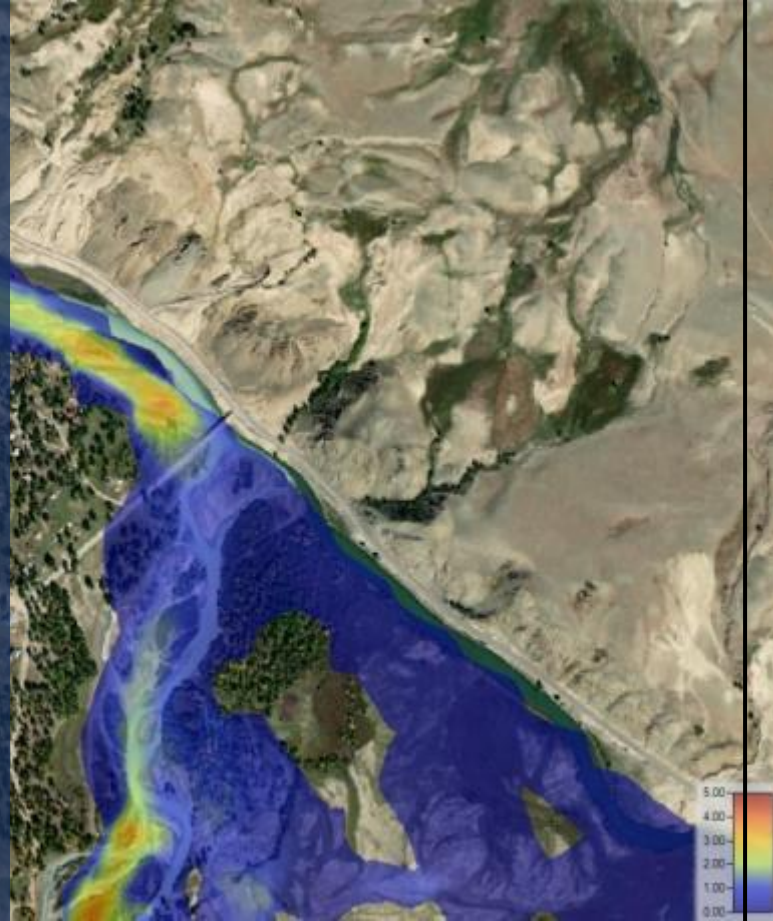


Hazard Assessment of  
Glacial Lake Outburst  
Floods in Russian,  
Mongolian, and Chinese  
Altai

500 m



CRRP2021-03MY-Borodavko

2023



Project Reference Number: CRRP2021-03MY-Borodavko

Project Duration: 2 years

Funding Awarded: USD 70,000

Grant DOI: <https://doi.org/10.30852/p.18092>

Date of Publication: Oct 31, 2023

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Recommended Citation:

Borodavko, P., Vershinin, D., Lkhagvasuren, Ch., Chun, Xi. (2023) Hazard Assessment of Glacial Lake Outburst Floods in Russian, Mongolian, and Chinese Altai. Project Final Report. Asia-Pacific Network for Global Change Research.



Asia-Pacific Network for Global Change Research (APN)

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## **1. Summary**

The modern process of glacial retreat in the Altai is resulting in the formation of glacial lakes. The number of these lakes is increasing as glaciers continue to retreat. GIS analysis of remote sensing data spanning a period of fifty years indicates that certain glacial lakes have significantly increased in size. This is a clear indicator of their instability and susceptibility to sudden ruptures. Glacial lake outbursts can result in catastrophic floods and debris flows that have the potential to cause significant damage to downstream infrastructure, agriculture, and even human lives. It is crucial to comprehend the causes and impacts of these outbursts to prepare for future occurrences. Notable instances of such events occurring in the Altai Mountains include the floods caused by glacial lake outbursts in Lake Turoi in 2000, Lake Maasheyskoye in 2012, and a subglacial lake in Tsambagarav Ridge in 2021. The hazards associated with such occurrences in the Altai Mountains are ongoing and escalating, as demonstrated by the emergence of fresh glacial lakes owing to glacial recession. Effective disaster management forms a crucial component of a sustainable development plan. Accordingly, forecasting and reducing the adverse consequences of natural disasters demands immediate attention. In this context, the investigation and observation of glacial lakes in the Altai, which can cause catastrophic processes, are gaining significance. This is because of the growing tourist activity in the Altai Highlands and the abundance of farming and residential structures situated in the possible impact area of glacial floods. The project team created an algorithm to evaluate the potential dangers of glacial lakes in mountainous areas. This involved recognizing potential hydrogenic threats, gauging the social, economic, and environmental implications if the lakes overflowed, and developing a collection of precautionary measures to lessen potential disasters. Successful testing of the algorithm has facilitated the identification of potentially hazardous glacial lakes within the Altai Republic. Additionally, the algorithm has been used to model potential floods and evaluate economic losses. To prevent a natural disaster, timely joint efforts between the Kosh-Agach Municipality and the Government of the Altai Republic were initiated.

## **2. Objectives**

This project contributes to the development of a comprehensive GLOF risk management approach, which involves improved hazard identification, early warning, and mitigation measures. It has two primary objectives: To develop a GLOF risk management strategy that is applicable to the local region and that can be used to reduce risk factors.

1. To perform a GLOF risk assessment of the Altai and to enhance the scientific and human capacities of public institutions and vulnerable communities in the Altai to comprehend and manage GLOF risks and their repercussions on human and economic development across all sectors.
2. Establish monitoring of potentially hazardous lakes in the Altai region and implement a GLOF early warning system.

This requires assessing the stability of specific glacial lakes as well as analyzing the vulnerability of downstream communities and property. Strengthened partnerships must be established

between key stakeholders, including local communities and regional government, to achieve this dual objective.

### 3. Outputs, Outcomes and Impacts

Outputs	Outcomes	Impacts
GIS-based inventory and mapping of glacial lakes in the Altai Mountains	Inventory of glacial lakes in Altai was carried out using ultra-high resolution satellite images in a specially created GIS "AltaiGLOF"	The project created an algorithm for evaluating the danger of glacial lakes in mountainous areas. This algorithm employs methods for recognizing lakes that pose a potential threat, evaluating the social, economic, and environmental damage resulting from an outburst flood, and creating preventative measures aimed at reducing the risk of potential disasters. Successful testing of the algorithm enabled identification of potentially hazardous glacial lakes in the Altai Republic, modelling of floods and assessment of potential economic damage. Close cooperation with the Kosh-Agach Municipality and the Government of the Altai Republic allowed taking early action to help prevent potential disaster. Presently, a Watch group of Chagan-Uzun settlement residents monitors the condition of the Upper Akkol Lake voluntarily. If there are any alterations in the hydrological regime or dam of the lake, the team leader will
Identification of potential GLOF sites in the Altai Mountains and assessment of potential socio-economic vulnerability	Based on comparative GIS analysis and field studies, lakes with the highest degree of instability were identified. Numerical modelling of a potential outburst flood was carried out for Upper Akkol Lake. The potential economic damage from a highly probable flood was calculated	
Establish and strengthen dialogue with relevant local government departments to develop a common strategy for coordinating GLOF prevention activities	In cooperation with the authorities of the Altai Republic and the Administration of the Kosh-agach district, a plan of engineering measures have been developed to artificially lower the level of Upper Akkol Lake. There are plans for the allocation of funds from the federal budget in the new fiscal year for the elimination of the potential threat	
Establishing valley Watch groups involving local community representatives to raise local awareness and local	A Watch group was organized to monitor the condition of the Upper Akkol Lake. The members of the group learnt	

monitoring of potentially dangerous lakes	how to monitor the lake by attending a training workshop.	promptly notify the Department of Emergency Situations' on-duty officer via mobile communication channels.
Publication of research results on the project website, in printed materials and video products. Incorporating project results into educational programs to train a new generation of environmental scientists.	The project results, research methodology and all related materials are posted on the project website, published as a video report and information leaflets. The scientific and theoretical basis of the research was tested in the course of teaching seminars and field training practice with students of Tomsk and Khovd State Universities.	

#### 4. Key facts/figures

- Inventory of glacial lakes in Altai was carried out
- Four expeditions to the high mountains of the Russian and Mongolian Altai were organised and executed.
- Numerical simulation of a potential outburst flood was carried out for Upper Akkol Lake. The potential economic damage was calculated.
- Three regional workshops were held to disseminate the project results and methodologies
- A Watch group was organized to monitor the condition of the Upper Akkol Lake
- Four presentations on conference have been done.
- Project website has been developed.
- Four publications (one peer-reviewed, and three proceedings) have been published

#### 5. Publications

1. Ekaterina D. Korf., Pavel S. Borodavko., Elena S. Volkova., Dmitrii A. Vershinin. (2023) Assessment of potential damage in case of Upper Akkol lake outburst (South-Eastern Altai, Russia). E3S Web of Conferences, Volume 440 (under review)
2. Borodavko P.S., Korf E.D., Melnik M.A., Volkova E.S. (2022) GIS inventory of glacial lakes in the Altai Mountains within Russia, Mongolia and China. ENVIROMIS – 2022. Tomsk. 199-202
3. Borodavko P.S., Korf E.D., Volkova E.S, Vershinin D.A.( 2023) Threat of outbursts of high-mountain lakes of the Great Altai. Natural conditions, resources, history and culture of Western Mongolia and consolidated regions. Khovd. 25-27 (In Russ.)

4. Vershinin. D.A. (2023) Assessment of the consequences of flood, as a result of outburst of Upper Akkol Lake (South-Chuya Range, Altai Republic) based on a two-dimensional computer modeling. Thirty-eighth plenary interuniversity coordination meeting on the problem of erosion, riverbed and estuarine processes: reports and communications. Perm. 85-87 (In Russ.)

## 6. Media reports, videos and other digital content

1. Project website - <http://greataltai-apn.ru/>
2. Project Video report - <https://www.youtube.com/watch?v=ooO1w3ThBYc>
3. Interview with the Project Leader Dr. Pavel Borodavko on the importance of a comprehensive study of Altai to reduce the risks of natural hazards. Mongolian national TV, Khovd News.30.09.2023 (from 3.55 min) [http://greataltai-apn.ru/f/whatsapp\\_video\\_2023-10-29\\_at\\_110122.mp4](http://greataltai-apn.ru/f/whatsapp_video_2023-10-29_at_110122.mp4)

## 7. Pull quotes

*«Natural disaster risk management is an important element of the sustainable development strategy for mountain regions. To succeed, such management must involve public authorities, scientists and local communities».*

*Mr. S. Kadyrbaev. Head of Kosh-Agach District Municipality*

*«I was proud to learn about the results of the project carried out under the auspices of APN and believe that these results will benefit not only the population of Transboundary Altai, but also the people of other high mountain regions».*

*Prof. E. Golovatskaya. IMCES SB RAS Director*

*«During our research project, we identified areas with potential hydrogen hazards and collaborated with governmental institutions to develop strategies to mitigate the associated risks. The collaboration between academic science and policy has generated beneficial outcomes»*

*Dr. P. Borodavko. Project leader*

## 8. Acknowledgments

We are grateful to the Asia-Pacific Network for Global Change Research (APN) for funding the project, with additional co-funding provided by the Russian Foundation for Basic Research (RFBR). We also extend our appreciation to Mr. Kadyrbaev S.M., Head of the Administration of Kosh-Agach District, Altai Republic, Mr. Metreev A., and all members of the Volunteer Watch group “Akkol”. We extend our sincere gratitude to several researchers, government officials, and non-governmental organisations for their invaluable contributions to this project. Their participation in workshops and consultations has provided us with vital data sets necessary for our research.

## 9. Appendices

### Appendix 1: Workshop "Mongolia's glacial lakes and the risks associated with their outburst"

A single-day workshop on "Mongolia's glacial lakes and the risks associated with their outburst" was convened on 4th August 2022, within the Department of Nature Conservation in Khovd, Mongolia.

In April 2022, the launch of construction was expected to take place on Mongolia's most extensive hydroelectric power station to date. The proposed Erdeneburen hydroelectric power plant is intended to be erected on the Khovd River in Western Mongolia, inside the ecologically susceptible vicinity of a National park. The previous year saw a disastrous subglacial lake outburst from Tsambagarav Ridge, causing a mudflow that altered the landscape of the Hovd River's tributary valley irreversibly. What are the dangers facing the new hydropower plant, and to what extent are they of concern? During the workshop, the two principal concerns were discussed.

The meeting was attended by Prof. Lhagvasuren, Dr. Borodavko, Dr. Burmaa, Dr. Redkin and 15 experts from the Department of Nature Conservation and Tsambagarav National Park.

#### Some photo highlights of the workshop



Presentation by Dr. Borodavko techniques for identification of dangerous glacial lakes





Workshop discussion

**Appendix 2: Training workshop. Climate-driven Dynamics of Altai lake-glacial systems and associated natural hazards. Khovd State University. Mongolia. 04. 17-18. 2023.**

A two-day training workshop was arranged for geography students from Hovd State University as a part of the project's educational component. Lectures were delivered by Dr. Otgonbayar D., Dr. P. Borodavko, Dr. D.Vershinin. The workshop was organized into three sections and the educational process was conducted in three directions:

- Inner Asia's Climate and Modern Analytical Techniques. Methods for Obtaining and Processing Long-Term Meteorological Data.
- Glacial Lakes: Fundamental Concepts, Global Glacial Lakes Research Experience. A Study of Glacial Lakes in Altai and the Physiographic Conditions of their Formation. Stages of Lake Evolution. Outburst Hazard Factors and Probability of outbursts. Glacial Lakes in the Transboundary Altai Region.
- Methods for researching glacial-lake systems include field research, remote sensing methods, GIS and hydrological modelling.



Start of the seminar. Introductory lecture by Dr. Otgonbayar D. and Dr. P. Borodavko



Practical training on the use of GIS technologies in GLOF forecasting



**Appendix 3: Project closure seminar "Climatogenic transformation of lake-glacial systems of Altai and related natural hazards" September 20, 2023, Tomsk State University.**

The two-year APN project concluded with a final workshop, where project participants gave presentations summarising their research. The workshop was held in a hybrid format, with participants from Mongolia and China joining remotely. Professor Sergey Kirpotin delivered an introductory speech and congratulated the workshop participants on their successful completion of the project. Subsequently, key participants made presentations, including project leader Dr. Pavel Borodavko who presented the research methodology, sequence, and results. Dr. Dmitry Vershinin informed the seminar attendees of the findings from the GLOF simulation of Upper Akkol Lake, and discussed its distinctive characteristics and origins.

Dr. Ekaterina Korf and Dr. Elena Volkova briefed the participants and project implementers on the economic and social impacts associated with the outburst of the Upper Akkol lake, as well as the methodology used to calculate them. Dr. Maria Melnik presented the findings of a study on the Altai region's climate impact on glacial recession and the formation of glacial lakes. The analysis reveals how the climate changes have contributed to the reduction in the size and coverage of glaciers, leading to the emergence of new lakes across the region.

Video clips of the speeches can be accessed through the links provided:

<http://v.oml.ru/v/mp4/5b2f194677391c1a87e1b097d17c1f7b/360>

<http://v.oml.ru/v/mp4/6fe4c229d3f575fe59687df6a8cd4b12/360>

<http://v.oml.ru/v/mp4/7bafc51fd818ecfadedf2a4c1231e9f9/360>



## **Appendix 4: Journal Articles**

**Assessment of potential damage in case of Upper Akkol lake outburst (South-Eastern Altai, Russia).** (under review, will be published in E3S Web of Conferences, IF 0.38)

### Abstract

At present, due to the gradual reduction of glaciation area in high mountainous areas around the world, there is an active transformation of landscapes freed from ice. Namely, the number of glacial moraine-dammed lakes is increasing. Such lakes are often unstable, rapidly changing their morphometric characteristics, which require observation. It is also known that recently there have been more frequent cases of catastrophic outbursts of such lakes and flooding of the territories below. Populations living in such areas are exposed to significant and often uncontrollable risks. One of such lakes, representing a potential threat of breaching, is the Upper Akkol Lake, located on the slope of the South Chuysky Ridge in South-Eastern Altai (Russia, Altai Republic). In this article, we assessed the potential damage from a possible lake outburst, and the information was communicated to local administrations in order to take timely measures to minimize damage or avoid a catastrophe.

### *Keywords*

Altai Mountains, outburst flood, losses assessment

**GIS inventory of glacial lakes in the Altai Mountains within Russia, Mongolia and China.** (ENVIROMIS – 2022 Selected papers)

### Abstract

Since the Little Ice Age, the altitudinal and latitudinal range of the Earth's cryogenic formations has been steadily narrowing and expressed in a progressive reduction of the glaciopause. Subject to global climatic trends, the glaciation of the Altai (Russian, Mongolian, Chinese) has been in steady regression for a century and a half, and the glaciers of its main centres demonstrate a negative mass balance and decrease in the area occupied. A characteristic element of landscapes of the Altai periglacial belt, as an area with actively shrinking glaciation, are complexes of polygenic and polymorphic lake water bodies, the number of which increases in proportion to the rate of glaciation reduction. The uneven distribution of lakes across the mountain-glacial basins of the Altai is dictated by their morphological features: most of the lake water bodies are confined to the gentle precipices of valley and car-valley glaciers with well-defined marginal moraine complexes, which act either as natural dams or provide conditions for the development of thermokarst limnogenesis. In basins dominated by glaciers of flat-top or slope type, there are no conditions for the formation of water bodies. A comparative analysis of the space survey materials from 1968 to 2020 shows that most of them were formed in the last half-century.

### *Keywords*

Glacial lakes, GIS inventory, Altai

## Appendix 5: Conference Presentation

Topic	Authors	Conference/Symposium/Seminar Name	Year
GIS inventory of glacial lakes in the Altai Mountains within Russia, Mongolia and China	Borodavko P.S., Korf E.D., Melnik M.A., Volkova E.S.	ENVIROMIS–2022: International Conference and School of Young Scientists on Measurements, Modeling and Information Systems for Environmental Studies, Tomsk. <a href="http://www.scert.ru/ru/conference/ENVIROMIS-2022">http://www.scert.ru/ru/conference/ENVIROMIS-2022</a>	2022
Hydrogenic catastrophes of the Great Altai. Causes, time and scale	P.S. Borodavko	Web seminar "Cataphluvial Events in the Pleistocene History of Altai - Problems and Solutions". Moscow, Russia <a href="https://www.geogr.msu.ru/structure/labs/notl/news/index.php?amp=&amp;print=Y">https://www.geogr.msu.ru/structure/labs/notl/news/index.php?amp=&amp;print=Y</a>	2023
Assessment of the consequences of flood, as a result of the breakout of Upper Akkol lake (South-Chuya ridge, Altai Republic) based on a two-dimensional computer modeling	D.A. Vershinin	Thirty-eighth plenary interuniversity coordination meeting on the problem of erosion, riverbed and estuarine processes: reports and communications. Russia, Perm	2023
Threat of outbursts of high-mountain lakes of the Great Altai	P.S. Borodavko, E.D. Korf, E.S. Volkova, D.A. Vershinin	XVI International Scientific Conference "Natural conditions, resources, history and culture of Western Mongolia and consolidated regions" Khovd. Mongolia <a href="http://www.khu.edu.mn/news/651aa70cdce7bf06db8cf32b">http://www.khu.edu.mn/news/651aa70cdce7bf06db8cf32b</a>	2023
Hazardous natural processes of the Altai Mountains as a limiting factor of economic development of the region	P.S. Borodavko	XX International Scientific and Practical Conference. Opportunities for Development of Local History and Tourism in the Siberian region and Neighbouring Territories, Tomsk, Russia <a href="https://ggf.tsu.ru/konferentsii/geokonf_tourism/">https://ggf.tsu.ru/konferentsii/geokonf_tourism/</a>	2023

## Appendix 6: List of young researchers

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## Appendix 7: Field Research. Short report with photos

Expedition to investigate the ecological aftermath of a disastrous subglacial lake burst in the upper Ganga River, a tributary to the Ulyasutai River. Taking place at Tsambagarav Ridge in the Mongolian Altai. August 2022.



A glacier located at the source of the Ganga River (marked by red arrow) created a reservoir of melted water beneath its tongue. The subsequent discharge of this reservoir resulted in a significant mudflow, causing ecological harm to both the Ganga and Ulyasutai River valleys.







Transformation of the landscape at the mouth of the Ulyasutai River, caused by a sudden flood burst. The top photo is from 2019, while the bottom photo is from 2022. Photos from a drone.



Field Camp and Group Photo of the Expedition Participants

**Glacial lakes of the Munhairhan Range. Mongolian Altai.2022**

Data was gathered on the hydrological features of glacial lakes during field studies, whilst also investigating the condition, structure and composition of moraine dams.



Bathymetric survey of Upper Shuurkhai Lake



Field camp at elevation 2750 m. View from drone.



Dulun Valley Cascade Lakes

**Glacial lakes of the Russian Altai 2022.**

During the expedition, research was conducted on glacial lakes located in the South Chuysky, Kuraisky, North Chuysky, and Chikhachev Ridges. Field analysis indicated that the majority of the examined lakes do not pose a threat due to several reasons, principally small lake volumes, shallow depths, and dams that are sufficiently reliable. Special attention was given to investigating remnants of past devastating floods in the river valleys of Maashey and Tingedu.



Cascade of moraine-dammed lakes in the Tete valley. North Chuysky Ridge.



Glacial lakes in the valleys of Turaoyuk (pictured at the top) and Yelangash (pictured at the bottom) in the South Chuyskiy ridge.



Debris cone formed by GLOF at the junction of the Tingedu River valley. South Chuyskiy Ridge.



Moraine-dammed lake in the upstream of Kubadru River. Kurayskiy Ridge

**Glacial lakes of the Tsambagarav Range. Mongolian Altai 2023**

During the fieldwork, we conducted a bathymetric investigation of glacial lakes, examining their hydrological patterns and backwater dam morphology.



Unnamed thermokarst lake formed in a lateral moraine in the Tumurt valley



Moraine-dammed lake near Tumurt Glacier, in the upstream of Khar-Asga basin



**Upper Akkol Lake. South-Chuyskiy Range.2023**

We have designated the Upper Akkol Lake as highly hazardous. After modelling a potential outburst flood, we evaluated the potential economic and social damage to the population residing in the valleys of the Chagan and Chagan-Uzun rivers based on its parameters.

