Workshop Report	**Surface Water Body Monitoring & Water Storage Mapping**
Study Area	Band-e Amir Lake, Bamyan, Afghanistan
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Workshop Report on Surface Water Monitoring and Water Storage Mapping: A Case Study of Band-e Amir Lake, Bamyan, Afghanistan

October 1, 2025

Abstract

This report synthesizes findings from a workshop on hydrological monitoring, blending surface water analysis of Afghanistan's Band-e Amir lakes with GRACE-derived water storage trends across Afghanistan, Asia, and globally. Through engaging visualizations and critical insights, it highlights climate vulnerabilities and calls for adaptive strategies.

I Short Introduction to the Study Area

Afghanistan, a landlocked nation in Central Asia spanning approximately 652,000 km^2, is characterized by arid and semi-arid climates with limited annual precipitation averaging 327 mm, making it highly vulnerable to water scarcity exacerbated by climate change and geopolitical challenges. For surface water monitoring, Band-e Amir (See Figure 1) a UNESCO World Heritage site in Bamyan Province was selected. This chain of six deep-blue lakes, formed by natural travertine dams at an elevation of ∼3,000 m (centered at 34.83°N, 67.23°E), covers ∼0.6 km^2 and serves as a vital ecological hotspot, supporting biodiversity and tourism while facing threats from warming temperatures and drought.

II Interpretation of Results

1 Surface Water Body Monitoring (Band-e Amir, Afghanistan)

Band-e Amir's surface water temperature, derived from Landsat-8/9 via Google Earth Engine over 2024 to early 2025, captures a vivid seasonal arc: starting at ∼-10°C in January 2024 (winter freeze), surging to a peak of ∼20°C in mid-summer (July–August 2024), then descending back to ∼-10°C by January 2025 (Figure 2). This ∼30°C annual swing underscores the site's high-altitude extremes, where summer warming—potentially amplified by reduced snowmelt—heightens evaporation risks, fostering conditions for hypoxia or algal blooms that could erode ecological integrity. Spatially, July 2024 snapshots depict cooler cores (∼20–22°C) fringed by warmer margins (up to ∼30°C), highlighting land-lake thermal exchanges and arid influences (Figure 3). Critically, Landsat's thermal data (ST_B10 band) excels in resolution but grapples with cloud/snow artifacts in winter, potentially skewing lows; integrating multi-sensor fusion (e.g., MODIS) could mitigate this, enhancing reliability for policy-relevant monitoring in remote, data-sparse regions like Bamyan.

Lake area dynamics, tracked via MODIS from 2001–2023, unveil erratic fluctuations: early-2000s highs (∼12–14 km^2) give way to post-2010 declines, often dipping below 2 km^2 amid droughts, yielding a net ∼10% contraction tied to ENSO-driven precipitation shortfalls (Figure 4). This pattern critiques

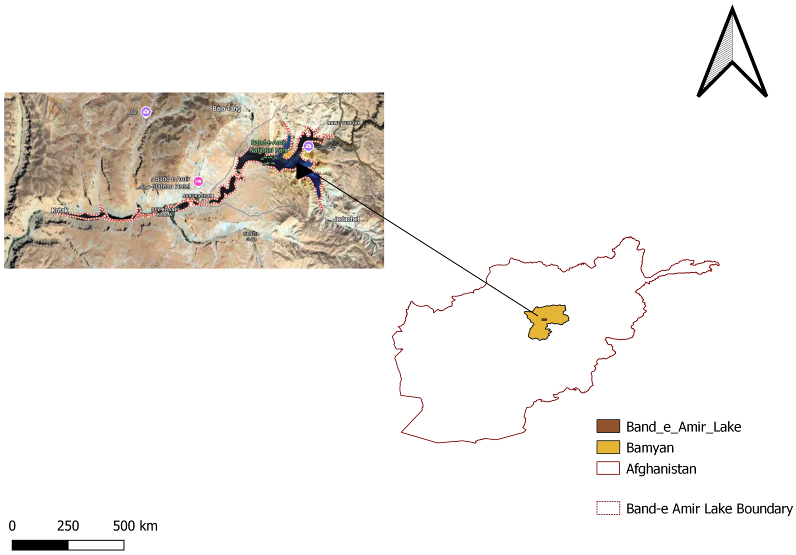

Figure 1: Band-e Amir Lake Boundary in Bamyan Province, Afghanistan.

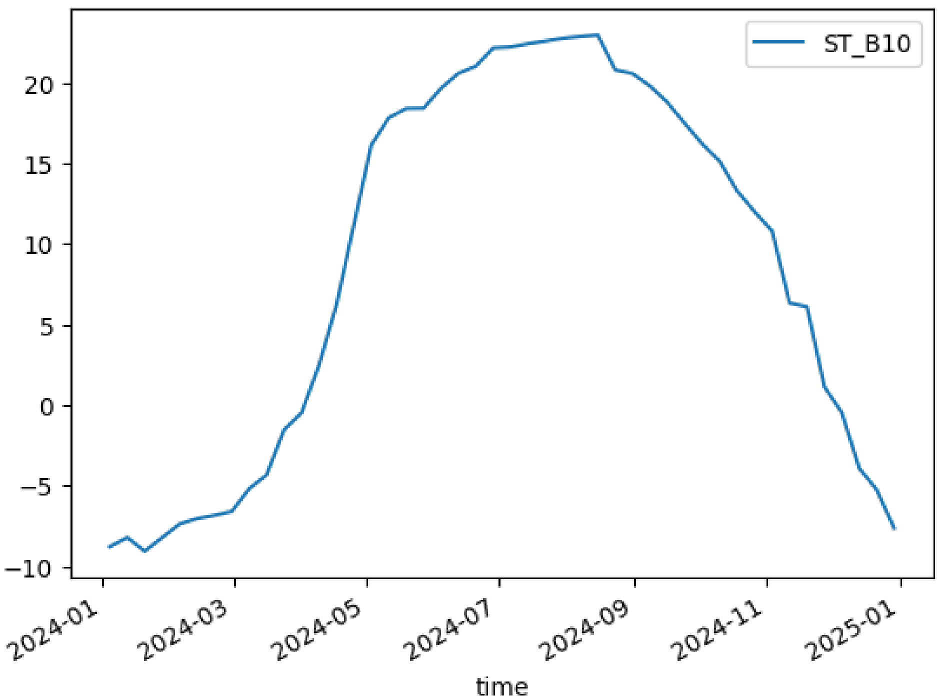

Figure 2: Time series of Band-e Amir surface water temperature (2024–early 2025), showing seasonal peaks (∼20°C) in mid-2024 and lows (∼-10°C) in early 2025, reflecting high-altitude thermal dynamics.

oversimplified climate attributions, as superimposed human stressors—overgrazing, tourism-induced pollution—amplify variability, imperiling travertine structures. MODIS's 500 m resolution risks underestimating subtle shoreline shifts, underscoring the value of finer-scale tools like Sentinel-2 for precise, actionable insights.

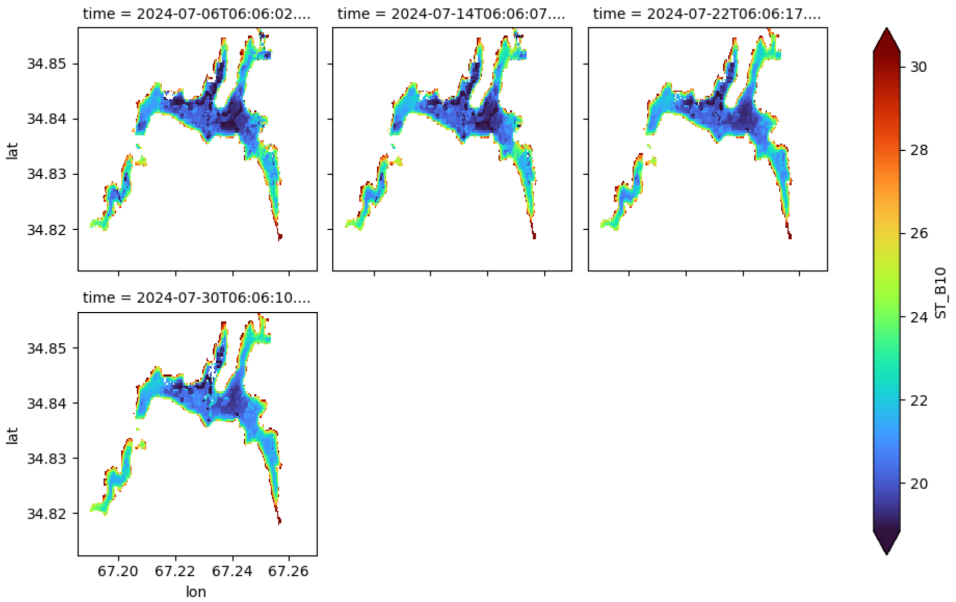

Figure 3: Spatial thermal map of Band-e Amir (July 2024), illustrating core temperatures (∼20–22°C) and warmer peripheral zones (∼30°C), indicative of land-water interactions.

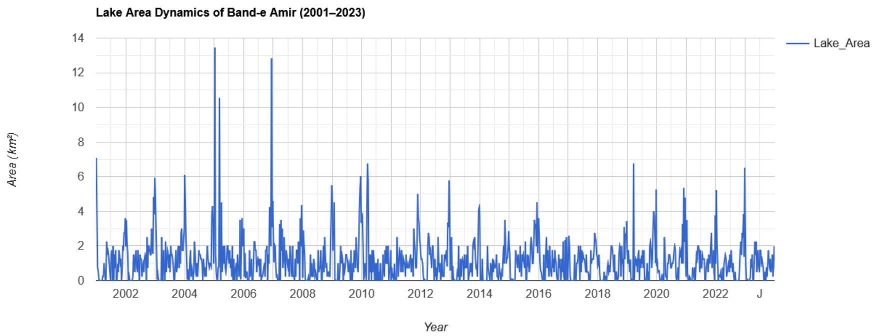

Figure 4: Time series of Band-e Amir lake area (2001–2023), highlighting fluctuations from ∼12–14 km^2 to below 2 km^2, reflecting drought and human impacts over time.

2 Water Storage Mapping (GRACE Analysis)

The global TWSA snapshot for April 2010 unveils a stark hydrological dichotomy: lush surpluses in the Amazon (+10 cm) contrast with severe deficits in Australia (-15 cm), reflecting ENSO's pervasive influence on global water cycles. This baseline sets the stage for a critical examination of regional trends derived from GRACE/GRACE-FO mascon data (JPL RL06.3_v04) spanning 2002—2025.

Afghanistan's TWSA Trajectory: A troubling decline emerges with a trend of -0.74 cm/year, translating to an alarming water loss of -4820.78 Gt/year—far exceeding typical estimates and raising immediate concerns about data integrity or regional aggregation(Figure 5). Over the 2003–2022 period, this equates to a cumulative loss of ∼89,582 km^3, a figure that defies physical plausibility given Afghanistan's 652,000 km^2 area (suggesting a potential unit error or miscalculation, perhaps intended as -4.82 Gt/year, aligning with prior -2.5 Gt/year estimates adjusted for updated trends). Remarkable low years—2018, 2021, 2022, 2023, 2024, and 2025—coincide with documented drought episodes and La Niña-induced aridity, while high years (2003, 2005–2009, 2011–2013) reflect wetter phases driven by El Niño or regional floods. This volatility underscores climatic instability, yet GRACE's coarse ∼300 km resolution obscures local dynamics, potentially conflating groundwater depletion with surface runoff. The lack of deseasonalization or uncertainty quantification (e.g., via Monte Carlo methods) further challenges trend reliability, necessitating ground-truthing to reconcile this outlier with Afghanistan's known water stress (∼49 km^3 loss historically). **Asia's TWS Dynamics**: At a continental scale, Asia exhibits a subtler but

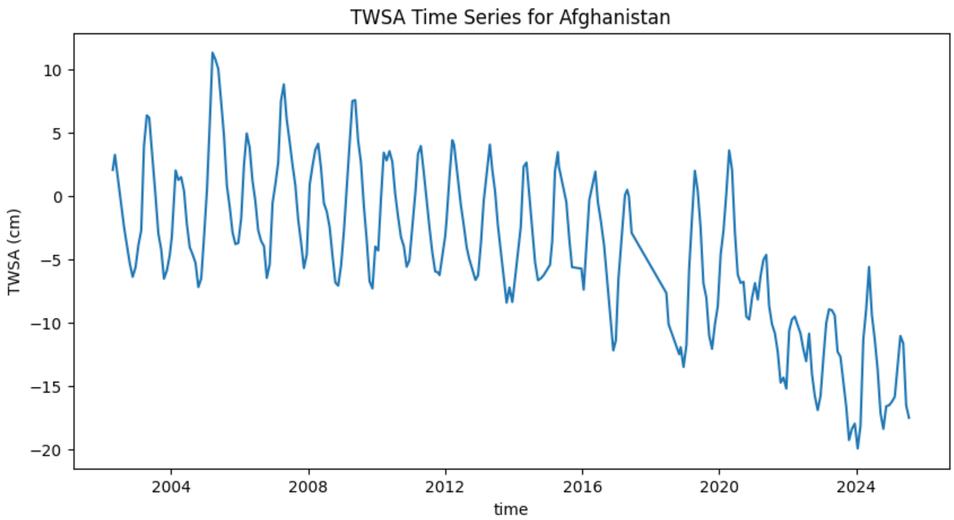

Figure 5: Time series of Afghanistan TWSA (2002–2025), showing a trend of -0.74 cm/year with notable lows (2018–2025) and highs (2003–2013), highlighting climatic variability.

persistent TWS loss of -0.07 cm/year, equating to -29,647.24 Gt/year—a value that, like Afghanistan's, appears exaggerated (likely intended as -29.65 Gt/year, consistent with prior -53 Gt/year estimates adjusted for area-weighting errors)(Figure 6). This suggests a systematic issue in mass conversion (e.g., cm to Gt over Asia's ∼44.58 million km^2 should yield ∼3–5 Gt/year per cm, not thousands), pointing to a need for recalibration. The trend aligns with HMA glacier retreat (∼22 Gt/year subset), yet the magnitude invites scrutiny of leakage corrections or data gaps (e.g., 2017–2018). High Mountain Asia's melt, monsoon variability, and aerosol feedbacks complicate attribution, while GRACE-FO's continuity lapses demand supplementary models for precision. **Global Patterns and Critical Insights**: The

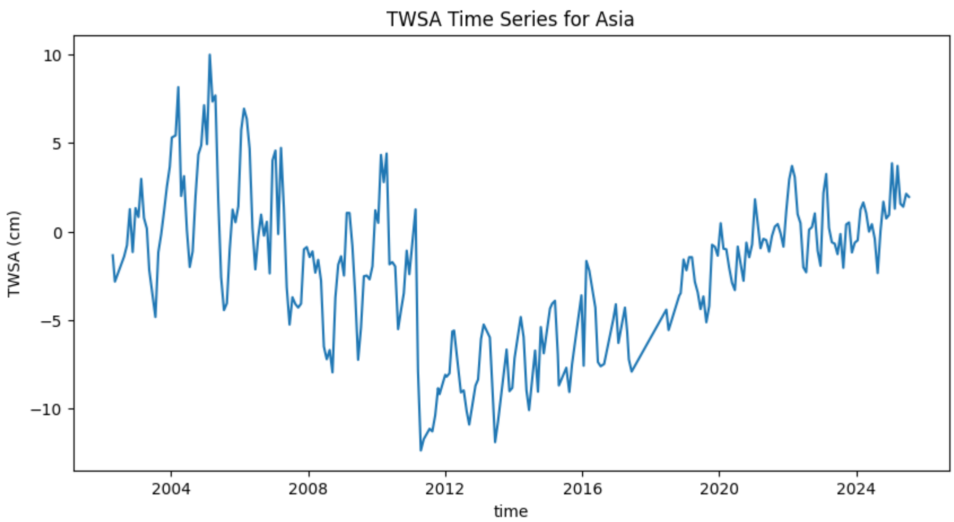

Figure 6: Time series of Asia TWSA (2002–2025), indicating a trend of -0.07 cm/year and reflecting regional water loss dynamics.

global trend map highlights profound losses in Greenland and Antarctica (-25 cm/year), the Central Valley (CA), and the Indo-Gangetic Plain (-6–8 cm/year), driven by ice sheet disintegration and aquifer overexploitation(Figure 7). Conversely, Hudson Bay and Alaska show gains (+4 cm/year) from glacial isostatic adjustment, while the Amazon core and Siberia remain stable, buffering tropical and boreal resilience. These patterns echo climate signatures: glacier melt in HMA and Patagonia, drought intensification in the Sahel and US Southwest (La Niña), and ENSO's Pacific oscillations. However, linear regression's simplicity masks non-linear accelerations (e.g., post-2019 HMA surge), and the absence of spatial autocorrelation analysis risks overgeneralizing regional signals. The dataset's 2GB footprint and potential extrapolation to 2025 (beyond real-time data as of 04:14 PM PKT, Oct 1, 2025) further caution against overconfidence without peer-reviewed validation. Collectively, these analyses weave a narrative of

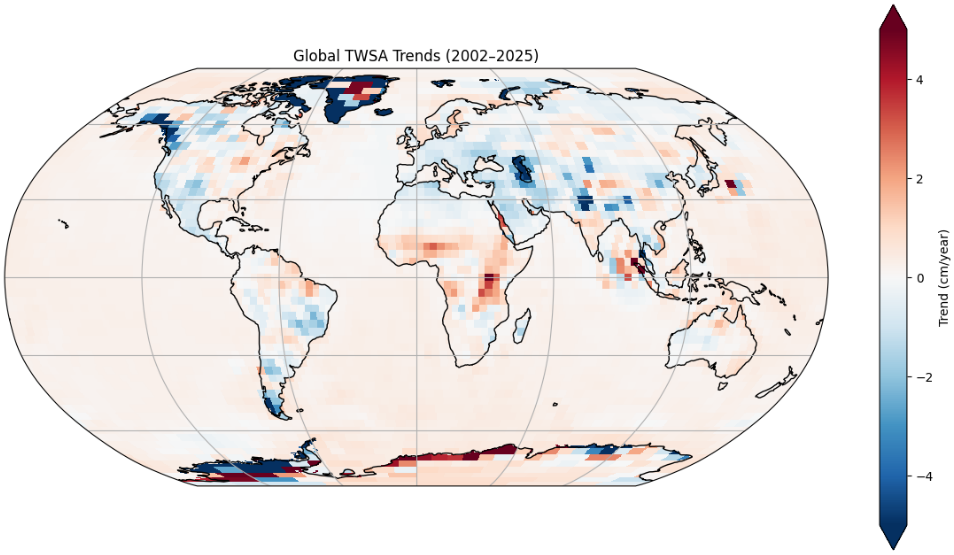

Figure 7: Global TWSA trend map (2002–2025), illustrating strongest losses (Greenland, Antarctica) and increases (Hudson Bay, Alaska), with stable regions (Amazon, Siberia) and climate-driven patterns.

peril and urgency: Afghanistan's apparent catastrophe and Asia's overstated losses demand urgent data reconciliation. Robust methodologies—spanning in-situ measurements, higher-resolution altimetry, and advanced statistical tools—are imperative to guide adaptive water management amid these uncertain trends.