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Defining a new hydrological normal for the Vietnamese Mekong Delta: distinguishing upstream regulation from climate variability

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Abstract

Purpose – The Vietnamese Mekong Delta (VMD) is confronting a fundamental hydrological shift. This study aims to quantify this emerging hydrological normal by distinguishing the effects of upstream regulation from basin-wide climate variability.

Design/methodology/approach – We analyzed daily discharge and rainfall data for 2000–2024 at Tan Chau and at upstream stations (Luang Prabang, Pakse, Mukdahan and Kratie). The analysis combines Mann–Kendall tests, Sen's slope estimator, the range of variability approach (RVA), the hydrologic alteration factor (HAF) and Mann–Whitney *U* tests for the 2000–2009 baseline and 2010–2024 regulated period.

Findings – The analysis reveals a profound hydrological homogenization of the annual hydrograph. Key findings include: While upstream rainfall trends were non-significant or decreasing ($Z < 0$), dry-season discharge increased significantly across upstream and mid-basin stations (e.g. + 110.0 m^3/s/year at Luang Prabang), whereas Tan Chau showed no statistically significant trend, indicating downstream attenuation of the regulated signal; RVA analysis shows high alteration levels for discharge (HAF~−0.87 to −1.00), whereas rainfall RVA/HAF includes some high-magnitude monthly values but is mostly not statistically significant in Mann–Whitney tests, supporting discharge-rainfall decoupling; The flood pulse has been severely dampened. Notably, the strong La Niña year of 2021 produced flood peaks 41.3% below the 2000–2008 baseline at Pakse

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and 25.5% below the baseline at Kratie, confirming that reservoirs are systematically overriding natural climate signals.

Originality/value – The revised analysis shows that upstream regulation has reshaped the basin hydrograph most clearly in the upper and middle Mekong, while the delta gateway response is buffered by tributary inflows, Tonle Sap storage and channel-scale attenuation. This distinction provides a more defensible basis for adaptation planning in the VMD.

Keywords Hydrological alteration, Mekong Delta, Range of variability approach (RVA), Dam regulation, Climate variability, Water management

Paper type Research paper

I. Introduction

River deltas represent some of the most dynamic, biologically diverse and economically vital landscapes on Earth (Giosan *et al.*, 2014; Syvitski *et al.*, 2009). Acting as the critical interface between terrestrial and marine environments, these systems support dense human populations and serve as global agricultural powerhouses (Bui and Dang, 2025; Rogozhina, 2022). However, their sustainability relies heavily on a delicate equilibrium between sediment deposition, which counters subsidence, and the erosive forces of the ocean (Xue *et al.*, 2012; Zoccarato *et al.*, 2018; Minderhoud *et al.*, 2019). This balance is increasingly threatened by anthropogenic interventions, particularly the construction of mega-dams that fundamentally alter riverine hydrology and sediment transport (Kondolf *et al.*, 2014; Schmitt *et al.*, 2017).

The Vietnamese Mekong Delta (VMD), often described as the "rice bowl" of Southeast Asia, exemplifies this precarious existence (Syvitski *et al.*, 2009; Giosan *et al.*, 2014). Home to nearly 20 million people and accounting for a significant portion of Vietnam's rice exports and aquaculture, the VMD's ecological health has evolved over millennia in sync with the Mekong River's natural flood pulse (Bui and Dang, 2025; Kummu and Varis, 2007). This unique hydrological rhythm – characterized by a distinct monsoon-driven flood season and a dry season – is the engine of the delta's productivity (Bui and Dang, 2025; MRC, 2019). The annual floods deliver essential nutrient-rich sediments to the floodplains, replenish groundwater aquifers and, critically, provide the hydraulic pressure necessary to flush saline water out of the intricate canal network (Chau *et al.*, 2026; Quang *et al.*, 2026; Wang *et al.*, 2011). Consequently, the livelihoods, culture and biodiversity of the region are intrinsically linked to the predictability and variability of this natural flow regime (Bui and Dang, 2025; MRC, 2019).

Over the past three decades, however, the Mekong River Basin has undergone a radical transformation, becoming a focal point for one of the world's most intensive hydropower development campaigns (Lu *et al.*, 2021; Ly *et al.*, 2023; Grumbine and Xu, 2011). The construction of a cascade of large-scale dams on the Upper Mekong (Lancang) in China, followed by mainstream and tributary dams in the Lower Mekong Basin (Laos PDR, Cambodia), has created a massive active storage capacity capable of reshaping the river's hydrology (Lauri *et al.*, 2012; Hecht *et al.*, 2019). The operational logic of these reservoirs is consistent: store water during the wet season to mitigate floods and generate power, and release water during the dry season to maintain electricity production. While this regulation offers theoretical benefits such as flood control and dry-season irrigation, it inadvertently disrupts the natural flood pulse that the VMD ecosystem depends upon (Richter *et al.*, 1996; Li *et al.*, 2017).

Despite the growing body of literature documenting flow alterations in the Mekong (Binh *et al.*, 2020; Räsänen *et al.*, 2017), a scientific debate persists regarding the primary driver of these changes. Is the observed hydrological shift predominantly a consequence of upstream reservoir operations, or is it merely a reflection of basin-wide climate variability, such as changing precipitation patterns driven by El-Niño-Southern Oscillation (ENSO)? Critics of the “dam-driven” hypothesis argue that analyzing discharge solely at the delta’s gateway (e.g. Tan Chau and Chau Doc stations) is insufficient to rule out climatic drivers, as local rainfall anomalies could skew the interpretation. Furthermore, existing studies often lack a rigorous, basin-wide attribution framework that quantitatively disentangles the effects of rainfall variability from flow regulation.

This ambiguity presents a significant challenge for policymakers in the VMD. Without a definitive attribution of causes, developing effective adaptation strategies is fraught with uncertainty (Binh *et al.*, 2020). If the changes are climate-driven, they might be cyclical or random; if they are dam-driven, they represent a structural, permanent shift – a “new normal” that requires a fundamental overhaul of water management paradigms. The lack of a clear, quantified baseline for this regulated era hampers the ability to model salinity intrusion accurately, plan agricultural calendars and negotiate transboundary water release protocols.

2. Material and methods

2.1 Study area and data collection

The study encompasses the Mekong River Basin, stretching from the Upper Mekong cascade down to the VMD. The VMD is a vast, low-lying coastal plain highly susceptible to the interplay between river discharge and marine tides (Nguyen *et al.*, 2025b; Zoccarato *et al.*, 2018). To ensure spatial representativeness and capture the downstream propagation of hydrological signals, we utilized daily discharge and rainfall data from five key stations along the mainstream: Luang Prabang (Laos, immediately downstream of the Lancang cascade), Mukdahan (Thailand), Pakse (Laos), Kratie (Cambodia – the primary control station before the delta) and Tan Chau (Vietnam – the primary gateway to the VMD). Figure 1 illustrates the study area and the geographical distribution of these hydrological and meteorological stations. The basin’s morphology plays a crucial role, with the mean slope decreasing significantly from the mountainous upper reaches to the flat deltaic plains, facilitating sediment deposition and flow attenuation (Bussi *et al.*, 2021; Wolman and Miller, 1960).

Data were collected for the 25-year period from 2000 to 2024, sourced from the Mekong River Commission and the Vietnam National Center for Hydro-Meteorological Forecasting. Table 1 summarizes the specific characteristics and data duration for these stations. The data set was divided into two periods based on the timeline of major dam commissioning (e.g. Xiaowan in 2010, Nuozhadu in 2014):

(1) Growth-dam period (2000–2009): This 10-year period represents the initial phase of major dam construction. While some regulation effects were emerging from dams, the river’s flow regime retained significant natural variability, making it a suitable baseline for a “pre-mega-dam” state.

(2) Mega-dam period (2010–2024): This 15-year period covers the full operational phase of the Lancang cascade’s largest reservoirs and subsequent downstream developments, representing the current, highly regulated state of the river.

2.2 Methodology

2.2.1 Trend analysis. We employed the Mann–Kendall test and Sen’s slope estimator to detect monotonic trends in both discharge and rainfall time series (Lee and Dang, 2019; Nguyen *et al.*, 2025a). This non-parametric approach is widely accepted in hydro-climatic studies as it is robust against outliers and non-normally distributed data (Lee and Dang, 2019; Huy *et al.*, 2025). A trend is considered statistically significant if the p-value is less than 0.05 (Kendall, 1975; Mann, 1945).

Figure 1. Map of the study area with gauge locations shown in pink triangles

Table 1. Basic information on precipitation gauges and water level observation stations

Station	Long	Lat	Rainfall (mm)	Discharge (m^3/s)	Duration (year)
Luang Prabang	102.13	19.88	x	x	2000–2024
Kratie	106.01	12.48	x	x	2000–2024
Pakse	105.81	15.09	x	x	2000–2024
Mukdahan	104.73	16.58		x	2000–2024
Tan Chau	105.24	10.80	x	x	2000–2024

Note(s): X in Table 1 only means that the stations Luang Prabang, Kratie, Pakse and Tan Chau have both rainfall and discharge while Mukdahan only has discharge data

2.2.2 Range of variability approach and hydrologic alteration factor. To move beyond simple trend detection and quantify hydrological alteration, we applied the Range of Variability Approach (RVA) of Richter *et al.* (1996). The target range was defined as the 25th–75th percentile of the baseline period (2000–2009) and post-regulation observations (2010–2024) were assessed against this range. The HAF was interpreted as a magnitude metric, whereas the Mann–Whitney *U* test was used as a statistical test of distributional differences.

Hydromorphometric descriptors such as basin centre of gravity, drainage density and catchment form were not included as inputs to the RVA/HAF calculation because RVA/HAF is a time-series alteration framework based on observed flow and rainfall regimes. These relatively static basin descriptors are instead used conceptually to interpret spatial attenuation and lag-time effects along the river continuum:

$$\mathrm{HAF} = (\text{Observed frequency} - \text{Expected frequency})/\text{Expected frequency} \quad (1)$$

where observed frequency is the percentage of post-regulation years falling within the RVA target range, and expected frequency is 50% because the target range is defined by the 25th–75th percentiles of the baseline period. $|\mathrm{HAF}| < 0.33$: low alteration $0.33 \leq |\mathrm{HAF}| < 0.67$: moderate alteration; $|\mathrm{HAF}| \geq 0.67$: high alteration. Attribution was based on the combined evidence from discharge HAF, rainfall HAF, Mann–Whitney *U* tests and spatial consistency across stations, rather than on HAF magnitude alone.

3. Results

3.1 Divergent trends: decoupling of discharge from rainfall

The Mann–Kendall analysis reveals a clear decoupling between discharge and rainfall, but the strength of this signal varies by station (Figure 2 and Table 2). Dry-season discharge increased significantly at Luang Prabang (Sen's slope = +110.0 m^3/s/year, $p = 0.002$), Pakse (+36.8 m^3/s/year, $p = 0.038$) and Mukdahan (+393.4 m^3/s/year, $p < 0.001$). Kratie showed a non-significant dry-season trend ($p = 0.072$) but a significant flood-season decrease, while Tan Chau showed no significant trend in annual, dry-season or flood-season discharge. These

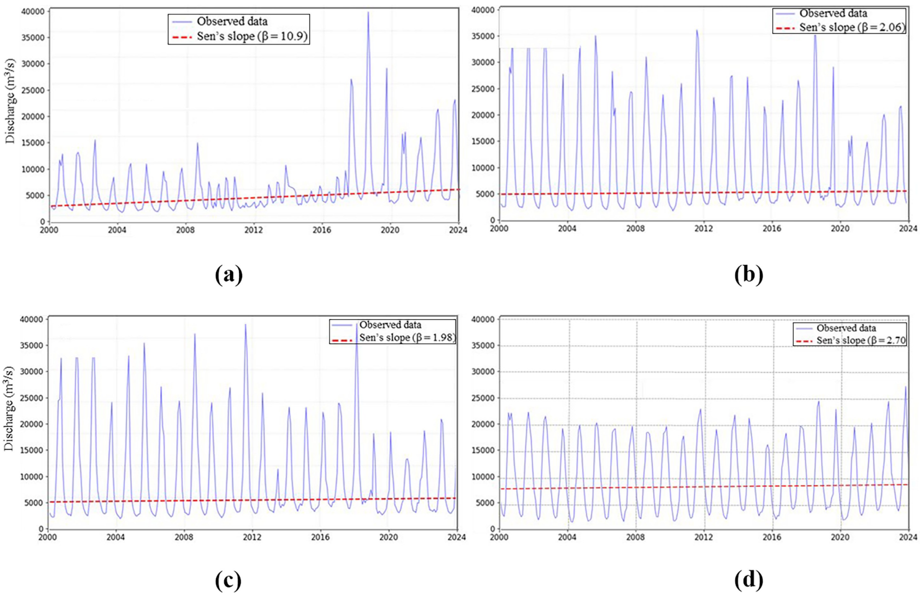


Figure 2. Discharge trends at (a) Luang Prabang, (b) Pakse, (c) Mukdahan and (d) Tan Chau during 2000–2024

Table 2. Trend analysis results for discharge at stations along the Mekong River (2000–2024)

Type	Trend	*p*-value	β	Significant	τ	Duration
Luang Prabang						
Annual	Increasing	0.011	206.6	Yes	0.367	2000–2024
Dry season	Increasing	0.002	110.0	Yes	0.453	2000–2024
Flood season	No trend	0.118	287.8	No	0.227	2000–2024
Pakse						
Annual	Decreasing	0.007	−152.9	Yes	−0.387	2000–2024
Dry season	Increasing	0.038	36.8	Yes	0.300	2000–2024
Flood season	Decreasing	0.003	−351.3	Yes	−0.427	2000–2024
Mukdahan						
Annual	Decreasing	0.038	−107.6	Yes	−0.300	2000–2024
Dry season	Increasing	<0.001	393.4	Yes	0.547	2000–2024
Flood season	Decreasing	<0.001	−645.7	Yes	−0.647	2000–2024
Kratie						
Annual	Decreasing	0.034	−137.5	Yes	−0.307	2000–2024
Dry season	No trend	0.072	34.1	No	0.260	2000–2024
Flood season	Decreasing	0.012	−299.4	Yes	−0.360	2000–2024
Tan Chau						
Annual	No trend	0.691	21.6	No	0.060	2000–2024
Dry season	No trend	0.441	21.9	No	0.113	2000–2024
Flood season	No trend	0.944	−15.4	No	−0.013	2000–2024

Note(s): β: Sen's slope

results support a regulated-flow signal that is strongest upstream and becomes attenuated toward the delta gateway.

Rainfall patterns do not show a corresponding basin-wide increase (Figure 3 and Table 3). Recomputed Mann–Kendall tests indicate no significant increasing trend in dry-season rainfall at Luang Prabang, Kratie, Pakse or Tan Chau (Figure 3(A)). Annual and rainy-season rainfall decreased significantly only at Tan Chau, while the remaining rainfall series were statistically non-significant (Figure 3(B)). Thus, the observed dry-season discharge increases in the upstream and mid-basin stations cannot be explained by a general wetting of the basin.

3.2 Disruption of the flood pulse: the "La-Niña paradox"

To further isolate the anthropogenic footprint from natural climate variability, we analyzed flood-pulse dynamics during selected ENSO years, noting that ENSO-monsoon interactions can substantially modulate Southeast Asian rainfall (Webster and Yang, 1992). Table 4 has been regenerated to reconcile station identities and percentage changes. In the La Niña year 2021, the flood peak at Pakse was 21,993 m^3/s, 41.3% below the 2000–2008 baseline, while the Kratie flood peak was 32,655 m^3/s, 25.5% below the baseline. The previously reported value of 14,617 m^3/s was therefore removed because it did not correspond consistently to Kratie in the verified discharge table. Mukdahan was excluded from the ENSO-year comparison in Table 4 because rechecking showed physically implausible event-year values in the available source series, suggesting a source, unit or station-labelling problem that should not be used as evidence.

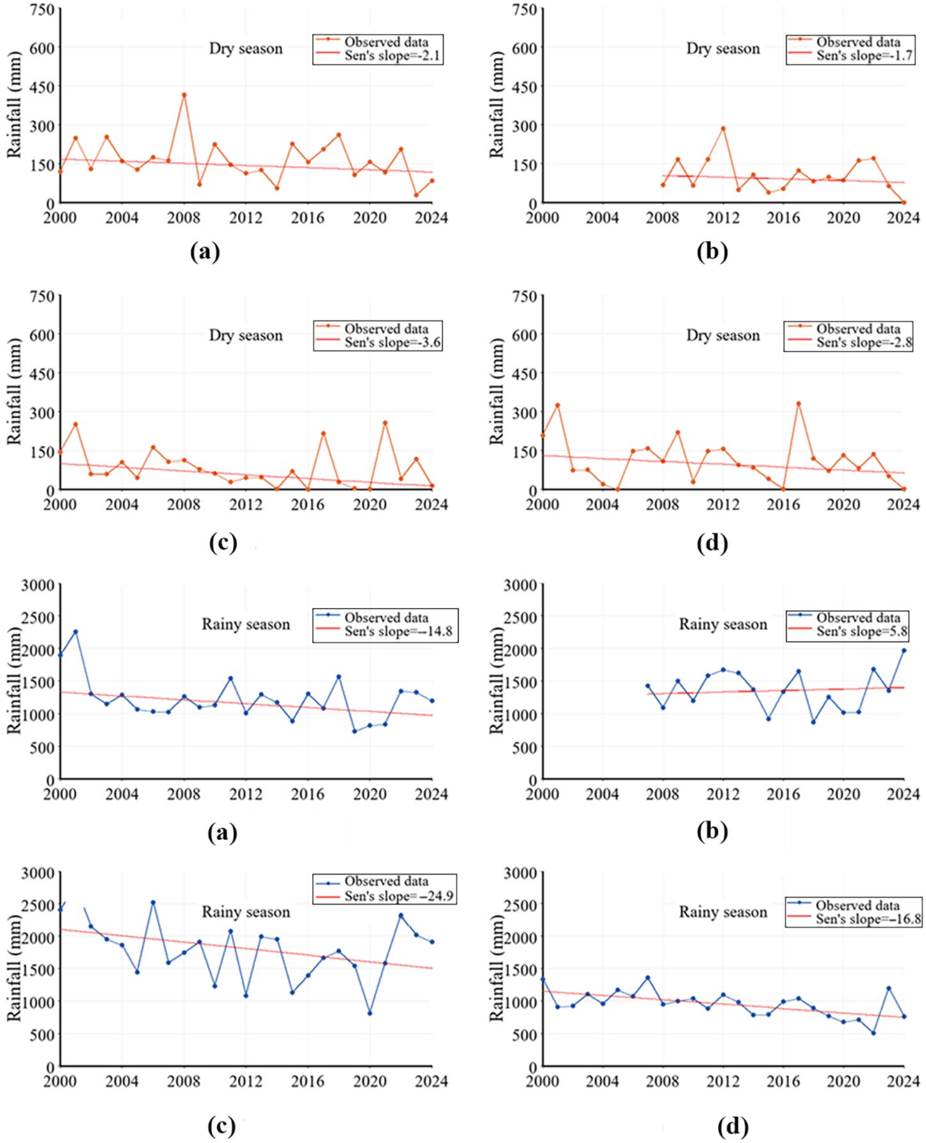


Figure 3. Rainfall trends at (a) Luang Prabang, (b) Kratie, (c) Pakse and (d) Tan Chau in the dry season (upper) and the rainy season (below) during 2000–2024

Dry-season dynamics also indicate regulation, but the magnitude is station-specific. For example, Pakse dry-season discharge was 37.5% above the baseline in 2019 and 4.4% above the baseline in 2024, whereas Kratie was 26.5% above the baseline in 2019 and 0.9% above it in 2024. These revised values support elevated dry-season baseflow in parts of the mainstream, but they do not justify a blanket statement that all stations increased strongly in all recent years.

Table 3. Trend analysis results for rainfall characteristics along the Mekong River (2000–2024)

Season	Trend	p-value	β	Significant
Luang Prabang				
Annual	No trend	0.129	−16.2	No
Dry season	No trend	0.053	−7.1	No
Rainy season	No trend	0.168	−9.3	No
Kratie				
Annual	No trend	0.880	4.4	No
Dry season	No trend	0.544	3.8	No
Rainy season	No trend	0.762	−2.3	No
Pakse				
Annual	No trend	0.088	−21.9	No
Dry season	No trend	0.053	−10.2	No
Rainy season	No trend	0.338	−11.6	No
Tan Chau				
Annual	Decreasing	0.011	−20.1	Yes
Dry season	No trend	0.216	−4.1	No
Rainy season	Decreasing	0.021	−12.9	Yes

Note(s): β: Sen's slope

Although Kratie is not displayed as a separate panel in Figure 4 to maintain figure readability, it is retained in the inferential scope and is fully analysed in Tables 2, 4 and 5.

3.3 Quantification of hydrological alteration using range of variability approach

The RVA analysis provides a statistical quantification of this regime shift (Table 5). At Luang Prabang, discharge during February, March and April exhibits high alteration (HAF = −0.87 to −1.00) with significant Mann–Whitney *U* results. Pakse, Mukdahan and Kratie also show high dry-season discharge alteration in several months, whereas Tan Chau shows mainly low-to-moderate alteration, with only April significant. This spatial pattern is consistent with strong upstream regulation and downstream attenuation.

Applying the same RVA framework to rainfall (Table 6) requires a distinction between HAF magnitude and statistical significance. Several rainfall months have high-magnitude HAF values, but most Mann–Whitney *U* tests are not significant; the main significant rainfall change occurs at Pakse in March. The defensible contrast is therefore not that rainfall has no high HAF values, but that rainfall alterations are generally less statistically consistent than discharge alterations. Physically, this means that month-to-month rainfall redistribution can occasionally fall outside the baseline interquartile range, yet it does not reproduce the coherent, multi-station dry-season discharge increase created by reservoir storage and release operations. This contrast supports, rather than proves on its own, the interpretation that the observed discharge alteration is not primarily explained by rainfall variability.

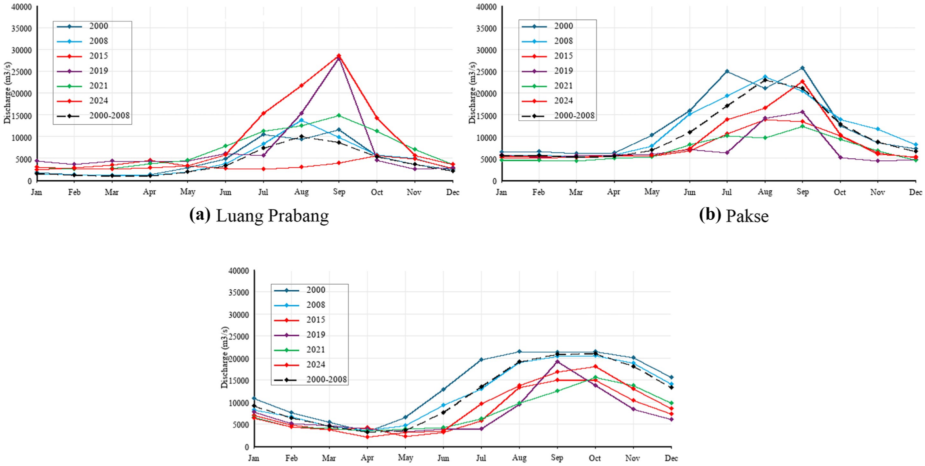
4. Discussion

4.1 Attribution of changes: dams and climate

Our findings directly address the attribution question raised in previous studies. Rainfall does not show a basin-wide increase capable of explaining the dry-season flow rise at Luang Prabang,

Table 4. Comparison of flood peak and dry season discharge between El-Niño/La-Niña years and the 2000–2008 baseline

Metric	Baseline (2000–2008)	La Nina 2000 (%)	La Nina 2008 (%)	La Nina 2021 (%)	El Nino 2015 (%)	El Nino 2019 (%)	El Nino 2024 (%)
Luang Prabang							
Flood peak (m^3/s)	15,809	17,714 + 12.0	21,841 + 38.2	21,993 + 39.1	8,747 −44.7	48,262 + 205.3	37,306 + 136.0
Dry season (m^3/s)	1,470	1,814 + 23.4	1,593 + 8.4	3,412 + 132.1	3,278 + 123.0	4,043 + 175.0	3,042 + 106.9
Pakse							
Flood peak (m^3/s)	37,496	45,149 + 20.4	34,099 −9.1	21,993 −41.3	29,222 −22.1	48,262 + 28.7	37,306 −0.5
Dry season (m^3/s)	2,934	3578 + 22.0	3,520 + 20.0	3,430 + 16.9	3,578 + 22.0	4,034 + 37.5	3,062 + 4.4
Kratie							
Flood peak (m^3/s)	43,854	48,461 + 10.5	39,374 −10.2	32,655 −25.5	31,558 −28.0	49,793 + 13.5	45,067 + 2.8
Dry season (m^3/s)	3,780	4356 + 15.2	4,257 + 12.6	4,225 + 11.8	4,021 + 6.4	4,782 + 26.5	3,815 + 0.9
Tan Chau							
Flood peak (m^3/s)	22,406	26,000 + 16.0	19,762 −11.8	23,100 + 3.1	17,633 −21.3	25,012 + 11.6	26,700 + 19.2
Dry season (m^3/s)	4,928	5,491 + 11.4	5,475 + 11.1	5,253 + 6.6	4,270 −13.4	4,942 + 0.3	4,993 + 1.3



(a) Luang Prabang **(b)** Pakse

(c) Tan Chau

Figure 4. Relationship between discharge and special weather events (ENSO) at selected Mekong monitoring stations shown in the figure; Table 4 provides the corresponding ENSO-year comparison for Luang Prabang, Pakse, Kratie and Tan Chau

Pakse and Mukdahan, whereas discharge exhibits a coherent regulation signal in the upper and middle basin. At Tan Chau, the absence of a significant trend indicates attenuation rather than absence of upstream influence, because tributary inflows, Tonle Sap storage and delta-channel hydraulics can buffer the upstream signal before it reaches the VMD gateway.

4.2 Spatial propagation and lag time

The analysis of stations from upstream to downstream (Luang Prabang, Mukdahan, Pakse, Kratie and Tan Chau) confirms that the regulated signal is strongest in the upper and middle Mekong and becomes less statistically distinct toward the VMD gateway. This revision avoids overstating Tan Chau: the delta gateway does not show a significant monotonic trend in Table 2, but it remains exposed to a regulated upstream hydrograph whose effects are moderated by intervening storage, tributary inflows and travel time.

It is crucial to note the phenomenon of lag time in this propagation. Water released from upstream reservoirs takes days to weeks to reach the VMD, depending on season, flow velocity and intervening storage. The weaker statistical signal at Tan Chau should therefore be interpreted as downstream buffering rather than a contradiction of the upstream-regulation finding. This lag time has practical value because transboundary reservoir-operation information could improve early warning and adaptive water management in the delta.

4.3 Implications for the "new normal"

The results define a "new normal" characterized by: Elimination of the natural flood pulse: The "beautiful floods" that historically brought sediment and fisheries wealth to the VMD are disappearing (Table 4), threatening the delta's geomorphic stability and aquaculture productivity (Anthony *et al.*, 2015; Uy *et al.*, 2025).

Table 5. Discharge analysis results using RVA and HAF indices for Mekong stations

Month	Target range (m^3/s)	Observed frequency (%)	HAF factor	Alteration level	MWU *p*-value
Luang Prabang					
Feb	976.7–1372.7	6.7	−0.87	High	<0.001
Mar	935.9–1174.5	0.0	−1.00	High	<0.001
Apr	928.5–1170.2	0.0	−1.00	High	<0.001
Aug	8,024.2–11,412.7	0.0	−1.00	High	0.846
Sep	6,690.9–9,839.0	0.0	−1.00	High	0.560
Oct	4,725.6–5,980.4	13.3	−0.73	High	0.028
Pakse					
Feb	2,227.6–2,645.7	6.7	−0.87	High	0.003
Mar	1,989.5–2,318.4	0.0	−1.00	High	<0.001
Apr	1,956.6–2,409.4	6.7	−0.87	High	<0.001
Aug	24,501.0–33,415.4	20.0	−0.60	Moderate	0.028
Sep	24,385.5–32,285.4	40.0	−0.20	Low	0.127
Oct	15,203.1–17,523.0	20.0	−0.60	Moderate	0.255
Mukdahan					
Feb	2,125.9–2574.7	0.0	−1.00	High	<0.001
Mar	1,994.8–2261.3	0.0	−1.00	High	<0.001
Apr	2,024.6–2354.0	6.7	−0.87	High	<0.001
Aug	19,940.2–29,441.1	13.3	−0.73	High	0.001
Sep	19,933.3–24,854.2	6.7	−0.87	High	0.001
Oct	10,350.0–14,138.7	6.7	−0.87	High	0.001
Kratie					
Feb	2,763.2–3,075.3	0.0	−1.00	High	0.033
Mar	2,468.8–2,796.4	6.7	−0.87	High	0.010
Apr	2,666.3–2,879.3	0.0	−1.00	High	<0.001
Aug	32,411.0–39,384.2	20.0	−0.60	Moderate	0.018
Sep	29,689.9–39,948.2	46.7	−0.07	Low	0.157
Oct	22,283.6–26,796.8	35.7	−0.29	Low	0.188
Tan Chau					
Feb	3,775.6–4,846.6	46.7	−0.07	Low	0.560
Mar	2,532.0–3,151.5	26.7	−0.47	Moderate	0.174
Apr	2,109.1–2,673.3	20.0	−0.60	Moderate	0.004
Aug	18,574.7–20,117.4	20.0	−0.60	Moderate	0.454
Sep	18,908.1–21,442.0	26.7	−0.47	Moderate	1.000
Oct	18,520.7–19,793.6	20.0	−0.60	Moderate	0.598

Note(s): MWU is Mann–Whitney *U* test

Artificial dry-season flows: While beneficial for salinity repulsion in the short term, permanently elevated low flows disrupt ecosystems adapted to seasonal drought cues (Arias *et al.*, 2014) and may encourage unsustainable agricultural expansion.

Unpredictability: Flash floods in 2019 and 2024 (Table 4) suggest that while average floods are lower, sudden releases from dams can cause unexpected surges, creating a “hybrid” hazard profile that is difficult to predict with traditional statistical methods.

5. Conclusion

This study provides a revised quantitative baseline for the Mekong mainstream entering the regulated era. By distinguishing discharge and rainfall responses across multiple stations, we

Table 6. Rainfall analysis results using RVA and HAF indices for Mekong stations

Month	Target range (mm)	Observed frequency (%)	HAF factor	Alteration level	MWU *p* -value	Significance
Luang Prabang						
Feb	0.0–20.0	88.9	+0.78	High	0.513	Not sig.
Mar	24.0–89.0	77.8	+0.56	Moderate	0.288	Not sig.
Apr	51.0–140.0	66.7	+0.33	Moderate	0.567	Not sig.
Aug	259.0–322.0	11.1	−0.78	High	0.806	Not sig.
Sep	161.0–256.0	33.3	−0.33	Moderate	0.567	Not sig.
Oct	50.0–166.0	77.8	+0.56	Moderate	0.934	Not sig.
Kratie						
Apr	90.8–140.3	12.5	−0.75	High	0.292	Not sig.
May	100.0–194.0	37.5	−0.25	Low	0.866	Not sig.
Aug	273.0–375.0	12.5	−0.75	High	0.131	Not sig.
Sep	283.5–385.5	37.5	−0.25	Low	0.737	Not sig.
Oct	154.0–195.5	20.0	−0.6	Moderate	0.635	Not sig.
Pakse						
Feb	0.0–2.0	88.9	+0.78	High	0.369	Not sig.
Mar	10.0–71.0	11.1	−0.78	High	0.001	Significant
Apr	23.0–67.0	55.6	+0.11	Low	0.806	Not sig.
Aug	385.0–691.0	44.4	−0.11	Low	0.165	Not sig.
Sep	236.0–388.0	11.1	−0.78	High	0.414	Not sig.
Oct	51.0–206.0	55.6	+0.11	Low	0.462	Not sig.
Tan Chau						
Feb	0.0–5.0	66.7	+0.33	Moderate	0.183	Not sig.
Mar	0.0–37.0	86.7	+0.73	High	0.405	Not sig.
Apr	40.0–120.0	46.7	−0.07	Low	0.579	Not sig.
Aug	118.0–200.0	40.0	−0.20	Low	0.267	Not sig.
Sep	150.0–240.0	60.0	+0.20	Low	0.541	Not sig.
Oct	251.0–318.0	33.3	−0.33	Moderate	0.244	Not sig.

conclude that upstream reservoir regulation is the dominant driver of the altered hydrograph in the upper and middle basin, while the signal at Tan Chau is attenuated and not statistically significant as a monotonic trend. The VMD should therefore be managed under a new hydrological normal defined by dampened flood pulses, altered dry-season baseflows and greater dependence on upstream operational decisions.

This reality demands a strategic pivot in management: from relying on historical statistical probabilities to operating within a regulated, albeit less predictable, framework. Future adaptation must prioritize sediment management, transboundary data sharing on dam operations, and flexible agricultural models that do not rely on the predictable flood pulses of the past.

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