

# Three Glacial Lakes Change Data at the Foot of Mt. Everest, Himalaya

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**Abstract:** The Himalaya is *the most extensively glacierized region in the world, other than the polar regions*. It is also a sensitive region to climate change. Changes of glacial regime become one of indicators of climate change. The three glacial lakes, which are Rongbuk Lake (China), Karda Lake (China), and Imja Lake (Nepal), at the foot of Mt. Everest were time-series analyzed. The dataset of the glacial lakes were produced in Arc/GIS (.shp) and Google Earth (.kmz) formats using the remote sensing imageries integrated with DEM data. The attribute of dataset includes period, name, area, sensor, and location. The result showed that Rongbuk Lake did not exist in 1976 until its area reached to 580,239 m<sup>2</sup> by 2014; the area of Karda Lake increased from 389,317 m<sup>2</sup> in 1976 to 809,388 m<sup>2</sup> in 2014; and the area of Imja Lake expanded from 284,411 m<sup>2</sup> in 1976 to 1,260,218 m<sup>2</sup> in 2014.

**Keywords:** glacial lake data; Rongbuk Lake; Karda Lake; Imja lake; Mt. Everest

## 1 Introduction

Known as the third polar of the world in climate change, the Himalayas play an important role in the regional climate dynamics. Since the second half of the 20th century, numerous glaciers in the Himalayan region have retreated due to climate changes<sup>[1-6]</sup>. The glaciers retreating directly influenced the glacial lake formation and expansion. The changes of glacial lakes could be one of indicators of climate changes. Thus, time-series monitoring the changes of glacial lakes would efficiently illustrate the regional climate changes.

However, because of large spatial scale, remoteness<sup>[7]</sup>, high altitude, and atrocious weather<sup>[8]</sup> in the Himalayan region, physically to access to the region and measuring the

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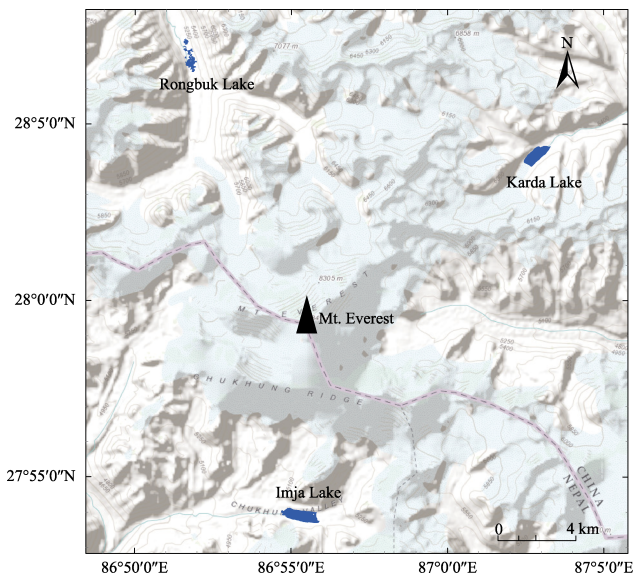
**Received:** 08-09-2014; **Accepted:** 20-11-2014; **Published:** 25-03-2017

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**Article Citation:** Chen, W. B., Fukui, H., Doko, T., *et al.*. Three glacial lakes change data at the foot of Mt. Everest, Himalaya [J]. *Journal of Global Change Data & Discovery*, 2017, 1(1): 86-92. DOI:10.3974/geodp.2017.01.13.

**Dataset Citation:** Chen, W. B., Fukui, H., Doko, T., *et al.*. Three Glacial lakes (Rongbuk, Karda, Imja) Change data at the Foot of Mt. Everest, Himalaya [DB], *Global Change Research Data Publishing & Repository*, DOI:10.3974/geodb.2014.02.05.V1.

changes are the primary challenges for conducting scientific researches. Therefore, remote sensing technique is an effective method to accomplish those arduous tasks. The authors developed the time-series dataset of three glacial lakes at the foot of Mt. Everest using a conventional method based on field survey and remote sensing (see Figure 1). Because of the different periods, the data of the Landsat MSS in 1976, the Landsat TM in 1992, the Landsat ETM+ in 2000, the ASTER in 2008, the DigitalGlobe in 2014, and the ASTER GDEM were used for this study. This



**Figure 1** Location of the three glacial lakes

dataset (Three Glacial lakes (Rongbuk, Karda, Imja) Change data at the Foot of Mt. Everest, Himalaya. “GL\_RKI”) could be used as the reference to the research on global change in the Himalayan region. At the same time, the dataset would be valuable as a historic dataset for long-term study of regional environment changes.

These dataset<sup>[9]</sup> are fundamental for the two published research papers by Chen, W., Doko, T., Fukui, H., et al., Changes in Imja Lake and Karda Lake in the Everest Region of Himalaya. *Natural Resources*, 2013, 4: 449-455<sup>[10]</sup>, and Chen, W., Doko, T., Liu, C., et al., Changes in Rongbuk lake and Imja lake in the Everest region of Himalaya, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XL-2, 2014, 259-266<sup>[11]</sup>.

## 2 Metadata for the GL\_RKI dataset

The GL\_RKI dataset<sup>[9]</sup> is summarized in Table 1. It includes the dataset full name, short name, authors, geographical centroid coordinate, year of the dataset, data format, dataset and data files, data publisher, data access and services platform, and data sharing policy.

## 3 Methodology for the dataset development

The methodology to produce the dataset was developed and illustrated in the two published papers<sup>[11-12]</sup>. Here, we summarize the main methodology for the dataset development from those published papers.

### 3.1 Dataset development

To develop the dataset included satellite imagery selection and processing, modeling the glacial lakes identification, creating the spatial database, editing the attribute database, field survey both on the southern and northern slopes of Mt. Everest, and data comparative analysis in different periods, etc. Figure 2 presents the flowchart of the glacial lake dataset development.

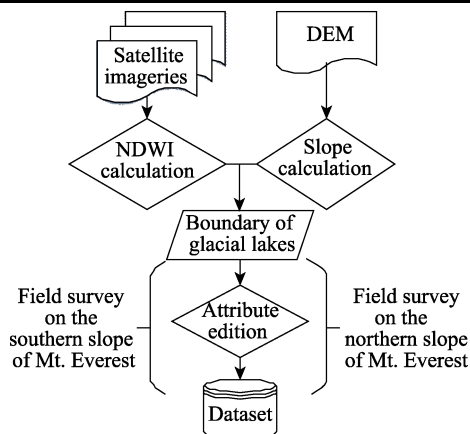
**Table 1** Metadata summary of the GL\_RKI dataset

Items	Description
Dataset full name	Three glacial lakes (Rongbuk, Karda, Imja) change data at the foot of Mt. Everest, Himalaya
Dataset short name	GL_RKI
Authors	Chen, W. B. L-5715-2016, Keio Research Institute at SFC; Keio University, chenwb3@gmail.com Fukui H. D-3797-2017, Chubu Institute for Advanced Studies, fukui@isc.chubu.ac.jp Doko T. L-6494-2016, Keio Research Institute at SFC; Keio University, dokochan@sfc.keio.ac.jp Liu, C. L-3684-2016, Institute of Geographic Sciences and Natural Resources Research, CAS, lchuang@igsrr.ac.cn Feng, Q. D-6727-2017, Institute of Remote Sensing and Digital Earth, CAS, fengqiang@radi.ac.cn Gou, P. L-6876-2016, Institute of Tibetan Plateau Research, CAS, goupeng@itpcas.ac.cn Shi, R. X. L-4389-2016, Institute of Geographic Sciences and Natural Resources Research, CAS, shirx@igsrr.ac.cn
Geographical centroid coordinate	Rongbuk Lake: 86°51'47"E, 28°6'48"N Karda Lake: 87°2'51"E, 28°4'7"N Imja Lake: 86°55'21"E, 27°53'54"N
Year	1976, 1992, 2000, 2008, 2014
Data format and size	.shp; .kmz; .rar; data size: 728.4KB, data compressed size: 444 KB
Data files	The dataset consists of two files: The dataset of three glacial lakes (Rongbuk, Karda, Imja) changes. It consists of three compressed files: Rongbuk.rar, 302KB; Karda.rar, 52.7 KB; Imja.rar, 89.4 KB. Each compressed file contains ARC/GIS (.shp) format and Google Earth (.kmz) format. Two filed survey documentary files: 1) field work in Himalaya, Nepal (Chen_Imja_2008.pdf); 2) naming and forming of Rongbuk Lake (Liu_Rongbuk_2012.pdf).
Data publisher	Global Change Research Data Publishing & Repository, <a href="http://www.geodoi.ac.cn">http://www.geodoi.ac.cn</a>
Address	No. 11 A, Datun Road, Chaoyang District, Beijing, 100101, China
Data sharing policy	<b>Data</b> from the Global Change Research Data Publishing & Repository includes metadata, datasets (data products), and publications (in this case, in the <i>Journal of Global Change Data &amp; Discovery</i> ). <b>Data</b> sharing policy includes: (1) <b>Data</b> are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use <b>Data</b> subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute <b>Data</b> subject to written permission from the GCdataPR Editorial Office and the issuance of a <b>Data</b> redistribution license, and; (4) If <b>Data</b> are used to compile new datasets, the 'ten per cent principal' should be followed such that <b>Data</b> records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset <sup>[12]</sup> .

## 3.2 Data sources and processing

### 3.2.1 Data sources

Satellite imageries with minimal obstruction by clouds and snow coverage were used in this study (see Table 2). These imageries were the Landsat MSS in December 1976 with a spatial resolution of 60 m, the Landsat TM in November 1992 with a spatial resolution of 30 m, the Landsat ETM+ in October 2000 with a spatial resolution of 30 m, the ASTER in January 2008 with a spatial resolution of 15 m, and the Digital



**Figure 2** Flowchart of glacial lake dataset development

Globe in 2014 with a spatial resolution of 1 m. For the terrain analysis, ASTER Global DEM data were downloaded from the ASTER GDEM website.

**Table 2** Summary of satellite imageries

Sensor	Date	Path	Row	Resolution (m)	No. of bands
MSS	Dec.19, 1976	150	41	60	4
TM	Nov.17, 1992	140	41	30	7
ETM+	Oct.30, 2000	140	40/41	30	8
ASTER	Jan.6, 2008	140	115/116	15	3 (1-3)
				30	6 (4-9)
				90	5 (10-14)
Digital Globe (Google Earth)	Apr. 8, 2014 Rongbuk Lake May 18, 2014 Karda Lake Dec. 18, 2014 Imja Lake	–	–	1	
ASTER GDEM	2009	–	–	30	1

Note: original MSS pixel size was  $79 \times 57$  meters; production systems resample the data to 60 meters.

### 3.2.2 Pre-processing of time series remote sensing data

Since the satellite imageries merely present the digital number (DN), it was needed to convert to the top of atmosphere (TOA) reflectance in order to calculate the NDWI which was conducted using reflectance data. Different time period data used different resolution.

## 3.3 Modeling the glacial lakes identification

### 3.3.1 NDWI calculation

The NDWI (normalized difference water index) was calculated to allow identification of water bodies from the satellite imageries. NDWI is defined as the difference of reflectance observed in the green band and the NIR band divided by the sum of the two reflectance values<sup>[13]</sup>. The equation was presented below:

$$NDWI = \frac{\rho_{Green} - \rho_{NIR}}{\rho_{Green} + \rho_{NIR}}$$

where  $\rho_{Green}$  and  $\rho_{NIR}$  are reflectance in green and near infrared bands, respectively.

### 3.3.2 Slope calculation

A model of the terrain was developed from a digital elevation model (DEM) derived from the ASTER GDEM data. Based on our previous field work in the Himalaya and Tibet, China, it was recognized that the angle of inclination that allowed drainage of melt water had gradients greater than  $10^\circ$ . Study in Bhutan<sup>[14]</sup> and study in China and Nepal<sup>[15]</sup> reported similar observations. Thus, a threshold value of a ground angle of  $10^\circ$  (maximum) was adopted in this study. In the end, the boundaries of the glacial lakes were identified by integrating the NDWI and angle of inclination criteria. The satellite imagery analysis and data processing were performed using ENVI<sup>®</sup> 4.7, to convert from raster data of glacial lakes to vector data of glacial lakes and to edit attribute database were performed using ArcMAP<sup>®</sup> 10.

## 3.4 Field work on Imja Lake and Rongbuk Lake

During April and May of 2008, there was a fieldwork on Imja Lake which was located on the southern slope of Mt. Everest, Nepal. The leader was Prof. Fukui financed by Ministry

of Education, Culture, Sports, Science & Technology (MEXT), Japan. From May to June in 2012, there was a fieldwork on Rongbuk Lake, which was located on the northern slope of Mt. Everest, China, led by Prof. Liu and financed by Chinese Academy Science (CAS) and Asia-Pacific Network for Global Change Research (APN). The purpose of the fieldworks were to validate the modeling of glacial lakes development, and collect geographic information associated with glacial lakes development. These geographic information could be useful for the research on glacial lakes expansion and global climate change responses in the Himalayan region.



**Figure 3** Imja Lake taken on May 1st, 2008  
(photographer: CHEN Wenbo)



**Figure 4** Rongbuk Lake taken on Jun. 1st, 2012  
(photographer: CHEN Wenbo)

## 4 Results

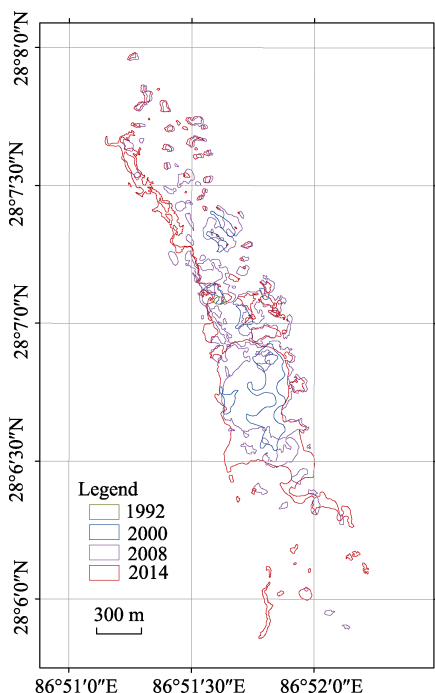
The results were embodied in three data files. They are: 1) data of Rongbuk Lake from 1992 to 2014 (Rongbuk.rar); 2) data of Karda Lake from 1976 to 2014 (Karda.rar); and 3) data of Imja Lake from 1976 to 2014 (Imja.rar). There are two type data formats, which are Arc/GIS (.shp) and Google Earth (.kmz), in the compressed files.

The result showed that Rongbuk Lake did not exist in 1976 until its area reached to 580,239 m<sup>2</sup> by 2014; the area of Karda Lake increased from 389,317 m<sup>2</sup> in 1976 to 809,388 m<sup>2</sup> in 2014; and the area of Imja Lake expanded from 284,411 m<sup>2</sup> in 1976 to 1,260,218 m<sup>2</sup> in 2014. The surface areas among the three glacial lakes in 1976, 1992, 2000, 2008, and 2014 were summarized in Table 3. The result analysis will be explained in another file.

Map comparison showed the changes of the three glacial lakes (see Figure 5, Figure 6, and Figure 7).

**Table 3** Time-series changes among the three glacial lakes

Year	Area (m <sup>2</sup> )		
	Rongbuk Lake (China)	Karda Lake (China)	Imja Lake (Nepal)
1976	NA	389,317	284,411
1992	3,051	550,732	567,360
2000	124,576	623,236	724,365
2008	509,381	684,966	894,881
2014	580,239	809,388	1,260,218



**Figure 5** Rongbuk Lake changes (Rongbuk Lake was born in 1992)

### Author contributions

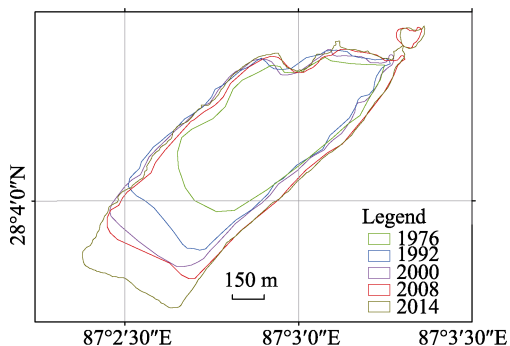
Fukui, H. designed and organized the field work in Imujia Lake, Nepal in summer of 2008. Chen, W. B. and Fukui, H. participate the field work in Imujia Lake in 2008. Liu, C. designed and organized the field work in Rongbuk Lake, China in May – June 2012. Liu, C., Chen, W. B., Feng, Q. and Gou, P. participated the field work in Rongbuk Lake of China in 2012. Doko, T. participated the field work in Xining-Lhasa-Namtso of the Tibet Plateau. Chen, W. B. completed the data pre-processing and analysis, Doko, T., Shi, R. X., Feng, Q. and Gong, P. participated the data analysis. Feng, Q. and Gong, P. made the detail arrangement for the field work in Rongbuk Lake in 2012. Chen, W. B. drafted the data paper, Liu, C., Fukui, H. and Doko, T. checked the dataset and reviewed the paper.

### Acknowledgement

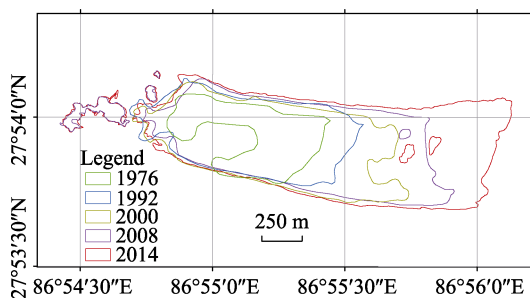
The authors appreciate that the MEXT financed the fieldwork in 2008 on Imja Lake. Nagoya University, Chubu University, AIT, and ICIMOD joined the fieldwork. The authors would like to thank the supports from Institute of Geographic Sciences and Natural Resources Research, CAS and Qumulangma station of Institute of Tibetan Plateau Research, CAS, and financed by APN and Prof. LI Guoqing from Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences organized the fieldwork on Xining, Lhasa and Namtso. Prof. Zhou, X. et al. participated the fieldwork in 2012.

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**Figure 6** Karda Lake changes



**Figure 7** Imja Lake changes

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