

Reviewer#2

General comment: The overall objective of this manuscript is to systematically review and synthesize recent advances (spanning from the years of 2000–2025) at the intersection of reservoir operation strategies, hydrodynamic flood modelling, and optimization frameworks. Using the Dong Nai-Sai Gon river basin as a representative tropical, tide-influenced case study, the paper aims to identify critical knowledge gaps regarding compound flooding and to propose an integrated conceptual framework that transitions reservoir management from static, rule-based operations toward adaptive, risk-informed, and AI-driven floodplain protection. The manuscript has highlighted several pivotal findings drawn from the literature. Regarding the limitations of traditional operations, the authors revealed that conventional, static rule curves are increasingly inadequate under non-stationary climatic conditions, historically leading to uncoordinated releases and resulting in a 30–40% performance deficit compared to adaptive strategies. In terms of advancements in modelling and optimization, coupled 1D-2D hydrodynamic models have significantly enhanced the representation of lateral floodplain dynamics, while advanced multi-objective optimization methods (such as evolutionary algorithms and deep reinforcement learning) can reduce peak discharges by 25–30% and greatly improve system reliability. By considering the compound flooding gap, critical research disconnected persists where spatial floodplain inundation metrics and compound flood drivers (the non-linear interaction of fluvial discharge, intense local rainfall, and tidal backwater) are rarely embedded directly into reservoir optimization objective functions. Finally, since the future AI-driven integration was critically discussed, the study outlined a progressive transition toward “Modern FIRO” (Forecast-Informed Reservoir Operations), proposing a framework that leverages real-time data, hybrid physics-machine learning models, and stochastic multi-hazard optimization to manage extreme, compound flood events in complex deltaic environments.

The manuscript offers a highly relevant and timely synthesis of reservoir operation strategies, hydrodynamic modelling, and compound flooding dynamics. The categorization of the literature into four distinct thematic areas provides a robust structure for navigating a complex interdisciplinary field, and the conceptual integration framework, particularly Figures 3B and 4, is a standout contribution that clearly visualizes the transition from static rule curves to AI-driven modern operations. This work effectively highlights the pressing need to move beyond isolated 1D stage-discharge relationships and stationary assumptions, making it a valuable addition to the literature on climate-resilient water management. Although the literature review is relatively successful in noting the above valuable findings in the field, I suggest a moderate revision before the manuscript could be considered for publication under NHESS.

Response: We sincerely thank the reviewer for this comprehensive, encouraging, and accurate synthesis of our manuscript. We deeply appreciate the reviewer’s recognition of the timeliness of this review, the value of our four-theme categorization, and the utility of the conceptual integration frameworks in advancing climate-resilient water management. The reviewer’s constructive assessment is highly appreciated, and we have carefully implemented the recommended moderate revisions by addressing all specific comments and suggestions point-by-point below to significantly enhance the clarity, precision, and overall quality of the paper.

Comment 1: First, while the methodological framework outlined in Figure 1 is visually intuitive, the narrative description of the literature screening process requires greater transparency. The manuscript notes that the initial searches yielded 297 papers from primary databases and 260 from supplementary sources, yet the final synthesis matrix details only 20 primary studies. To strengthen the rigor and reproducibility of this review, it is necessary to explicitly define the quantitative or qualitative rationale used to distill these hundreds of initial records down to the 20 studies featured in Table 1. Clarifying whether these studies were selected for their specific focus on tropical monsoon basins, their benchmark algorithmic contributions, or citation impact will elevate the academic rigor of the methodology section.

Response 1: We agree with the reviewer that clarifying the screening funnel and the distillation criteria between the broader literature synthesized across the text and the 20 primary studies (actually 19 primary studies eventually for in-depth analysis classified into 4 themes) summarized in Table 1 (and we put the number order in first column of Table 1) is essential for transparency and reproducibility.

Based on the reviewer’s suggestion, we have revised Section 2.2 (Study selection criteria) and Section 2.4 (Literature synthesis approach) to define this multi-stage distillation process explicitly.

Text in Section 2.2 has been revised:

“Following the search strategy outlined in Section 2.1, records were screened in two sequential stages: title and abstract screening across all 557 retrieved records (297 from Web of Science and Scopus, and 260 from Google Scholar), followed by full-text assessment that yielded 39 eligible articles categorized into three thematic clusters.

From these, only 19 benchmark studies were selected for in-depth across four thematic groups to fit the review's scope. Studies were included if they were peer-reviewed, English-language publications that substantively addressed at least one of the four targeted pillars: reservoir operation strategies, numerical flood propagation modelling, optimization methods applied to water infrastructure, or compound flood interactions (see Section 2.3 for details). Articles limited strictly to standalone rainfall-runoff modelling without hydrodynamic flood routing, non-peer-reviewed conference abstracts, or non-reservoir flood protection structures were excluded. No minimum citation threshold was imposed, ensuring recent high-impact publications (2020–2025) were thoroughly captured.”

Text in Section 2.4 has been revised:

“To facilitate structured comparison, Table 1 maps the 19 selected benchmark studies across the groups, detailing each study’s objective, methodology, primary findings, and operational implications. Notably, the limited overlap between Theme 3 (optimization) and Theme 4 (compound flooding) within the matrix reflects the core knowledge gap this review addresses: the scarcity of operational frameworks that directly couple multi-reservoir optimization with compound flood inundation metrics in tropical, tide-influenced basins”.

Comment 2: Second, the manuscript would benefit from weaving the case perspective of the Dong Nai-Sai Gon basin more organically throughout the earlier sections, rather than reserving it predominantly for Section 6.3. Introducing the specific compound flooding challenges of Ho Chi Minh City and the Dau Tieng reservoir earlier would ground the theoretical discussions of optimization and 2D modelling in a tangible reality. Furthermore, in the specific context of the Dong Nai–Sai Gon basin, the authors should incorporate additional discussion of upstream flooding in the Dong Nai River, as highlighted by recent runoff forecasting research (10.1080/02626667.2025.2461705), as well as the bidirectional interactions between tidal flows and riverine flows in the downstream Dong Nai–Sai Gon system. These hydrodynamic interactions are particularly relevant to compound flooding and should be explicitly considered in the proposed integrated framework. Previous studies have demonstrated the importance of hydrodynamic and morphodynamic processes in the lower basin and estuarine system (10.1016/j.jhydrol.2022.127572; 10.1080/00221686.2025.2456727), while recent research has further highlighted the strong influence of tidal dynamics on peak water-level forecasting in the tidal-dominated Dong Nai–Sai Gon basin (10.1080/02626667.2026.2671902).

Response 2: We fully agree that anchoring the theoretical discussions in the tangible, empirical reality of the Dong Nai–Sai Gon (DN–SG) basin and Ho Chi Minh City (HCMC) throughout the earlier sections significantly strengthens the manuscript’s cohesion.

In accordance with the reviewer’s recommendations, we have revised the manuscript across four major dimensions:

- 1. Introducing the case study into earlier sections:* We have introduced the practical management dilemmas of Dau Tieng and Tri An reservoirs and HCMC’s compound vulnerability into the Introduction (Section 1), the reservoir rule-curve critique (Section 3.2), the hydrodynamic modelling analysis (Section 4.3), and the optimization discussion (Section 5.3).
- 2. Upstream flooding and runoff forecasting in the Dong Nai River:* We have incorporated explicit discussions on upstream hydrologic variability, runoff forecasting challenges, and inflow uncertainty in the Dong Nai river basin, citing recent findings (doi:10.1080/02626667.2025.2461705).
- 3. Bidirectional tidal–fluvial and estuarine morphodynamics:* We have expanded our evaluation of the complex downstream estuarine dynamics, highlighting how bidirectional tidal flows interact with fluvial discharge, and how anthropogenic and natural morphodynamic shifts (such as riverbed bathymetry alterations and sand mining) reshape tidal propagation and coastal backwater profiles in the lower DN–SG system (doi:10.1080/00221686.2025.2456727).
- 4. Tidal influence on peak water-level forecasting:* We integrated recent advances on how strong semi-diurnal tidal modulation governs peak water-level forecasting and compound flood timing in the tidal transition zone of HCMC (citing doi:10.1080/02626667.2026.2671902), emphasizing that downstream optimization targets cannot be formulated without accounting for these tidal mechanics.

All corresponding citations have been incorporated into the narrative and added to the Reference list.

Section 1 (Introduction):

“This review synthesizes the current state of the art in coupling reservoir operations with downstream hydrodynamic modelling and optimization. To anchor this synthesis in operational reality, we thread empirical perspectives

throughout this paper from the Dong Nai–Sai Gon (DN–SG) river basin in southern Vietnam—a globally representative archetype of heavily urbanized, tide-dominated tropical deltas. With about 13 million inhabitants across Ho Chi Minh City and Binh Duong Province, downstream flood vulnerability is acutely shaped by the physical interplay between upstream multi-reservoir releases (principally Dau Tieng and Tri An), local monsoonal downpours, and strong semi-diurnal East Sea tides. The paper maps key knowledge gaps across these domains and examines how emerging tools can chart a course from reactive reservoir management toward proactive, risk-informed floodplain protection.”

Section 3.2 (Traditional reservoir operating rules):

“Second, conventional rule curves treat downstream boundaries as static stage–discharge relationships rather than dynamic, backwater-dominated environments. This operational mismatch is clearly evident in the DN–SG basin: Dau Tieng reservoir (Sai Gon sub-basin) and Tri An reservoir (Dong Nai sub-basin) are historically governed by deterministic seasonal rule curves that dictate releases based almost solely on current pool elevation and historical inflow patterns. However, recent hydrological investigations reveal that upstream runoff in the mountainous Dong Nai catchment exhibits intense non-stationarity and rapid rainfall-runoff response times, creating substantial inflow forecasting errors when relying on traditional routing (Le et al., 2025). When upstream runoff pulses are poorly forecasted, rigid rule curves force sudden, large-volume spillway discharges that coincide with rising downstream tides, turning independent reservoir safety protocols into inadvertent drivers of downstream inundation as demonstrated by the International Commission on Large Dams (ICOLD), (2025). Third, static rules lack the predictive feedback loops necessary to balance upstream retention against shifting downstream carrying capacities under climate change (Giuliani et al., 2021).”

Section 4.3 (Coupled 1D–2D modelling frameworks):

“The necessity of this explicit dimensional coupling becomes even more pronounced when analysing the systemic impacts of structural flood interventions. For instance, coupled applications within the Sai Gon–Dong Nai river system demonstrate that flood mitigation cannot be conceptualized merely as total volume reduction, but as a complex spatial redistribution of hydrodynamic risk across tidally influenced networks (Markova et al., 2025). Crucially, the lower DN–SG system and its estuarine distributaries (such as the Soai Rap and Ganh Rai estuaries) are characterized by strong bidirectional tidal flows, where incoming tidal surges regularly reverse river currents more than 80 km upstream of the coast. Recent hydrodynamic and morphodynamic research indicates that pervasive anthropogenic alterations, particularly intensive riverbed sand mining and channel deepening, have drastically modified downstream bathymetry and estuarine conveyance, driving non-linear tidal amplification and allowing tidal backwater to propagate further upstream into Ho Chi Minh City’s urban core (Ngoc Anh et al., 2022). Coupled 1D–2D numerical configurations are therefore essential: they resolve both the 1D bidirectional momentum transfer within deepened estuarine channels and the 2D hydrodynamic overbank spilling that occurs when upstream releases from Dau Tieng and Tri An encounter tide-locked coastal boundaries.”

Section 5.3 (Simulation-optimization frameworks):

“...Instead, the vast majority of existing studies continue to rely on simplified discharge or water stage thresholds measured at a single downstream gauge to serve as surrogate flood objectives. This creates a severe misrepresentation of floodplain hazard in estuaries dominated by compound dynamics. In the tidal-dominated lower DN–SG basin, for example, peak water levels at urban control points (such as Phu An on the Sai Gon River and Bien Hoa on the Dong Nai River) are governed far more strongly by the phase alignment of semi-diurnal astronomical tides than by upstream discharge volume alone (Le et al., 2026). Recent forecasting studies demonstrate that incorporating bidirectional tidal interactions and estuarine water-level dynamics is paramount for predicting downstream peak stage exceedances accurately. If an optimization algorithm evaluates candidate releases from Dau Tieng or Tri An against a static, unidirectional stage–discharge curve without accounting for this tidal modulation, it will fail to identify release timings that prevent catastrophic downstream water-level peaks. Closing this gap requires optimization engines driven directly by coupled models or surrogate emulators that explicitly integrate dynamic coastal tidal boundaries.”

Section 6.3.1 (Case perspective: Dong Nai–Sai Gon river basin):

“...To meet water supply requirements for irrigation and flushing saltwater intrusion in the dry seasons, Dau Tieng reservoir receives a supplemental transfer of 30–40 m³/s in average annually from the Phuoc Hoa reservoir on the Be River. In parallel, the Tri An reservoir on the Dong Nai River (2.76 billion m³) regulates the upper Dong Nai River. Recent research underlines that upstream runoff in the Dong Nai basin is subject to extreme orographic

precipitation events and rapid flood peaking, demanding advanced data-driven runoff forecasting frameworks to capture inflow surges into Tri An (Le et al., 2025). Downstream, the confluence of the Sai Gon and Dong Nai rivers discharges through a heavily modified estuarine complex into the East Sea, where pervasive riverbed morphodynamic changes and sand mining have systematically altered tidal wave propagation and amplified estuarine flood peaks (Le et al., 2025). The strong bidirectional flow regime means that downstream flood severity in HCMC is dictated by the precise temporal synchronization between upstream reservoir release waves and peak tidal phases (Le et al., 2026)."

Comment 3: Third, to enhance the practical feasibility of the proposed framework, the authors should consider incorporating an assessment of data availability in Vietnam. In the proposed Integrated Framework for the Dong Nai–Sai Gon (DN–SG) basin, the authors mention weather radar, IoT, and digital twins. However, in practice, Vietnam’s monitoring network remains relatively sparse, while data sharing between reservoirs (e.g., Dau Tieng and Tri An) is sometimes interrupted or does not provide real-time data. The authors should include a brief discussion of data-related challenges and how AI models can help address the problem of data scarcity.

Response 3: We thank the reviewer for this practical observation. While in-situ monitoring networks in Vietnam are relatively sparse and inter-agency data sharing between Dau Tieng and Tri An can experience latency, this practical constraint actually highlights the necessity of AI-driven tools. Machine learning models directly mitigate observational gaps through satellite data fusion, deep-learning-based imputation of missing telemetry, and physics-informed learning that reduces reliance on dense physical sensor arrays. We have added a targeted paragraph in Section 6.3.2 to discuss these data-related challenges and their AI-enabled solutions.

In Section 6.3.2, text has been revised: *“...In applying this framework to the DN–SG basin, operational implementation must account for practical data constraints, including relatively sparse in-situ hydro-meteorological gauge networks and episodic or asynchronous data sharing between Dau Tieng (managed for irrigation and flood control) and Tri An (managed for hydropower). Rather than hindering modern operations, these constraints highlight the critical utility of AI approaches to overcome data scarcity. Machine learning algorithms can fuse sparse ground observations with satellite-derived rainfall (e.g., GPM-IMERG) and remote sensing altimetry to bridge spatial gaps across upstream catchments. Furthermore, deep learning imputation models (such as Bi-LSTMs) can reconstruct missing or delayed telemetry during transmission outages, while Physics-Informed Neural Networks (PINNs) integrate fundamental conservation laws to maintain predictive accuracy with limited training observations, thereby ensuring operational feasibility even within data-sparse environments.*

In Conclusions section, text (paragraph 1, last part) has been revised:

“...Last but not least, real-time reservoir management under compound uncertainty and institutional fragmentation: operational decision-making in coastal deltas requires simultaneous quantification of multi-source uncertainty across rainfall nowcasts, catchment inflows, tidal surges, and hydrodynamic parameters, while contending with sparse hydrometric networks and administrative silos that restrict real-time data exchange between independent agricultural and hydropower reservoirs.”

Comment 4: Fourth, although Deep Reinforcement Learning (DRL) algorithms can achieve very high predictive or decision-making accuracy, they are often characterized as “black-box” models, making it difficult to explain the rationale behind a particular flood-release decision. Meanwhile, reservoir managers require transparency, interpretability, and safety assurance before implementing operational decisions. The authors should therefore further discuss Explainable Artificial Intelligence (XAI) in the Future Directions section to strengthen the framework’s credibility and acceptance among policymakers and reservoir managers.

Response 4: We agree with the reviewer’s valuable suggestion. While Deep Reinforcement Learning (DRL) and complex ML architectures demonstrate superior optimization efficiency, their opaque “black-box” nature creates significant hesitation among reservoir operators and water authorities who demand physical interpretability, auditability, and safety assurances.

In the revised manuscript, we have updated the first point in our future directions (Conclusions Section, paragraph 2) to explicitly incorporate Explainable Artificial Intelligence (XAI). We highlight how interpretable methods (e.g., attention mechanisms, feature attribution, and physics-constrained surrogate architectures) provide human-in-the-loop transparency, elucidating why a particular release trajectory is selected and fostering institutional trust among managers and policymakers.

“Future research directions should prioritize three interconnected advances. First, hybrid physics–AI frameworks and Explainable Artificial Intelligence (XAI) offer both the computational efficiency and operational transparency

required to close the gap between optimization, dam safety governance, and full floodplain impact assessment. Here, AI encompasses three specific functional tools: (i) sequence-learning models (e.g., LSTMs and Transformers) for reservoir inflow and storm surge forecasting, (ii) physics-informed neural networks (PINNs) surrogates that emulate 2D flood inundation in real time, and (iii) deep reinforcement learning (DRL) algorithms that map forecast states to multi-reservoir release decisions under non-stationary conditions (Bhargav et al., 2025). Long Short-Term Memory (LSTM) networks have emerged as the dominant algorithm in data-driven flood forecasting (21% of implementations), while hybrid and ensemble approaches showed the most dramatic growth from 2% to 10% of implementations between 2019 and 2024, confirming a rapid transition toward hybrid physics–ML frameworks as an operational standard. Crucially, because the opaque “black-box” architecture of DRL and deep neural surrogates poses a major barrier to real-world deployment, future work must integrate XAI techniques—such as post-hoc feature attribution (e.g., SHAP, attention maps) and symbolic policy distillation into verifiable decision trees—coupled with hard, physics-based safety envelopes. This interpretability is vital to ensure transparency, satisfy regulatory accountability, and provide reservoir managers with the safety assurance required to execute high-stakes flood release decisions. Second, digital twins for flood forecasting—virtual replicas of river basins updated in real-time from IoT sensors, satellite observations, and numerical weather prediction—provide the integrated observational–predictive infrastructure needed to support compound-aware reservoir decisions (Hlal et al., 2025). Digital twin technology applied to urban flood risk management has demonstrated reduced flood response times of up to 40% through real-time data integration and predictive modelling, with remote sensing and machine learning serving as key enabling technologies. Third, climate-resilient reservoir management must explicitly account for non-stationary hydrological conditions by embedding climate projections into optimization frameworks, rather than assuming the stationarity of historical inflow statistics that underlies conventional rule curve design (Hlal et al., 2025).”

Comment 5: Fifth, when multi-objective optimization algorithms such as NSGA-III are applied to reservoir operation, reducing downstream flood risk will inevitably involve some trade-offs with other objectives, such as hydropower generation and dry-season water storage. The manuscript should place greater emphasis on how this economic–safety trade-off is quantified and evaluated within the objective functions.

Response 5: Thanks the reviewer for pointing out this. In multi-objective reservoir optimization, the economic–safety trade-off is quantified by balancing flood mitigation goals against economic and conservation targets across a multi-dimensional objective space. In keeping with the broad synthesis scope of this review paper, we have avoided heavy mathematical formulations and instead added a clear textual explanation in Section 5.2 (second paragraph) describing how these competing priorities are evaluated along the Pareto frontier.

“...While NSGA-III introduces reference-point-based diversity preservation to better manage three or more objectives, an enhanced iteration (ENSGA-III) deployed at the Three Gorges Reservoir incorporates orthogonal design for initial population generation alongside an ϵ -dominance strategy to produce exceptionally well-distributed Pareto-optimal solutions. In these frameworks, the economic–safety trade-off is evaluated by contrasting flood risk reduction metrics—such as minimizing downstream peak discharges or suppressing peak reservoir water levels—against economic and conservation priorities, primarily maximizing hydropower revenue and securing full storage refill for dry-season municipal, agricultural, and salinity-flushing demands. The resulting Pareto front allows decision-makers to directly quantify the marginal loss in energy output or dry-season water availability incurred for each incremental gain in downstream flood protection...”

Comment 6: Finally, while the advocacy for AI, machine learning, and digital twins in the “Modern FIRO” framework is forward-looking, a critical discussion on the feasibility of deploying these computationally heavy and data-reliant frameworks in developing or data-scarce regions would provide a more balanced, pragmatic conclusion to this excellent review.

Response 6: We thank the reviewer for this insightful and pragmatic comment. We completely agree that the operationalization of data-intensive and computationally heavy architectures, such as full digital twins and continuous online simulation, faces substantial logistical and resource hurdles in developing and data-scarce settings. In these regions, limited computational infrastructure, high cloud-computing costs, and sparse or unreliable sensor networks often prevent immediate, full-scale deployment.

To provide a balanced and pragmatic perspective, we have expanded Section 7 (Conclusions / Future Directions) to address deployment feasibility directly. We emphasize a phased, resource-appropriate transition pathway: utilizing open-access satellite earth observations to overcome ground data gaps, leveraging pre-trained lightweight offline surrogate models that run efficiently on standard desktop hardware during emergencies, and adopting tiered, hybrid

operational frameworks that bridge traditional rule curves and AI-driven decision-making without requiring prohibitive high-performance computing investments.

References:

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