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Conservation of Gosainkunda and Associated Lakes: Morphological, Hydrochemistry, and Cultural Perspectives

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Abstract

In this paper, we present the current situation of the Gosainkunda and associated lakes based on the preparation of an inventory of lakes using the Google Earth Engine and 2020 Sentinel 2A satellite imagery. Furthermore, we discuss the hydrology, hydrochemistry, and cultural significance of the lakes based on the systematic review of available literatures. In 2020, there are 22 lakes along with Gosaikunda (12.7±0.4 ha) in the Upper Trishuli watershed (59.2 km2), extending from 1274 to 4993 m elevation and covering a total area of 80 ha. The largest lake is *Bhairabkunda*, with an area of 15.5±0.5 ha. The water bodies in the region are drying, and some of the lakes have already disappeared from the region. But some lakes in the region are evolving as temporary water bodies. The high-altitude lakes are sensitive indicators of anthropogenic disturbance and changing climate. Though the lakes have better hydrochemical quality than the urban lakes located in the southern part of the country, the evidence shows increasing local and long-range transport and deposition of the pollutants in the lake water. The presence of chemical constituents of anthropogenic sources in the water of oligotrophic lakes is possibly evidence of the long-range transport of pollutants. Considering the cultural importance of the region, the number of visitors is increasing annually. Increasing human activities in and around the lake, long-range transport of pollutants, and changing environment in the area are demanding for the lake's conservation. We suggest regular monitoring of the high-altitude lakes to understand the ongoing climate change and anthropogenic impacts.

Keywords: Alpine lake, Himalaya, hydrochemistry, satellite imagery, surface area

Introduction

Lakes (stagnant water bodies including pond or *kunda* in Nepali) are considered a suitable indicator for evaluating climate change impacts at high elevations (Salerno et al., 2014; Shijin & Tao, 2014; Salerno et al., 2016). Nepal Himalaya is home to a large number of lakes. Nepal's high altitudes (>3000 m) host more than 1,500 lakes that have originated from the melting of snow and ice (Khadka et al., 2018). In the high-altitude lakes, direct anthropogenic impacts are expected to be minimal, and the natural geochemical processes seem to control the chemistry (Bhatta et al., 2014); however, mountain lakes located at the high elevation are more susceptible to atmospheric pollutants than lowland lakes due to their typical climate, shallow soil layers, small watersheds and rapid flushing rates (Lami et al., 1998). Changes in the distribution and number of lakes have implications for hydrology and the ecosystem (Shrestha et al., 2019). Previous studies have indicated that the alpine environments experience increased human disturbances, changes in the temperature and precipitation pattern, increased solid and atmospheric pollutants (Salerno et al., 2016; Salerno et al., 2015; Sharma et al., 2015).

Remote sensing is commonly used techniques for the study of high-altitude and remote lakes since it can easily provide knowledge on evolution of lakes, their morphological characteristics, potential hazard or risk without the need of extensive field efforts. Despite this capability, it has not been used and generated the basic knowledge about the abundance of lakes in the remote mountain watershed of Nepal which is important to unravelling the status and knowledge on the small-scale variability of the lakes. Several different lakes are located at high-altitude, including those glacial lakes. Gosainkunda and associate lakes are extra glacial lakes (Petrov et al., 2017) which are not directly connected with the glacier ice, but contributed by the melted water from the snow and ice. This paper aims to present the current situation of Gosainkunda and associated lakes based on remote sensing observation in the high mountains of central Nepal Himalaya. Furthermore, we discuss the morphology, hydrochemistry, and cultural significance of the lakes based on the systematic review of the literature.

Study area

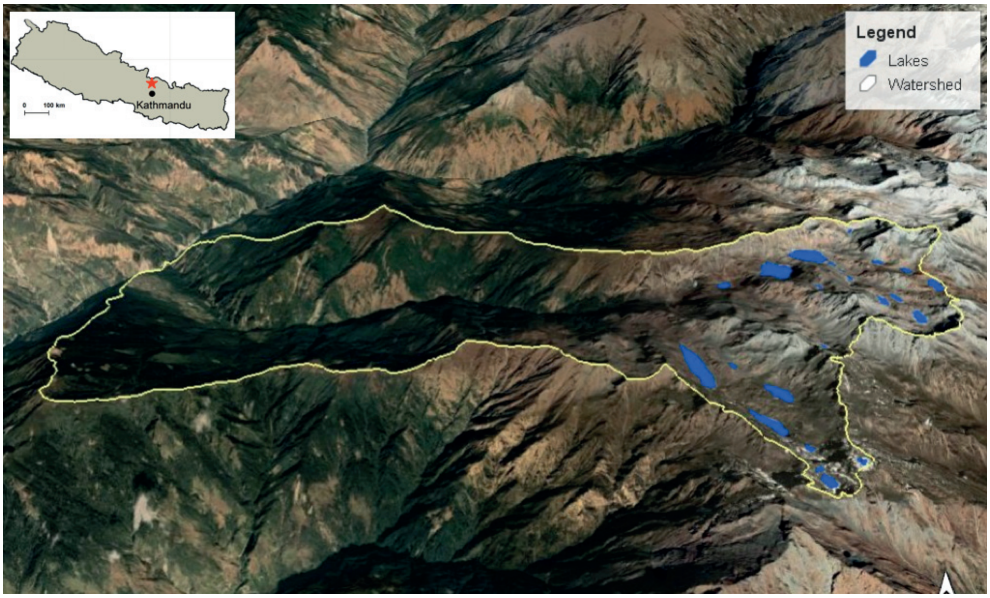

Figure 1: *Location of the study area: the upper Trisuli Watershed. The inset map of Nepal shows the study site, marked by a star sign.*

Gosainkunda and associated lakes are situated in the upper Trisuli River watershed of Nepal (Figure 1). It is an essential source of water for the Trishuli River. The lakes are located in Ward Number 5 of Gosaikunda Rural Municipality, previously Dhunche and Syafru Village Development Committees, in the Rasuwa district of Bagmati Province. It is located about 30 km north (aerial distance) of Kathmandu valley and is about one and a half days walk from Dhunche, the headquarter of Rasuwa district.

Geographically, the freshwater wetland lies in a U-shaped valley above 4000 m on the lap of hill Gosai, from where it burrows its name (Bhatta et al., 2018; Upadhaya et al., 2009). Gosaikunda is suggested as the largest lake among all lakes in the Gosaikunda lake system, with a mean depth of about 12 m. The lake's surface area is 13.8 ha, and the maximum depth is 24.1 m, reported by Rupakheti et al. (2017). It is an alpine freshwater oligotrophic lake; however, nutrients and dissolved organic carbon concentration is high near lakeshore (Bhatt et al., 2014). The lake has 35 liters/sec water input from the inlet and consists of 1.472 million m3 water volume and discharges 60 liters/sec of water through the outlet. It is reported that the entire lake system comprises 108 different-sized lakes with an area of 10.30 km2 (Bhatt et al., 2014). The region comprises land without trees but with sparsely distributed shrubland, rocky slopes, and pasture. The area is culturally recognized, biologically rich, inhibiting much vulnerable flora and fauna (Shrestha et al., 2020).

Gosaikunda and associated lakes: A Ramsar site of international importance

Nepal currently has ten sites designated as Wetlands of International Importance (Ramsar Sites; Figure 2), with a surface area of 60,561 ha. Gosaikunda and Associated Lakes, located in the Langtang National Park, is one of the Ramsar Sites. Gosainkunda complex was designated in the Ramsar site (Ramsar site no. 1693), covering 1,030 ha on September 23, 2007 (Karki et al., 2007; Upadhaya et al., 2009). It was designated as the Ramsar site due to the presence of the IUCN Red-listed endangered and vulnerable species of fauna and flora. Furthermore, the site has religious associations for Hindus and Buddhists and is the center of the *Gangadashahara*, a Hindu festival celebrating the *avatarana* (descent) of the Ganges, and *Janaipurnima*, a sacred thread festival of Hindu. Human uses include grazing during

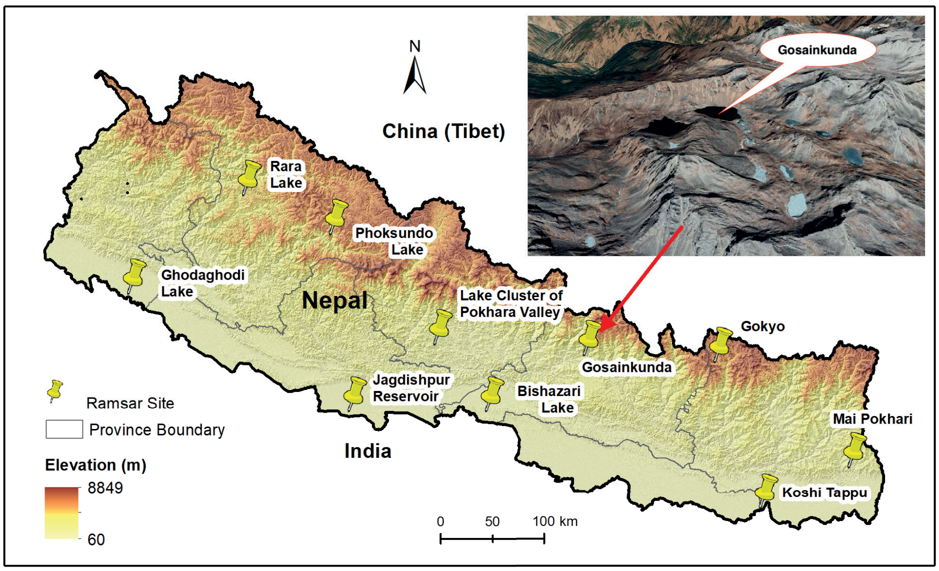

Figure 2: *Location of Gosainkunda and associated lakes, and other 9 Ramsar sites (wetlands) of international importance of Nepal.*

summers, and there are also hotels with campgrounds for trekking groups and pilgrims. Solid waste pollution due to a large-scale gathering of humans during the festive seasons and the long-range transport and deposition of the pollutants on waters have been threats to the site.

Data and methods

The Google Earth Image (GEI) and Sentinel image of December 11, 2020 (Scene ID: S2A_MSIL1C_20201211T050211) were the primary data source for preparing an inventory of the lakes. Initially, lakes were identified and digitized in the GEI and exported as a KML file. We used ArcGIS10.7 for further processing of the data. We used Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM; a product of METI and NASA) of 30 m resolution for extracting the river, and watershed boundary. To validate the lake inventory, we compared GEI lake inventory with the Sentinel satellite image and Nepal's official topographic map (1992) and also compared the dimensions (area, perimeter) of selected large lakes. The volume of each lake was estimated using the empirical equation based on the surface area of the lake. We used the equation successfully applied by Khanal et al. (2015) in the Poiqu/Bhote Koshi/Sun Koshi River basin, a similar geographic and climatic region located close to the current study site. This equation was proposed based on the trend line derived from the area and volume of high altitude lakes in the Hindu-Kush-Himalaya region.

The equation is represented as,

Volume of the lake (m^3) = $0.0578*A^{1.4683}$

Where, A = surface area of the lake.

Furthermore, we used the Web of Science database and Google Scholar to search the literature. We reviewed the existing hydrological, hydrochemical, morphological, climatic and cultural studies of the Gosainkunda and associate lakes. We found only a few articles published in these areas, and all of them were focused on the Gosainkunda. No hydrochemical and morphological studies available for other associated lakes.

Results and discussion

Morphology of the lakes

The study area, the upper Trisuli watershed, covers about 59.2 km2 of the Narayani River system (Figure 3). The watershed extends from 1274 to 4993 m. A total of 22 lakes, with a total surface area of 80 ha in 2020, were identified within the watershed, ranging from 0.2 to 15.5 ha in size (Table 1; Figure 3). We estimated the water volume at 1805,000 m3 of the Gosainkunda. An estimated 9,491,000 m3 of water volume available on the surface as the stagnant water body in the watershed.

Table 1. Lakes and their morphological characteristics in the upper Trishuli River Watershed.

Lake Number (LN)	Latitude (°N)	Longitude (°E)	Elevation (m)	Lake Name	Perimeter (m)	Surface Area (ha)	Volume (linear scaling) x1000m^3
LN1	28.080	85.400	4095	Saraswotikunda	747	2.3±0.2	146

LN2	28.080	85.407	4315	Bhairabkunda	1861	15.5±0.5	2416
LN3	28.083	85.414	4383	Gosainkunda	1520	12.7±0.4	1805
LN4	28.081	85.417	4379	-	409	0.8±0.1	30
LN5	28.079	85.417	4382	-	170	0.2±0.0	3
LN6	28.077	85.418	4388	Dudhkunda	313	0.6±0.1	20
LN7	28.086	85.421	4609	-	332	0.5±0.1	16
LN8	28.078	85.422	4562	-	429	1.1±0.1	51
LN9	28.076	85.425	4600	Nilkunda	460	1.4±0.1	68
LN10	28.071	85.422	4477	Chandrakunda	577	1.7±0.1	92
LN11	28.070	85.419	4493	Ragatkunda	695	2.0±0.2	121
LN12	28.066	85.423	4517	Amakunda	844	3.8±0.2	312
LN13	28.073	85.411	4572	-	433	0.8±0.1	29
LN14	28.061	85.407	4464	Batas Kunda	315	0.6±0.1	21
LN15	28.061	85.389	4185	Lamu Kunda	2191	16.4±0.5	2615
LN16	28.059	85.393	4313	Rani Kunda	368	0.7±0.1	28
LN17	28.054	85.398	4342	Rajakunda	1128	5.8±0.3	577
LN18	28.050	85.395	4236	Naukunda	1416	7.5±0.4	838
LN19	28.045	85.398	4278	Chherakunda	449	1.1±0.1	48
LN20	28.040	85.398	4406	-	481	0.7±0.1	27
LN21	28.039	85.398	4408	-	737	2.7±0.2	188
LN22	28.040	85.402	4556	-	672	1.0±0.2	41

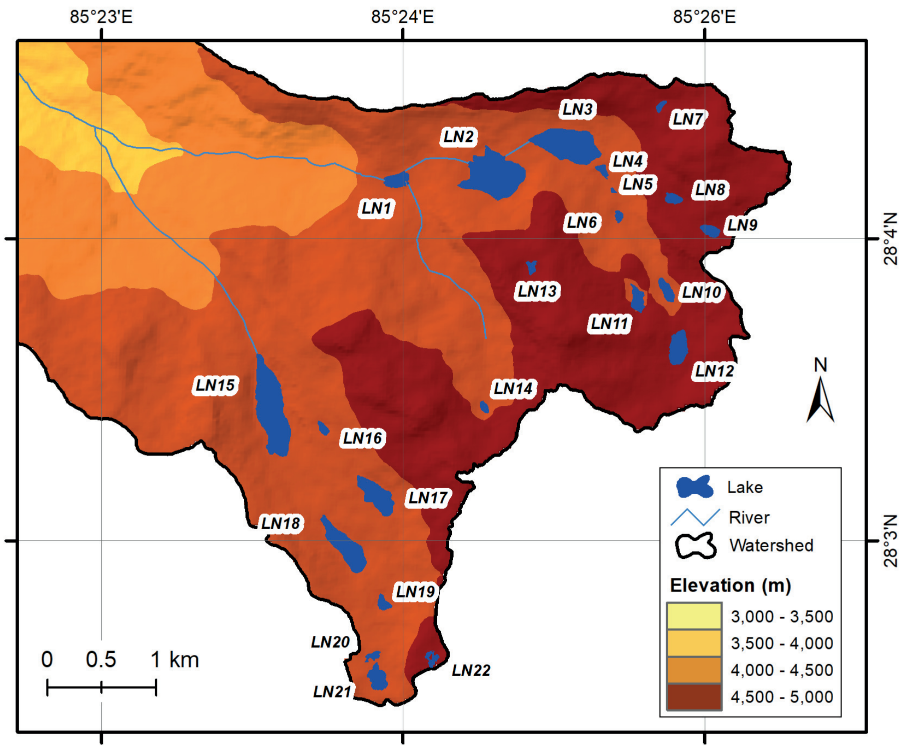

Figure 3: *Mapping of the lakes: Gosaikunda and associated lakes in the upper Trishuli watershed of Nepal. The elevation represents the ASTER-GDEM 30 m resolution.*

Hydrology and hydrochemistry

Gosainkunda and associated lakes are located in the Rasuwa district in central Nepal. Trishuli River, one of the seven tributaries of the Gandaki River, originates from *Gosainkunda* (Figure 4). Gosaikunda and associated lakes remain frozen nearly for six months during the winter season. Precipitation occurs mainly as snowfall except during summer monsoon season (Bhatt et al., 2014; Khadka et al., 2020). From the meteorological data from the nearly Kyangjing station (28.21°N; 85.61°E; elevation: 3920 m), for the last three decades, shows that the annual rainfall varies from 600 mm to 900 mm, the mean temperature is around 5.5°C with minimum temperature -12°C to maximum temperature 20°C. Thapa et al. (2020), studying the climatic and hydrological trends in the Langtang Basin, shows that the total precipitation decreases in the winter season and increases in the monsoon and post monsoon seasons, with an annual precipitation increase of 5.7 mm yr^{-1}. The mean temperature is in rising trend in all seasons and annual scale from 0.040 to 0.068°C yr^{-1}. The snow cover from 2001-2017 in the same basin had significant decreasing trends in the winter (1.24 km^2 yr^{-1}) and the monsoon seasons (1.17 km^2 yr^{-1}). As a consequence, the river discharge in the basin is in a significant increasing trend in all seasons. Hotels and residents nearby and downstream of Gosainkunda use lake water for drinking and household purposes (Rupakheti et al., 2017). Downstream communities also depend on this water source for sanitation, agriculture, industries, and hydroelectricity generation. Furthermore, it supports aquatic life and ecosystems.

Figure 4: *Gosainkunda, the main lake in the area with hydrological and cultural significance.*

Different lake watershed and lake water processes, like sedimentation, deposition, resuspension, and flushing, determine the pollution level. Different studies considered the physico-chemical analysis of the Gosainkunda lake water (Raut et al., 2012; Bhatta et al., 2014; Sharma et al., 2015; Rupakheti et al., 2017). The Ca^{+2} (64%) is the dominant cation, and Cl^- (49%) is the dominant anion of the lake water (Raut et al., 2012). The order of cation concentrations in the lake was $Ca^{+2} > Mg^{2+} > Na^+ > K^+$ (Raut et al., 2012). In contrast, Begnas lake, located in the lower urbanized area, had slightly higher concentrations of Na^+ than that of Mg^{2+} (Khadka & Ramanathan, 2012). Higher concentrations of major solutes appear at the northern lakeshore near the trail areas due to human and livestock influence (Bhatt et al., 2014).

Based on the water quality index (WQI), high-altitude lakes (e.g., Lake Gosainkunda) were found to have better water quality than the urban lakes (e.g., Lake Phewa). WQI suggests an excellent water quality of the Gosainkunda lake due to its remoteness and less direct contact from human activities (Rupakheti et al., 2017). The high-altitude lakes are helpful in detecting anthropogenic disturbance as they can serve as an indicator. A previous study based on water chemical constituents' analysis shows the increased anthropogenic disturbance in the lake. The Mercury concentration is reported higher in the Gosainkunda lake compared to low altitude Phewa lake, possibly due to long-range transport of pollutants and partially contributing from the natural geological sources. Further, the trace element constituents of water such as Ni, Cu, Zn, Cd, and Pb in the water contributed to anthropogenic sources (Sharma et al., 2015).

Cultural perspective

Gosainkunda and associated lake areas, one of the holiest and sacred lands in the country is an alpine freshwater oligotrophic lake series formed by glacial water and remains frozen for at least six months of the year (Lacoul & Freedman, 2005; Shrestha et al., 2020). Langtang is a place of pilgrimage for both Hindus and Buddhists. More than 10,000 people visit Langtang to take a holy bath at Gosainkunda (Koju & Chalise, 2012). The number of pilgrims has increased from nearly 5,000 in 1999 (Basnyat et al., 2000) to more than 20,000 during the 7 days around the Janai Purnima festival in August 2017 (Bhandari & Koirala, 2017).

Every year on the day of the *Janai Purnima* and *Dashain* festival, thousands of national and foreign pilgrims climb up the hill and take a bath in this holy *Kunda* (lake). Socio-cultural significance Hindu mythology mentions Gosaikunda as a residing place of Hindu deities like the Lord Shiva and the Goddess Gauri. Hindu scriptures like *Bhagawat Gita* and *Bishnu Puran* and Hindu epics like *Rāmāyana* and *Mahābhārata* mention *Samundra Manthan* (Sea exploring), which is directly related to the origin of Gosaikunda. It is believed that the lake originated when the *Trishul* (trident) threw by the Shiva pierced the wall, and *Gangajal* (supposely holy water) filled the pond. The holy water of Gosaikunda is used during *Gangadashahara* and *Janai Purnima* by thousands of people visiting the place from Nepal and India to celebrate the festival. People believe that after bathing in the lakes one's' ancestors and one can go to heaven. The area is culturally rich, with Tamang as a major ethnic group (Upadhaya et al., 2009). The site is equally famous for Yak cheese. About 25-30% of the tourist visiting Langtang National Park visit the Gosaikunda area.

Emerging issues of the lakes

Disappearance of the lakes

The Gosainkunda lake and its surroundings were expected to have 108 lakes, but some of the lakes have already disappeared/dried at present. Several lakes have become ephemeral. In Figure 5, we compare the images of different years to demonstrate the changing status of the lakes in the region. The figure shows that the lakes are disappearing from the region.

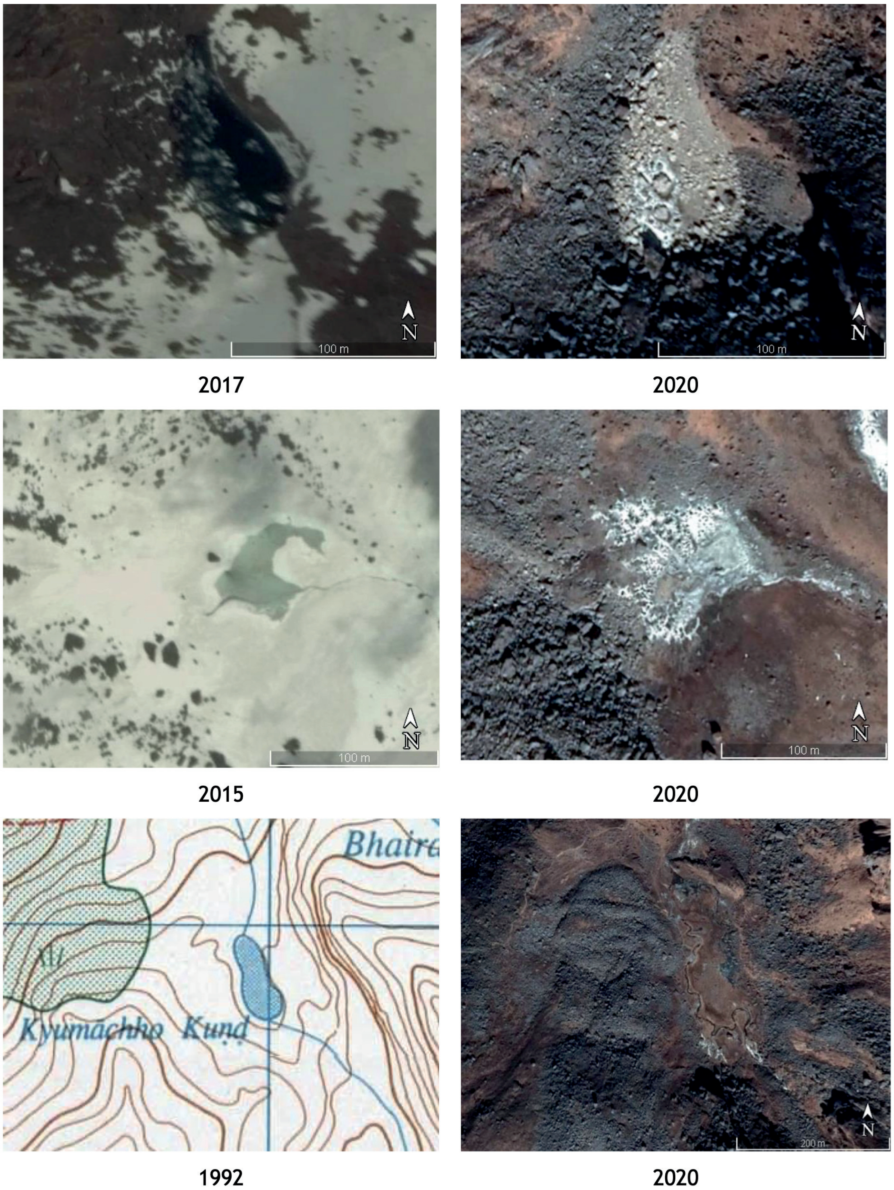

Figure 5: *The lakes are disappearing in the region, and some of the lakes have become seasonal. In the first column of the figure, the lakes were present, but they disappeared/dried in the inventory year 2020.*

High altitude lakes: An indicator of climate change

The maximum temperature of Nepal increased by 0.45 °C/decade and the minimum temperature by 0.09 °C/decade from 1976-2015 (Thakuri et al., 2019). Further, the diurnal air temperature range has increased by 0.034 °C per year in the same period. The average rate of temperature change in Nepal is higher than in other regions due to the elevation gradient of Nepal. The high mountain areas are more rapidly warming compared to the southern lowlands of Nepal. In areas above 1000 m elevation of Nepal, the maximum temperature has increased by 0.072 °C per year, while in the areas below 1000 m, the maximum temperature has only increased by 0.028 °C per year in the last four decades (1976-2015). Elevation-dependent warming can accelerate the rate of change in mountain ecosystems, cryospheric systems, hydrological regimes, and biodiversity. Rising temperature causes fluctuation in the rainfall, snow cover in the high mountains, which are important sources of water for the downstream population and ecosystems. Salerno et al. (2016) confirmed that glacial melting and precipitation trends could be detected by surface area changes of the Himalayan lakes. Thus, the lakes are a good indicator of precipitation and temperature change.

Salerno et al. (2014) demonstrated that the alpine ponds shift upwards as average temperatures increase. Increasing temperature enhances the glacier and permanent snowmelt process and creates a favourable condition for the formation of the lakes in high altitudes. Increased evaporation/precipitation ratio associated with climate warming can be the possible cause for the disappearance of the lakes. Salerno et al. (2015) showed the weakening monsoon precipitation in the Nepal Himalaya since the early 1990s.

Increasing pollutants

Though the high-altitude lakes have better water quality than the urban lakes located in the southern part of the country, the evidence shows increasing local and long-range transport and deposition of the pollutants in the lake water. Increasing human activities in and around the lake, long-range transport of pollutants, and changing environment in the area are demanding for the lake's conservation.

Conclusion and way forward

Lakes are under increasing pressure due to changing climate and the human disturbances through local and long-range transport of the pollutants. The upper Trishuli River watershed has 22 lakes, extending from 1274 to 4993 m elevation and covering 80 ha. The water bodies (lake) are drying in the region. Some of the lakes have already disappeared from the region and some are evolving as temporary water bodies. The reported chemical constituents of anthropogenic sources in the lake water of oligotrophic lakes is possibly evidence of the long-range transport of pollutants.

The number of visitors are increasing annually considenting the cultural importance of the region. Due to increasing human pressure in and around the lake, long-range transport of pollutants, and issue of the climate changes in the area are possibly threatening the existence of the lakes and appealing for their conservation needs. For effective management of the lakes, information on the status is inevitable, which can be achieved through regular monitoring. Monitoring of physico-chemical parameters, nutrient dynamics, primary productivity, community structure is helpful for detecting the ongoing changes. The field-based measurements of the lakes will be the next step for the quantification of water volume, quality, and detailed morphometric assessment of the situation. Nepal tourism board identifies this region as one of the tourist destinations in the country and promotes trekking and cultural tourism at the national and international markets. In this regard, we should ensure lake conservation and sustainable use. The wetland policy of Nepal also envisioned their conservation and wise use. Nepal adopted the national wetland policy in 2012. National Biodiversity Strategies and Action Plans also recognize the importance of such wetlands.

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