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Glacial Lake Bathymetry and Inventory Dataset in the Poiqu Basin, Central Himalayas

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Abstract: The Poiqu Basin is located in the Central Himalayas, with extensive glacial landforms and a complex and changing environment. It is one of the areas with the most glacial lakes and the most frequent glacial lake outburst floods worldwide. In September 2020, the authors conducted an *in-situ* bathymetric survey for five moraine-dammed lakes in this region. Additionally, glacial lake boundaries were extracted using 33 Landsat images from 1988, 2000, 2010 and 2020, as well as maps from 1974. On this basis, the optimal glacial lake volume estimation equation was then used to determine the lakes' volume. The resulting dataset comprises (1) glacial lake bathymetry, (2) a glacial lake inventory from 1974 to 2020 and the boundary data of five glacial lakes in September 2020 and (3) glacial lake volume data. The dataset is archived in 102 data files in three group files in .tif, .shp, and .xls data formats with a total file size of 4.92 MB (compressed into a single 766 KB file).

Keywords: lake bathymetry; glacial lake inventory; glacial lake volume; Poiqu; Central Himalayas

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Dataset Availability Statement:

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2022.07.05.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2022.07.05.V1.

1 Introduction

The Poiqu Basin (Sun Koshi) is a Koshi River tributary in the central Himalaya Region with highly concentrated glacial lakes between China and Nepal and frequent glacial lake outburst floods (GLOFs)[1]. This basin contains important international trade ports

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[2] Qi, M. M., Liu, S. Y., Gao, Y. P., *et al*. Glacial lake bathymetry and inventory dataset in the Poiqu and adjacent area of the central Himalayas [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2022. https://doi.org/10.3974/geodb.2022.07.05.V1. https://cstr.escience.org.cn/CSTR:20146.11.2022.07.05.V1.

(Zhangmu Port) and major highways (China–Nepal Highway) between China and Nepal. Under the influence of global warming, GLOFs have induced a series of secondary disasters in recent decades such as downstream mudslides that have caused extensive damage to Zhangmu Port and the China–Nepal Highway. In addition, the GLOFs that caused heavy casualties in 1981 and the transboundary floods that destroyed hydropower stations in Nepal in 2016 all originated from the Poiqu Basin[2]. The frequent occurrence of GLOFs has seriously affected the lives and property safety of residents in disaster-affected areas, as well as influencing the development of transportation, infrastructure, agriculture and animal husbandry, ice and snow tourism, and even national defence in cold areas[3,4]; thus, GLOFs have become a key factor restricting the sustainable economic and social development of cold areas[5]. Therefore, to improve understanding of GLOF risk, it is essential to develop glacial lake bathymetry and water storage datasets for the Poiqu for disaster avoidance and mitigation purposes.

Glacial lake bathymetry is directly related to GLOFs and is a key indicator of both flood volume and peak discharge[6]. The echo principle can be used to measure the depth of glacial lakes. Lake basin 3D views can be obtained from complete bathymetric point cloud data of the entire lake surface and, based on this method, the precise depth and volume of the glacial lake can be obtained. In recent years, the use of unmanned boats has become the preferred approach for glacial lake depth sounding—such vehicles can carry a variety of data acquisition equipment, and use precise satellite positioning and a range of sensors to achieve integrated underwater measurements[1,7]. However, due to traffic and environmental constraints, it is very difficult to measure the water depth of all glacial lakes. In the currently published literature, there are likely less than 100 measured glacial lake depth data points on the third pole; however, according to the latest glacial lake inventories, there are more than 30,000 glacial lakes in this region[8]. Accurately estimating glacial lake volumes is critical to assessing the potential of GLOFs. Accordingly, this issue has motivated the development of a range of empirical relationships to estimate the link between lake depths, areas and volumes. Qi *et al*. (2022)[1] constructed a new glacial lake volume method based on extensive bathymetry data; compared with other existing formulas, this method significantly reduces the uncertainty of estimation results. Here, we provide bathymetric data for five glacial lakes in the Poiqu Basin. In addition, we provide multi-period glacial lake volume estimation results from 1974 and 2020 based on the new volume estimation method[1], which can provide essential basic data for assessing the GLOF risk in this region.

2 Metadata of the Dataset

The content of the dataset[9] consists of three parts, including: (1) glacial lake bathymetry; (2) glacial lake inventory from 1974 to 2020 and (3) glacial lake volume. A detailed description of the dataset is shown in Table 1.

3 Methods for Data Production Development

3.1 Glacial Lake Bathymetry

In this study, we used an unmanned boat with a single-beam echo sounder (CHCNAV D230) for bathymetric surveying. This equipment combines a dual Global Navigation Satellite System positioning and heading sensor with a stable and reliable hull attitude and an Inertial Measurement Unit sensor. To ensure that the transducer was always immersed in the water and to prevent the transducer and propeller from touching the lake bedrock, the measurement route was located at least 2–5 m from the lake’s shore. Given the harsh survey environment, with risks including frequent falling rocks and floating ice, using an automatic route planning method would have been hazardous; thus, the sensor systems were manually remotely controlled. Accordingly, some inaccessible parts of the lakes near the glacier terminus were not surveyed for Jialong Co, Longmuqie Co and Chamaqudan Co. However, the investigation tracks and sampling points were not arranged polygonally, the investigation tracks nonetheless covered most of the lake and fulfilled the data density requirements for spatial interpolation. The depth-sounding process and bathymetric survey routes for the five glacial lakes are shown in Figure 2.

Table 1 Metadata summary of the Glacial lake bathymetry and inventory dataset in the Poiqu and adjacent area of the central Himalayas

Items	Description
Dataset full name	Glacial lake bathymetry and inventory dataset in the Poiqu and adjacent area of the central Himalayas
Dataset short name	GlacialLakes_Poiqu
Authors	Qi, M. M. GLQ-7037-2022, Institute of International Rivers and Eco-Security, Yunnan University, qmm@mail.ynu.edu.cn Liu, S. Y. AAT-4278-2020, Institute of International Rivers and Eco-Security, Yunnan University, shiyin.liu@ynu.edu.cn Gao, Y. P. GLQ-7281-2022, Institute of International Rivers and Eco-Security, Yunnan University, gyp_geogis@mail.ynu.edu.cn Zhu, Y. ABD-2058-2020, Institute of International Rivers and Eco-Security, Yunnan University, yuzhu@mail.ynu.edu.cn Xie, F. M. ABD-3175-2020, Institute of International Rivers and Eco-Security, Yunnan University, xfm@mail.ynu.edu.cn Wu, K. P. AEB-7274-2022, Institute of International Rivers and Eco-Security, Yunnan University, wukunpeng@ynu.edu.cn Yao, X. J. H-1333-2015, College of Geography and Environmental Science, Northwest Normal University, xj_yao@nwnu.edu.cn
Geographical region	85°40′E–86°20′E, 27°20′N–28°40′N
Time resolution	Sep. 1. 2020–Sep. 14. 2020; 1974–2020
Spatial resolution	4 m
Data files	.shp, .tif, .xls
Data size	6.12 MB
Data files	(1) glacial lake bathymetry; (2) glacial lake inventory; (3) glacial lake volume
Foundations	Ministry of Science and Technology of P. R. China (2019QZKK0208, 2021YFE0116800); National Natural Science Foundation of China (42171129); Yunnan University (YJRC3201702, 2021Z018, 2020Z47); Scientific Research Fund project of Yunnan Education Department (2022Y059)
Computing environment	Python 3.7, MATLAB R2021a
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (in the *Digital Journal of Global Change Data Repository*), and publications (in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new datase[10]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

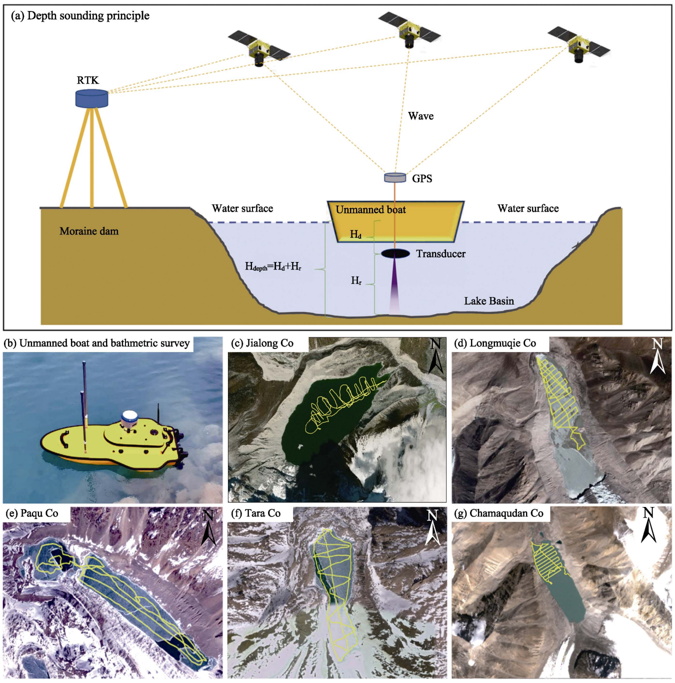

Figure 1 The depth-sounding process

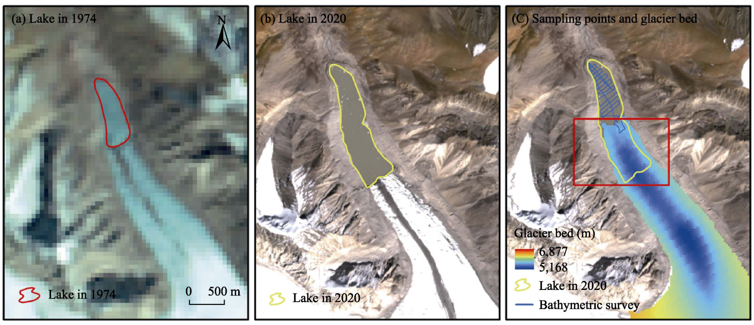

Figure 2 (a) Longmuqie Co and mother glacier in 1974; (b) Longmuqie Co and mother glacier in 2020; (c) Bathymetric surveying route of the Longmuqie Co in 2020 and glacier bed topography in 1974. The base maps are Landsat and Sentinel-2 images

In this study, the incomplete bathymetric data for Jialong Co, Longmuqie Co and Chamaqudan Co were supplemented based on the glacier bed topography. These lakes were classified as proglacial lakes whose expansion is caused by glacier retreat; in this case, we interpreted the underwater terrain of these lakes near the glacier terminus to be equivalent to the basal topography of the glacier tongue before retreating. We first estimated the ice thickness and bed topography of glaciers using the Volume and Topography Automation (VOLTA) tool[11,12]. The glacial bed topography of the 1970s, as modeled by VOLTA, was then used to supplement the areas where no sampling points were available in this study, as shown in Figure 2. The lake volume can then be estimated by interpolating between the limited sampling points and the glacier bed data.

3.2 Glacial Lake Inventory

In this study, a total of 33 Landsat images with a spatial resolution of 30 m from 1988 to

2020, were obtained via the Google Earth Engine platform, and two topographic maps of 1974 were used to extract glacial lake boundaries. The annual lake boundary was then mapped via the satellite imagery-derived normalized difference water index (NDWI) followed by strict visual quality assurance and case-by-case manual inspection.

3.3 Glacial Lake Volume

The volume of glacial lakes can be calculated by the following equations[1]:

If A larger than 0.1 km^2,

$$V = 40.67 \times A^{1.184} - 3.218 \times R \tag{1}$$

If A less than 0.1 km^2,

$$V = 557.4 \times A^{2.455} + 0.2005 \times R \tag{2}$$

$$R = \frac{W}{L} \tag{3}$$

where V was the lake volume (×10^6 km^3), A was the lake area (km^2), and R was the maximum width (m) divided by the maximum length (m) of the glacial lake.

3.4 Uncertainty Analysis

The water volume estimation uncertainty mainly relates to two aspects: the reliability of the bathymetric survey and the glacier bed topography data. In this study, we performed rigorous error analysis for both the bathymetric data and calculation methods. The accuracy of the individual survey points ($\delta_{\Delta ob}$), interpolation error ($\delta_{\Delta in}$) and error in lake area ($\delta_{\Delta ar}$) were quantitatively estimated. Given their low degree of dependence (if any), these errors can be assumed to be independent (Martínespañol *et al*., 2016). The uncertainties in volume estimation ($\delta_{\Delta V}$) can be estimated as:

$$\delta_{\Delta v} = \sqrt{\delta^2{}_{\Delta ob} + \delta^2{}_{\Delta in} + \delta^2{}_{\Delta ar}} \tag{4}$$

The $\delta_{\Delta ob}$ term mainly results from measurement errors (such as the actual sound velocity and motor rotation speed) and external factors (such as water temperature differences, bubbles in the water, the rocking of the boat, etc.)[14]. In this study, the echo sounder data accuracy is assumed to be 0.01 m ± 0.1% of the measured depth. Furthermore, given a ±2 °C temperature uncertainty, the corresponding depth error is around ±0.7% based on similar previous studies[14]. Additionally, we assumed a further 0.1% depth uncertainty due to the presence of nearshore rock outcrops[14] and measurement errors, thus making our overall uncertainty for bathymetric analysis ±1.9% of the water depth. The value of $\delta_{\Delta in}$ depends primarily on the representativeness of the observed points. Here, we applied the cross-validation technique to assess the spatial interpolation of the bathymetric data; in this approach, 80% of the observation points were used for interpolation and the remaining 20% was used for testing, with the average deviation between the two values then calculated. The value of $\delta_{\Delta ar}$ can be calculated using the following formula[15]:

$$\delta_{\Delta ar} = \frac{P}{G} \times \frac{G^2}{2} \times 0.6872 \tag{5}$$

where P (m) was the perimeter of the lake, and G (m) was the spatial resolution of the images used.

4 Data Results and Validation

4.1 Dataset Composition

The dataset includes (1) glacial lake bathymetry; (2) glacial lake inventory from 1974 to

2020, and the boundary data of 5 glacial lakes in September 2020; and (3) glacial lake volume. The dataset is archived in 102 data files in three group files in .tif, .shp, and .xls data formats. The detailed description of the dataset is shown in Table 2 and the meanings of each field in the glacial lake inventory are shown in Table 3.

Table 2 Descriptions of the dataset files

Data Name	Data Properties				Data Size
	File Name	Time Range	Resolution	Descriptions	
Glacial lake bathymetry.tif	Lake bathymetry_Jialong Co.tif Lake bathymetry_Tara Co.tif Lake bathymetry_Paqu Co.tif Lake bathymetry_Longmuqie Co.tif Lake bathymetry_Chmaqudan Co.tif	Sep. 1. 2020–Sep. 14. 2020	4 m	Lake bathymetry	3.5 MB
Glacial lake inventory.shp	Lake_boundary_JialongCo.shp Lake_boundary_TaraCo.shp Lake_boundary_PaquCo.shp Lake_boundary_LongmuqieCo.shp Lake_boundary_ChamaqudanCo.shp	Sep.2020	10 m	Lake bathymetry	1.34 MB
	Glacial lake_1974.shp	1974	9 m	Lake inventory	
	Glacial lake_1988.shp	1988	30 m		
	Glacial lake_2000.shp	2000			
	Glacial lake_2010.shp	2010			
	Glacial lake_2020.shp	2020			
Glacial lake volume.xls	Glacial lake volume.xls	1974–2020	/	Lake volume	84 KB

Table 3 Descriptions of each field name in the glacial lake inventory

Field name	GLAKE_ID	GL_Type	GL_Elev	GL_Area
Mean	Lake number	Lake type	Lake elevation (m)	Lake area
Field name	GL_Peri	GL_A_Error	GL_Long	GL_Lati
Mean	Lake perimeter (m)	Area error	Longitude	Latitude
Field name	Width	Length	Ratio	
Mean	Maximum width (m)	Maximum length (m)	The ratio of width to length	

4.2 Data Results

Table 4 shows the bathymetric results for the five glacial lakes. Jialong Co and Chawuqudan Co had the maximum water depths of 136 m and 74 m, whereas the other three glacial lakes were all less than 40 m in depth. A 3D view of the lakes' basin morphology was created based on the bathymetric data (Figure 3). Not all glacial lake bottoms are as flat as those of Jialong Co and Chawuqudan Co. For example, the Paqu Co and Tara Co lakes exhibit a basin bottom morphology with their deepest regions near the moraine dam and glacier terminus. We suggest that this morphology is the result of the formation and coalescence of two small glacial lakes, an interpretation that is strongly supported by earlier remote sensing images.

In 2020, 103 glacial lakes with a total area of 20.35 ± 1.51 km^2 were identified above 4,200 m elevation in the Poiqu Basin (Figure 4a). Most of the glacial lakes were less than 0.1 km^2 in size, and the ice-contacted lakes had the largest average area (0.61 ± 0.02 km^2). A total of 24 lakes were newly formed in the Poiqu Basin between 1974 and 2020, and the total lake area increased by 97%. This expansion was mainly contributed by the moraine-dammed lakes directly connected to the glacier. Using the formulas in section 3.3, the total lake volume in the Poiqu Basin in 2020 was estimated as 831±30.1 million m^3. The corresponding estimated lake volumes in previous decades were 764±23.3 million m^3 in 2010, 574±21.5 million m^3 in 2000, 448±14.5 million m^3 in 1988 and 335±7.8 million m^3 in 1974. Overall, the total glacial lake volume increased by 148% from 1974 to 2020 (Figure 4b).

Table 4 The results of bathymetry for five glacial lakes in 2020

Attributes	Jialong Co	Longmuqie Co*	Paqu Co	Tara Co	Chamaqudan Co*
Position (°)	85.85E, 28.21N	86.23E, 28.35N	86.16E, 28.30N	86.13E, 28.29N	86.19E, 28.33N
Date	2020.09.04	2020.09.01	2020.09.13	2020.09.14	2020.09.03
Area (km^2)	0.58±0.03	0.59±0.04	0.58±0.05	0.24±0.02	0.54±0.03
Width $_{max}$ (m)	608	508	318	342	443
Length $_{max}$ (m)	1,433	1,770	2,162	1,054	1,482
Depth $_{mean}$ (m)	62	14	16	12	36
Depth $_{max}$ (m)	135.80±2.58	30.70±0.58	36.30±0.68	24.20±0.45	73.68±1.40
Volume (10^6 m^3)	37.53±0.03	8.28±0.04	8.80±0.05	2.64±0.02	19.60±0.03

(* indicates sampling sites not completely covering the whole lake surface)

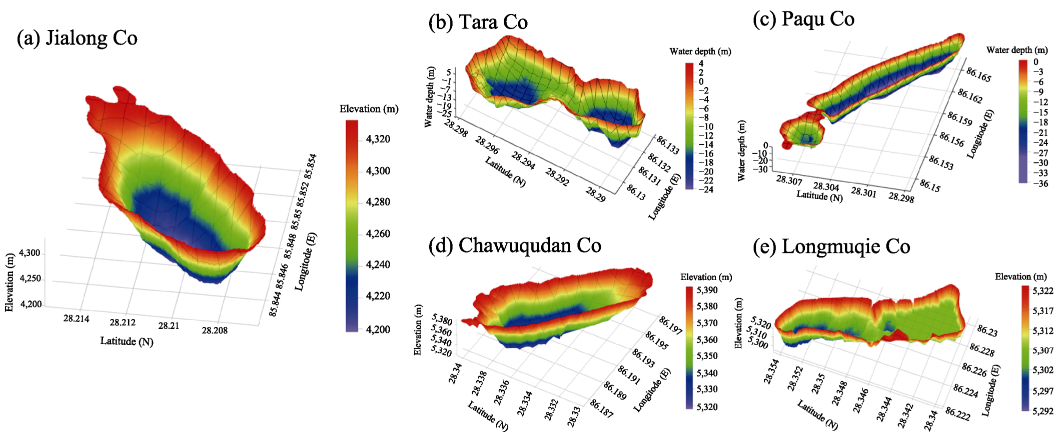

Figure 3 The 3D view of lake basin morphology based on the bathymetric data

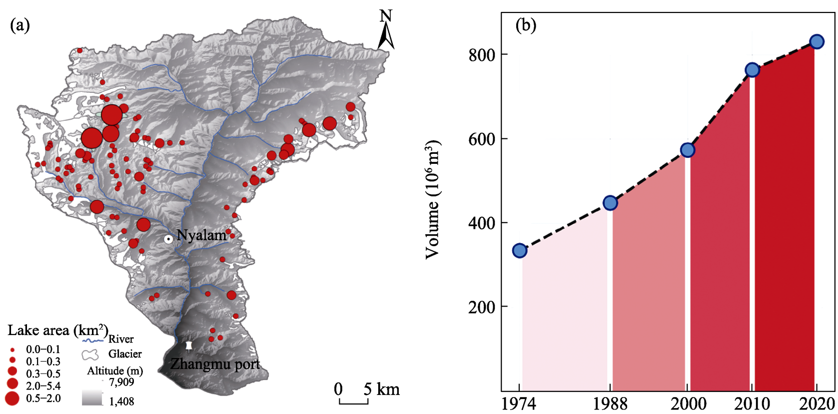

Figure 4 Glacial lake inventory and volume change from 1974 and 2020.

4.3 Data Validation

Table 5 shows the lake volume error based on the bathymetric survey. Overall, the uncertainties in volume estimation ($\delta_{\Delta V}$) based on the bathymetric data were all below 50 m^3 and the mean error was 34 m^3. By considering the three types of uncertainties, a mean uncertainty of 0.4% was obtained based on the bathymetric data, which was deemed accurately reflect the lake volume. In practical applications, since the error is small and unlikely to affect the results, it can be ignored.

Table 5 The error of lake volume based on the bathymetry

Name	$\delta_{\Delta ob}$ (m)	$\delta_{\Delta in}$ (m)	$\delta_{\Delta ar}$ (km^2)	$\delta_{\Delta V}$ ($\times 10^6$ m^3)
Jialong Co	±2.58	1.5	±0.03	±0.03
Chamaqudan Co	±1.40	0.69	±0.03	±0.03
Longmuqie Co	±0.58	0.51	±0.04	±0.04
Paqu Co	±0.68	1.00	±0.05	±0.05
Tare Co	±0.45	1.01	±0.02	±0.02

In this study, we selected Jialong Co, with complete bathymetric data[16], as an example to verify the glacier bed data availability. Figure 5 shows a significant difference between the bathymetric map (Figure 5a) and the simulated glacier bed topography (Figure 5b); however, after the corrections were applied, the water depth changes between both datasets indicate some similarities (Figure 5a, c and d). The estimated lake volume was 37,535,223 m^3 before correction and 38,999,117 m^3 after correction, i.e. a relative error of +3.9%, suggesting that our calculation provides a reasonable approximate estimate. In addition, this outcome also demonstrates that using glacier bed topography data to estimate lake volumes was a valid approach where bathymetric data are not available.

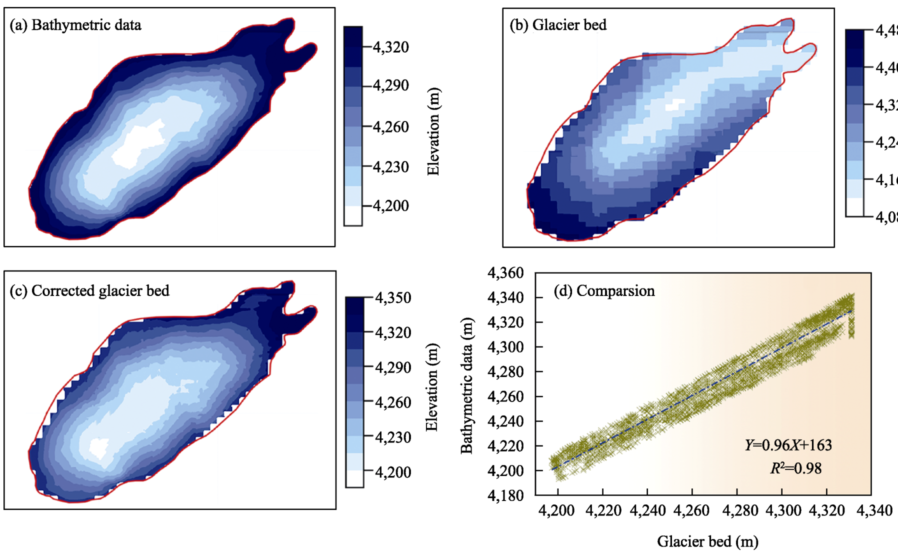

Figure 5 Comparison between bathymetric data and simulated glacier bed topography

5 Discussion and Summary

In this dataset, the basal topography of five glacial lakes was constructed based on an *in-situ* bathymetric survey combined with simulated glacier bed data. In addition, we mapped a glacial lake inventory from 1974 and 2020 in the Poiqu Basin. Finally, the volumes of all the lakes were estimated using the optimized water volume estimation formula.

Due to the harsh field survey environment of the glacial lakes, the bathymetric data of the three lakes in this dataset were incomplete. Therefore, this study used simulated glacier bed topography to supplement the missing data and systematically evaluate the feasibility and accuracy of this method. The final data after secondary development was highly credible enough to be used as important input data in the assessment of glacial lake outburst flood disasters.

This dataset provides bathymetric data for five glacial lakes. The lake inventory and volume results can systematically and comprehensively reveal changes in both the area and water storage of the glacial lakes from 1974 to 2020. In summary, the compilation of basic data provided in this dataset will help to assist in assessing glacial lake outburst risks and disasters in this area and provide an important reference for the sustainable development of alpine regions.

Author Contributions

Liu, S. Y. and Qi, M. M. designed the algorithms and research framework of the dataset. Gao, Y. P., Zhu, Y., Xie, F. M., Wu, K. P. and Yao, X. J. performed the bathymetric survey. Qi, M. M. wrote the data paper and Liu, S. Y. reviewed the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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