Expansion of Lirung Glacial Lake in the Langtang Basin, Nepal: Implications for Mountain Water Sustainability and GLOF Risks

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Abstract

Glaciers are natural reservoirs of freshwater that cater to the millions of people in a mountainous country like Nepal. However, these freshwater sources are retreating at an alarming rate, altering the downstream flow. Furthermore, this has led to an increase in glacier lake areas and their number, which may eventually be at risk of Glacial Lake Outburst Floods (GLOFs). This study focuses on the expansion of Lirung Glacial Lake in the Langtang Basin from 2010 to 2024, utilizing multi-temporal satellite imagery from Landsat and Sentinel. The Normalized Difference Water Index (NDWI) was applied to delineate lake boundaries, which were then analyzed in conjunction with climate data from the basin. The result shows that over 14 years, the lake's area has increased at an approximate rate of 0.0035 km² yr⁻¹, from 0.016 km² in 2010 to 0.064 km² in 2024, representing a 60.8% increase, indicating significant glacier retreat. The mean annual temperature in the basin is increasing, and precipitation is slightly declining, which are conditions favourable for accelerated glacier mass loss. These findings underscore the heightened risk of GLOFs, with potential impacts on downstream communities and critical infrastructure, including Nepal's only operational glacial lake-fed micro-hydropower plant. The study highlights the urgent need for continuous monitoring, community-based early warning systems, and adaptive water resource management to safeguard downstream communities against increasing GLOF risks associated with climate change.

Keywords: climate change, glacier retreat, glacial lake expansion, Glacial Lake Outburst Flood (GLOF), Lirung Glacial Lake

Introduction

Glaciers are of considerable interest due to their high sensitivity to climate change (Zheng et al., 2022). The IPCC (2023) report states that glaciers will continue to lose mass for several decades even if global temperatures stabilize. In context of the Nepal Himalayas, it has been warming at a rate of 0.02 °C - 0.16 °C per year in recent decades (Khadka et al., 2023), resulting in shifts in snowfall patterns, greater ice melt, and increasing in formation and size of glacial lakes (King et al., 2019; Nie et al., 2013). Rapid climatic changes have altered the accumulation and melting patterns of snowfields and glaciers, increasing the size of glacier lakes and floods associated with them. Their retreat impacts water resources, influencing their basin hydrological regime due to their capacity to store water on seasonal to decadal time scales (Jansson et al., 2003).

Due to the rapid melting of glaciers, the number and area of glacial lakes have grown rapidly. Since 1990, global glacial lake area has increased by over 50% (Shugar et al., 2020).

According to Kumar et al. (2025), the number of glacial lakes in the Hindukush Karakoram region increased by 9.31% and their area expanded by 10.09% from 1990 to 2010. Furthermore, 110 GLOF events have been recorded in the Third Pole region since 1900, causing approximately 7,000 fatalities (Taylor et al., 2023). A recent report by Bajracharya et al. (2020) highlights that there are 21 potentially dangerous glacial lakes in Nepal, and this number is expected to grow further with unprecedented changes in the climate. For instance, a recent GLOF from Thyanbo glacier lake in Thame village of the Khumbu region caused the loss of properties, infrastructure, and biodiversity (ICIMOD, 2024). The outburst of Lhonak Lake in Sikkim in October 2023 killed over 150 people and destroyed infrastructure downstream (Pokhrel, 2024). Also in 1985 GLOF from Dig Tsho in the Everest region destroyed the Namche hydropower plant and caused USD 2 - 3 million in damage (Shah & Ishtiaque, 2025). These events underscore the urgent need to monitor expanding lakes and protect vulnerable communities.

Despite these regional concerns, the Langtang basin in Nepal stands out due to its unique role as the country's only operational glacial lake-fed hydropower project. The proglacial lake at the terminus of the Lirung Glacier holds significance as it generates 100 kW of hydropower energy consumed by two villages, Kyanjing and Langtang, which comprise around 120-175 households (Dixit, 2021). The rapid expansion of Lirung Lake could increase the risk of a GLOF that would endanger not only downstream communities and tourism but also the hydropower infrastructure itself. In this context, our study focuses on (a) quantifying Lirung Lakes expansion from 2010 to 2024, (b) relating observed changes to climatic trends, and c) discussing implications for hydrology and GLOF risk.

Methodology

Study area

Langtang Basin is a U-shaped valley with boulders, rock fragments, and debris covering the steep slopes and high plateaus, while forest and grassland are at lower altitudes (Raj Adhikari et al., 2014; Ragettli et al., 2015). The basin extends from a longitude of 85°31’E to 85°48’E and a latitude of 28°08’N to 28°24’N (WGS84 datum), where 46% of the total basin area is glacierized (Immerzeel et al., 2012; Zhou et al., 2017). The elevation ranges from 3800 m.a.s.l. up to 7234 m.a.s.l. and has an average altitude of 5169 m.a.s.l. with a mean slope of 26.7° (Immerzeel et al., 2012; Pradhananga et al., 2014; Zhou et al., 2017).

The Lirung Glacial Lake, also locally known as Kyanjing Lake, lies at the terminus of the Lirung Glacier, which originates from the Langtang Lirung peak (7,234 meters above sea level). The Langtang Valley is a region of glaciological and hydrological interest due to its high-altitude environment, numerous retreating glaciers, and emerging glacial lakes.

Figure 1

Kyanjing Meteorological Station and Lirung Glacial Lake

Note:

A. Kyanjing meteorological station, photograph @D. Pradhananga, and B. Lirung Glacial Lake and the micro-hydropower operated from the lake (Dixit, 2021).

Data

The study analyses the extent of Lirung Glacial Lake for the years 2010, 2015, 2020, and 2024 to assess decadal changes and trends in glacial lake dynamics. The study employs post-monsoon satellite imagery from two different sources to analyze changes in lake extent over time. For 2010, Landsat-8 imagery with a spatial resolution of 30 m was used. For 2015, 2020, and 2024, Sentinel-2 imagery with a higher spatial resolution of 10 m was used, allowing for more accurate lake boundaries.

To delineate water boundaries Normalized Difference Water Index (NDWI) was applied. This method is widely used to access and identify water bodies in satellite imagery (Gardelle et al., 2011; Sarp & Ozcelik, 2017; Watson et al., 2018).

$NDWI_{(Green,\ NIR)} = (Green - NIR) / (Green + NIR)$

For Sentinel 2,

$$NDWI = (B03 - B08) / (B03 + B08)$$

For Landsat-8

$$NDWI = (B03 - B05) / (B03 + B05)$$

The glacier outline used for this study is accessed from the ICIMOD Regional Database System. The study area was delineated using the QGIS platform. The satellite imagery used for this study is available at the Sentinel Hub EO Browser. Climate data were analyzed using the bias-corrected WFDEI (WATCH Forcing Data ERA-Interim) reanalysis dataset archived from Pradhananga et al. (2024). Key climate variables, temperature and precipitation, were analyzed for the years 1979 to 2024.

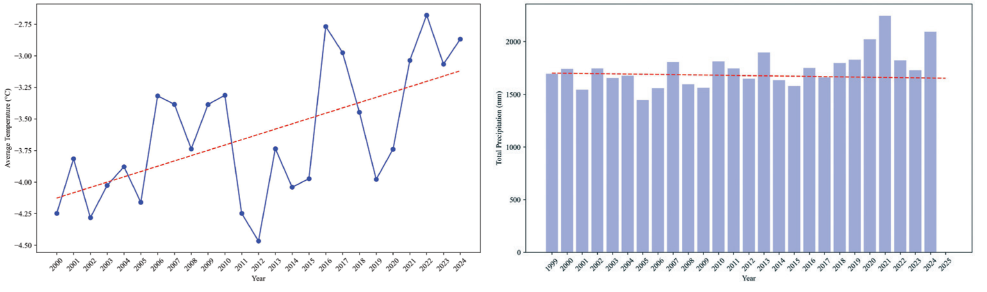
Results

Climate analysis

The analysis of bias-corrected WFDEI data from Kyanjing Station in Langtang Basin (Fig. 1) for the period (1979 – 2018) shows significant changes in climatic variables, critical for understanding glacier melt rates. The mean annual temperature at the Station, as shown in Figure 2a, has an increasing rate of 0.0095 °C per year (1979-2018) with a p-value of 0.0003, suggesting a statistically significant trend. The total annual precipitation depicts a slight negative slope of 0.05 mmyear, indicating a very nominal decline in the precipitation trend. However, the p-value of 0.97 implies that the trend is not statistically significant. The precipitation has remained relatively stable over the period (1979-2018), even though there is yearly variation, as illustrated in Figure 2b. These suggest that precipitation has not changed significantly; the warming temperature may have had an impact on glacier melt, snow-to-rain phase change, causing the melting of glaciers, adding water volume to the lake, and increasing its area.

Figure 2

Bias-corrected WFDEI data and precipitation at Kyanjing



Note:

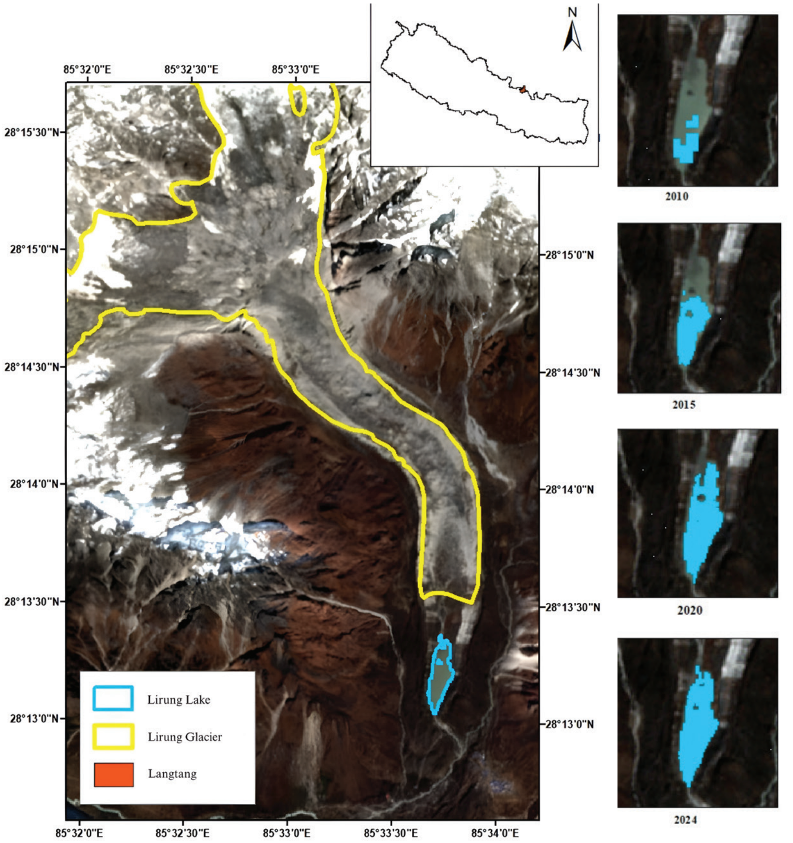
Bias-corrected WFDEI data from Kyanjing Station for Langtang Basin during the period 1979-2018 (A) Mean annual temperature and (B) Total precipitation at Kyanjing Station

Lake area extent analysis

Table 1, Figures 3 and 4 show that the lake area has increased significantly over the past 14 years. Between 2010 and 2024, the lake area increased by approximately 60.8%, changing from 0.016 km^2 to 0.064 km^2. Approximately, the lake has expanded its area by 0.0035 km^2 yr^{-1}. The expansion trend in the linear graph of Figure 4 is supported by the remote sensing data from Figure 3. The changes observed are due to climatic conditions and the accelerated glacial melt from the adjacent Lirung Glacier. Further, a high $R^2 = 0.99$ value indicates that the data fits the trend well, raising long-term concerns regarding water availability for hydropower generation and downstream communities.

Figure 3

Lirung Glacial Lake area evolution over time from 2010 to 2024



Note:

Multi-temporal satellite imagery of Lirung Glacial Lake showing expansion from 2010 to 2024 (Sources: Landsat 8, Sentinel-2).

Figure 4

Lirung Lake area change from 2010 to 2024.

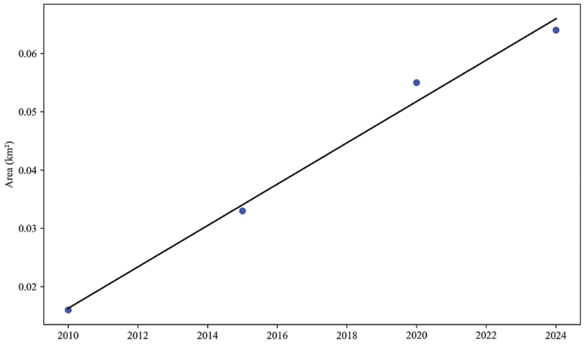


Table 1

·ea increased in a certain year

Years	Area (Km²)
2010	0.016
2015	0.033
2020	0.055
2024	0.064

Discussion

The rapid expansion of Lirung Glacial Lake from 0.016 km^2 in 2010 to 0.064 km^2 in 2024 highlights a fourfold increase over just 14 years. Notably, this trend suggests that the rate of expansion may accelerate under future warming scenarios, as indicated by the high correlation ($R^2 = 0.99$). While this rate is lower than the basin-wide averages reported for the Koshi (0.3 $km^2\ yr^{-1}$), Gandaki (0.11 $km^2\ yr^{-1}$), and Karnali (0.132 $km^2\ yr^{-1}$) basins (Khadka et al., 2023), the proportional increase in Lirung's area is significant. It underscores the heightened vulnerability of small, debris-covered glaciers to localized climate changes. Given the proximity of Lirung Glacial Lake to local settlements and the glacial lake-fed hydropower system, even a relatively small outburst could result in severe localized impacts, including damage to infrastructure, disruption of livelihoods, and loss of ecological integrity in downstream areas.

Further, under worst-case scenarios, glaciers are projected to recede up to 80% of their mass by the end of the 21st century, which will likely further accelerate glacial lake expansion (IPCC, 2023; Khadka et al., 2020; Pradhananga et al., 2024; Prasad et al., 2019).

In the Langtang region of Nepal, glaciers are already exhibiting negative mass balances (Khadka et al., 2023). Specifically, Lirung Glacier has been downwasting at rates of −1.3 to −1.8 m yr^{-1} during the period (1974–2010), leading to increased snow and ice loss from the glaciers, and contributing directly to lake growth (Nuimura et al., 2017). In this context, our findings of a 60.8% increase in lake area are consistent with these regional trends in glacier thinning and retreat. Further, Khadka et al. (2023) also reported that, on a regional scale, glacial lake areas in the Nepal Himalayas increased by approximately 25% from 1977 to 2017.

These findings highlight the urgent need for sustained monitoring, community-based early warning systems, and proactive risk mitigation strategies to safeguard both human communities and fragile mountain ecosystems in the Nepal Himalayas.

Conclusion

This study demonstrates a significant expansion of Lirung Glacial Lake in the Langtang Basin between 2010 and 2024, with its area increasing by 60.8% over 14 years. This growth is closely linked to the rapid retreat of the Lirung Glacier, driven by a warming climate and subtle shifts in precipitation patterns. The consistently increasing linear trend ($R^2 = 0.99$) suggests continued lake growth in the future, heightening the risk of GLOF events.

The statistically significant warming trend ($p = 0.0003$) and relatively stable precipitation suggest that temperature-driven processes, such as increased meltwater generation and phase shift from snow to rain, as the primary factors of lake expansion. Given the proximity of the lake to settlements and vital infrastructure, including Nepal's only operational glacial-fed micro-hydropower system, even relatively small-scale outbursts could have disproportionately severe impacts. These underscore the need for integrated, multi-disciplinary approaches to hazard mitigation, combining satellite-based monitoring with in-situ observations, community-based early warning systems, and adaptive water resource management strategies.

As climate change continues to intensify, adopting proactive measures to monitor and mitigate GLOF risks will be essential to safeguard livelihoods, ecosystems, and critical infrastructure in mountain regions like the Langtang Basin and beyond. Furthermore, enhancing institutional coordination and incorporating a community-based early warning system would be critical for reducing downstream vulnerability and ensuring sustainable water resource governance in glacierized basins.

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