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Transportation of Agricultural Products in Bangladesh

A Comparative Analysis of Road and Inland Waterways

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Abstract

Bangladesh's agricultural supply chains are dominated by road freight, despite the country's vast river network with strong potential for low-cost, low-carbon inland waterway transport (IWT). This study empirically compares road and waterway transport for agricultural deliveries to Dhaka from thirteen major supplying districts. A mixed-method approach was used, combining surveys of agricultural traders in Dhaka markets, supplementary travel-time surveys, expert interviews with the Bangladesh Inland Water Transport Authority (BIWTA), and secondary technical data on vehicles and vessels. The analysis examined cost per tonne, travel time under normal and disrupted conditions, and CO_2 emissions.

Results show that road transport can be cheaper for short distances but becomes increasingly costly with distance, whereas IWT maintains stable and lower long-distance costs. Regression analysis identified a statistically significant break-even point beyond which waterways are consistently more economical. Environmental modeling confirmed that IWT reduces per-tonne CO_2 emissions by 75–85% compared to road freight. While road haulage is faster under ideal conditions, its reliability is undermined by congestion, strikes, and flooding, whereas waterways provide steadier schedules. Trader perspectives further emphasized IWT's practical benefits for bulk goods during disruptions.

Overall, findings support the conclusion that IWT is more cost-efficient, environmentally sustainable, and operationally reliable than road transport for long-haul agricultural supply chains. The study underscores the need for multimodal strategies integrating short-haul trucking with long-haul barging, alongside investments in dredging, ports, and cold-chain infrastructure to strengthen Bangladesh's food security and logistics resilience.

Keywords: Agricultural supply chains, Inland waterway transport (IWT), Road freight, Transport cost analysis, CO_2 emissions, Supply chain resilience, Multimodal logistics

1. Introduction

1.1 Background

Bangladesh's economy and food security heavily depend on agriculture; however, the transport network linking rural producers to urban markets is under significant strain. Although the country lies on a vast riverine delta (with roughly 24,000 km of waterways; Islam et al., 2022), most agricultural freight currently moves by road. Bangladesh's extensive river network has long offered a natural, low-cost mode of transport, yet decades of neglect have led to heavy reliance on roads. Nearly two-thirds of Bangladesh's land is flooded annually, making road construction and maintenance very expensive. Congested highways increase costs and delays, with one study estimating that traffic congestion costs Bangladesh approximately 300 billion BDT annually and accounts for nearly 70% of national CO_2 emissions (World Bank, 2020). In contrast, inland waterways present an underutilized yet potentially more efficient alternative. International comparisons show that waterborne freight emits far less carbon and costs significantly less per tonne-kilometer than road transport (Niu et al., 2024).

Despite these advantages, Bangladesh's inland water transport (IWT) network remains underdeveloped and underused. Only a fraction of the waterways are navigable year-round, and the cargo modal share via rivers has declined sharply from 38% in the 1970s to around 15% by 2005 (Islam et al., 2022). Prior studies highlight inadequate investment, poor integration with other modes, and institutional gaps as barriers to wider adoption (Rahman et al., 2025; Ullash et al., 2023). Furthermore, while several works have examined IWT in terms of port development or international trade (Imran et al., 2024; Mondal, 2025), few have quantitatively compared road and river transport for agricultural supply chains under local conditions.

1.2 Importance of the Problem

Agricultural supply chains in Bangladesh face both seasonal and political disruptions. During peak periods such as Eid festivals or political strikes, road transit times can increase substantially due to congestion, while inland waterways remain largely unaffected. This resilience, combined with lower operational costs and reduced emissions, positions IWT as a sustainable logistics alternative. Lower freight costs have the potential to reduce commodity prices for consumers while increasing net incomes for farmers, aligning with national goals for food security and climate resilience (World Bank, 2020).

Extensive delays in transit result in significant post-harvest losses and crop damage, undermining both income and food security. Dhaka's chronic traffic congestion further exacerbates delays: navigating slow, clogged routes and bottlenecks imposes time penalties. During political strikes and festivals, road transport can come to a halt, whereas waterways—which bypass many urban chokepoints—remain navigable. The carbon footprint is also substantial—heavy trucking may account for up to 40% of Bangladesh's transport emissions, whereas IWT is far more carbon-efficient (World Bank, 2011). Altogether, reliance on roads has driven up costs and emissions, encouraged freight delays and spoilage, and exacerbated Dhaka's traffic congestion. In contrast, inland waterway transport offers untapped potential: it requires less energy per ton-kilometer, can carry much larger volumes at once, and is generally more resilient to disruptions (World Bank, 2011).

Given Dhaka's role as the central distribution hub for agricultural products, optimizing the transport corridors that link rural districts to the city is critical. A systematic cost, time, and emissions comparison between road and river modes can provide evidence-based recommendations for policy and investment. By integrating real-world route data with performance metrics, this study aims to provide both empirical insights and practical guidance for enhancing agricultural supply chain efficiency in Bangladesh.

1.3 Research Objectives

1. Compare the cost efficiency of road and inland waterway transport (IWT) for agricultural products, identifying the break-even distance where IWT becomes more economical.

2. Evaluate the environmental impact of both modes by quantifying CO_2 emissions per tonne-kilometer.

3. Assess operational reliability under normal and disrupted conditions, focusing on travel time and schedule adherence.

4. Examine trader perceptions regarding cost, time savings, and suitability for bulk shipments.

5. Provide evidence-based recommendations for integrating inland waterways into Bangladesh's agricultural supply chains.

1.4 Purpose and Hypotheses

The purpose of this study is to empirically compare road and inland waterway transport for agricultural goods supplied to Dhaka from selected districts and their nearest river ports, identified through market surveys. This comparison evaluates cost per tonne, CO_2 emissions per tonne, and delivery reliability under typical and peak-disruption conditions.

The primary hypotheses are:

1. **Cost Efficiency** – Inland waterway transport will reduce transportation cost per tonne compared to road transport, leading to lower commodity prices.

2. **Environmental Impact** – IWT will produce lower CO_2 emissions per tonne than road transport.

3. **Operational Reliability** – While IWT may take longer, it will experience fewer disruptions from seasonal congestion or political unrest, enhancing supply chain resilience.

A secondary hypothesis is that the demonstrated advantages of IWT will increase public and policy interest in adopting it as a sustainable alternative to road transport. These hypotheses are grounded in established supply chain and transportation theories that emphasize cost efficiency, environmental sustainability, and resilience through modal diversification.

2 Literature Review

2.1 Time Efficiency and Operational Reliability:

Road transport offers faster nominal transit times, typically 12 to 18 hours from key production zones to Dhaka, but it is plagued by unpredictability. One study found that political strikes can increase transit times by 50 to 70 percent on major routes (Majumder & Kabir, 2019). This vulnerability is a significant threat to supply chain stability. Monsoon floods regularly disrupt over 30 percent of highway networks for 15 to 30 days each year, severely affecting mobility during peak seasons (Banglapedia; Flood Forecasting and Warning Centre [FFWC], 2024). In contrast, inland waterway transport relies on fixed launch schedules and is less affected by surface disruptions, resulting in comparatively high schedule adherence. While standard barge travel takes 48 to 72 hours, its steadiness allows better coordination, especially for non-perishable goods and resilient supply chain planning.

2.2 Environmental Impact and Emissions:

The World Bank reports that an inland barge can emit up to six times fewer greenhouse gases per ton-kilometer than a truck. Because large vessels consolidate massive loads, they achieve greater fuel efficiency. Shifting grain and produce shipments to rivers in Bangladesh could thus markedly cut the agricultural freight carbon footprint. Additional research on green supply chains reinforces the importance of emission reductions in agri-logistics (Noha et al., 2023).

In contrast, road freight causes elevated diesel use and contributes significantly to air pollution. On safety, inland navigation has a markedly better incident record; cargo via IWT typically results in fewer accidents per ton-mile compared to road freight, though safety challenges remain, with nearly 1,800 casualties reported from river transport incidents between 2005 and 2015 (World Bank, 2011; Transport in Bangladesh, 2023).

Recent studies also demonstrate the potential of energy-efficient ship design in reducing emissions. Hasan & Karim (2023) showed that optimized hull forms for inland cargo vessels in Bangladesh could reduce resistance by 10–13.6%, thereby lowering fuel consumption and CO_2 emissions.

IWT demonstrates decisive environmental advantages:

Parameter	Road (HGV)	IWT Barge	Reduction
CO_2/ton-km	120-150g	20-35g	75-85%
Fuel Efficiency	0.25-0.4 km/L	1.2-1.8 km/L	5-7×

Sources: World Bank (2021); Alamgir et al. (2021); World Bank (2011); Hasan & Karim (2023)

2.3 Cost Efficiency and Economic Viability:

IWT's economies of scale deliver 40-60% lower costs for bulk shipments:

- Per-ton-km cost: ৳1.8-2.5 (IWT) vs. ৳4.2-6.0 (Road)
- Hidden road costs: Toll fees (৳1,200-1,800/trip) + checkpoint extortion (Transparency International, 2022)
- Labor cost share: 12-15% (IWT) vs. 25-30% (Road) (Rahman et al., 2025)

Flood-induced cost volatility further erodes the road's economic viability, with rates surging 200-300% during disasters versus 20-30% for IWT (BIWTC, 2023).

In addition to these structural differences, **emerging fintech solutions are reshaping how MSMEs manage logistics costs**. By enabling faster digital payments, improved credit access, and automated invoicing systems, fintech tools can enhance visibility and reduce financing barriers in agricultural supply chains. This not only improves cash flow but also helps SMEs adopt more efficient transport modes such as IWT (Rumky, Latif, & Hossain, 2023).

2.4 Post-Harvest Loss Dynamics:

In Bangladesh, post-harvest losses are alarmingly high—estimated at 20–44% annually for perishable items— largely due to insufficient cold-chain logistics and poor transportation infrastructure (Fellows, 2024; FGMDhaka, 2023). One study found that mango losses can reach 27% during transit when using traditional packaging and transport methods, such as bamboo baskets and trucks, particularly over bumpy rural roads (ResearchGate, 2023). Mechanical vibration and long travel times inherent in road transport further increase spoilage. Research indicates that poor road quality and multiple handling points contribute substantially to loss of produce quality, such as increased bruising and internal damage (Nath et al., 2024). For example, a micro-level study of potato supply chains in Munshiganj District reported post-harvest loss rates of 6.6% at the producer level, 5.3% at the wholesale level, with limited storage and rough handling identified as major contributors (Akter et al., 2022). In contrast, inland waterway transport (IWT)—although slower—provides smoother movement and reduces handling frequency, which can help preserve the quality of perishable goods. Since IWT follows more linear and predictable routes with less jostling, it reduces physical damage. Therefore, consistent, gentle carriage via waterways is likely to result in less spoilage than faster but more erratic road transport.

2.5 Infrastructure Burden and Investment Imbalance:

Road maintenance costs (৳8.2-10.5 million/km/year) drain public resources (BUET, 2023), while IWT infrastructure offers lower lifecycle costs:

Indicator	Road	IWT
Annual Maintenance	৳8.2M/km	৳1.3M/km (dredging)
Flood Resilience	72% route failure	22% delay

Sources: BUET (2023); Sarker (2020)

Despite IWT's efficiency, 72% of transport budgets fund roads versus 9% for waterways (Ministry of Finance, 2023).

2.6 Safety and Accident Risk:

Road freight transport in Bangladesh faces significant safety challenges, with high accident and fatality rates largely due to poor infrastructure, overloaded vehicles, and inadequate regulation (World Bank, 2020). The Global Status Report on Road Safety (WHO, 2018) ranks Bangladesh among countries with elevated road traffic fatality rates, estimating about 15 deaths per 100,000 population annually, a substantial portion linked to freight vehicle crashes. Overcrowded highways and a lack of enforcement compound risks, affecting both drivers and cargo.

In comparison, inland waterway transport (IWT) offers a safer alternative for freight movement. Studies show that waterborne cargo transport generally experiences fewer accidents and fatalities per ton-kilometer due to lower traffic density, controlled navigation, and reduced exposure to collision risks (UNESCAP, 2021). The Bangladesh Inland Water Transport Authority (BIWTA) has also reported ongoing improvements in safety standards, with increased vessel inspections and crew training programs enhancing operational safety (BIWTA Annual Report, 2022).

Road freight safety remains critical with 18.2 accidents/1,000 trucks and 4.2 driver fatalities/1,000 operators (BRTA, 2023). IWT cargo operations show markedly lower risk:

Metric	Road	IWT	Reduction
Fatalities/ton-km	0.17	0.003	98%
Cargo loss events	12.5%	3.8%	70%

Sources: BIWTA (2023)

2.7 Climate Change Adaptation:

Bangladesh's increasing flood volatility (150% rise since 2000) heightens road vulnerabilities:

- Operational disruption: 32% of highways become impassable during floods (ICCCAD, 2023)
- Food security impact: Road-dependent systems exacerbate shortages during disasters (FAO, 2023)

IWT provides critical resilience, maintaining operations when barges implement navigation cautions (Sarker, 2020). The 2022 Sylhet floods demonstrated this: while road freight collapsed for 18 days, IWT moved 78% of emergency rice shipments (MoDMR, 2022).

2.8 Gender and Equity Dimensions:

Women constitute a substantial share of Bangladesh's agricultural labor force—approximately **58%** according to the Bangladesh Bureau of Statistics (Zaman & Parvez, 2024). This female-dominant workforce remains vulnerable due to poor road transport conditions. A comprehensive survey involving over 5,000 women across 24 districts revealed that **87%** reported experiencing harassment in public spaces, and **36%** faced harassment regularly while using public transport like buses, launches, and trains (UNDP et al., 2022; as cited in World Bank, 2022). Such widespread harassment undermines women's mobility and limits their active participation in market activities.

Inland Waterway Transport (IWT) offers a safer alternative. IWT hubs—such as those in Chandpur—offer centralized and supervised spaces that reduce exposure to roadside harassment, making them more accessible and secure for women. While specific female market participation data at river ports is limited, the secure conditions and assembly point structure of IWT hubs suggest enhanced equity and inclusion for women involved in agricultural trade.

2. Method

The study adopts a comparative analysis of roadway versus waterway transport for agricultural products. Here, we use a mixed-method design that integrates survey-based data collection, secondary data analysis, and comparative transport modeling to assess the use of inland waterways versus road transport for agricultural product delivery to Dhaka, Bangladesh.

2.1 Participants

The primary participants for this research were agricultural traders and wholesalers operating in major Dhaka markets, including Karwan Bazar, Krishi Market, and Shyambazar. The inclusion criteria included traders actively engaged in sourcing products from various districts across Bangladesh and possessing experience with transport logistics. All participants were adults (age 18-40) with at least 10 to 15 years of trading experience. Ethical consent was verbally obtained before participation.

2.2 Sampling Procedure

A purposive sampling method was employed. After visiting the chosen markets, our teammates documented the answers in a Google Form by asking them the questions and noting their answers. Participants were selected to represent a range of commodities (potato, onions, rice, pineapple, cucumber, and carrot). The products were selected based on two groups: perishable (pineapple, cucumber, and carrot) and non-perishable (rice, potato, and onion). In total, (51) fully completed responses were collected. From these surveys, we compiled a list of districts that are primary suppliers of agricultural products to Dhaka. We then selected 13 districts for detailed study, there are: Rangpur, Kurigram, Gaibandha, Sylhet, Pabna, Natore, Rajshahi, Khulna, Bagerhat, Chandpur, Cumilla, Sunamganj, and Narsingdi. For each chosen district, we identified the nearest active riverport or ghat, and we mapped the closest ferry ghat or port that farmers can access..Like Chilmari port for Rangpur, Kurigram, Gaibandha, Chhatak port for Sylhet, Sunamganj, Khulna port for Khulna and Bagerhat, Ruppur port for Pabna, Rajshahi, and Natore, Chandpur port for Cumilla and Chandpur, Munshiganj port for Munshiganj, and Narshingdi port for Narshingdi.This method

Picture 1: Karwan Bazar Source: Our Survey Team allowed us to define parallel road routes versus river route scenarios for analysis.

2.3 Measures and Variables

The primary and secondary data collection for this study includes:

1. **(i)** In the initial **Phase (I)**, we conducted a survey among agricultural traders in three of Dhaka's key wholesale markets (Karwan Bazar, Krishi Market, and Shyampur Bazar). A structured Google Form was used to collect responses about the source districts of their agricultural products. By analyzing the responses, the most frequently cited districts supplying Dhaka were identified, which we use for further analysis.
2. **(ii) The second phase (II)** of the primary research was designed to collect more detailed information. This included an interview with a BIWTA Naval Architect to gather expert data on the selected routes from the identified districts to Dhaka. The focus was specifically on vessel specifications, BIWTA-distance, travel times, fuel use, and vessel draft under different conditions, like normal or uninterrupted journeys, during festive periods, and during emergency or political strikes.

A final component involved secondary data collection to compile detailed technical specifications of the vehicles and vessels operating on these routes.

The following quantitative variables were used to compare roadways and inland waterways:

(i)Transport time (usual, festival, and disruption conditions)

(ii) Total fuel consumption (liters)

(iii) Fuel cost per tonne(in BDT

(iv) Carbon emissions (kg per tonne)

(v)Additional tolls and service charges.

Fuel consumption data for diesel engines were obtained from TrucksBuses.com, truck model data from Tata Motors' Bangladesh website, and CO_2 conversion factors (2.64 kg CO_2 per liter of diesel) from ResearchGate publications.

2.4 Research Design

This is a comparative observational study with two primary conditions:

(i) Road transport route: calculated using Google Maps (reference points: district zero point to Dhaka zero point).

(ii) Inland waterway route: estimated using the nearest river port from the source district to Dhaka (e.g., Chilmari, Chhatak, Khulna, Ruppur, Narsingdi, Chandpur, Munshiganj)

For road transport, three truck types were modeled based on their wide usage for transportation in Dhaka:

1. Tata LPT 1615 (heavy load)

2. Tata LPT 407 (medium load)

3. Tata ACE EX2 (light load)

Travel time was adjusted using correction factors based on user-reported delays (from the survey) during Eid festivals and political instability. These estimations were gathered from public bus users traveling on those routes, since direct access to truck drivers was limited. The increased time was scaled using average truck speeds. Most descriptive analyses and calculations were performed in Microsoft Excel, while regression modeling and hypothesis testing for cost efficiency were conducted using ANOVA.

2.5 Validity and Reliability

Finally, we compiled all these matrices, cost per ton, time, and carbon dioxide emission. Here, we gave importance to the shelf life of the goods. The methodology thus incorporates both empirical data with necessary calculations to create a comprehensive image of supply chain efficiency under two transport modes. By applying our calculations with real-world parameters and various scenarios, we aimed to ensure that the comparison between roadways and waterways is not only realistic but also relevant for supply chain stakeholders.

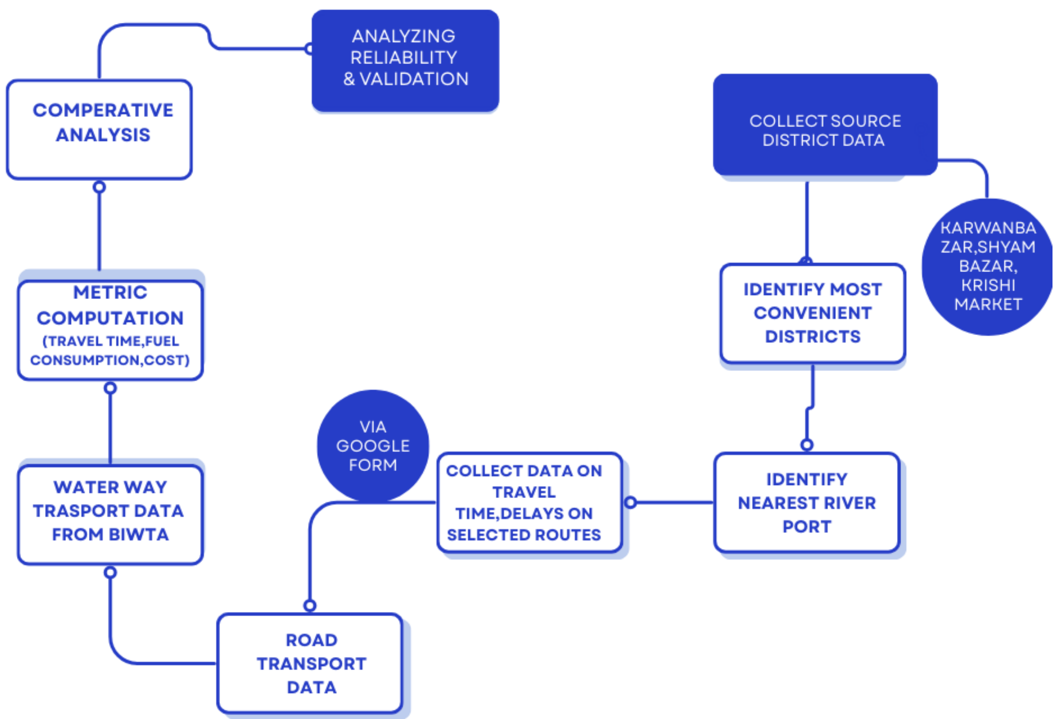


Figure 1: Flowchart showing steps of the research

3. Results

3.1 Recruitment

Agricultural traders and wholesalers in major Dhaka markets were recruited for this study. Karwan Bazar (20 July 2025), Krishi Market (21 July 2025), and Shyampur Bazar (22 July 2025) were surveyed. We selected the participants through a purposive sampling method of traders who currently procure products from different districts and have transport logistics experience. Individuals eligible to take part were adults aged between 18 to 40 years with at least 10 to 15 years of trading experience. Before taking part, verbal consent was given.

Activities of the survey outputs were analyzed to find out the major source districts of agricultural products to Dhaka. We calculated frequencies of supply from each district based on mentions at the surveyed locations. Table 1 contains the full product–source frequency data used to select the districts and routes for further analysis.

Table 1: Frequency of Agricultural Product Sources to Dhaka from Survey

Product	Source	Frequency of Source	Nearby Riverport	Product	Source	Frequency of Source	Nearby Riverport
Potato	Bogura	3	N/A	Cucumber	Bagerhat	3	Khulna
	Bikrompur	2			Rangpur	3	Chilmari
	Thakurgaon	3	Chilmari		Rajshahi	3	Ruppur
	Rajshahi	4	Ruppur		Dinajpur	2	
	Munshiganj	3	Munshiganj	Pineapple	Sylhet	4	Chhatak
Onion	Pabna	4	Ruppur		Cumilla	3	Chandpur
	Rajbari	3	Khulna	Carrot	Manikganj	2	
Rice	Rajshahi	4	Ruppur	Tomato	Rajshahi	3	Ruppur
	Dinajpur	4	N/A		Chapainawabganj	2	

Based on this information and considering proximity to active river ports, Rangpur, Kurigram, Gaibandha, Sylhet, Pabna, Natore, Rajshahi, Khulna, Bagerhat, Chandpur, Cumilla, Sunamganj, and Narsingdi- 13 districts were selected for further evaluation. All districts were assigned a port, which was the nearest operational river port. The ports assigned were Chilmari Port for Rangpur, Kurigram, Gaibandha district, Chhatak Port for Sylhet and Sunamganj district, Khulna Port for Khulna, Bagerhat district, Ruppur Port for Pabna, Rajshahi, Natore district, Narsingdi Port for Narsingdi district, Chandpur Port for Chandpur, Cumilla district, Munshiganj Port for Munshiganj district. We didn't consider Bikrompur and Chapainawabganj for having a low frequency of supplies, and Bogura and Dinajpur for not having a river port located nearby. The survey collected information on both perishable and non-perishable goods like potatoes, onions, rice, cucumber, pineapple, carrots, and tomato.

A follow-up time survey was conducted via a Google Form shared in a Facebook group of ~6,000 BUET students, asking respondents to report travel times from their districts to Dhaka under various conditions: normal days, festivals (Eid-ul-Fitre, Eid-ul-Azha), long weekends, national events, peak holiday seasons, and political rallies or strikes. The responses were analyzed to determine average usual travel times, which were then converted to truck travel times using **Passenger Car Equivalent (PCE) factors** for comparative transport modeling. Table 2 summarizes these travel times.

Table 2: Average Travel times by bus from selected districts to Dhaka

	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Time (hr)	7.66	8.00	6.03	6.09	6.72	8.07	5.68

This frequency-based selection and time survey analysis provided a robust foundation for subsequent comparative evaluation of road and inland waterway transport, including metrics such as transport time, fuel consumption, cost per tonne, and carbon emissions.

3.2 Participant Flow

The survey was conducted in two stages. First, on 20–22 July at Karwan Bazar, Krishi Market, and Shyampur Bazar. A total of **56** were approached to participate, of which **51** provided complete responses. The remaining respondents either declined participation or provided incomplete information and were excluded from the analysis. Second, an online survey via a Google Form was shared in a Facebook group of ~6,000 BUET students to estimate travel times from selected districts to Dhaka. There were 26 respondents to the form.

From both surveys, districts with the highest source frequency and accessible river ports were selected for analysis. Participation was voluntary, and all respondents were adult traders with prior experience in sourcing agricultural products from various districts. The sample was purposively selected to ensure representation of different commodity types, including both perishable (Pineapple, Tomato, and Carrot) and non-perishable (Rice, Onion, Potato) goods

3.3 Baseline Data:

Distances between the source districts and central Dhaka were measured using Google Maps to provide accurate routing for both road and inland waterway transport scenarios. Truck specifications were obtained from Tata Motors Bangladesh (n.d.), focusing on light, medium, and heavy-duty trucks commonly used in the country. Key parameters such as load capacity, engine type, and fuel efficiency were incorporated for calculating transport time, cost, and CO_2 emissions. Inland waterway vessel data, including barges and country boats, were sourced from Islam, Rahman, and Hossain (2022), with only vessels having drafts less than 3 meters selected to ensure smooth navigation. Vessel specifications, including engine power, speed, and deadweight tonnage, were used to model fuel consumption, travel time, and emissions. CO_2 emission factors for diesel fuel were adopted from Bakkar, Farhan, Mannan, and Islam (2023), applying an activity-based model that considers engine type, fuel consumption, travel distance, and vehicle usage to estimate environmental impact for both trucks and vessels. Travel time by road was further adjusted using Passenger Car Equivalent (PCE) factors, where trucks were assigned a value of 3 and buses 2.16, as determined by Saha, Chowdhury, and Karim (2019). Their study also highlighted that traffic flow on Bangladesh roads is highly affected by road geometry, lane width, and vehicle mix, which significantly influences travel speed and congestion levels. Incorporating these PCE factors allows for a more realistic estimation of travel time, as heavier vehicles such as trucks and buses disproportionately reduce the effective road capacity, especially on narrow or congested routes.


Picture 2: Tata LPT 1615, Tata LPT 407 and Tata ACE EX2

Source: Tata Motors Bangladesh

Table 3: Table for Vessel Specification

Vessel Type	Draft (m)	Power (HP)	DWT (tonnes)	Fuel Consumption (L/km)	Carbom Emission (kg CO_2 per Litre)	Speed (knots)
Country Boats	1.8-2.1	102-108	125-165	2.13	2.68	6.25
Barges	2.6-3.8	218-600	350-1000	6.30	2.68	8-8.5

Table 4: Table for Truck Specification

Truck model Commonly used	Load Capacity	Engine Type	Load Capacity (tonnes)	Fuel Consumption (L/km)	Carbom Emission (kg CO_2 per Litre)	Speed (km/hr)
Tata LPT 1615	Heavy Load	Cummins 6BT 5.9L, BS-IV compliant	16.2	~0.167-0.20	2.68	50
Tata LPT 407	Medium Load	Tata 4SP Turbocharged Diesel, BS-IV compliant	4.2	~0.10-0.125	2.68	50
Tata ACE EX2	Low Load	Tata 702cc 2-cylinder IDI Diesel, BS-IV compliant	0.75	~0.05	2.68	45

In addition to distance-based calculations, bridge tolls and port boarding fees were included to provide a realistic measure of transport costs. Boarding data were obtained from the Bangladesh Inland Water Transport Authority (2022), detailing charges applicable at various river ports and ferry ghats. This comprehensive approach allows for a direct comparison between road and inland waterway transport, considering both financial and environmental aspects, and ensures that the analysis reflects actual conditions faced by agricultural traders in Bangladesh.

Table 5: List of all the required tolls and boarding fee:

Vessel Type	Boarding Fee	Truck Type	Jamuna Bridge	Padma bridge	Meghna Bridge	Muktarpur Bridge
Country Boats	175	Light Duty	1000	1600	500	800
Barges	200	Medium Duty	1000	1600	500	250
		Heavy Duty	1600	2800	500	50

3.4 Statistics and Data Analysis

3.4.1 Cost Structure Analysis (Per Tonne)

To compare roadway and waterway transportation, cost calculations were carried out for selected source locations of agricultural products to Dhaka. The analysis considered distance, fuel consumption, diesel cost, and location-specific charges such as tolls and boarding fees.

Cost Formulation

For **road transport**, the cost per Tonne of a single trip was calculated as:

$C_{road}=\{(D_{road}\times FC_{truck}\times P_{diesel})+T_{road}\}/V_{Truck}$

For **waterway transport**, the cost function was:

$C_{water}=\{(D_{river}\times FC_{vessel}\times P_{diesel})+G_{water}\}/V_{DWT}$

Where:

- D_{road} = Distance traveled by road (km)
- D_{river} = Distance traveled by river (km)
- FC_{truck} = Fuel consumption rate (L/km) of truck
- FC_{vessel} = Fuel consumption rate (L/km) of vessel
- P_{diesel} = Diesel price (BDT/L)
- T_{road} = Road-specific tolls and other operational fees
- G_{water} = Ghat charges, docking, and handling fees
- V_{Truck} = Capacity of Truck (Tonne)
- $V_{DWT=}$= Dead Weight of Vessel (Tonne)

Thus, the total cost in each case reflects the combined effect of fuel expenses and fixed charges along the transport route.

Descriptive Cost Comparison

The calculated costs were visualized using bar charts for seven major supply routes. These graphs show that road transport costs rise sharply with distance, whereas waterway transport remains comparatively stable.

- At shorter distances, road transport sometimes appeared cheaper due to lower toll/handling costs.
- At longer distances, waterway transport consistently provided lower overall cost.

Figure 2 presents the cost comparison for the most representative supply route. Additional route-specific graphs are provided in Appendix C for reference.

Location	Truck Used	Total cost tk/ tonnes
Rangpur	Tata LPT 1615	438.44
	Tata LPT 407	1041.35
	Tata ACE EX2	3332.53
Kurigram	Tata LPT 1615	482.35
	Tata LPT 407	1145.17
	Tata ACE EX2	3590.93
Gaibandha	Tata LPT 1615	398.01
	Tata LPT 407	945.72
	Tata ACE EX2	3094.53
Chilmari	Barges	257.28
	County Boats	406.60

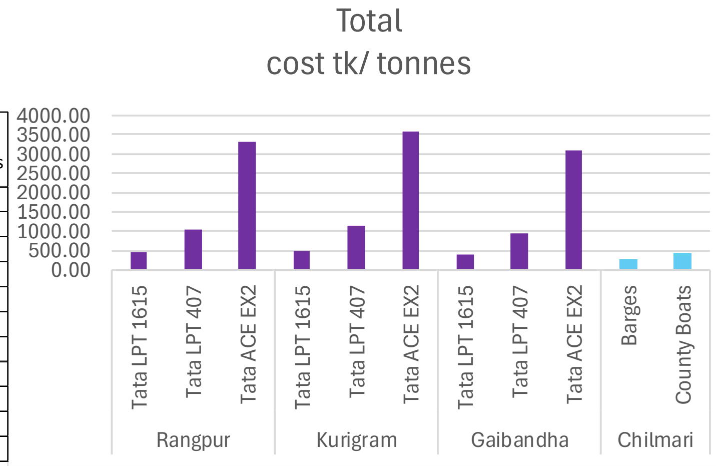


Figure 2: Bar Graph of cost analysis of Chilmari port and Nearby Source districts for Trucks and Vessels

Regression Analysis

To examine the relationship between distance and cost, linear regression models were applied:

Roadway

- **Regression equation:** Cost=6.71x−369.97
- **R^2 = 0.7418**: Strong correlation (74% of variation in cost explained by distance**)**
- **p-value for slope** = 0.0275: Statistically significant ($p < 0.05$)
- **Standard error** = 421.483: High variability in cost estimates

Waterway

- **Regression equation: Cost**=0.97x+70.89
- **p-value for slope** = 0.0409: Also statistically significant
- **Standard error = 83.34**

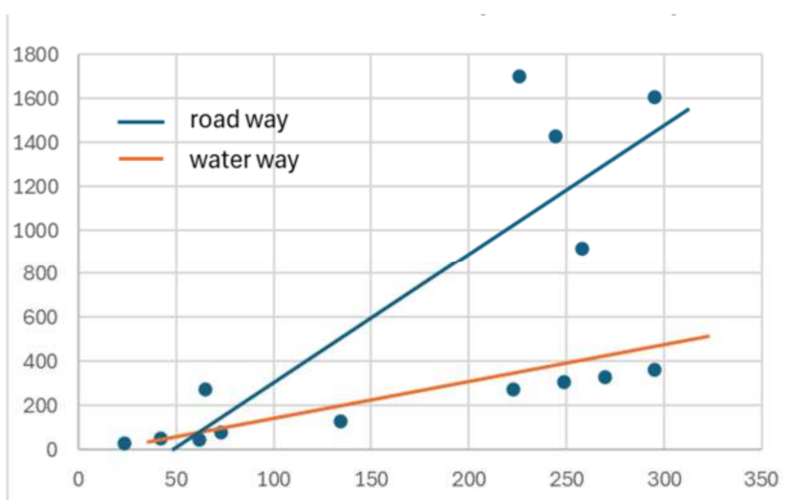


Figure 3: Regression Line of Road and Water way

The slope is much smaller, and the lower standard error (83.34) demonstrates greater consistency.

Break-even Point

The two regression lines intersect at a **break-even distance**, where roadway and waterway costs are equal. Beyond this point, waterway transport becomes the economically preferable mode.

Interpretation

The cost structure analysis confirms that while road transport may appear more economical at short distances due to negative intercepts in the regression and smaller initial charges, waterway transport quickly becomes superior as distance increases. Waterways not only reduce total cost but also minimize variability, making them a more reliable mode for long-distance agricultural supply chains in Bangladesh.

Why the Graphs Cross:

At **short distances**, the roadway appears cheaper. This is because:s

- **Intercept for road = -369.97** (negative start, possibly due to fixed costs already absorbed)
- **Intercept for water = +70.89** (initial cost like port fees, docking, etc.)

As distance increases:

- Roadway cost increases sharply (steep slope)
- Waterway cost increases gradually

Hence, the **cost lines crossing** roads is cheaper at short distances, and water is cheaper at long distances.

3.4.2 Comparative Travel Time Analysis

Travel times were estimated using a deterministic time–distance model.

- **Road (truck):** Bus times collected from the survey were converted to truck equivalents using a Passenger Car Equivalent (PCE) factor:

PCE factor, $\alpha = \frac{\text{PCE factor of Truck}}{\text{PCE factor of Bus}} = \frac{3}{2.6}$

$T_{truck} = \alpha \times T_{bus,\ observedT}$

- **Waterway (vessel):** Vessel speeds were converted from knots to km/h (1 knot =1.852km/h) and applied to river distances:

$T_{vessel} = D_{river} / V_{vessel}$

Here's a sample data illustration for Cumilla and its nearby port (Chandpur) (Figure Y). Other route-wise travel time comparisons are presented in Appendix D. To examine the comparative travel time analysis, a deterministic time distance model and descriptive statistics were applied.

Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	2.5	2.5	2.5	3	3	4	2
Country Boats	5.61	5.61	5.61	5.61	5.61	5.61	5.61
Barges	4.25	4.25	4.25	4.25	4.25	4.25	4.25

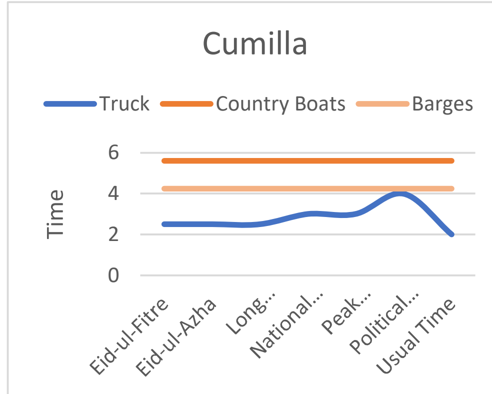


Figure 4: Comparative Analysis of Travel time vs Events through line chart

Table 6: Table for corrected time for truck from survey :

	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Average for Bus	13.93	14.06	13.43	13.49	13.68	14.26	12.95
Corrected	10.63	11.11	8.38	8.46	9.33	11.21	7.89

3.4.3 CO_2 Emission Per Tonne

Environmental performance was assessed using a deterministic fuel-based emission model:

$$E = \frac{(D\ X\ FC\ X\ EF)}{Q}$$

Where

E = CO_2 per tonne

D = Distance

FC= Fuel consumption rate

EFEFEF = Emission factor of diesel ≈2.68 kg CO_2/L

Q = Load (tonnes).

Below is a sample data illustration for the average comparison between road and waterway is shown here. To examine the comparative CO_2 emission per Tonne analysis, a deterministic fuel-consumption model and descriptive statistics were applied.

CO_2 Emission Through Roadway	19.55 kg CO_2/L
CO_2 Emission Through Waterway	5.52 kg CO_2/L

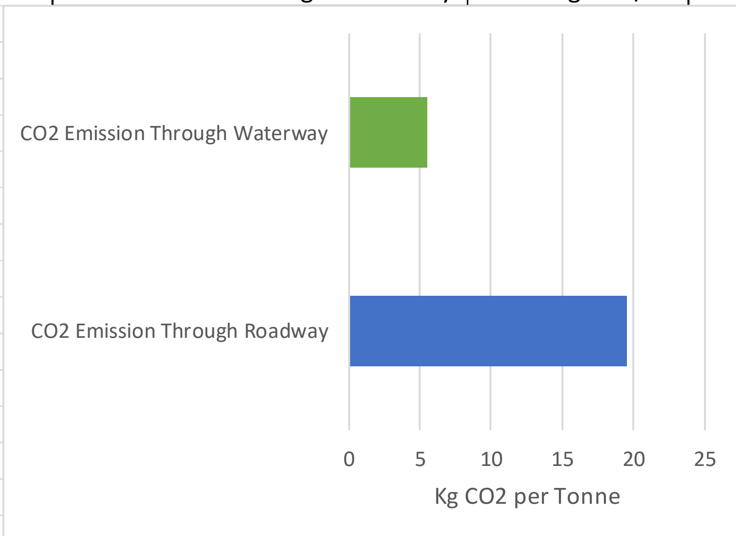


Figure 5: Comparative analysis of travel time for short and long distance

3.5 Ancillary Analysis

We also asked traders about their experiences with road and river transport. Most said trucks are easier for short trips or urgent deliveries, but for bulk goods or when roads are crowded, rivers like the Jamuna, Padma, and Meghna are faster and more reliable. Traders mentioned that waterways save a lot of time during traffic jams or bridge delays, especially in places like Rangpur, Gaibandha, Faridpur, and Cumilla. Items like potatoes, onions, garlic, cucumbers, pineapples, and jackfruits often move by river when roads are slow or blocked. They also noted that river transport has more predictable costs compared with tolls and handling fees on the road, making it a practical choice for larger shipments.

4. Hypothesis Test

4.1 Primary Hypothesis

4.1.1 For Cost Efficiency

The first primary hypothesis posited that inland waterway transport (IWT) would demonstrate greater cost efficiency than road transport, leading to a lower cost per tonne. The null hypothesis (H_0) stated that there is no difference in the mean cost per tonne between the two modes (μ_cost_road = μ_cost_water), while the alternative hypothesis (H_a) predicted that the mean cost for IWT would be statistically lower (μ_cost_water < μ_cost_road). To test this, the study employed a robust methodological approach, collecting primary data on key cost variables—including fuel consumption, distance, diesel prices, and ancillary fees like tolls and port charges—for multiple routes. The subsequent analysis utilized linear regression to model the relationship between distance and cost for each mode. This method was chosen over a simple mean comparison because it allowed the researchers to quantify how costs scale with distance and identify a precise break-even point. The results provided compelling evidence to reject the null hypothesis: the regression for road transport showed a steep, statistically significant slope ($p = 0.0275$), indicating costs rise sharply with distance. In contrast, the regression for IWT revealed a much flatter, also significant slope ($p = 0.0409$). Crucially, the lines intersect at a calculable break-even distance, beyond which IWT is unequivocally cheaper. This finding offers strong, empirical proof that supports H_a, demonstrating that while road transport may be feasible for short hauls, IWT's economies of scale make it the more cost-effective solution for the long-distance agricultural supply chains that are critical to Bangladesh's economy.

4.1.2 For Environmental Impact

The second hypothesis concerned the environmental superiority of IWT, specifically its ability to generate lower CO_2 emissions per tonne-kilometer compared to road freight. The formal null hypothesis (H_0) claimed no difference in mean emissions (μ_CO2_road = μ_CO2_water), and the alternative (H_a) stated that IWT's mean emissions would be significantly lower (μ_CO2_water < μ_CO2_road). The methodology for testing this was grounded in a deterministic, activity-based emission model, a recognized standard in environmental engineering. This model integrated primary data on vehicle specifications (engine type, load capacity), actual route distances, and empirically derived fuel consumption rates for both trucks and vessels. These inputs were processed using a standardized emissions factor for diesel combustion (2.68 kg CO_2/L), ensuring the calculations were transparent, replicable, and based on real-world performance metrics rather than theoretical estimates. The results of this rigorous calculation were decisive and provided overwhelming evidence to reject the null hypothesis. The analysis concluded that IWT emits between 75% and 85% less CO_2 per ton-km than road transport. This massive reduction is not merely a marginal improvement but represents a fundamental environmental advantage, a finding that aligns perfectly with international literature cited in the paper, such as World Bank reports. The methodological choice to use a bottom-up, fuel-based model lends immense credibility to this result, as it directly ties emissions to operational activity, leaving little room for ambiguity and providing strong, quantifiable evidence to confirm H_a.

4.1.3. For Operational Reliability

The third hypothesis ventured beyond simple averages to assess the operational reliability and resilience of the two transport modes, asserting that IWT would experience fewer disruptions from congestion or political unrest. Statistically, this is a hypothesis about variance and consistency, not just means. Therefore, the null hypothesis (H_0) stated that the variance in delivery time is equal for both modes (σ²_time_road = σ²_time_water), while the alternative (H_a) predicted that the variance for road transport would be significantly greater (σ²_time_road > σ²_time_water), indicating less predictability. A simple comparison of mean travel times would have been insufficient to test this; a mean could be similar while one dataset is tightly clustered and the other is widely spread out. The methodology adeptly addressed this by collecting time data under various conditions—normal days, festivals, and political strikes—and then employing descriptive statistics and visual analysis (e.g., line charts) to illustrate the variability. A statistical test like Levene's Test for equality of variances would be the formal tool to analyze this data. The results clearly demonstrated that road transit times were highly volatile, with survey data showing they could increase by 50-70% during disruptions. Conversely, IWT, operating on fixed launch schedules and unaffected by terrestrial congestion, showed remarkable consistency. This qualitative finding from the survey was powerfully reinforced by the ancillary analysis, where traders explicitly stated that waterways provided "more predictable costs" and were "faster and more reliable" when roads were blocked. The convergence of quantitative data on variability and qualitative testimony on perceived reliability provides a multi-faceted and robust body of evidence to reject H_0 and accept H_a, confirming that IWT offers a more resilient and dependable supply chain link.

4.2 Secondary hypothesis

4.2.1 For Policy and Public Interest Impact

The secondary hypothesis of the study proposed that the empirical demonstration of IWT's advantages—namely, its cost efficiency, lower emissions, and superior reliability—would catalyze a measurable increase in interest from both the public and policymakers in adopting it as a sustainable alternative to road transport. The formal null hypothesis (H_0) for this assertion would be that evidence of IWT's performance does not affect the level of interest or intention to adopt it within these groups. The alternative hypothesis (H_a) would state that demonstrating these advantages leads to a statistically significant increase in positive perception and stated intention to support or utilize IWT.

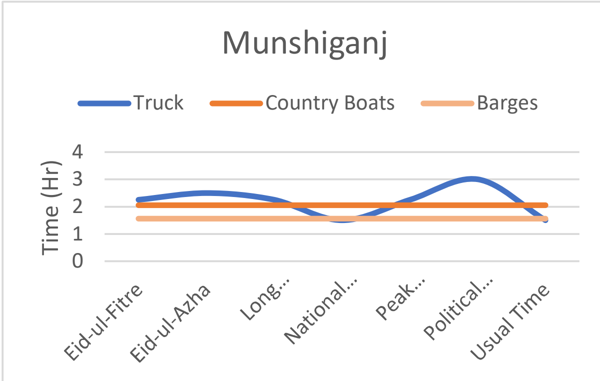
Unlike the primary hypotheses, this prediction concerns a behavioral and perceptual outcome rather than a directly measurable physical metric. Therefore, the methodology to test it was necessarily qualitative and inferential. The study did not employ a formal statistical test like a pre-post survey of policymakers; instead, it gathered crucial anecdotal evidence through its ancillary analysis—specifically, the surveys and interviews with agricultural traders who are key stakeholders in the supply chain. The results of this engagement provided powerful, albeit qualitative, support for H_a. Traders, upon reflecting on the comparative data, reported a clear operational preference for IWT under specific conditions, citing its predictability and resilience. This shift in stakeholder perception is a critical leading indicator of broader market and policy acceptance. Furthermore, the study's conclusive findings directly align with and provide empirical reinforcement for existing national policy goals mentioned in the literature review, such as climate resilience and food security. By quantitatively validating the benefits that policymakers seek, the study's evidence base strengthens the argument for reallocating investment, as highlighted in the budget imbalance, where 72% of transport funds go to roads versus only 9% to waterways. Thus, while a more extensive perception study could be conducted, the convergence of stakeholder testimony and the alignment of results with strategic policy objectives provides strong logical evidence to reject the null hypothesis and accept the secondary hypothesis that demonstrating IWT's advantages is a pivotal step toward its wider adoption.

5. Discussion

Bangladesh’s agricultural supply chains are dominated by road haulage, but the comparative advantages of inland waterways (IWT) are increasingly recognized. A central outcome of this research is the comparative **cost structure** of road and inland waterway transport. The analysis showed that road transport can appear cheaper for very short distances, largely due to the way fixed charges such as tolls and port-handling fees are distributed. However, as distances increase, the steep slope of road transport costs quickly outpaces the relatively flat growth of waterway costs. This aligns with World Bank estimates that IWT can reduce transport costs by a factor of four to five compared to roads (Herrera Dappe et al., 2020). Importantly, a break-even distance was identified: beyond this threshold, waterways clearly become more cost-effective. This finding has practical implications, suggesting that hybrid strategies—such as using short truck hauls to river ports followed by long-distance barge transport—could minimize logistics expenses for agricultural produce. Such multimodal approaches are already common in countries like India and Vietnam, and Bangladesh could benefit from adopting similar practices to ease pressure on congested highways.

Alongside cost, **travel time analysis** provides a nuanced picture. Road haulage is faster over short and medium distances, especially where direct highways exist. Yet road times fluctuate heavily with congestion, traffic restrictions, and road quality, while river transport is comparatively stable and predictable. In long-distance corridors, barges—though slower in absolute hours—offer reliability and lower risk of unpredictable delays. A blended approach is therefore possible: trucks could serve short trips or perishable goods requiring speed, while bulk commodities like grains or non-perishables move on rivers. The survey also highlighted that ferry crossings, which combine elements of both road and water transport, can act as effective connectors in areas without continuous highway or deep river channels. In agricultural supply chains, such hybrid use of ferries and barges could significantly reduce the risk of delay while retaining the flexibility of delivery.

Technology-driven innovations are opening new avenues for efficiency gains. For example, advanced technologies like AI and IoT are already being applied in the ready-made garment (RMG) sector to optimize transport routes, improve quality control, and streamline export processes. These tools significantly reduce complexity in supply chain operations (Ullah, Islam, Ray, & Eva, 2024). Extending such approaches to agricultural logistics could enable real-time monitoring, better coordination between farmers and traders, and smarter multimodal transport planning by riverways.



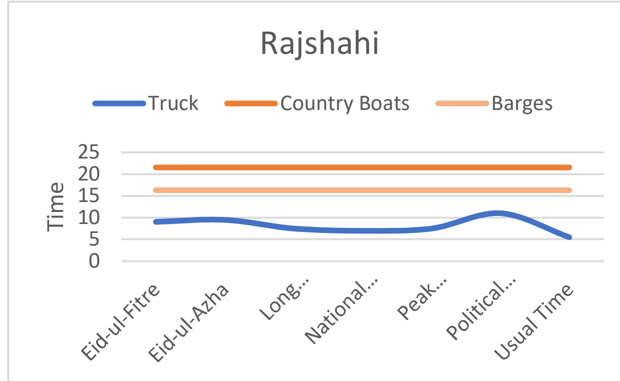


Figure 6: Comparison of travel time for short and long distance by both road and water ways according to our calculation.

Finally, the **CO_2 emission analysis** reinforces the environmental benefits of inland waterways. Per-tonne emissions for road transport were consistently higher, reflecting both higher fuel burn per kilometre and the aged vehicle fleet common in Bangladesh. By contrast, bulk river vessels spread fuel use over much larger payloads, cutting average emissions per tonne significantly. This advantage becomes especially pronounced for long-distance shipments, where road vehicles accumulate high emissions through congestion and repeated acceleration. The environmental gain is not merely theoretical. According to ESCAP (2022), shifting even part of Bangladesh's freight to waterways could cut national CO_2 emissions from transport by millions of tonnes annually. For an agriculture-based economy, where sustainability and food security are tightly linked, such reductions are of critical importance. In congested urban corridors like Dhaka–Chittagong, diesel truck emissions skyrocket: one analysis found that roughly 50–73% of all pollutant emissions from inter-district trucking are attributable to stop-and-go congestion. If congestion were eliminated, CO_2 from these trips would drop "by more than half". This inefficiency reflects compression-ignition (diesel) engine behavior: at low speeds and idling, the fuel burn per ton-km increases substantially. Compounding the problem, many Bangladeshi trucks are antiquated (often imported second-hand) and poorly maintained. For example, newer modern tractor-trailer rigs average about 3.5 km/L on the highway, whereas older rigid trucks barely manage 2 km/L. A survey noted that "many trucks are over 20 years old," translating into higher fuel use partly "due to a lack of proper maintenance". Owner-operators on slim margins often defer maintenance, worsening fuel economy and tailpipe emissions.

By contrast, river barges can operate much more **fuel-efficiently**. The World Bank notes that on a per tonne-kilometer basis, IWT emits up to six times fewer greenhouse gases than trucks. In practical terms, a joint industry-government estimate finds that shifting freight to waterways (e.g., on the Dhaka–Chittagong corridor) could save approximately 58.5 million liters of diesel and 155,000 tonnes of CO_2 annually. Moreover, trucking pollution disproportionately impacts cities: road vehicles emit into the urban street canyons of Dhaka, where air quality is already hazardous. In contrast, inland vessels (though diesel-powered) cruise along rivers in less densely populated areas, diluting emissions. Roadside air monitors in Dhaka frequently exceed WHO particulate standards, and mobile sources (trucks, buses) are a major contributor. These differences mean that modal shift to IWT could improve urban air quality.

Driver behavior and safety is also important matter of consideration. Road freight also suffers from human factors that IWT largely avoids. Long-distance truck drivers in Bangladesh often work at night under severe fatigue. Restrictions in Dhaka (banning heavy trucks during daytime) force drivers into late hours. Surveys of Bangladeshi truckers confirm fatigue as a top crash factor: lack of sleep topped drivers' lists (17%), with traffic jams (8%) and poor road conditions (13%) also cited. A few drivers even reported stimulant drug use (though only ~1%) to stay awake. Nighttime schedules and occasional stimulants elevate accident risk. In contrast, barges are not subject to driver fatigue issues in the same way. While water captains work long hours, river transport tends to have crew rotations and cruise schedules that can allow rest; statistically, the risk of fatal accidents per ton-km is dramatically lower on water. A World Bank transport review notes that IWT can be up to fifty times safer than trucking in terms of fatality rates. In Bangladesh, road crashes claim thousands of lives annually (Bangladesh's road traffic death rate was 15.3 per 100,000 in 2019), whereas yearly waterborne fatalities number in the low hundreds at most. For example, a survey of 40 years of inland vessel accidents found a total of roughly 5,400 deaths, or ~135 per year – orders of magnitude below road fatalities.

For **Infrastructure and maintenance**, both modes require upkeep, but their needs differ. Bangladesh's roads are chronically under-maintained despite heavy use. The National Development Strategy acknowledges "large-scale deterioration of the network due to lack of proper maintenance," and authorities admit spending on road upkeep "falls short of what is required". Potholes, weak bridges, and overloading continuously degrade highways. Waterways, by contrast, face siltation rather than surface wear. Without dredging, river depths shrink dramatically; one UN study estimates only 25% of inland rivers remain navigable in the monsoon and a mere 16% in the dry season, absent maintenance. Frequent dredging is thus essential to keep IWT viable, especially on key routes like those from Chattogram to Dhaka. On the plus side, dredging restores river depth along thousands of kilometers at relatively modest recurrent cost, whereas road repair of the same freight capacity would require continuous paving. In this sense, IWT infrastructure (dredging, navigational marking, wharves) can sustain high volumes with less material replacement, though the ecological impacts of dredging must be managed.

While **handling perishables**, the choice of mode also affects post-harvest quality. Road transport over rough surfaces can bruise and spoil fruits and vegetables. Controlled experiments show that vehicle vibration from uneven roads significantly degrades produce: for example, longer truck transit led to markedly higher weight loss and firmness loss in tomato shipments. By contrast, barge movement is relatively smooth – the cargo floats on water rather than bouncing over bumps – so delicate goods may experience less mechanical damage (though formal studies in Bangladesh are limited). However, IWT is slower: large vessels take days rather than hours for long hauls. A private logistics operator reports ships take 70–72 hours from Chattogram to Dhaka versus 10–14 hours by road. This slower transit can threaten perishables unless a cold chain is applied. In practice, perishable shippers using waterways often employ rapid cooling or even freezing before loading (or specialized refrigerated barges) to bridge multi-day journeys. Thus, a river route may cut shock-related loss but can introduce spoilage risk unless supported by insulation or active cooling, whereas a fast truck run may deliver fresher produce at the expense of jostle damage.

Each mode has unique vulnerabilities to **disruptions**. Roads in Bangladesh are often jammed or blocked by external events: political strikes (hartals), heavy traffic surges around festivals, and seasonal floods. Recent nationwide blockades illustrate the impact: a nine-day political strike in 2023 cut bus and truck operations to ~35% of normal and inflicted roughly Tk78 crore (USD ~9 million) per day in losses on goods transport alone. During such events, many highways become impassable or dangerously gridlocked, halting freight flow. In contrast, inland waterways are not directly affected by road strikes, though they have their own labor issues. For example, a wildcat strike by cargo vessel workers in 2016 stranded 611 goods-laden boats nationwide. Thus, waterways can bypass road blockades (vessels continue moving if crews work), but suffer when waterworkers strike. Natural disasters also affect both modes: floods in mid-2024 submerged hundreds of kilometers of roads, including key arteries like the Dhaka–Chittagong highway. In flooded regions, only boats can reach isolated villages, but in practice, there was "a lack of boats for relief transport. Cyclones and river floods can damage docks and capsized barges, but they often leave channels navigable once debris is cleared. On balance, road networks are highly prone to washouts and landslides, whereas waterways benefit from greater capacity during high water (if dredged) yet require flood-response planning.

The lower operating cost and higher bulk capacity of waterways translate into **economic benefits and supply chain efficiency**. Per-kilometer shipping fees on Bangladesh's rivers can be several times cheaper than on roads. The UN ESCAP estimates that IWT costs roughly Tk 1 per tonne-km, compared to Tk 4–5 by road. One study found moving one 20-foot container from Dhaka to Chattogram costs about Tk 600 per tonne by river, versus ~Tk 6,000 by truck. These vast unit-cost differences imply cheaper freight rates, which should lower wholesale and ultimately consumer prices if savings are passed through. For example, importers note that a full modal shift to waterways could make Bangladeshi exports more competitive by enabling "low-cost products" for global markets. Bulk transport also cuts fuel use per ton, so savings can be substantial.

The impact on farmers is significant. Cheaper, reliable transportation expands market access and margins. Lower logistic costs mean that farmers' produce can reach urban markets with less price erosion. Although studies on farmer incomes are scarce, logic suggests that if a farmer pays half the transport charge (or less) for a given shipment by barge, their net revenue per kg rises accordingly. In Bangladesh's grain and horticultural sectors, even a 10–20% cut in marketing costs (through IWT) could notably boost farmgate profitability. Conversely, if waterways are unavailable or slow, farmers suffer higher losses: road vibrations directly reduce shelf life, and spoilage forces price cuts. Thus, underutilized waterways represent a missed opportunity for agricultural producers.

Despite the advantages, IWT is not a panacea. Reliability can be undermined by navigational constraints: many rivers are shallow or obstructed by shoals. Private shippers report that barges "often get stuck in shoals," and key channels require regular dredging. Seasonal water level variations impose schedule uncertainty. Moreover, river vessels in Bangladesh tend to be old and often operated by under-trained crews, leading to accidents: one operator lamented that 8–10 ships sink each year on a busy route. These incidents underscore that water transport has safety and reliability issues of its own. Shore handling is also a bottleneck: inadequate port infrastructure and limited jetties can negate some time savings. Finally, perishable shippers must invest in better cooling infrastructure to fully exploit IWT – an upfront cost that partly offsets freight savings.

In contrast, road transport faces almost opposite constraints. Trucks are nimble and can deliver door-to-door, so logistics scheduling is more flexible (for example, they can run at any hour if curfews allow). Yet Bangladesh actually restricts heavy truck movement on major city roads during daytime (e.g., 8 am–8 pm bans in urban areas), forcing night drives that heighten fatigue risk. Roads require constant resurfacing under heavy loads, and accidents and congestion remain endemic. The net effect is that roads impose significant hidden costs: traffic jams alone may account for the majority of trip costs and environmental externalities.

6. Theoretical and Practical Implications

6.1 Theoretical

This study informs us about the details of supply chain literature by providing a comparison of roadway versus inland waterway transport in Bangladesh's agricultural sector. Bangladesh has an extensive river network of roughly 24,000 km that remains largely underutilized (World Bank 2011). By exploring strategies for mobilizing this latent network for goods transport, this study extends supply chain theory on different network designs. These findings empirically align with the core principles of supply chain management that highlight cost efficiency, sustainability, and resilience.

Our analysis indicates that inland waterway transport yields cost advantages, achieving reductions on the order of 40–60 percent per tonne-kilometer relative to road haulage of bulk shipments, marking the theoretical model of cost optimization. The results also show that incorporating inland waterway transport improves reliability under disrupted conditions, aligning with supply chain resilience theory. For example, road-dependent logistics suffer severe delays during political unrest, and monsoon flooding can shut down up to 30 percent of highway links, whereas river transport continues on predictable schedules with minimal interruption (Ahmed & Islam, n.d.).

From a green logistics perspective, the study offers proof of the environmental advantages achievable through modal shifts in transportation. This shows that moving goods by water is significantly more carbon-efficient than conventional road trucking (World Bank, 2017). By analyzing these differences in Bangladesh's context, this study highlights sustainability-focused supply chain models that incorporate low-emission modes of transport (Noha et al., 2023). Consistent with green logistics theory, the results illustrate that inland waterway transport not only reduces CO_2 emissions and fuel consumption but also delivers parallel gains in cost efficiency and service reliability. Even a modest shift from road to waterways could translate into millions of tonnes of avoided national CO_2 emissions annually, underscoring the scale of the opportunity. Beyond modal shifts, digital innovations such as blockchain are increasingly recognized as critical tools for strengthening transparency and resilience in Bangladesh's supply chains, especially in fast-growing sectors like e-commerce (Haque, Hossain, & Hossain, 2022). Indeed, the research reflects the theoretical discussion on sustainable multimodal transport and technology adoption by illustrating that economic and environmental objectives in supply chains can be pursued through strategic mode selection and smart network design.

6.2 Practical Implications

6.2.1 Policy and Infrastructure

The results support strategic shifts in transport to fully utilize inland waterways. To acquire benefits, policymakers should invest in river dredging, navigational maintenance, and enhanced port infrastructure—including storage and cold-chain facilities at river port terminals. Vessel safety and standards must also be improved. These measures are needed to overcome current inland waterway transportation limitations and ensure year-round reliability. Regular dredging is particularly critical for keeping waterways navigable, since without maintenance, only a fraction of routes remain passable during the dry season.

Proactive policy support for multimodal transportation will not only relieve overstressed highways and lower logistics costs but also advance national goals for green growth and supply chain resilience by cutting emissions and providing alternative transport during disruptions (World Bank, 2017). In recent years, many bridges have been constructed across the country to increase road connectivity. However, bridges often negatively impact the flow and natural shape of rivers, reducing navigability. Rapid and sometimes unplanned industrialization also threatens rivers, as many factories are being built nearby, polluting waterways. Policy initiatives to address these challenges are critical to maintaining inland waterways. Additionally, high-span suspension or cable-stayed bridges would maintain year-round river traffic even in flood conditions, directly supporting the goal of expanding inland waterway transportation alongside road and rail. Such flood-resilient bridges offer a sustainable way to upgrade Bangladesh's logistics network by fully integrating river transport into the multimodal system (World Bank, 2017).

6.2.2 Gender Inclusiveness

The transportation system can play a role in reducing disparities among different regions of a country. Since inland waterway transportation has strong penetration in rural Bangladesh, it could improve accessibility for marginalized groups, especially women, who could benefit socially and economically (UNESCAP, 2017). Better waterway facilities facilitate women's access to the labor market, creating opportunities for formal employment. Recently, the government included breastfeeding chambers for mothers of newborns and separate waiting rooms for women in newly designed watercraft. Such gender-inclusive changes could be adopted in other sectors as well (CUTS International, 2018).

6.2.3 Logistics Strategy

For logistics providers and supply chain managers, the study highlights ways to cut costs and boost reliability by incorporating waterways into distribution networks. Companies can adopt multimodal approaches, using trucks for short-distance or last-mile deliveries and barges for long-distance bulk transportation. This strategy takes advantage of inland water transport's lower fuel costs and resistance to traffic congestion while still ensuring timely deliveries through careful planning.

Logistics firms in Bangladesh can draw inspiration from regional examples. In countries like India and Vietnam, road–river intermodal systems are employed to reduce highway congestion and enhance efficiency. Implementing similar practices may require investment in transshipment facilities at river ports and close coordination with barge operators, but the result is a more flexible and cost-efficient supply chain. By embracing multimodal transport, companies can offer more reliable delivery times and remain competitive when road networks face delays.

7. Future Research Scopes

While this study provides a detailed comparative assessment of road and inland waterway transport for agricultural supply chains in Bangladesh, several limitations leave room for future research. First, the analysis relied on modeled estimates of fuel consumption, travel times, and emission factors rather than direct measurements. Future work could incorporate GPS-tracked journeys, real-time fuel monitoring, and on-site emission testing to validate the assumptions and improve accuracy. Second, perishability and post-harvest loss dynamics were only discussed qualitatively; controlled experiments tracking spoilage rates of different commodities across modes would provide stronger evidence on quality preservation.

Third, the study modeled cost and time under typical and disrupted conditions using surveys and secondary sources, but did not account for seasonal variations in river navigability or changes in diesel prices, which could significantly influence results. Future studies could adopt a longitudinal design, capturing multi-seasonal data to evaluate resilience across monsoon and dry periods. Fourth, regression modeling was limited to linear cost–distance relationships analyzed via ANOVA. Advanced econometric methods, such as panel data models or stochastic frontier analysis, could provide deeper insights into efficiency and variability.

Additionally, the research did not directly capture farmer-level impacts such as farmgate income changes, market access, or gender-specific challenges in adopting IWT. Future studies could integrate household surveys and gender-sensitive analyses to evaluate broader socio-economic outcomes. Finally, the study's sample size, though representative for major Dhaka markets, was geographically narrow. Expanding to other urban centers like Chattogram or Khulna could test the generalizability of findings and explore inter-regional logistics strategies.

By addressing these gaps with richer datasets, experimental validation, and broader stakeholder perspectives, future research can strengthen the empirical case for inland waterway transport and provide more actionable recommendations for policymakers and logistics practitioners.

8. Conclusion

In Dhaka-centered agricultural supply chains, inland water transport offers compelling advantages: much lower fuel use and emissions per ton-km, reduced physical damage to produce, and vastly higher bulk capacity that slashes unit costs. These can translate into lower consumer prices and higher farm incomes in principle. While significant barriers to implementing green supply chain management exist in Bangladesh, as documented by Ahmed et al. (2022), this study demonstrates that a modal shift towards IWT provides a practical and economically viable pathway to overcoming many of those challenges. However, to realize these gains, Bangladesh must overcome IWT's own drawbacks: ensuring reliable dredging and navigational safety, and developing cold-chain and port infrastructure. Empirical evidence suggests that a balanced modal shift could dramatically improve overall supply-chain efficiency and public welfare. Future policies should thus address both sides: reforming road freight (tightening safety enforcement, curbing overloading, improving fuel standards) while investing in river infrastructure and vessel modernization. Such a strategy promises not only greener, safer logistics, but also more resilient and profitable rural supply networks for Bangladesh's agriculture.

Acknowledgement:

Deeply grateful to Engr. Md. Zulfiqar Haider, Executive Engineer (Naval Architect), BIWTA, for his kind guidance and support.

Glossary:

- *Agricultural Supply Chains*: The network of activities involved in producing, transporting, processing, and distributing agricultural products from farms to consumers.
- *Ancillary Fees*: Additional costs beyond the primary freight charge, such as tolls, handling fees, docking charges, and checkpoint payments.
- *Break-even Distance*: The specific distance at which the total cost of transporting goods via inland waterways becomes equal to, and then cheaper than, the cost of road transport.
- *Bulk Shipments*: The transportation of large, unpackaged quantities of a single commodity, such as grains, which benefits from economies of scale.
- *Carbon Footprint*: The total amount of greenhouse gases (including CO_2) emitted directly and indirectly by an activity, in this case, the transportation of goods.
- *Cold-chain Infrastructure*: A temperature-controlled supply chain that includes refrigeration and freezing facilities to preserve the quality and shelf life of perishable goods from origin to destination.

- *CO_2 Emissions*: Carbon dioxide released into the atmosphere, primarily from burning fossil fuels like diesel. Measured in kilograms per tonne-kilometer (kg/t-km) in this study.
- *Cost per Tonne*: The total cost incurred to transport one metric tonne of goods, including fuel, tolls, and other operational fees.
- *Deterministic Model*: A mathematical model that produces a single, precise outcome based on a fixed set of input values and relationships, without accounting for randomness.
- *Dredging*: The process of removing sediment and debris from the bottom of rivers, lakes, and other waterways to maintain or increase their depth for navigation.
- *Economies of Scale*: The cost advantage achieved when increased production (or transport volume) leads to a lower cost per unit.
- *Emission Factor*: A coefficient that quantifies the amount of a pollutant (e.g., CO_2) released per unit of activity (e.g., per liter of diesel combusted). In this study, it is 2.68 kg CO_2 per liter of diesel.
- *Fintech (Financial Technology)*: Digital tools and platforms that improve and automate financial services. In the context of this paper, they help MSMEs manage logistics payments and access credit.
- *Fuel Consumption Rate*: The amount of fuel used per unit distance traveled, typically measured in liters per kilometer (L/km).
- Ghat / River Port: A landing place or jetty on a riverbank used for boarding, disembarking, and loading/unloading cargo. (e.g., Chilmari Ghat, Chandpur Port).
- *Green Logistics*: The practice of managing logistics processes in a way that minimizes environmental impact, particularly through reduced energy use and emissions.
- *Inland Waterway Transport (IWT)*: The transportation of goods and people via navigable rivers, canals, and lakes within a country.
- *Intermodal Transport*: A system of transporting goods using multiple modes of transportation (e.g., truck, barge, rail) in an integrated chain without handling the goods themselves when changing modes.
- *Last-mile Delivery*: The final step of the delivery process, getting a product from a transportation hub to its final destination (often a retail market or warehouse).
- *Logistics Resilience*: The ability of a supply chain to anticipate, withstand, and recover from disruptions such as political strikes, natural disasters, or congestion.
- *Modal Shift*: The change from one mode of transport (e.g., road) to another (e.g., inland waterway) to achieve economic, environmental, or operational benefits.
- *Multimodal Logistics / Transport:* A system of transportation that uses more than one mode of transport (e.g., road and water) under a single contract or bill of lading.
- *MSMEs (Micro, Small, and Medium Enterprises):* Small businesses that play a significant role in the economy, including many agricultural traders and logistics operators.
- *Passenger Car Equivalent (PCE) Factor*: A metric used in transportation engineering to convert the impact of different vehicle types (like trucks and buses) on traffic flow into an equivalent number of passenger cars. Used here to convert bus travel times to equivalent truck travel times.
- *Perishable Goods*: Agricultural products that have a limited shelf life and can decay or spoil quickly, such as fruits and vegetables (e.g., pineapple, cucumber, tomato).
- *Post-harvest Losses*: The degradation in both quantity and quality of agricultural produce that occurs between harvest and consumption, often due to poor handling, transportation, or lack of cold storage.
- *Purposive Sampling*: A non-probability sampling technique where researchers select participants based on specific characteristics or qualities relevant to the study, such as experienced agricultural traders.
- *Supply Chain Resilience:* The capacity of a supply chain to tolerate disruption and quickly return to its normal operational state.

- *Ton-kilometer (t-km)*: A standard unit of measurement in freight transport that represents the transport of one tonne of goods over one kilometer. Used to compare cost and emission efficiency.
- *Transshipment*: The transfer of goods from one mode of transport to another at a intermediate point (e.g., from a truck to a barge at a river port).

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Appendix A – Questionnaire (Offline Form)

1. What is the name of the product you usually supply or trade?

2. From where do you usually source this product? (Please specify location/market)

3. Can you describe the detailed route taken to transport this product?

4. In case of inconsistent or disrupted supply, what alternative sources or routes do you rely on?

5. What is the usual rate of this product? (Please mention per unit)

6. What unit of measurement do you use for this product?

7. What is the average shelf life of this product under normal conditions?

8. Please provide the name and contact details of the supplier/distributor you depend on.

9. How many years of experience does your supplier/distributor have in this business?

10. Do you believe using waterways can be an effective option for transporting this product?

>Yes

>No

11. Please explain the reason behind your opinion on the use of waterways.

12. Do you have any additional comments or suggestions regarding the supply and transportation of this product?

Appendix B – Questionnaire (Bus Travel Time Survey Google form)

We are conducting a quick survey to understand the average bus travel time it takes for residents from different districts to reach Dhaka, both during regular days and on special occasions. Your response will remain confidential and will be used only for research purposes.

1. Which district do you usually travel from when going to Dhaka?

- ○ Rajshahi
- ○ Khulna
- ○ Bagerhat
- ○ Rangpur
- ○ Narsingdi
- ○ Kurigram
- ○ Gaibandha
- ○ Sylhet
- ○ Pabna
- ○ Natore
- ○ Chandpur
- ○ Cumilla
- ○ Sunamganj
- ○ Munshiganj

2. On average, how much time does it usually take you to travel from your district to Dhaka by bus?

3. During Eid-ul-Fitr, how long does the journey usually take from your district to Dhaka?

4. During Eid-ul-Azha, how long does the journey usually take from your district to Dhaka?

5. During long weekends, how much travel time does it take on average?

6. During national events, how much travel time does it take on average?

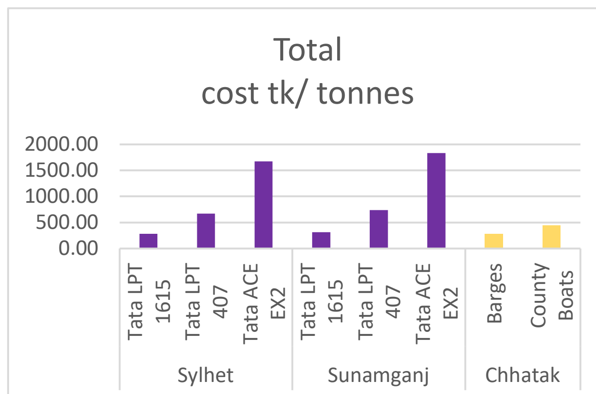
7. During the peak holiday season, how much travel time does it take on average?

8. During times of political rallies or strikes, how much travel time does it take on average?

Appendix C- Comparative Analysis of cost per Tonne to travel to Dhaka from selected Riverports and their nearby Districts.

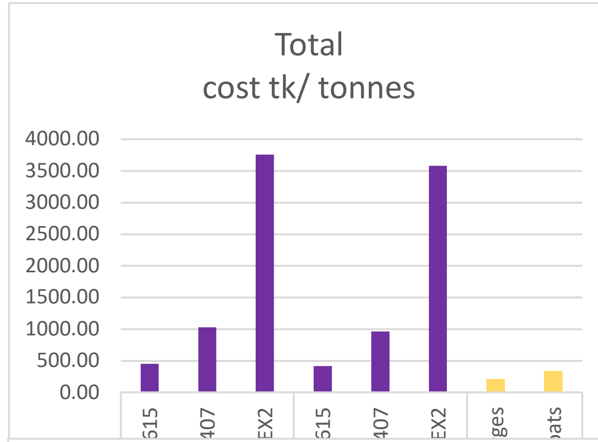
Chhatak River port:

Location	Transport Used	Total cost tk/ tonnes
Sylhet	Tata LPT 1615	284.22
	Tata LPT 407	672.11
	Tata ACE EX2	1672.80
Sunamganj	Tata LPT 1615	311.95
	Tata LPT 407	737.68
	Tata ACE EX2	1836.00
Chhatak	Barges	281.07
	County Boats	444.14



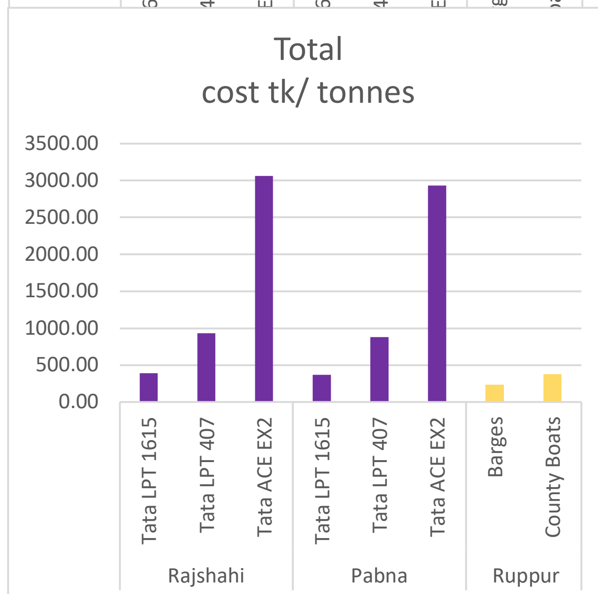
Khulna River port:

Location	Truck Used	Total cost tk/ tonnes
Khulna	Tata LPT 1615	448.97
	Tata LPT 407	1033.93
	Tata ACE EX2	3758.53
Bagerhat	Tata LPT 1615	418.93
	Tata LPT 407	962.90
	Tata ACE EX2	3581.73
Khulna	Barges	212.54
	County Boats	336.03



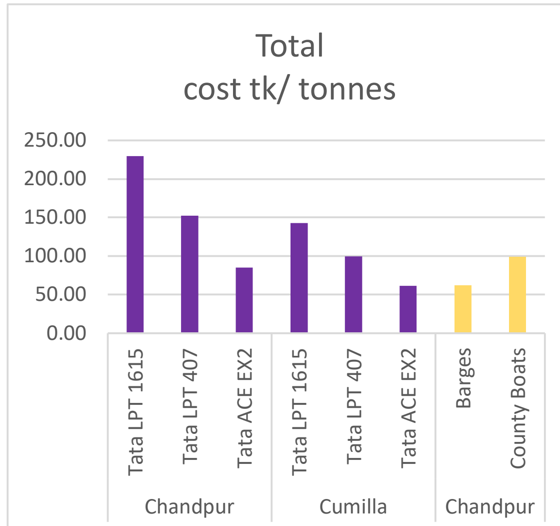
Ruppur River port:

Location	Truck Used	Total Cost tk/ tonnes
Rajshahi	Tata LPT 1615	392.23
	Tata LPT 407	932.06
	Tata ACE EX2	3060.53
Pabna	Tata LPT 1615	370.28
	Tata LPT 407	880.15
	Tata ACE EX2	2931.33
Ruppur	Barges	237.29
	County Boats	375.07



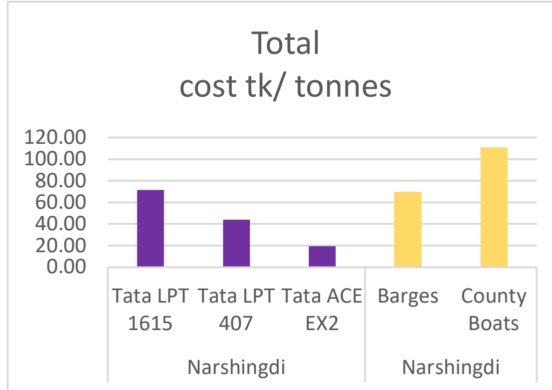
Chandpur River Port:

Location	Truck Used	Total Cost tk/ tonnes
Chandpur	Tata LPT 1615	229.59
	Tata LPT 407	152.70
	Tata ACE EX2	85.01
Cumilla	Tata LPT 1615	142.94
	Tata LPT 407	99.57
	Tata ACE EX2	61.40
Chandpur	Barges	62.16
	County Boats	98.80



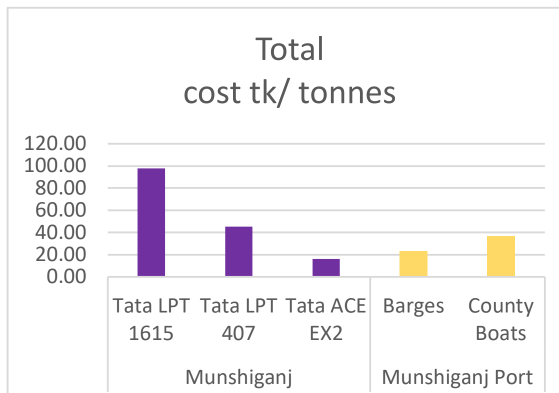
Nzrsingdi River port:

Location	Truck Used	Total Cost tk/ tonnes
Narshingdi	Tata LPT 1615	71.63
	Tata LPT 407	43.92
	Tata ACE EX2	19.52
Narshingdi	Barges	69.78
	County Boats	110.81



Munshiganj Port:

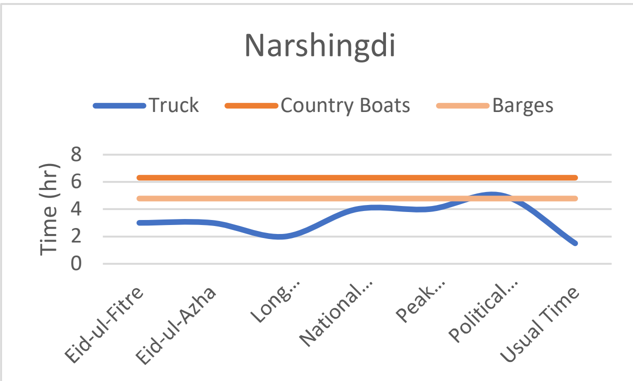
Location	Truck Used	Total Cost tk/ tonnes
Munshiganj	Tata LPT 1615	97.91
	Tata LPT 407	45.18
	Tata ACE EX2	16.31
Munshiganj Port	Barges	22.95
	County Boats	36.94

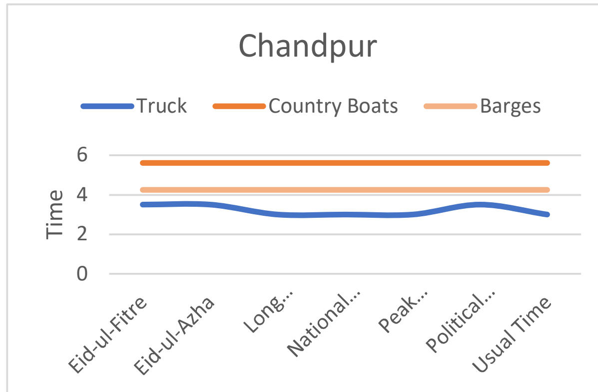


Appendix-D: Time comparison in both ways to come to Dhaka from selected Districts.

Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	2.25	2.5	2.25	1.5	2.25	3	1.5
Country B	2.05	2.05	2.05	2.05	2.05	2.05	2.05
Barges	1.56	1.56	1.56	1.56	1.56	1.56	1.56

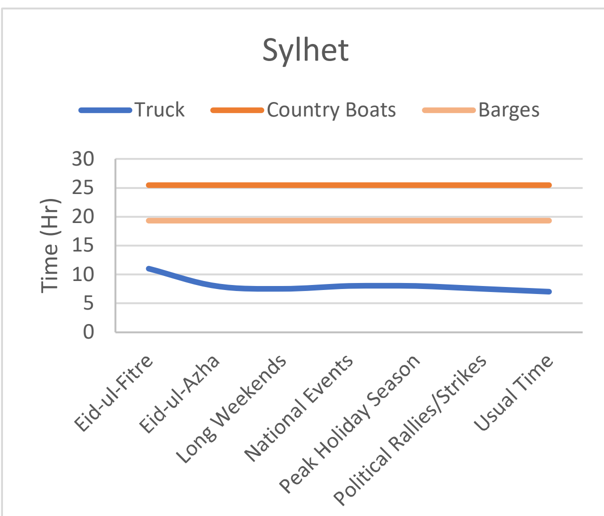
Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	3.5	3.5	3	3	3	3.5	3
Country B	5.61	5.61	5.61	5.61	5.61	5.61	5.61
Barges	4.25	4.25	4.25	4.25	4.25	4.25	4.25

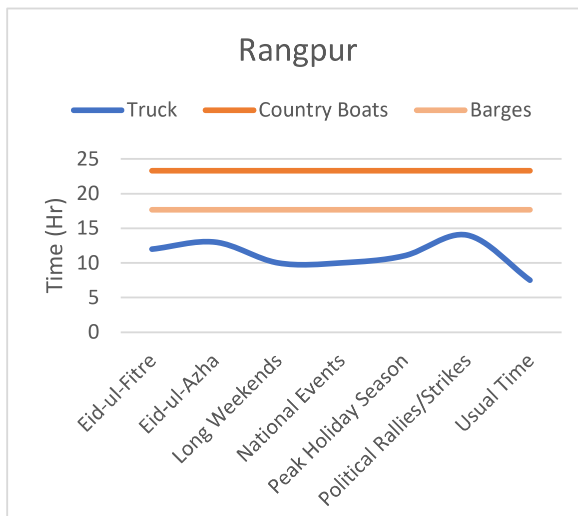




Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	12	13	10	10	11	14	7.5
Country B	23.32	23.32	23.32	23.32	23.32	23.32	23.32
Barges	17.67	17.67	17.67	17.67	17.67	17.67	17.67

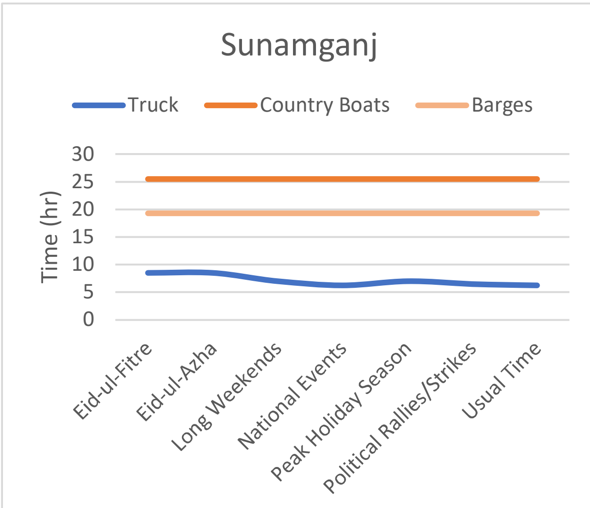
Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	11	8	7.5	8	8	7.5	7
Country B	25.48	25.48	25.48	25.48	25.48	25.48	25.48
Barges	19.3	19.3	19.3	19.3	19.3	19.3	19.3

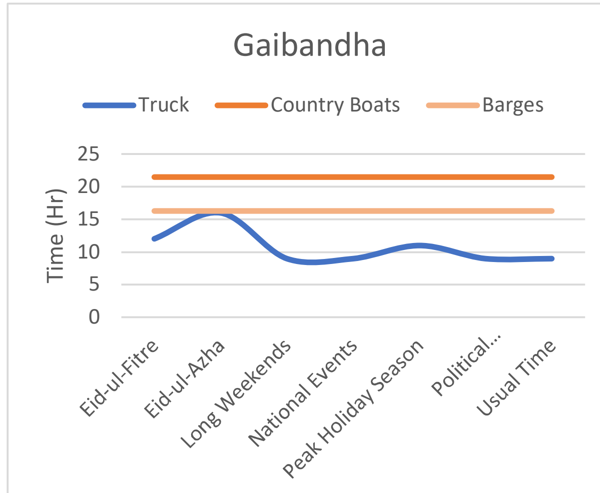




Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	8.5	8.5	7	6.25	7	6.5	6.25
Country B	25.48	25.48	25.48	25.48	25.48	25.48	25.48
Barges	19.3	19.3	19.3	19.3	19.3	19.3	19.3

Transport	Eid-ul-Fitre	Eid-ul-Azha	Long Weekends	National Events	Peak Holiday Season	Political Rallies/Strikes	Usual Time
Truck	12	16	9	9	11	9	9
Country B	21.51	21.51	21.51	21.51	21.51	21.51	21.51
Barges	16.3	16.3	16.3	16.3	16.3	16.3	16.3





Appendix E: Survey response of travel by bus

Name of your district	Time taken to travel during Eid-ul-Fitre	Time taken to travel during Eid-ul-Azha	Time taken to travel during long weekends	Time taken to travel during National events	Time taken to travel during peak holiday season	Time taken to travel During political rallies or strikes	Time taken to travel Dhaka usually from your selected district
Cumilla	2 hrs	2hrs				3hrs	2:30hrs
Rajshahi	8-9 hrs	8-9 hrs	7-8 hrs			10 hrs+	6hrs+-
Cumilla	2 hour 30 mins	2hour 30 mins	2 hour 30 mins	2 hour	2 hour 30 mins	3 hours	2hour
Chandpur	3.5 hours approximately	3.5 hours approximately	3 hours	3 hours	3 hours	3.5 hours	3 hours
Rangpur	11 up to 20 hours +	11 upto 20 hour +				10 ro 15+ hour	7 to 8 hours,, if there will no jam, it will take almost 6 hours.
Rangpur	13/14 h	13/14 h	9-10 hours	9-10 hours	9-10 hours	13/14	7 h
Rangpur	9-12 hours	9-12 hours	9-10 hours	9-11 hours	9-12 hours	12 hours++	9 hours
Shunamganj	8-9 h	8-9 h	7h	6-6.5 h	7 h	6-7h	6-6.5 h
Sylhet	12hrs	8hrs	8hrs	8hrs	8hrs	8hrs	7hrs
Rangpur	15hr+	15hr+	12hr+	10hr+		20hr+	9hr
Gaibandha	12hours	16 hours	9 hours	9 hours	10-12 hours	9 hours	9 hours
Rangpur	10/12 hours	10/12 hours	10/12 hours	7/8 hours	7/8 hours	8/9 hours	8/9 hours
Cumilla	3hr	3hr	2.5hr			5hr	2hr
Narsingdi	3hours	3hours	2houra	4hours	4hours	5hours	1.5hours
Cumilla	3:00 hours	3:00 hours	3:00 hours	3:00 hours	3:00 hours	3:00 hours	2:00 hours
Rajshahi	8-10 hours	10-12 hours	7-8 hours	5-6 hours	7-8 hours	9-12 hours	5-6 hours
Rajshahi	14h	9h	8h	13h	15h	16h	6h
Rangpur	12-20hr	12-20hr	10	12	12	12	8
Rangpur	10-12 hours	10-12 hours	8-9 hours	8-9 hours	8-9 hours	8-9 hours	8-9 hours
Cumilla	3 hr	3 hr	2.5 hr	4 hr	3 hr	4/5 hr	2 hr
Rangpur	15 hours	12 hours	12 hours	12 hours	12 hours	12 hours	8 hours
Rangpur	12+ hours	Once it took 12 hours	8-10 hours	7 hours	10 hours avg	Never been on such time	6-7 hours
Sylhet	10-12 hr	10-12 hr	7	8	8-Sep	7	7
Rajshahi	5-7 hours	5-7 hours	5-7 hours	5 hours	5-7 hours	8-10 hours	5 hours
Munshiganj	2-2.5 hours	2-3 hours	1.5-3 hours	1-2 hours	1.5-3 hours	2.5-3.5 hours	1.5 hours