Extended Abstract DOI: https://doi.org/10.64862/ajeg.2025.2sp.01.034 Open Access

Lake Sarez – The Potential Hazard Assessment Based on the Natural Analogues of the Anticipated Hazard Chain

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Received: June 2, 2025, Accepted: August 13, 2025

Abstract: Lake Sarez, situated in the Central Pamir Mountains of Tajikistan, was formed in 1911 when the Murgab River was blocked by the massive (~2.2 km^3) Usoi rockslide triggered by a M7.3–7.7 earthquake. The resulting lake, containing approximately 16–17 km^3 of water behind a 500 m-high natural dam, represents a significant transboundary hazard to populations along the Bartang–Panj–Amu Darya River system across Tajikistan, Afghanistan, Uzbekistan, and Turkmenistan. Although the Usoi dam is presently considered stable against seepage and internal deformation, satellite radar interferometry (InSAR) data from Envisat and Sentinel-1 (2003–2006, 2015–2020, 2023–2024) show active slope movements of up to 250 mm/year on the right- and left-bank slopes, covering 5 km^2 and 2 km^2, respectively. These indicate evolving deep-seated landslides capable of generating catastrophic impulse waves if they collapse into the lake. Analysis of global rockslide-induced wave events suggest that a right-bank collapse of ~0.5 km^3 could reach velocities over 200 km/h, producing waves with runups exceeding 100 m, potentially overtopping the dam and initiating rapid erosion. Due to uncertainties in slope geometry and dam properties, deterministic modeling is limited; hence, hazard assessment relies on natural analogues. Gradual controlled lowering of the lake, alongside international cooperation, is recommended to prevent potential disaster, and timely proactive interventions are feasible only during the current stable phase.

Keywords: ***Lake Sarez, Usoi dam, Rockslide, Impulse wave, InSAR.***

Introduction

Lake Sarez (Figure 1) is one of the most hazardous natural lakes globally due to its massive volume and high elevation. Formed by the 1911 Usoi rockslide, it impounds the Murgab River at 3,260 m a. s. l., creating a deep lake of over 16 km^3 capacity. Despite the dam's apparent stability, its slopes show evidence of active deformation that could evolve into large-scale slope failures. This study aims to assess the potential hazard chain: rockslide, impulse waves, dam overtopping, and possible breach through the analysis of natural analogues and recent remote sensing data.

Figure 1, Position of the Sarez lake in central Pamir, Tajikistan.

Geological and geotechnical setting

The Usoi dam consists of a chaotic assemblage of fragmented rock and boulders, typical of large rockslide deposits. The steep slopes bordering Lake Sarez exhibit

continuous deformation, as confirmed by InSAR measurements showing displacements up to 250 mm/year. The right-bank slope covers about 5 km^2, extending 2 km along the shoreline and ~2.7 km upslope from the lake margin. The left-bank slope, though smaller (2 km^2), lies closer to the dam. Estimated potential sliding depth (~100 m) suggests an unstable right-bank rock volume of ~0.5 km^3. These active deformations, combined with seismicity of the Pamir region, raise concern about potential mass movements capable of generating destructive waves.

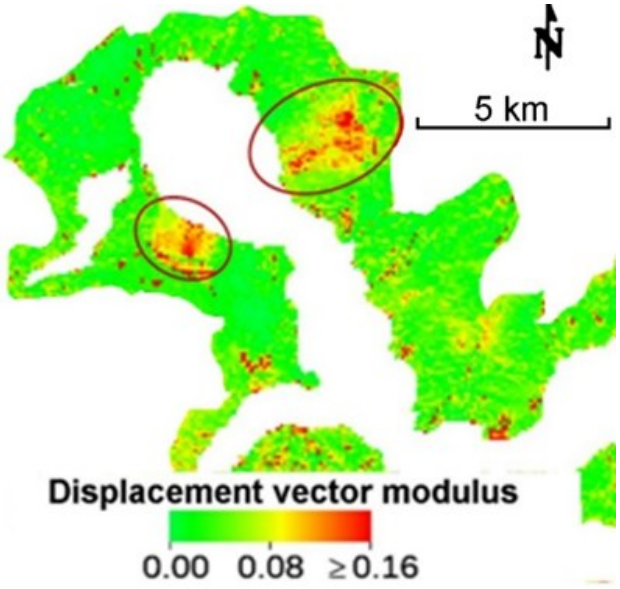

Figure 2, Modulus of the displacement vector (in meters) of the study area for the period between february 2023 and february 2024 (after Zakharova et al., 2025). Right-bank and left-bank unstable slopes are outlined. Notice practical absence of deformations of the Usoi dam body.

Assessment of the anticipated hazard chain

The anticipated hazard chain begins with a catastrophic slope failure entering the lake, producing an impulse wave that may overtop the dam. Based on global analogues, slide velocities of 100–200 km/h are realistic for a failure of this magnitude. Historical mega tsunami data (Ferrer and González-de-Vallejo, 2024) show that similar, but smaller, events generated wave runups exceeding 100 m. If overtopping occurs, erosion of the dam's coarse carapace could expose its weak internal matrix-supported debris, triggering progressive incision similar to the Issyk Lake failure (Gerasimov, 1965). The resultant outburst flood would propagate through the Bartang, Panj, and Amu-Darya River systems, impacting vast areas downstream.

Discussion

Due to the uncertainty in slope geometry, slide dynamics, and dam composition, numerical modeling of the Sarez hazard chain is unreliable. Instead, comparative analysis with natural analogues allows estimation of realistic hazard magnitudes. The potential impact ranging from dam overtopping to complete breach demands immediate consideration of risk reduction strategies. Preventive measures, such as controlled lake level reduction, would substantially decrease the risk of overtopping and catastrophic failure. International coordination is critical, given the transboundary implications and logistical challenges of implementing mitigation works in the remote Pamir region.

Conclusion

Although the Usoi dam currently remains stable, active slope deformations detected near its margins justify continuous monitoring and preemptive mitigation planning. The analogue-based hazard assessment indicates that even low-probability failure scenarios could result in catastrophic regional flooding. The study emphasizes the urgency of implementing controlled lake-level measures and continued international collaboration to ensure the long-term safety and preservation of Lake Sarez as a unique natural heritage site.

References

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