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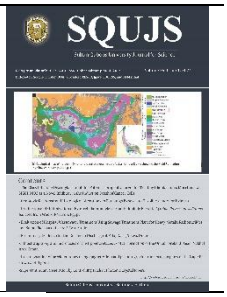

A Census of Lakes in Gandaki Province based on Remote Sensing

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Abstract: Lakes in Nepal play a crucial role in supporting biodiversity conservation, regulating ecosystems, and providing livelihood opportunities for local communities. Many lakes in Nepal hold immense religious and cultural significance for the local community, serving as sacred pilgrimage sites and embodying spiritual entities that are integral to the traditions, beliefs, and practices of the people, making them important cultural landmarks of the country. Despite their significance and importance, lakes in Nepal have faced degradation and challenges. Due to inappropriate infrastructure development, encroachment, and anthropogenic activities, lakes are degraded in Nepal. In recent years, Gandaki Province also witnessed the degradation of lakes. Therefore, this study aimed to assess the status of lake degradation as well as find out the total number of lakes in the Gandaki Province. The study was conducted utilizing both Remote Sensing (RS) techniques and conducting field visits. First of all, the Normalized Difference Water Index (NDWI) was calculated with the help of Google Earth Engine with Sentinal 2A/B satellite. That gives the water area, and then polygons of water bodies were created throughout the province in an identified area. These polygons were uploaded in ArcGIS and a base map was added. In the ArcGIS platform, polygons were further edited for the precise area using very high-resolution imagery. These edited polygons were further verified in Google Earth. Field visits, personal phone inquiries, and group discussions were conducted for further verification. Data were also collected from municipality/rural municipality, elected representatives, and key informants. Altogether 290 lakes (including ponds, lakes, and glacier lakes) were mapped and identified in the Gandaki Province. These lakes cover about 0.1045% of the total surface area of the Gandaki Province. Approximately 60% of the lakes were identified above 3000 m above sea level (asl). Lakes identified below 3000 m asl were mostly mapped from the Kaski, Parbat, and Nawalparasi Districts. The highest number of lakes discovered in Mustang (a total of 73 lakes), encompasses both lakes situated below 3000 m asl and those above 4500 m asl. Many of the wetland areas, most of which are located below 3000 m are currently facing the threat of extinction. Numerous lakes have already been transformed into playgrounds and residential areas, leading to the loss of valuable wetland ecosystems in the Gandaki Province.

It is crucial to develop a comprehensive provincial inventory of lakes that includes detailed information divided across new political boundaries. This practice would aid in effective lake management and conservation efforts in the Gandaki Province.

Keywords: ArcGIS, biodiversity; Gandaki Province; Lake inventory; Remote sensing.

الحديث العلمي للبحيرات في مقاطعة غانداكي بالاعتماد على الاستشعار عن بعد

أنوب جورونج، بيندو مالا ثاكوري، ساروج بانثي، كريبا بوخريل، رنا باهادور بي كيه، شيفا باريار، نيشال

الملخص: تلعب البحيرات في نيبال دورًا مهما في الحفاظ على التنوع الحيوى، وتنظيم النظم البيئية، وتوفير فرص كسب العيش للمجتمعات المحلية. تحمل العديد من البحيرات في نيبال أهمية دينية وثقافية هائلة للمجتمع المحلي، فهي بمثابة مواقع مقدسة وتجسد الكيانات الروحية التي تعد جزءًا لا يتجزأ من تقاليد ومعتقدات وممارسات المجتمع، مما يجعلها معالم ثقافية مهمة للبلاد. وعلى الرغم من أهميتها، فقد واجهت البحيرات في نيبال التدهور والتحديات، بسبب التطوير غير العقلاني للبنية التحتية، وكذلك الأنشطة البشرية. وفي السنوات الأخيرة، شهدت مقاطعة غانداكي أيضًا تدهور البحيرات. ولذلك، هدفت هذه الدراسة إلى تقييم حالة تدهور البحيرات وكذلك معرفة العدد الإجمالي للبحيرات في مقاطعة غانداكي. وأجريت الدراسة باستخدام تقنيات الاستشعار عن بعد وإجراء الزيارات الميدانية. وقد تم حساب مؤشر اختلاف المياه الطبيعي (NDWI) بمساعدة محرك جوجل ايرث باستخدام صور القمر الصناعي Sentinal 2A/B. وهذا يعطي مساحة المياه، ومن ثم تم إنشاء مضلعات من المسطحات المائية في جميع أنحاء المحافظة في منطقة محددة. كما تم تحميل هذه المضلعات في ArcGIS وتم ايضا إضافة خريطة أساسية. في نظام ArcGIS الأساسي، تم تعديل المضلعات بشكل أكبر للمنطقة المحددة باستخدام صور عالية الدقة. كما تم التحقق من هذه المضلعات المعدلة بشكل أكبر في برنامج جوجل ايرث. كما تم إجراء زيارات ميدانية واستفسارات هاتفية شخصية ومناقشات جماعية لمزيد من التحقق. تم أيضا جمع البيانات من البلدية/البلدية الريفية والممثلين المنتخبين والمخبرين الرئيسيين. وتم رسم خرائط وتحديد 290 بحيرة (بما في ذلك البرك والبحيرات والبحيرات الجليدية) في مقاطعة غانداكي. تغطي هذه البحيرات حوالي 0.1045% من إجمالي مساحة مقاطعة غانداكي. تم تحديد حوالي 60% من البحيرات فوق ارتفاع 3000 متر فوق مستوى سطح البحر. كما تم رسم خرائط البحيرات التي تم تحديدها على عمق أقل من 3000 متر من مناطق كاسكي وباربات وناوالباراسي. وقد وجد ان أكبر عدد من البحيرات المكتشفة في موستانج (إجمالي 73 بحيرة) يشمل البحيرات التي تقع على ارتفاع أقل من 3000 متر فوق سطح البحر وتلك التي يزيد ارتفاعها عن 4500 متر فوق سطح البحر. تواجه حاليًا العديد من مناطق الأراضي الرطبة، والتي يقع معظمها تحت 3000 متر خطر الانقراض. وقد تم بالفعل تحويل العديد من البحيرات إلى ملاعب ومناطق سكنية، مما أدى إلى فقدان النظم البيئية القيمة للأراضي الرطبة في مقاطعة غانداكي. ومن المهم تطوير قائمة جرد إقليمية شاملة للبحيرات تتضمن معلومات مفصلة مقسمة عبر الحدود السياسية الجديدة. من شأن هذه الممارسة أن تساعد في الإدارة الفعالة للبحيرات وجهود الحفاظ عليها في مقاطعة غانداكي.

الكلمات المفتاحية: نظام ArcGIS ، التنوع البيولوجي، مقاطعة غانداكي، جرد البحيرات، الاستشعار عن بعد.

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1. Introduction

Wetlands are defined as the lands or areas where water plays a vital role in controlling the surrounding environment and the associated biological life [1-2]. Nepal's National Wetland Policy [3] defines wetlands as naturally or artificially created areas and formed by underground sources of water or rainfalls. Thus, this definition recognizes lakes and ponds as types of wetlands. According to the Nepal National Wetland Policy (2003), rivers, streams, lakes, marshes, bogs, and swamps are natural wetlands whereas canals, ponds, paddy fields, fish farms etc., are man-made wetlands [1] Wetlands cover approximately six percent of the surface area of the earth [4] and occur from tropical areas to the Tundra region [2,5]. Wetlands are amongst the most productive or resourceful environments of the world and play a pivotal role in the foundation grounds of natural diversity as well as human development throughout history [1,2,6].

Lakes are blue jewels that have been used by humans for centuries to fulfil their water demands as well as for many commercial purposes [7]. Lakes play an important role in adding diversity to the landscape, providing opportunities for recreation, regulating the flow of rivers, recharging groundwater, and providing habitat for aquatic and semi-aquatic plants and animals [7-9]. Another role of the lake is to moderate the climate of the surroundings and ease the impact of flood or drought by storing large amounts of water [7,9]. However, the lakes are fragile due to the increasing use of lakes and their basins by humans since time immemorial [7,9]. Lakes, especially in urban areas are degrading and getting polluted due to the continuously increasing pressure of urbanization and industrialization [7,9]. Not only lakes, but its watershed areas are also becoming fragile due to the dumping of domestic wastes and disposal of untreated sewage and both domestic and industrial effluents to the water resources [7]. The common major problems in lakes

include sedimentation, invasive species, eutrophication, encroachment, and conflict among lake users [1].

Nepal has a rich history of over thirty years with wetlands of international importance, but has a limited history in terms of their effective management [10]. However, lake conservation and management programs remain unsatisfactory. In this regard, the National Lake Conservation Development Committee (NLCDC) was formed under the Ministry of Culture, Tourism, and Civil Aviation in 2007 [11]. The first government entity NLCDC was established with the primary objective of conservation and management of lakes by prioritizing the development of lakes as tourism destinations, protecting them from pollution, encroachment, and other detrimental activities [11,12]. In the past years, the NLCDC initiated a nationwide inventory of lakes to collect very basic information. However, the inventory was limited up to the altitude of 3,000 m above sea level (asl).

Gandaki Province is rich in water resources since there are several lakes and perennial rivers [13]. Several famous lakes such as Phewa Lake, Begnas Lake, Rupa Lake, Tilicho Lake, etc., and Perennial River, such as Kali Gandaki, Budhi Gandaki, Seti Gandaki, Marshyangdi, Madi, Daraundi, and Seti are important water resources of this province [13]. The Gandaki Province has enacted the Lake Conservation and Development Act 2019 and simultaneously formulated the Lake Conservation and Development Regulation 2020. Based on these legislations, the Lake Conservation and Development Authority (LCDA) was established in Gandaki Province in 2020 with the primary objective to conserve and manage the lakes of Gandaki Province. Lakes play a pivotal role in supporting biodiversity conservation, regulating ecosystems, and providing livelihood opportunities for local communities in Gandaki Province [14]. For example, lakes such as Fewa and Tilicho located in Gandaki Province, known for their breathtaking beauty, attract visitors from all over the world, contributing to both local and national tourism revenues, supporting the economy and livelihoods of the communities in the wetland areas [13,14]. Nevertheless, lakes in Nepal have faced degradation and challenges [15]. Lakes in Nepal are mainly degraded due to inappropriate infrastructure development, encroachment, and anthropogenic activities [14]. Recently, Gandaki Province also witnessed the degradation of wetlands, which ultimately threatened the loss of valuable water resources in the surroundings. Therefore, it is of outmost importance for Gandaki Province to create a comprehensive baseline inventory of lakes to serve as a fundamental tool for guiding overall policies and programs aimed at the sustainable development, conservation, and management of wetlands. Through lake inventory, we can gather essential information about wetlands, including their ecological characteristics, biodiversity, water quality, and surrounding landscape [14]. Thus, the main objective of this study was to create a comprehensive baseline inventory of lakes in Gandaki Province. The study was conducted utilizing both Remote Sensing (RS) techniques and conducting field visits. It is believed that the systematic lake inventory enables us to make informed decisions, set conservation priorities, and implement effective management strategies to ensure the long-term health and viability of wetlands. Moreover, the outcome of this study will create a well-developed baseline inventory that acts as a solid foundation for achieving the balance between human needs and the preservation of these vital ecosystems.

2. Materials and Methods

2.1 Study area

The study was conducted in the Gandaki Province which is located in the central part of Nepal. This province consists of 11 districts, namely: Nawalpur, Tanahun, Gorkha, Lamjung, Kaski, Syanjya, Parbat, Baglung, Myagdi, Manang, and Mustang (Figure 1). There are 85 local administrative bodies in this province: one metropolitan city, 26 municipalities, and 58 rural municipalities [13].

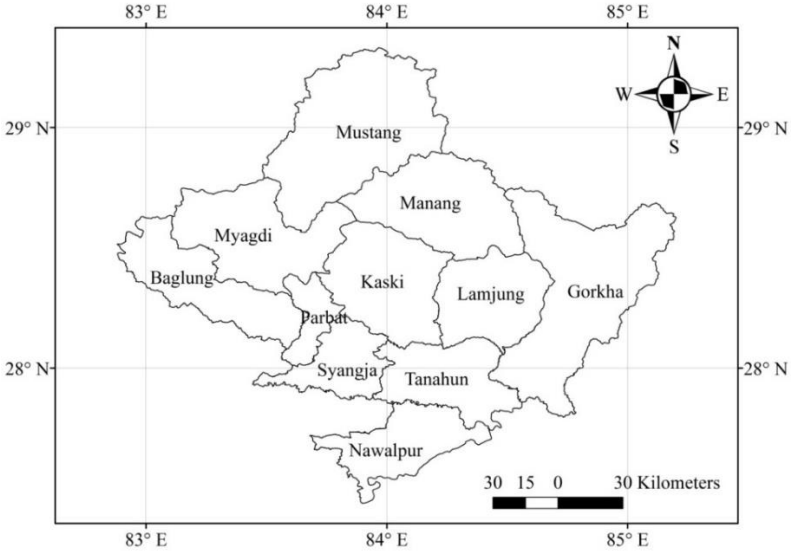

Figure 1. Map of Gandaki Province showing 11 districts

Gandaki Province extends from Himal to Terai from north to south in the north-central part of Nepal. The total area of this province is 21,976.34 km^2, i.e., 14.93% of the total area of Nepal [16]. The valley is situated in the upper part of Manang, Mustang, and Gorkha [13]. The major forest management systems practiced in the provinces are collaborative forest management, community forest management, and block forest management. This province is rich in valuable forest resources, including some valuable non-timber forest products (NTFPs), such as Guchchi Chyau (*Morchella esculenta*), Kurilo (*Asparagus officinalis*), Lauth Salla (*Taxus baccta*), Nirmasi (*Delphinium denudatum*), Okhar (*Juglans regia*), Paakhanved (*Bergenia ciliate*), Panchaule (*Dactylorhizahatageria*), Satuwa (*Paris polyphylla*), Sungadhwal (*Valerianajatamansi*) and Timur (*Zanthoxylum piperitum*) [13].

This province is also rich in protected areas. It is home to several important protected areas, such as the Annapurna Conservation Area (ACA), Chitwan National Park (CNP), and Dhorpatan Hunting Reserve (DHR) [13]. Similarly, Chitwan National Park is famous for rhinos and tigers, and the Manaslu Conservation Area is famous for trekking, unique landscapes, and mountain biodiversity [13,17]. Moreover, the diversity of orchids is high, especially in the Panchase Hills [18]. Being situated at the divide of the Eastern and Western Himalayas, the Kali Gandaki gorge is a recognized corridor for birds to migrate [18].

Major land-use types of the province are needle-leaved forest, broad-leaved forest, shrubland, grassland, agricultural land, built-up area, bare area, lake, river, and snow/glacier [13]. Figure 2 shows the land use pattern of the province [19]. Like the other natural resources, Gandaki Province is rich in water resources. A total of nineteen perennial rivers are there in this province. Similarly, 368 sub-watersheds are in this province [13]. This province is also rich in wetlands and lakes. Nine lakes (Phewa, Begnas, Rupa, Maidi, Dipang, Gunde, Khaste, Niureni, and Kamal Pokhari) of Pokhara Valley have been listed in Ramsar sites covering 172.83 km^2 [13].

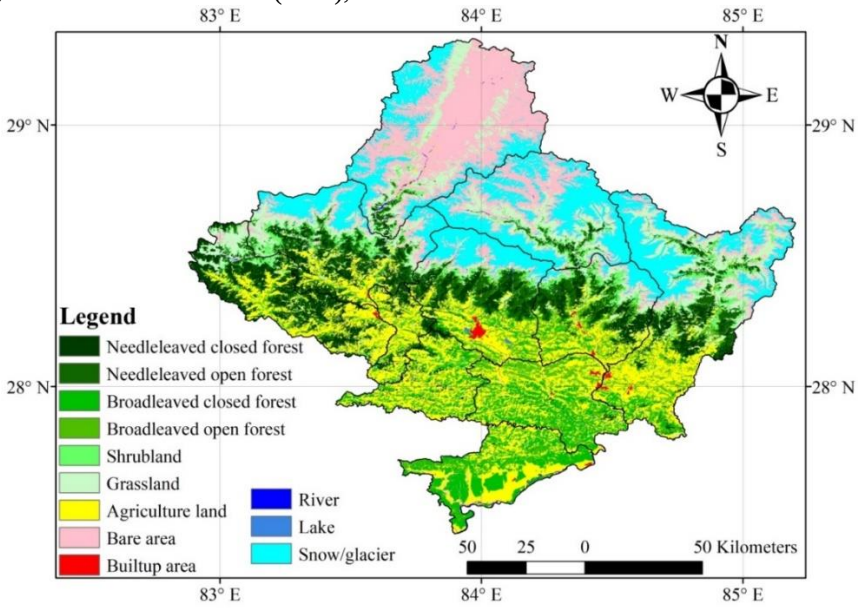

Figure 2. Landuse of Gandaki Province across all districts.

2.2 Study design

Satellite images are easily available and widely used sources and Geographical Information System (GIS) is an established platform to identify the potential area for lake formation [20] and glacier inventory [15,21-24]. Similarly, satellite images are used to identify the glacial lake expansion [25]. In Nepal, a glacial lake inventory and glacial lake outburst flood monitoring were conducted using topographic maps and aerial photography [26]. Similarly, this study used satellite imagery and GIS along with field verification to identify the area of all lakes and glacial lakes in Gandaki Province. The study used both primary and secondary data from the field. Secondary information was collected from various sources and agencies such as previous study reports, municipalities, and rural municipalities.

2.3 Digitization of lakes and ponds

This study used the Normalized Difference Water Index (NDWI) in the Google Earth engine. Polygons of water bodies were created. These polygons were uploaded to ArcGIS and added to the base map. In ArcGIS, these polygons were verified and corrected to optimize the accuracy. Again, layer polygon files were converted to Keyhole Markup Language (KML) format and verified with Google Earth. This study used the three platforms (Google Earth Engine, ArcGIS, and Google Earth) for digitization and verification. Therefore, this type of study is the most

comprehensive of Lake Inventory to date. During digitization, we used data prepared by the International Centre for Integrated Mountain Development (ICIMOD) and the National Lake Inventory for further verification. This study digitized the dry and wet boundaries of lakes so stakeholders can get information on the status of water in both seasons. This information will be helpful for stakeholders to conserve and manage the lakes for the betterment of the environment and human society.

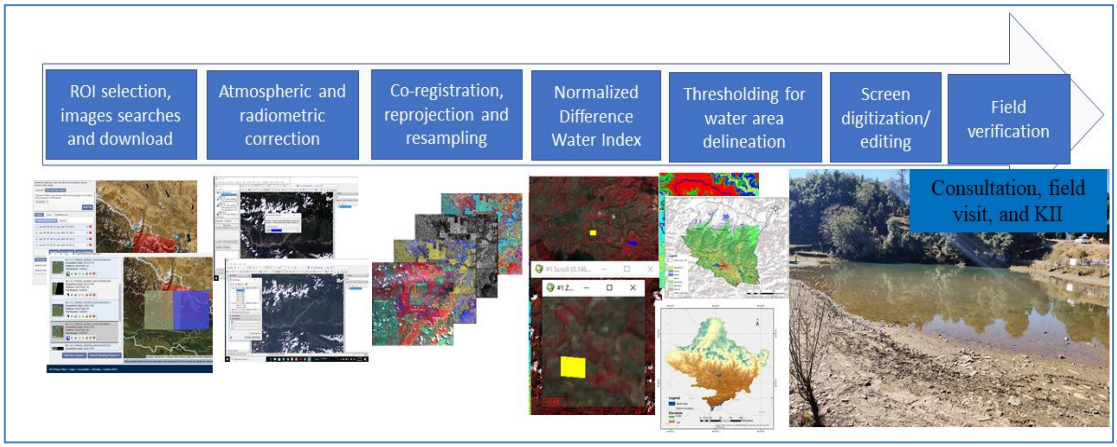

Figure 3. shows the flow chart for inventorying lakes in Gandaki Province.

2.4 Verification of digitization

Field verification

- **Field base survey:** This survey was carried out, particularly for lake area verification and base map updates. This survey was a technical survey with Global Positioning System (GPS) tracking including hard copy map to update in the field. In addition to the geospatial information, cultural, ecological, socio-economic, hydrological, archaeological, etc. implications of the lake were acquired.
- **Consultation meeting:** Consultation meetings were conducted in two stages. At the authority level overall project objectives, requirements, importance, coordination part and capacity development, etc. were discussed. At the field level, field meetings at the lake were organized to list out the potential threats to the lakes, their uses, and their importance at the local level.
- Similarly, other necessary data were collected through observation/informal conversation at the local level.

2.5 Preparation of the final map

After field verification, prepared maps were edited according to the field situation if there was any difference between satellite images and field conditions. Final maps of lakes were prepared on the WGS1984 geographical projection system with the help of ArcGIS [27].

2.6 Area calculation

Shapefiles of dry and wet seasons of all lakes of individual districts were merged. Then 11 maps of the wet season and 11 maps of the dry season were prepared. These maps were projected to the projected coordinate system (UTM Zone 44N for Mustang, Myagdi, Baglung, Parbat, and Syangja and UTM Zone 45N for Manang, Lamjung, Gorkha, Tanahun, and Nawalparasi (Bardaghat Susta Purba). Finally, the area of both seasons (dry and wet) of all lakes was calculated with the help of ArcGIS.

3. Results and Discussion

3.1. Lakes distribution across physiography

A total of 290 lakes, including ponds, lakes, and glacier lakes were identified in the Gandaki Province that have values for biodiversity, religion and culture, and livelihoods. The study mapped and reported the district-wise distribution of lakes as seven in Baglung, 32 in Gorkha, 35 in Kaski, 11 in Lamjung, 54 in Manang, 73 in Mustang, 12 in Myagdi, 21 in Nawalparasi (Susta Bardaghat Purba), 33 in Parbat, five in Syangja and seven in Tanahun. A total of 126 glacier lakes (above 4500 m) were inventoried in the province. Similarly, 48 lakes were mapped between the altitudes of 3000-4000 m. Likewise, 117 lakes were inventoried below 3000 m. Lakes above 3000 meters were not studied in detail due to the limitation of time as well as the budget of the program. Only lakes below 3000 m were explored and studied extensively concerning their ecological, cultural, and socioeconomic parameters. Table 1 shows the physiographic distribution of lakes in Gandaki Province.

The study reported that the majority of the lakes identified below 3000 m in Gandaki Province are degrading. Most of them are suffering from pollution, encroachment, sedimentation, and invasive species. Invasive species like water hyacinth are very common in lakes of Kaski District. In the past people used to rely on ponds and lakes to fulfill their water demands including drinking, cooking, and other purposes. However, in recent years, the water quality in the majority of the ponds and lakes are not suitable for drinking without treatment. Lakes and ponds not only provide aesthetic value and beauty to the surroundings but also

provide options for livelihood support to the communities. For example, a fishing community (Jalahari) in Phewa and Begnas, entirely rely on fish for their livelihood. Some lakes are of great tourism value like Phewa Lake and Begnas Lake of Kaski District as these lakes are visited by thousands of domestic and international visitors each year. The Rupa Lake of Kaski District generates a decent amount from fish farming.

Table 1. Physiographic distribution of lakes in Gandaki Province.

S.N.	District	Glacier Lakes (above 4500 m)	Lakes between 3000-4500 m	Lakes below 3000 m	Total
1	Baglung	0	2	5	7
2	Gorkha	18	12	2	32
3	Kaski	2	2	31	35
4	Lamjung	1	4	6	11
5	Manang	40	14	0	54
6	Mustang	60	9	4	73
7	Myagdi	5	5	2	12
8	Nawalparasi_E	0	0	21	21
9	Parbat	0	0	33	33
10	Syangja	0	0	5	5
11	Tanahun	0	0	7	7
	Total	**126**	**48**	**116**	**290**

The Barah Lake (Taal) and GajaDaha in Baglung are of important religious significance to Hindu devotees. Similarly, Dhumba Lake of Mustang District has a great religious value for Buddhists. Most low-altitude lakes are used for fish farming, especially in the Nawalparasi (Susta Bardaghat Purba) District.

Table 2. Basic features of lakes in Gandaki Province.

S.N.	District	Lakes have cultural importance	Lakes have touristic importance	Perennial	Seasonal	Area of lakes (m^2) below 4500 m	Area of Glacial lakes only (m^2) above 4500m	Total area of all lakes (m^2)
1	Baglung	6	1	6	1	22833	0	22833
2	Gorkha	3	0	32	0	720623	472978	1193601
3	Kaski	0	7	28	7	10496557	94414	10590971
4	Lamjung	1	2	10	1	175248	13411	188659
5	Manang	0	6	54	0	1606495	5347080	6953575
6	Mustang	1	8	71	2	157536	2946388	3103924
7	Myagdi	1	0	12	0	292403	78984	371387
8	Nawalparasi_E	0	21	21	0	519767	0	519767
9	Parbat	1	1	18	15	12359		12359
10	Syangja	0	0	0	5	5646	0	5646
11	Tanahun	0	0	7	0	3382	0	3382
	Total	13	46	260	31	14012849	8953255	22966104

Although 33 lakes were mapped in Parbat District, only six of them are more than 1,000 m^2 in area and 45% of the lakes are seasonal. All these lakes in total have an area of 2,29,66,104 m^2 in Gandaki Province, which is 0.1045% of the total surface area of the province.

3.2. Lakes distribution across districts in Gandaki Province

Gandaki Province is divided into 11 districts: Baglung, Gorkha, Kaski, Lamjung, Manang, Mustang, Nawalparasi (Susta Bardaghat Purba), Parbat, Syangja and Tanahun. Among these, no glacier lakes were reported in Baglung, Nawalparasi (Susta Bardaghat Purba), Parbat, Syangja, and

Tanahun Districts. Table 3 displays the total number of lakes identified below 3000 m in the Gandaki Province.

Table 3. Lakes in all districts of Gandaki Province below 3000 m.

District	Name of Lake	Type of Lake	Area-wet season (m^2)	Conditions
Baglung	Barah Tal- I	Freshwater, Aquifer, Perennial	3,282	Good
	Barah Tal- II	Freshwater, Aquifer, Perennial	1,775	Degraded
	Barah Tal- III	Freshwater, Perennial	4,567	Degrading
	GajaDaha	Freshwater, Aquifer, Perennial	4,736	Degrading
	Rudra Tal	Freshwater, Aquifer, Perennial	5,030	Degraded
Gorkha	Gunchowk Pokhari	Freshwater, Palustrine, Perennial	11,280	Degrading
	Tal Pokhari	Freshwater, Palustrine, Perennial	12,689	Degraded
Kaski	Aalaiche Pokhari	Freshwater, Lacustrine	339	Degraded
	Begnas Lake	Freshwater, Lacustrine, Permanent	31,21,562	Good
	Begnas Thulo Pokhari	Natural, Seasonal	2,569	Degraded
	Bhanjyang Pokhari	Freshwater, Lacustrine, Perennial	6,043	Degraded
	Dhikur Pokhari	Natural, Seasonal	1,914	Degraded
	Dipang Lake	Freshwater, Lacustrine, Permanent	1,67,973	Good
	Phewa Lake	Freshwater, Lacustrine, Permanent	54,03,906	Degraded
	Friendship Pokhari -I	Natural, Seasonal	1,332	Degrading
	Friendship Pokhari -II	Freshwater, Perennial	770	Degrading
	Gunde Lake	Freshwater, Lacustrine, Permanent	91,921	Degraded
	Kalikasthan Pokhari	Natural, Seasonal	1,952	Degraded
	Kaluwa Pokhari	Natural, Seasonal	1,557	Degraded
	Kamal Pokhari	Freshwater, Lacustrine, Permanent	13,096	Degrading
	Kapuche Glacier Lake	Freshwater, Lacustrine, Permanent	1,07,928	Good
	Kashyap Lake	Freshwater, Lacustrine, Permanent	8,993	Degrading
	Khadgaun Pokhari	Natural, Seasonal	1,176	Degrading
	Khaste Lake	Freshwater, Lacustrine, Permanent	1,32,532	Degrading
	Khode Pokhari	Freshwater, Lacustrine, Permanent	3,967	Degraded
	Machha Pokhari	Freshwater, Lacustrine, Perennial	6,900	Good
	Maidi Lake	Freshwater, Lacustrine, Permanent	10,828	Degraded
	Maula Pokhari	Freshwater, Palustrine, Seasonal	940	Degraded
	Naya Pokhari	Freshwater, Permanent	707	Degrading
	Nirmal Pokhari	Natural, Palustrine, Seasonal	478	Degraded
	Neureni Lake	Freshwater, Lacustrine, Permanent	41,156	Degrading
	Pokhari	Freshwater, Perennial	965	Degrading
	Rani Pokhari	Freshwater, Palustrine, Perennial	1,716	Degrading
	Rupa Lake	Freshwater, Lacustrine, Permanent	12,03,758	Degrading
	Shiva Pokhari	Man-made, Seasonal	231	Degraded
	Sundar Pokhari	Natural, Seasonal	416	Degraded
	Thuli Pokhari	Freshwater, Lacustrine, Perennial	2,752	Degrading
	Yangjakot Pokhari	Man-made, Perennial	1,067	Good
Lamjung	Damrang Pokhari	Freshwater, Palustrine, Perennial	1,362	Degraded
	Deurali Sano Pokhari	Freshwater, Palustrine, Perennial	1,869	Good
	Deurali Thulo Pokhari	Freshwater, Palustrine, Perennial	2,183	Degrading
	Ilam Pokhari	Freshwater, Palustrine, Perennial	3,480	Degrading
	Murunje Pokhari	Freshwater, Lacustrine, Perennial	408	Degraded

	Tinghare Thulo Pokhari	Freshwater, Palustrine, Perennial	1,119	Degraded
Mustang	Bhuchutro Lake	Freshwater, Aquifer, Perennial	8,386	Good
	Dhumba Lake	Freshwater, Aquifer, Perennial	12,607	Good
	Sekong Lake	Freshwater, Lacustrine, Permanent	9,877	Good
	Titi Lake	Freshwater, Aquifer, Perennial	96,593	Good
Myagdi	Barah Lake	Freshwater, Lacustrine, Perennial	3,355	Good
	Gaikharke Lake	Freshwater, Lacustrine, Permanent	1,484	Degrading
Nawalparasi (BardaghatSustaPurba)	Bhutaha Dhaap 1	Freshwater, Lacustrine, Perennial	2,156	Degraded
	Bhutaha Dhaap 2	Freshwater, Palustrine, Perennial	65,685	Degraded
	Century Tal	Freshwater, Lacustrine, Permanent	1,72,458	Degraded
	Chanauli Pokhari	Freshwater, Palustrine, Perennial	199	Degraded
	Dhawaha Tal	Freshwater, Lacustrine, Permanent	22,437	Degraded
	Gaida Tal 2	Freshwater, Aqua-culture, Perennial	952	Degraded
	GaidaTal 1	Freshwater, Lacustrine, Seasonal	2,998	Degraded
	Hatemalo Pokhari	Man-made, Seasonal	203	None
	Hattilid Pokhari	Freshwater, Palustrine, Perennial	1,926	Degraded
	Jabaha Pokhari	Freshwater, Lacustrine, Perennial	3,150	Degraded
	Jhyalbas Pokhari	Man-made, Aqua-culture, Perennial	3,216	Degrading
	Matikhani Pokhari	Freshwater, Lacustrine, Permanent	3,773	Degraded
	Mayur Pokhari	Man-made, Dried up	6,869	Degraded
	Pathauwa Dhaap	Man-made, Palustrine, Perennial	1,587	Degrading
	Pokhari Tal	Freshwater, Lacustrine, Permanent	59,979	Good
	Sanischare Tal	Freshwater, Lacustrine, Permanent	1,18,141	Degraded
	Simsar Tal 1	Man-made, Palustrine, Perennial	469	Degraded
	Simsar Tal 2	Freshwater, Palustrine, Perennial	506	Degraded
	Taruwa Tal	Freshwater, Lacustrine, Permanent	32,899	Degraded
	Thulo Pokhari	Freshwater, Palustrine, Perennial	1,512	Degraded
	Umtauli Tal	Freshwater, Palustrine, Perennial	18,652	Degraded
Parbat	San Daha	Freshwater, Lacustrine, Permanent	1,543	Good
	Hari Pokhari	Natural, Seasonal	26	Degraded
	Panchase Pokhari	Freshwater, Lacustrine, Perennial	1,785	Degrading
	Ramja Thuli Pokhari	Freshwater, Lacustrine, Seasonal	6,246	Degraded
	Thuli Pokhari	Freshwater, Lacustrine, Seasonal	2,178	Degraded
	Simtal Ghibrang Pokhari	Man-made, Palustrine, Perennial	3,543	Degraded
	Tallo Gijan Pokhari	Man-made, Palustrine, Seasonal	175	Degraded
	Paiyunkot Pokhari	Freshwater, Seasonal	90	Degraded
	Gorlang Pokhari	Freshwater, Palustrine, Perennial	150	Degraded
	Jaljala Purnagaun Pokhari	Freshwater, Lacustrine, Permanent	900	Good
	Pokhari Baraha, Tangle	Man-made, Lacustrine, Perennial	850	Degraded
	Deupur Thulo Pokhari	Freshwater, Palustrine, Seasonal	145	Degraded
	Sati Pokhari, Khurkot	Freshwater, Palustrine, Perennial	230	Good
	Shankar Pokhari	Freshwater, Palustrine, Perennial	45	Degraded
	Pokhara Bhittako Pokhari	Natural, Seasonal	85	Degraded
	Chhammiko Pokhari	Freshwater, Palustrine, Perennial	65	Degraded
	Jampur Pokhari	Freshwater, Seasonal	65	Degraded
	Gauradi Pokhari	Freshwater, Palustrine, Seasonal	73	Degraded
	Lamtun Pokhari, Pakhapaani	Freshwater, Lacustrine, Perennial	775	Degrading

	Ekkane Pokhari, Pakhapani	Freshwater, Palustrine, Perennial	325	Degrading
	Malkawang Pokhari, Pakhapani	Freshwater, Palustrine, Seasonal	425	Degraded
	Sarunchaur Pokhari	Freshwater, Palustrine, Seasonal	63	Degraded
	Arjikot Pokhari	Natural, Seasonal	103	Degraded
	Gainewari Pokhari	Freshwater, Palustrine, Perennial	53	Degraded
	Kaule Pokhari	Freshwater, Palustrine, Perennial	71	Good
	Okhreni Pokhari	Natural, Seasonal	103	Good
	Hareja Pokhari	Natural, Seasonal	133	Good
	Jesara Pokhari	Man-made, Palustrine, Perennial	75	Good
	Aahale Pokhari	Natural, Seasonal	61	Degraded
	Saptarisi Pokhari	Natural, Palustrine, Seasonal	83	Degraded
	Bhakimle Thulo Pokhari	Freshwater, Palustrine, Seasonal	305	Degraded
	Chihan Danda Pokhari	Natural, Seasonal	43	Degraded
	Ghante Danda Pokhari	Freshwater, Palustrine, Seasonal	31	Degraded
Syangja	Katunje Sundar Lake	Freshwater, Lacustrine, Perennial	2,000	Degrading
	Sani Daha	Freshwater, Seasonal	706	Degraded
	Sun Pokhari	Man-made, Palustrine, Perennial	141	Degrading
	Swarek Pokhari	Freshwater, Seasonal	723	Good
	Thuli Daha	Freshwater, Lacustrine, Seasonal	2,076	Degraded
Tanahun	Aadhimul Pokhari 1	Freshwater, Lacustrine, Perennial	911	Degrading
	Aadhimul Pokhari 2	Freshwater, Lacustrine, Perennial	255	Good
	Aadhimul Pokhari 3	Freshwater, Palustrine, Perennial	324	Degrading
	Bumurse Pokhari	Man-made, Aqua-culture, Perennial	248	Good
	Pipalthar Pokhari 1	Man-made, Aqua-culture, Perennial	212	Good
	Pipalthar Pokhari 2	Man-made, Aqua-culture, Perennial	629	Good
	Pipalthar Pokhari 3	Man-made, Aqua-culture, Perennial	805	Good
Total			648,908	

Baglung District: A total of seven lakes were identified in Baglung District. Among these, the name of six lakes was identified whereas that of one lake is not identified. In this district, five lakes were identified below 3000 m. As depicted in **Table 3**, one lake is in good condition, two lakes are degrading and two lakes were degraded. Rudra Tal with a total area of 5,030 m^2 is the biggest lake in this district which is situated in ward number nine of Dhorpatan Municipality. Jalpa Lake (1,682 m^2) is situated at an altitude of 4,283 m and is situated at the highest elevation in the district.

Gorkha District: Altogether 32 lakes were identified in the Gorkha District. Out of 32, the names of six lakes were explored whereas that of twenty-six lakes were not identified. Gunchowk Pokhari and Tal Pokhari are mapped below 3000 m and both lakes are degrading. Birendra Tal (2,97,877 m^2) is the biggest lake in Gorkha District which is situated at ward number one of Chum Nubri Rural Municipality. There are 18 glacier lakes in Gorkha District and the highest glacier lake is situated at the altitude of 5,463 m.

Kaski District: There are 35 lakes in Kaski District. Names of 30 lakes were explored and the remaining four were not explored. In Kaski District two lakes were mapped between the altitude of 4000-4500 m and two lakes were mapped above 4500 m (glacier lakes). Phewa is the biggest lake of Kaski District with a total area of 54,03,906 m^2. Shiva Pokhari, Aalaiche Pokhari, and Nirmal Pokhari are the smallest ones with a total area of 231 m^2, 339 m^2, and 478 m^2, respectively. The majority of the lakes are degrading.

Lamjung District: A total of eleven lakes were identified in Lamjung District. Names of eight lakes were identified whereas three lakes were not identified. One glacier lake was identified at an altitude of 4,598 m. All lakes are degrading and are situated below 3000 m. Meme Pokhari with a total area of 1,23,996 m^2 is the biggest lake in this district that is situated at ward number seven of Dordi Rural Municipality.

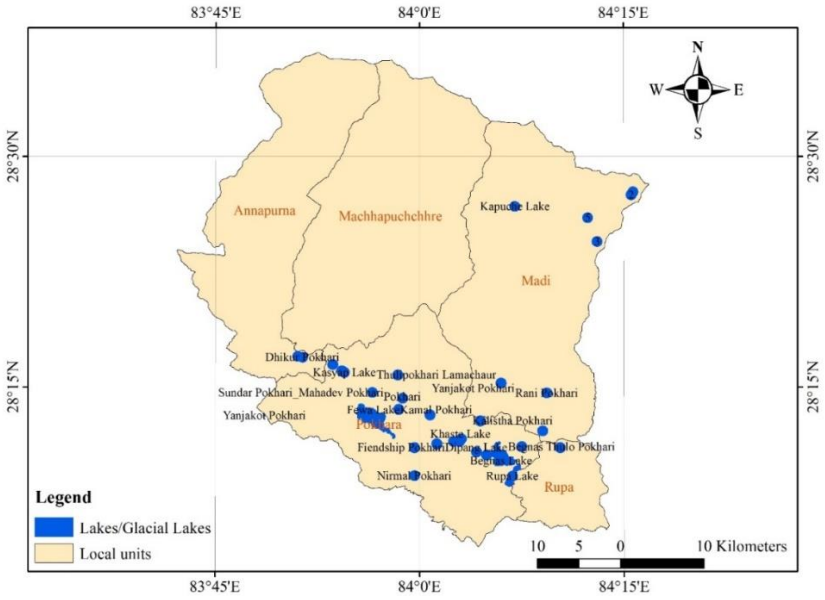

Figure 4. Spatial distribution of lakes in Kaski District.

Manang District: Altogether 54 lakes were identified in Manang District and all lakes are situated above 3000 m. A total of 13 lakes were explored while the remaining lakes were not explored. In this district, forty glacier lakes were identified. Tilicho Lake (40,54,457 m^2) is the biggest lake in Manang District and is situated in ward number nine of Neshyang Rural Municipality. Manang District holds famous lakes including Dona Lake, Gangapurna Lake, Ice Lake, Kajin Sara Lake, Mring Lake, Khicho Lake, Ponkar Lake and Nayamlo Lake.

Mustang District: This study identified 73 lakes in the Mustang District. Among these lakes, the names of thirteen lakes confirmed whereas that of 60 lakes were not identified. In this district, sixty lakes were identified as glacier lakes. Having a 4,99,360 m^2 area, the biggest lake in this district is (No 54) which is situated at ward number one of Loghekar Damodar Kunda. Bhuchutro Lake, Sekong Lake, Dhumba Lake, and Titi Lake are situated below 3000 m and all lakes are in good condition. Among the explored lakes, Titi Lake having an area of 96,593 m^2 is the biggest lake. The lake which has not been named yet (No 43), situated in Loghekar Damodar Kunda, is at the highest elevation of 5900 m. **Figure 5** shows the spatial distribution of lakes in Mustang District.

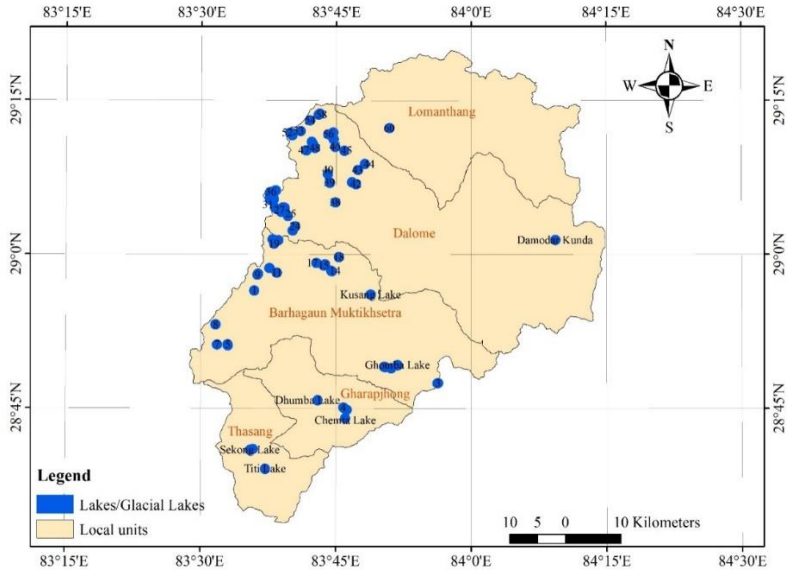

Figure 5. Spatial distribution of lakes in Mustang District.

Myagdi District: A total of 12 lakes were identified in Myagdi District. Only four lakes were explored whereas eight lakes were not explored in Myagdi. In Myagdi District, five lakes are situated at an altitude between 3000 m to 4500 m, and five lakes are situated above 4500 m. Having a 2,24,298 m^2 area, the biggest lake in this district is (No 1) which is situated at ward number four of Annapurna Rural Municipality. Among the explored four lakes, Bhujunge Lake having an area of 14,148 m^2 is the biggest lake.

Nawalparasi District (Bardaghat Susta Purba): This study identified 21 lakes in the Nawalparasi District. Century Lake with a total area of 1,72,458 m^2 is the largest lake which is situated at Kawasoti Municipality. Hatemalo Pokhari, Simar Tal I, and Simsar Tal II are the smallest ones with an area of 203 m^2, 469 $m^{2,}$ and 506 m^2, respectively. All lakes are degrading in this district.

Parbat District: This study identified 33 lakes in the Parbat District. There are no glacier lakes in the Parbat District. Hari Pokhari (26 m^2), Shankar Pokhari (45 m^2), Chhammiko Pokhari (65 m2), Jampur Pokhari (65 m^2), Gauradi Pokhari (73 m^2), Pokharai Bhittako Pokhari (85 m^2) and Painyukot Pokhari (90 m^2) are the smallest ones. Ramja Thuli Pokhari (6,246 m^2) is the biggest lake in this district and is situated in ward number seven of Modi Rural Municipality.

Syangja District: A total of five lakes were identified in the Syangja District. Thuli Daha is the biggest lake with a total area of 2,076 m^2 and is situated at Aandhikhola Rural Municipality. Sun Pokhari is the smallest lake with a total area of 141 m^2. All the lakes are in degrading condition.

Tanahun District: This study identified seven lakes/ponds in the Tanahun District. Having a 911 m^2 area, Aadhimul Pokhari 1 is the biggest lake in this district which is situated i ward number one of Anbukhaireni Rural Municipality.

3.3. Current status of lakes in Gandaki Province

The current study revealed that Gandaki Province has a high number of glacier lakes. The study found that 43.44% of the lakes were glaciers, 40.34% of the lakes situated below 3000 m above sea level, and 16.55% of the lakes situated between the altitudes of 3000 to 4500 m above sea level. A higher number of glacier lakes were identified in Mustang District and Manang District. The main reason for the occurrence of higher glacier lakes in Mustang and Manang Districts may be due to global climate change as the formation of glacier lakes is closely associated with climatic variation and topographic conditions (Wang et al., 2013). Lakes identified above the altitude of more than 3000 m above sea level were not studied in detail due to lack of time and budget. Additionally, most of the lakes above 3000 m in altitude are situated in difficult geographical settings. It is, therefore, necessary to carry out a detailed study of these glacier lakes especially in Mustang and Manang Districts so that proper conservation and management plans can be made.

It is evident from the current field study that the wetlands of Gandaki Province play an important role in the socioeconomic and cultural value of the local population. Directly or indirectly, local people residing in the vicinity of the lakes are getting benefits from the lakes. For example, Jalahari communities (fishing communities) in Phewa Lake and Begnas Lake rely entirely on lakes to fulfill their basic needs by selling fish. Apart from Jalahari, those who live near the lakes in Gandaki Province are getting benefits from the lakes. For example, the population living in the Himalayas entirely relies on lakes and springs for drinking water and other domestic water needs. Dams have been built on the majority of the large lakes thereby irrigating thousands of hectares of land downstream. Lakes also play a pivotal role in generating financial revenue in Gandaki Province. Phewa Lake in Pokhara attract thousands of domestic and international visitors each year to observe its beauty and uniqueness. Likewise, Tilicho Lake in Manang District is one of the famous lakes that is situated at the highest altitude in the world.

In developing countries like Nepal, the conservation and management of wetlands are underestimated and undervalued [1]. Consequently, the majority of the lakes are degrading in Gandaki Province. The field study revealed that the haphazard construction of roads leads to soil erosion that ultimately enriches sediment in the lake system. Another important factor of lake degradation is the land encroachment in Gandaki Province. The field survey results indicate a significant shrinkage of Phewa Lake over the past three decades, mainly due to land encroachment. Generally, it is difficult to quantify the loss of wetlands in terms of number and area until a comprehensive study is conducted [1]. It was found that local people outweighed the natural functions of the lake over the short-term benefit in Gandaki Province. Such a mindset results in lake degradation and undermines the conservation efforts in the locality.

Our study revealed that the short-term benefits derived from wetland resources/lakes promote lake degradation. In some areas, it was found that converting lakes into recreational areas has led to the degradation of many lakes. For instance, a Pokhari (Shankar Pokhari) in Parbat District, which was once a vital source of fresh water, has unfortunately been transformed into a recreational area. Likewise, in Parbat District, Melpokhari has recently suffered the same fate of being transformed into a bus park as depicted in Figure 6. This Pokhari was once a pristine and invaluable water source, cherished for its purity and ecological importance in the locality. The study revealed that the degradation of lakes is a common issue across all districts in Gandaki Province, posing significant challenges to the conservation and sustainability of these vital water resources. Tinghare Thulo Pokhari in Lamjung District also faced the same fate of being converted into a playground in the past years. In other parts of the Province, an alarming portion of wetlands are being converted into a playground, leading to the degradation of this one precious water body. It was found that although local government authorities are adopting lake conservation and management activities, their efforts are not effective in controlling encroachment and pollution in lake bodies within the Province.

Figure 6. Melpokhari in Parbat has been converted into a bus park.

It is believed that the process of conversion of wetlands into other landforms will continue unless and until concerned departments make effective wetland policies and incorporate conservation within the government framework of land use planning [1]. As unsustainable use of wetlands results in damage to their functions [28], the majority of the lakes are degrading in Gandaki Province. Anthropogenic activities like the disruption of a natural drainage system, diversion of water flow, and unsustainable agricultural practices damage the wetlands [1,29,30]. Therefore, lake conservation is becoming a pressing issue for the local, provincial, and central governments in Nepal.

In the current study, a total number of 117 lakes were identified below 3000 m which is much higher as compared to the similar study conducted by the NLCDC in 2009. A total number of 42 lakes were identified by the NLCDC in Gandaki Province [14]. However, several lakes that were identified by the NLCDC disappeared. The main reason for the disappearance of these lakes may be due to a lack of conservation practices for the degraded lakes [12]. Lakes may disappear if they are not revitalized in a timely manner [1] and this action is underestimated in the case of lakes in Gandaki Province. During the field visits, local residents were asked about the main reasons for lake degradation in the Province, and they provided various explanations. One explanation was that after the promulgation of the Constitution of Nepal in 2015, three tiers of government were formed at different levels, i.e., central, provincial, and local government. After the formation of three tiers of government, budgets were primarily focused on developmental projects, such as constructing roads, playgrounds, and community buildings at the local levels. Although these infrastructures were aimed at providing better livelihoods for the residents, an essential balance between development and environmental conservation to ensure the sustainable management of natural resources like lakes was not considered or undermined. In this regard, the major degradation factor for the wetlands in Gandaki Province may be associated with unplanned developments resulting in rapid deterioration of wetlands [30].

The findings indicated that the expansion of infrastructure (roads and buildings) and intensification of economic activities have caused a great and mostly irreversible loss of lakes, especially the Phewa Lake in Pokhara. These activities have further accelerated the degradation process of the lake by increasing the sediment load, nutrients, and toxic substances in the lake and thus, the majority of the lakes in Gandaki Province are experiencing these conditions. At present, there are no sewage and waste management facilities in Gandaki Province, thus, domestic effluents are directly discharged into the lake without treatment. Consequently, most of the lakes in Gandaki Province are experiencing a series of problems including sedimentation, pollution, encroachment, and invasive species. On the other hand, it is believed that agriculture is the primary reason for wetlands loss [1] which is prominent in Phewa Lake as parts of the lake have been converted into agricultural land.

According to the local residents, migratory birds from Siberia come to Phewa Lake, Khaste Lake, Maidi Lake, Dipang Lake, Neureni Lake, and Begnas Lake in Pokhara Valley during the winter season. However, in recent years, due to the degradation of these lakes, several birds are no longer visiting the lakes. This may be due to the resulting impact of wetland loss as degradation of wetlands causes loss of habitat that ultimately hinders migration [31] and also the population density increased in the periphery of the lakes.

The study also revealed that the majority of the residents do not have proper knowledge awareness and education about the importance of lakes and their conservation. Residents perform unregulated human activities such as illegal waste dumping, encroachments, and illegal construction around the lakes. In addition, many

people have developed their businesses on the bank of the lake to serve the visitors and these small shops do not care at all while discarding their solid waste. Moreover, many big hotels are built on the periphery of Phewa Lake without any checks and balances, and this could damage the lake shortly. Efforts have been made by different organizations including government and non-governmental organizations to conserve Phewa Lake. Not only Phewa Lake and Begnas Lake need special attention, but also many small lakes/ponds need to be protected for ecological restoration. Most of the lakes are heavily infested by invasive species and control solutions for species should be maintained. Furthermore, a strong collaborative effort should be made by the stakeholders to take care of these natural resources. Moreover, it can be concluded that insufficient government policies and enforcement to protect and preserve wetlands as well as inadequate community involvement and participation in lake conservation efforts have led to lake degradation in Gandaki province.

Conclusions and Recommendations

This study is the first comprehensive study of lakes in Gandaki Province which identified detailed addresses, elevations, and locations with coordinates as well as areas during the wet and dry season. This study utilized three platforms, including Google Earth Engine, ArcGIS, and Google Earth, along with images from Sentinel-2 and local knowledge to identify the details of lakes in Gandaki Province. This study identified a total of 290 lakes, including ponds, lakes, and glacier lakes) throughout the Gandaki Province. Throughout the survey, only names and addresses of small, seasonal, and less ecologically and socio-economically significant lakes were collected. 126 lakes were identified as glacier lakes and 47.61% of them were identified in the Mustang District. Likewise, 117 lakes were identified below 3000 m altitude and 48 between the altitude of 3000 m and 4500 m. Surprisingly a higher number of lakes was identified in the mountain districts, i.e., Mustang and Manang. A total number of 73 and 54 lakes were mapped and identified in Mustang and Manang Districts, respectively which is equal to the area of 31,03,924 m^2 and 69,53,575 m^2.

This study can have a significant impact at the policy level by providing valuable data for designing developmental projects and reference purposes. The combination of remote sensing data and local expertise enables the policymakers to identify potential areas for development, taking into account ecological and socio-economic factors. The study indicated that the majority of the lakes are degrading due to anthropogenic activities. The results found that irrational infrastructure development, encroachment, and lack of awareness about wetlands were the primary reasons for the lake degradation. Therefore, this study can be used in the decision-making process by policymakers to make wise plans, ensuring a balanced approach to developmental projects that considers the sustainable balance between the use of natural resources and the environment.

Based on the analysis of satellite images and field surveys, several recommendations have been drawn for the involved stakeholders.

- A detailed study should be conducted to identify the threats to lakes and measures to combat these threats.
- Identified lakes should be protected and managed for the benefit of humans and the ecosystem.
- If it is necessary, then establish protected areas around the lakes to prevent illegal human activities that could degrade the lakes.
- Further study should be focused on invasive species present in the lakes and their sustainable management.
- The potential risks of climate change on the lakes should be studied.
- It is better to conduct the study to include the Tilicho and associated lakes in Ramsar Sites.

Conflict of interest

The authors declare no conflict of interest.

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