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**TÁC ĐỘNG CỦA MỨC NƯỚC THẤP ĐẾN HIỆU QUẢ HOẠT ĐỘNG DỊCH VỤ  
KHO BÃI Ở ĐỒNG BẰNG SÔNG CỬU LONG, VIỆT NAM: TRƯỜNG HỢP  
NGHIÊN CỨU TẠI TỈNH ĐỒNG THÁP**

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**Tóm tắt**

Nghiên cứu này phân tích tác động của biến động mực nước sông đối với doanh thu dịch vụ kho bãi tại tỉnh Đồng Tháp, một khu vực logistics phụ thuộc mạnh vào vận tải thủy nội địa ở Đồng bằng sông Cửu Long. Sử dụng dữ liệu chuỗi thời gian theo tháng giai đoạn 2018–2025, nghiên cứu áp dụng mô hình hồi quy OLS với sai số chuẩn hiệu chỉnh, mô hình Prais–Winsten và distributed lag để đánh giá cả tác động tức thời và tác động trễ của

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các cú sốc thủy văn. Kết quả cho thấy mực nước sông có mối quan hệ nghịch chiều có ý nghĩa thống kê với doanh thu kho bãi: khi mực nước giảm, doanh thu kho bãi có xu hướng tăng do phát sinh hành vi “lưu kho chờ vận chuyển” trong chuỗi cung ứng. Tác động này xuất hiện với độ trễ khoảng hai đến ba tháng và không được điều tiết đáng kể bởi hoạt động vận tải đường bộ. Kết quả cho thấy các cú sốc thủy văn không chỉ ảnh hưởng đến vận tải mà còn lan tỏa tới hệ thống logistics thông qua sự gia tăng nhu cầu lưu trữ tạm thời.

**Từ khoá:** Đồng bằng sông Cửu Long, Đồng Tháp, mực nước thấp, hiệu quả dịch vụ kho bãi, vận tải đường thủy nội địa

## THE IMPACT OF LOW WATER LEVELS ON WAREHOUSE SERVICE PERFORMANCE IN VIETNAM’S MEKONG DELTA: EVIDENCE FROM DONG THAP PROVINCE

### Abstract

This study analyzes the impact of river water level fluctuations on warehousing service revenue in Dong Thap Province, a logistics region that relies heavily on inland waterway transport in the Mekong Delta. Using monthly time-series data for the period 2018–2025, the study applies OLS regression with robust standard errors, the Prais–Winsten model, and a distributed lag model to evaluate both the contemporaneous and delayed effects of hydrological shocks. The results show that river water levels have a statistically significant inverse relationship with warehouse revenue: when water levels decrease, warehouse revenue tends to increase due to the emergence of “store-and-wait” behavior within the supply chain. This effect appears with a lag of approximately two to three months and is not significantly moderated by road freight activity. The findings indicate that hydrological shocks not only affect transport operations but also propagate to the logistics system through an increase in temporary storage demand.

**Keywords:** Mekong Delta, Dong Thap, low water levels, warehouse service performance, inland waterway transport

### 1. Introduction

Warehouse and storage services are an important component of the logistics system in Vietnam’s Mekong Delta, supporting agricultural exports and cargo flows to major seaports. As the region relies heavily on inland waterway transport (IWT), fluctuations in river water levels can disrupt cargo movements and indirectly affect warehouse operations. Periods of low water reduce vessel draft and payload capacity, increase transport costs, and weaken service reliability, which may influence warehouse utilization and service revenue.

While a growing body of literature examines the impacts of low water levels on inland waterway transport performance, empirical evidence on downstream logistics services remains limited. In the Mekong Delta, existing studies mainly focus on navigational constraints and infrastructure bottlenecks, with little attention to the financial performance of warehousing

services. In particular, econometric evidence linking hydrological shocks to warehouse service revenue in waterway-dependent provinces such as Dong Thap remains scarce.

This study empirically examines the impact of water-level fluctuations on warehouse service revenue in Dong Thap Province using monthly data from 2018 to 2025. The analysis addresses three research questions:

- RQ1: How do low-water conditions affect warehouse service revenue in Dong Thap Province?
- RQ2: Do the impacts of low water occur contemporaneously or with time lags due to inventory accumulation and operational adjustments?
- RQ3: During low-water periods, does warehouse service revenue increase through “store-and-wait” behavior or decrease due to modal diversion to road transport, and how does this interact with dry-season dynamics?

## **2. Literature review**

### ***2.1. Hydrological constraints and inland waterway transport performance***

#### *2.1.1. Hydrological constraints and water-level liability*

Inland waterway transport (IWT) is fundamentally constrained by hydrological conditions, as navigability depends directly on river water levels, discharge regimes, and seasonal variability (Vinke et al., 2025). Since inland waterways are largely natural systems rather than fully engineered infrastructures, fluctuations in water levels introduce inherent uncertainty into transport operations and planning (World Bank, 2019). Variability in river discharge affects available navigable depth, channel continuity, and safety margins, thereby shaping the baseline performance of inland navigation systems.

In many developing countries, hydrological constraints are reinforced by structural and institutional limitations (World Bank, 2019). Inland waterways frequently rely on natural depth conditions, with limited hydraulic regulation, irregular dredging, and insufficient maintenance (Vinke et al., 2025). Evidence from Vietnam, indicates that seasonal fluctuations, sedimentation, and uneven investment result in unstable navigational conditions across large parts of the inland waterway network (Vu, 2019; World Bank, 2019). From a systems perspective, such variability becomes a persistent constraint affecting long-term planning and the strategic role of inland waterways within national and regional logistics networks (Long, 2025).

#### *2.1.2. Effects of Low Water Levels on Inland Waterway Transport Performance*

These hydrological constraints, particularly low water levels, translate directly into tangible performance losses for inland waterway transport (World Bank, 2019). Reduced water depth restricts allowable vessel draft, forcing vessels to operate with partial loads and lowering

effective transport capacity. Even modest reductions in water levels can lead to disproportionate capacity losses, undermining the economic efficiency of inland navigation (Vinke et al., 2025).

At the network level, low water conditions affect both capacity utilization and operational reliability. Reduced payloads require additional vessel movements to satisfy freight demand, increasing pressure on already constrained river sections and terminals. The deterioration in performance is not limited to isolated locations but can propagate through inland logistics chains, affecting scheduling, coordination, and service levels (Long, 2025; World Bank, 2019).

Low water levels also have broader implications for logistics system integration. Studies on inland–dry port connectivity emphasize that reliable and predictable waterway conditions are essential for the effective integration of inland ports into multimodal transport networks (Long, 2025). Persistent or recurrent low water levels weaken this integration by increasing uncertainty and reducing throughput capacity. In contexts such as Vietnam, where inland waterways already face structural depth limitations, low water levels therefore represent not merely short-term operational disturbances but a systematic constraint on the long-term performance and competitiveness of inland waterway transport (Vu, 2019; World Bank, 2019).

## ***2.2. Low water level to capacity-induced congestion***

Low water levels are widely recognized in the literature as a major physical constraint on inland waterway transport, as insufficient channel depth directly limits the navigable draft and payload capacity of vessels (Jonkeren & Rietveld, 2009; Jonkeren et al., 2014). Draft restrictions force vessels to operate under partial loading conditions, leading to a non-linear reduction in effective transport capacity. This effect particularly impacts larger vessels, whose economic efficiency depends on high load factors, thereby increasing the number of vessel movements required to meet the same freight demand (van Dorsser et al., 2020).

At the system level, reduced vessel capacity during low water periods may create an imbalance between transport demand and available waterway capacity. Lower payloads and slower sailing speeds increase traffic density on inland waterways, especially during peak demand periods. These impacts are further intensified by safety requirements in shallow-water navigation, such as greater under-keel clearance and wider passing distances, which reduce effective channel capacity and contribute to congestion (van Dorsser et al., 2020; Zhang et al., 2024). Congestion therefore tends to concentrate at network bottlenecks, including shallow river sections, narrow channels, locks, and transshipment points (Jonkeren & Rietveld, 2009).

Beyond physical constraints, low water levels also generate significant operational and economic impacts. Congestion and reduced sailing speeds lead to longer and less predictable travel times (van Dorsser et al., 2020). Since schedule reliability is critical for shippers, particularly in time-sensitive supply chains, declining reliability reduces the competitiveness

of inland waterways relative to other transport modes (Jonkeren et al., 2014). Although operators may attempt mitigation strategies—such as increasing sailing frequency, adjusting schedules, or deploying smaller vessels—the effectiveness of these measures is often limited by fleet characteristics, infrastructure constraints, and rising operating costs (Zhang et al., 2024).

These challenges are particularly evident in river systems with strong seasonal hydrological variability, such as the Mekong Delta. Many waterways in the region fail to maintain their designed navigational depth during the dry season due to seasonal low flows, sedimentation, and limited dredging capacity (JICA, 2019). As a result, vessel loading restrictions and congestion are recurrent conditions rather than exceptional events, making inland navigation in the Mekong Delta highly sensitive to water level fluctuations and increasingly vulnerable to climate-induced hydrological changes.

### ***2.3. Inventory buffering and modal substitution as supply-chain adjustment mechanisms.***

#### ***2.3.1. Inventory Buffering***

Inventory buffering, also referred to as inventory slack, is an adjustment mechanism external to an existing supply chain relationship, aimed at reducing a firm’s exposure to its current exchange partners and mitigating the adverse consequences of disruptions (Bode et al., 2011). Essentially, it builds backup resources to function as “shock absorbers” against fluctuations.

Inventory buffering involves maintaining excess inventory to hedge against uncertainty in supply and demand (Bode et al., 2011). Its primary objective is to mitigate the consequences of supply disruptions, such as supplier shutdowns or output volatility (Jeon, 2021). In this way, it reduces the need for information processing related to a specific exchange relationship (Bode et al., 2011).

Forms of inventory buffering include:

- **Higher inventory levels:** Maintaining inventory levels higher than those required for normal operations (Bode et al., 2011).
- **Safety stock:** Additional inventory held to guard against uncertainty in demand or supply. For example, a firm may increase orders of organic products to compensate for uncertainty in production and reduce dependence on substitute products (Jeon, 2021).

Enhancing supply chain resilience through inventory buffering is often associated with increased costs. While inventory buffers can help rapidly restore inventory levels after disruptions, they may also lead to higher production costs and lower robustness (Spiegler et al., 2012). Similarly, a supply chain designed for high resilience (e.g., short inventory and transportation recovery times) can be costly and less robust, as evidenced by large fluctuations in order rates, inventory levels, and transportation performance. Therefore, balancing

transportation costs and resilience represents a trade-off that must be carefully managed (Spiegler et al., 2012)

### *2.3.2. Modal Substitution*

Modal substitution refers to the shift of freight transport between different transport modes, such as inland waterways, road, and rail, in response to environmental, operational, or economic changes (Jonkeren et al., 2007; Jonkerena et al., 2008; Nistor, 2020). This mechanism enables freight transport systems to maintain cargo flows and adapt to disruptions, including those associated with climate change (Jonkeren et al., 2007). By redirecting freight from one transport mode to another, modal substitution helps optimize transportation costs and transit times while ensuring continuity in freight movements (Jonkeren et al., 2007; Nistor, 2020).

Several factors drive modal substitution in freight transport. Climate change plays a significant role, particularly when low water levels on inland waterways reduce vessel loading capacity and increase transportation costs per ton. Under such conditions, rail and road transport may become more competitive, leading to shifts in modal choice (Jonkeren et al., 2007; Jonkerena et al., 2008). In addition, extreme weather conditions, such as heavy rainfall, can disrupt road transport operations and influence modal selection (Nistor, 2020). Transportation costs are also a key determinant, as increases in the cost of one mode may encourage the use of alternative modes to minimize total logistics costs (Jonkeren et al., 2007). Beyond cost considerations, service availability, transit time reliability, and infrastructure conditions also influence decisions regarding modal substitution (Nistor, 2020).

To analyze these dynamics, models such as NODUS, a GIS-based freight transport model, are widely used to examine freight flows in multimodal networks (Jonkeren et al., 2007; Jonkerena et al., 2008). The model evaluates the impact of disruptions, such as low water levels, on transportation costs and modal split by minimizing total freight transport costs across different modes, routes, and vehicle types, including intermodal combinations (Jonkeren et al., 2007; Jonkerena et al., 2008). In this context, concepts such as “virtual links” and multi-flow approaches allow researchers to identify alternative routes and transport modes, leading to more realistic predictions of modal shifts (Jonkerena et al., 2008).

### **2.4. Research gap**

Existing studies have extensively analyzed the impacts of low water levels on inland waterway transport, focusing on hydrological constraints, capacity reductions, congestion, and supply-chain adjustments. In Vietnam, the literature similarly emphasizes navigational and infrastructure limitations in the Mekong Delta during low-water periods.

However, prior research remains largely transport-oriented and provides limited evidence on downstream logistics services. In particular, the financial impacts of low water as well as induced disruptions on warehouse service revenue are rarely examined, especially in

waterway-dependent developing deltas such as Vietnam's Mekong Delta. Moreover, existing studies are predominantly descriptive and lack econometric analysis linking seasonal hydrological shocks to warehouse-level financial performance at the provincial scale, including Dong Thap Province.

### **3. Methodology**

#### **3.1. Research procedures**

This paper is based on a structured empirical research procedure with the foundation of research in the inland waterway transport (IWT) economics and climate-adaptation literature, with particular reference to the welfare and adaptation framework developed by Jonkeren et al. (2007, 2013).

The research proceeds in five main steps.

First, a conceptual framework is established linking water level to warehouse service revenue with response to other control variables like IIP and Rice export output, emphasizing capacity constraints affecting inland waterway transport and downstream adjustments in logistics services (Jonkeren et al., 2007; Hendrickx & Breemersch, 2012).

Second, monthly data on warehouse revenue, river water levels, freight activity, and macroeconomic controls are collected and harmonized.

Third, key variables are constructed, including logarithmic transformations and water-level anomalies, to ensure comparability and economic interpretability, consistent with standard practice in transport economics (Jonkeren et al., 2013).

Fourth, a set of econometric models is specified to address the research questions concerning the existence, timing, and mechanism of water-level impacts.

Finally, robustness checks and diagnostic tests are conducted, and the empirical findings are interpreted in light of recent empirical evidence on supply-chain disruptions caused by low-water events (Chen et al., 2025).

#### **3.2. Research methods**

The study adopts a quantitative econometric approach using time-series regression analysis. Ordinary Least Squares (OLS) models with heteroskedasticity-robust standard errors are used to estimate the relationship between water level and warehouse service revenue, considering two possible transportation strategy, including mode shift and wait-n-store commonly applied in inland waterway transport studies (Jonkeren et al., 2007; Hendrickx & Breemersch, 2012).

Monthly fixed effects are included to control for seasonality in agricultural production, trade cycles, and logistics demand, which is a standard concern in river-based transport systems subject to strong seasonal hydrology (Jonkeren et al., 2013). Interaction terms are used to test

mechanism dominance, reflecting the adaptation logic discussed in the literature on modal adjustment and logistics resilience (Behdani et al., 2021; Chen et al., 2025).

### *3.2.1. Theoretical Framework and Hypothesis Development*

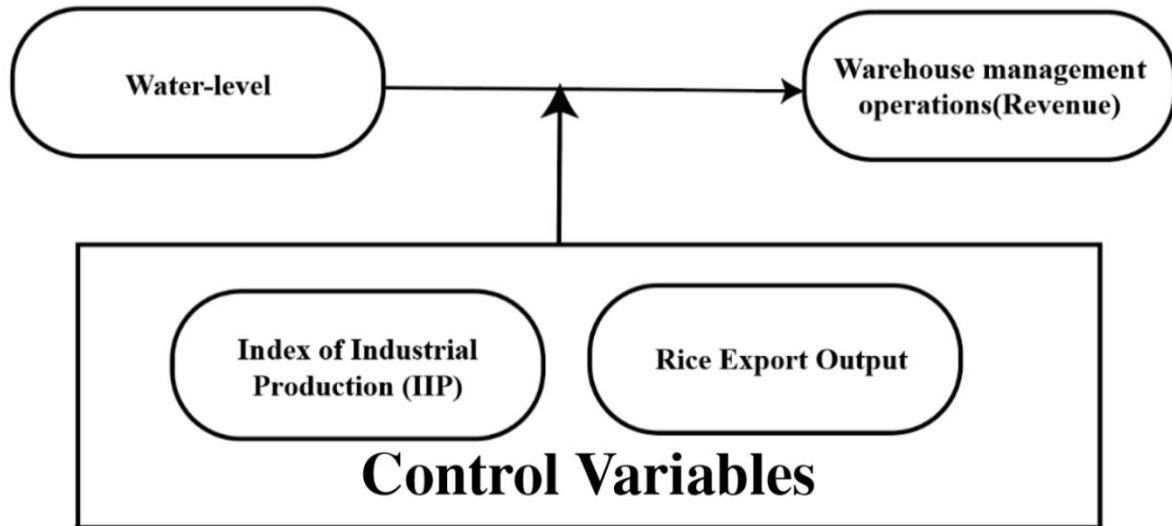
This study is grounded in two theories on inland waterway transport performance and logistics system adjustment under capacity constraints. Drawing on the framework developed by Jonkeren et al. (2007, 2013), low-water events are conceptualized as negative capacity shocks that reduce effective navigability by constraining vessel draft and load factors. These constraints increase generalized transport costs and disrupt the timing and reliability of cargo flows.

The first theoretical mechanism concerns the transmission of transport performance deterioration to downstream logistics services. When inland waterway capacity is reduced due to low water levels, cargo arrivals at logistics nodes become irregular and delayed. Warehousing services respond to these disruptions through increased inventory accumulation and longer dwell times, implying that warehouse service revenue reflects the extent of logistics system stress induced by hydrological shocks (Jonkeren et al., 2007; Hendrickx & Breemers, 2012).

The second theoretical mechanism relates to adjustment behavior under congestion and capacity stress. Faced with reduced inland waterway reliability, shippers and logistics operators may adjust through alternative strategies. One strategy involves modal reallocation, whereby cargo is shifted to alternative transport modes, such as road transport, to maintain delivery schedules (Behdani et al., 2021). An alternative strategy involves inventory-based adjustment, commonly described as “store-and-wait” behavior, in which cargo is temporarily held in storage facilities until navigation conditions improve (Jonkeren et al., 2007; Chen et al., 2025).

### *3.2.2. Data sources and conceptual framework*

From these given theories and hypothesis, we suggest a framework to test the effect of water level on warehouse service revenue in accordance to two control variables



**Figure 1:** Conceptual framework

*Source: Author's compilation*

The dataset consists of monthly data regarding the August 2018 – March 2025 period:

Warehouse revenue data are obtained from provincial monthly socio-economic reports from the Statistics Office Department and represent service income generated by warehouse revenue. However, there still exist 2 missing values among 90 existing ones, with the unit of million dong.

River water-level data are collected from Mekong River Commission within the Tan Chau station, located at the upstream of the Tien river, merely the starting point to Dong Thap with the unit of meter. In particular, this is the height of water level compared to the station baseline level, not the thread depth. However, this is consistent with approaches used in prior inland waterway transport research (Jonkeren et al., 2007; Hendrickx & Breemersch, 2012) and consistent with the approach of the paper which is determining the effect of water level on warehouse revenue

Road freight activity, IIP and Rice export output is also obtained from provincial monthly socio-economic reports. To be specific, freight tonnage is measured in thousand ton-kilometers and reflects the intensity of alternative transport mode usage, as suggested by the literature on modal substitution under transport disruptions (Behdani et al., 2021). Additional control variables include an industrial production indicator (IIP) and rice export output. We believe that factors that require barge cargo like rice or industrial products would be heavily affected by water level which subsequently will affect warehouse revenue. These variables capture macroeconomic demand and commodity-specific trade dynamics which are relevant to the Mekong Delta context (Chen et al., 2025).

All datasets are aligned to a monthly frequency and merged by time. To reduce scale differences and heteroskedasticity, monetary and quantity variables are transformed using natural logarithms. Water-level data are further processed to construct anomaly measures that capture deviations from long-run average conditions, a common strategy to isolate exogenous hydrological shocks (Jonkeren et al., 2013).

### 3.2.3. *Dependent variable*

The dependent variable is the natural logarithm of monthly warehouse service revenue (*ln\_rev*). The variable measures the intensity of warehouse utilization and is interpreted as an outcome of logistics demand and buffering behavior. Warehousing is conceptualized as a key short-run adjustment mechanism when inland waterway transport capacity is constrained by low water levels, consistent with the buffering role emphasized in the inland waterway transport literature (Jonkeren et al., 2007; Chen et al., 2025).

### 3.2.4. *Water-level variable*

Variables are defined to reflect economic mechanisms highlighted in the inland waterway transport and climate-adaptation literature. Revenue and freight variables are expressed in logarithmic form to allow coefficient interpretation as elasticities and to stabilize variance (Jonkeren et al., 2007). Hydrological variables are specified to capture short-term shocks rather than long-term trends, following the focus on disruption effects rather than climate averages (Hendrickx & Breemersch, 2012). Seasonal patterns are addressed through monthly dummy variables to account for recurring harvest, export, and navigation cycles (Jonkeren et al., 2013).

### 3.2.5. *Control variables*

Two control variables are included to isolate the effect of water-level shocks. The industrial production index (*iip*) controls for overall economic activity and demand-side fluctuations, while the of rice export ton (*rice\_export*) captures commodity-specific trade dynamics relevant to the study region (Chen et al., 2025). Monthly fixed effects explain seasonality related to harvest cycles, export timing, and recurring logistics patterns.

## 3.3. *Econometric Model Specifications*

The econometric strategy follows a reduced-form approach commonly adopted in the inland waterway transport and climate-impact literature, particularly the framework developed by Jonkeren et al. (2007, 2013). The objective is to identify how short-run hydrological shocks are associated with changes in logistics outcomes, without imposing structural assumptions on behavioral responses.

The baseline specification relates warehouse service revenue to hydrological conditions and a set of control variables:

$$\ln Revenue_t = \beta_0 + \beta_1 \cdot WaterLevel + \beta_2 \cdot Controls_t + \lambda_m + \varepsilon_t \quad (1)$$

Where:

- $\ln Revenue_t$  denotes the logarithm of warehouse service revenue in month  $t$ ,

- *WaterLevel* is the water-level anomaly capturing deviations from normal navigation conditions,
- *Controls<sub>t</sub>* is a vector of control variables,
- $\lambda_m$  represents monthly fixed effects accounting for seasonality,
- and  $\varepsilon_t$  is the error term. This specification mirrors the reduced-form estimation strategy used by Jonkeren et al. (2007) to quantify the economic consequences of low-water events through observable market outcomes.

This formulation specification is designed to test whether different adjustment channels operate under varying transport conditions, consistent with the adaptation and modal interaction logic discussed in the inland waterway transport and logistics literature (Behdani et al., 2021; Chen et al., 2025).

All models are estimated using Ordinary Least Squares with heteroskedasticity-robust standard errors. The econometric specifications are presented ex ante as part of the research design, and no assumptions are made at this stage regarding the expected sign or statistical significance of the estimated coefficients.

### **3.4. Assumptions and Limitations**

This study relies on several assumptions.

First, the regression framework assumes a stable short-run relationship between hydrological conditions and logistics outcomes, abstracting from long-term structural changes and infrastructure adaptation (Jonkeren et al., 2007).

Second, water-levels are treated as exogenous shocks, an assumption supported by their hydrological origin but potentially weakened by unobserved concurrent economic events (Hendrickx & Breemers, 2012).

Third, warehouse revenue is used as a proxy for buffering behavior, which may not fully capture all forms of logistics adjustment.

Several limitations should be acknowledged.

The analysis is conducted at an aggregate monthly level, which may mask firm-level heterogeneity in adaptation strategies.

Data limitation limits the inclusion of detailed transport cost variables and infrastructure capacity indicators.

The results are context-specific and should be interpreted as reflecting short-run adaptation dynamics rather than long-run equilibrium adjustments, as emphasized in the broader inland waterway transport literature (Jonkeren et al., 2013; Chen et al., 2025).

## **4. Statistical results**

### **4.1. Descriptive Statistics**

This section presents descriptive statistics of the main variables used in the empirical analysis. The dataset includes 78 monthly observations for Dong Thap province, covering warehouse service revenue, hydrological indicators, and control variables reflecting logistics and economic activity.

Warehouse service revenue (in logarithmic form) shows significant variation over time, largely driven by seasonal logistics demand linked to agricultural production and export cycles in the Mekong Delta, particularly rice. Revenue tends to rise during harvest and export peaks and decline during off-peak periods.

Water-level indicators also vary across months. Low water levels occur mainly in the dry season, when inland waterway navigation becomes more difficult. These periods often coincide with reduced cargo movements, suggesting a possible link between hydrological conditions and logistics performance.

Regarding control variables, rice export output varies considerably and closely follows the movement of warehouse revenue, highlighting the importance of agricultural exports in driving warehousing demand in Dong Thap. In contrast, the industrial production index (IIP) shows relatively limited variation and weaker association with warehouse revenue, reflecting the province's limited industrial base.

Note that p-values reported as 0.000 indicate values below 0.001, rounded to three decimal places.

Overall, the descriptive statistics reveal three main characteristics:

- (i) strong seasonality in warehouse revenue,
- (ii) sensitivity of logistics activity to hydrological conditions, and
- (iii) the dominant role of agricultural exports in shaping warehousing demand. These findings motivate the regression analysis in the following sections.

## 4.2. The effect of low water on Warehousing revenue

### 4.2.1. Pairwise Correlation Analysis

*p-values in parentheses. \* significant at 10%.*

**Table 1:** Pairwise Correlation Matrix

	ln_rev	water_level	iip	rice_export
ln_rev	1.000			
water_level	-0.197* (0.081)	1.000		
iip	-0.012 (0.920)	0.070 (0.540)	1.000	
rice_export	0.557* (0.000)	0.025 (0.830)	0.038 (0.744)	1.000

*Source: Authors' calculations using Stata 17*

The bivariate relationship between water levels and warehouse service revenue is examined using Pearson correlation statistics. The correlation coefficient between water\_level and ln\_rev is  $-0.197$ , with a  $p$ -value of  $0.081$ , indicating a modest negative association that is statistically significant at the 10% level. This suggests that months with higher water levels tend to coincide with lower warehouse revenue, although the magnitude of this raw relationship remains limited.

The correlation analysis also indicates that rice\_export is strongly and positively correlated with ln\_rev ( $r = 0.557$ ,  $p = 0.000$ ), implying that export activity constitutes a major determinant of warehouse revenue in the descriptive data. In contrast, iip exhibits virtually no correlation with ln\_rev ( $r = -0.012$ ,  $p = 0.920$ ), suggesting limited direct association at the bivariate level. While these statistics provide preliminary insight into linear co-movement, correlation analysis does not control for seasonality or other confounding factors. A multivariate regression framework is therefore required to assess the conditional effect of water levels on revenue.

### 4.2.2. Stationarity Tests (ADF Unit Root Tests)

*ADF tests with 6 lags. H0: series has a unit root.*

**Table 2:** Augmented Dickey–Fuller Unit Root Tests

Variable	Obs	Z(t) stat	1% CV	5% CV	10% CV	p-value	Conclusion
ln_rev	65	-2.177	-3.559	-2.918	-2.594	0.215	Fail to reject H0 (non-stationary)
water_level	73	-5.629	-3.548	-2.912	-2.591	0.000	Reject H0 (stationary)

iip	65	-2.795	-3.559	-2.918	-2.594	0.059	Stationary at 10% level
rice_export	65	3.394	-3.559	-2.918	-2.594	1.000	Fail to reject H0 (non-stationary)

Source: Authors' calculations using Stata 17

Given the monthly time-series structure of the dataset, Augmented Dickey–Fuller tests are conducted to assess the stationarity properties of the variables. The results indicate that *water\_level* is stationary, with a test statistic of  $-5.629$  and a  $p$ -value of  $0.000$ , leading to strong rejection of the unit-root null hypothesis. By contrast, *ln\_rev* fails to reject the null hypothesis of a unit root ( $p = 0.215$ ), suggesting non-stationarity in levels. *Rice\_export* also appears non-stationary ( $p = 1.000$ ), while *iip* is borderline stationary at the 10% significance level ( $p = 0.059$ ).

The presence of mixed integration orders implies that the estimated relationships should be interpreted primarily as conditional short-run associations rather than strict long-run equilibrium effects. However, because the key explanatory variable *water\_level* is stationary, estimation in levels remains appropriate for assessing its contemporaneous relationship with warehouse revenue, particularly after controlling for seasonal fixed effects.

#### 4.2.3. Baseline OLS Estimation

Dependent variable:  $\ln(\text{Revenue})$ . Robust standard errors in parentheses.

**Table 3:** Baseline OLS Regression (RQ1)

Variable	Coefficient	Std. Error	t-stat	p-value	95% CI
<i>water_level</i>	-0.638**	0.221	-2.89	0.005	[-1.080, -0.197]
<i>iip</i>	0.176	0.745	0.24	0.814	[-1.313, 1.666]
<i>rice_export</i>	9.19e-06***	1.17e-06	7.83	0.000	[6.84e-06, 1.15e-05]
<i>Month FE</i>	Yes				
Constant	9.842***	0.203	48.54	0.000	[9.437, 10.248]
<i>Observations</i>					78
<i>R-squared</i>					0.5633
<i>Root MSE</i>					0.459
<i>F-statistic</i>					5.49
					Prob > F = 0.0000

Source: Authors' calculations using Stata 17

The baseline specification estimates  $\ln(\text{Revenue})$  as a function of `water_level`, `rice_export`, `iip`, and month fixed effects. The estimated coefficient on `water_level` is  $-0.638$ , with a robust standard error of  $0.221$ , yielding a t-statistic of  $-2.89$  and a p-value of  $0.005$ . The 95% confidence interval ranges from  $-1.080$  to  $-0.197$ , confirming statistical significance at conventional levels.

The negative coefficient indicates that higher water levels are associated with lower warehouse revenue, holding other factors constant. Equivalently, a one-meter decline in water level corresponds to an approximate  $0.638$  log-point increase in revenue. Given the logarithmic specification of the dependent variable, this represents a substantial semi-elastic response. In simple terms, there is an inverse relationship between water levels and warehouse revenue: When the water level drops by just one meter, the warehouse revenue faces a significant increase, with revenue increasing by roughly 89% (which is the real-world equivalent of the  $0.638$  log-point increase mentioned in the data)

The model explains 56.3% of the variation in revenue, and the overall regression is highly significant ( $\text{Prob} > F = 0.0000$ ), indicating strong joint explanatory power.

Among the control variables, `rice_export` is positive and highly significant ( $\beta = 9.19e-06$ ,  $p < 0.001$ ), reinforcing the central role of agricultural export throughput in shaping warehouse revenue dynamics. In contrast, `iip` is statistically insignificant ( $p = 0.814$ ), suggesting limited short-run influence of industrial production within this regional context

#### 4.2.4. Multicollinearity Diagnostics

Based on baseline OLS regression (Table 1).  $VIF > 10$  typically indicates severe multicollinearity.

**Table 4:** Variance Inflation Factors (VIF)

Variable	VIF	1/VIF
<code>water_level</code>	5.38	0.186
<code>iip</code>	1.33	0.749
<code>rice_export</code>	1.05	0.956
month = 2	1.85	0.540
month = 3	2.13	0.470
month = 4	1.88	0.533
month = 5	1.90	0.526
month = 6	1.82	0.549
month = 7	1.72	0.583
month = 8	2.37	0.422
month = 9	3.46	0.289
month = 10	3.54	0.283

month = 11	2.37	0.421
month = 12	1.90	0.525
<i>Mean VIF</i>	2.34	

*Source: Authors' calculations using Stata 17*

To assess potential multicollinearity among regressors, Variance Inflation Factors are calculated. The VIF for *water\_level* is 5.38, while the corresponding values for *iip* and *rice\_export* are 1.33 and 1.05, respectively, with a mean VIF of 2.34. Although the VIF for *water\_level* reflects moderate correlation with other explanatory variables, likely due to seasonal co-movement with month indicators, it remains well below conventional thresholds for severe multicollinearity. These results indicate that coefficient estimates are unlikely to be materially distorted by linear dependence among regressors.

#### 4.2.5. Serial Correlation and Prais–Winsten Correction

*Dependent variable: ln(Revenue). Iterated Prais–Winsten estimator correcting for first-order serial correlation.*

**Table 5:** Prais–Winsten AR(1) Regression

Variable	Coefficient	Std. Error	t-stat	p-value	95% CI
<i>water_level</i>	-0.409**	0.145	-2.81	0.007	[-0.700, -0.118]
<i>iip</i>	-0.568	0.703	-0.81	0.422	[-1.974, 0.837]
<i>rice_export</i>	7.01e-06***	1.78e-06	3.94	0.000	[3.45e-06, 1.06e-05]
<i>Month FE</i>	Yes				
Constant	9.735***	0.231	42.23	0.000	[9.274, 10.196]
<i>Observations</i>					78
<i>R-squared</i>					0.7017
<i>Adj. R-squared</i>					0.6354
<i>rho (AR1)</i>					0.5508
<i>DW (original)</i>					1.030
<i>DW (transformed)</i>					2.044

*Source: Authors' calculations using Stata 17*

Given the monthly time-series structure of the data, residual serial correlation may bias standard errors in the baseline OLS estimation. The Durbin–Watson statistic from the OLS regression is 1.030, substantially below the benchmark value of 2, indicating positive first-order serial correlation.

To address this issue, the model is re-estimated using the iterated Prais–Winsten AR(1) transformation. The estimated autoregressive parameter is  $\rho = 0.5508$ , indicating moderate persistence in the error term. Following transformation, the Durbin–Watson statistic increases to 2.044, suggesting that serial correlation has been effectively mitigated.

Importantly, the coefficient on `water_level` remains negative and statistically significant after correction. The Prais–Winsten estimate is  $-0.409$  with a standard error of 0.145 and a p-value of 0.007. Although the magnitude decreases relative to the baseline OLS estimate, both the sign and statistical significance are preserved. This confirms that the negative association between water level and warehouse revenue is not driven by autocorrelation bias.

#### 4.2.6. Robustness Checks

*Dependent variable:  $\ln(\text{Revenue})$ . Robust standard errors in parentheses. All specifications include month fixed effects.*

**Table 6:** Robustness Checks – Alternative Specifications

Specification	water_level Coeff.	Std. Error	p-value	R <sup>2</sup>	N
(1) Baseline: <code>water_level</code> + <code>iip</code> + <code>rice_export</code>	-0.638**	0.221	0.005	0.563	78
(2) Exclude <code>iip</code> ( <code>water_level</code> + <code>rice_export</code> )	-0.607**	0.208	0.005	0.561	79
(3) Exclude <code>rice_export</code> ( <code>water_level</code> + <code>iip</code> )	-0.594**	0.285	0.041	0.186	78
(4) No controls (month FE only)	-0.541**	0.265	0.046	0.179	79
(5) WL anomaly – demeaned water level	-0.638**	0.221	0.005	0.563	78
(6) Low-water dummy (bottom 10th percentile)	0.234	0.170	0.175	0.439	78

*Source: Authors' calculations using Stata 17*

A series of alternative specifications are estimated to evaluate the stability of the baseline result. When `iip` is excluded from the regression, the coefficient on `water_level` remains negative and statistically significant ( $-0.607$ ,  $p = 0.005$ ). When `rice_export` is excluded, the negative relationship persists and remains significant ( $-0.594$ ,  $p = 0.041$ ). Even in a specification including only month fixed effects, the coefficient remains negative and statistically significant ( $-0.541$ ,  $p = 0.046$ ).

Using a demeaned water-level anomaly yields an identical estimate to the baseline model, as expected by construction. However, replacing the continuous water-level variable with a dummy for the bottom 10th percentile produces a statistically insignificant coefficient ( $p =$

0.175), indicating that the observed relationship operates through continuous variation rather than being driven solely by extreme low-water episodes.

#### *4.2.7. Conclusion for RQ1*

The empirical evidence consistently supports a statistically significant negative relationship between water levels and warehouse service revenue. The estimated effect remains robust under baseline OLS estimation, persists across multiple alternative model specifications, and continues to hold after correcting for first-order serial correlation using the Prais–Winsten AR(1) procedure. Diagnostic tests indicate that the findings are not driven by multicollinearity or residual serial dependence, strengthening confidence in the stability of the result.

The negative coefficient implies that lower water levels are associated with higher warehouse revenue in the contemporaneous period. This finding is consistent with the “store-and-wait” mechanism proposed in the theoretical framework. When water levels decline and inland waterway transport performance deteriorates, shipments may be delayed or temporarily held, leading to increased reliance on warehousing services. In this interpretation, low-water conditions constitute not only a transport disruption but also a broader logistics shock that increases inventory dwell time and buffers demand within storage facilities.

The results further indicate that agricultural export activity is a primary determinant of warehouse revenue. The estimated coefficient on rice export output is positive and statistically significant ( $\beta = 9.19\text{e-}06$ ,  $p < 0.001$ ), suggesting that higher export volumes are strongly associated with increased warehouse revenue. This finding aligns with prior research showing that warehouse performance in agrarian regions is closely tied to commodity throughput rather than storage duration alone (MRC, 2018). By contrast, the index of industrial production is statistically insignificant ( $p = 0.814$ ), indicating that industrial activity plays a comparatively limited role in shaping warehouse revenue in this predominantly agricultural province.

Taken together, the baseline results provide robust evidence that hydrological variation exerts a meaningful contemporaneous effect on warehouse revenue. The findings support the view that environmental shocks influence regional logistics systems not only through transport capacity but also through adjustments in storage demand and inventory management behavior.

#### ***4.3. Distributed lag regarding the low water effect (RQ2)***

To examine whether hydrological shocks affect warehouse revenue with delay, a distributed lag model including the contemporaneous water level and three monthly lags is estimated. The contemporaneous effect is statistically insignificant ( $\beta = 0.044$ ,  $p = 0.681$ ), as is the one-month lag ( $\beta = 0.132$ ,  $p = 0.475$ ). In contrast, longer lags are negative: the two-month lag is marginally significant ( $\beta = -0.236$ ,  $p = 0.088$ ), and the three-month lag is negative and statistically significant at the 5% level ( $\beta = -0.221$ ,  $p = 0.015$ ; 95% CI:  $[-0.398, -0.044]$ ). Although the cumulative four-month effect is negative ( $-0.281$ ), it is not statistically significant ( $p = 0.148$ ). However, the joint test of all water-level terms rejects the null of no dynamic effect ( $\text{Prob} > F = 0.0134$ ).

Dependent variable:  $\ln(\text{Revenue})$ . Robust standard errors in parentheses.

**Table 7:** Distributed Lag Model – Water Level (RQ2)

Variable	Coefficient	Std. Error	t-stat	p-value	95% CI
water_level (t)	0.044	0.105	0.41	0.681	[-0.168, 0.255]
water_level (t-1)	0.132	0.184	0.72	0.475	[-0.236, 0.500]
water_level (t-2)	-0.236	0.136	-1.73	0.088	[-0.508, 0.036]
water_level (t-3)	-0.221**	0.088	-2.50	0.015	[-0.398, -0.044]
iip	-0.040	0.716	-0.06	0.955	[-1.474, 1.394]
rice_export	8.23e-06***	1.14e-06	7.21	0.000	[5.95e-06, 1.05e-05]
Month FE	Yes				
Constant	10.109***	0.274	36.92	0.000	[9.561, 10.658]
Observations					75
R-squared					0.6275
F (joint WL lags)					3.46
					Prob > F = 0.0134
Cumulative effect	-0.281	0.192	-1.46	0.148	[-0.665, 0.103]

Source: Authors' calculations using Stata 17

These results indicate that water-level shocks do not immediately affect warehouse revenue but instead materialize after approximately two to three months. This lag structure is consistent with inland waterway research showing that low-water disruptions operate through reduced navigability and carrying capacity, leading to slower movements and logistical backlogs rather than immediate quantity adjustments (Chen et al., 2025; Hendrickx & Breemers, 2012). Evidence from the Rhine further shows that operators respond through operational adjustments and cost pass-through mechanisms, generating dynamic rather than purely contemporaneous impacts (Jonkeren et al., 2007; Jonkeren et al., 2013).

From a logistics perspective, delayed effects are plausible because real-time modal substitution is not frictionless and depends on coordination and multimodal availability. Where inland waterways remain central and alternatives are limited, low-water shocks may affect shipment scheduling and inventory handling gradually, with revenue consequences emerging only after operational adjustments take place (Behdani et al., n.d.). Overall, the evidence supports the conclusion that the influence of water levels on warehouse revenue operates through delayed dynamics rather than purely contemporaneous effects.

#### 4.4. Related effects due to low water (store-wait or modal shift – RQ3)

RQ3 examines whether low-water conditions modify the relationship between road freight activity and warehouse service revenue. The results show that the main effect of water level is negative but not statistically significant ( $\beta = -1.219$ ,  $p = 0.268$ ). In contrast, road freight activity ( $\ln(\text{road\_freight})$ ) is positive and statistically significant ( $\beta = 0.599$ ,  $p = 0.003$ ), indicating that warehouse revenue generally increases with higher road freight volumes. However, the interaction term between water level and road freight is small and insignificant ( $\beta = 0.068$ ,  $p = 0.571$ ), suggesting no evidence that road freight intensity changes the water-level–revenue relationship.

*Dependent variable:  $\ln(\text{Revenue})$ . Robust standard errors in parentheses.*

**Table 8:** Interaction test: Water Level x Road Freight (RQ3)

Variable	Coefficient	Std. Error	t-stat	p-value	95% CI
water_level	-1.219	1.091	-1.12	0.268	[-3.401, 0.962]
$\ln(\text{road\_freight})$	0.599**	0.195	3.07	0.003	[0.209, 0.990]
water_level x $\ln(\text{road})$	0.068	0.120	0.57	0.571	[-0.172, 0.309]
iip	-0.615	0.653	-0.94	0.350	[-1.921, 0.690]
rice_export	2.49e-06	2.20e-06	1.13	0.262	[-1.91e-06, 6.89e-06]
<i>Month FE</i>	Yes				
Constant	4.134**	1.857	2.23	0.030	[0.421, 7.847]
<i>Observations</i>					78
<i>R-squared</i>					0.6842
<i>F-statistic</i>					14.26
					Prob > F = 0.0000

*Source: Authors' calculations using Stata 17*

These findings imply that although road freight and warehouse revenue move together with overall logistics demand, road freight does not significantly moderate the impact of water-level variation on warehouse revenue during low-water periods.

This result is consistent with studies on inland waterway transport, which suggest that low-water disruptions mainly affect capacity and operations, such as load restrictions, rather than immediately triggering full modal substitution (Chen et al., 2025; Hendrickx & Breemers, 2012). From a synchromodality perspective, mode switching requires coordination, infrastructure, and information sharing; when these conditions are limited, substitution tends to be partial or slow (Behdani et al., n.d.). Similarly, climate-related low-water research

indicates that cost increases and capacity constraints often dominate, meaning disruptions may not lead to clear mode-dependent differences in downstream revenue (Jonkeren et al., 2013).

Overall, the insignificant interaction term does not support the RQ3 moderation hypothesis. While road freight activity is positively associated with warehouse revenue, it does not significantly alter the relationship between water-level variation and warehouse revenue during the study period.

## **5. Discussion & Implications**

### ***5.1. Contextualizing Mekong Delta region's infrastructure upon its potential***

#### ***5.1.1. Summary of Empirical Findings***

The empirical analysis in Chapter 3 reveals three critical characteristics of the Mekong Delta's logistics system:

1. Low water levels significantly reduce warehouse service revenue;
2. This effect involves a delayed three-month adjustment period, highlighting dynamic supply chain disruptions;
3. Road freight fails to significantly moderate these revenue impacts.

By highlighting the region's vulnerability to climate fluctuations, these realities expose a clear disconnect between the Delta's agricultural potential and its actual logistics capabilities, setting the stage for the proposed strategic measures below.

#### ***5.1.2. Mekong Delta region's infrastructure upon its potential***

To contextualize these findings, it is crucial to examine the region's structural infrastructure rigidities against its agricultural potential.

First, economic constraints severely limit modal substitution. Transporting a 40-foot container from the Mekong Delta to Ho Chi Minh City by road costs approximately 7 million VND, compared to 2.5 million VND via inland waterways (Bao Nguoi Lao Dong, 2024). This stark disparity prevents low-margin agricultural commodities from switching modes during low-water periods.

Second, physical infrastructure bottlenecks restrict diversion capacity. Key corridors like National Highway 30 (QL30) face severe congestion, which anticipated traffic from projects like the Rach Mieu 2 Bridge may exacerbate (VOH News, 2026). Thus, the road network functions as a constrained system rather than a flexible alternative.

Third, regional warehousing lacks buffering capacity. River ports such as Sa Dec and Tran Quoc Toan function primarily as transshipment hubs lacking integrated cold-chain or long-term storage capabilities (Bao Dong Thap, 2025). Consequently, hydrological shocks lead directly to reduced throughput rather than increased storage demand.

Overall, the Delta's logistics system remains structurally dependent on waterways. Unlocking its development potential requires restructuring the system toward multimodal integration, storage resilience, and operational flexibility.

## ***5.2. Development Orientation of the Mekong Delta Region***

The empirical findings indicate that hydrological variability poses a measurable economic risk to the logistics system of the Mekong Delta. Low water levels reduce warehouse service revenue and generate effects that propagate over several months, reflecting disruptions to transport capacity and goods circulation rather than temporary fluctuations. This pattern is consistent with international evidence showing that reduced navigable depth constrains inland shipping capacity and lowers corridor throughput (Jonkeren et al., 2007; Van Dorsser, 2015; Vinke et al., 2022).

From a development perspective, these results underscore the urgency of transitioning toward a resilience-oriented logistics strategy, as advocated in Resolution 120/NQ-CP (Bao Chinh Phu, 2022). The absence of significant modal substitution toward road transport suggests the current system lacks sufficient flexibility to absorb hydrological shocks. Similar constraints have been observed in European inland corridors, where alternative modes could not fully offset drought-induced capacity losses (Hendrickx & Breemers, 2012; Vinke et al., 2022).

For Dong Thap, which aims to become a regional agricultural processing and trade hub (VIOIT, 2024), future development cannot rely solely on expanding river-based throughput. Instead, policy should prioritize the transformation of existing river ports into integrated logistics centers equipped with multimodal connectivity and modern storage capacity. Strengthening system flexibility, rather than merely maximizing single-mode efficiency, is essential. In short, the development orientation must shift from dependence on hydrological stability toward a structurally resilient, multimodal logistics network.

## ***5.3. Suggested Policies for the Government and Measures for Vietnamese Warehousing Enterprises***

The identified structural rigidities highlight the limitations of relying on a single transport mode. Strengthening resilience requires coordinated interventions at both the macro (government) and micro (enterprise) levels.

### ***5.3.1. Suggested Policies for the Government***

First, infrastructure policy should prioritize multimodal synchronization rather than isolated modal expansion. The empirical results show that road transport does not significantly mitigate revenue losses during low water periods, suggesting that the current road network lacks sufficient capacity and flexibility to act as a reliable substitute when inland waterway transport is constrained. Therefore, infrastructure policy should focus on coordinated upgrades across arterial roads and key provincial connectors rather than relying solely on individual expressway projects. The timely completion of projects such as the Cao Lanh – An Huu

Expressway, together with congestion relief at bottlenecks along National Highway 30, would strengthen diversion capacity during hydrological stress.

Second, maintaining minimum navigability remains an important stabilization measure. As water level fluctuations negatively affect logistics revenue, targeted and scientifically managed dredging of critical river sections, such as the Tien River channel, can help preserve vessel capacity during dry seasons. However, such measures must follow environmental sustainability principles to avoid long term ecological damage. The goal should be to reduce extreme operational disruptions rather than eliminate natural hydrological variability.

Third, medium to long term development strategies should incorporate rail connectivity as an additional pillar of resilience. The absence of effective modal substitution in the regression results highlights the risks of relying on a single alternative mode. Developing rail corridors connecting major agricultural zones in the Mekong Delta with Ho Chi Minh City and deep sea ports would introduce a strategic redundancy layer in the transport system. Rail development should also be accompanied by intermodal terminals that connect river, road, and rail networks to reduce switching costs and improve coordination.

Finally, the government should promote integrated logistics planning at the corridor level. Supporting the development of logistics centers, cold chain infrastructure, and digital coordination platforms can improve system adaptability. International experience shows that resilience in inland waterway systems depends less on maximizing single mode throughput and more on strengthening multimodal flexibility and network integration.

### *5.3.2. Suggested Measures for Vietnamese Warehousing Enterprises*

At the enterprise level, warehousing firms need to strengthen buffering and adaptive capacity. The distributed lag results indicate that hydrological shocks generate delayed revenue effects, suggesting that current operations remain highly sensitive to throughput disruptions. To reduce vulnerability, firms should invest in modern storage infrastructure, particularly cold-chain systems for agricultural products. Expanded storage capacity would allow enterprises to manage temporary transport interruptions more effectively and smooth revenue fluctuations.

In addition to physical infrastructure, digital transformation plays a critical role. Warehousing firms should adopt integrated Transport Management Systems (TMS) linked to hydrological monitoring data. By incorporating real-time water depth and navigation information into planning systems, firms can anticipate navigability constraints and adjust shipment schedules proactively. Predictive scheduling, such as advancing shipments or modifying inventory cycles when water levels approach critical thresholds, can help mitigate operational disruptions.

Enterprises should also diversify their service offerings beyond basic transshipment. Developing value-added logistics services, such as packaging, consolidation, and light

processing, can reduce dependence on pure throughput volumes and stabilize revenue streams when transport flows fluctuate.

Overall, improving resilience in the Mekong Delta's warehousing sector requires coordinated structural adjustments. Government policy should prioritize multimodal integration and infrastructure redundancy, including road connectivity and rail development, while enterprises enhance storage capacity, digital coordination, and service diversification. Together, these measures can reduce the economic sensitivity of logistics performance to hydrological variability and support sustainable regional development.

## 6. Conclusion

This study examines the impact of river water level fluctuations on warehouse service revenue in Dong Thap Province in Vietnam's Mekong Delta. Using monthly data from August 2018 to March 2025 and time-series regression models, the results reveal a significant inverse relationship between water levels and warehouse revenue. Lower water levels are associated with higher warehouse revenue, supporting the "store-and-wait" mechanism in which shipments are temporarily held when inland waterway performance deteriorates. The distributed lag analysis further indicates that this effect emerges after approximately two to three months, suggesting delayed adjustments within the logistics system. In addition, the results provide no evidence that road freight activity moderates the water-level effect, implying limited effective modal substitution during low-water periods.

These findings highlight the strong dependence of the Mekong Delta's logistics system on inland waterways and show that hydrological shocks affect not only transport performance but also warehouse-level financial outcomes. However, the analysis relies on aggregate provincial data and focuses on short-run dynamics. Future research could incorporate firm-level operational data and transport cost variables to better understand logistics adjustment mechanisms and resilience strategies under increasing hydrological variability.

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