Characterization and Morphological Analysis of Trio-Glacial Lakes (Sankha Lake, Kukur Lake, and Thakur Jyu Lake) of Barekot Patan, Jajarkot, Nepal [1]

Ganesh Rawat, Nabraj Khanal, & Pitri Bhakta Adhikari

Abstract

Glacial lakes are essential elements of alpine ecosystems, with important functions in the hydrology and ecology of the area. However, the rapid retreat of glaciers due to climate change has led to the formation and expansion of glacial lakes, increasing the risk of glacial lake outburst floods (GLOFs) and other associated hazards. Sankha, Kukur, and Thakur Jyu, the three glacier lakes in Barekot Patan, Jajarkot, Nepal, have not yet been the subject of any scientific studies. The main objectives of this research are to provide an overview and analyze three glacial lakes in the Barekot Patan area of Jajarkot, Nepal, from a morphological perspective. Both primary and secondary sources of information were gathered. The collected data were analyzed by applying suitable statistical and GIS tools. Through field surveys, remote sensing, and GIS analysis, the study put contrast to understand the current state and potential risks associated with these lakes. The study has covered and concluded the overview of morphological characteristics, including the shape, size, and characteristics of these lakes, as well as evaluated precipitation patterns in the study area. From the study, the shape of three glacial lakes has been calculated, and from different qualitative and quantitative analyses of data, the lakes are found to be high-altitude glacial lakes. This study has offered critical insights into glacial lake dynamics in Barekot Patan, aiding sustainable development and disaster risk reduction

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decisions. It will empower policymakers, researchers, and communities to craft effective strategies for mitigating GLOF impacts and ensuring regional safety and sustainability. The dissemination work includes academic publications, workshops, and engagement with local communities, governmental bodies, and non-governmental organizations.

***Keywords*:** Barekot, disaster, glacial lake, GOLFs, morphology, precipitation, risk

Introduction

Nepal is a landlocked country in South Asia, situated between latitudes 28.3949°N and longitudes 84.1240° E, covering an area of 147,519 square kilometers. It shares borders with China to the north and India to the east, west, and south. Nepal is divided into three geographical regions.

The study site is located at the Barekot Patan of Jajarkot district, where numerous glacial and high-altitude lakes are situated, which are yet to be studied scientifically. To address this problem, the research is carried out to analyze the morphological characteristics of three glacial lakes. Glaciers are large masses of ice that are formed over many years as snow accumulates and compacts. They are found in Polar Regions as well as high-altitude mountain ranges around the world. Glaciers move slowly under the force of gravity, flowing like rivers of ice. This movement occurs due to the weight of the ice and the internal deformation caused by pressure. Water bodies known as glacial lakes develop in valleys left behind by glacier retreat. They are frequently tucked away amid hilly landscapes and range in size from tiny ponds to vast stretches of water. Snowmelt, precipitation, and glacier melt water are the main sources of water for glacial lakes. Glacial lakes, however, can be dangerous, especially if their ice- or debris-based natural dams begin to deteriorate or collapse. Glacial lake outburst floods (GLOFs) are unexpected, massive water releases that have disastrous effects on ecosystems, infrastructure, and the human population downstream. Climate change has a big impact on glacial lakes in the Himalayan region. These changes pose risks like glacial lake outburst floods (GLOFs). Nepal is particularly susceptible to these phenomena due to its extensive glacier cover. The trio of glacial lakes, Sankha Lake, Kukur Lake, and Thakur Jyu Lake are located in Barekot Patan, Jajarkot, has the potential to be GLOFs and has an ecological significance. This research aims to conduct a study that characterizes and morphologically analyzes these lakes in order to gain a better understanding of their present condition and to determine any potential risks.

The trio-glacial lakes lie in the Patan of Barekot, Jajarkot district. The characterization and morphological analysis of Trio-Glacial Lakes (Sankha Lake, Kukur Lake, and Thakur Jyu Lake) in Barekot Patan, Jajarkot, Nepal, is imperative for several reasons. Firstly, these lakes are not studied yet and these lakes are still unknown of their morphological characteristics such as their shape, size, volume, latitude and altitude of their situations and the hydro-meteorological phenomenon around them. And the main aim of this study is to contribute of their morphological characteristics. Also, it facilitates the assessment of Glacial Lake Outburst Flood (GLOF) risks, crucial in the context of climate change impacts on glaciers. Glacial lakes are vital components of high-altitude ecosystems, serving as critical water sources and habitats for various species. However, the rapid retreat of glaciers due to climate change has led to the formation and expansion of glacial lakes, increasing the risk of glacial lake outburst floods and other associated hazards. In Nepal, a country highly vulnerable to the impacts of climate change, the characterization and morphological analysis of glacial lakes are essential for understanding their dynamics and assessing the risks they pose to local communities and ecosystems. Nevertheless, the three glacier lakes in Barekot Patan, Jajarkot, Nepal, Sankha, Kukur, and Thakur Jyu lakes have not yet been the focus of any scientific research. This research attempts to close this gap by offering an in-depth study of these lakes' physical characteristics, volume fluctuations, and possible hazards.

The creation of the moraine-dam glacial lake on debris-covered glacier tongues in the Himalayan region was caused by glacier retreat. A sequence of ponds initially formed, which later combined to form a massive lake. Identifying these lakes as soon as feasible is essential for planning remediation activities since they pose a risk to the infrastructure and communities downstream. However, it is unclear how glacier dynamics and glacial lake creation are related (Mool et al., 2011). Where the glacier surface gradient from the glacier terminus is less than 2°, the supraglacial lake forms (Quincey et al., 2007; R. Bajracharya, 2010). It is also clear that the glacial lake typically forms at the glacier's relatively thin debris layers (Rounce & McKinney, 2014). Therefore, a glacial lake is likely to form at the terminus of a glacier with a higher rate of ablation. Kirkbride (1993) also mentioned that the formation of the Supraglacial Lake occurred as a result of the glacier surface being lowered.

The ablation usually peaked at the glacier terminus in a debris-free glacier. In contrast, the ablation rate in a glacier coated in debris is small at the glacier terminal but rises as the glacier advances toward the equilibrium line from the terminus. From the debris-cover glacier's equilibrium line, the thickness of the debris grows, reaching over one meter near the glacier's terminal. Because of the height and dropping air temperature, the ablation rate reaches a maximum in the center of the ablation zone and then steadily declines as it approaches the equilibrium line. Nuimura et al. (2011) examined field observation data from 1978, 1995, and 2004 and discovered a considerable surface lowering in the center of the Khumbu glacier ablation area in Nepal (Kadota et al., 2000).The alteration of glaciers and their state as a result of climatic change are natural phenomena in the five billion-year history of the Earth. This has been happening ever since, but in recent decades, a different section of the world—particularly the Himalaya region—has seen a considerable risk due to climate change and rising global temperatures. The catastrophic discharge of glacial lakes is one of the biggest risks associated with the Himalayan glaciers. Glacial lake outburst floods are the name for these floods brought on by the collapse of natural moraine dams (GLOFs). Continuous glacial lake expansion is a major risk factor for glacial lake outburst floods (GLOF), which can release millions of cubic meters of water in a short amount of time and cause flash flooding, debris flows, and floods with high peak discharges and exceptional erosive and transport capacities (Shrestha & Aryal, 2010). These floods are caused by a variety of anthropogenic and natural factors. Therefore, in order to comprehend the temporal and spatial changes of such glaciers, glacial lakes, and to predict future worst-case scenarios, it is imperative to examine the current status of glaciers and the surrounding glacial lakes and environs. Agassiz et al. (1847) carried out the first thorough scientific investigation of glacier ice, which paved the way for systematic monitoring in the early nineteenth century (*Response to Mölg et al.: Glacier Loss on Kilimanjaro Is Consistent with Widespread Ice Loss in Low Latitudes | PNAS*, n.d.). The extent of the region's glacier changes may be seen using satellite-based virtual viewpoints, which include images and topography information, as knowledge and technology progress. This has made it feasible to obtain geomorphological information on the remote area, which would have been difficult or impossible in any other case. The quantity and volume of potentially dangerous moraine-dammed lakes in the Himalayas are rising as a result of glaciers retreating due to climate change. These lakes might explode catastrophically, creating severe GLOFs, because they form beneath unstable ice-cored moraines. Debris flows go above 150 km when there is a significant discharge (9500 m3 /s, Tam Pokhari GLOF, 1998) (Osti et al., 2010). Hazardous lakes may be effectively assessed and mitigated regardless of the extent of the danger. Utilizing satellite imagery to identify hazards has proven feasible for isolated regions of Bhutan, and restoration methods that were effective in the Andes of Peru are already being used in Nepal. Based on remote sensing, this study has created a vulnerability assessment for the Himalayan glacial lakes.

These newly formed or existing glacial lakes are mostly unstable as they formed behind loosely tight end moraine dams. People who live in the floodplain downstream of these glacial lakes might be at risk if there is a catastrophic dam failure. A GLOF is defined as an abrupt lake discharge and the debris flow that is connected to it with a strong current. The glacial lake's fast expansion in recent decades has increased the harm that it poses to the communities downstream. Several of these incidents, such the Bhote-Koshi GLOF in 1964, the Sun Koshi GLOF in 1981, and the Dig Tsho GLOF in 1985, resulted in significant damage and fatalities in Nepal (Mool et al., 2011). Devastating devastation was caused by the Dig Tsho GLOF to its floodplain, which included the demolition of the almost finished Namche Small Hydroelectric Project. And the sole route between Nepal and China was destroyed in the 1981 GLOF for a few months. What is recognized as "the single most influential paper on rock glaciers" was published in 1959 by Clyde Wahrhaftig and Allan Cox. Their article, "Rock glaciers in the Alaska Range," aroused interest in these features all over the world, and since the middle of the 20th century, the number of studies published on the topic has increased significantly. More than 2000 publications were published about rock glaciers between 2000 and 2009; this is a significant rise especially when compared to the 1990s, when less than 1000 papers were published about rock glaciers. There is a wealth of contemporary research on the topic of rock glaciers, their dynamics, and descriptions of both, which is coupled with the growing interest in the significance of rock glaciers and the cryosphere(Bajracharya et al., 2020; R. Bajracharya, 2010).The discussion of geographic constraints on rock glaciers in the Lemhi Range of Idaho by Johnson, Thackray, and Van Kirk (2007) had a significant impact on the variables that I chose to gather for my thesis. This research examines the rock glaciers in the area, down to the level of individual mountain cirques. Using geographic factors that will be employed in this thesis, Johnson, Thackray, and

Van Kirk's (2007) research sought to describe the spatial controls of rock glaciers in the range. Johnson, Thackray, and Van Kirk's 2007 study, which was similar to the research I did for my thesis, manually analyzed images of 171 mountain valleys and cirques in the Lemhi Range in central Idaho, noting the geographic factors mentioned in earlier sections for each cirque. After that, they discussed the apparent restrictions that lithology and insolation have on rock glaciers and proposed a genetic connection between rock glaciers in the range and protalus lobes, which are cryogenic, geomorphic landforms that resemble rock glaciers (Johnson et al., 2007).The ICIMOD investigates the impact of climate change on glaciers and glacial lakes in two major glacial hotspots in the Himalayas: the Dudh Koshi sub-basin in the Khumbu-Everest region in Nepal, and the Pho Chu sub-basin in Bhutan. The focus was on changes in the number and size of glacial lakes forming behind exposed end moraines as glaciers retreat, and the resulting potential threat of glacial lake outburst floods (GLOFs) and also studied glacial lakes in the Koshi, Gandaki, and Karnali river basins of Nepal, the Tibet Autonomous Region of China, and India (Bajracharya et al., 2020). The potential danger of outburst floods depends on various factors like the lake's area and volume, glacier change, morphometry of the glacier and its surrounding moraines and valley, and glacier velocity. Remote sensing offers an efficient tool for displacement calculations and risk assessment of the identification of potentially dangerous glacial lakes (PDGLs) and is especially helpful for remote mountainous areas (Bolch et al., 2008).

Those three glacial lakes hold a significant amount of water and have huge impacts on the ecosystem. However, these lakes lack a comprehensive characterization, including shape, size, and other morphological characteristics. The physical, hydrological, and water quality of Sankha Lake, Kukur Lake, and Thakur Jyu Lake are not well characterized. Accurately estimating the possible risks connected with these lakes is difficult without a full grasp of these factors. The motto of this study is to analyse the physical, hydrological, and morphological characteristics of Sankha Lake, Kukur Lake, and Thakur Jyu Lake, as well as to identify and analyze changes in the morphological characteristics of the glacial lakes over time, particularly in response to climate change and to identify the precipitation pattern around these lakes.

Research design and methodology

Study area

The study area is located in the Jajarkot district of Karnali Province of the Federal Democratic Republic of Nepal. It is located in western Nepal. The district with Jajarkot Khalanga as its district headquarters, covers the area of 2230km.sq and a population of 1, 89,360 (National Census, 2078 BS).The trio-lakes are located in the Barekot Deurali Patan of Barekot rural municipality and are at an altitude of 4400 to 4700 meter above the sea level. The Kukur Daha is located at 4486 meters while Sankha Lake is situated at 4503 meters and Thakur Jyu Lake is situated at 4622 meters above the sea level.

In Jajarkot, there are 2 meteorological stations, one is at Khalanga of Bheri municipality and another is at Maina village of Barekot rural municipality. Among them the station of Khalanga is an automatic weather station (AWS) where temperature, precipitation, wind speed and velocity, sunshine duration are recording in regular basis. Another station of Maina village is manual precipitation station (Jajajrkot-0404) where only precipitation data is recording manually.

Figure 1*: Study area/ site*

Figure 2*: Weather station with station care taker*

The study area of our project work belongs to the Jajarkot-0404 precipitation station, which is not exactly, but around 15 km from the station. The trio-glacial lakes are situated at the Barekot Deurali Patan area, so the precipitation pattern in that region might be similar to the area where the station is located. The data of annual rainfall of precipitation station Jajarkot-404 from year 2000-2023 A.D. is taken from the Department of Hydrology and Meteorology. Then the taken data is plotted in the histogram or graph to identify the variation of rainfall annually in the study area. The annual total precipitation from 2000-2023 is represented as follows in the graph:

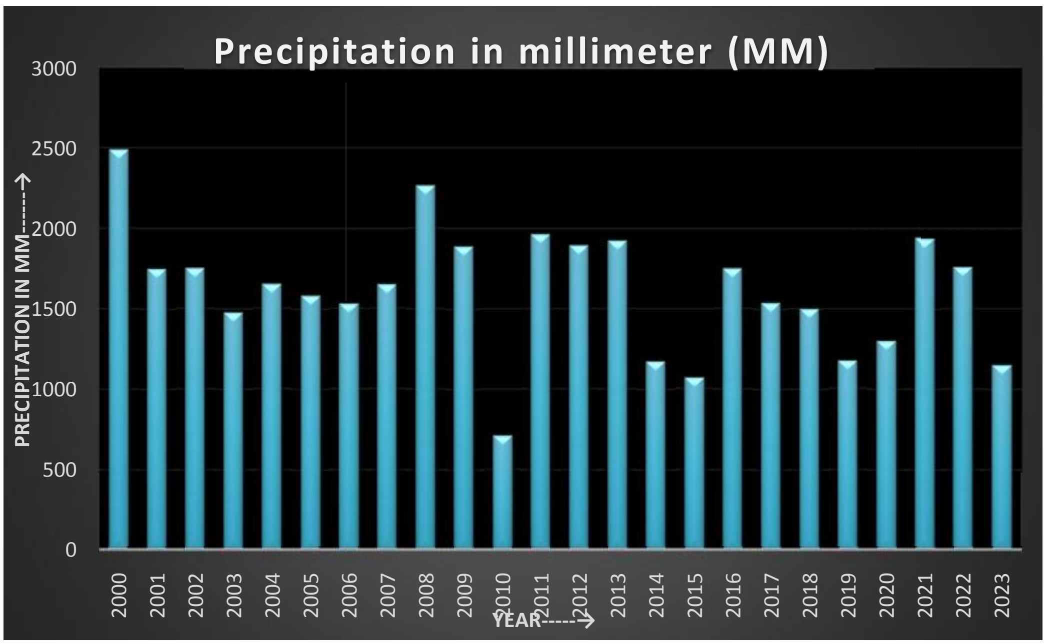

Figure 3: *Annual precipitation of Barekot Patan region*

The above graph shows that the year 2010 A.D. experienced the lowest rainfall around the study area of 706.3 mm of annual rainfall while the year 2000 A.D. experienced the highest annual rainfall of 2487.8 mm between the periods of 24 years. In the summery, there is no significant variation or changes are observed for the precipitation in the study area.

Method of study

Both qualitative and quantitative types of data were used in the study. Primary data were collected from the study sites, while secondary data were collected from published and unpublished documents regarding glacier lakes, and more secondary data of precipitation of the nearest station, i.e., Jajarkot-0404, has been taken from the Department of Hydrology and Meteorology. The required data were collected through field visits and surveys to conduct the project work. To identify the morphological characteristics, i.e., shape, size, and structure of lakes, the primary data of all three lakes were collected. The sizes of Sankha Daha, Kukur Daha, and Thakur Jyu Daha were calculated by two methods. By measuring the width and length and taking the average, and secondly by measuring the perimeter of lakes and calculating the size of lakes. The altimeter was used to measure the altitude of lakes. The instruments, such as a measuring tape, an altimeter, and stationery, were used while collecting data. The research was conducted with the help of locals. The shape, altitude, and sizes of three lakes were initially measured, and then the other morphological characteristics were examined and noted as data.

The actual data of morphological characteristics of Trio-glacial lakes, i.e., Sankha Daha, Kukur Daha, and Thakur Jyu Daha, were not recorded or found due to the lack of a meteorological station and observations regarding those lakes. So, to locate and identify any changes regarding the morphological characteristics of those lakes over a long period of time can only be found out by the locals who were eyewitnesses to these lakes over many years. So we decided to choose a questionnaire method to conduct the research.

We selected three villages located nearest to the lakes, from where locals regularly visit the lake areas. From these villages, we chose 40 local residents who were familiar with the lakes and prepared a set of 20 questionnaire items, which we administered individually. Through this questionnaire method, we collected data regarding the changes in the morphological characteristics of the lakes over time.

The shape and size of the three lakes have not remained the same over the past 30 years. A gradual change in both shape and size has been observed in all three lakes. Thirty years ago, the lakes were completely covered by glacial snow; however, at present, they are only partially covered during the monsoon season. Locals have reported increasing snowmelt in and around the lake areas. Based on field visits, observations, and interviews with the locals, it was found that Sankha Daha, Kukur Daha, and Thakur Jyu

Daha are characterized as glacial lakes, but they more closely resemble high-altitude lakes rather than typical glacial lakes. Therefore, these lakes can be classified as high-altitude glacial lakes. Sankha Daha, Kukur Daha, and Thakur Jyu Daha all contribute as tributaries to the Nalagad River.

The project site is located in a remote part of Jajarkot District, where there is significant variation in precipitation patterns due to its unique topography. The site lies at an altitude of approximately 4,400 to 4,700 meters above sea level. The high-altitude topography of the Barekot Patan region experiences considerable precipitation. To analyze the precipitation pattern of the project area, we collected precipitation data for the period from 2000 A.D. to 2023 A.D. from the Department of Hydrology and Meteorology. The data was obtained from the Maina Precipitation Station in Barekot, located about 20 km from the project site. Using this data, we analyzed the annual precipitation pattern of the Barekot Patan region from 2000 to 2023 A.D. to understand the yearly variation in precipitation within the project area.

Results and Discussion

Precipitation pattern of the project site

The precipitation pattern of the project site has been found as following.

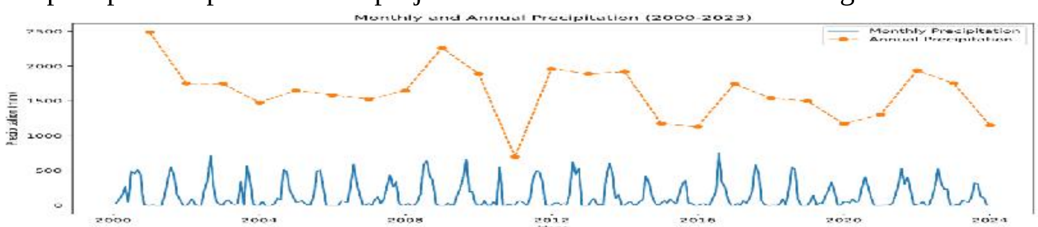

Figure 4: *Monthly and annual precipitation of project site*

The precipitation data of the project site has been collected from the Department of Hydrology and Meteorology. The annual rainfall data from 2000 A.D. to 2023 A.D. have been collected and analysed. From which it is found that in the year 2000 the region experiences maximum rainfall of 2487.8 mm of rainfall while year 2010 experiences the lowest amount of rainfall of about only 706.3 mm. The above graph shows that the trends of rainfall around the project site i.e. Barekot Patan, where three lakes are situated, is between 1000-2000 mm annually normally.

Morphological characteristics of lakes

Lakes exhibit various morphological characteristics, including their shape, size, depth, and basin structure. Typically, the surrounding topography, including the presence of inflows/ outflows, affects water levels and the lake's overall hydrology. Additionally, sediment deposition and erosion continuously reshape lake basins over time.

Shape and size of the lakes

Shankha Daha. Shankha Daha is located at the Barekot Patan of Jajarkot district. It is situated at an altitude of 4503 meters above the mean sea level, which was measured using the altimeter. The shape of the Shankha Daha Lake looks like the divine conch “Shankha”, which is why the name is. In remote areas of Jajarkot and other districts, locals used to say the large stagnant water bodies as a Daha. This is the reason why the name of this lake is Sankha Daha. The size of the Sankha Daha is measured as follows:

Length of the lake (L) = 520 m; Width of the lake (W) = 212 m

The area of the lake is calculated by using the formula: $A = L \times W$= 1, 01,755.75 m^2

A = Area of lake	Area (A) = 520 × 212
L = Length of lake	= 1, 10,240 square meter
W = Width of lake	= 0.110240 square km

Hence, by the calculation the total area of the Shankha Daha is 0.110240 sq. km.

Figure 5: *Perimeter of Sankha Daha*

The area of the three lakes was measured and calculated from two methods: by using length and width and by using Google Maps. The area of Sankha Daha is calculated by measuring the length and width is found to be 1,10,240 square meters, while the area of Sankha Lake is found by using Google Maps is 1,01,755.75 square meters. From this result it is seen that there is a slight variation in the size of lakes from two different methods. However, it is not the big issue because the difference is not too wide to concern, and we can assume that both results are almost the same.

Kukur Daha. Kukur Daha is located at the Barekot Patan of Jajarkot district. It is situated at an altitude of 4486 meters above mean sea level, as measured by me using an altimeter. The shape of the Kukur Daha Lake is round and oval. Locals don't know exactly why the name of that lake is KukurDaha. But according to some old locals, once the dog of one villager has been thrown into the lake and that dog neither returns nor is seen on the surface of the water. After that incident, people used to say and know that lake as the name of Kukur Daha. In the Nepali language, Kukur means dog, which is why the name is. In remote areas of Jajarkot and other districts, locals used to say the large stagnant water bodies as a Daha. This is the reason why the name of this lake is KukurDaha. The size of the KukurDaha is measured as follows:

Length of the lake (L) = 212m; Width of the lake (W) = 164 m

The area of the lake is calculated by using the following formula $A = L \times W$

Area (A) = 213 × 164 = 34,932 square meter = 0.034932 square km

The area of Kukur Daha is calculated by measuring the length and width is found to be 34932 square meters, while the area of Kukur Lake is found by using Google Maps to be 30557.27 square meters.

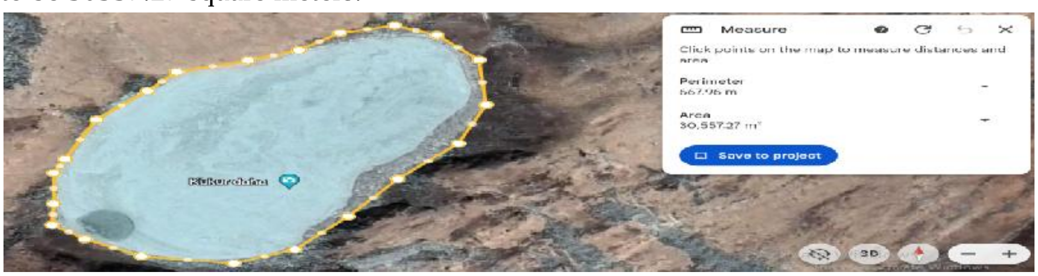

Figure 6: *Perimeter of Kukur Daha*

Thakur Jyu Daha. Thakur Jyu Daha is located at the Barekot Patan of Jajarkot district. It is situated at an altitude of 4622 meters above the mean sea level, which was measured using the altimeter by the researchers. The shape of the Thakur Jyu Daha Lake is round and elongated from eastward. The name behind this lake is quite religious and historical. In the village of Jajarkot and other remote areas, the Thakur Jyu means the person whom the local people treated as the parents of the village. Later on, they started celebrating and worshiping their Thakur Jyu by going for a ford in that lake and started saying the lake Thakur Jyu Daha, that's why the name is. In remote areas of Jajarkot and other districts, locals used to say the large stagnant water bodies as a Daha. This is the reason why the name of this lake is Thakur Daha. The size of the Thakur JyuDaha is measured as

$A = L \times W$= 820 m × 156 m = 1, 27,920 square meter = 0.127920 square km

From this result, it is seen that there is a slight variation in the size of lakes from two different methods. However, it is not a big issue because the difference is not too wide to concern, and we can assume that both results are almost the same.

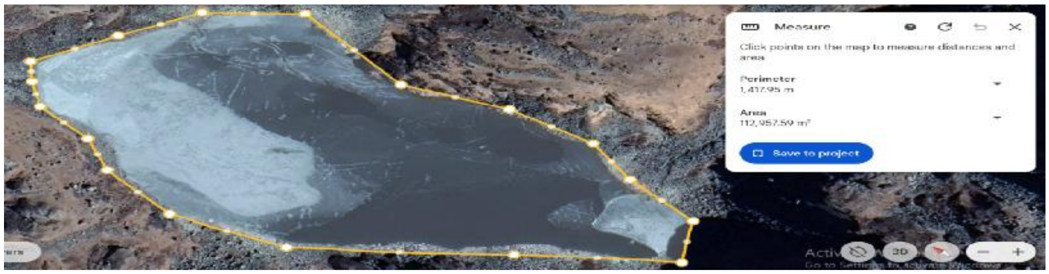

Figure 7: *Perimeter of Thakur Jyu Daha*

The size of Trio-glacial including Sankha Daha, Kukur Daha and Thakur Jyu Daha lakes from the study has been found to be 1,10,240 square meters, 34,932 square meters, and 1,27,920 square meter respectively.

The shape of all three lakes is different from each other, i.e., Sankha Daha looks like the divine conch "Shankha"; that's why the name of the lake is Sankha Daha. Similarly, the shape of Kukur Daha is round and oval, and the Thakur Jyu Daha is round and elongated from eastward, respectively. Kukur Daha is situated at 4486 meters above sea level, while the Sankha Daha and Thakur JyuDaha are situated at 4503 m and 4622 meters above mean sea level.

Characterization of trio-glacial lakes

The trio of lakes, Sankha Daha, Kukur Daha, and Thakur Jyu Daha, are located in Barekot Patan, Jajarkot District, at altitudes ranging from 4,400 to 4,700 meters above sea level. Although locally recognized as *glacial lakes*, geomorphological and hydrological analysis suggest that they are more accurately classified as high-altitudinal (tarn-type) lakes that have evolved from earlier glacial origins.

Geomorphologically, typical glacial lakes are formed directly by glacial retreat and are often enclosed by moraine or ice-cored dams, showing distinct U-shaped valleys, glacial till, and unstable end-moraine deposits (ICIMOD, 2011; Bajracharya et al., 2020). In contrast, high-altitudinal lakes are usually found in deglaciated cirques or basins that once hosted glaciers but are now sustained primarily by snowmelt and precipitation rather than active glacier melt water (Bolch et al., 2008).

Field measurements and topographic analysis of the Barekot lakes indicate the absence of current glacial ice or active moraine structures, suggesting post-glacial modification. The lakes are embedded within gently sloping cirques rather than steep-walled glacial valleys, and no visible debris-covered glacier tongues are present near their margins. Moreover, all three lakes exhibit relatively stable shorelines, minimal sediment delta formation, and no visible proglacial outlet channels, features inconsistent with currently active glacial lakes.

Hydrologically, the lakes are largely fed by seasonal snowmelt and localized precipitation, as confirmed by meteorological data from the nearby Maina (Jajarkot-0404) station. The mean annual precipitation of 1,000–2,000 mm supports continuous hydrological input even in the absence of active glacier melt. Water level variation observed during the monsoon and pre-winter periods is typical of high-altitudinal hydrologic systems where freeze-thaw cycles dominate the annual water balance.

The trio-glacial lakes (Sankha Daha, Kukur Daha, and Thakur Jyu Daha) are situated in the Barekot Patan of Jajarkot district at an altitude of 4400 meters to 4700 meters above sea level. These lakes are formed by the glacial snow, so they are in a frozen state for the whole year, although the snow melts in the rainy season and the lakes are in a liquid state in the months of 'Shrawn & Bhadra'. The shape and size of these lakes are continuously changing across different seasons. The actual data regarding the formation and changes of the morphological characteristics of those lakes are not in the record. So, we conducted a questionnaire method to outreach the shape and size of those lakes over a long period of time.

Therefore, the geomorphological evidence (cirque-basin morphology, absence of morainic barriers) and hydrological regime (precipitation- and snow-fed input) support that the Sankha, Kukur, and Thakur Jyu Lakes are relict glacial or periglacial water bodies that have transitioned into stable high-altitudinal lakes. Their classification as "high-altitudinal glacial lakes" acknowledges both their glacial heritage and their present-day hydrological independence from active glacial processes. This distinction is essential for assessing their long-term stability, climatic sensitivity, and potential risk of future glacial lake outburst floods (GLOFs).

Discussion

According to the study, the Barekot Patan area of Jajarkot district's lake features and precipitation pattern disclose a lot. Precipitation changed considerably between 2000 and 2023. The largest amount of rain ever recorded was 2477. 8 mm in 2000 and 706. 3 mm in 2010. This fluctuation may indicate how local weather patterns are affected by climate change. Lake levels and deposition patterns are influenced by precipitation data. Every one of the three lakes, Thakur Jyu Daha, Kukur Daha, and Sankha Daha, has a different morphology. The conch-like form of Sankha Daha, which has an area of 0.110240 sq. km., gave rise to its name. Kukur Daha, which is oval and round in shape, covers 0.034932 square kilometres, whereas Thakur Jyu Daha, which extends eastward, covers 0.127920 square kilometres. These data demonstrate the significant changes in the size and shape of the lakes, which are most likely caused by both geological formations and ongoing silt deposition and erosion. Interestingly, all three lakes have similar elevations; Thakur Jyu Daha is 4622 meters above sea level. Based on their altitudinal range, these lakes are assumed to have formed from glacial snow, which keeps them frozen for much of the year. However, during the monsoon season, some of the snow evaporates and disappears from the lakes.

Over the past 30 years, residents have seen visible morphological changes in the lakes, including a reduction in the amount of snow cover. The study shows that, although being officially designated as glacial lakes, these lakes would be better described as high-altitudinal lakes given their behavior and interactions with the environment. Their role as tributaries of the Nalagad River further emphasizes their relevance to the area's hydrological system. In addition to the ongoing physical alterations in the lakes, fluctuations in the patterns of precipitation that have been recorded point to possible consequences of climate change, particularly in regions with high altitude glaciers. The continuous observation of these lakes is essential to comprehending the long-term environmental changes occurring in this region.

Conclusion

The morphological characteristics of the trio-glacial lakes has been measured and calculated by using different methods. The project elaborate and put contrast on their shape and sizes. The conch-like form of Sankha Daha, which has an area of 1, 01,755.7 square meters, gave rise to its name. Kukur Daha, which is oval and round in shape, covers 30,557.27square meters, whereas Thakur Jyu Daha, which extends eastward, covers 1, 12,957.59 square meters.

A typical annual range between 1000 mm and 2000 mm is indicated by the examination of precipitation data from the project site, which shows substantial variability. Annual rainfall ranges from a maximum of 2487.8 mm in 2000 to a minimum of 706.3 mm in 2010. Understanding the hydrological conditions influencing the region—especially those around the three lakes in Barekot Patan, namely Kukur Daha, Sankha Daha, and Thakur Jyu Daha—requires having this knowledge.

The research, which notes variances in the forms, sizes, and heights of the Sankha Daha, Kukur Daha, and Thakur Jyu Daha lakes situated in the Jajarkot area, underlines the varied morphological features and distinctive cultural value of these bodies of water. The location and unique naming practices of each lake are reflections of the water bodies' natural features as well as the local customs that have influenced the way the community views them. All three lakes are located over 4500 meters above sea level in a high-altitude zone. Because the Barekot Patan glacier is the source of all three of these lakes, they are collectively referred to as glacial lakes. The sizes and forms of these lakes have been measured and computed through study and project work, both manually and with the use of Google Maps.

The three trio-glacial lakes in BarekotPatan have changed significantly morphologically in the last several years, going from completely glacial to partly cover in snow, and now more closely resemble high altitudinal lakes. Each of the three lakes has a special religious and cultural importance; the most devoted people visit Thakur Jyu Lake every year during the monsoon season. This alteration emphasizes how these habitats, which are tributaries of the Nalagad River, are being impacted by climate change.

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