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Temporal Variation Analysis in Clean Ice Glacier of Annapurna Basin

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Abstract - Glaciers of the Himalayas are the storehouse of fresh water. The impacts of climate change, mainly the melting of snow cover have been noticed in Nepal's Himalayas. These changes have local as well as regional implications on water resources, and at global level on the sea level rise. This study is carried out to analyze the temporal variation of glacier retreat in the Annapurna valley from 2000 to 2020 using remote sensing technology. It is a multi-step process and involves the computation of several mathematical indices for glaciers based on the spectral properties of Landsat imagery. The final outcome is the delineation of Clean Ice Glacier (CIG) area of Annapurna basin for the years 2000, 2010 and 2020. The findings from this study reveal that the glaciers of Annapurna basin are shrinking more rapidly in the recent years than before. The decrease in CIG area coupled with the increase in the CIG number clearly indicate that the glaciers are being fragmented into smaller parts creating several disconnected ice bodies. Monitoring the dynamics of glaciers along with their trend analysis is crucial for strengthening the climate change mitigation and adaptation strategies.

***Key Words*:** Clean Ice Glacier, Temporal Variation, Annapurna Basin, Remote Sensing, Climate Change

1 INTRODUCTION

Nepal is a mountainous country with most of the area covered by mountains and hills. Glaciers of the Himalayas are the storehouse of fresh water from which hundreds of millions of people downstream benefit in dry season. These Himalayas are also termed as the "water tower" and "third pole" of the earth (Tsering, 2012). It was documented that there are 3,252 glaciers in Nepal alone and the area of 5,324 sq km is covered by high frozen reservoirs that release water at the top of their watershed (Mool et al., 2002).

Mountains are particularly vulnerable to climate change. The impacts of climate change, mainly melting of snow cover have been noticed in Nepal's Himalayas. Temperature rise between 0.15 and 0.6 degree per decade has been recorded in Nepal since 1971 to 1994 (Shrestha, 1999), which is two to eight times higher than the global mean warming of 0.74°C over the last 100 years (IPCC, 2013). The average annual mean temperature in the Langtang and Imja (Khumbu) sub-basins rose at an average rate of 0.12°C/year and 0.09°C/year respectively, between years 1988 and 2008 (ICIMOD, 2014). Increased snow and glacial melt and the frequency of extreme weather have exacerbated livelihood risks including poverty, food insecurity, natural hazards and social inequity in Nepal (WMO, 2021).

Climate change is a burning issue which is widely prevalent all over the world. Impacts of climate change are gradually becoming visible in the nature particularly in the sectors of hydrology, ecology, biodiversity and even in the status of snow and glaciers of the Himalayas. In recent years, receding snow line, growing glacial lakes and retreating glaciers have been noticed in the high mountain regions of Nepal (Shrestha and Aryal, 2011). These changes have local as well as regional implications on water resources, and at global level on the sea level rise. Hence, it is necessary to continuously monitor the changes that occur in the size and properties of glaciers. This study is therefore carried out to analyze the temporal variation of glacier retreat in the Annapurna valley from 2000 to 2020 using remote sensing technology.

2 RESEARCH METHODOLOGY

2.1 Study Area

The study area for this analysis is the Annapurna basin. It lies in the northern part of Kaski district of Gandaki Province, Nepal. The lowest point has an elevation of 1850 meters and is located at 28˚24'30.84"N and 83˚49'31.56"E whereas the elevation of the highest point is 7994 meters which is located at 28˚35'41.30"N and 83˚49'16.36"E (Google Earth, 2020). The Annapurna basin is a part of the Annapurna Conservation Area Project (NTNC, 2022). It is mostly popular for tourism activities including trekking and mountaineering.

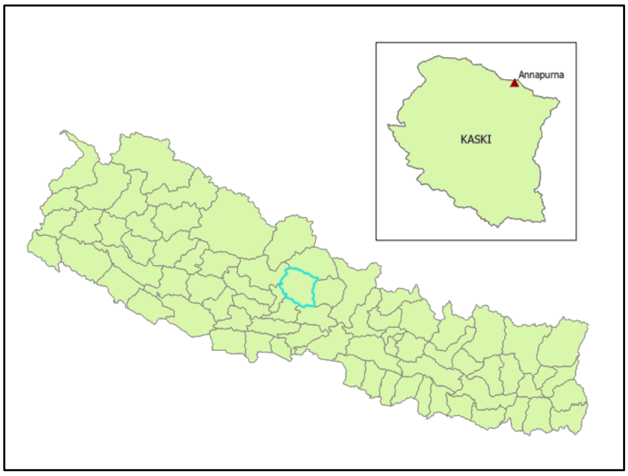


Fig -1: Location Map

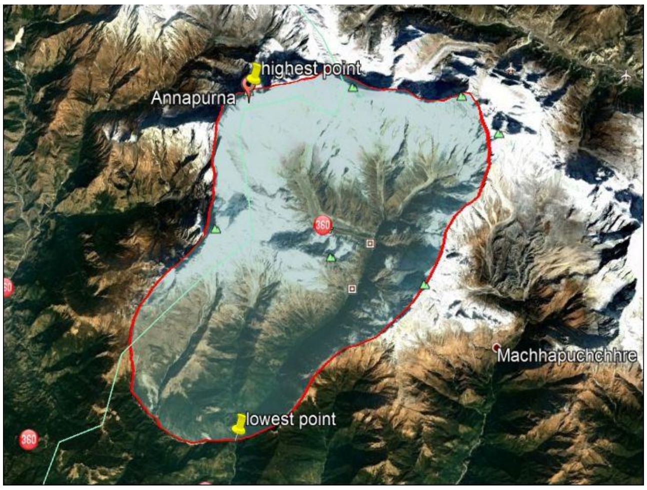


Fig -2: Study Area

2.2 Datasets

For this research, three Landsat 7 ETM+ images of the study area have been acquired from the official site of United States Geological Survey for the years 2000, 2010 and 2020 respectively. Landsat 7 ETM+ captures data in eight spectral bands including seven multispectral and one panchromatic band (USGS, 2022). The acquired images are Level 2 products which by default, are radiometrically and geometrically corrected that reduces the time for additional preprocessing. Overall, the images belong to a period from late winter (March) and pre-monsoon (May) as the images between this period tend to have a low cloud cover, less than 30%. All the three images used for this analysis have a spatial resolution of 30 meters. Also, a Digital Elevation Model (DEM) of the study area has been downloaded from Open Topography with 30 meters resolution.

3 METHODOLOGY

This analysis is a multi-step process and involves the computation of several mathematical indices for glaciers based on the spectral properties of Landsat imagery. The entire workflow of the study can be summarized in the flowchart as shown in Figure 3 below.

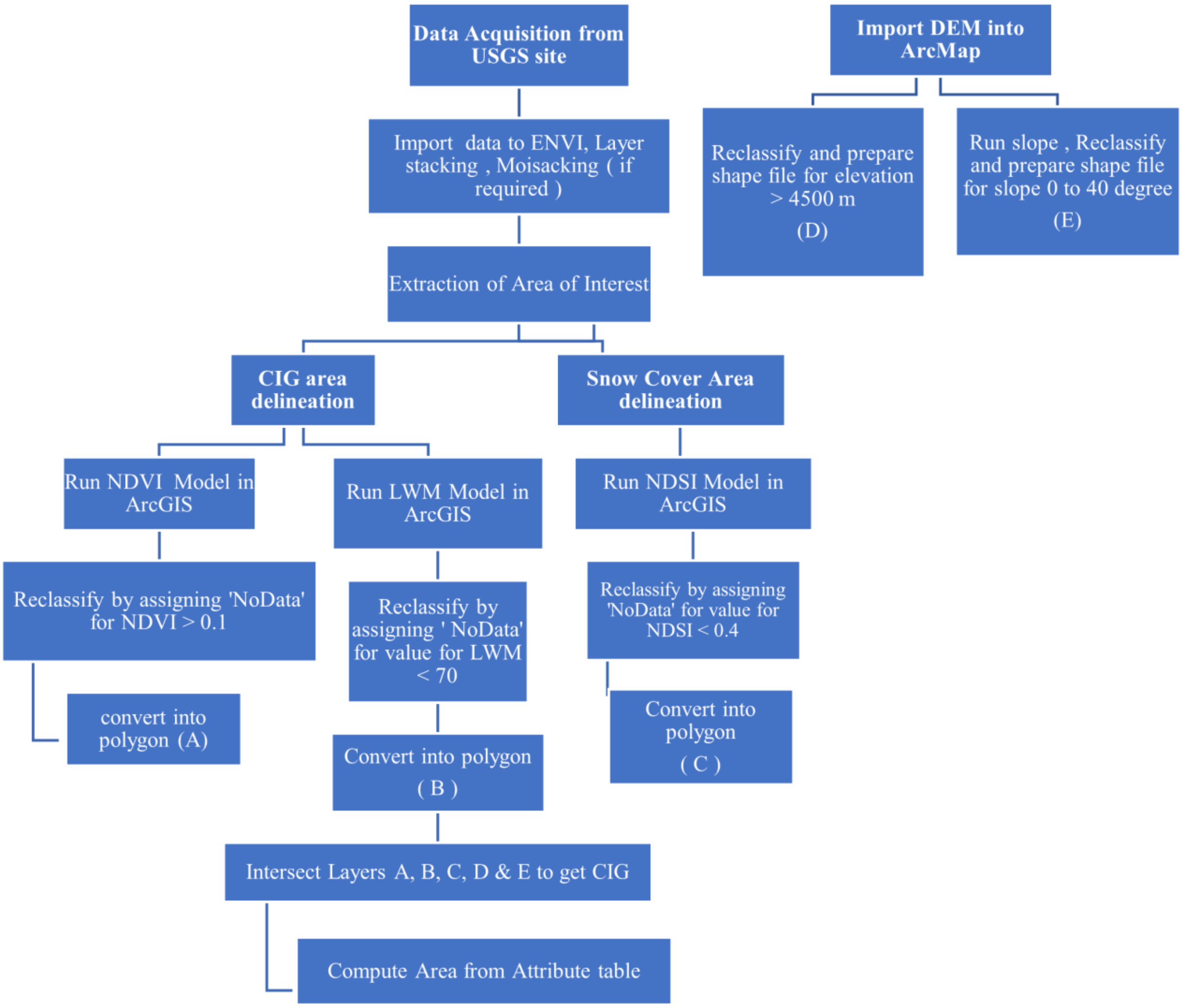


Fig -3: Methodology

3.1 Snow Cover Area Delineation

The snow cover area delineation is done by using the NDSI Model.

Normalized Difference Snow Index (NDSI)

In order to distinguish snow from similarly bright soil, rock and cloud, Normalized Difference Snow Index (hereinafter referred as NDSI) is calculated as:

$$NDSI = (TM2 - TM5) / (TM2 + TM5)$$

Where, TM2 and TM5 are Landsat TM band data. TM2 band is the green band of visible spectrum of the light whereas TM5 band is the short-wave infrared band of the electromagnetic spectrum.

The values of NDSI obtained are then reclassified into two categories: 1 for NDSI >= 0.4 (snow) and 0 for NDSI < 0.4 (no snow). Only the former values are taken for further analysis.

3.2 Clean Ice Cover Area Delineation

The clean ice cover area delineation is done by using the NDVI Model and the LWM Model.

Normalized Difference Vegetation Index (NDVI)

In order to separate glaciers from the vegetation area in the single image, Normalized Difference Vegetation Index (hereinafter referred as NDVI) is calculated as:

$$NDVI = (TM4 - TM3) / (TM4 + TM3)$$

Where, TM3 band is the red band of visible spectrum of the light whereas TM4 band is the near infrared band of the electromagnetic spectrum.

The values of NDVI obtained are then reclassified into two categories: 1 for NDVI <= 0.1 (no vegetation) and 0 for NDVI > 0.1 (vegetation). The later values are discarded for this analysis.

Land and Water Mask (LWM)

In order to separate land from water bodies in the single image, Land and Water Mask (hereinafter referred as LWM) is calculated as:

$$LWM = (TM5/(TM2 + 0.0001)) * 100$$

Where, TM2 band is the green band of visible spectrum of the light whereas TM5 band is the short-wave infrared band of the electromagnetic spectrum.

The values of LWM obtained are then reclassified into two categories: 1 for LWM >= 70 (no water) and 0 for LWM < 70 (water). The later values are discarded for this analysis.

3.3 Slope of Basin

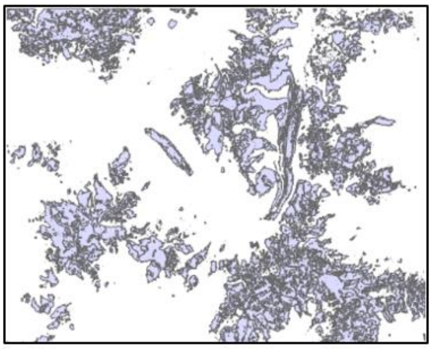
The DEM data of the basin is used to evaluate the slope of the basin. The slope values for the basin are reclassified as per the requirement. For clean ice-covered glacier area delineation, 0 to 40 degree slope is required (Bajracharya & Shrestha, 2011).

3.4 Elevation of Basin

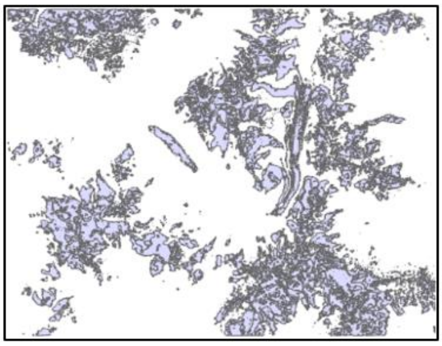
Furthermore, the elevation values for the DEM of the basin are also reclassified to obtain the spatial distribution of the basin area having an elevation above 4500 meters. This is required for the delineation clean ice-covered glacier basin area (Bajracharya & Shrestha, 2011).

4 RESULTS AND DISCUSSION

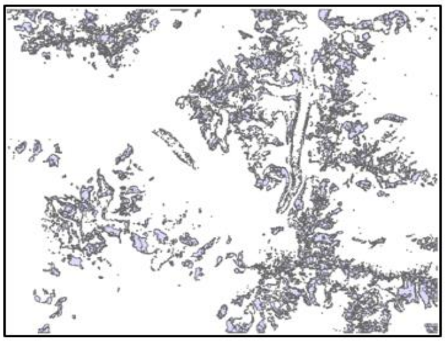
The final outcome of the analysis is the clean ice glacier area which is obtained by the intersection of the selected layers of NDSI, NDVI, LWM, slope and elevation. The respective Clean Ice Glacier (CIG) area for the Annapurna basin in the years 2000, 2010 and 2020 are represented in Figure 4 and summarized in Table 1 below.



(a)



(b)



(c)

Fig -4: CIG Area in the Years 2000 (a), 2010 (b) and 2020 (c)

Table -1: CIG Area in the Years 2000, 2010 and 2020

S.N.	Year	CIG Area (sq. km.)	Number of CIGs
1	2000	377.62	598
2	2010	310.35	835
3	2020	183.05	3366

The data from the table indicate that there is a decreasing trend of CIG area in each decade in the Annapurna basin. More specifically, the amount of decrease in CIG area in the recent decade (2010 – 2020) is much higher as compared to the amount of decrease in the earlier decade (2000 – 2010). On the contrary, there is an increasing trend of CIG number in each decade with a significant rise in the number of CIGs in the later decade (2010-2020) than the previous one (2000-2010). The decreasing trend of CIG area and the increasing trend of the GIG number in the Annapurna basin are represented in the charts as shown in Figure 5 and 6 respectively.

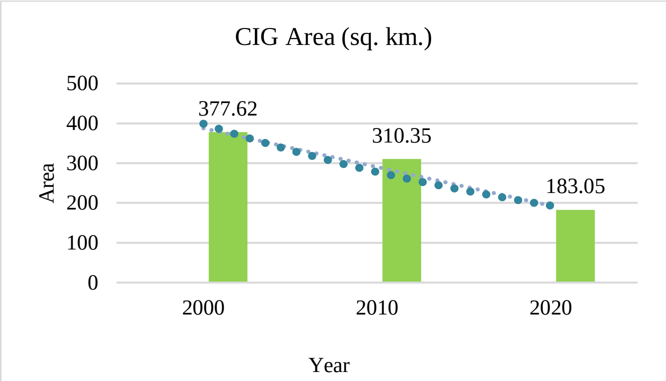


Fig -5: Decreasing trend of CIG Area

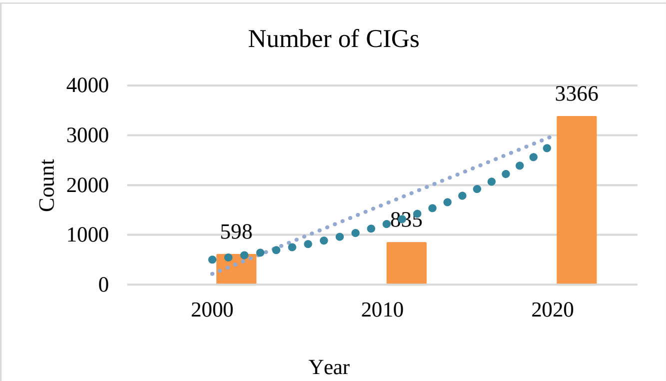


Fig -6: Increasing trend of CIG Number

In order to ensure the accuracy of the results, a validation process was conducted using the CIG shapefiles from the year 2020. These shapefiles were first converted to KML format and then overlaid on Google Earth for visual inspection. This allowed for a detailed comparison between the spatial data and the actual geographic features visible on Google Earth's high-resolution imagery. The overlay provided a clear visual alignment, confirming a satisfactory validation of the outcome as demonstrated in Figure 7.

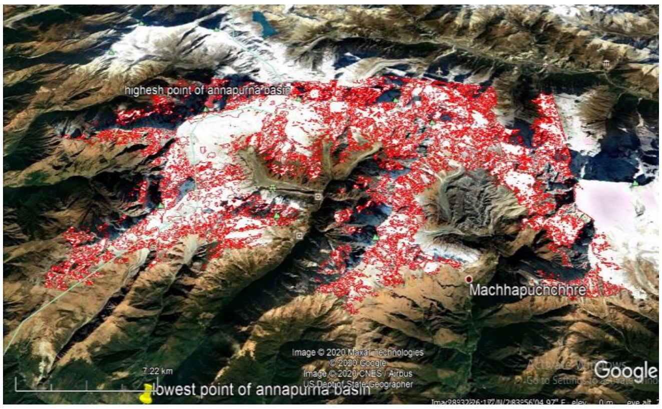


Fig -7: CIG Area Overlay on Google Earth (2020)

5 CONCLUSION

Monitoring the dynamics of glaciers along with their trend analysis is crucial for strengthening the climate change mitigation and adaptation strategies. Satellite images from remote sensing techniques serve as a powerful tool for mapping the glaciers of Himalayas and analyzing their temporal variations. However, the accuracy of the results is greatly dependent on the availability of suitable images. In glaciology, the selection of images is comparably difficult due to challenges such as cloud cover, seasonal variations in snow and ice conditions, and the need for high spatial and temporal resolution to accurately capture the glacial dynamics.

The findings from this study reveal that the glaciers of Annapurna basin are shrinking more rapidly in the recent years than before. The decrease in CIG area coupled with the increase in the CIG number clearly indicate that the glaciers are being fragmented into smaller parts creating several disconnected ice bodies. This could possibly be the effect of global warming since glacial lakes are highly sensitive to rise in temperature. However, hydrological and geological studies are recommended prior to drawing any conclusions. Also, it is important to note that analyzing a limited set of sample images from a specific point in time does not provide a comprehensive understanding of the overall decadal trend.

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