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ARTICLE

Meteo-Hydrological Context of the February 2024 Urban Flooding Event in My Tho City, Tien Giang Province, Vietnam

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ABSTRACT

Urban flooding in low-lying coastal regions (LCRs) is intensifying due to climate change and sea-level rise; however, the complex interplay of hydrological, climatic, and anthropogenic drivers remains poorly understood. This study investigates the specific meteo-hydrological factors linking climate-induced changes and human activities to the urban flooding event in My Tho City, a vulnerable coastal city in Vietnam's Tien Giang Province, from February 9 to 12, 2024. Analyzing historical meteo-hydrological data (rainfall, monsoon winds, river discharge, and water levels), we examined the contributing factors. Our findings reveal that the flooding was predominantly driven by the combination of high astronomical tidal levels and significant water surges. These surges were amplified by northeast monsoon circulation. This situation was compounded by critically low Mekong River discharge during the dry season, which enhanced the inland penetration of tidal effects. Rainfall during the period was minimal and did not contribute significantly. We utilized a filtering technique to differentiate between astronomical tides and non-tidal surges in the water level data. These results provide empirical evidence demonstrating that climate-driven sea-level influences (manifesting as high tides and surges) and anthropogenic alterations to river flow governed the urban flooding dynamics. The study underscores the urgent

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need for integrated adaptation solutions addressing the complex land-ocean interactions, particularly in the context of climate change and relative sea-level rise.

Keywords: Coastal Regions; High Tides; Monsoon Winds; Water Surge; Rising Sea Levels; Urban Flooding

1. Introduction

Urban flooding presents a critical challenge in low-lying coastal regions (LCRs), particularly as climate change and rapid urbanization converge [1–3]. Global sea-level rise, extensively documented in recent literature [4,5], significantly increases the vulnerability of these coastal areas to urban flooding events [6,7]. LCRs face a complex interplay of climatic and anthropogenic factors that complicate urban flood dynamics [8–10], demanding a nuanced understanding of the underlying mechanisms. The escalating severity of urban flooding results from combined high tidal levels, extreme weather patterns (like intensified monsoons), land subsidence, low river discharge during certain periods, and deficiencies in urban infrastructure [11,12]. Consequently, analyzing the interactions among these elements is essential, especially given intensified climate variability [13,14].

Increasing urbanization in coastal regions amplifies flooding risks and necessitates tailored management strategies [8,15]. Urban flooding in LCRs arises from multifaceted interactions involving rainfall [1,16], river discharge [17], and tidal water levels (including both astronomical tides and surges) [18,19], which highlights the complexity of flood risk assessments [20]. The potential for simultaneous extreme events, such as high tides coinciding with strong monsoon winds or low river flow, requires a comprehensive approach to understanding flood risks [9,11]. Urban centers near estuaries prove particularly susceptible when these hydrological factors converge [21,22]. Moreover, underlying geographical characteristics like land subsidence and tidal influences further intensify the vulnerability of LCRs [16,22].

In Vietnamese coastal regions, distinctive hydrological dynamics create particularly precarious conditions for urban flooding [23,24]. Although these areas experience fewer direct tropical storm impacts compared to other coastal regions [13,25], they remain susceptible to flooding, especially during high spring tides [10,26]. Recent weather trends show increasingly unpredictable patterns, including unusual rainfall and intensified monsoon seasons [23,27], further complicating the urban flooding landscape [13,24]. The northeast monsoon, locally known as "Gio Chuong," occurs from October to April annually and significantly influences hydrological conditions in the Vietnamese Mekong Delta (VMD) [23,27]. This seasonal pattern affects rainfall distribution, sea levels (including surges), and salinity intrusion, ultimately impacting agricultural productivity and urban flooding potential [2,24].

Field observations reveal that urban flooding in the VMD stems from complex interactions between multiple hydrological factors, including upstream flow discharge and local rainfall [17,27,28]. A positive correlation between tidal conditions and local rainfall suggests heightened flooding risks in coastal urban areas [1,2,23]. Furthermore, the increasing frequency of compound flooding events underscores the urgent need for integrated risk assessments that comprehensively analyze these intricate interactions [1,23,29]. During monsoon periods, VMD coastal areas often experience sea level rise (partly due to surges) and saltwater intrusion, affecting both agricultural productivity and urban flooding likelihood [2,24]. The increasing intensity of the northeast monsoon has amplified urban flooding risks, particularly when combined with high spring tides, local rainfall, and low river flows [13,17]. Field observations indicate that urban flooding in the VMD is not solely a consequence of elevated tidal levels but is also influenced by the interaction between various hydrological factors, including upstream flow discharge and local rainfall [7,13,16,17,27,28].

Compound flooding, where multiple factors converge, is becoming more frequent. This trend highlights an urgent need for improved methods to assess flood risks that account for these complex interactions [1,23,29]. Urban flooding impacts extend beyond buildings and roads, triggering social and economic consequences [2,9]. For populations in flood-prone areas, especially vulnerable groups, floods can lead to health problems [22,26]. This study aims to investigate the specific meteo-hydrological context of the urban flooding event in My Tho City between February 9 and 12, 2024. We analyze the relative contributions of key factors—rainfall, monsoon wind circulation, river discharge, astronomical tides, and associated water surges—to understand the primary drivers of this specific event within this frequently flooded LCR.

2. Materials and Methods

2.1. The Study Area

Our research focuses on My Tho city, Tien Giang province, situated in the northeastern part of the VMD (**Figure 1a**). This province stretches along the north bank of the Tien River for over 120 km [24]. The terrain of Tien Giang province is predominantly flat, with elevations ranging from 0 to 1.7 m above mean sea level, and land slopes of less than 1% (**Figure 1b**). The province covers 2,556 km², approximately 6.2% of the VMD. It serves as a key transportation hub connecting the southern and southwestern coastal provinces to Ho Chi Minh City [1]. Tien Giang experiences a tropical monsoon climate [1], receiving an average annual rainfall of about 1,500 mm, mostly during the wet season from May to November [1]. Both the northeast and southwest monsoons influence the area. The northeast monsoon—locally termed "Gio Chuong"—prevails from October to April [1]. This circulation pattern commonly features strong winds that significantly contribute to water surges, saltwater intrusion, and urban flooding [1,24].

Note: Observation stations listed in **Table 1** are located within the Tien Giang province area shown in map (b), with Tan Chau and Chau Doc situated upstream on the main rivers entering the delta shown in map (a), Vam Kenh near the coast within Tien Giang, and Vung Tau on the open coast southeast of the study area.

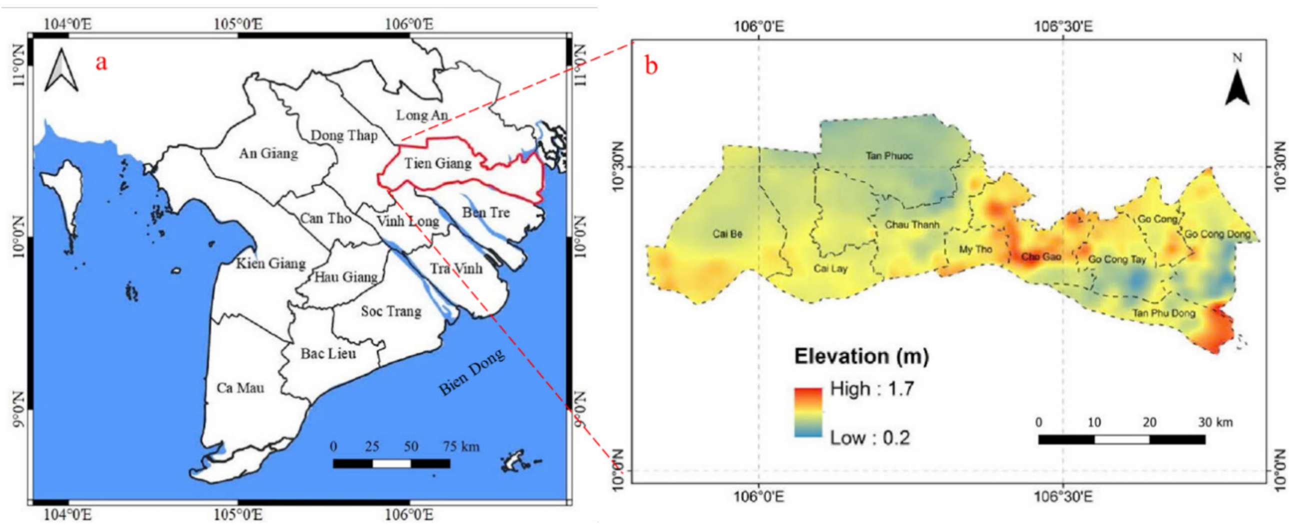

Figure 1. Map of **(a)** the Vietnamese Mekong Delta and **(b)** the Map of Topography of Study Area.

Table 1. Basic Characteristics of the Monitoring Stations Used in This Study.

Station	Latitude (°N)	Longitude (°E)	Data Type		Note
			Water Level	Discharge	
Tan Chau	105°14′52″	10°48′02″	x	x	The upper reach of the Tien River
Chau Doc	105°08′01″	10°42′19″	x	x	The upper reach of the Bassac River
Vam Kenh	106°44′14″	10°16′28″	x		Near an estuary
Vung Tau	107°04′16″	10°20′22″	x		Open coast

2.2. Data Collection

For this study, we used daily water level and flow data from the Tan Chau, Chau Doc, Vam Kenh, and Vung Tau stations (**Table 1**). We also obtained reanalyzed monsoon circulation (wind data) and rainfall data for the entire VMD from the European Centre for Medium-Range Weather Forecasts (ECMWF) (https://cds.climate.copernicus.eu/). We gathered these comprehensive datasets to ensure accurate and reliable findings regarding the specific flood event period (February 9–12, 2024).

2.3 Methods for Analyzing Meteo-Hydrological Factors

This study analyzes the influence of several meteo-hydrological factors on the February 9–12, 2024 flooding Rainfall: We analyzed daily gridded rainfall data from ECMWF covering the VMD to assess the spatial distribution and magnitude of precipitation during the event period.

Monsoon Circulation: We examined ECMWF and re-analyzed wind field data (speed and direction) over the VMD and surrounding sea area to understand the influence of the prevailing northeast monsoon on coastal water levels during the event.

Flow Discharge: We analyzed daily river discharge data from the upstream Tan Chau (Tien River) and Chau Doc (Bassac River) stations (Table 1) to determine the background river flow conditions entering the delta system during the dry season event.

Tidal Levels and Water Surges: Urban flooding often occurs when high tides combine with rising sea levels and meteorological surges. The observed water level ($H_{observation}$) at coastal and estuarine stations (Vam Kenh, Vung Tau) comprises the astronomical tide height (H_{tide}) and the non-tidal residual, commonly referred to as surge water height (H_{surge}):

$$H_{observation}=H_{surge}+H_{tide} \quad (1)$$

Accurate tidal prediction is crucial [9,11], but traditional harmonic analysis can be insufficient when non-astronomical factors like wind-driven surges are significant [28,30]. To isolate the non-tidal influences (including surges) and understand the baseline water level variations, we applied the Doodson X_0 low-pass filter to the hourly water level data [28]. This 39-point symmetric filter effectively removes principal diurnal and semi-diurnal tidal components while preserving lower-frequency signals [28,31,32]. The filter calculation is expressed as:

$$X_F(\mathrm{t})=\sum_{\mathrm{m}=-19}^{19}F_{\mathrm{t}.}[X(t+d)+X(t\text{-}d)] \quad (2)$$

where X(t) is the hourly water level, XF(t) is the filtered (non-tidal) water level, t is time, d is the time increment, and Fm are the Doodson coefficients [28]. By subtracting the predicted astronomical tide (or approximating it with the filtered mean water level over a longer period, though not explicitly done here) from the observed water level ($H_{observation}$), we can estimate the surge component (H_{surge}). In this study, we analyze the total observed water levels and use the filtered data to understand the contribution of non-tidal factors (surges) relative to the overall high-water levels during the event, particularly comparing coastal (Vung Tau) and estuarine (Vam Kenh) locations with inland stations (Tan Chau, Chau Doc).

3. Results and Discussion

3.1. The Impact of Local Rainfall on Urban Flooding

Analysis of ECMWF rainfall data shows that precipitation across Vietnam from February 9 to 12, 2024, was notably low (**Figure 2**). The rainfall maps indicate minimal contributions during this period; most of the country received less than 2.4 mm, and many regions recorded no rainfall. This limited rainfall demonstrates that precipitation did not significantly affect the urban flooding event in My Tho city between February 9–12. However, the flood event's timing coincided with high tides. This timing indicates that tidal influences primarily caused by the elevated water levels, despite negligible recorded rainfall. The interaction between these tidal influences and other hydrological factors played a more critical role in My Tho city's flooding than the minimal rainfall observed.

Overall, the rainfall data from February 9 to 12, 2024, clearly show that precipitation was not a primary contributor to this urban flooding event. This finding aligns with research by Xu et al. (2019) [33], who confirmed a positive correlation between rainfall and tidal levels in coastal cities, highlighting the complex interplay of factors in urban flooding events, although in this specific case, rainfall's role was minimal.

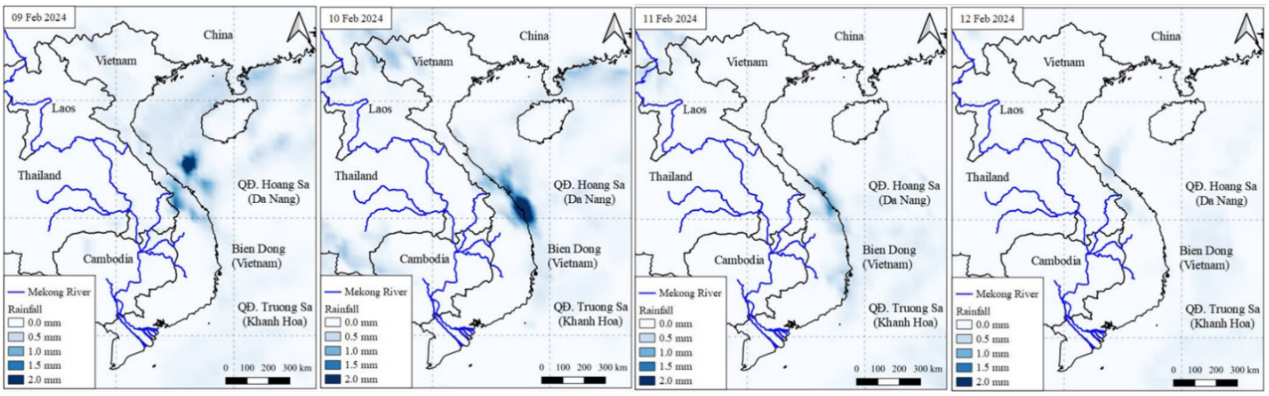

Figure 2. Map of Rainfall Distribution Across Viet Nam from 9 to 12, February 2024.

Source: https://cds.climate.copernicus.eu/.

3.2. The Impact of Monsoon Circulation on Urban Flooding

The reanalyzed wind data from ECMWF offer crucial insights into the meteorological conditions affecting Vietnam from February 9 to 12, 2024. The wind distribution over this period (**Figure 3**) reveals critical patterns in wind direction and speed that contributed to the urban flooding event in My Tho City. Throughout this period, winds predominantly originated from the northeast, with speeds increasing notably on February 12. The direction and strength of these winds contributed to a rise in sea level (water surge) along the coast, slightly enhanced by the convergence of strong winds against the coastal geography of the VMD. This interaction between the wind and estuarine morphology resulted in elevated water levels, especially during high tide—a recurring phenomenon. On February 12, wind speeds reached sufficient levels to push seawater inland, reducing the drainage capacity of estuaries. Consequently, LCRs like My Tho City experienced severe flooding, with water levels rising rapidly (**Figure 4**). The combination of elevated sea levels (tide + surge) and My Tho city's low topography means that even moderate tidal forces combined with surge can lead to urban flooding.

The wind field data underscore the importance of wind dynamics (monsoon circulation) in driving coastal surges contributing to urban flooding in My Tho city during this event. These findings align with Thuy et al. (2019) [23], who studied monsoon-induced water surges along the Southeast Coast of Vietnam and reported that strong winds can cause surges up to 40 cm near Vung Tau.

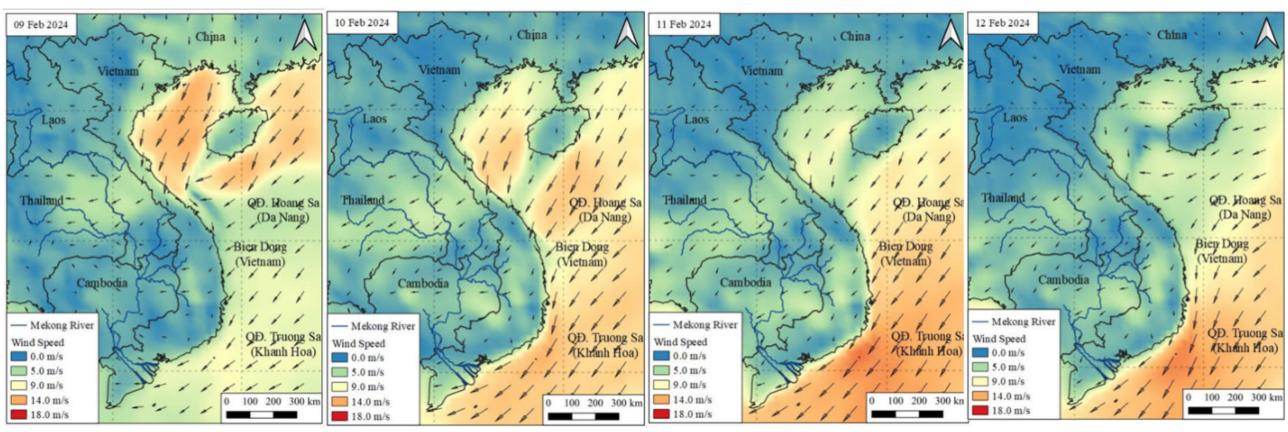

Figure 3. Map of Monsoon Circulation Distribution Across Viet Nam from 9 to 12, February 2024.

Source: https://cds.climate.copernicus.eu/.

Figure 4. Urban flooding at My Tho city of Tien Giang province on February 12, 2024.

3.3. The Impact of Flow Discharge on Urban Flooding

Analysis of flow discharge data from the Tan Chau and Chau Doc monitoring stations provides critical insights into the urban flooding event in My Tho from February 9 to 12, 2024 (**Figure 5**). During this period, flow discharge at both upstream stations exhibited a slight decrease (**Figure 5a** for Tan Chau, **Figure 5b** for Chau Doc), characteristic of the dry season. Although minimal, this reduction in flow discharge played a crucial role by facilitating tidal influences and seawater intrusion into LCRs like My Tho City. As flow discharge decreased, the hydraulic pressure within the river system lessened, allowing more effective transmission of tidal forces (high tides and surges) from the main estuaries into inland areas. This phenomenon is particularly concerning in regions like My Tho city, where low elevation makes it highly susceptible to flooding, as the reduced river outflow offers less resistance to incoming tidal waters.

The interplay between reduced flow discharge and tidally influenced rising sea levels created conditions conducive to tidal surges penetrating further inland, exacerbating the flooding. The combination of strong tidal forces and limited opposing flow discharge resulted in heightened water levels along the river section feeding into My Tho city. The low flow discharge from the Tien River (Tan Chau) and Hau River (Chau Doc) effectively enhanced the tidal impact. Furthermore, the timing of tidal peaks coinciding with the urban flooding event on February 12 underscores the critical importance of understanding flow dynamics. The reduced flow discharge did not provide sufficient resistance against incoming tidal forces, allowing rising water levels to overwhelm the city's drainage infrastructure.

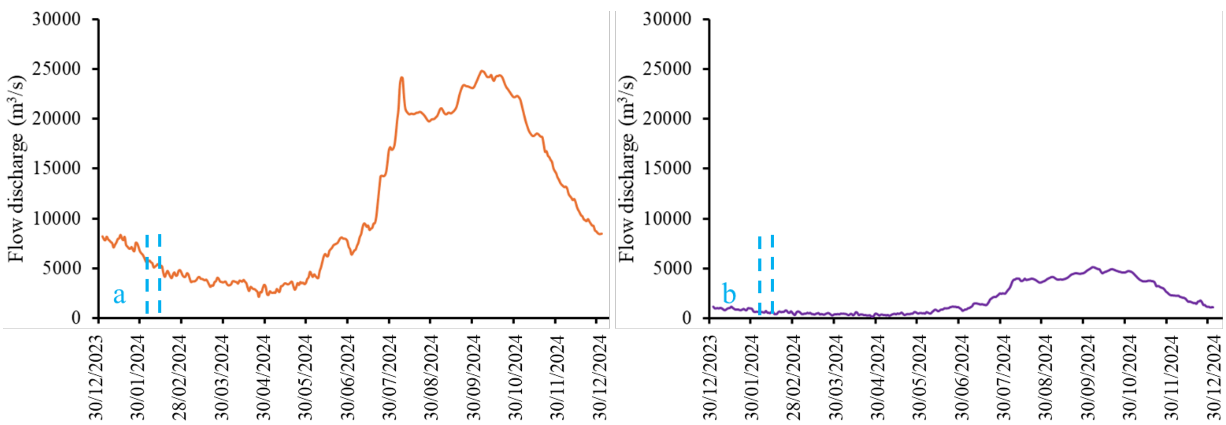

Figure 5. Flow Discharge Distribution at (**a**) Tan Chau Station and (**b**) Chau Doc Station During the Period Leading Up to and Including the Urban Flooding Event (February 9–12, 2024). Note the Generally Low and Slightly Decreasing Discharge Characteristics of the Dry Season.

3.4. The Impact of Tidal on Urban Flooding

Figure 6 illustrates the time series of observed water levels and the Doodson-filtered non-tidal water level component at the Tan Chau (inland, **Figure 6a**), Vung Tau (coastal, **Figure 6b**), Chau Doc (inland, **Figure 6c**), and Vam Kenh (estuarine, **Figure 6d**) stations in 2024. The analysis reveals that the highest peak of observed water levels in February occurred around the 12th, coinciding with the flooding event. This period saw strong Northeast monsoon winds. These results indicate that the urban flooding event resulted from a combination of high astronomical tides and significant water surges, particularly evident in the coastal Vung Tau and estuarine Vam Kenh data (**Figure 6b,d**).

The data indicate February 12 marked peak tidal levels. Variations in observed water levels (solid lines) compared to the filtered non-tidal component (dashed lines, representing baseline water level plus surge) show that February 12 was among the highest tide days in 2024. The difference between observed and filtered levels indicates the tidal range, while the elevation of the filtered level above a longer-term mean (approximated by the lowest points of the filtered curve) indicates the surge contribution. Wind-induced surges contributed considerably to the total water level extremes. At the inland Tan Chau and Chau Doc stations (**Figure 6a, 6c**), the surge impact (elevation of dashed line) was attenuated (~15 cm and ~22 cm peak residual above local baseline, respectively). However, surge water levels of 30 to 40 cm predominated on the coasts (Vung Tau, **Figure 6b**) and significantly influenced the estuary (Vam Kenh, **Figure 6d**). The Doodson filter helps visualize this non-tidal contribution (surge) riding on top of the mean water level. Peak total observed water levels occurred around February 12, 2024, driven by the superposition of high astronomical tides and this significant water surge. These factors explain the severe urban flooding in central My Tho city (**Figure 4**). Analysis of the Vung Tau station confirms the largest surges occurred in February 2024. Although direct storm impacts are rare, monsoon-induced surges are highly significant [23]. This surge increased the total water level, amplifying impacts in LCRs like My Tho City. As noted by Thuy et al. [23], these low, flat regions are highly sensitive, and surges over 40 cm have been reported along this coast during high tides.

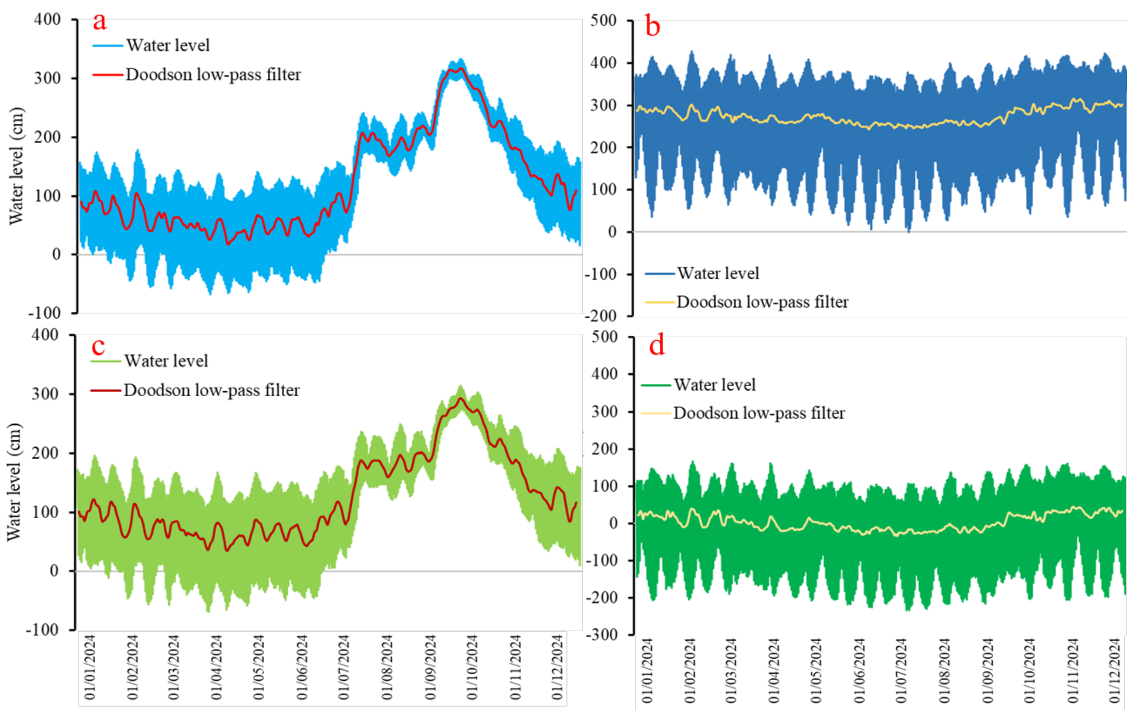

Figure 6. Time series of observed water levels (solid lines) and Doodson low-pass filtered water levels (dashed lines, indicating non-tidal variations including surge) at **(a)** Tan Chau, **(b)** Vung Tau, **(c)** Chau Doc and **(d)** Vam Kenh stations in 2024. The difference between the solid and dashed lines approximates the tidal oscillation, while the elevation of the dashed line reflects the surge and other low-frequency variations.

4. Discussion

This study elucidated the multifaceted meteo-hydrological context of the urban flooding event in My Tho, Tien Giang Province on February 12, 2024. Our analysis reveals that urban flooding in this LCR resulted from a specific combination of factors, dominated by tidal dynamics interacting with meteorological forcing and background hydrological conditions. Individually assessing the contributing factors, we found:

Precipitation during the February 9–12 period was minimal across the region (**Figure 2**) and did not contribute significantly to the flooding in My Tho city. This contrasts with scenarios where heavy local rainfall is a primary driver [1,16].

Strong northeast monsoon winds prevailed, peaking around February 12 (**Figure 3**). These winds generated significant water surges along the coast, reaching magnitudes (up to 40 cm near Vung Tau, consistent with Thuy et al.) sufficient to elevate coastal and estuarine water levels substantially (**Figure 6b,d**) [23].

The event occurred during the dry season, characterized by low and slightly decreasing Mekong River discharge (**Figure 5**). While not a direct cause of flooding, this low outflow reduced the river's capacity to resist incoming tidal waters, thereby facilitating the inland penetration of high tides and surges. This highlights the importance of river flow conditions even during non-flood seasons in tidally influenced deltas [17].

The flooding coincided with a period of high spring tides. The combination of these high astronomical tides with the strong monsoon-induced water surge resulted in exceptionally high observed water levels at the coast and estuary (**Figure 6b,d**). Our analysis using the Doodson filter allowed us to qualitatively assess the significant contribution of the surge component to the peak water levels.

The combination of these factors proved critical. The primary drivers were the high astronomical tides compounded by the monsoon-induced water surge. The effectiveness of these drivers in causing inland flooding in My Tho was significantly enhanced by the concurrent low river discharge, which allowed tidal influence to extend further upstream with less opposition. Prevailing winds not only generated the surge but also facilitated the inland movement of saline water, further impacting the estuarine dynamics. While previous studies have noted correlations between rainfall and tides or the general impact of factors like sea-level rise and land subsidence [6,7,16,21,33], this analysis pinpoints the specific synergy of high tides, strong monsoon surge, and low river flow as the cause of this particular February 2024 event.

These results underscore the need for comprehensive flood management solutions in LCRs like VMD. Management must account for the complex interactions among multiple hydrological and climatic factors, including seasonal variations in river flow and monsoon intensity, alongside tidal cycles and the overarching influence of sea-level rise [9,11]. Integrated approaches considering rainfall, monsoon patterns, river discharge, tidal influences, and water surges are essential for enhancing flood predictability and developing effective adaptation strategies. As climate change continues to impact sea levels, weather patterns (including monsoon intensity), and potentially river flows [13,14], adaptive solutions become increasingly critical. This research provides foundational insights for informed decision-making, emphasizing the need for interdisciplinary collaboration to address urban flooding challenges in vulnerable deltaic cities like My Tho. Future studies should continue developing predictive models incorporating these multiple interacting factors and explore tailored urban planning and infrastructure solutions.

5. Conclusions

This study evaluated the hydrological and climatic contributions to the urban flooding event in My Tho City, Tien Giang Province, on February 12, 2024. Analyzing historical meteorological and hydrological data, we identified that the urban flooding was primarily driven by a combination of elevated astronomical tidal levels and significant water surges amplified by northeast monsoon circulation. Reduced Mekong River flow discharge during the dry season further exacerbated the situation by facilitating the inland intrusion of these tidal waters. Rainfall played a negligible role in this specific event.

The findings indicate that the flooding event from February 9 to 12, 2024, resulted from the compounded effects of high tides and surges induced by the northeast monsoon, acting upon a system made more vulnerable by low river outflow. This observation highlights the necessity of considering a comprehensive range of interacting hydrological and climatic factors—tides, surges, winds, and river flow—when evaluating flooding events and risks, particularly in low-lying coastal regions sensitive to subtle shifts in these drivers.

Effective forecasting models must integrate these factors to improve flood prediction accuracy, supporting more robust urban planning. Comprehensive flood mitigation solutions should address these complex interactions to reduce future risks. By doing so, we can enhance resilience against future flooding events, especially in vulnerable urban areas like My Tho City.

The insights gained provide a critical foundation for designing adaptive solutions to address urban flooding challenges considering climate change and rising sea levels. As climate change-related threats escalate, researchers, policymakers, and urban planners must collaborate to address the complexities of flooding risks, developing inclusive, evidence-based strategies to protect vulnerable populations and promote sustainable urban development.

Author Contributions

Conceptualization, D.T.A., N.C.T., P.T.D., P.V.T. and L.V.H.; methodology, D.T.A., N.C.T., P.T.D., P.V.T. and L.V.H.; formal analysis, D.T.A., N.C.T., P.T.D., P.V.T. and L.V.H.; writing—original draft preparation, N.C.T., P.T.D., P.V.T. and L.V.H.; writing—review and editing, D.T.A. and N.C.T.; investigation, D.T.A. and N.C.T. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study have been generated but are not currently available in a public repository. The data can be made available by the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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