Glacial Lake Outburst Floods in the Karakoram Mountains, P.R. China

Early Warning and Climate Change Monitoring

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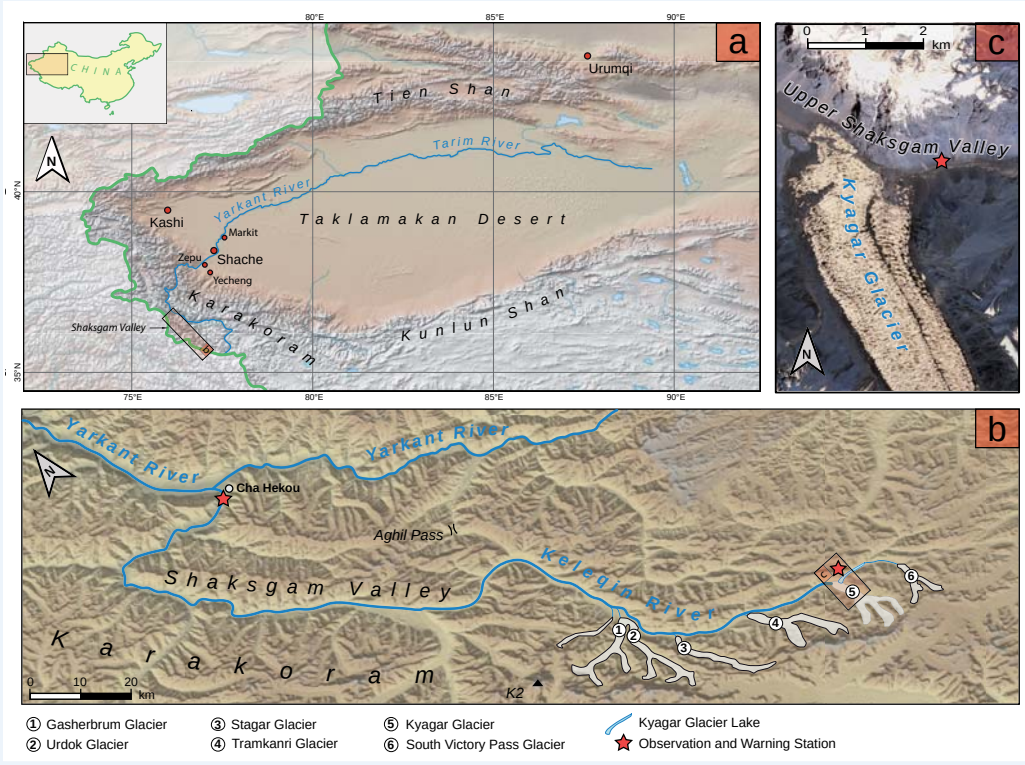
INTRODUCTION

In the last decade, 5 glacial lake outburst floods (GLOF) damaged infrastructure and claimed human lives along Yarkant River, Xinjiang, P.R. China. The spontaneous floods are a threat for over 1 million inhabitants in the floodplains of Yarkant River and are causing an annual monetary loss of approx. 10 million Euro.

Yarkant River drains the Karakoram Mountains with a catchment area of 50'248 km² and ranks as number one in terms of flood frequency and damages in Xinjiang. The glacial outburst floods with peak discharges of up to 6'000 m³/s originate from a remote ice-dammed glacier lake at 4'750 m a.s.l. in the Shaksgam Valley, approx. 560 km upstream of the floodplains. There, the Kyagar Glacier snout blocks the riverbed. Hence, a lake with a volume over 200 million m³ has built-up periodically in the past.



Situation of Yarkant River in the Tarim Basin a, Shaksgam Valley b and Kyagar Glacier c

GOALS AND ACTIVITIES

The activities aim to improve the management of the high flood risks of Yarkant River, predominantly caused by glacial lake outburst floods and the long-term monitoring of the respective glaciers and outburst hazards. The actions are structured into three phases:

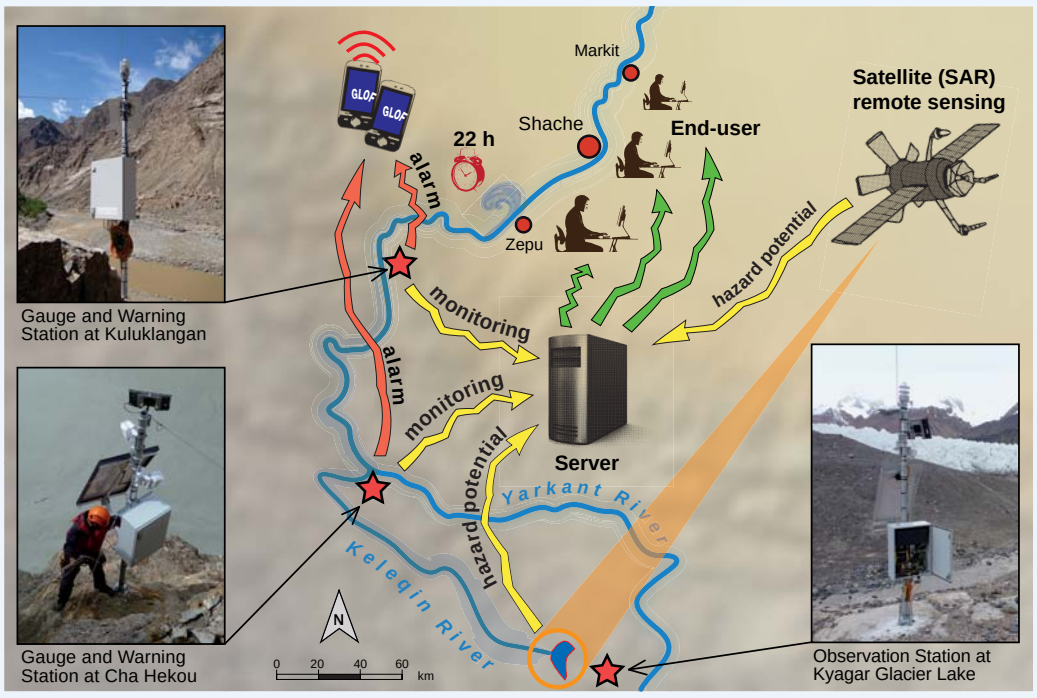
1) Establishment of an **Early Warning System** (EWS) for GLOFs

2) **Risk management** for the potential flood areas

3) **Climate Change monitoring** and analysis

CONCEPT OF EARLY WARNING AND MONITORING

Because the hazardous glacier lake is situated in a very remote area, the methods focus on satellite remote sensing and automatic terrestrial observation and warning stations.



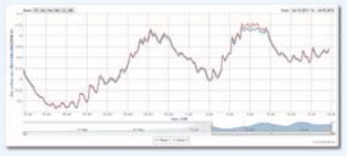
TERRESTRIAL OBSERVATION STATION

A terrestrial solar powered gauge and warning station was installed along Keleqin River, approx. 200 km downstream of Kyagar Glacier Lake. Radar sensors are continuously logging the water level and images of Keleqin River are taken. All data is automatically transmitted by satellite communication to the decision-makers.

In case of a detected GLOF, an automatically generated alarm-signal will immediately be sent to mobile phones of the Chinese authorities. Thus, emergency actions can be initiated. After the alarm-signal has been transmitted from the gauge and warning station, approx. 22 hours remain before the flood will reach the settlement area in the floodplains.

Observation and Warning Station

Water level

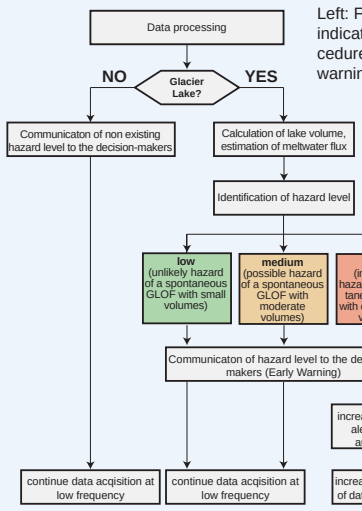


Daily system check

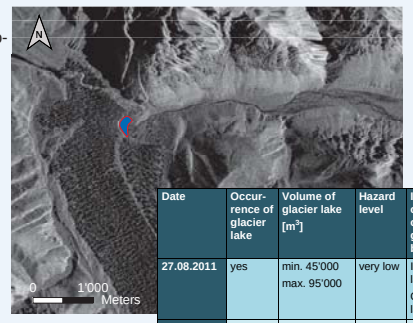
Automatic observation and climate monitoring station at Kyagar Glacier Lake.

SATELLITE REMOTE SENSING

The hazard level for a spontaneous GLOF is preliminarily assessed through the lake volume. Based on periodically tasked very high resolution Synthetic Aperture Radar (SAR) data, the existence and extent of a glacial lake can be clearly identified. Combining the shoreline with the digital elevation model (DEM), the volume can be calculated. In 2011 and 2012, the evolution of the glacier lake was observed within a time interval of up to 11 days. The current hazard level was then analyzed and transmitted to the Chinese decision-makers.



Left: Flow-chart indicates the procedure for early warning.

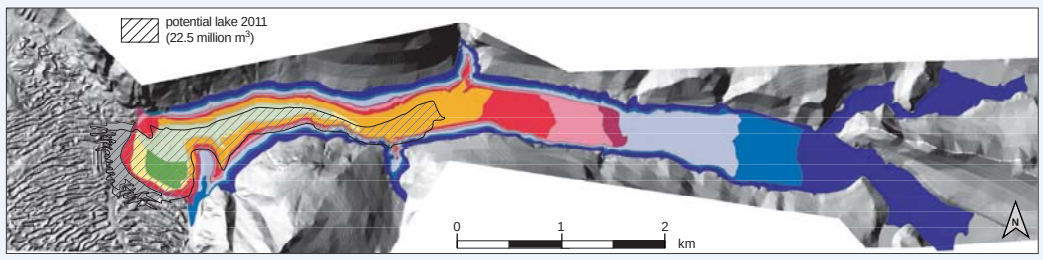


Identification of the glacial lake and its hazard potential based on satellite data (TerraSAR-X, July 25th, 2011). The glacial lake is marked with blue colour.

Date	Occurrence of glacier lake	Volume of glacier lake [m³]	Hazard level	In – and outflow of the glacier basin	Remarks
27.08.2011	yes	min. 45'000 max. 95'000	very low	Inflow: large Outflow: large	Lake surface is similar to August 5th 2011 Data: SAR backscatter (Terrasar-X)
07.09.2011	yes	min. 45'000 max. 95'000	very low	Inflow: moderate Outflow: moderate	Lake surface is similar to August 27th 2011 Data: SAR backscatter (Terrasar-X)
18.09.2011	yes	approx. 50'000	very low	Inflow: minor Outflow: moderate	Lake surface is approx. 50% smaller than 07.09.2011 Data: SAR backscatter (Terrasar-X)
21.10.2011	no	-	-	Inflow: dry Outflow: minor	Lake disappeared Data: SAR backscatter (Terrasar-X)

VOLUMES OF HISTORIC AND PRESENT GLACIAL LAKES

The volumes of impounded lake water are crucial for the floods in the lower reaches. Using optical satellite images, extents and volumes of former glacial lakes could be calculated from 1976 – 2009. At present, the maximum potential lake volume is estimated to be approx. 22 million m³. Comparing this value with historic records makes clear, that the volume of GLOFs from Kyagar Lake has decreased over time.



Observed glacial lakes based on satellite data from 1976 – 2009. Because the satellite images are not consistent with the timing of outburst events, the actual maximum volume cannot be calculated. The present potential lake volume is approx. 22 million m³ (hatched surface).

Date of observation	Volume [million m³]	Elevation of shore line [m a.s.l.]	Area [km²]
historic Max.	234	4952	5
13.06.1976	3.4	4745	0.3
14.07.1977	42.4	4789	1.7
07.06.1979	18.1	4770	1.0
15.11.1998	121.4	4919	3.4
09.08.2002	94.8	4910	2.8
15.09.2004	63.4	4792	2.1
27.04.2005	4.1	4741	0.3
03.07.2006	9.5	4749	0.5
27.07.2009	44.8	4781	1.6

CONCLUSIONS AND OUTLOOK

The implemented early warning system is fully operational. Both water level fluctuations and EWS functionality are continuously monitored.

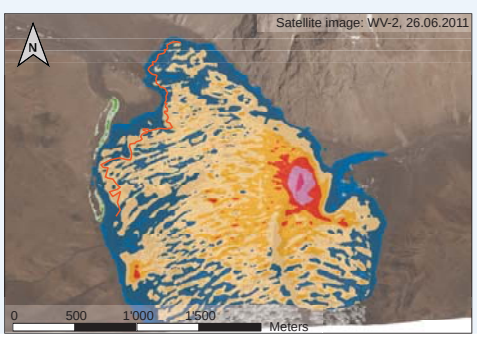
Because the potential volume of Kyagar Glacier Lake strongly depends on the thickness of its blocking ice-dam, mass-balance calculations in terms of accelerated melting of Kyagar Glacier are crucial. A surface lowering rate of > 5 m a^{-1} was observed at the glacier tongue based on the comparison of digital elevation models between 2002 and 2011. Such calculations are needed to define future hazard scenarios.

Surface lowering 2002 till 2011

- +20 till + 40 m
- +10 till +2 0m
- - 10 till -20 m
- - 20 till -40 m
- - 40 till -60 m
- - 60 till -80 m
- - 80 till -100 m
- - 100 till -120 m
- - 120 till -140 m
- Margin of visible glacier-ice 2011

2002 - 2011: surface lowering rates > 5 m / year

Calculations based on detailed DEMs indicate an average ice thickness loss at the glacier tongue of 47.5 m between 2002 and 2011.



ACKNOWLEDGMENTS

Based on a Memorandum of Understanding between the Ministry of Water Resources of P.R. China (MWRC) and the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC), it was decided to initiate a Sino-Swiss project to improve risk assessment and mitigation with respect to climate change, combining various technologies and know-how. The project is supported by a cooperation between the Swiss Agency for Development and Cooperation (SDC) and the Federal Office for the Environment (FOEN). On the Chinese side, the project is supported by local authorities, such as the Xinjiang Department of Water Resources and the Xinjiang Kashgar Hydrographic & Water Resources Survey Bureau. The Sino-Swiss project is based on a strong collaboration and experience exchange between experts from both countries which aim to implement practicable, cost-efficient and sustainable measures.