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Reservoirs Help, but Are not Enough: Preparing the Vu Gia Thu Bon River Basin for Future Flood Risk

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Reservoirs Help, but Are not Enough: Preparing the Vu Gia Thu Bon River Basin for Future Flood Risk

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Abstract
Central Vietnam is entering a period of rising flood uncertainty. In the Vu Gia Thu Bon (VGTB) River Basin, climate change is projected to intensify extreme rainfall, while flood management remains strongly dependent on upstream reservoirs. New modelling shows that the current cascade of 18 reservoirs can still reduce downstream inundation for modelled 20-year flood conditions under +2°C and +3°C of global warming. However, at higher levels of warming, flood extent would exceed the historical reference period, when streamflow regime was not heavily modulated by reservoirs – partly because reservoirs cannot control rainfall-generated runoff in the lower basin. This calls for a shift from reservoir-centered flood control toward integrated, data-driven, basin-wide adaptation.

Keywords
Climate change, Flood inundation, Vu Gia Thu Bon River Basin, Vietnam, Water management, Adaptation

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Résumé
Le centre du Vietnam entre dans une période d'incertitude croissante face aux inondations. Dans le bassin versant des rivières Vu Gia–Thu Bon (VGTB), les projections climatique indiquent une intensification des précipitations extrêmes, dans un contexte où la gestion des inondations reste fortement tributaire des réservoirs situés en amont. De nouvelles modélisations montrent que l'actuelle cascade de 18 réservoirs permet encore de réduire les inondations en aval pour les épisodes de crue modélisés correspondant à une période de retour de 20 ans, pour un réchauffement planétaire de +2 °C et +3 °C. Cependant, à des niveaux de réchauffement plus élevés, l'étendue des inondations dépasserait celle de la période de référence historique, au cours de laquelle le régime des débits était peu influencé par les réservoirs — notamment parce que ceux-ci ne peuvent pas contrôler le ruissellement généré par les précipitations dans la partie aval du bassin. Cette perspective montre la nécessité de passer d'une gestion des inondations centrée sur les réservoirs à une stratégie d'adaptation intégrée, fondée sur les données et déployée à l'échelle de l'ensemble du bassin versant.

Mots-clés
Changement climatique ; inondation ; bassin versant Vu Gia Thu Bon ; Vietnam, gestion de l'eau ; adaptation

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Highlights

- Floods are the most destructive natural hazards in Vietnam, with Central Vietnam frequently bearing the brunt of extreme precipitation and tropical cyclones. In the VGTB basin (central Vietnam), extreme rainfall is projected to increase by over 20% by the end of the century in a medium (SSP2-4.5) and very-high (SSP5-8.5) global greenhouse gas emissions scenarios.

- A hydrological model and a hydrodynamic model were combined to simulate future flood conditions in the Vu Gia – Thu Bon River Basin across different climate scenarios. The study focuses on 5% Annual Exceedance Probability (AEP) extreme rainfall and flood events, approximately equivalent to a 20-year return period.

- Results show substantial uncertainty in future streamflow, driven primarily by uncertainty in extreme rainfall projections. Reservoirs can still reduce flood extent and depth up to 3°C of global warming. However, at higher warming levels their buffering capacities may be overwhelmed, partly due to the impacts of rainfall over the floodplain itself.

- The findings underscore that the assumption that the future will look like the past is no longer a viable basis for water management. The significant threat posed by unregulated downstream runoff and the increasing frequency of compound flooding driven by extreme rainfall and high tide necessitate a shift to a holistic, basin-wide adaptation strategy. reservoirs remain indispensable, but they should be complemented by downstream drainage management, exposure reduction, emergency preparedness, and coordinated basin-scale governance.

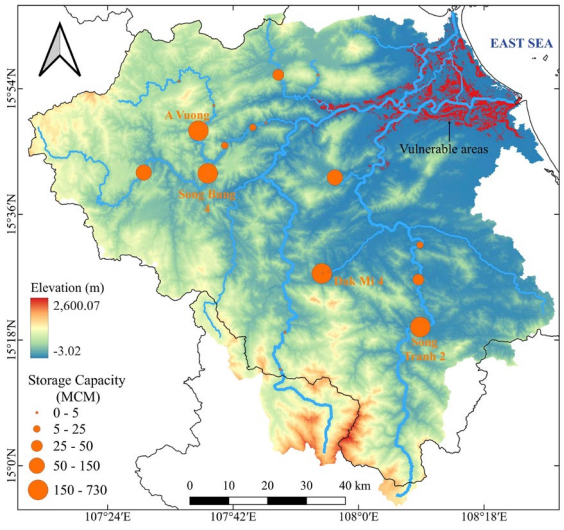
1. Context and motivation

Floods are the most destructive natural hazards in Vietnam, with Central Vietnam frequently bearing the brunt of extreme precipitation and tropical cyclones. Historically, events like the 1999 flood caused over 595 fatalities and economic losses equivalent to 1% of the national GDP. More recently, the 2020 floods resulted in approximately US$1.4 billion in damage. Current flood management in regulated basins largely relies on historical flood-frequency analysis, past flood records, and established reservoir operation rules to estimate flood hazards and design mitigation measures. These approaches remain essential, but they have important limitations under a changing climate. First, design standards based on historical return periods assume that the frequency and magnitude of extreme events remain broadly stable over time. Second, flood control measures centred around reservoirs can only regulates upstream inflows, while downstream rainfall, changing drainage networks, and urban expansion can still collectively lead to severe inundation in low lying areas. These limitations indicate that the current flood management regime may underestimate future compound and record-breaking flood hazards.

Recent extreme events across Vietnam further demonstrate why historical flood design assumptions should be revisited. In October 2025, the Bac Khe 1 hydropower incident in northern Vietnam occurred after the reservoir system experienced exceptional inflows. During the same month, the Bach Ma station in Central Vietnam recorded an unprecedented 1,739 millimeters in 24 hours, representing the highest rainfall value observed in Vietnam and the second-largest 24-hour rainfall total globally. These events illustrate how extreme events may intensify and become more frequent in a warmer climate, highlighting the urgent need to update flood risk management policies for a non-stationary future.

The VGTB basin (Figure 1), located in Central Vietnam and covering roughly 10,350 km², is characterized by steep topography and high population density in low-lying coastal cities like Da Nang and Hoi An. Climate change intensifies flood risks due to more extreme rainfall in a warmer climate. In the VGTB basin, extreme rainfall is projected to increase by over 20% by the end of the century in a medium (SSP2-4.5) and very-high (SSP5-8.5) global greenhouse gas emissions scenarios. Current flood management relies heavily on a cascade of 18 reservoirs, but their long-term effectiveness under high-warming scenarios remains a critical knowledge gap. We addressed this gap through a new modelling study (Nguyen et al., 2026) that projects future changes in river streamflow, flood extent, and flood depth under different future climate scenarios for a typical flood event.

Figure 1. Dams and vulnerable areas (water depth ≥ 1.2 m) across the VGTB basin, based on hydrodynamic simulation for 1995–2014 under the 5% Annual Exceedance Probability flood scenario.



2. Methods

We used an integrated modelling chain combining a hydrological model and a hydrodynamic model, forced by high-resolution and bias-corrected projections from 19 CMIP6 climate models under a medium (SSP2-4.5), high (SSP3-7.0) and very high (SSP5-8.5) global greenhouse gas emission scenarios (CMIP6-VN database, Tran-Anh et al., 2023). This relatively large ensemble of climate models is critical for assessing uncertainties arising from both future climate scenarios and inter-model variability.

Rather than focusing solely on selected future time periods, the analysis also assesses flood responses at global warming levels (GWLs) of +2°C, +3°C, and +4°C above pre-industrial levels. This approach uses all available climate projections corresponding to each warming level, capturing the full range of plausible climate outcomes regardless of when a given GWL is reached. Hence, the modelling exercise can be interpreted as a climate stress test of the existing flood-management system, rather than as a single deterministic forecast.

The analysis focused on 5% Annual Exceedance Probability (AEP) extreme rainfall and flood events, approximately equivalent to a 20-year return period. Upstream discharge scenarios used as inputs to the hydrodynamic model were generated using the observed temporal pattern of the 2020 flood hydrograph. Because the 2020 event was more extreme than a typical 5% AEP flood, the hourly hydrograph was rescaled according to the ratio between the simulated 5% AEP discharge and the peak discharge observed in the 2020 event. A similar scaling approach was applied to generate rainfall scenarios over the downstream hydraulic domain. This method preserves a consistent flood shape across scenarios, but assumes that the timing and temporal structure of the 2020 event are representative of 5% AEP floods.

3. Results

3.1. Large uncertainties in future precipitation and streamflow

Climate projections show an increasing trend in both total wet-season rainfall and extreme rainfall events over the low-lying parts of the basin, under all SSP scenarios, although the magnitude of change does not increase linearly with global warming levels. Another key finding is the large inter-model variability, with a range between the 25th and 75th percentiles of total wet-season and 5% AEP rainfall up to 450mm and 300mm respectively over 2015-2100, indicating high uncertainty in future rainfall.

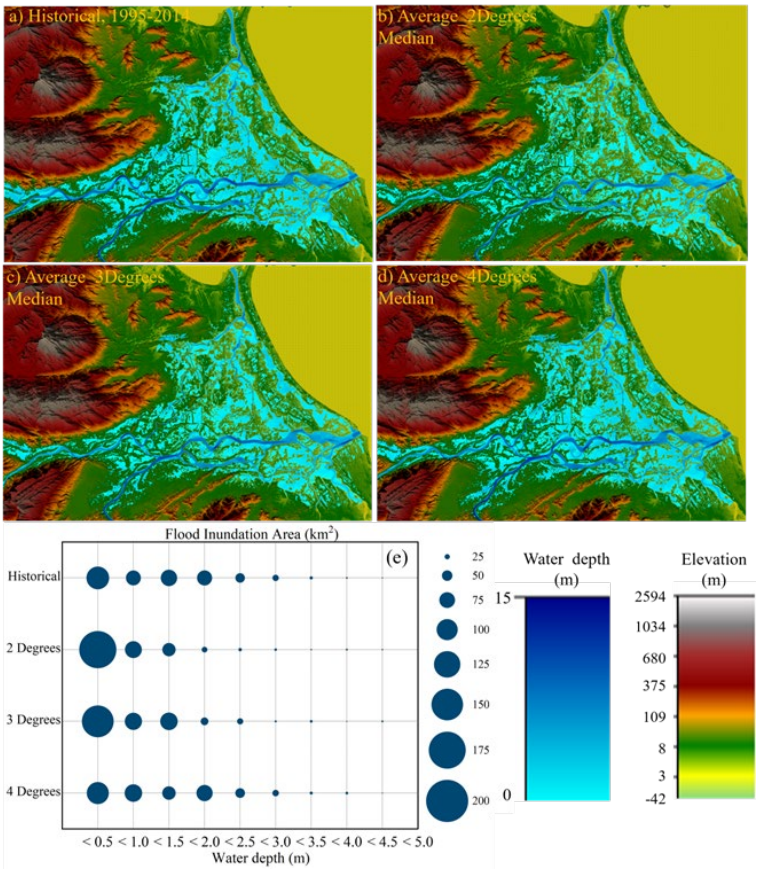
By contrast, projected river discharge upstream does not show any clear trend over future period and the median values are generally lower than for the simulated historical period, thanks to flow regulation by reservoir operations. However, projections also show substantial variability depending on the climate model inputs.

3.2. Reservoirs reduce flood extent up to 3°C of global warming

The current cascade of 18 reservoirs in the VGTB River Basin provides a clear flood-buffering effect under +2°C and +3°C GWLs. The median of the simulated inundation reaches ~440 km² under +2°C and ~465 km² under +3°C, both below the ~482 km² simulated for the pre-dam historical period.

Figure 2 also highlights the value of the reservoirs cascade, which reduces not only total inundation extent but also the area exposed to deeper water depth under moderate warming. This distinction is important for flood management policy because flood depth is closely associated with property damage, restricted emergency access, and disruption to critical services. The apparent safety margin provided by the reservoir cascade under +2°C and +3°C is therefore valuable, but it remains conditional on the magnitude and spatial distribution of future rainfall.

Figure 2. Spatial distribution of simulated floodwater depth across the floodplain under historical period (1995-2014) (a) and 2°C, 3°C and 4°C scenarios (b, c, d). (e) Total flood inundation area by water-depth class for each scenario. Results shown are based on the ensemble median projections of upstream river flow and downstream rainfall used to drive the hydrodynamic model.



3.3. At higher warming levels, reservoir buffering may be overwhelmed

Under +4°C of global warming, the simulated inundated area increases to 490 km², exceeding both the simulated historical reference and the observed 2020 flood extent. This suggests that stronger warming may reduce the safety margin currently provided by reservoir regulation. The result does not imply that reservoirs cease to influence flood dynamics or fail structurally. Nevertheless, it indicates that the net protective effect of the cascade can be offset substantially when stronger rainfall and runoff exceed the capacity of flood management measures based on reservoirs.

3.4. Downstream rainfall creates a flood-risk component that reservoirs cannot control.

Local rainfall over the downstream floodplain contributes about 30% of total floodwater input to the hydraulic domain, alongside approximately 70% from upstream inflow. Reservoirs can reduce the upstream component, but they cannot regulate floodwater generated by intense local rainfall over Da Nang, Hoi An, and other low-lying of the downstream floodplain. As extreme rainfall intensifies, this residual downstream risk may increasingly offset the flood buffering benefits of the reservoir cascade.

4. Implications

Despite some limitations — notably substantial uncertainty in AEP estimations due to limited sample sizes, distributional assumptions, and potential non-stationarity — our study shows that extreme precipitation events are projected to intensify across the VGTB River Basin. Under high global warming levels, this intensification may overwhelm reservoir flood regulation capacities, particularly for rare extreme events whose historically estimated low occurrence probabilities may no longer remain reliable under a non-stationary climate.

Large inter-model variability in climate projections creates significant uncertainty regarding the future magnitude and frequency of these events, one of the key challenges in developing new flood management policies. To address it, future policies should be stress tested across multiple climate models, warming levels, and reservoir operational assumptions, including low probability but high impact events.

The findings underscore that "stationarity" — the assumption that the future will look like the past — is no longer a viable basis for water management. The significant threat posed by unregulated downstream runoff and the increasing frequency of compound flooding driven by extreme rainfall and high tide necessitate a shift to a holistic, basin-wide adaptation strategy.

In addition, it will be crucial to also study the risks related to higher flood magnitude (e.g., 1% AEP) in future work, as more "record-shattering" events have been observed recently. Future studies should also examine the compound coastal and estuarine flood risks, defined as the co-occurrence of two or more extreme hydro-climatic conditions, particularly in Hoi An, Cua Dai, Da Nang, and other estuarine or coastal zones where river flooding may interact with coastal backwater effects.

Recommendations

By integrating non-stationary flood analysis, reservoir stress testing, real-time data sharing, and climate-resilient urban planning, Vietnam can better safeguard the socio-economic future of the VGTB basin. The key policy message is clear: reservoirs remain indispensable, but they should be complemented by downstream drainage management, exposure reduction, emergency preparedness, and coordinated basin-scale governance.

- **Shift from reservoir-centred flood control to basin-wide flood-risk management**. Flood policy must account for downstream rainfall, drainage constraints, land-use change, and growing exposure in low-lying areas. Reservoirs remain an important component of flood risk management, but they should be complemented by other lines of defence, including integrated infrastructure, non-structural measures, and early warning systems.
- **Protect and restore flood-retention spaces for risks that reservoirs cannot control**. Authorities should adopt and enforce policies to protect remaining floodplain storage areas such as wet-season paddy fields, ponds, and wetlands. These areas should be officially embedded as retention space in provincial planning. New urban development in Da Nang and Hoi An should also be required to integrate blue-green infrastructure to reduce local runoff and drainage pressure.
- **Stress-test reservoir operations across multiple future climate conditions**. Operating rules should be tested against different warming levels and more extreme conditions (e.g., 100-year return flood magnitude) to identify thresholds, failure points, and trade-offs between hydropower generation, flood safety, and downstream risk. Such tests should also explore coordinated multi reservoir operation rather than treating each reservoir as an isolated structure.
- **Build a shared flood-data and decision-support platform.** A basin-scale data hub, coordinated by basin management authorities, should integrate rainfall, discharge, water levels, reservoir operations, land use, topography, and flood exposure to support forecasting, scenario analysis, and inter-provincial coordination. This data hub should be institutionalized through coordination among relevant agencies, including the Vietnam Disaster and Dyke Management Authority, the Vietnam Hydro-Meteorological Administration, the Institute of Water Resources Planning, the Vietnam Academy of Water Resources, provincial authorities, and reservoir operators.
- **Mainstream future flood maps into planning.** High-resolution flood maps should guide infrastructure design, urban planning, emergency preparedness, and restrictions on new development in high-risk zones. Specifically, transport corridors, urban expansion areas, tourism infrastructure, and critical public services should be evaluated against future flood depths, not only historical flood records.

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