



Assessment of Sediment Distribution Patterns and Management Strategies in the Porong River Estuary, Sidoarjo

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Abstract: This study aims to identify the water surface profile of the Kali Porong River, analyze changes in riverbed contours at the Kali Porong estuary, and propose appropriate mitigation measures for sediment deposition in the estuarine area. The research methodology involves hydraulic and sediment transport modeling using one-dimensional (1D) and two-dimensional (2D) HEC-RAS, supported by Google Earth image interpretation, cross-section analysis, and riverbed elevation data evaluation. The results indicate significant morphological changes in the Kali Porong River during the period 2013–2023. The upstream and middle reaches tend to experience riverbed degradation due to increased flow energy, while the downstream and estuary segments undergo intensive aggradation, characterized by channel shallowing and delta expansion toward the sea. These riverbed changes directly affect the water surface profile and flow velocity, with the 2023 condition showing relatively higher flow velocities compared to those in 2013. Two-dimensional modeling results suggest that the river system has shifted from a dynamic equilibrium condition toward a morphological imbalance. Based on these findings, mitigation measures are recommended in the form of targeted dredging and the construction of sediment control structures at the estuary to maintain channel stability and reduce long-term sedimentation risks.

Keywords: Aggradation; HEC-RAS; Hydrodynamics; Porong River; River morphology; Sedimentation

Introduction

The Porong River is one of the major rivers in East Java Province and functions as an artificial diversion channel of the Brantas River system. The river flows eastward from the Mojokerto–Sidoarjo region and discharges into the eastern coast of Java, which is oceanographically part of the Java Sea. Administratively, the Porong River forms a boundary between Sidoarjo Regency and Pasuruan Regency and is located approximately 40 km south of Surabaya City (Wikipedia, 2023). The name “Porong” is derived from Porong District in southern Sidoarjo Regency.

Historically, the Porong River was constructed as an engineered channel to divert part of the Brantas River flow eastward in order to reduce hydraulic pressure on the downstream Brantas River and protect surrounding

settlements and activity centers. The initial construction of this diversion system is believed to have begun during the reign of King Airlangga in the 11th century as part of an early water management system of the Kahuripan Kingdom. The primary objective of this engineering effort was to direct floodwaters of the Brantas River toward the eastern lowlands, thereby preventing excessive inundation in the royal center, which is estimated to have been located in the lower Brantas–Mojokerto area. This function differs from that of the Kali Mas River, which naturally flows northward toward Surabaya and has long served as an important natural branch of the Brantas River (Wikipedia, 2023).

Over time, the Porong River has undergone various river control and improvement measures. Between July 1971 and March 1978, the Indonesian government implemented a major rehabilitation project along the

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Porong River, including the construction of levees, groins, and revetments, as well as the development of the Lengkong Baru Weir to replace the deteriorated old structure. Dredging of the riverbed and improvements at the river mouth were also carried out to maintain flow capacity and ensure effective sediment transport (Wikipedia, 2023).

The most significant alteration to the Porong River system occurred following the Lapindo mud eruption in 2006 in Sidoarjo Regency. As an emergency mitigation measure to control surface inundation, a substantial volume of hot mud material was discharged into the Porong River. This disposal drastically increased the sediment load, particularly fine-grained sediments, which were transported along the river channel and deposited predominantly in the downstream and estuarine zones (Putra et al., 2025). Consequently, severe channel aggradation, reduced conveyance capacity, and substantial changes in riverbed morphology occurred, especially in the lower reaches and at the river mouth.

Geochemical investigations conducted by the Geological Agency revealed that Lapindo mud sediments are dominated by very fine particles with grain sizes $\leq 2.5 \mu\text{m}$, which tend to settle rapidly in low-velocity flow zones (Geological Agency, 2012). Further studies by the Sepuluh Nopember Institute of Technology (ITS) indicated that, after 2006, the flow capacity of the Porong River declined due to the accumulation of mud and fine sand on the riverbed, with sediment thickness reaching 1–2 m in several river segments (Anggono et al., 2019). This condition has the potential to disrupt hydraulic equilibrium, reduce flood conveyance, increase flood risk during the rainy season, and induce morphological instability in the estuarine area.

Although numerous studies have examined the environmental and hydraulic impacts of the Lapindo mud disposal on the Porong River, comprehensive investigations that explicitly analyze spatial-temporal sediment distribution patterns and riverbed morphological changes by comparing pre- and post-Lapindo conditions remain limited. Furthermore, integrated applications of one-dimensional and two-dimensional numerical modeling (HEC-RAS 1D/2D) to simultaneously assess flow dynamics, sediment transport, and morphological responses from the upstream reaches to the estuary are still scarce.

Therefore, this study is essential to improve the understanding of sediment transport mechanisms from upstream to the estuary of the Porong River and their influence on riverbed morphology. The novelty of this research lies in the comparative temporal analysis of river morphology using integrated HEC-RAS 1D/2D hydrodynamic and sediment transport modeling, which is expected to provide a scientific basis for sustainable

sediment management strategies and estuarine restoration efforts in the Porong River system.

Method

This study was conducted through several main stages. Inflow discharge data for the year 2023 were prepared as the primary input for hydrodynamic modeling. Sediment data were used to define sediment material characteristics for morphological modeling, while tidal data were applied as the downstream boundary condition. Topographic data were compiled in the form of a Digital Elevation Model (DEM) to represent ground surface elevation and were integrated with river cross-section survey data from 2013 and 2023. After all input data were prepared, one-dimensional (1D) and two-dimensional (2D) geometric models were developed using the HEC-RAS software.

The 1D model geometry was constructed based on measured river cross-sections, whereas the 2D model geometry was generated by defining a 2D flow area with a grid resolution of $75 \text{ m} \times 75 \text{ m}$. Hydrodynamic simulations were then performed to obtain water surface profiles, followed by morphological modeling to analyze changes in riverbed elevation. Subsequently, model calibration was carried out to ensure agreement between simulation results and observed field conditions. Based on the calibrated model results, further analysis was conducted to formulate appropriate sediment management measures for the study area, and conclusions and recommendations were finally derived from the numerical modeling outcomes.

The study area is located in Porong District, Sidoarjo Regency, East Java Province. Sidoarjo covers an area of approximately 719 km^2 , consisting of 18 districts, with Jabon and Sedati being the largest. The region lies at an elevation of 0–25 meters above sea level and forms a deltaic landscape situated between two major distributaries of the Brantas River: the Surabaya River to the north and the Porong River to the south. Administratively, Sidoarjo is bordered by Surabaya City and Gresik Regency to the north, the Madura Strait to the east, Pasuruan Regency to the south, and Mojokerto Regency to the west.



Figure 1. Study area

Result and Discussion

River Channel Condition of the Porong River

Based on the interpretation of Google Earth imagery (Figure 2), significant changes in the channel pattern of the Porong River were observed between 2013 and 2023, particularly in the downstream reach and estuarine zone. These changes reflect the dynamic interaction between fluvial discharge, tidal influence, and sediment supply from upstream, which collectively control sediment transport and deposition processes in the lower river system (Bilal et al., 2020; Ji et al., 2020; Meselhe et al., 2021; Wilkes et al., 2019; Yan et al., 2024).

In the 2013 imagery (Figure 2a), the Porong River channel exhibits a relatively stable planform characterized by mild meandering. The channel geometry largely follows natural conditions, with limited widening observed only in several downstream segments. Sediment deposits during this period remain concentrated near the river mouth, with minimal offshore extension. This condition indicates that, in 2013, the flow energy was still sufficient to transport most sediments toward the estuary, while depositional processes were spatially limited and delta formation had not yet developed significantly.

In contrast, the 2023 imagery (Figure 2b) reveals a more complex morphological adjustment, particularly in the downstream and estuarine areas. The river mouth appears substantially widened, and the delta has expanded seaward, indicating a pronounced accumulation of sediments during the 2013–2023 period. These morphological changes suggest an imbalance between sediment transport capacity and sediment supply, whereby the incoming sediment load exceeds

the river's ability to convey material further offshore (Adesina et al., 2022; Facchini et al., 2024; McKie et al., 2021; Zhang et al., 2021).

From a fluvial hydraulics perspective, delta development at the Porong River estuary is closely associated with a marked reduction in flow velocity as the river approaches the estuarine zone. The combined effects of tidal forcing and channel widening result in a significant decrease in flow competence, thereby reducing sediment transport capacity and promoting deposition of suspended and bed material. This process is further enhanced by tidal oscillations that induce bidirectional flow, causing sediments to be repeatedly reworked and trapped within the river–sea transition zone (Collins et al., 2018; Y. Liu et al., 2025; Ouillon, 2018; Wang et al., 2024; Zarzuelo et al., 2019).

In addition to hydrodynamic controls, increased sediment supply from upstream plays a crucial role in accelerating sediment accumulation at the estuary (Dijkstra et al., 2019; Wang et al., 2019). Sediments that cannot be transported beyond the mouth progressively settle, leading to continuous delta progradation. The resulting aggradation contributes to channel shallowing in the downstream reach, which in turn may trigger lateral channel expansion and local flow realignment (D. Liu et al., 2023; Valenza et al., 2020).

Overall, the comparison of 2013 and 2023 satellite imagery demonstrates that the Porong River has undergone active morphological evolution, dominated by sedimentation processes in the downstream and estuarine zones. The combined influence of river discharge, tidal dynamics, and enhanced sediment supply has driven sustained delta growth and channel adjustment toward the offshore direction.



Figure 2. (a) Porong River channel condition in 2013, (b) Porong River channel condition in 2023

Analysis of River Morphological Changes Based on Measurement Results

Based on the comparison of river cross-sections from 2013 and 2023, significant morphological changes in the Porong River were identified over a one-decade

period. These changes are manifested in the form of channel degradation and aggradation, with varying characteristics at each observation point. This indicates that the Porong River morphological system is highly dynamic and responsive to hydrological conditions,

increased sediment supply associated with Lapindo mud disposal, and anthropogenic activities along the river corridor.

At cross-section C1 (Figure 4), the 2023 condition generally shows a lower riverbed elevation compared to 2013, indicating the dominance of bed degradation processes across most of the channel width. The most pronounced erosion occurs from the left bank toward the central part of the channel, suggesting an increase in flow energy or a shift in velocity distribution that promotes sediment entrainment and downstream transport. Although minor local variations are observed along the right bank, the overall riverbed elevation in 2023 remains lower than in 2013, confirming that erosion is relatively uniform across the cross-section rather than being localized.

At cross-section C2 (Figure 4), the morphological response exhibits a slightly different pattern. Bed degradation remains dominant but is concentrated primarily in the central channel. This pattern is associated with the tendency of the main flow to be focused in the center of the cross-section, resulting in higher flow velocity and bed shear stress compared to the channel margins. Consequently, sediment in the central channel is more susceptible to erosion and downstream transport, leading to the channel deepening observed in 2023.

In contrast to C1 and C2, cross-section C3 (Figure 4) displays a more uniform morphological trend characterized by an overall increase in riverbed elevation in 2023 relative to 2013. This condition indicates the dominance of aggradation processes across the cross-section. Such uniform deposition patterns are typically associated with river segments experiencing reduced flow energy, commonly found in downstream reaches closer to the estuary. The reduction in sediment transport capacity causes sediments delivered from upstream to accumulate in this segment, suggesting that C3 functions as a depositional zone and a transitional area between the hydraulically active upstream reaches and the tidally influenced estuarine zone.

Overall, the comparison of the three cross-sections demonstrates that morphological changes along the Porong River follow a typical fluvial pattern, with channel deepening occurring in high-energy segments and sediment deposition dominating in lower-energy zones. The prevalence of degradation at C1 and C2 reflects hydraulically active conditions, whereas the aggradational trend at C3 indicates a transition toward depositional environments. These spatial variations highlight that sediment dynamics in the Porong River are governed by a combination of river discharge, tidal influence, secondary flow patterns, and potential anthropogenic interventions such as dredging, levee construction, and channel normalization. These findings

confirm that the Porong River remains morphologically active and continues to adjust its channel form over time.

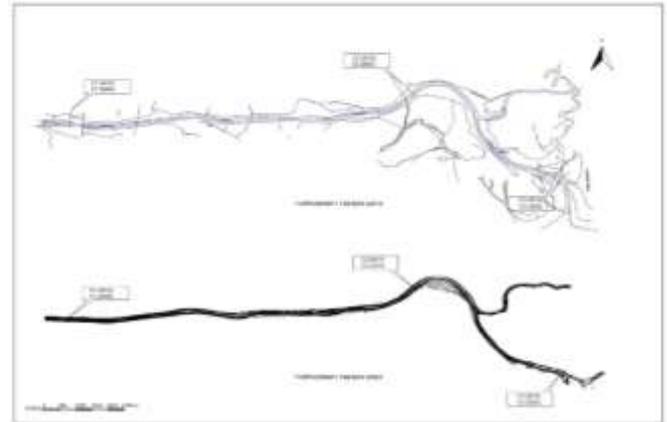


Figure 3. Cross-section positions in 2013 and 2023 in the Porong River

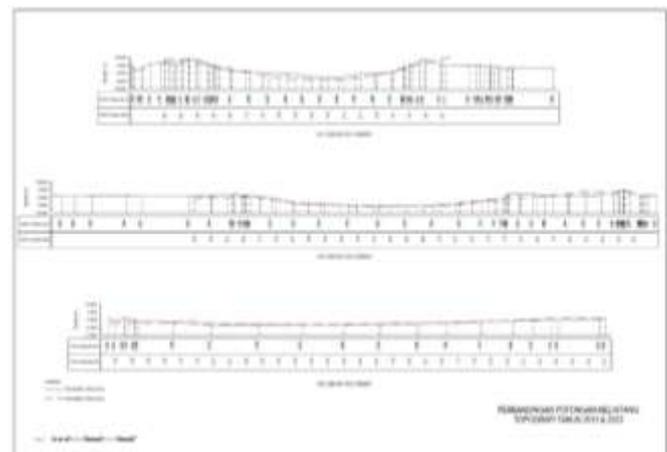


Figure 4. Comparison of river cross sections at selected locations in 2013 and 2023

Water Surface Profile

Based on the results of hydraulic modeling using HEC-RAS, clear differences in water surface profiles and riverbed elevations were identified between the 2013 and 2023 conditions across the upstream, middle, and downstream segments of the Porong River. In 2013, riverbed elevations were generally higher than in 2023, with relatively large variations in flow depth observed at several locations. In the upstream segment (C1), the riverbed elevation was approximately -4.10 m with a water surface elevation of 4.32 m. In the middle segment (C2), the riverbed elevation decreased to -5.28 m with a water surface elevation of 2.93 m, while in the downstream segment (C3), the riverbed elevation was -3.42 m with a water surface elevation of 2.04 m. Overall, the 2013 condition reflects a relatively deep channel profile, particularly in the upstream and middle reaches.

The 2023 condition exhibits a contrasting morphological response. In the upstream segment (C1),

the riverbed elevation declined markedly to -7.65 m, accompanied by a lower water surface elevation of 3.58 m. This pattern indicates the dominance of bed degradation processes, resulting in channel deepening and increased conveyance capacity. In the middle segment (C2), the riverbed elevation decreased to -6.02 m with a water surface elevation of 2.15 m. Although flow depth remains broadly comparable to the 2013 condition, the lowered bed elevation suggests ongoing and gradual erosion. The most pronounced change occurs in the downstream segment (C3), where the riverbed elevation increased substantially to approximately -0.33 m, while the water surface elevation remained relatively stable at about 2.03 m. This condition indicates intensive sediment deposition in the downstream reach over the past decade.

Overall, the analysis indicates that the upstream and middle segments of the Porong River are dominated by degradation processes, as reflected by riverbed lowering of approximately $1-3$ m relative to the 2013 condition. In contrast, the downstream segment has experienced significant aggradation due to sediment accumulation. These changes in riverbed elevation directly influence the formation of water surface profiles, with water levels in the upstream and middle reaches tending to decrease in 2023, while downstream water levels remain relatively stable despite substantial bed aggradation. This pattern suggests a redistribution of sediment from upstream toward downstream reaches, resulting in distinctly different morphological characteristics between the two periods.

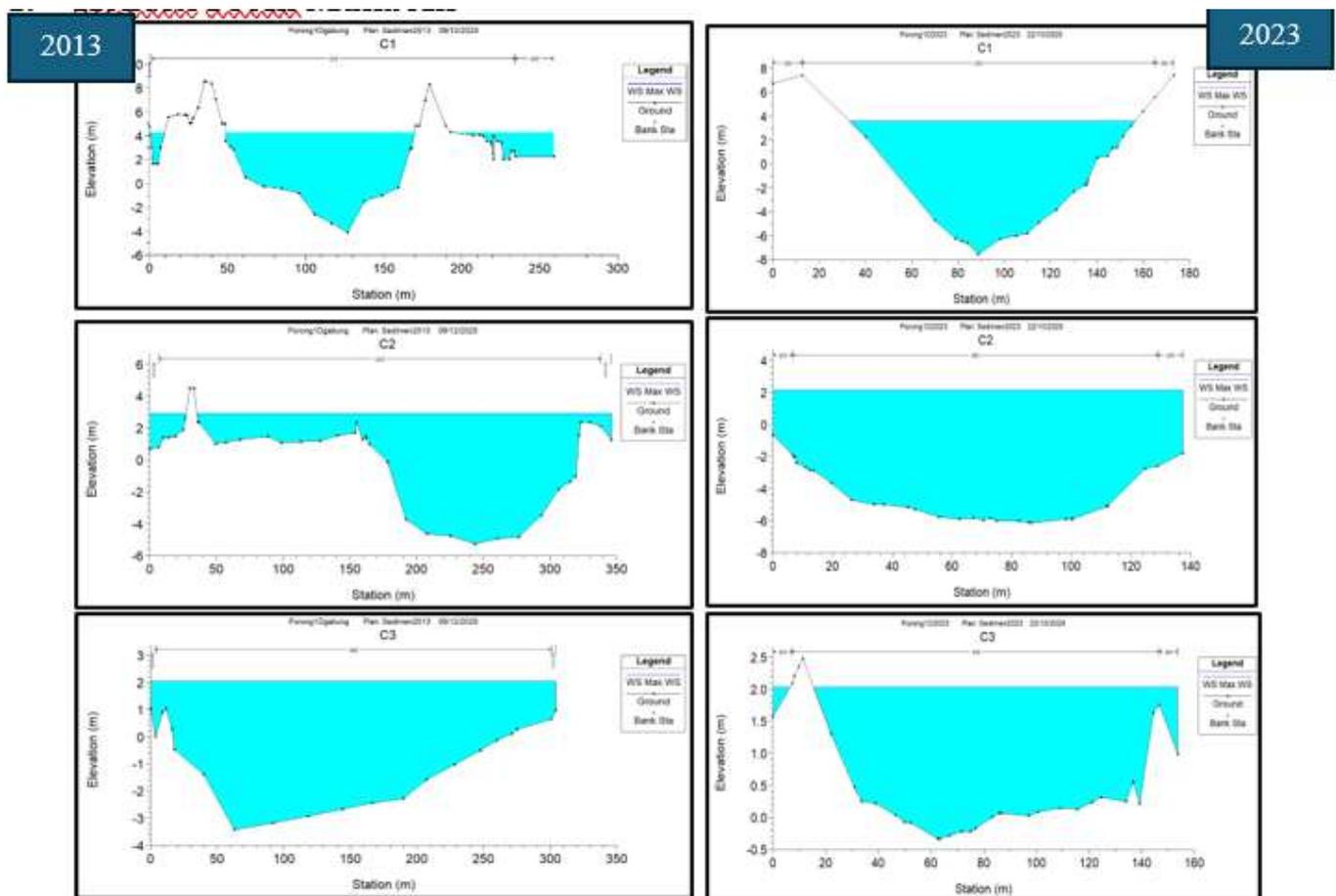


Figure 5. Water surface profile modeling results for 2013 and 2023 in the Porong River

Water Level Conditions and Bed Elevation Changes of the Porong River

Analysis of the 2013 condition indicates that changes in riverbed elevation along the Porong River were relatively small throughout the year, whereas water surface elevation exhibited dynamic fluctuations following tidal influence and daily discharge variations. In the upstream segment (C1), the water surface

elevation increased gradually from less than 1 m at the beginning of the year to approximately 4.3 m, while riverbed elevation changes were limited to about 0.25 m. This suggests that variations in water level at this segment were primarily controlled by hydraulic flow conditions rather than by changes in channel geometry.

In the middle segment (C2), water surface elevation showed relatively stable daily fluctuations within the

range of 1–2 m. Meanwhile, changes in riverbed elevation were minimal, approximately 0.05–0.1 m over one year. These conditions indicate that, in 2013, the middle reach of the Porong River was morphologically stable, with no dominant erosion or sedimentation processes affecting the channel cross-section. In contrast, the downstream segment (C3) exhibited lower water surface elevations, ranging from 0.5 to 1.7 m, with fluctuations primarily influenced by tidal forcing rather than by channel geometry changes. Riverbed elevation in this segment also remained relatively stable, with variations of about 0.1 m throughout the year, suggesting limited morphological change in the downstream reach during 2013.

Conversely, the 2023 condition reveals a markedly different pattern, largely associated with changes in channel geometry identified through sedimentation modeling. In the upstream segment (C1), riverbed

elevation increased consistently by more than 4 m, indicating substantial sediment accumulation. This aggradation directly affected the water surface elevation, resulting in a higher average water level compared to 2013, despite continued tidal fluctuations. In the middle segment (C2), riverbed elevation changes were negligible, approximately 0.01 m, causing water surface elevation to remain relatively unchanged over time and to be governed mainly by discharge variability and tidal effects.

A contrasting condition is observed in the downstream segment (C3), where riverbed elevation decreased drastically by more than –1 m. This reduction indicates strong bed erosion, possibly as a response to upstream morphological adjustments or changes in flow patterns. The resulting channel deepening allowed water surface elevations to remain relatively stable despite significant changes in bed elevation.

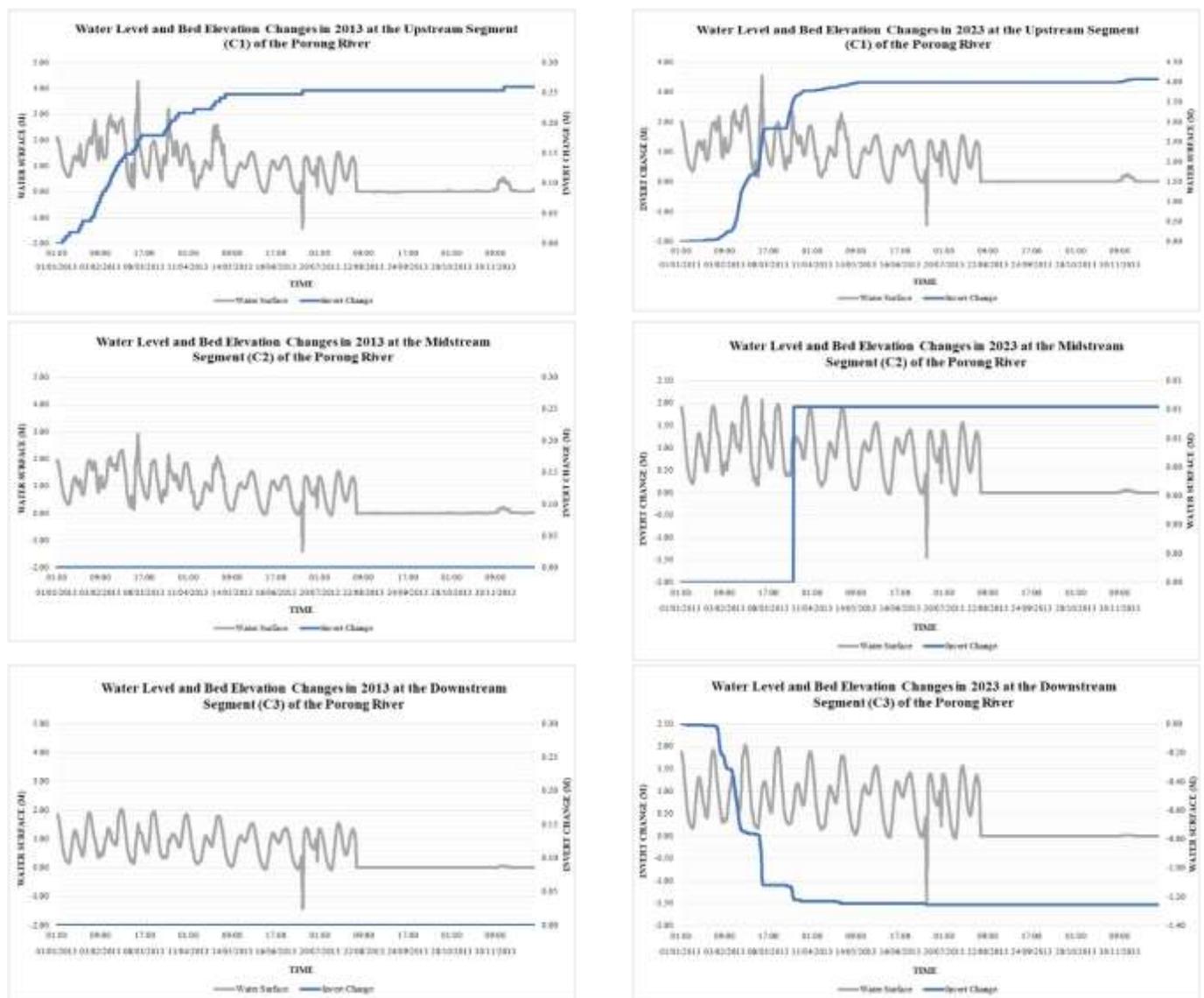


Figure 6. Water level conditions and bed elevation changes of the Porong River in 2013 and 2023

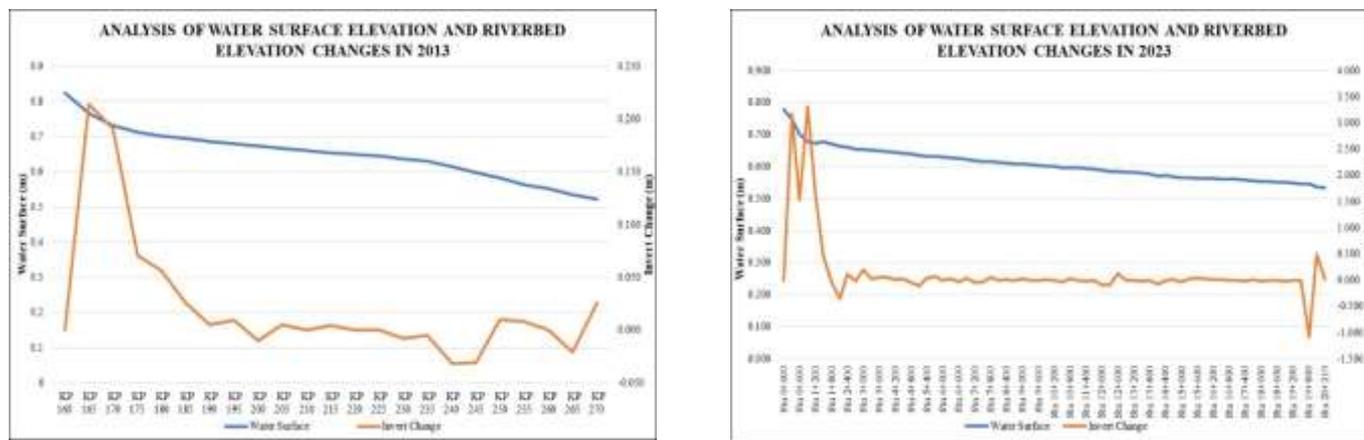


Figure 7. Water surface elevation and riverbed elevation changes in the Porong River in 2013 and 2023 based on cross sections

Analysis of the spatial patterns of riverbed elevation change and water surface elevation along the river in 2013 (Figure 7) shows a clear relationship between the two parameters. Water surface elevation generally decreases from upstream to downstream, while riverbed elevation changes remain within a small range (0.00–0.20 m), indicating a relatively stable bed morphology during that year. Variations in water surface elevation were mainly influenced by changes in the energy slope rather than by alterations in channel geometry.

In contrast, the 2023 analysis demonstrates substantially greater variability in riverbed elevation compared to 2013. Several locations, particularly in the upstream reach, experienced bed elevation increases of up to approximately 0.4 m, whereas downstream sections underwent bed lowering of up to -1 m. The contrasting patterns observed between 2013 and 2023 confirm that over the past decade the Porong River has undergone significant morphological changes driven by concurrent sedimentation and erosion processes, with different dominant mechanisms occurring in different river segments.

Results of Flow Velocity Analysis

In the upstream segment, the flow velocity patterns in 2013 and 2023 exhibit relatively similar temporal fluctuations; however, a notable difference is observed in the magnitude of peak velocities. In 2013, peak velocities ranged from approximately 1.2 to 1.5 m/s, whereas in 2023 they increased substantially to about 2.5–2.8 m/s. This increase indicates higher flow energy in 2023, which is likely associated with significant channel bed deepening in the upstream reach. Channel deepening increases the energy slope and flow conveyance, thereby resulting in higher flow velocities. During the period from June to September in both years, flow velocities decreased to values close to 0 m/s, reflecting the strong influence of tidal fluctuations combined with low inflow discharge during this period.

In the middle segment, flow velocity patterns in 2013 and 2023 are nearly identical. Velocities generally fluctuate within the range of 0.2–1.2 m/s, with peak values occurring in March and April. Although the overall temporal patterns are similar, flow velocities in 2023 are slightly higher during some peak periods. This increase is consistent with morphological findings indicating channel bed deepening in the middle reach, albeit to a lesser extent than in the upstream segment. Consequently, changes in bed geometry contribute to increased flow energy, although their overall impact remains moderate. During the June–September period, flow velocities in both years approach near-zero values, indicating a high sensitivity of the middle reach to tidal effects and reduced discharge conditions.

In the downstream segment, the flow velocity patterns for 2013 and 2023 also display strong similarities, with differences primarily observed in peak velocity values. In 2013, peak velocities ranged between approximately 1.0 and 1.5 m/s, while in 2023 they increased to about 1.8–2.0 m/s. This increase is likely influenced by significant bed erosion in the downstream reach in 2023, where riverbed elevation decreased by more than 1 m. Bed erosion leads to channel deepening and an increase in the energy slope, allowing higher flow velocities. Nevertheless, overall flow velocities in the downstream segment remain lower than those in the upstream reach due to the dominant influence of tidal forcing in this part of the river.

Morphological Model Calibration

Morphological model calibration was conducted to evaluate the model’s capability to realistically represent changes in riverbed elevation. The evaluation was performed by comparing simulated bed level changes with field observation data using the Brier Skill Score (BSS) as a statistical performance metric. This metric assesses the degree of agreement between modeled and observed riverbed elevations relative to the initial bed condition.

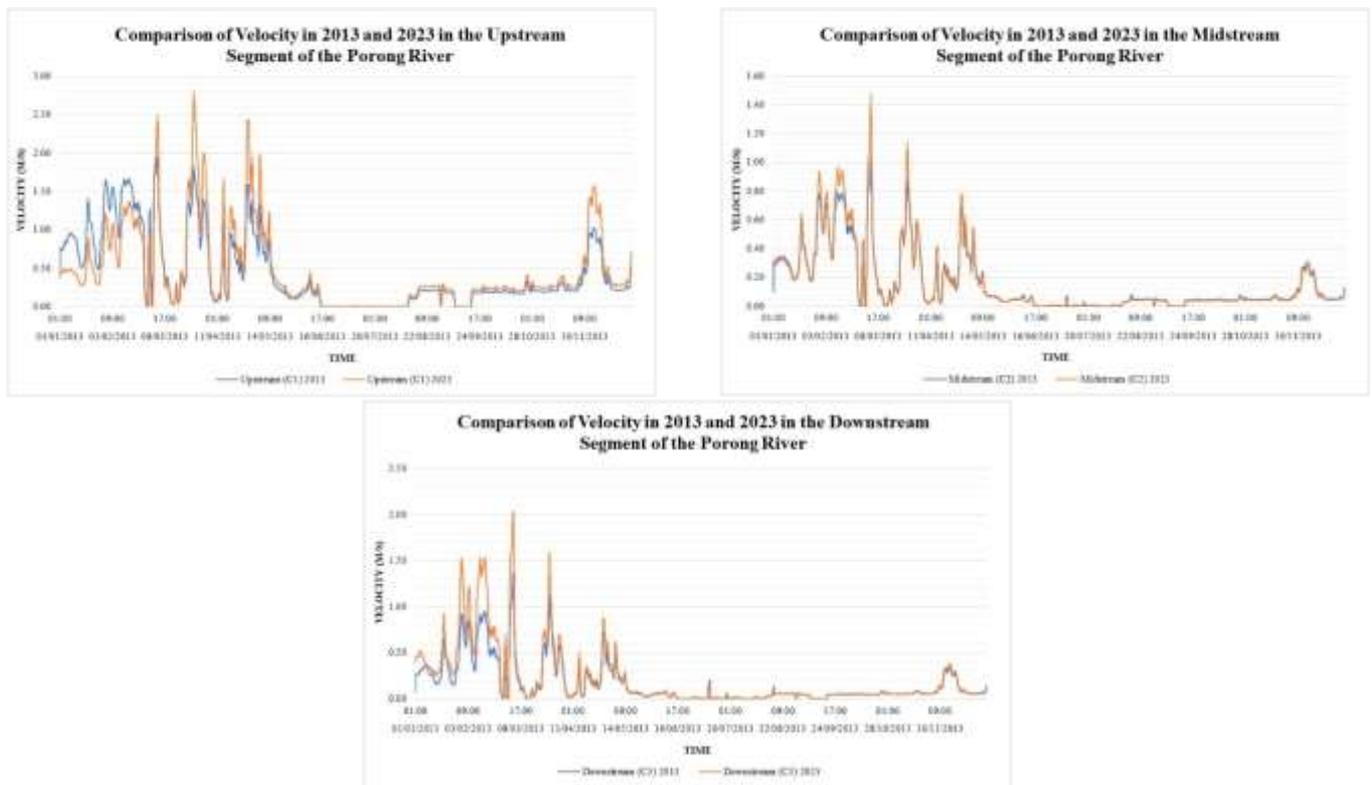


Figure 8. Comparison of velocity in 2013 and 2023 in the upstream, midstream and downstream segment of the Porong River

The calibration results yield a BSS value of 0.84, which is classified as good. This value indicates a high level of agreement between the simulated and observed riverbed elevations. A BSS value approaching unity suggests that the discrepancy between model results and field observations is relatively small compared to deviations from the initial condition, confirming that the model reliably captures riverbed morphological changes.

processes along the Porong River in accordance with field survey data from 2023. Furthermore, the calibration results indicate that the model can reasonably predict the spatial patterns and directions of sediment transport. Consequently, the calibrated model provides a robust basis for further analysis of sediment dynamics and for the development of effective sediment management and river restoration strategies in the Porong River system.

Riverbed Morphological Changes (2D)

The 2013 2D morphological analysis shows that the riverbed elevation of the Porong River ranged from -5 to +15 meters, with spatial patterns indicating that sedimentation dominated most sections of the channel. The upstream reach was characterized by predominantly green tones, reflecting relatively stable bed conditions. In the middle reach, zones of increased elevation began to appear, particularly along the inner bends where flow velocity is lower. In the downstream reach and near the estuary, areas with higher elevations (orange-red tones) became more extensive, indicating intensive sedimentation driven by reduced flow energy and tidal influences.

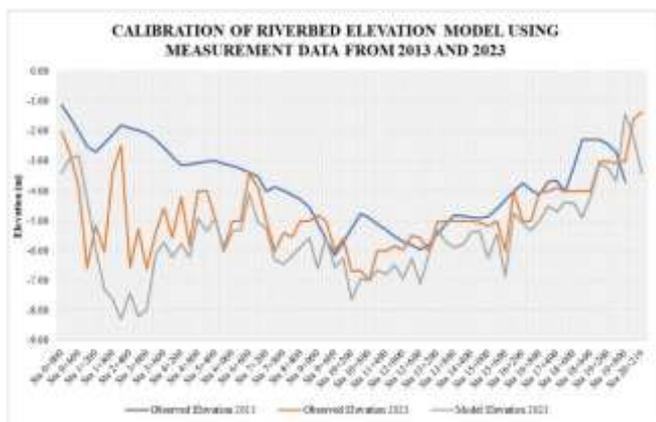


Figure 9. Calibration of the riverbed elevation model against measurement data from 2013 and 2023

The good calibration performance demonstrates that the HEC-RAS 2D morphological model is capable of consistently representing both erosion and deposition

The longitudinal bed elevation profile shows riverbed elevation increases of +4 to +6 meters between the 6000–15000 m section, reflecting substantial sediment accumulation in major bends and downstream segments. In contrast, the reach between 2000–5000 m remained relatively stable with minimal changes. These

results are consistent with the 1D model, which showed minor erosion in the upstream and middle reaches and dominant sedimentation in the downstream segment (up to +0.39 m) in 2013. The integration of 1D and 2D findings demonstrates that the river system was in a state of dynamic morphological equilibrium, with limited erosion along outer bends and sediment deposition along inner bends and the estuary.

Overall, the 2013 2D model indicates a river system that remained generally stable, although early signs of increased sedimentation were evident in the downstream and estuarine areas—providing an important baseline for comparison with the significant changes observed in 2023.

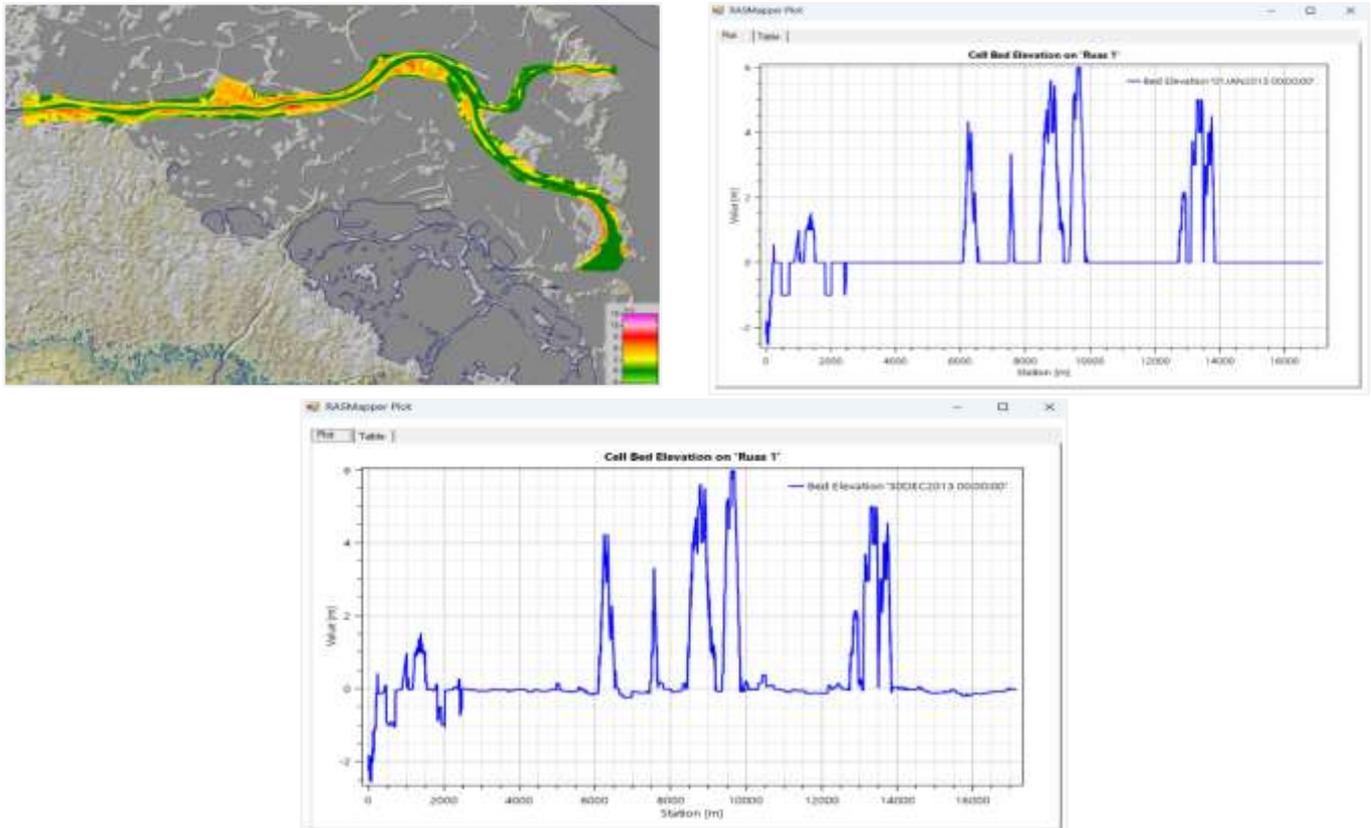


Figure 10. Results of the 2D bed elevation analysis of the Porong River in 2013

The 2023 2D morphological analysis indicates more pronounced changes in the bed elevation of the Porong River compared with 2013, with elevation values ranging from -5 to +15 meters. The modeling results show that the upstream segment remains relatively stable, characterized by predominantly green areas indicating minimal deviation from the initial bed level. In contrast, the middle to downstream segments exhibit more dynamic morphological behavior, marked by sedimentation zones on the inner bends (yellow–orange colors) and erosion zones on the outer bends.

Intensive sedimentation is clearly observed in the downstream section and in the transitional area toward the estuary, driven by reduced flow energy and tidal influences that promote sediment accumulation. The longitudinal profile for 2023 shows bed elevation increases exceeding +4 meters at distances of 6000–10000

m, alongside several deep erosion zones (up to -4 m) in the middle segment.

These findings are consistent with the 1D analysis, where invert change results indicate substantial bed aggradation up to +3.6 m in the middle reach (Sta 50–15) and minor sedimentation in the downstream area (+0.5–0.6 m). Overall, the 2023 conditions reflect a dominant aggradation process, contrasting with the relatively balanced conditions observed in 2013. The increase in sedimentation suggests an imbalance in sediment transport caused by reduced flow energy and altered discharge patterns.

This indicates that the river morphology in 2023 is undergoing a transition toward progressive bed aggradation in the middle and downstream segments, which may reduce channel capacity and increase flood risk in the lower basin, thereby necessitating more intensive sediment management strategies.

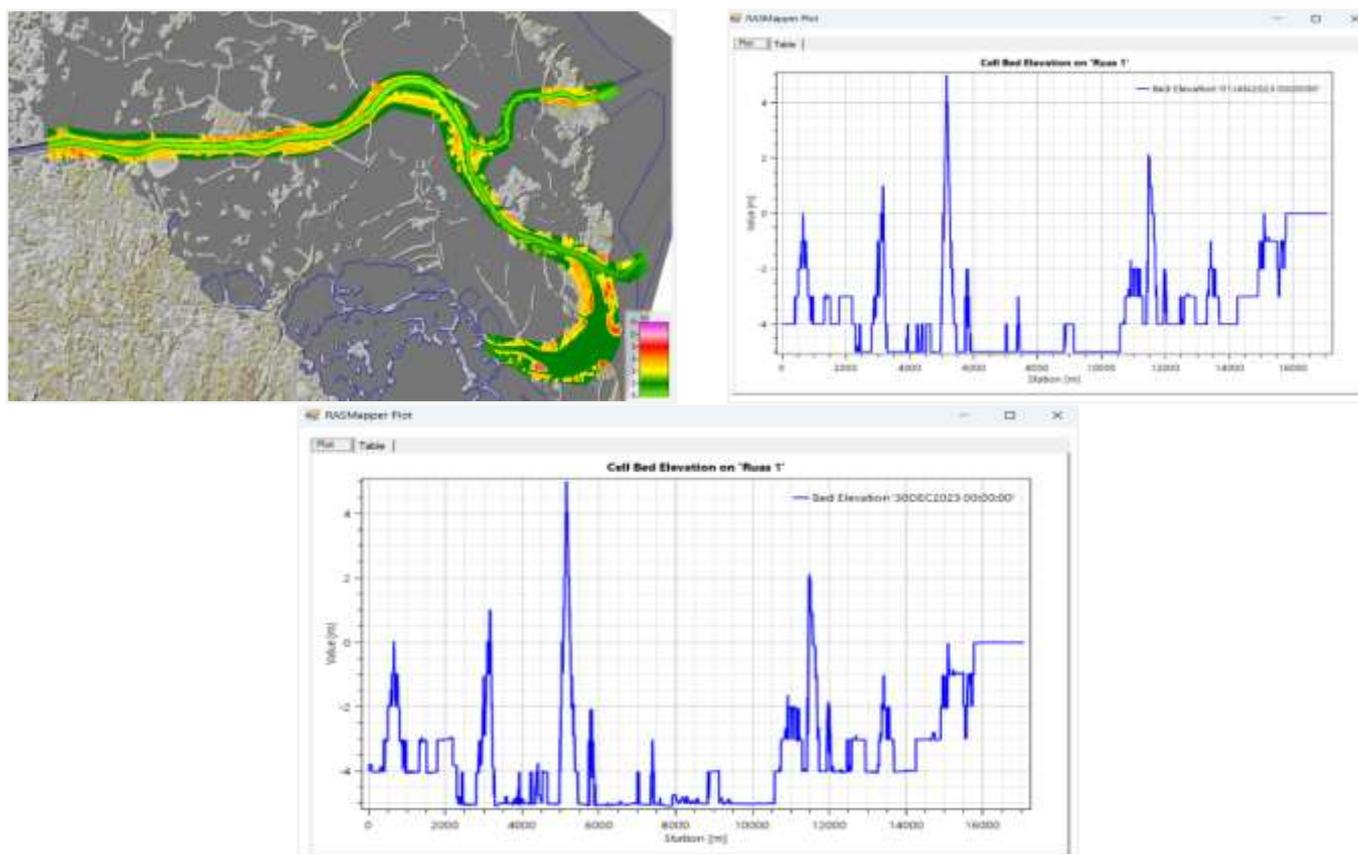


Figure 11. Results of the 2D bed elevation analysis of the Porong River in 2023

Comparison of the 2D morphological modeling results for 2013 and 2023 reveals significant changes in the bed elevation of the Porong River over the past decade. In 2013, the river system still exhibited characteristics of dynamic equilibrium, with bed elevation changes ranging from -2 to +6 m. Sedimentation dominated the middle and downstream segments, while erosion occurred only at limited locations such as the outer bends.

In contrast, the 2023 model shows a more pronounced morphological response, with elevation changes ranging from -5 to +4.5 m and a system dominated by degradation. Most river segments—particularly between the 2000–11000 m stations—experienced substantial bed lowering, indicating intensive scouring. Sedimentation occurred only locally at several bends and downstream zones, with relatively small magnitudes. These changes indicate a shift in river behavior from an aggradational condition in 2013 toward a degradational state in 2023, likely driven by alterations in discharge patterns, reduced sediment supply from upstream, and changes in flow hydrodynamics. The extensive bed lowering observed in 2023 has the potential to modify the river’s hydraulic capacity and affect channel stability.

Overall, the results confirm that the Porong River system is no longer in morphological balance,

emphasizing the need for sediment management and hydraulic assessment to prevent further degradation and to maintain channel function.

Sediment Mitigation Measures for the Porong River

Based on the identified patterns of riverbed elevation change (Figure 12), morphological management measures for the Porong River should be prioritized in two main segments, namely the upstream and downstream reaches. In the upstream reach, dredging is recommended at Sta 0+300 to Sta 1+200, where significant riverbed elevation changes have been detected and may affect channel stability as well as sediment transfer toward downstream reaches. Management actions in this segment aim to control bed degradation processes and maintain sediment transport balance, thereby preventing excessive sediment delivery to the downstream reach.

In the downstream reach, dredging should be prioritized at Sta 20+100 to Sta 20+219, which has been identified as the zone with the most pronounced sediment accumulation. Channel normalization through dredging in this segment is intended to restore channel depth, increase flow conveyance capacity, and facilitate sediment transport from the upstream and middle reaches toward the sea. This measure is expected to

reduce recurrent siltation that could otherwise impair the hydraulic performance of the river.

In addition to dredging, the construction of sediment control structures at strategically selected locations in the downstream reach is necessary to regulate flow patterns and mitigate long-term sediment accumulation. Structures such as jetties or flow-training works can help stabilize the riverbed, control sediment distribution, and minimize the formation of new sediment bars within the main channel. The implementation of such structures is expected to enhance estuarine morphological stability and reduce the frequency of dredging interventions in the future.

To ensure the effectiveness of these measures, regular monitoring of river morphology is essential. Periodic bathymetric surveys, riverbed elevation monitoring, and analyses of bed profile changes will allow early detection of morphological adjustments that may compromise channel capacity, enabling timely corrective actions.

Overall, a combined approach involving targeted dredging and the installation of sediment control structures in the downstream reach represents the most appropriate management strategy under the current morphological conditions of the Porong River, where sediment accumulation is most intense. This integrated approach is expected to restore flow capacity and maintain long-term morphological stability of the river system.

in the estuarine zone. The water surface profiles exhibit an overall declining trend along all river segments—upstream, middle, and downstream. In 2013, water surface elevations ranged from approximately 2.04 to 4.30 m, whereas in 2023 they decreased to about 2.00–3.40 m. This reduction is closely associated with progressive changes in riverbed morphology, particularly bed aggradation in certain segments, redistribution of discharge, and a reduction in the effective cross-sectional flow capacity. These effects are most pronounced in the downstream reach, where intensive sedimentation at the river mouth induces backwater conditions that reduce the river’s capacity to convey flow efficiently, especially during peak discharge events. From a morphological perspective, the magnitude of riverbed elevation changes differs markedly between 2013 and 2023. In 2013, bed elevation changes were relatively small, ranging from 0 to +0.30 m, indicating mild aggradation and degradation processes that remained within the natural dynamic equilibrium of the river. In contrast, the 2023 condition exhibits much more extreme variations, with riverbed elevation changes ranging from -1.40 to +4.00 m. Two-dimensional hydrodynamic modeling results indicate that river bends act as dominant depositional zones due to reduced flow velocities along the inner banks of meanders, leading to the formation of thick sediment deposits and a subsequent reduction in channel conveyance capacity. From a fluvial hydraulics perspective, the contrasting morphological responses between the upstream–middle and middle–downstream segments are strongly controlled by the distribution of flow energy and downstream boundary conditions. In the upstream and middle reaches, relatively steeper bed slopes and higher flow velocities increase bed shear stress, promoting erosion and channel degradation. Sediment eroded from these reaches is subsequently transported downstream as sediment supply. Conversely, in the middle to downstream reaches, tidal influence induces flow deceleration and backwater conditions, particularly during high tide, which significantly reduces sediment transport capacity and promotes intensive sediment deposition. Based on the spatial patterns of riverbed elevation change, morphological management of the Porong River should be prioritized in the upstream reach at Sta 0+300–1+200 and in the downstream reach at Sta 20+100–20+219, where the most significant bed elevation changes were identified. The primary recommended measure is channel normalization through dredging to restore channel depth, enhance flow conveyance capacity, and facilitate sediment transport toward the sea. In addition, the construction of sediment control structures in the downstream reach is required to regulate flow patterns and suppress recurrent sediment accumulation. To

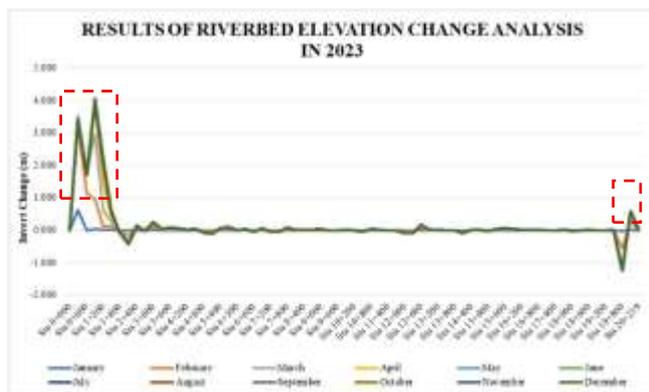


Figure 12. Results of riverbed elevation change analysis in 2023

Conclusion

Based on the results of hydrodynamic and morphological analyses using 1D and 2D numerical modeling for the Porong River under the 2013 and 2023 conditions, significant changes in flow characteristics and riverbed morphology have occurred over the past decade. These changes reflect the river system’s response to the interaction between flow dynamics, sediment supply, and downstream boundary conditions

ensure the long-term effectiveness of these measures, regular morphological monitoring through bathymetric surveys and riverbed elevation assessments is essential to maintain channel stability over time.

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Author Contributions

Conceptualization, T. C. M. L and S.; methodology, T. C. M. L.; software, T. C. M. L. and D. S.; validation, T. C. M. L., S., and D. S.; formal analysis, T. C. M. L.; investigation, T. C. M. L.; resources, T. C. M. L.; data curation, T. C. M. L.; writing – original draft preparation, T. C. M. L.; writing – review and editing, T. C. M. L. and S.; visualization, T. C. M. L.; supervision, S.; project administration, S.; funding acquisition, T. C. M. L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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