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Surface Area Change Analysis of Kimshung Glacier, Central Himalayas

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Abstract

This study has analyzed the glacial surface area changes on the Khimsung Glacier in the North-Central Himalayan region of the Bagmati Province of Nepal. This study has used different time series satellite images from the web platform data source i.e. SENTINEL-2 L2A and High-resolution DEM received from the Department of Survey to analyze the change of glacier. Geological and geomorphological maps have been prepared using the ArcGIS Pro software. The data have been assembled from the field visit and published research papers that has been considered to validate the maps. The geomorphological maps have been prepared with stratigraphy data from the field and research papers. The elevation variation map of the glacier has been prepared through digital elevation models (DEM) that have been co-registered with each other. This study has found -0.4 ± 0.1 km²/year from 2017 to 2018 as the rate of change in the surface area of the Khimsung Glacier. Similarly, the coverage area change from 2020 to 2021 has been also observed the same -0.4 ± 0.1 km²/year.

Keywords: Accumulation, Digital Elevation Model (DEM), Geomorphology, Sentinel satellites

Introduction

Glaciers form by accumulation and compaction of snow for many years compressing into large thickened ice masses. They form where snow accumulation exceeds its ablation by melting and sublimation over many years, often centuries. The special character of glaciers is their ability to move very slowly under their weight, flowing like very slow rivers. Some glaciers are as small as football fields, while others grow to be over a hundred kilometers long (ICIMOD, 2014). Snow and glaciers in the Himalayas are the major sources of perennial river systems that provide the lives of millions of people through drinking water and irrigation for crop production across south and central Asia. Therefore, retention and product of water from these ice mass are crucial for various aspects; hydroelectric power, flood forecasting, sediment transportation, and formation of landforms. Around 20,000 years ago, glaciers have covered 30 percent of the Earth's land area. In contrast, the1970s study based on satellite observations noticed that only 12.5 percent of Earth's land surface area covered by glaciers (Bamber et al., 2018), with most located in polar regions including Antarctica and Greenland. The leading mountain glaciers are found in the Himalayan region in Asia. The massive volume of water resources through the largest river basins from the Himalayan region sustains about 13 billion people's livelihoods in Asia (Khadka et al., 2018).

This region is located above 3500 m from mean sea level and the glacier covers approximately 33,000 km^2 in this range alone having 13 peaks with more than 8000 meters elevation. The Indus, Ganges and Brahmaputra major rivers of the world originate from glaciers in this region. Glaciers are highly sensitive to changes in atmospheric temperature. It is well documented that temperatures in the Himalayas have risen in recent decades and that glaciers in the region are losing mass, especially in the south slope of the central Himalayas (Schickhoff et al., 2016). Climate change is the main reason behind the augmented glacier evacuation witnessed in the Himalayas. Numerous glacial lakes have been shaped as a result of glacier retreats that leads to calamitous events like GLOF in valleys downstream. Present study in the Himalayan region of Nepal, has documented 3,252 major glaciers along with 2,323 glacial lakes, among them 20 lakes have been considered potentially dangerous (ICIMOD, 2021). The retreating glaciers are being the warning issues of climate change in the Nepal Himalayas. Empirical and model studies suggest that there will be more new glacier lakes and existing glacier lakes will grow rapidly in the Nepal Himalayas in the future because of climate change (Khadga et al., 2023). It will steadily influence the livelihood of the people who live downstream of the snow-fed river and may be probable to face the loss of property, infrastructures including tourism conveniences, trekking routes, roads, bridges and hydropower plants (Ragettli et al., 2016).

The influence of present and upcoming glacier changes on Himalayan hydrology and downstream water supply powerfully depends on the rate of such changes. However, planimetric and volumetric glacier changes are problematic to describe due to incomplete data availability, and many current studies have emphasized the spatially heterogeneous distribution of glacier depletion in the Himalayas. However, within the same climatic region, the rate of glacier changes can also be heterogeneous (Sugiyama et al., 2013). This study evaluates the changes in the surface area of Khimsung glacier in the Langtang region of Central Nepal.

Methods and Materials

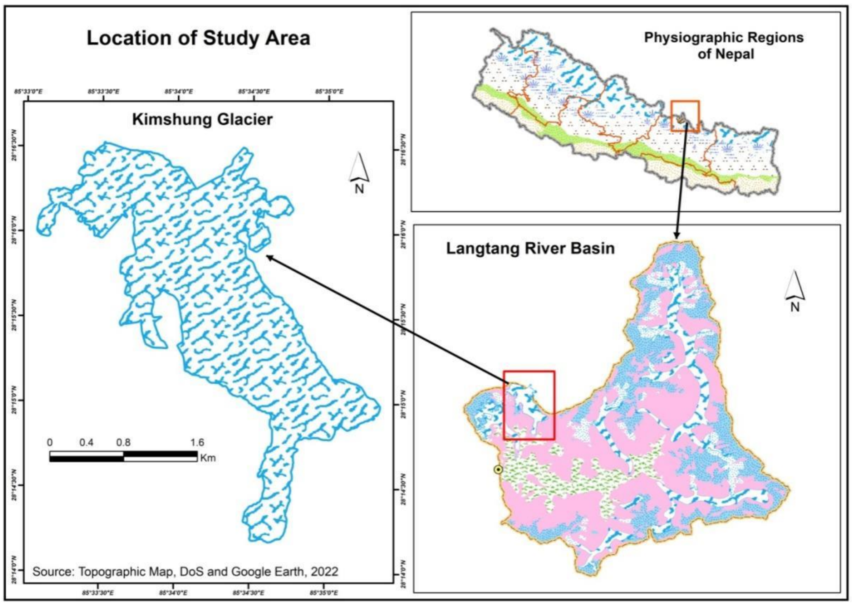
Study Area

Kimshung glacier lies within the Langtang Himalayan range on top of the Langtang Valley. It is along the Gandaki River Basin, which consists of 1,025 glaciers. This glacier, which is situated 80 kilometers north of the Kathmandu Valley, is extended in the north-central Himalayas in the Rasuwa district of the Bagmati Province (Figure 1).

In the meantime, during the mid-2010s, most natural springs have disappeared in the Langtang valley. Scientists have accredited the decrease in the glacier area of the Kimshung Glacier directly to anthropogenic climate change since the 1970s.

Figure 1

Location Map of Study Area



The ground-based studies are difficult to carry out due to harsh weather conditions. The effective method to monitor the glaciers is therefore using remote sensing techniques. The first observation of snow using a satellite has been carried out in April 1960 from the TIROS-1 satellite in eastern Canada. Since then, the development of remote sensing techniques for monitoring glaciers has been used abundantly. The glacier length, area, elevation, volume, and lakes can be efficiently monitored using satellite images and Digital Elevation Model. The DEM uses elevation data extracted from satellite images using photogrammetry or overlapping aerial images which are referenced to GCPs or interpolated under the dense canopy. The elevation model can be generated by extracting x, y and z values from data sets or manual measurement of point coordinates in the field using GPS devices. The spatial resolution is defined as the lowest noticeable entity in an image and is frequently approached by pixel size. The temporal resolution is the occurrence of achievement or interval among attainments. Medium spatial resolution imagery of 5-100 m pixels extracted using terrestrial, aerial, and space-borne remote sensing methods are used in cryosphere research, including glaciers and mountain permafrost (Williams, 2007). Optical satellite imageries such as World View, Geo Eye -1, Quickbird, Pleiades, and SPOT 6/7, along with declassified detective images of the 60s and 70s has a prolonged chronological range of medium and high-resolution images which are used for monitoring glacier changes.

The digital elevation model derived from aerial imagery can be used in GIS for monitoring glacial changes (Williams, 2007). The differencing of two digital elevation models of various time scales gives the elevation difference of the glacier and helps to estimate the per year surface lowering due to ice melting within the glacier. Remote sensing techniques is used to monitor the breaching of moraine dams, supraglacial ponds, and failure of ice dams, formation, and expansion of supraglacial lakes. In addition, it helps in the estimation of area and volume, glacier length and volume changes, advance, and retreat of glaciers. Further, it also applies to find changes in glacier runoff and velocity, mass movements near and in the glaciers, ice fall, and ice avalanches, rock fall, landslides, rock slides and rock avalanches, permafrost-related hazards, permafrost creep, debris flow due to permafrost (Karpilo, 2009).

Data Collection

The fieldwork has been carried out during the month of May 2022. Handheld GPS, compass, camera, geological field diary, topographic maps, satellite images and binocular/telescope have been used as the major equipment during the fieldwork. The field study has based on the actual validation of the geological and geomorphological aspects of the study area. Hydrological and meteorological stations (installed by the Government of Nepal and ICIMOD) at Kyanjin has been observed (elevation 3842 m) and locational reference data has been collected with the application of GPS device. In addition to primary data, published journals, research papers, literature, articles, and unpublished papers have been studied along with the geological and topographical map of the area. The satellite imagery of Google Earth pro has been used for viewing the study area. The satellite images from earth explorer & sentinel Asia have been used to locate the geology of the area along with 1:50000 topographic maps available at the Survey Department, Nepal. Secondary data and information on the glacial morphology of the area referenced from the articles and papers have been studied thoroughly. The regional geology, geomorphology, and sediment distribution of the Kimshung glacier have been reviewed from published research papers.

Data Acquisition

The data acquisition has been done from 1st December 2017 to 1stDecember 2022. The satellite images for the change analysis have been used from the web platform data source i.e. SENTINEL-2 L2A satellite image from the sentinel hub (ESA, 2015). The mapping of the glacier has been carried out through the digitization and classification of the satellite image from SENTINEL-2 L2A because it is specially designed for the show & glacier monitoring purposes.

Data Analysis, Interpretation, and Preparation of Maps

The data collected from the web platform has been accessed using computer applications. The glacier maps have been prepared using the ArcGIS Pro software. The data has been assembled and various research papers have been studied to validate the maps. The manual digitization & classification of the Kimshung glacier has performed using the Google Earth pro software and GIS environment provided by ArcGIS Pro.

Use of DEMs Data

The glacier elevation change is conventional practice for determining the surface lowering of glaciers over time. The increasing trend of glacier melting is observed in most of the world due to climate change and global warming (IPCC, 2014). The elevation change measurement is accurate when both the DEMs are properly aligned to each other and horizontal shifts are corrected by the process of co-registration. In this study, digital elevation models have been used to analyze the slope, aspect & drainage network of the glacier from 2017 to 2021. The SRTM DEMs of the Kimshung glaciers have been downloaded from the Earth Explorer. The accuracy of a stereo DEM is influenced by several factors including the sensor parameters, image resolution, acquisition viewing angle and base-to-height ratio, ground topography, and the number with accuracy of GCPs (Toutin, 2004). The DEMs used in this study are described below:

Table 1

Projection and Grid Details of SRTM DEM (Earth Explorer, 2022)

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters)
Raster Size	1-degree tiles
C-band Wavelength	5.6 cm

Layer Extraction From Images

Two satellite images from Google Earth pro from the year 2017 and 2021 have been used to extract the Kimshung glacier using the ArcGIS Pro software and its tools. The Images from the same month have been used during 2017 and 2021 with clear and less cloud coverage in the winter season. The number of polygons has been digitized and classified manually using ArcGIS Pro for further processing. Also, the area of Kimshung Glacier in different time series has been calculated by transforming the geographic coordinate system to the projected coordinate system.

Results

The total area of the glacier is considered in a horizontal projection in square kilometers (km²). The area of mountain glaciers is normally small in terms of area coverage due to their topography. In the Nepal Himalayas, areas of glaciers have a large variation. However, some of those have a larger area. The deviation of the range varies from a few km² up to about 82 km². The surface area of Kimshung glacier in 2017 was 5.867 km² that was obtained by analyzing the satellite images of that year. For the change analysis of the Kimshung glacier, recent 4 years (2017, 2018, 2020, and 2021) has been taken and the following changes in the area have been obtained (Figure 2 and 3).

Figure 2

Coverage change in study area

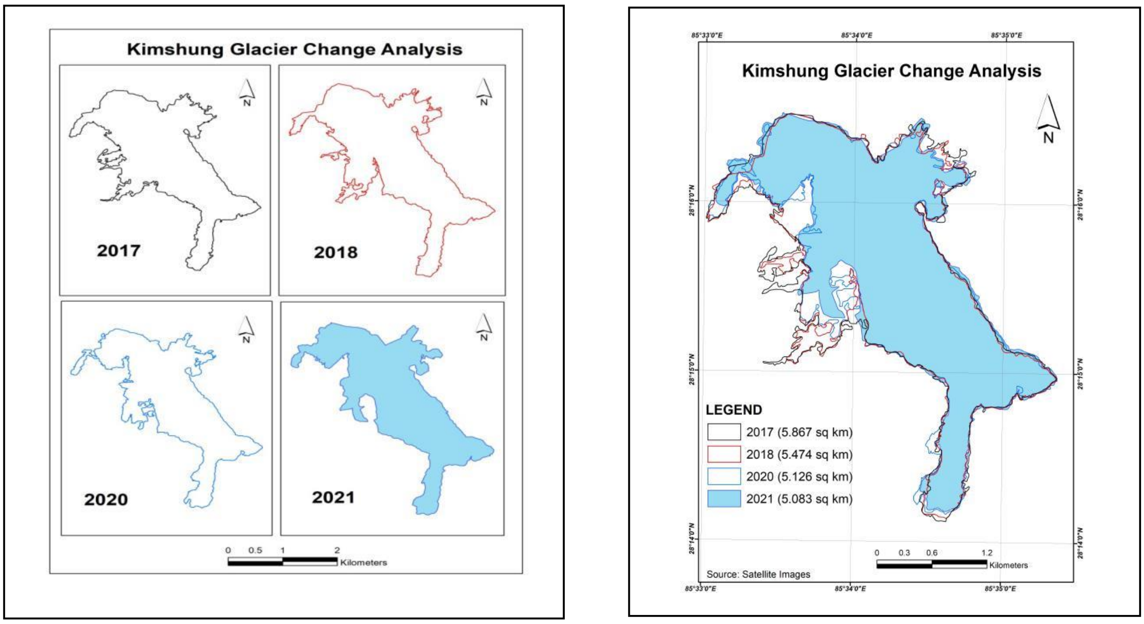
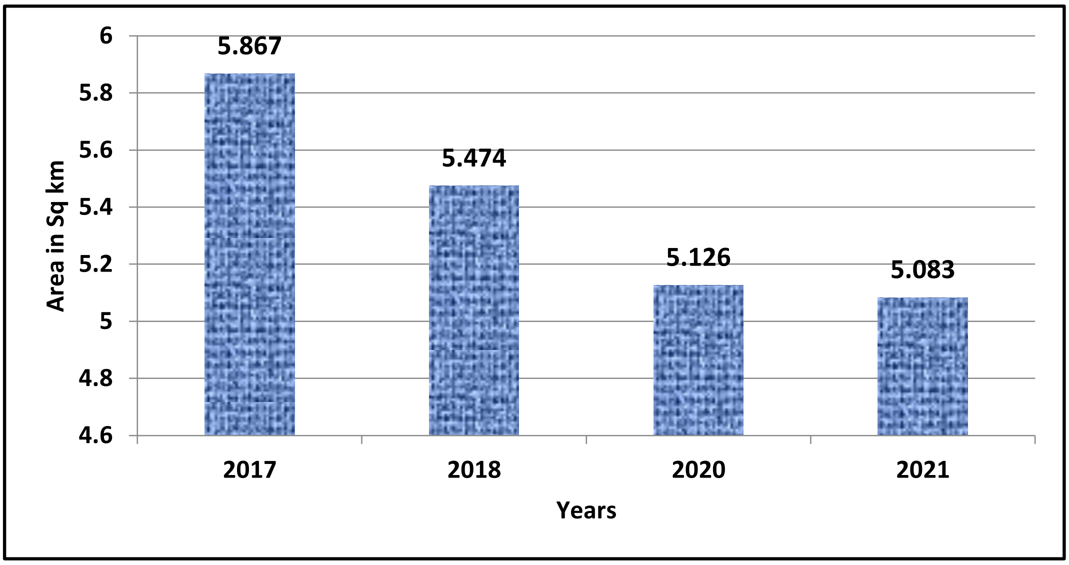


Figure 3

Trend of surface area change in Kimshung glacier



Discussion

Area changes of Kimshung Glacier are higher near the outlet of the glacier. The thin amount of debris that holds the ice is responsible for the faster melting of ice in the Langtang region. A thin amount of debris has low albedo which heats the surrounding ice at a faster rate. The elevation change is also an indication of the sub-glacial melting of ice, when the surface water penetrates the ice underneath, it cuts through the glacier to disintegrate ice mass into pieces, and glacier ice melts rapidly (Miles et al., 2022). The melt water from Kimshung at an elevation of 5500 m moves through the glacial channels towards the terminus at an elevation of 4200 m. The melt water either drains through glacial channels or remains stored as supraglacial ponds. The Langtang River drains from the lower-east margin of the glacier.

This study shows increased surface water and connectivity of supraglacial ponds near the eastern margin of the lower Kimshung glacier (Naito et al., 2000) coupled mass balance and glacier flow to investigate the shrinkage of the Kimshung glacier between 2017 and 2021. They have been forecast that the lowermost part of the glacier would deteriorate and ultimately decouple from the upper glacier, which could lead to the expansion of a huge and potentially dangerous glacial lake. The sediment matrix near Kimshung glacier is coarse sand with gravel. The coarse sediments have greater permeability due to which water can easily infiltrate the sub-glacial ice and flow within the ice cracks. The possibility of seepage reduces the strength of the moraine walls although a large number of soil samples need to be collected to understand the stability. The moraine with a coarse sediment matrix is susceptible to seepage. If a large lake is formed by coalescence, it might burst out as Glacial Lake Outburst Floods (GLOFs).

Conclusion

Glaciers are important natural resources over the Himalayan Region which plays a crucial role in the lives of many human beings. Moreover, glaciers are exceptionally significant since they are predominantly vulnerable to climate change and their loss directly affects human populations and ecosystems. Glaciers are located in the very complex topography of the Himalayan region and very little research has been done on it. The increasing population and the intensifying infrastructures such as transportations, bridges, buildings and many present and planned ambitious hydropower projects in the river valleys enclosed by such glacier lakes, have enlarged the threat of the GLOF hazards in Nepal. This threat infers a serious encounter to development ventures. The study has found surface area changes at an average rate during both periods of study for 2017 to 2019 and 2020 to 22021 by-0.4 ± 0.1 km²/year in the region of Kimshung glacier.

Area of conflict. Authors declared that there is no any area of conflict.

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