Evaluating Erosion Rates Through Advanced DEM Differencing and Co-Registration Techniques Using Underutilized Satellite Data: A Case Study from Southern Taiwan

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Gopal Kumar[1,2,3], Yu-Chang Chan[1,2], Cheng-Wei Sun[2,4], Chih-Tung Chen[1,3]

1 Taiwan International Graduate Program (TIGP), Academia Sinica, Taipei, Taiwan 2 Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan
3 Department of Earth Sciences, National Central University, Taoyuan, Taiwan 4 Department of Geosciences, National Taiwan University, Taipei, Taiwan

Introduction

Abstract Taiwan's tectonic setting and extreme rainfall provide a natural laboratory for studying sediment flux in dynamic mountain basins. This study assesses decadal erosion in the Laonong River Basin using underutilized satellite-derived DEMs, including ASTER GDEM, SRTM, NASADEM, AW3D30, Copernicus DEM, FABDEM, and TanDEM-X EDEM, benchmarked against high-resolution LiDAR. Spatial-domain metrics (RMSE, bias, SD), Void Fill assessment, and Fourier-based spectral analysis were used to evaluate accuracy and detect vertical bias. ASTER GDEM and most radar DEMs with void-filling from external sources were excluded due to high uncertainty. NASADEM emerged as the most reliable for multitemporal analysis, exhibiting minimal bias and high vertical fidelity. Sub-pixel horizontal alignment via the Nuth and Kääb method and vertical referencing via Fourier analysis ensured precise DEM differencing. Estimated sediment export over 20 years was ~119 Mm³, validated through Google Earth satellite imagery. These findings highlight the capability of underutilized satellite-derived DEMs in capturing sediment erosion rates over multiple decades, demonstrating their utility in environments where erosional signals are dominant over the inherent noise in the dataset.

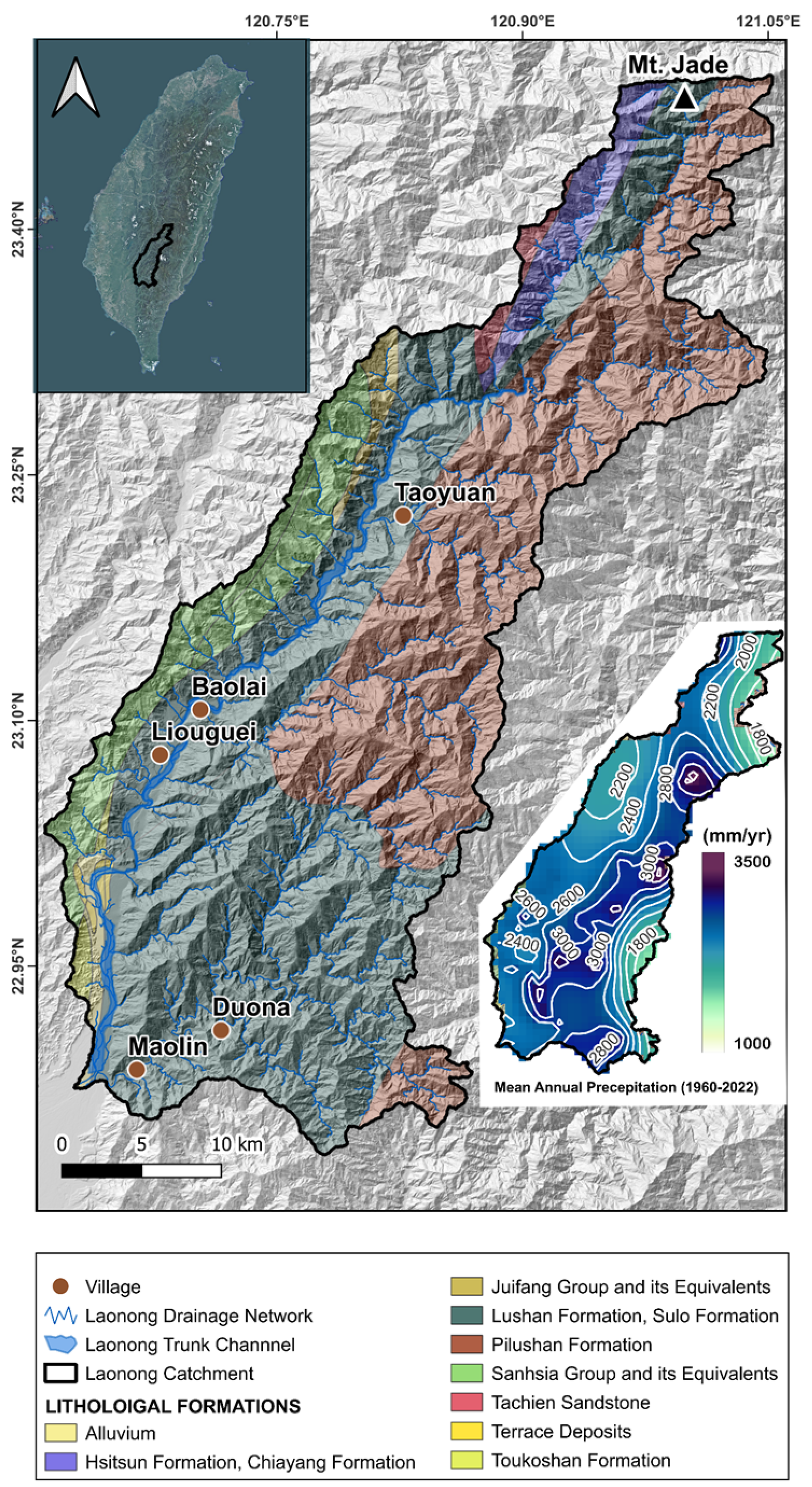

Figure 1. Geographic location, geological setting, and precipitation patterns of the study area.

Methodology

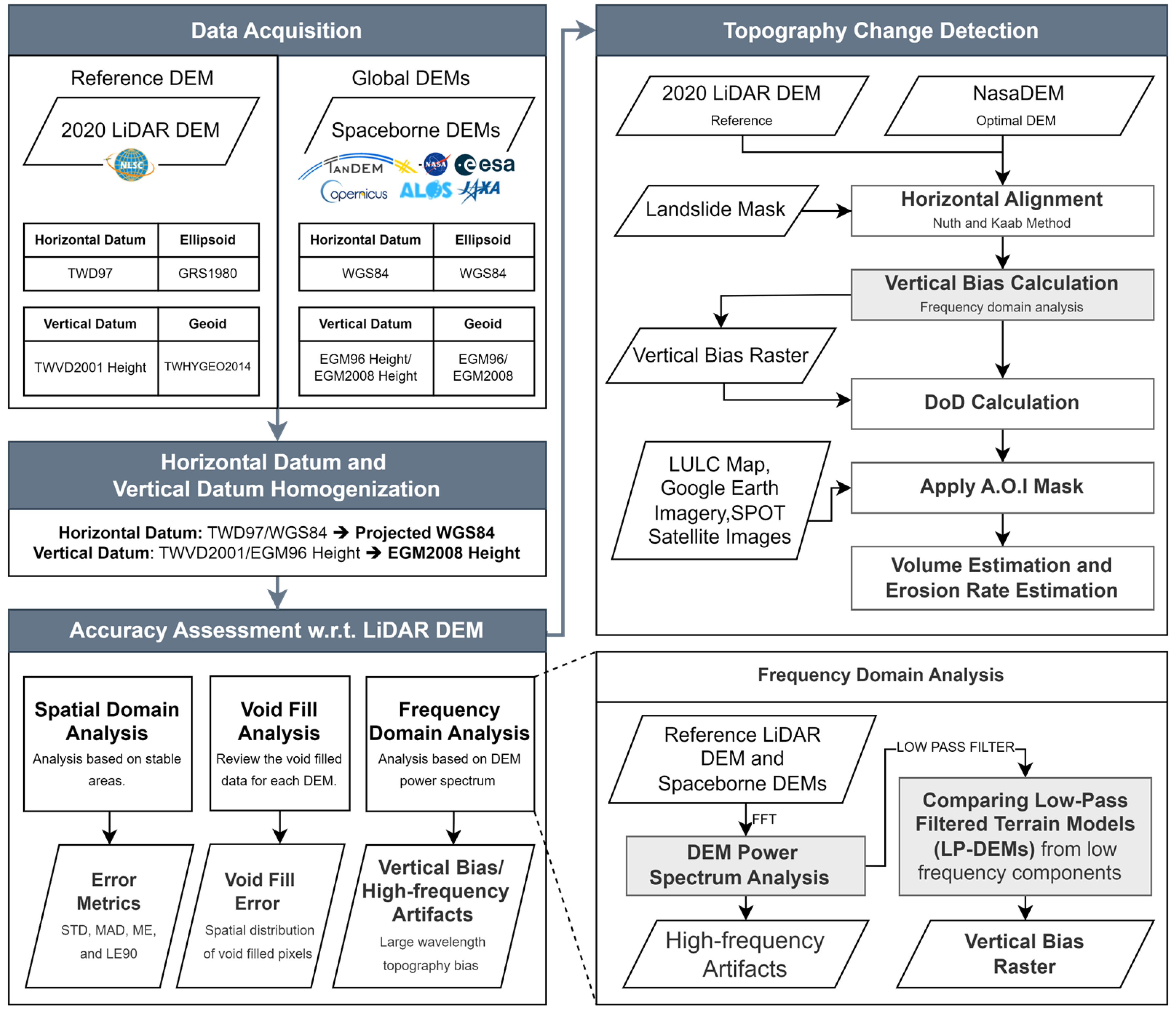

Figure 2. Methodological workflow illustrating (left) DEM suitability assessment and optimal DEM selection, and (right) sediment volume estimation, including novel Fourier-based vertical bias correction for accurate DEM differencing.

Power Spectra Analysis

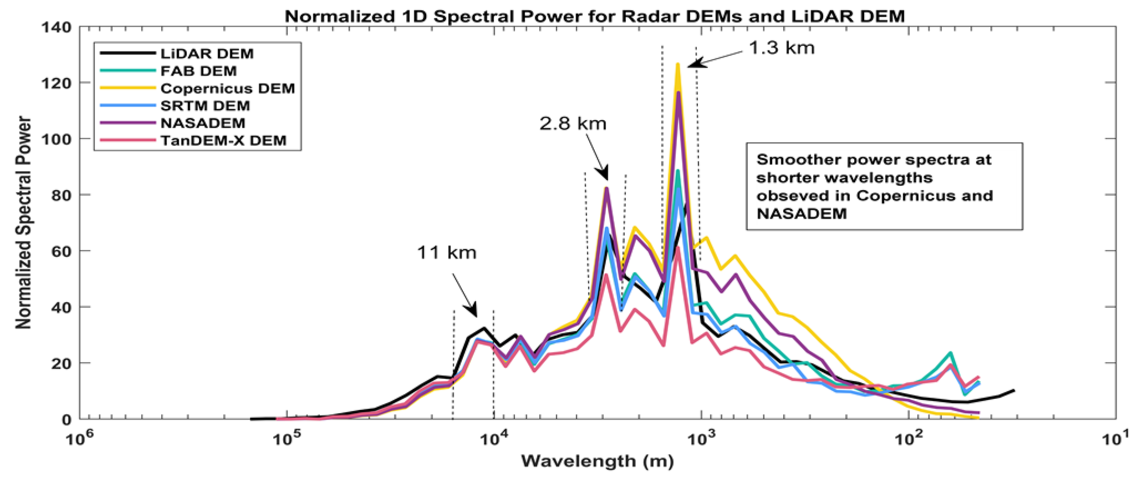

Figure 3. Normalized one-dimensional power spectra envelopes for different optical DEMs evaluated in the study. High-frequency peaks were observed at 2–8 pixel intervals in the optical DEMs, with similar artifacts reported in the AW3D5 and ALOS 3D DEMs by Purinton and Bookhagen (2017) and Kumar et al. (2024), respectively.

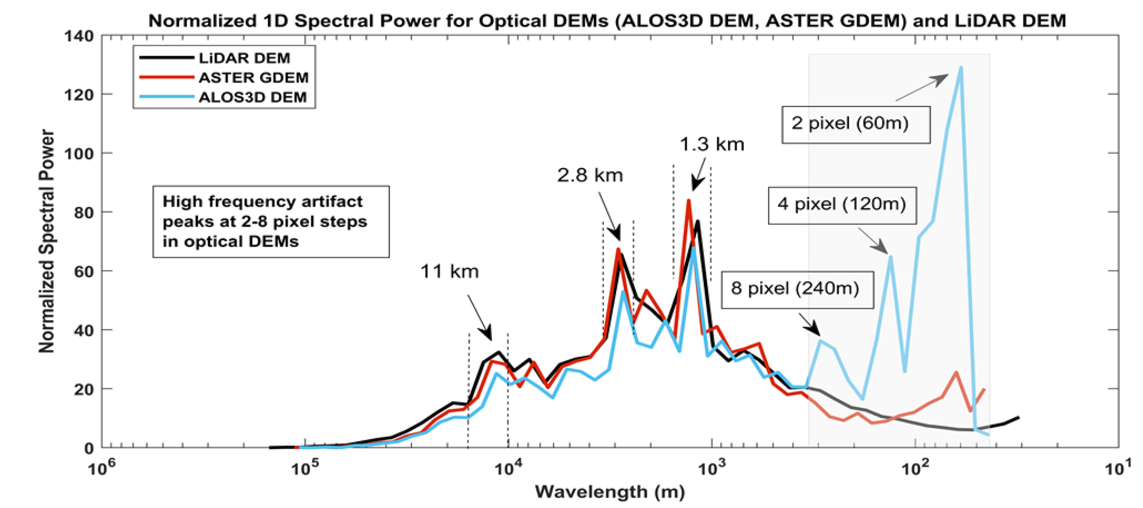

Figure 4. Normalized one-dimensional power spectra envelopes for various radar-based DEMs evaluated in the study. Radar-based DEMs generally exhibit smoother spectra and fewer high-frequency artifacts. Notably, the Copernicus and NASA DEM display exceptionally smooth spectral curves with no significant high-frequency peaks.

Landslide Evolution

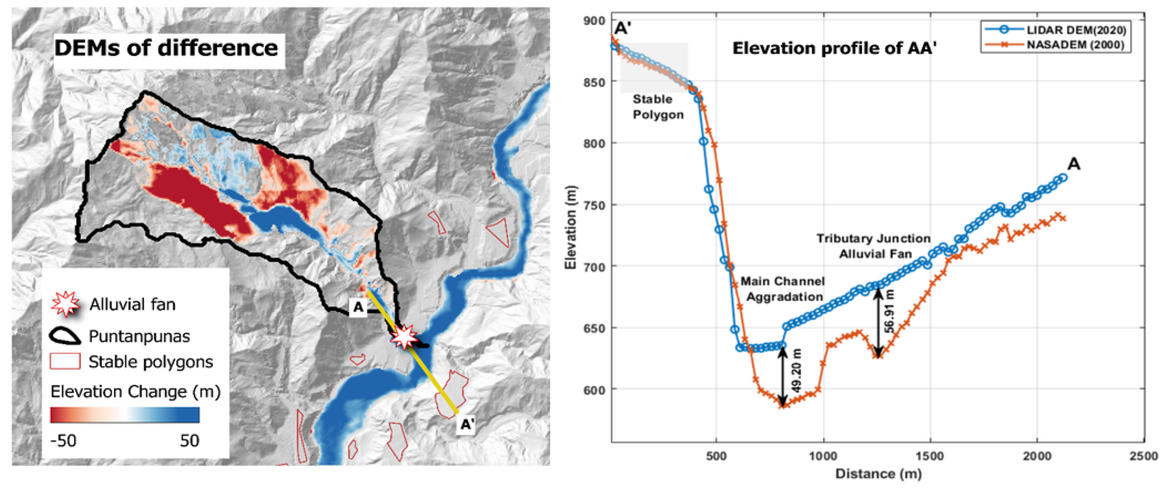

Figure 5. Left panel shows 20-year elevation changes with aggradation from a deep-seated landslide; right panel displays cross-section AA' highlighting major channel aggradation and debris fan buildup.

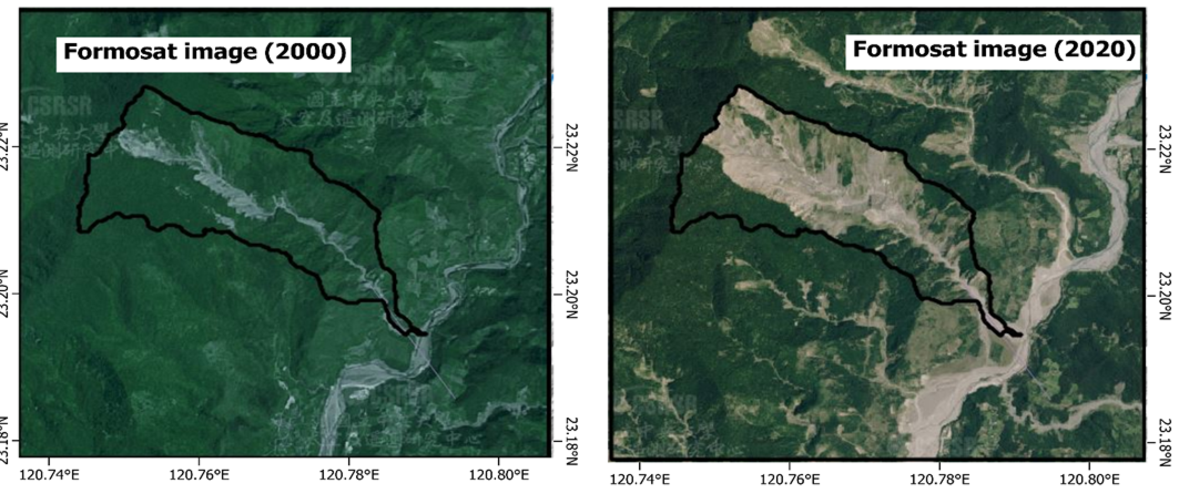

Figure 6. Satellite images of the Putanpunas catchment, taken 20 years apart, reveal significant and lasting topographic changes caused by the extreme impact of Typhoon Morakot.

DoD Map

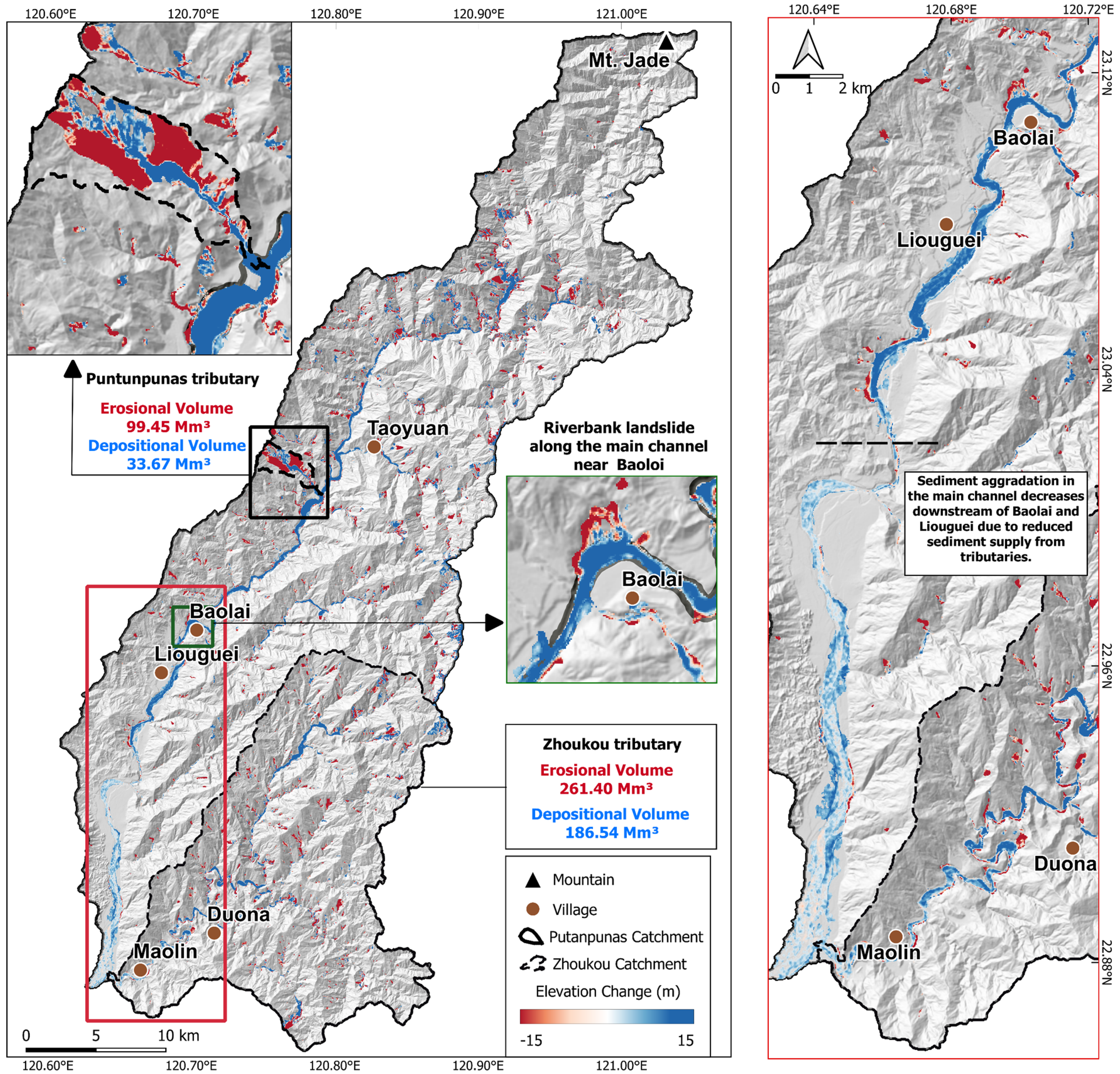

Figure 7. DEMs of Difference (DoD) map of the Laonong River Basin (2000–2020): The left panel shows basin-wide elevation changes, with erosion (red) in scars and banks, and deposition (blue) in toes and channels, highlighting extensive sediment redistribution. Key features include aggradation near tributaries, the Baolai bank-erosion landslide (green box), and the large Putanpunas landslide (black box). The right panel shows channel aggradation decreases downstream of Baolai and Liouguei.

Discussion & Conclusion

- Sub-catchment analysis reveals intense localized erosion (up to 62.86 cm/yr), often masked at basin scale; DoD maps help identify geomorphic hotspots critical for hazard assessment.
- Archival DEMs like NASADEM, when corrected and analyzed properly, provide reliable insights into decadal-scale sediment redistribution.
- Integrating spatial, spectral, and metadata assessments significantly improves the accuracy of DEM-based erosion rate estimation.
- DEM differencing is a powerful approach for both large-scale landscape evolution and sub-catchment scale hazard evaluation, capturing spatial patterns beyond what point-based gauging stations offer.

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Email: gopal16iiserb@gmail.com/ gopal16@earth.sinica.edu.tw