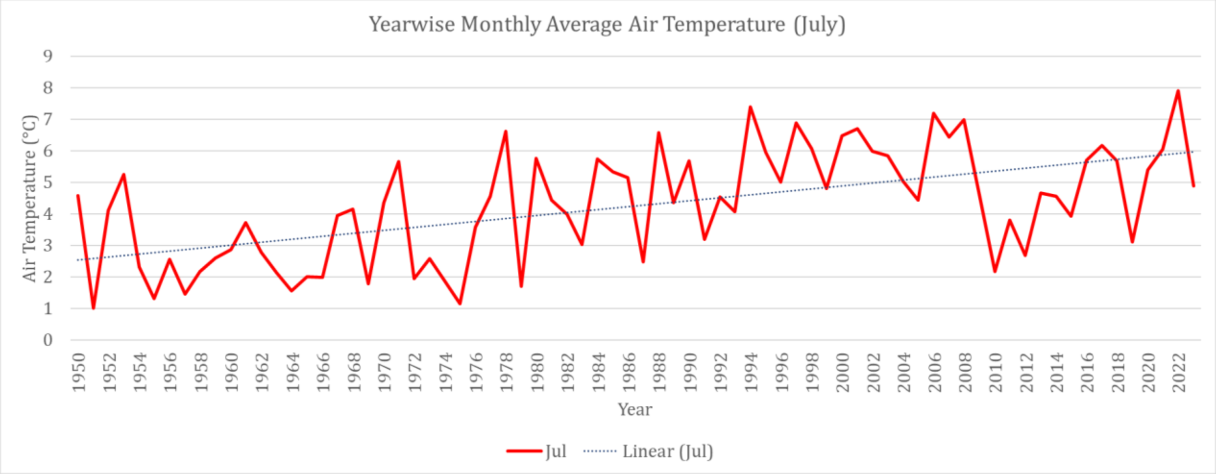

Figure 11: The plot shows the yearwise monthly average air temperature of Lindur for the month of July from 1950 to 2023.

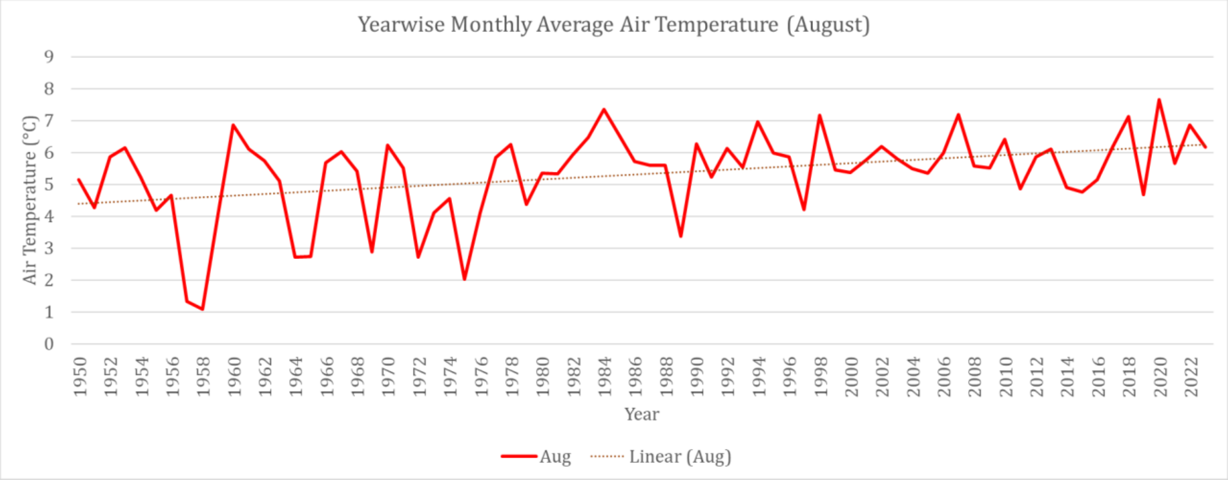

Figure 12: The plot shows the yearwise monthly average air temperature of Lindur for the month of August from 1950 to 2023.

We examined the monthly average air temperatures for June, July, and August (Figures 10-12) spanning the years 1950 to 2023. Our analysis revealed a cyclic pattern characterized by temperature fluctuations, with noticeable increases and decreases. Despite the cyclic nature, there is an overall upward trend in air temperatures from 1950 to 2023 for each of the three months. Notably, the increase in temperature is most pronounced in July compared to June and August.

6.2. Trend in Precipitation and Snow

Precipitation, in the form of rain or snow, directly impacts the water content within rock glaciers. The amount and distribution of precipitation can influence the rate of erosion and subsidence. Excessive precipitation can accelerate the melting of ice within rock glaciers, leading to increased water flow and erosion. Changes in precipitation patterns affect the water content within the rock glacier. Increased precipitation can saturate the rock mass, reducing its stability and potentially triggering subsidence. Increased water content can weaken the interlocking structure of rock particles, making them more susceptible to displacement. Intense precipitation, particularly in freezing conditions, can lead to hydrofracturing. The expansion of freezing water within existing fractures or weak points initiates crack formation. The combined effect of precipitation-induced water infiltration and subsequent freezing contributes to the development of a network of cracks within the rock glacier.

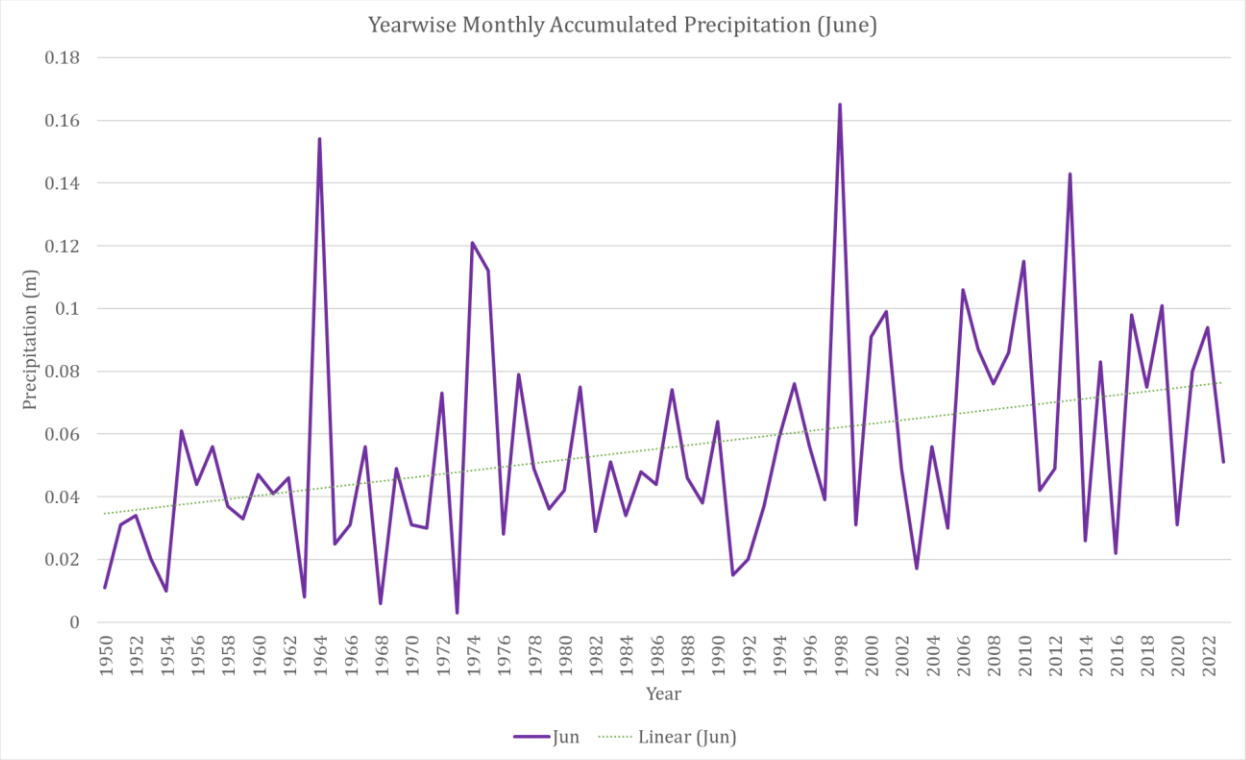

Figure 13: The plot shows the yearwise monthly accumulated precipitation (Rain + Snow) of Lindur for the month of June from 1950 to 2023.

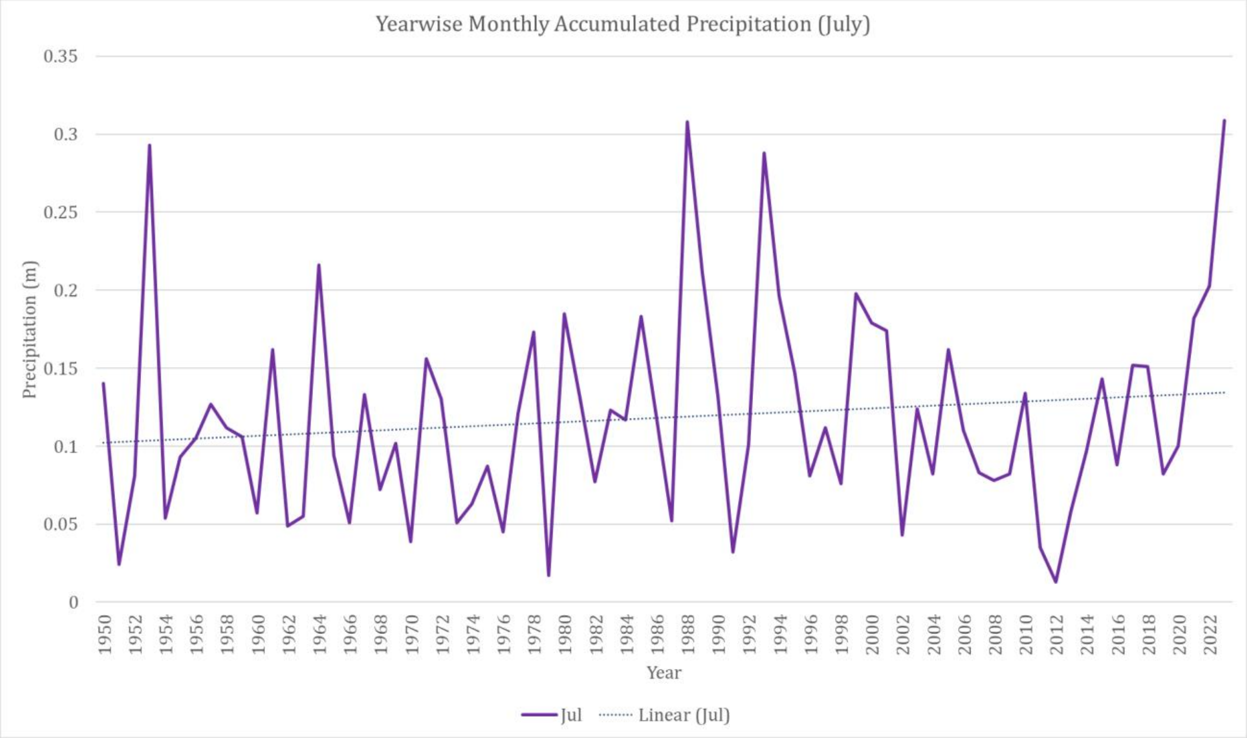

Figure 14: The plot shows the yearwise monthly accumulated precipitation (Rain + Snow) of Lindur for the month of July from 1950 to 2023.

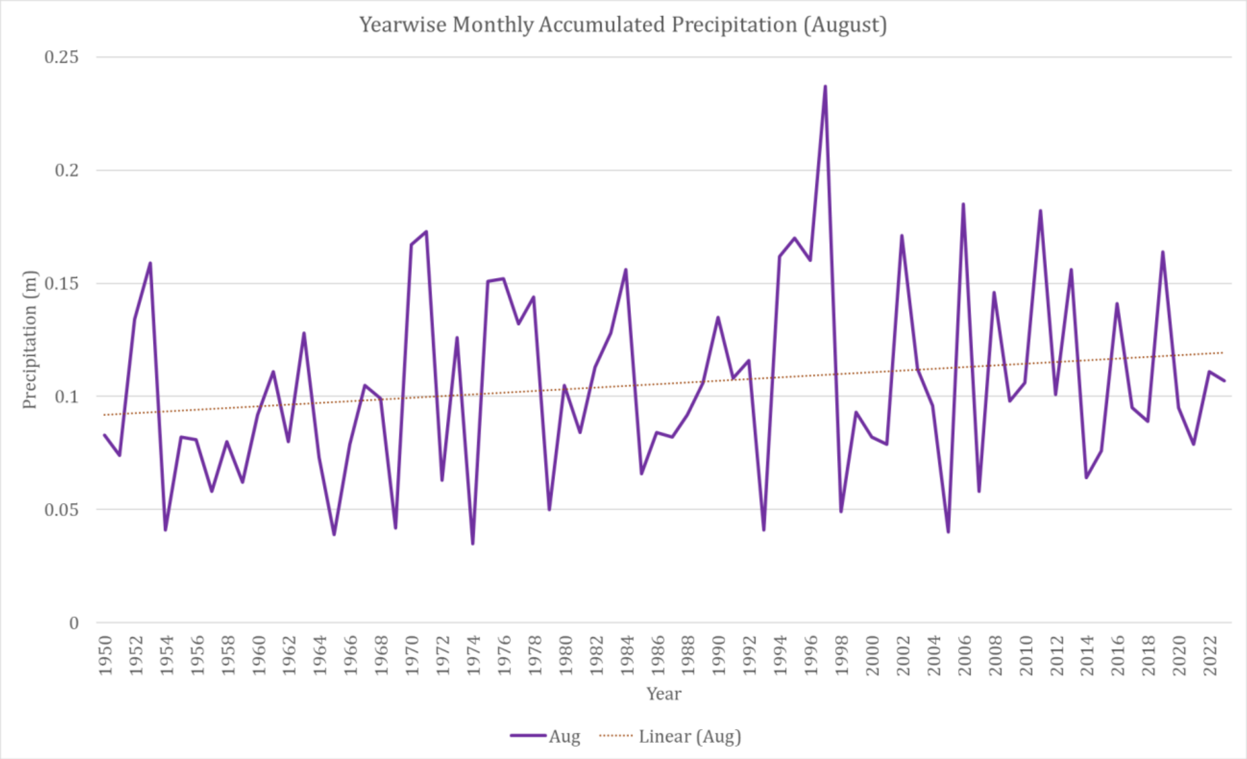

Figure 15: The plot shows the yearwise monthly accumulated precipitation (Rain + Snow) of Lindur for the month of August from 1950 to 2023.

We analysed the monthly total accumulated precipitation for June, July, and August (Figures 13-15) of each year from 1950 to 2023. Total accumulated precipitation encompasses both liquid and frozen water, including rain and snow. Similar to the air temperature, a rising trend is evident in the total accumulated precipitation for all three months over the period from 1950 to 2023.

Snowfall contributes to the buildup of ice and snow, providing a protective layer that can mitigate erosion. However, excessive snowfall, coupled with temperature fluctuations, can lead to increased meltwater production, potentially intensifying erosion processes. Snowfall can affect subsidence by influencing the thermal conductivity of the rock mass. Snow cover acts as insulation, reducing temperature fluctuations and minimizing stress-induced subsidence.

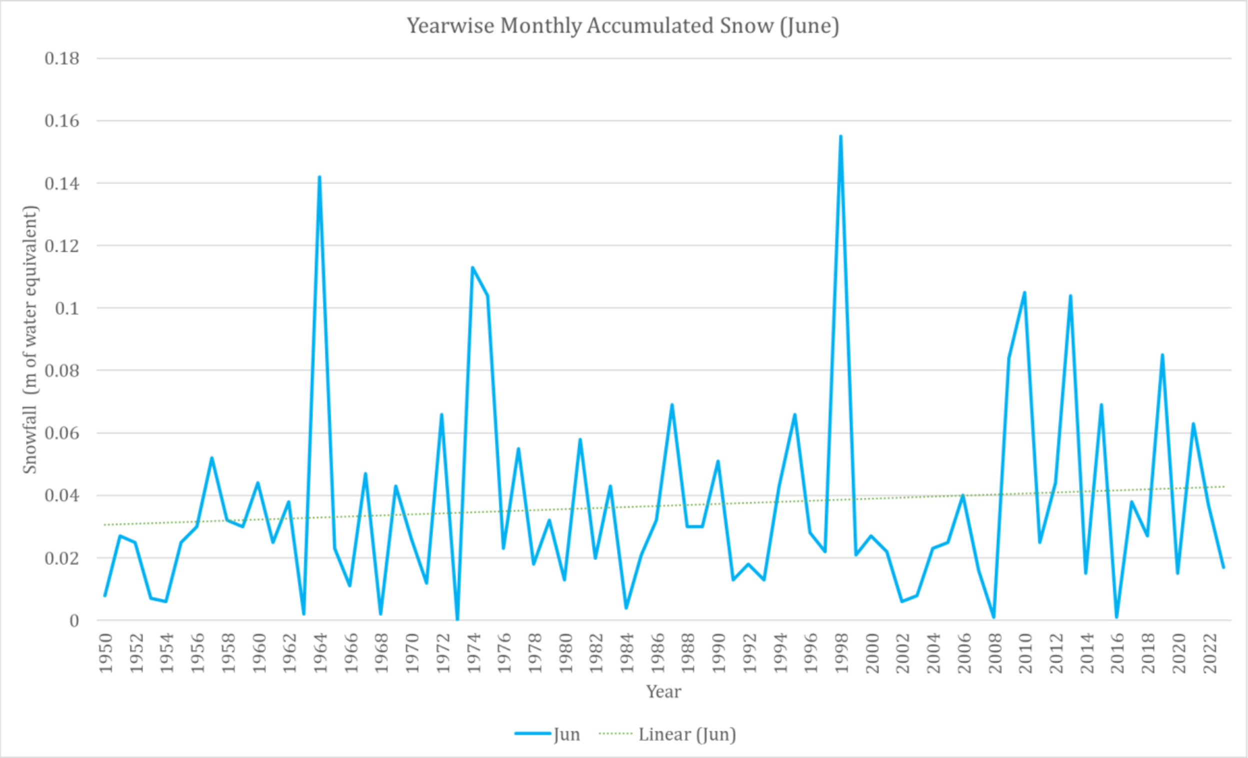

Figure 16: The plot shows the yearwise monthly accumulated snow of Lindur for the month of June from 1950 to 2023.

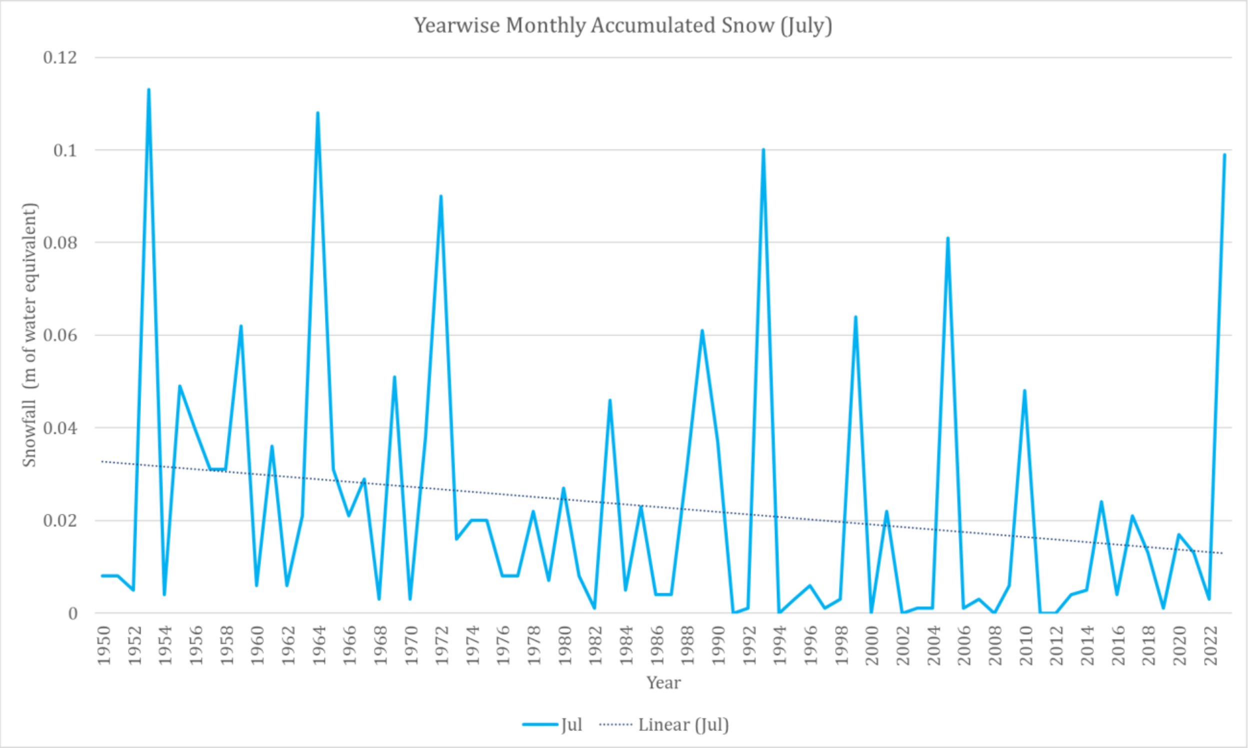

Figure 17: The plot shows the yearwise monthly accumulated snow of Lindur for the month of July from 1950 to 2023.

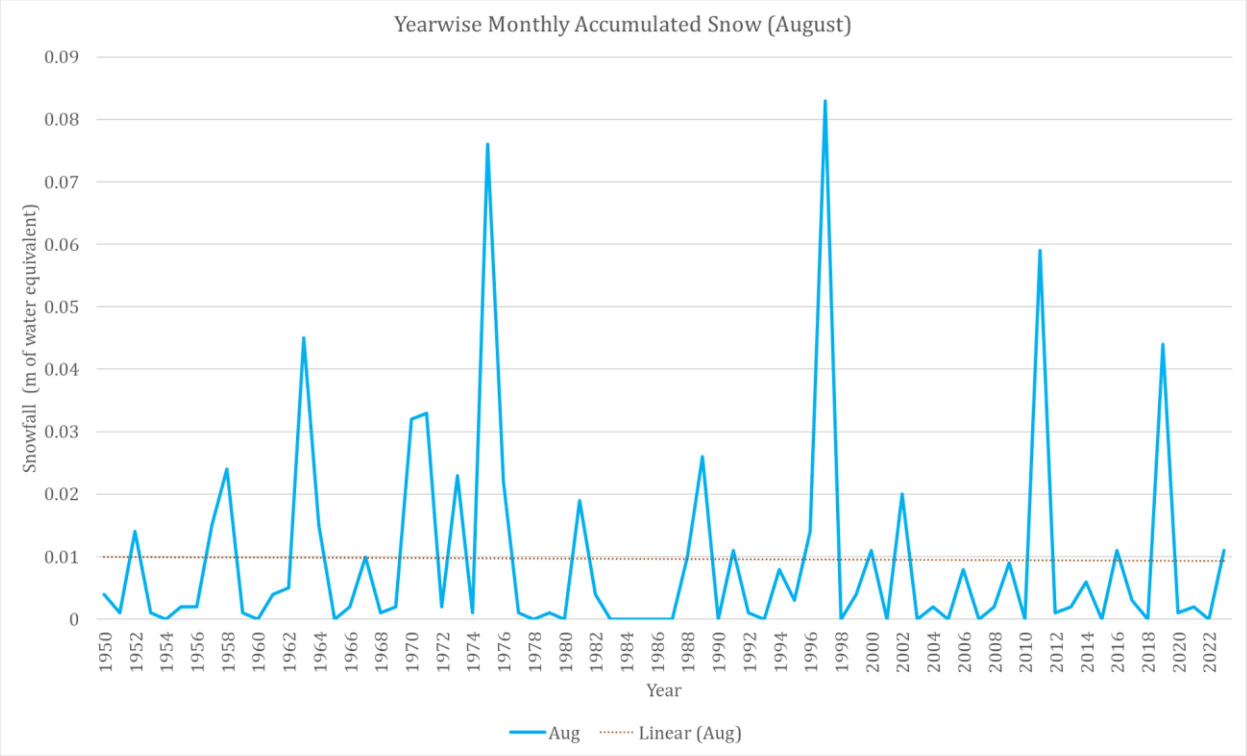

Figure 18: The plot shows the yearwise monthly accumulated snow of Lindur for the month of August from 1950 to 2023.

We conducted an analysis of the monthly total accumulated snowfall for June, July, and August (Figures 16-18) in each year from 1950 to 2023. The total accumulated snowfall includes snow resulting from large-scale atmospheric flow and convection, as well as smaller scale areas where warm air rises. Our findings suggest that there was a progressive increase in snowfall during the month of June. In contrast, an observed decline in the total accumulated snowfall is noted during the months of July and August.

6.3. Trend in Soil Temperature

Soil temperature has a significant impact on the behavior of rock glaciers, influencing deformation, crack formation, erosion, and subsidence. When the temperature of the soil rises, the ice inside the rock glacier can melt faster, which increases the production of meltwater. As this water percolates through the soil, its erosive properties contribute to the degradation of the underlying rock. The topography of a rock glacier is influenced by thermo-erosional processes, which are accelerated by elevated soil temperatures. These processes involve the combined action of meltwater flow and thermal stress, which result in the disintegration of rock particles. Changes in soil temperature can affect the stability of permafrost within the rock glacier. Temperature increases have the potential to induce permafrost degradation, which can result in structural deterioration and a higher probability of subsidence.

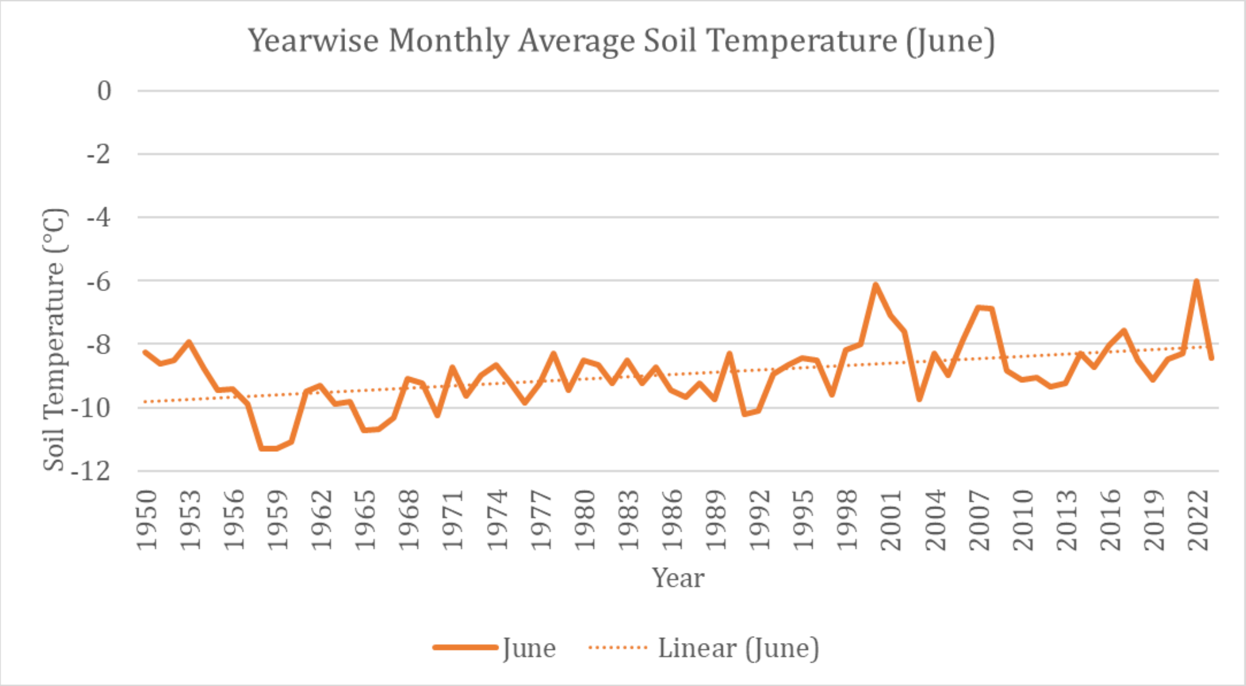

Figure 19: The plot shows the yearwise monthly average soil temperature in layer 1 (0-7cm) of Lindur for the month of June from 1950 to 2023.

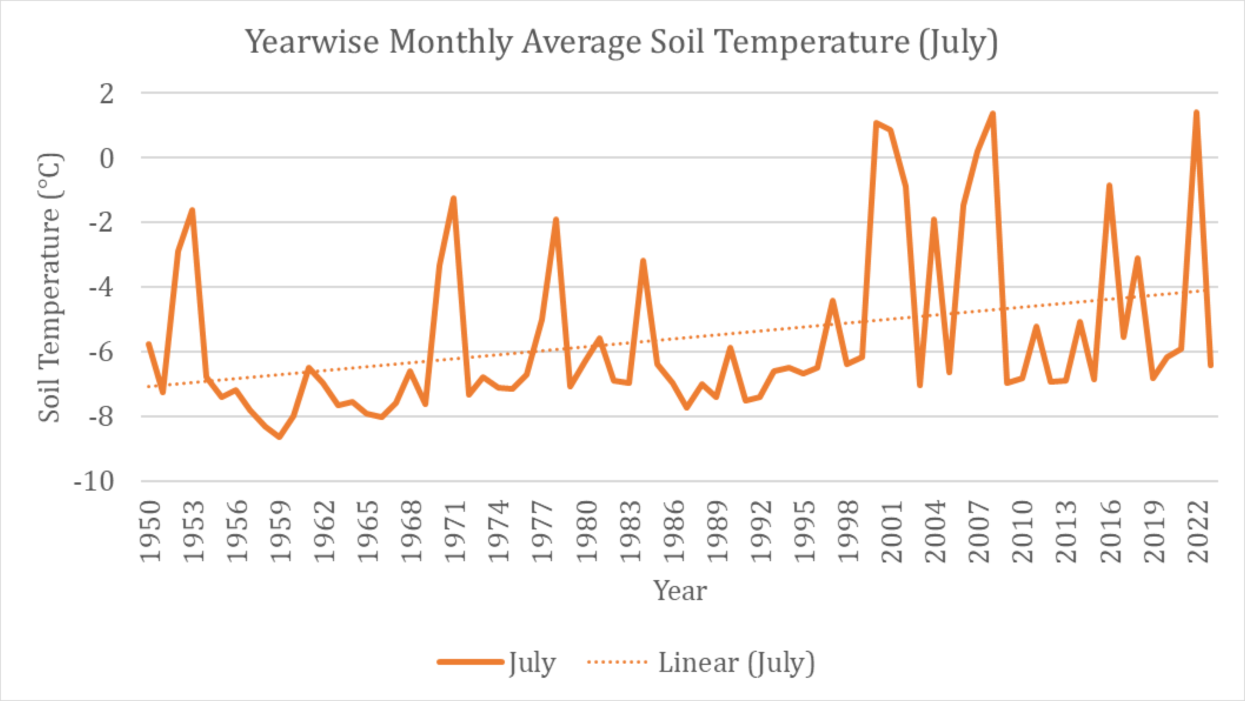

Figure 20: The plot shows the yearwise monthly average soil temperature in layer 1 (0-7cm) of Lindur for the month of July from 1950 to 2023.

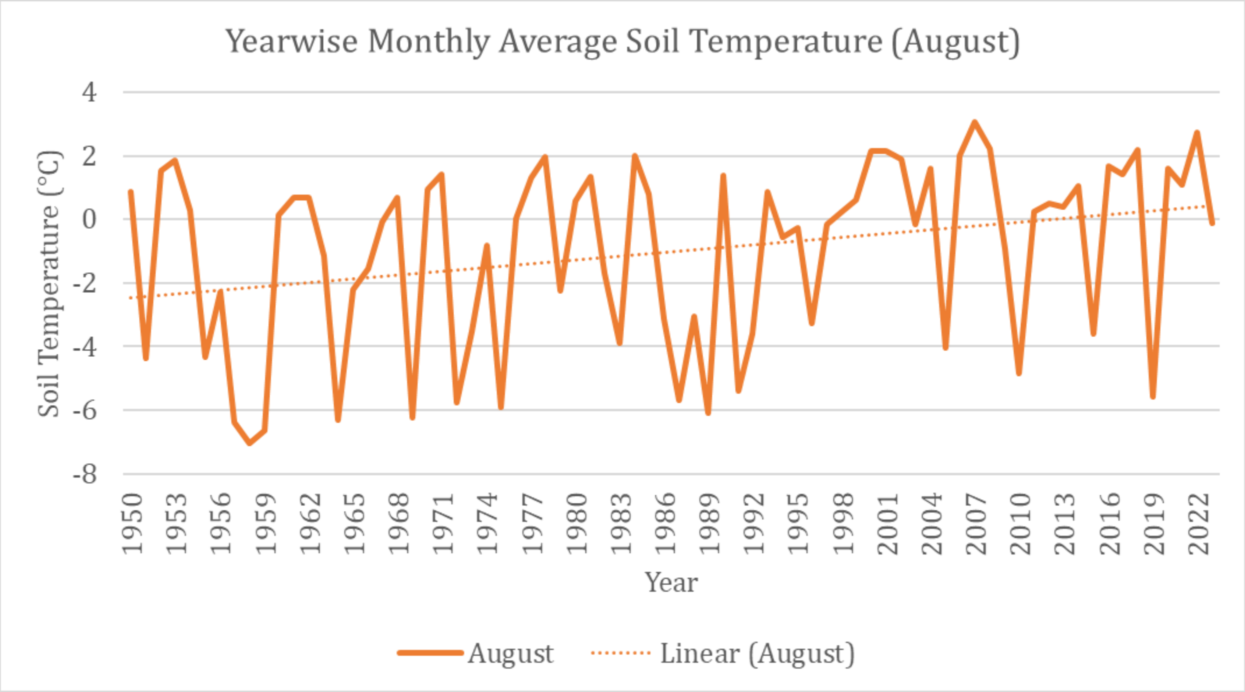

Figure 21: The plot shows the yearwise monthly average soil temperature in layer 1 (0-7cm) of Lindur for the month of August from 1950 to 2023.

The monthly average soil temperature in the 0-7 cm layer was examined for the months of June, July, and August (Figures 19-21) between 1950 and 2023. Soil temperatures exhibit a consistent and visible rising trend across all three months from 1950 to 2023.

6.4. Trend in Surface Pressure

The analysis of surface pressure is integral to understanding the dynamic interactions between air temperature, soil temperature, and broader atmospheric conditions.

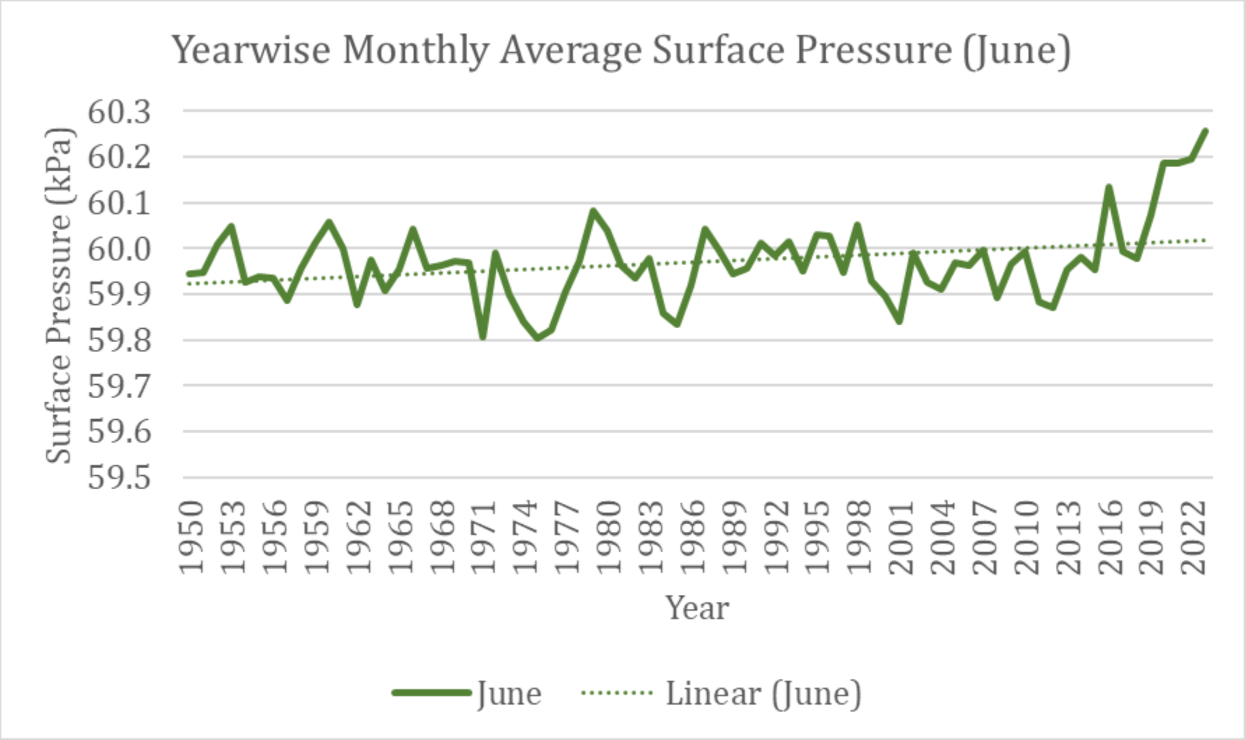

Figure 22: The plot shows the yearwise monthly average surface pressure of Lindur for the month of June from 1950 to 2023.

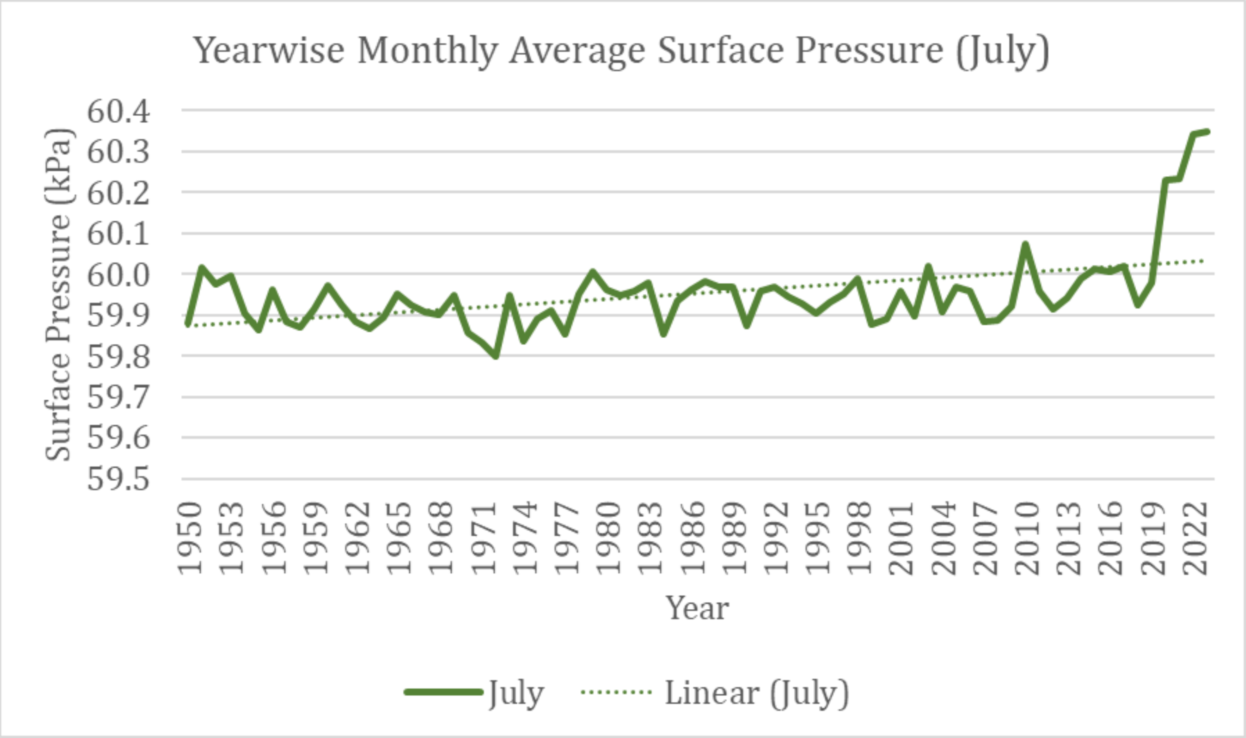

Figure 23: The plot shows the yearwise monthly average surface pressure of Lindur for the month of July from 1950 to 2023.

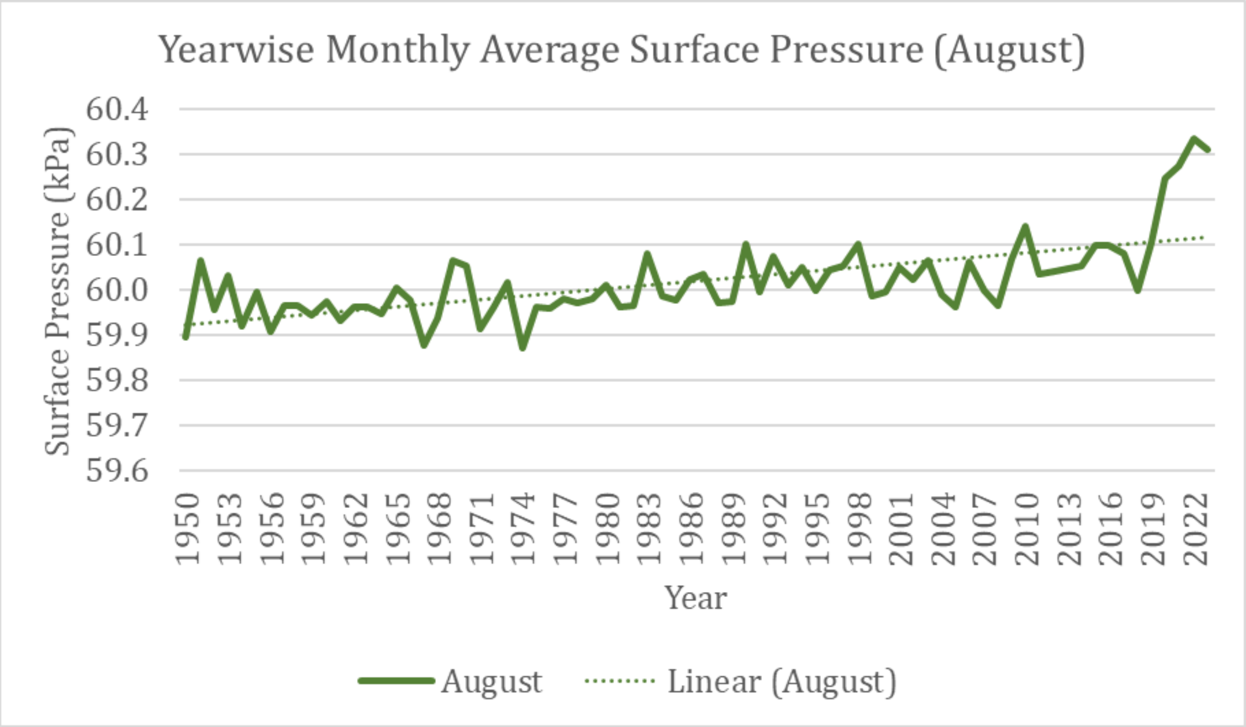

Figure 24: The plot shows the yearwise monthly average surface pressure of Lindur for the month of August from 1950 to 2023.

We examined the monthly average surface pressure for the months of June, July, and August (Figures 22-24) from 1950 to 2023. We noticed an increasing trend in surface pressure throughout all three months, from 1950 to 2023.

6.5. Trend in Snow Albedo

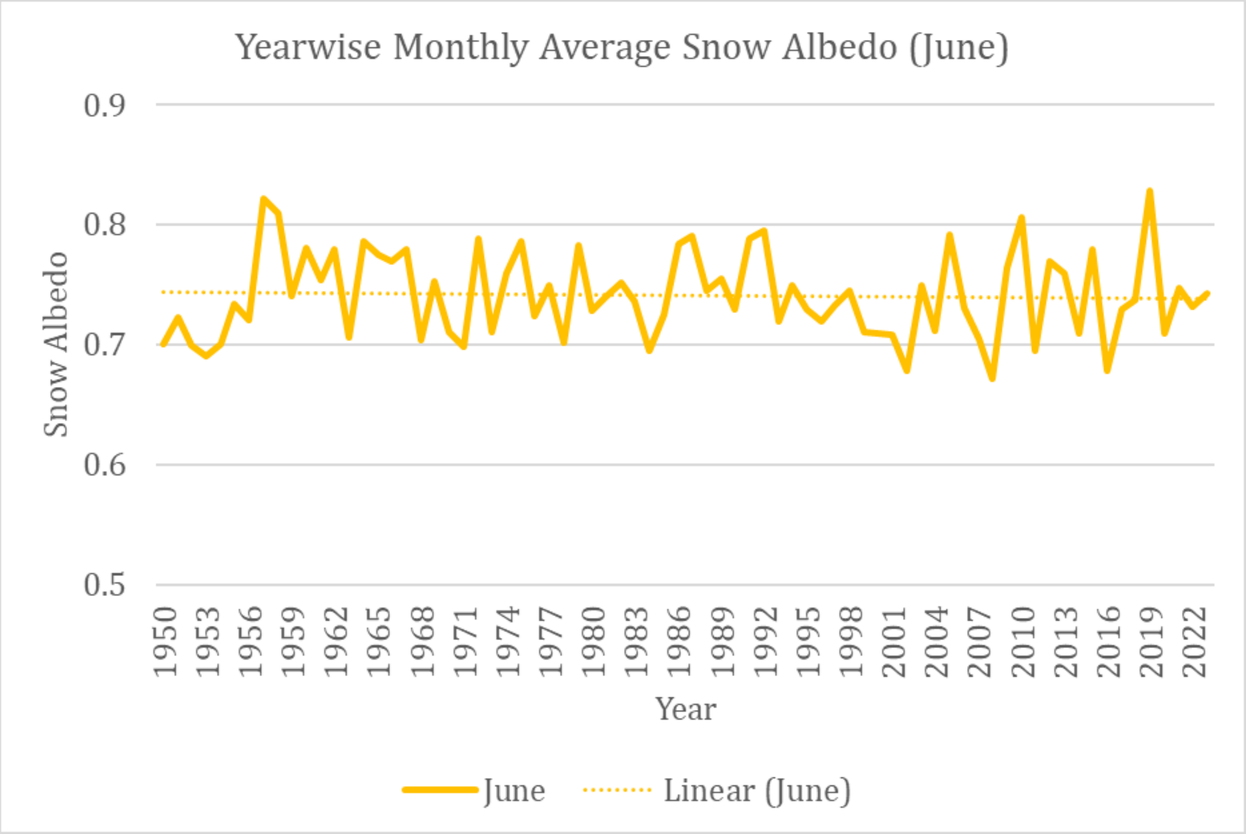

Figure 25: The plot shows the yearwise monthly average snow albedo of Lindur for the month of June from 1950 to 2023.

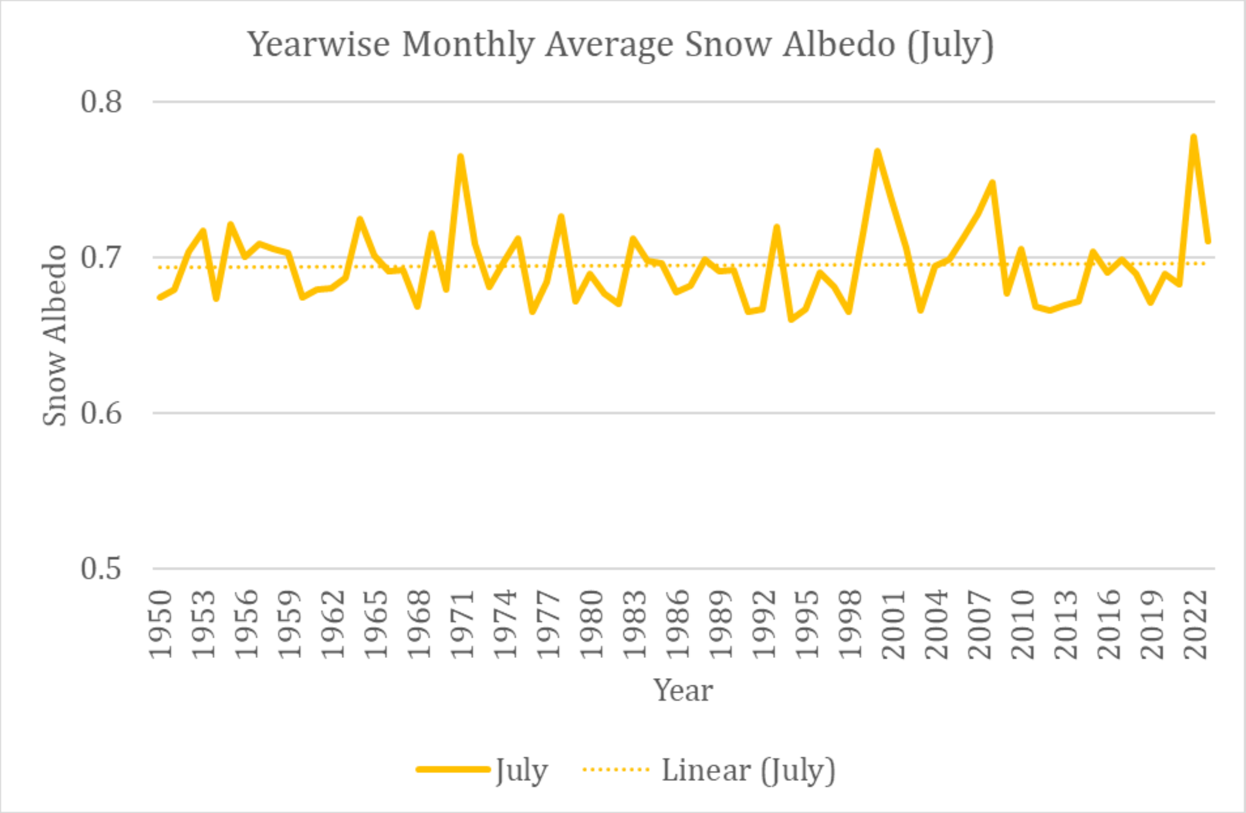

Figure 26: The plot shows the yearwise monthly average snow albedo of Lindur for the month of July from 1950 to 2023.

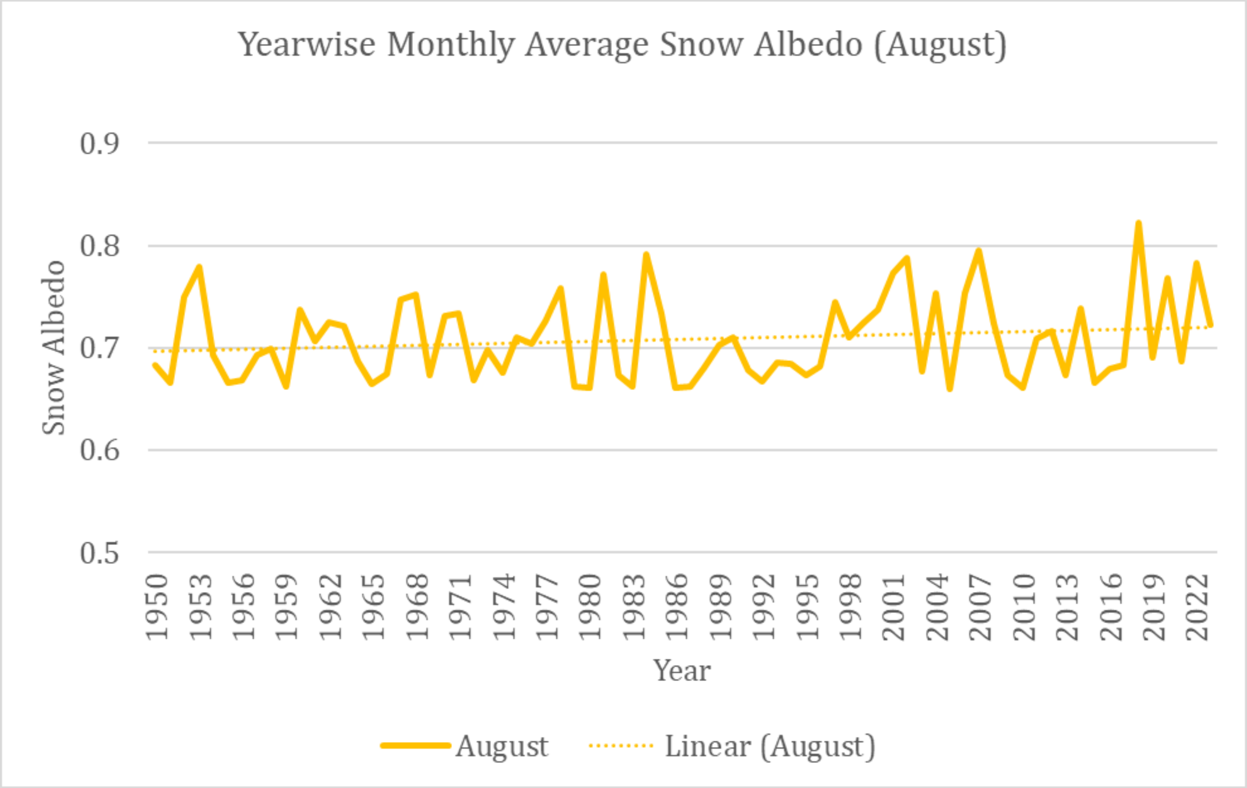

Figure 27: The plot shows the yearwise monthly average snow albedo of Lindur for the month of August from 1950 to 2023.

We analyzed the monthly average snow albedo for June, July, and August (Figures 25-27) across the years from 1950 to 2023. A marginal decreasing trend in snow albedo is evident in June and July. In contrast, during August, there is an observable increasing trend in snow albedo.

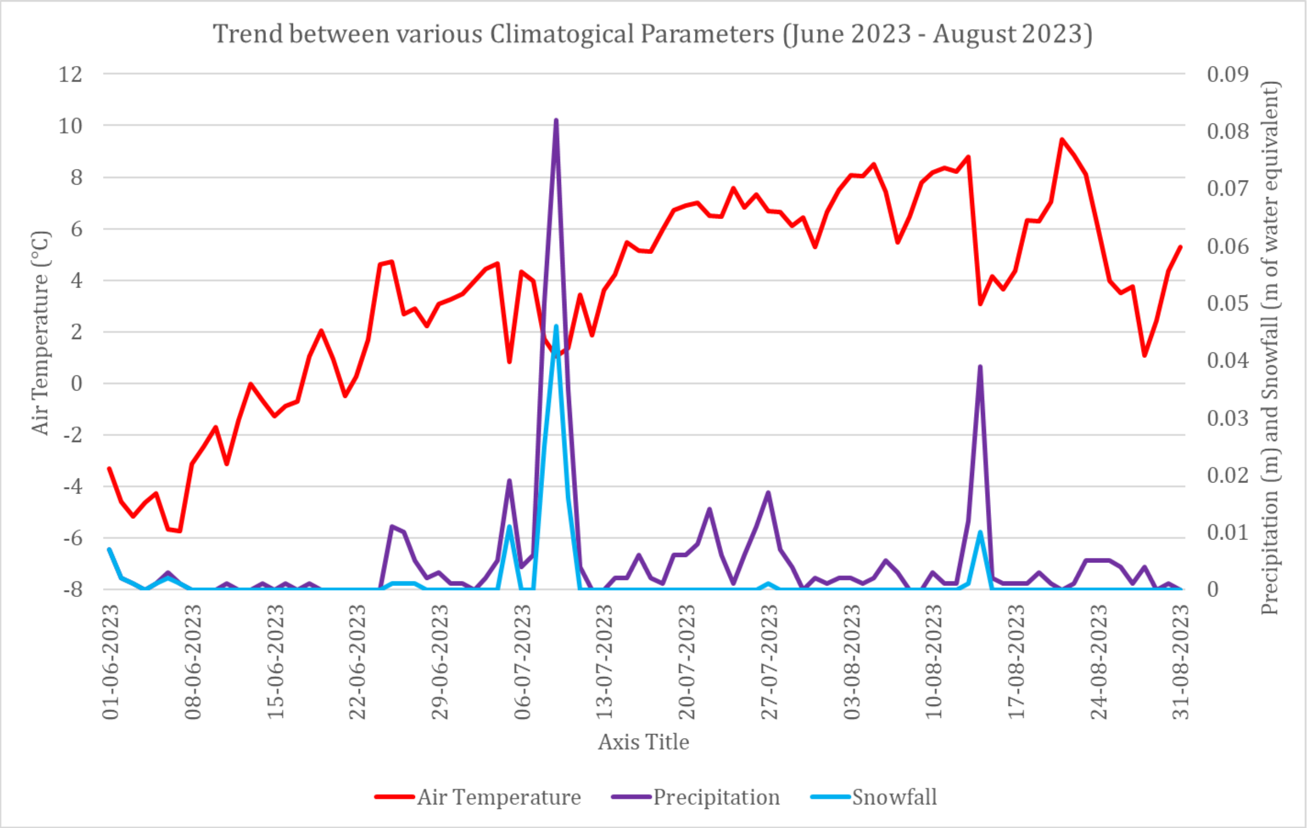

Figure 28: The plot shows the trend of air temperature, precipitation, and snowfall of Lundur from June 2023 to August 2023.

After analyzing the trends of key climatic parameters, including air temperature, precipitation, and snowfall, from June 2023 to August 2023, notable increases in total accumulated precipitation were observed on July 5, July 9, and August 14. The upsurge in total accumulated precipitation on these specific dates seems to be mainly influenced by moderate air temperatures that favor rainfall rather than substantial snowfall. Despite minimal snowfall recorded on these dates, the primary contributor to the heightened precipitation levels is identified as rain. This underscores the significance of rain in driving the observed elevated levels of total accumulated precipitation during these periods.

7. Recommendations:

Short term measures need to be taken such as providing structural stability, reinforcement to the buildings, retrofitting of the buildings may be carried out but this will give a temporary solution. Detailed study needs to be carried out to assess the real threat of the area. Being situated in the colder region that receives good snowfall and with changing climate the occurrence of rainfall events will increase. This may impact on the subsidence situation and the threat may increase in future. We suggest to carry out detailed study as mentioned below.

7.1. Continuous Monitoring:

Establishing a robust and continuous monitoring system is crucial for tracking the evolution of the crack and understanding the ongoing geological dynamics. In addition to conventional monitoring methods, consider implementing advanced technologies such as Interferometric Synthetic Aperture Radar (InSAR). InSAR can provide high-resolution, satellite-based observations, allowing for the detection of ground deformation over time. This technology offers a valuable tool to complement field surveys and enhance the accuracy of monitoring efforts. This method will help to detect the deformation rate over the years so that we can suggest short term and long-term preventive measures. Establishment of corner reflector is required to assess the InSAR deformation in this area.

7.2. Geological and geophysical survey:

A detailed geological survey is required to unravel the subsurface conditions and characteristics of the rock glaciers and permafrost in the region. Traditional field surveys, augmented by advanced techniques like Electrical Resistivity Tomography (ERT) and Ground-Penetrating Radar (GPR), can offer insights into the geological structure and composition beneath the surface. ERT measures subsurface resistivity, helping identify variations in permafrost conditions, while GPR provides high-resolution images of subsurface features, aiding in the identification of potential weaknesses contributing to the crack formation.

7.3. Installation of Weather Station:

The influence of climatic parameters is crucial in the formation of cracks, underscoring the necessity for continuous monitoring to identify and mitigate potential future events. Presently, our reliance on low-resolution ERA 5 data, available at an 11 km resolution, poses limitations in accurately representing weather conditions for Lindur village. This data also incorporates surrounding glaciers, which may not be reflective of the village's specific conditions. Consequently, there is an urgent need to install a dedicated weather station in Lindur village. Long-term monitoring at this station is essential for effective mitigation strategies.

8. Conclusion

The upward trend in air temperatures may contribute to thermal stress, leading to deformation and crack formation in rock glaciers. Changes in soil temperature and the observed cyclic pattern can influence the thermal expansion and contraction of the ground, potentially contributing to crack initiation and propagation. Increasing soil temperatures and surface pressure may affect permafrost stability, potentially leading to subsidence. Higher temperatures can enhance meltwater production, influencing erosion processes in the rock mass. The observed patterns in snowfall, with an increase in June and a decline in July and August, may impact the protective layer on rock glaciers. Reduced snowfall in July and August may expose the rock glacier to increased meltwater, contributing to erosion and potential subsidence.