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Temporal Changes of Temperature, Snow Cover and Glacier Area of Lumding Tsho Lake Watershed

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Abstract

The Himalayan region has a history of Glacial Lake Outburst Flood (GLOF) events which have caused loss of lives and properties downstream. Some of the glacial lakes in Nepal are among Potentially Dangerous Glacial Lakes(PDGL) having high risk of potential flood hazards. Lumding Tsho Glacier is one of the six PDGL with significant change in its lake volume over the few decades. This study aims to study temporal changes in Temperature, Snow Cover and Glacial cover over the lake catchment in the past few decades. The study provides valuable information regarding temporal changes of Temperature, Snow Cover and Glacier Area that supports the lake volume changes which has been already studied. The mean daily temperature was found to have an uptrend at the rate of 0.01825 ℃ per year and the snow line was found to be decreasing at maximum rate at elevation range of 4000m to 5000m at 0.00219 km^2/year. Similarly, the glacial coverage was found to have a significant decline over the past few decades at a rate of 3.362 km^2 per decade which also confirms that the glacial melt contributed to the increased lake volume.

Keywords

temporal change, temperature, snow cover, glacier

1. Introduction

Nepal is a country in South Asia with around 800 km length of Himalayan range [1]. This Himalayan range as more than 1500 glacial lakes [2]. Meteorological studies of available records show that there has been an increase in mean annual temperature. The mean annual temperature is found to be on an upward trend from late 1970 [3] with more prominent increase during summer period. The upward trend was found to be more in Himalayan region among five physiographic regions [3]. The land use – land cover pattern in the Himalayan region suggests that there has been no significant urbanization which supports the fact that the temperature trend is not due to urbanization but due to global warming. The global warming has led to appearance of new glacial lakes in Himalayan region [4].

The glaciers in Himalayan regions of Nepal have been recorded to be retreating (ICIMOD 2001). This retreat has increased the risk of Glacial Lake Outburst Flood (GLOF) events [5]. ICIMOD (2001) identified 6 Potentially Dangerous Glacial Lake (PDGL) in Nepal having high risk of GLOF due to glacial retreats. 35 GLOF events have been recorded in Hindu Kush Himalaya (HKH) region in the past out of which 25 events have been recorded in Nepal.

Lumding Tsho Glacier is one of the six potential dangerous glacial lakes of Nepal. It has been expanding rapidly with three hanging glaciers in the side valley and also in contact with calving glaciers. Semi quantitative hazard assessment [6] concluded that Lumding Tso lake has high risk of potential GLOF. Similarly, quantitative hazard assessment Wang (2011) and Emmer and Vilimek (2014) found that Lumding Tsho lake was medium and highly dangerous respectively [7],[8]. Rounce et al (2016) in their hazard assessment found that Lumding Tsho glacier had a high risk of dynamic failure and medium risk of self-destructive failure [9]. Both these risk combined were considered as a very high risk hazard. They also found that the lake is susceptible to avalanches and rock falls. The lake was also studied to be susceptible to possible GLOF from Lumding Tsho Teng, a glacial lake situated at 27°47.40' N, 86°37.30' E, 5141 m.a.s.l with an area of 0.34 km^2.

The main objective of this study is

1. To analyze the trend in temperature in the Lumding Tsho lake catchment by using Bias Corrected ERA5 hourly temperature data.
2. To study the snow cover trend in the catchment area by the assessment of cloud corrected MODIS data.
3. To analyze the temporal variation in Glacial Coverage area of Lumding Tsho lake catchment through assessment of Glacial inventory image data.

2. Study Area

The outlet of Lumding Tso Lake (86°36.8' E, 27°46.8' N) is located at 4819.3 amsl in the Himalayan region of Nepal. The outlet from Lumding Tsho lake mixes with Dudhkoshi at about 20 km downstream. The area of the lake was found to be 1.18 km^2 [9] with catchment area of 52.13 km^2.

Lumding Tsho glacier was found to have an SLA (Snow Line Altitude) of 10.5°, which is more than the stable threshold [9]. Detailed study also revealed that the lake has been growing at the rate of 0.023 ± 0.002 km^2/yr. Bathymetric survey conducted during the hazard assessment by Rounce et al (2016) found that the average depth of the lake was 51 m with maximum depth of 114 m with total water volume of 57.7x10^6 m^3 [9].

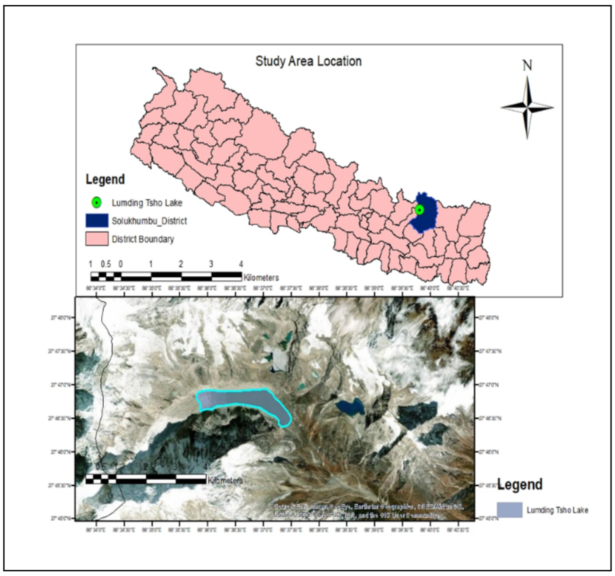

Figure 1: Lumding Tsho Glacier Location

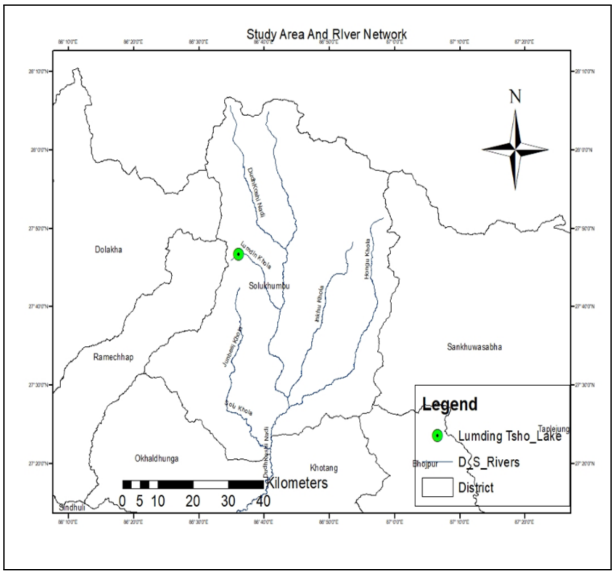

Figure 2: Contribution to Dudhkoshi Basin

3. Data and Method

3.1 Temperature trend

ERA5 Land hourly temperature from 1981 AD to 2020 AD were used for temperature trend analysis. The hourly temperature data were downloaded from https://cds.climate.copernicus.eu. The hourly temperature was used to find the daily average temperature which where bias corrected with meteorological station at Salleri Station (Department of Hydrology and Meteorology). ERA5 Land is a reanalyzed data which has an enhanced resolution compared to ERA5 data. It contains hourly record from 1981 to present [10]. The spatial resolution of ERA5 Land hourly data is 9 km on a reduced Gaussian grid which have been re-gridded into a 0.1 x 0.1 degree Lat-Long grid. 2 m land surface data is used for temperature trend analysis.

Due to lack of long-term observation data, ERA5 land reanalysis data was used for the temperature trend analysis. Before using the ERA-5 data, it was bias corrected with meteorological station at Salleri Station (Department of Hydrology and Meteorology). The bias correction was made aggregating the hourly data at daily resolution.

ERA5 Land hourly temperature were extracted using codes in Python. The mean maximum and minimum daily temperature were calculated from the obtained hourly temperature. The calculated mean temperature was corrected for mean bias using recorded data. For temperature additive bias correction was used [11].

Mathematically:

Mean Bias = $Mean\ Daily\ Temperature_{ERA5}$- $Mean\ Daily\ Temperature_{RecordedStation}$

Corrected ERA5 Temperature = Modelled ERA5 Temperature – Mean Bias

3.2 Snow Cover Trend

MODIS 8-day maximum snow cover data is a combined product of NASA's Aqua and Terra satellite with 500 m resolution. The snow mapping was performed by using grouped-criteria technique such as Normalized Difference Snow Index (NDSI) and other spectral threshold tests which identifies and classifies snow on each pixel. The 8-day maximum snow cover data is a dataset of maximum snow cover over a compositing period of 8 days and the data is chronologically compressed in Hierarchical Data Format – Earth Observatory System (HDF-EOS) format (National Snow and Ice Data Center).

8 –day maximum snow cover product from cloud corrected MODIS (Moderate Resolution Imaging Spectroradiometer) data were downloaded from ICIMOD regional database. The data is a product of combination of combined Aqua and Terra combined 8-day C6 product and Randolph Glacier Inventory Version 6.0 (RGI 6.0). The output product was found to have an increased accuracy by 10% as compared to Landsat data [12].

The 8-day maximum snow cover data was converted into ASCII format using ARCGIS and trend analysis was performed as per elevation using Python code. The elevation of the watershed ranges from 3900 m to 6700 m. The snow cover was first calculated at a range of 1000 m from 4000 m to 6700 m. The Fractional Snow Cover Area (FSCA) was calculated as: FSCA= Snow Cover Area / Total Watershed Area

3.3 Glacial Coverage

The cloud filtered polygon data of snow coverage of 1981,1991,2001 and 2011 AD obtained from ICIMOD regional database was used for glacial coverage analysis. The polygon data of Glacial Lake Inventory is created using various satellite images from Landsat MSS, ETM+ and TM of four respective decades. The image validation was done by using high resolution Google Earth images. The glacial coverage polygon map was then imported and calculated for decadal area in ARCGIS.

4. Results and Discussion

4.1 Temperature Trend

The time series data of Lumding Tsho glacier was studied. The analysis showed an increasing trend in mean temperature (Figure 3) with trend line equation as y = 5E-05x - 7.2655 at 0.01825°C per year.

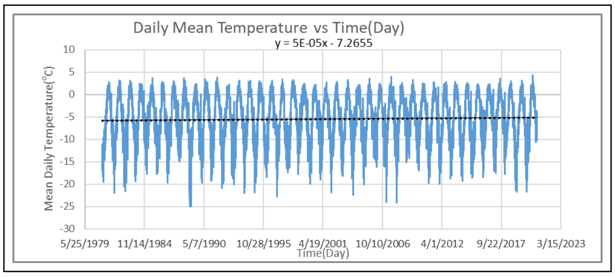

Figure 3: Mean Daily temperature of Lumding Tsho Catchment

4.2 Snow cover Trend

At elevation range from 4000 m to 5000 m the snow cover trend was found to be negative (Figure 4) with equation y = -6E-06x + 12.358 at the rate of 0.00219 km^2/year.

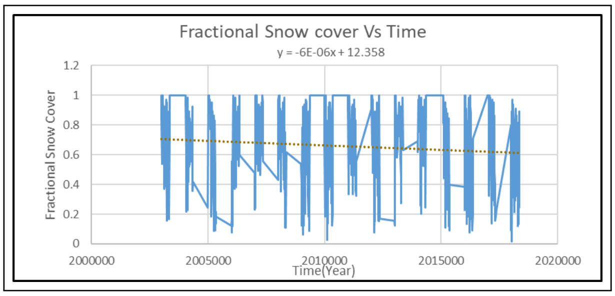

Figure 4: Fractional Snow Cover vs Time Graph of catchment within elevation range 4000 m – 5000m

At elevation range from 5000 m to 6000 m, the snow cover trend was studied to be on a downward trend (Figure 5) with equation y = -2E-06x + 5.017 at the rate of 0.00073 km^2/year.

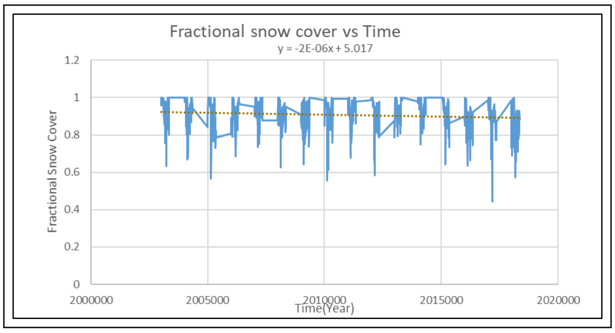

Figure 5: Fractional Snow Cover vs Time graph in at catchment within elevation range 5000m - 6000m

At an elevation range of 6000 m to 6700 m, the snow cover trend was found to be decreasing (Figure 6) with equation y = -1E-07x + 1.2576 at the rate of -3.65 x 10^{-6} km^2/year.

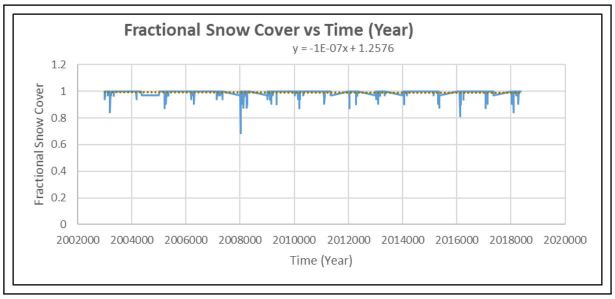

Figure 6: Fractional Snow Cover vs Time at catchment within elevation range 6000 m - 6700m

The elevation results of fractional snow cover area can be summarized in the following table:

Table 1: Elevation results of fractional snow cover area

Elevation Range	Slope	Intercept
4000 m – 5000 m	-6x10^{-6}	12.358
5000 m – 6000 m	-2 x10^{-6}	5.017
6000 m- 6700 m	-1x10^{-7}	1.2576

The slope of the downward trend line is less prominent as we move towards higher elevation. In the lower elevation range 4000 m to 5000 m, the snow cover was found to be decreasing at the rate of 0.00219 km^2/year.

4.3 Glacial Coverage

From the glacier data collected from RSD of ICIMOD, the glacial coverage area of Lumding Tsho catchment was calculated and it was found that there is a decreasing trend of glacier area in this region as mentioned in the table. The decrease in glacier area is plotted in the Figure 7.

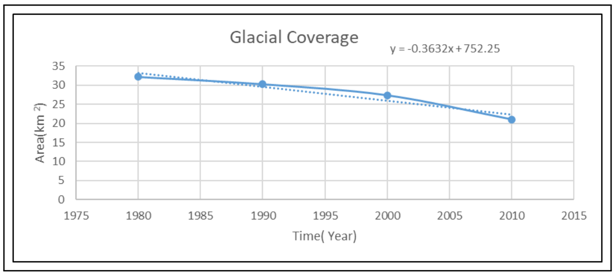

Figure 7: Decadal Glacial Coverage of Lumding Tsho Catchment

The decadal change can also be viewed in table:

Table 2: Glacial Coverage Change

Year	Glacial Coverage(km^2)	Decrease in Glacial Coverage(km^2)
1980	32.152	-
1990	30.242	1.91
2000	27.349	2.893
2010	21.02	6.339

The decadal trend of Glacial Coverage shows that the glacial region has been decreasing at a rate of 3.5 km^2/year.

With increasing temperature, the glacier area decreases and the snow line shifts to the higher elevation there is high chance of formation of glacier lake in the lower section of the glacier. With time the size of glacier lake increases while the size of the glacier decreases. This increase of glacial lake size can be seen in the image below.

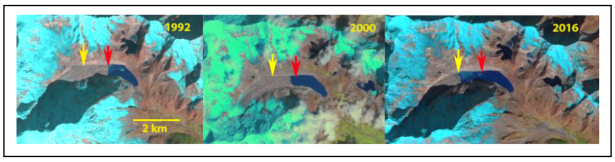

Figure 8: Landsat image comparison of Lumding Tsho Lake at various years [13, 14]

5. Conclusion

To study the trend analysis of temperature in Lumding Tsho Glacial catchment, we used the ERA5 hourly temperature from 1981 AD to 2020 AD and converted it into daily mean temperature. The daily mean temperature was corrected for mean bias using recorded data of nearest station at Salleri. The trend line of daily mean temperature was studied. The uptrend of mean temperature suggested that the temperature around the glacier catchment is rising which would contribute to increase in glacial melt.

Similarly, Cloud corrected MODIS data was studied for change in snow cover area in the glacial catchment. The study found that snow cover area was declining along the catchment area. The study also concluded that the recession of snow line was more along the lower elevation range of the catchment.

Glacial coverage of the Lumding Tsho catchment was also investigated in our study. Polygon data of 1981, 1991, 2001 and 2011 AD available in ICIMOD regional database were used. Decadal comparison of glacial coverage found that there was decrease in glacial area around the catchment which could contribute to the increased lake size of Lumding Tsho.

With time, the size of the lake increases while the size of the glacier decreases. These type of lakes could have hazardous consequences if it breaks under natural condition. Hence a thorough impact of Lumding Tsho glacier lake must be assessed. For now, this study is out of scope for the present context but hopefully will be carried out in the future.

References

[1] Patrick Le Fort. Himalayas: the collided range. present knowledge of the continental arc. *American Journal of Science*, 275(1):1–44, 1975.

[2] Nitesh Khadka, Guoqing Zhang, and Sudeep Thakuri. Glacial lakes in the nepal himalaya: Inventory and decadal dynamics (1977–2017). *Remote Sensing*, 10(12):1913, 2018.

[3] Arun B Shrestha, Cameron P Wake, Paul A Mayewski, and Jack E Dibb. Maximum temperature trends in the himalaya and its vicinity: an analysis based on temperature records from nepal for the period 1971–94. *Journal of climate*, 12(9):2775–2786, 1999.

[4] Tobias Bolch, Anil Kulkarni, Andreas Kääb, Christian Huggel, Frank Paul, J Graham Cogley, Holger Frey, Jeffrey S Kargel, Koji Fujita, Marlene Scheel, et al. The state and fate of himalayan glaciers. *Science*, 336(6079):310–314, 2012.

[5] J.D. Ives. Glacial lake outburst floods and risk engineering in the himalaya. *ICIMOD occasional paper*, 1986.

[6] T Bolch, T Pieczonka, and DI Benn. Multi-decadal mass loss of glaciers in the everest area (nepal himalaya) derived from stereo imagery. *The Cryosphere*, 5(2):349–358, 2011.

[7] Weicai Wang, Tandong Yao, Yang Gao, Xiaoxin Yang, and Dambaru Ballab Kattel. A first-order method to identify potentially dangerous glacial lakes in a region of the southeastern tibetan plateau. *Mountain Research and Development*, 31(2):122–130, 2011.

[8] A. Emmer and V. Vilímek. New method for assessing the susceptibility of glacial lakes to outburst floods in the cordillera blanca, peru. *Hydrology and Earth System Sciences*, 18(9):3461–3479, 2014.

[9] David R Rounce, Daene C McKinney, Jonathan M Lala, Alton C Byers, and C Scott Watson. A new remote hazard and risk assessment framework for glacial lakes in the nepal himalaya. *Hydrology and Earth System Sciences*, 20(9):3455–3475, 2016.

[10] Hans Hersbach, Bill Bell, Paul Berrisford, Shoji Hirahara, András Horányi, Joaquín Muñoz-Sabater, Julien Nicolas, Carole Peubey, Raluca Radu, Dinand Schepers, et al. The era5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146(730):1999–2049, 2020.

[11] FC Sperna Weiland, LPH Van Beek, JCJ Kwadijk, and MFP Bierkens. The ability of a gcm-forced hydrological model to reproduce global discharge variability. *Hydrology and Earth System Sciences*, 14(8):1595–1621, 2010.

[12] Sher Muhammad and Amrit Thapa. An improved terra–aqua modis snow cover and randolph glacier inventory 6.0 combined product (moydgl06*) for high-mountain asia between 2002 and 2018. *Earth System Science Data*, 12(1):345–356, 2020.

[13] Samjwal Ratna Bajracharya and Pradeep Mool. Glaciers, glacial lakes and glacial lake outburst floods in the mount everest region, nepal. *Annals of Glaciology*, 50(53):81–86, 2009.

[14] Mauri Pelto. https://blogs.agu.org/fromaglaciers perspective/2014/07/13/himalayan-glacier-change-index/. 2017.