Modeling and Analysis of Inland Waterways Connectivity Using Complex Network Analysis: A Case Study of Bangladesh

by

Firoza Tabassum
18366004

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Declaration

It is hereby declared that

1. The thesis submitted is my/our own original work while completing degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
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Student's Full Name & Signature:

Firoza

Firoza Tabassum
18366004

Approval

The thesis/project titled "Modeling and Analysis of Inland Waterways Connectivity Using Complex Network Analysis: A Case Study of Bangladesh" submitted by

1. Firoza Tabassum (18366004)

Of Fall, 2024 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. in Computer Science and Engineering on December 01, 2024.

Examining Committee:

Supervisor:
(Member)

Dr. Moinul Islam Zaber
Professor
Department of Computer Science and Engineering
University of Dhaka, Bangladesh

Co-Supervisor:
(Member)

1/12/2024

Dr. Matin Saad Abdullah
Professor
Department of Computer Science and Engineering
BRAC University, Bangladesh

Program Coordinator:
(Member)

Sadek

Dr. Md Sadek Ferdous
Associate Professor
Department of Computer Science and Engineering
BRAC University, Bangladesh

Examining Committee:

Head of Department (Chair):
&
Examiner-1 (Internal):

Dr. Sadia Hamid Kazi
Chairperson and Associate Professor
Department of Computer Science and Engineering
BRAC University

Examiner-2:
(External)

Dr. Sarker Tanveer Ahmed Rumee
Associate Professor
Department of Computer Science and Engineering
University of Dhaka, Bangladesh

Abstract

The Bengal Delta is considered as world's largest delta with three largest rivers flowing across Bangladesh, namely the Ganges, Brahmaputra, and Meghna. Bangladesh has thousands of rivers and hundreds of ports. As a heavily populated, riverine developing nation, Bangladesh has historically been the hub of social and economic activity thanks to its eleven major inland ports, twenty-three coastal island ports, and hundreds of inland waterway ports. Inland waterway vehicles are the most economical and crucial mode of transportation for connecting ecosystems, making them the most economically significant for both people and goods. To provide a more comprehensive picture of the state of Bangladesh's inland waterways, this study provides the first-ever data analysis of ports and the frequency of vessels using a special dataset. Complex network analysis has shown to be a useful tool for comprehending the inland waterways structure, enabling the identification of crucial ports, clusters, bottlenecks, and port connectivity. The paper offers valuable insights for policymaking, infrastructure development, port connectivity enhancement, identifying weak points, ensuring network resilience, and developing backup plans for inland water transportation disruptions. This opens the door for datafication and digitization, paving the way for a smart Bangladesh.

Keywords: Complex Network Analysis; Inland Waterways; Models of Complex Networks; Vessel Augmentation

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Chapter 1

Introduction

1.1 Problem Statement

Waterways transportation is a vital industry in countries connected by rivers and seas, serving intercity passengers at lower costs than railway or bus transportation. For the 169.4 million people who live in Bangladesh, a riverine nation with 700 rivers and 241 ports, an affordable form of transportation is crucial. Roads, trains, and waterways are common means of transportation. While logistics costs can range from 6% to 25%, transportation has an impact on the national GDP of developed economies of 6% to 12% [1]. Due to famine and seasonal deprivation brought on by low grain and wage prices in Bangladesh, people temporarily migrate to urban areas in search of better employment opportunities. Rivers that can be navigated are essential for trade, and when these inland water ports are used properly, heavy traffic flows of people and goods are produced. An increasing trend can be seen in the analysis of cargo and passenger flow in specific inland river ports between 2005 and 2010 [2].

Inland waterways network structure is crucial for understanding economic growth, infrastructure development, environmental sustainability, risk mitigation, regional development, and trade competitiveness. It aids in optimizing trade routes, reducing transportation costs, and boosting economic growth. Identifying and improving connectivity between inland water ports helps prioritize infrastructure projects, such as upgrades to waterways, bridges, and transportation networks. The shipping network topology encourages transportation modeling and simulation practitioners to investigate its role in network performance. Efficient use of waterways reduces carbon footprints and eases road and rail congestion, promoting environmentally friendly transportation options. Knowledge of network structure is important for risk mitigation, disaster management, and planning. Inland water ports often serve as catalysts for regional development, spurring growth in underserved areas. Policymakers must make wise choices that maintain the balance between exploitation and proper use of inland waterways resources and protection of the waterway's environment. A comprehensive understanding of inland water port connectivity enhances a country's trade competitiveness, as navigable rivers are important for trading purposes [3]. Policies informed by this data can lead to streamlined logistics, attracting investments, and bolstering international trade relations.

Hence, a network of scientific scrutiny of the structure of the connectivity of the ports is very important for assessing the socio-economic condition of the country. Transportation networks have been studied using a variety of models, including complex networks, graph theory, and social network analysis. Complex network analysis is a crucial tool [4] for understanding the topological structure and existence of communities or clusters in transportation networks. It provides insights into the structure, dynamics, and key characteristics of inland water port connections. This comprehensive and systematic approach equips policymakers and stakeholders with valuable information for strategic planning, infrastructure development, and policy interventions aimed at enhancing inland water port connectivity.

1.2 Aim of this Study

In this study, we will analyze the Bangladesh Inland Waterways Network (BIWN) based on district and port connectivity. This research aims to analyze the structure and port characteristics of the inland waterways of Bangladesh. This will help to understand the different types of ports based on their importance and placement in the network. We hope this analysis will give a way forward to design a more optimized and resilient port-connectivity network that can contribute largely to the sustainable economic growth of Bangladesh.

1.3 Thesis Outline

The rest of the thesis works has been organized as below:

- Chapter 2 provides our motivation and pre–assumptions for the thesis.
- In Chapter 3, we have provided the summary of our literature review on previous works of different network analysis.
- In Chapter 4, our analysis methodology using complex network centrality and network level parameters have been discussed.
- In Chapter 5, details have been provided on steps of Bangladesh Inland Waterway Network data collection, digitization, preparation and network generation.
- Chapter 6 describes our findings on Bangladesh Inland Waterway Network structure and port characteristics.
- In Chapter 7, we conclude the study by providing a summary on our works and aiming of future work direction.

Chapter 2

Motivation and Pre-assumption of the Study

2.1 Geographical Location Environmental Factor

The Meghna Delta, the largest and most populous delta in Asia, is facing challenges due to rising water pollution, causing river damage and destroying 31 of its 64 river ports. The delta, comprising 7% of the surface, has 448 secondary stations and 22 major ports. Its 7100 thousand river vessels carry 50 million passengers annually. Overcrowding increases fatalities in passenger ship accidents. To reduce this, higher capacity passenger launch vessels are needed. The government's 7th Five Year Plan aims to construct 10 river ports, modernize 9 ports, and digitize services. [1]

2.2 Socio-economic Condition of Bangladesh

The socio-economic condition of Bangladesh has been a great motivation for our study. We have analyzed passenger count data for the last 10 years from 2010 to 2019. In Fig. 2.1, the change for different years have been shown. As observed in the graph, Dhaka, and Narayanganj have increasing passenger count. Dawlatdia, Paturia, Mawa, Kathalbari, and Ashuganj ports have had a sharp increase in passenger count in the last 10 years. Whereas Aricha, Chittagong, and Kazirhat had a steady increase from 2010 to 2018 but a steady fall happened in 2019. Based on the total headcount of passengers traveling in ports, we have conducted a comparison of passenger count and rate of poverty. To analyze the data, we have considered the living conditions of people in the mentioned ports of Passenger Count Data.

In Table 2.1, a comparison has been shown for the passenger count of listed districts and upper poverty headcount ratio (%) by districts. We have also generated a chart based on the result and it is shown in Fig. 2.2. From Table 2.1 we can observe that the highest number of passengers traveling through vessels in Dhaka has a low poverty rate. Thus the living conditions of Dhaka are better compared to other districts. Whereas, Munshiganj and Narayanganj have higher passenger counts with a very low poverty rate which can be explained, although more people travel through vessels in in these districts have better economic conditions. On the contrary, Rajbari has the second highest passenger count with a higher rate of poverty which states that the living conditions of Rajbari are inferior compared to others. Although Barisal is located at the southern region of Bangladesh surrounded by rivers has a higher count with a higher poverty rate. Other riverine districts like Borguna, Patuakhali, and Bhola have poor economic conditions. [3] This result indicates that although riverine ports have great potential towards better waterway connectivity, but economic condition impacts the transportation system. Thus, passenger count mostly found lesser in districts which belong to higher poverty rate range.

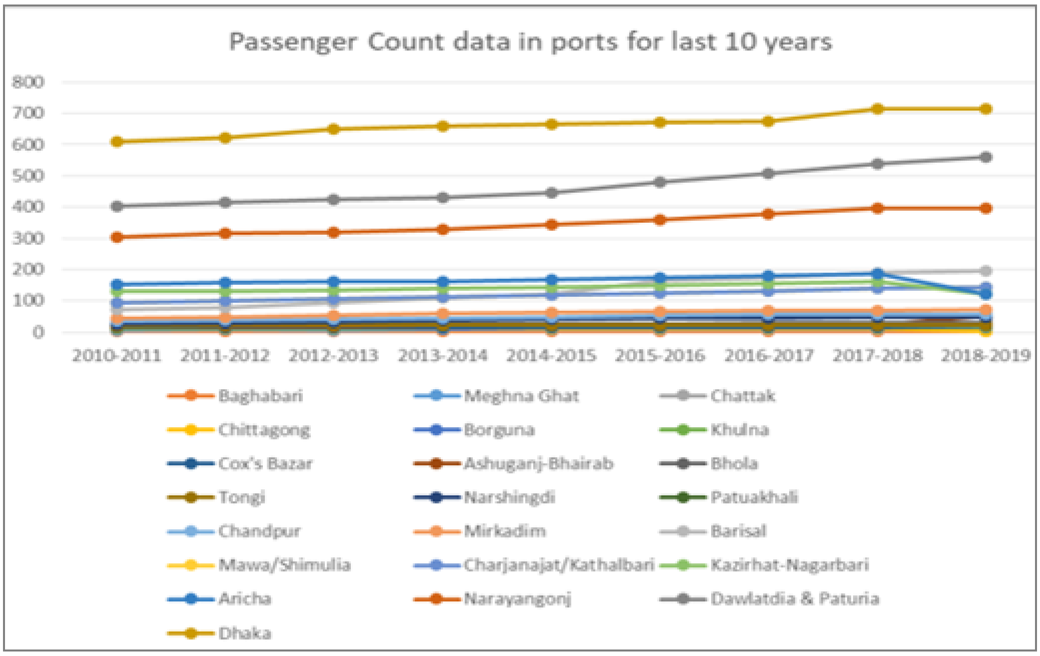


Figure 2.1: Passenger count data from 2010-2019. Source: Bangladesh Inland Waterways Transport Authority (BIWTA).

2.3 Migration Probability across Coastal Area

Fig. 2.3 shows data on migration in coastal districts depending on a survey conducted in the Deputy Commissioner's Office in every selected district. In each district data on the "Ashrayan Project by the Prime Minister" was collected from January to February 2020, where the number of migrant families was mentioned. On average five members have been assumed in every family. Data has been collected and plotted district-wise in Fig. 2.2. From the collected data, Patuakhali has the highest number of migrations among all districts (38715) and Satkhira has the lowest number of migrations. Except for Bhola rest of the districts have migrants less than 10000. [2]

SL	Districts	Passenger Count (in lacs)	Poverty Rate (%)
1	Narayanganj	405.47	2.6
2	Munshiganj	212.53	3.1
3	Madaripur	2	3.7
4	Gazipur	22.98	6.9
5	Dhaka	1002.03	10
6	Brahmanbaria	50.79	10.3
7	Narsingdi	46.87	10.5
8	Sylhet	142.75	13
9	Chittagong	123.47	13.7
10	Bhola	29.1	15.5
11	Cox's Bazar	32.81	16.6
12	Borguna	16.05	25.7
13	Sunamgonj	54.3	26
14	Barisal	195	27.4
15	Chandpur	56.99	29.3
16	Sirajganj	2.5	30.5
17	Manikganj	120.25	30.7
18	Khulna	17.54	30.8
19	Rajbari	560	33.8
20	Patuakhali	45.97	37.2
21	Kurigram	8	70.8

Table 2.1: Comparison between passenger count (in lacs) of listed districts and upper poverty headcount ratio (%) by districts

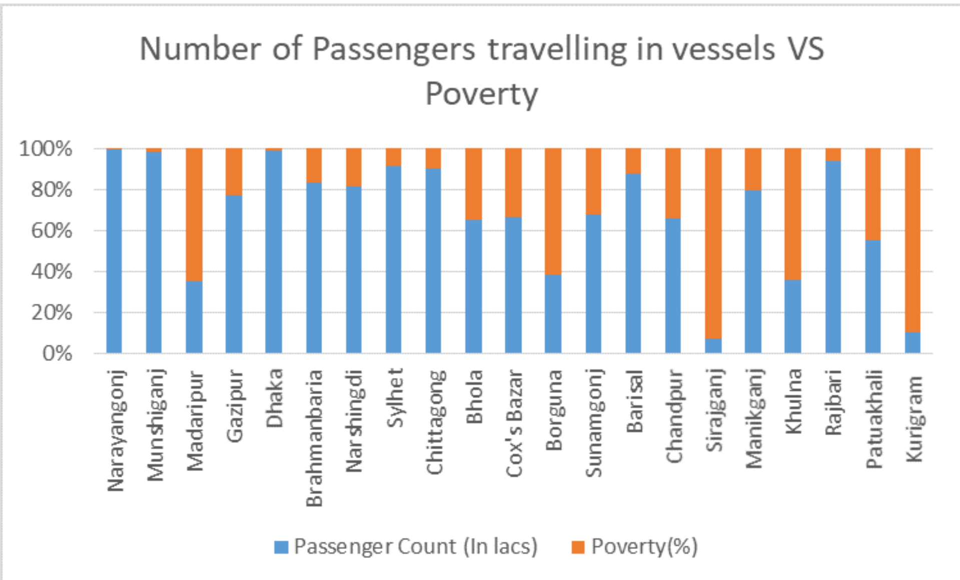


Figure 2.2: Comparison on Passenger Count (in lacs) vs. Poverty Rate

District	Total Population	Living within Zila (%)	Number of Migrants to other Zila	Migration for Natural Calamities (2.1% of total migrants)
Barguna	892129	95.4	40913	860
Barishal	2347223	96.3	86047	1807
Bhola	1822125	99	18280	384
Jhalokati	680589	93.5	44182	928
Patuakhali	1624619	97.6	38681	812
Pirojpur	1122791	95.4	51756	1087
Khulna	2301947	86.2	316454	6645
Bagerhat	1523667	94.2	87634	1850
Satkhira	2018217	97.9	42392	890

**District i.e. study sites have been used as Zila here*

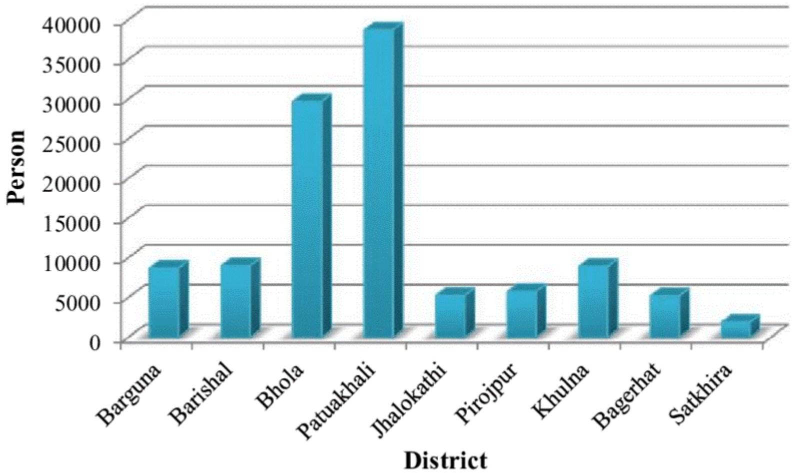


Figure 2.3: District-wise migrants in Bangladesh (2020). Source: DC office of the respective districts [4].

2.4 Affordable Mode of Transportation

The economy of Bangladesh largely depends on a functional waterway transportation industry that carries goods and people between towns and cities at an affordable cost. For the majority of the people, river vessels offer the only affordable means of intercity transportation since it is cheaper and affordable. From the economical perspective, waterway transportation is the cheapest mode of transportation. For example the ticket price from Dhaka to Barisal is: by Air - Tk. 3015, by Road - Tk. 500, and by Waterways - Tk. 250. So, waterway transportation is a lot cheaper than other modes. Also, river transportation is environmentally friendly as less fuel is consumed for sailing. It has no chronic roadway traffic jams that occur in the major cities. Hence, transportation networks play a vital role in economic development and migration.

However, if we look into the current condition of river port establishment, only 31 ports of among 64 districts have established ports. In Fig. 2.4, we can also visualize that fewer ports exist compared to river numbers and most ports are clustered around the central region

So, there are lot of scopes for waterway transportation in Bangladesh but there is a lack of proper utilization in this field. This situation had motivated us to study the waterway network so maximum utilization is possible. And for that, we need to understand the structure of ports and vessels first. Network analysis gives a way forward to design a more optimized and resilient port-connectivity network that can contribute largely to the sustainable economic growth of a country. Hence, we have studied a number of previous researches on network analysis which has been presented in our next section

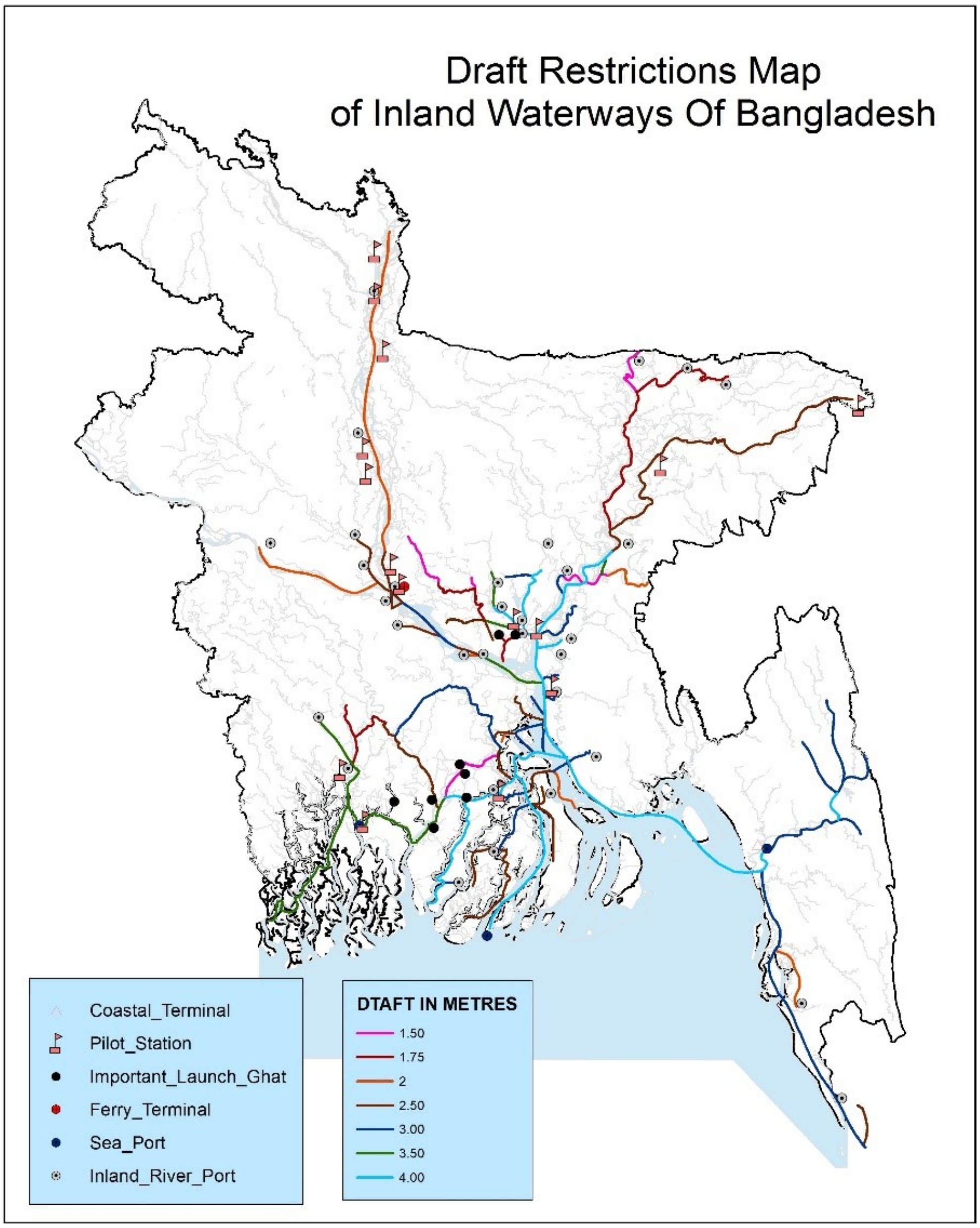


Figure 2.4: Port placements across 64 districts

Chapter 3

Previous Works on Network Analysis

Several networks in the real world, including social, information, biological, transportation, and technical networks, have been researched for many years [5]. Different models have been used to study transportation networks, such as graph theory, social network analysis complex networks, etc. In prior research, a significant amount of research has been conducted to analyze transportation networks by using Complex Network Analysis. The studies show, using complex network centrality and cluster analyzing parameters, important network nodes, probable congestion points, and clusters can be identified for transportation networks.

The Indian Railway Network (IRN) [6] and Shanghai Rail Transit System (RTS) [8] are analyzed using complex network theory to understand traffic correlations and network topology. High-connected stations are identified as having high traffic flow, while the evolution of the Chinese Railway network [7] from 2008 to 2017 reveals small-world characteristics. The Xi'an bus network's [9] degree distribution, average path length, aggregation coefficient, and betweenness centrality are also analyzed using complex network theory. The Pakistan National Highway Network (PNHN) [10] is analyzed to improve road infrastructure in major cities with traffic congestion. The United States Air Transportation system [11] and liner shipping networks [12] are also analyzed using complex network analysis to identify relationships between port network characteristics and cargo throughput.

Numerous studies have utilized complex network analysis methods to analyze maritime transport and cruise networks. Indonesia's non-directed graph [13], with 191 nodes and 400 links, does not fit the small-world structure hypothesis. The Caribbean port network [14] has been analyzed to understand its structure and influence on passenger flow. Centrality measures have been used to identify top ports and the shortest trajectory between distant nodes. The Caribbean region's [15] 902 ports were identified using five centrality measures The study analyzed international port competition trends [16] using the Social Network Analysis method, revealing changes in concentration due to globalization. The COVID-19 pandemic's impact on the Asian-Australasian Cruise Shipping Network [17] revealed increased network density, links, and flow efficiency. Using a data set of 452 links between 122 cruise ports, another study on the Asian-Australasian region [18] investigates how the characteristics of ports affect the connectivity and structure of the cruise shipping network In the Southeast Asian river cruise network study [19], authors discovered influential ports and small-world properties using complex network analysis on a network of 31 ports connected by 94 links. A study on 2016 Intra-Asia port positions [20] evaluates maritime container networks using centrality measures, revealing that traditional hub ports like Singapore, Hong Kong, Busan, and Shanghai maintain pivotal positions in the network.

Complex network models have also been applied in biological and healthcare systems. In Protein Networks Analysis [21], authors use betweenness centrality to identify protein bottlenecks as key connectors in both networks, observing proteins as nodes and links. Another study in Patient Care Team [22] explores the possibility of finding informal care teams using Social Network Analysis techniques in physician-physician networks with common patients.

The Bangladesh Inland Waterways Network (BIWN) has been the subject of limited research, with few studies focusing on its connectivity. A study using the Complex Network Analysis method analyzed the network's connectivity in 31 districts [23], considering each district having a single port. The network was found to be undirected, with dense connections among close neighbors and a few crucial connections among distant neighbors. Most ports are not neighbors but can be reached through intermediary ports. The network is particularly dependent on large hubs, creating a supply chain bottleneck. The network displayed small-world network characteristics.

To understand the inland waterway structure, complex network analysis has proven to be an important tool through which we can identify port connectivity, bottlenecks, significant ports, and clusters. Complex network analysis uses different categories of measures and network models to identify network characteristics. As we observe the BD inland waterways as Complex Networks, we have analyzed properties using different Complex Network measures.

Chapter 4

Analysis Approach

4.1 Complex Network Analysis

We have followed the Complex Network Analysis method to mitigate the scope of our study. Complex network analysis has proven to be an important tool. When a graph exhibits non-trivial topological characteristics, which are indicative of real-world networks, it is said to be a complex network [25]. Complex network analysis uses different categories of measures and network models to identify network characteristics. In this section, different complex network properties and models have been explained that are used to analyze our objectives.

4.2 Centrality Measures

4.2.1 Degree Centrality

The number of links each node in a network has with other nodes is shown by degree centrality [15]. The degree centrality for port i can be written as [17]:

$$C_d(i) = \sum_{j=1}^{n} a_{ij} \tag{4.1}$$

Where,
$a_{ij} = 1$; if ports i and j are connected by a link
$a_{ij} = 0$; if ports i and j have no connected link

4.2.2 Betweenness Centrality

Betweenness centrality indicates a node's frequency of appearance in pathways, with higher centrality indicating more frequent bridge selection [12]. Betweenness centrality is calculated as [15]:

$$C_b(i) = \sum_{j<k}^{n} \frac{g_{jk}(i)}{g_{jk}}. \tag{4.2}$$

Where,
$g_{jk}(i)$ = represents the number of shortest paths that are associated with node i and
g_{jk}= shortest distance between two nodes

4.2.3 Closeness Centrality

Closeness centrality measures the number of steps a node must take on average to reach other nodes over a network. Nodes with higher closeness centrality values can contact most efficiently with other nodes in the network. For n number of nodes, the closeness centrality of port i is defined as [17]:

$$C_c(i) = \frac{n-1}{\sum_{j=1} d(i,j)} \tag{4.3}$$

4.2.4 Eigenvector Centrality

Eigenvector centrality accounts for the importance of extra network ports. A port that has a higher eigenvector centrality shows that it has a greater influence because of its connections to other important ports. It's used to assess a port's growth potential. The formula for port I's eigenvector centrality is [17]:

$$C_e(i) = \frac{1}{a} \sum_j g_{ij} c_j \tag{4.4}$$

4.2.5 PageRank Centrality

Nodes with the same in-degree (degree) may not all have the same importance in the network, according to the fundamental tenet of the definition of PageRank centrality [31]. It gives a stronger weight to an incoming link originating from a node with many connections than it does to one with few.

$$PR(i) = (1-\lambda)\frac{1}{n} + \lambda \sum_{j:j\to i} \frac{PR(j)}{d_j}. \tag{4.5}$$

4.2.6 Hub & Authority Centrality (HAC)

Kleinberg's HAC, in addition to degree centrality, prioritizes association among nodes, promoting mutual strengthening when high-hub centrality nodes are linked to high-authority centrality nodes [15]. HAC is calculated as:

$$\sum_{i \epsilon s_\sigma} \left(x^{(i)}\right)^2 = 1 \quad \text{and} \quad \sum_{i \epsilon s_\sigma} \left(y^{(i)}\right)^2 = 1 \tag{4.6}$$

4.3 Network Level Measures

4.3.1 Clustering Coefficient

The clustering coefficient, a key metric for measuring local connections, indicates the strength of triangles surrounding a node, indicating that larger values increase the likelihood of quick node connections within its neighbors. The clustering coefficient of port i is calculated as [17]:

$$C_i = \frac{E_i}{k_i(k_i - 1)/2} \tag{4.7}$$

Where,
E_i = the number of neighboring pairs that are linked together
k_i = the number of links connected to port i
Hence, the average clustering coefficient for all ports of a network can be denoted as:

$$C = \frac{1}{n}\sum_{i=1}^{n} C_i \tag{4.8}$$

4.3.2 Average Path Length

The least amount of edges needed to travel between two nodes on a network is known as the average path length. Better node connectivity is shown by the shorter average path length [27]. The average path length for n number of nodes is [17]:

$$L = \frac{1}{n(n-1)}\sum_{i \neq j}^{n} d(i,j) \tag{4.9}$$

Where,
$d(i,j)$ = shortest path length between nodes i and j

4.4 Network Models

4.4.1 Random Network

In a Random network, nodes have an equal probability of being connected [28] and are connected to each other without any preference. A new link can appear between any pair of nodes randomly [13].

4.4.2 Small-world Network

Small-world networks are densely connected in local regions, generally exhibiting a small path length and high clustering coefficient value [29].

4.4.3 Scale-free Network

A Scale-free Network brings in the "Preferential attachment" concept [30] where high-degree nodes tend to connect to other high-degree nodes which creates a strong hierarchical structure. Scale Free Network follows a power law degree distribution [13].

Chapter 5

Data Collection & Network Construction

In this section, the research workflow has been described in this section detailing 4 steps: data collection, data digitization, data preparation, and network generation.

5.1 Data Collection

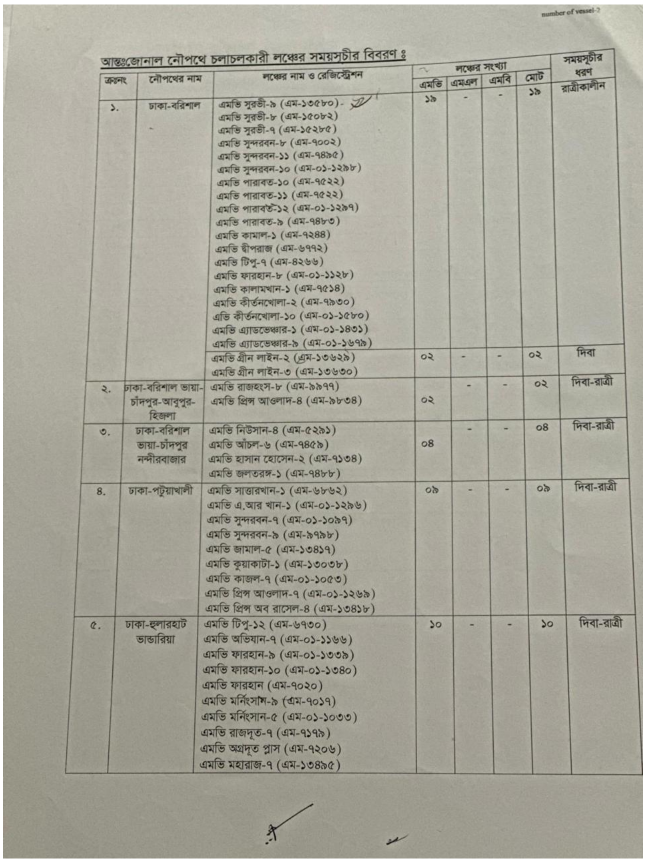
The topological data of river networks were collected from the Bangladesh Inland Waterways Transport Authority (BIWTA). River port locations were identified from the GIS map. We find there are a total of 10 major river ports and many small ports from 31 districts in the dataset. There are 55 river routes in total. The size of the vessels was also classified into 2 Groups, Motor vessels or Motor Boat (MV and MB) for carrying passengers and ML vessels for carrying goods. We have calculated our data based on passenger-carrying vessels. The frequency of vessels varies across different river routes. The average frequency of vessels in each route is two. The data provides detailed descriptions of river routes, vessel frequency, and time schedules. The data was gathered in 2018 and updated in 2022.

5.2 Data Digitization

Data were collected in manuscripts which were converted to digital format. Most of the data were written in Bengali which were then converted and gathered. Some of the data were written in English so it was difficult to extract data from the documents. There was no document centrally available, we had to collect, digitize, and then convert it to a usable format.

5.2.1 Different Zonal Areas of Inland Waterways Port

Fig. 5.1 and Fig. 5.2 show the different zonal areas of Inland waterways port. The first column refers the serial number, travel route, vessel name, number of vessels, time-table. This snapshot shows only description of one route similarly there are many different routes in 8 different zones present in the division. It shows the types of vessels traveling from one district to another, for instance, from Dhaka to Barisal, 19 vessels travel during night-time.



number of vessel-2

আন্তঃজোনাল নৌপথে চলাচলকারী লঞ্চের সময়সূচীর বিবরণ ঃ

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		এমভি গ্রীন লাইন-২ (এম-১৩৬২৯) এমভি গ্রীন লাইন-৩ (এম-১৩৬৩০)	০২	-	-	০২	দিবা
২.	ঢাকা-বরিশাল ভায়া-চাঁদপুর-আবুপুর-হিজলা	এমভি রাজহংস-৮ (এম-৯৯৭৭) এমভি প্রিন্স আওলাদ-৪ (এম-৯৮৩৪)	০২	-	-	০২	দিবা-রাত্রী
৩.	ঢাকা-বরিশাল ভায়া-চাঁদপুর নন্দীরবাজার	এমভি নিউসান-৪ (এম-৫২৯১) এমভি আঁচল-৬ (এম-৭৪৫৯) এমভি হাসান হোসেন-২ (এম-৭১৩৪) এমভি জলতরঙ্গ-১ (এম-৭৪৮৮)	০৪	-	-	০৪	দিবা-রাত্রী
৪.	ঢাকা-পটুয়াখালী	এমভি সাত্তারখান-১ (এম-৬৮৬২) এমভি এ.আর খান-১ (এম-০১-১২৯৬) এমভি সুন্দরবন-৭ (এম-০১-১০৯৭) এমভি সুন্দরবন-৯ (এম-৯৭৯৮) এমভি জামাল-৫ (এম-১৩৪১৭) এমভি কুয়াকাটা-১ (এম-১৩০৩৮) এমভি কাজল-৭ (এম-০১-১০৫৩) এমভি প্রিন্স আওলাদ-৭ (এম-০১-১২৬৯) এমভি প্রিন্স অব রাসেল-৪ (এম-১৩৪১৮)	০৯	-	-	০৯	দিবা-রাত্রী
৫.	ঢাকা-হুলারহাট ভান্ডারিয়া	এমভি টিপু-১২ (এম-৬৭৩০) এমভি অভিযান-৭ (এম-০১-১১৬৬) এমভি ফারহান-৯ (এম-০১-১৩৩৯) এমভি ফারহান-১০ (এম-০১-১৩৪০) এমভি ফারহান (এম-৭০২০) এমভি মর্নিংসান-৯ (এম-৭০১৭) এমভি মর্নিংসান-৫ (এম-০১-১০৩৩) এমভি রাজদূত-৭ (এম-৭১৭৯) এমভি অগ্রদূত প্লাস (এম-৭২০৬) এমভি মহারাজ-৭ (এম-১৩৪৯৫)	১০	-	-	১০	দিবা-রাত্রী

Figure 5.1: Manuscripts Collected from BIWTA

আন্তঃজোনাল নৌপথে চলাচলকারী লঞ্চের সময়সূচীর বিবরণ ঃ

ক্রঃনং	নৌপথের নাম	লঞ্চের নাম ও রেজিস্ট্রেশন	লঞ্চের সংখ্যা				সময়সূচীর ধরণ
			এমভি	এমএল	এমবি	মোট	
১.	ঢাকা-বরিশাল	এমভি সুরভী-৯ (এম-১৩৫৮০) এমভি সুরভী-৮ (এম-১৫০৮২) এমভি সুরভী-৭ (এম-১৫২৮৫) এমভি সুন্দরবন-৮ (এম-৭০০২) এমভি সুন্দরবন-১১ (এম-৭৪৯৫) এমভি সুন্দরবন-১০ (এম-০১-১২৯৮) এমভি পারাবত-১০ (এম-৭৫২২) এমভি পারাবত-১১ (এম-৭৫২২) এমভি পারাবত-১২ (এম-০১-১২৯৭) এমভি পারাবত-৯ (এম-৭৪৮৩) এমভি কামাল-১ (এম-৭২৪৪) এমভি দ্বীপরাজ (এম-৬৭৭২) এমভি টিপু-৭ (এম-৪২৬৬) এমভি ফারহান-৮ (এম-০১-১১২৮) এমভি কালামখান-১ (এম-৭৫১৪) এমভি কীর্তনখোলা-২ (এম-৭৯৩০) এভি কীর্তনখোলা-১০ (এম-০১-১৫৮০) এমভি এ্যাডভেঞ্চার-১ (এম-০১-১৪৩১) এমভি এ্যাডভেঞ্চার-৯ (এম-০১-১৬৭৯)	১৯	-	-	১৯	রাত্রীকালীন
		এমভি গ্রীন লাইন-২ (এম-১৩৬২৯) এমভি গ্রীন লাইন-৩ (এম-১৩৬৩০)	০২	-	-	০২	দিবা

Figure 5.2: Converted to Digitized Format (.docx)

5.2.2 Detailed Description of Water Route

Fig. 5.3 and Fig. 5.4 show detailed route from Dhaka to Monpura port, including the stoppage and the time period. The columns refer the time table, time of departure, port name, time of arrival, duration stayed in each port.

5.2.3 Detailed Description List of the Port Location in Different Districts and Sub-districts

Fig. 5.5 and Fig. 5.6 show the manuscript which describes detailed description list of the port location in different districts and sub-districts. The columns refer the port name, detailed description, sub-district and district.

5.3 Data Preparation

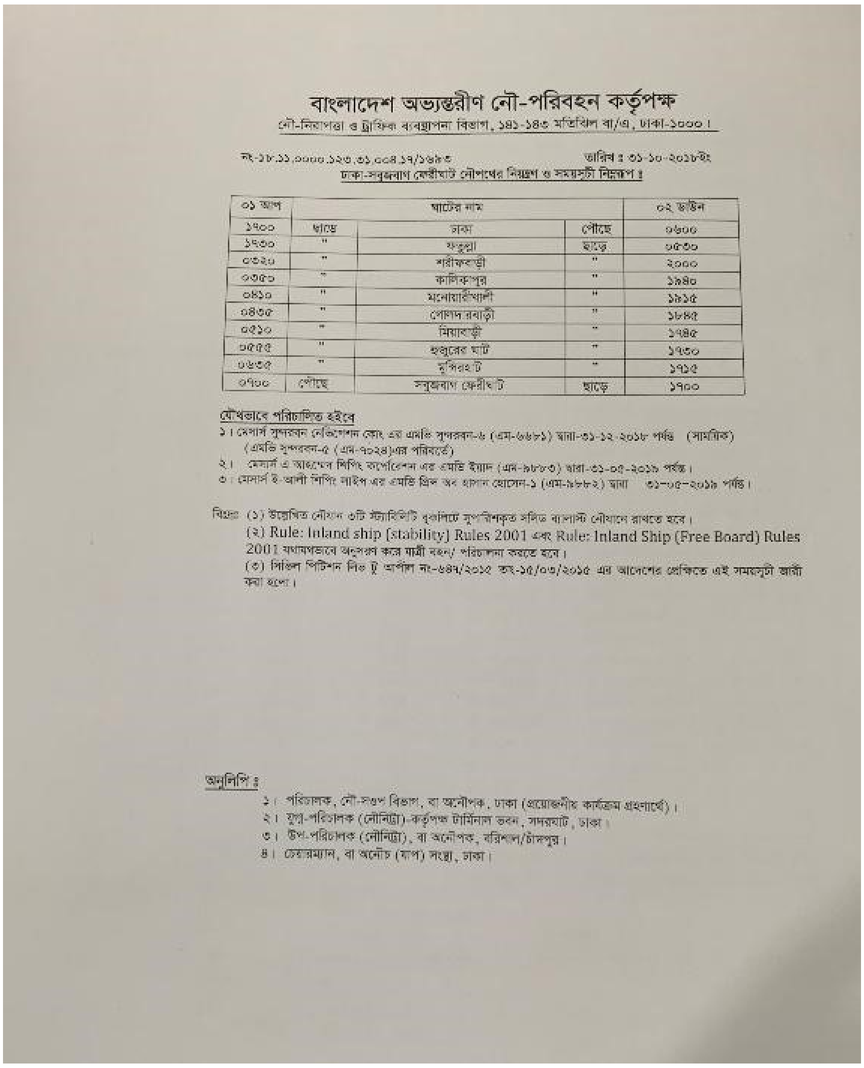
From collected and digitized data, the network matrix is developed as an n x n matrix M, representing n as the number of nodes. The connection Mij is the strength between the nodes i and j. In BIWN, the ports and the river routes between them are considered as nodes and edges respectively. In this network, the origin and destination of the route are similar, thus, M is assumed to be symmetrical (M_{ij}= M_{ji}). In the Connectivity network matrix, for Dhaka to Gazipur, 1 represents the connection between the ports and 0 represents no connectivity. Based on the data collected from BIWTA, another data matrix is prepared where vessel frequency has been calculated based on port connectivity. For example, from Dhaka to Fotulla, 38 incoming vessels travel daily, similarly from Fotulla to Dhaka travel 38 outgoing vessels. There are 241 ports in total and 5636 edges in BIWN. Fig. 5.7 and Fig. 5.8 represents the sample matrix prepared for Connectivity and Vessel Augmented networks, respectively.

5.4 Network Generation

From network data matrix, two networks have been generated: Connectivity and Vessel Augmented. In the connectivity network, we have considered only the districts that have ports, whereas, in the vessel augmented network we have considered all the ports present in each district. To generate networks, a network analysis tool - ORA[1]has been used.

The connectivity network was generated in 31 districts with available ports, displaying only district connectivity. Districts are nodes, and links are connectivity, as shown in Fig. 5.9. The number of passenger-carrying vessels that travel to and from the ports following a river route is augmented in the vessel augmented network. Ships, boats, and other waterborne vehicles are classified as water vessels. Fig. 5.10 illustrates a network with 241 ports in 31 districts, 49 river routes in 241 ports, and millions of people traveling through rivers. The links represent vessel frequency between ports.

[1]ORA is a tool for network analysis which is jointly created by CASOS center at Carnegie Mellon University and Netanomics



বাংলাদেশ অভ্যন্তরীণ নৌ-পরিবহন কর্তৃপক্ষ

নৌ-নিরাপত্তা ও ট্রাফিক ব্যবস্থাপনা বিভাগ, ১৪১-১৪৩ মতিঝিল বা/এ, ঢাকা-১০০০।

নং-১৮.১১.০০০০.১২৩.৩১.০০৪.১৭/১৬৯৩ তারিখ ঃ ৩১-১০-২০১৮ইং

ঢাকা-সুবর্ণবাগ ফেরীঘাট নৌপথের নিয়ন্ত্রণ ও সময়সূচী নিম্নরূপ ঃ

০১ আপ	ঘাটের নাম			০২ ডাউন
১৭০০	ছাড়ে	ঢাকা	পৌঁছে	০৬০০
১৭৩০	"	ফতুল্লা	ছাড়ে	০৫৩০
০৩২০	"	শরীফবাড়ী	"	২০০০
০৩৫০	"	কালিকাপুর	"	১৯৪০
০৪১০	"	মনোয়ারখালী	"	১৯১৫
০৪৩৫	"	গোলদারবাড়ী	"	১৮৪৫
০৫১০	"	মিয়াবাড়ী	"	১৭৪৫
০৫৫৫	"	হুজুরের ঘাট	"	১৭৩০
০৬৩৫	"	মুন্সিরহাট	"	১৭১৫
০৭০০	পৌঁছে	সুবর্ণবাগ ফেরীঘাট	ছাড়ে	১৭০০

যৌথভাবে পরিচালিত হইবে

১। মেসার্স সুন্দরবন নেভিগেশন কোং এর এমভি সুন্দরবন-৬ (এম-৬৬৮১) দ্বারা-৩১-১২-২০১৮ পর্যন্ত (সাময়িক) (এমভি সুন্দরবন-৫ (এম-৭০২৪)এর পরিবর্তে)

২। মেসার্স এ আহমেদ শিপিং কর্পোরেশন এর এমভি ইয়াদ (এম-৯৮৮৩) দ্বারা-৩১-০৫-২০১৯ পর্যন্ত।

৩। মেসার্স ই-আলী শিপিং লাইন এর এমভি প্রিন্স অব হাসান হোসেন-১ (এম-৯৮৮২) দ্বারা ৩১-০৫-২০১৯ পর্যন্ত।

বিঃদ্রঃ (১) উল্লেখিত নৌযানে ৩টি স্ট্যাবিলিটি বুকলিটে সুপারিশকৃত সলিড ব্যালাস্ট নৌযানে রাখতে হবে।

(২) Rule: Inland ship [stability] Rules 2001 এবং Rule: Inland Ship (Free Board) Rules 2001 যথাযথভাবে অনুসরণ করে যাত্রী বহন/ পরিচালনা করতে হবে।

(৩) সিভিল পিটিশন লিভ টু আপীল নং-৬৪৭/২০১২ তাং-১৫/০৩/২০১৫ এর আদেশের প্রেক্ষিতে এই সময়সূচী জারী করা হলো।

অনুলিপি ঃ

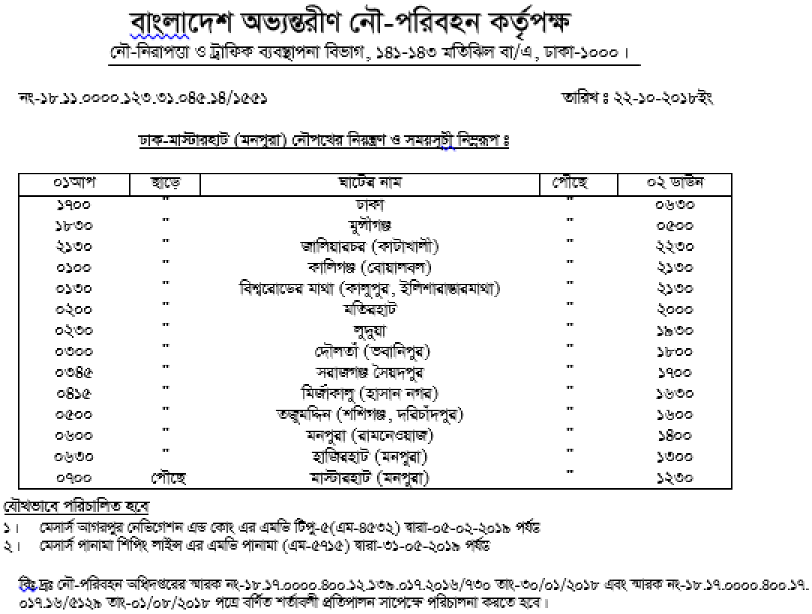
১। পরিচালক, নৌ-সংরক্ষণ বিভাগ, বা অনৌপক, ঢাকা (প্রয়োজনীয় কার্যক্রম গ্রহণার্থে)।

২। যুগ্ম-পরিচালক (নৌনিট্রা)-কর্তৃপক্ষ টার্মিনাল ভবন, সদরঘাট, ঢাকা।

৩। উপ-পরিচালক (নৌনিট্রা), বা অনৌপক, বরিশাল/চাঁদপুর।

৪। চেয়ারম্যান, বা অনৌচ (যাপ) সংস্থা, ঢাকা।

Figure 5.3: Manuscripts Collected from BIWTA



বাংলাদেশ অভ্যন্তরীণ নৌ-পরিবহন কর্তৃপক্ষ

নৌ-নিরাপত্তা ও ট্রাফিক ব্যবস্থাপনা বিভাগ, ১৪১-১৪৩ মতিঝিল বা/এ, ঢাকা-১০০০।

নং-১৮.১১.০০০০.১২৩.৩১.০৪৫.১৪/১৫৫১ তারিখ ঃ ২২-১০-২০১৮ইং

ঢাক-মাস্টারহাট (মনপুরা) নৌপথের নিয়ন্ত্রণ ও সময়সূচী নিম্নরূপ ঃ

০১আপ	ছাড়ে	ঘাটের নাম	পৌঁছে	০২ ডাউন
১৭০০	"	ঢাকা	"	০৬৩০
১৮৩০	"	মুন্সীগঞ্জ	"	০৫০০
২১৩০	"	জালিয়ারচর (কাটাখালী)	"	২২৩০
০১০০	"	কালিগঞ্জ (বোয়ালকল)	"	২১৩০
০১৩০	"	বিশ্বরোডের মাথা (কালুপুর, ইলিশারাস্তারমাথা)	"	২১৩০
০২০০	"	মতিরহাট	"	২০০০
০২৩০	"	সুদুয়া	"	১৯৩০
০৩০০	"	দৌলতা (ভবানিপুর)	"	১৮০০
০৩৪৫	"	সরাজগঞ্জ সৈয়দপুর	"	১৭০০
০৪১৫	"	মির্জাকালু (হাসান নগর)	"	১৬৩০
০৫০০	"	তজুমদ্দিন (শশিগঞ্জ, দরিচাঁদপুর)	"	১৬০০
০৬০০	"	মনপুরা (রামনেওয়াজ)	"	১৪০০
০৬৩০	"	হাজিরহাট (মনপুরা)	"	১৩০০
০৭০০	পৌঁছে	মাস্টারহাট (মনপুরা)	"	১২৩০

যৌথভাবে পরিচালিত হবে

১। মেসার্স আগরপুর নেভিগেশন এন্ড কোং এর এমভি টিপু-৫(এম-৪৫৩২) দ্বারা-০৫-০২-২০১৯ পর্যন্ত

২। মেসার্স পানামা শিপিং লাইন এর এমভি পানামা (এম-৫৭১৫) দ্বারা-৩১-০৫-২০১৯ পর্যন্ত

বিঃদ্রঃ নৌ-পরিবহন অধিদপ্তরের স্মারক নং-১৮.১৭.০০০০.৪০০.১২.১৩৯.০১৭.২০১৬/৭৩০ তাং-৩০/০১/২০১৮ এবং স্মারক নং-১৮.১৭.০০০০.৪০০.১৭.০১৭.১৬/৫১২৯ তাং-০১/০৮/২০১৮ পত্রে বর্ণিত শর্তাবলী প্রতিপালন সাপেক্ষে পরিচালনা করতে হবে।

Figure 5.4: Converted to Digitized Format (.docx)

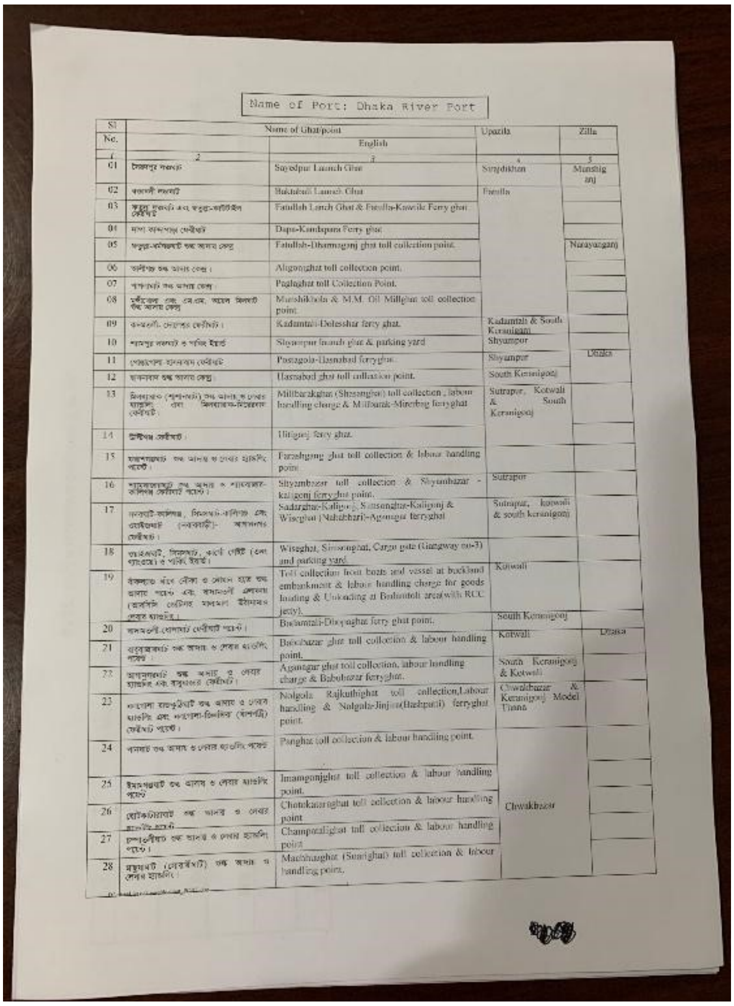


Figure 5.5: Manuscripts Collected from BIWTA

Name of Port: Dhaka River Port

SL	Name of Ghat/point		Upazila	Zilla
No.	বাংলা	English		
1	2	3	4	5
01	সৈয়দপুর লঞ্চঘাট	Sayedpur Launch Ghat	Sirajdikhan	Munshiganj
02	বক্তাবলী লঞ্চঘাট	Baktabali Launch Ghat		
03	ফতুল্লা লঞ্চঘাট এবং ফতুল্লা-কাউটাইল ফেরীঘাট	Fatullah Lanch Ghat & Fatulla-Kawtile Ferry ghat		
04	দাপা-কান্দাপাড়া ফেরীঘাট	Dapa-Kandapara Ferry ghat		
05	ফতুল্লা-ধর্মগঞ্জঘাট শুল্ক আদায় কেন্দ্র	Fatullah-Dharmaganj ghat toll collection point.	**Fatulla**	Narayanganj
06	আলীগঞ্জ শুল্ক আদায় কেন্দ্র।	Aligonjghat toll collection point.		
07	পাগলাঘাট শুল্ক আদায় কেন্দ্র।	Paglaghat toll Collection Point.		
08	মুন্সীখোলা এবং এম.এম. অয়েল মিলঘাট শুল্ক আদায় কেন্দ্র	Munshikhola & M.M. Oil Millghat toll collection point.		
09	কদমতলী- দোলেশ্বর ফেরীঘাট।	Kadamtali-Dolesshar ferry ghat.	Kadamtali & South Keraniganj	
10	শ্যামপুর লঞ্চঘাট ও পার্কিং ইয়ার্ড	Shyampur launch ghat & parking yard	Shyampur	
11	পোস্তাগোলা-হাসনাবাদ ফেরীঘাট	Postagola-Hasnabad ferryghat.	Shyampur	
12	হাসনাবাদ শুল্ক আদায় কেন্দ্র।	Hasnabad ghat toll collection point.	South Keranigonj	Dhaka
13	মিলব্যারাক (শ্মশানঘাট) শুল্ক আদায় ও লেবার হ্যান্ডলিং এবং মিলব্যারাক-মিরেরবাগ ফেরীঘাট।	Millbarakghat (Shasanghat) toll collection , labour handling charge & Millbarak-Mirerbag ferryghat	**Sutrapur, Kotwali & South Keranigonj**	
14	উত্তিগঞ্জ ফেরীঘাট।	Uitiganj ferry ghat.		

Figure 5.6: Converted to Digitized Format (.docx)

	Dhaka	Gazipur	Kishorganj	Manikganj	Munshiganj	Narayanganj	Narsingdi	Jhalokathi	Tangail	Faridpur	Rajbari	Shariatpur	Chittagong	Comilla	Chandpur	Noakhali
Dhaka	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	0
Gazipur	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Kishorganj	1	0	0	1	0	1	1	0	0	0	0	0	0	1	1	0
Manikganj	1	0	1	0	1	1	0	0	1	1	1	1	1	0	0	0
Munshiganj	1	0	1	1	0	1	1	0	1	0	0	1	0	1	1	0
Narayanganj	1	0	1	1	1	0	1	0	0	0	0	1	1	1	1	1
Narsingdi	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	1
Jhalokathi	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tangail	1	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0
Faridpur	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
Rajbari	1	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
Shariatpur	1	0	0	1	1	1	1	0	0	1	1	0	0	1	1	1
Chittagong	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Comilla	1	0	1	0	1	1	1	0	0	0	0	1	1	0	1	1
Chandpur	1	0	1	0	1	1	1	0	0	0	0	1	1	1	0	1
Noakhali	0	0	0	0	0	1	1	0	0	0	0	1	0	1	1	0
Barisal	1	0	0	0	0	1	1	1	0	0	0	1	0	1	1	1
Barguna	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1
Bhola	1	0	0	0	0	1	1	1	0	0	0	1	1	1	1	1
Patuakhali	1	0	0	0	0	0	0	1	0	1	1	1	0	1	1	1
Khulna	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0
Madaripur	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Lakhshmipur	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Bagerhat	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Pirojpur	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Kurigram	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
MoulviBazar	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Sunamgonj	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Netrokona	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Shatkhira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pabna	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5.7: Sample Connectivity Network Data Matrix

	Dhaka(Sadarghat Dhaka)	Fotulla	Shorifbari	Kalikapur	Monoyarikhali	Goldarbari	Miyabari	Hujurer Ghat	Munshirhat	Shobujbag Ferryghat	Mirkadim	Chandpur	Mridharhat	Chormalia	Chobipur
Dhaka(Sadarghat Dhaka)	0	38	3	3	3	3	3	3	3	3	48	71	13	9	5
Fotulla	38	0	3	3	3	3	3	3	3	3	14	27	4	2	0
Shorifbari	3	3	0	3	3	3	3	3	3	3	0	0	0	0	0
Kalikapur	3	3	3	0	3	3	3	3	3	3	0	0	0	0	0
Monoyarikhali	3	3	3	3	0	3	3	3	3	3	0	0	0	0	0
Goldarbari	3	3	3	3	3	0	3	3	3	3	0	0	0	0	0
Miyabari	3	3	3	3	3	3	0	3	3	3	0	0	0	0	0
Hujurer Ghat	3	3	3	3	3	3	3	0	3	3	0	0	0	0	0
Munshirhat	3	3	3	3	3	3	3	3	0	3	0	0	0	0	0
Shobujbag Ferryghat	3	3	3	3	3	3	3	3	3	0	0	0	0	0	0
Mirkadim	48	14	0	0	0	0	0	0	0	0	0	45	13	9	5
Chandpur	71	27	0	0	0	0	0	0	0	0	45	0	13	9	5
Mridharhat	13	4	0	0	0	0	0	0	0	0	13	13	0	9	5
Chormalia	9	2	0	0	0	0	0	0	0	0	9	9	9	0	5
Chobipur	5	0	0	0	0	0	0	0	0	0	5	5	5	5	0
Batamara(Walighat)	4	0	0	0	0	0	0	0	0	0	4	4	4	4	2
Ramchor	7	4	0	0	0	0	0	0	0	0	9	9	9	7	5
Ramarpul	7	4	0	0	0	0	0	0	0	0	9	9	9	7	5
Shahebrampur	5	0	0	0	0	0	0	0	0	0	5	5	5	5	5
Anderchor	5	0	0	0	0	0	0	0	0	0	5	5	5	5	5
Miyarhat	5	0	0	0	0	0	0	0	0	0	5	5	5	5	5
Shomitirhat	5	0	0	0	0	0	0	0	0	0	5	5	5	5	5
Khasherhat	7	0	0	0	0	0	0	0	0	0	7	7	5	5	5
Urarchor	3	0	0	0	0	0	0	0	0	0	3	3	3	3	3
Kachikata	5	1	0	0	0	0	0	0	0	0	4	2	2	2	2

Figure 5.8: Sample Vessel Augmented Network Data Matrix

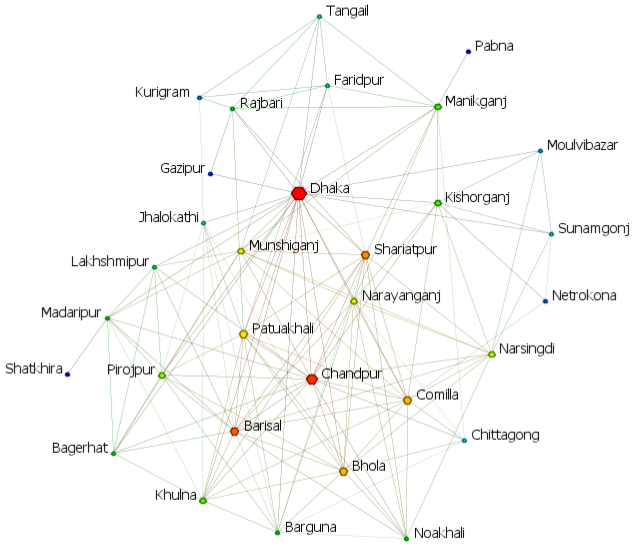


Figure 5.9: Connectivity Network of BIWN

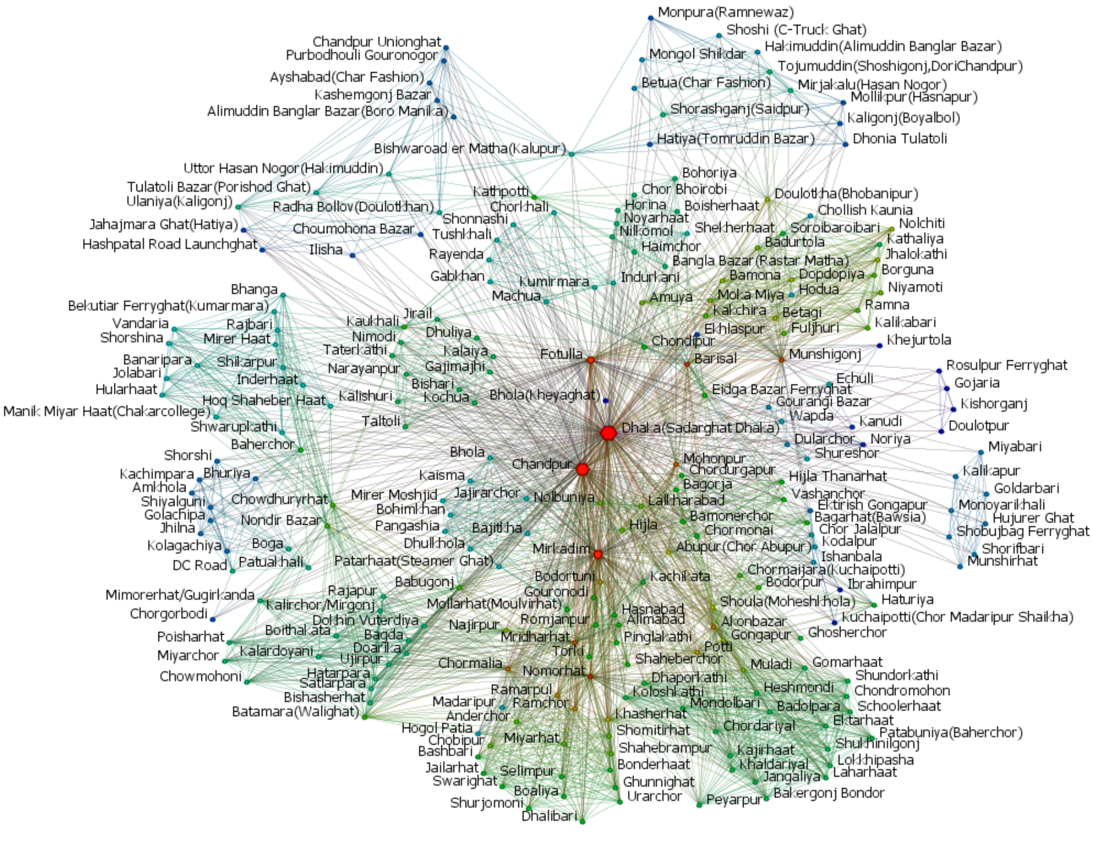


Figure 5.10: Vessel Augmented Network of BIWN

Chapter 6

Research Findings

An overview of topological properties calculation of Bangladesh Waterway Network has been shown in Table 6.1.

SL	Complex Network Properties	Connectivity Network	Vessel Augmented Network
1	Nodes	31	241
2	Edges	274	5636
3	Average Degree	0.497	0.062
4	Average Clustering Coefficient	0.502	0.899
5	Average Path Length	1.89	5.216

Table 6.1: Network Properties of BIWN

This section provides insights on our conducted analysis on BIWN using complex network properties.

6.1 Network Model Understanding

To identify the first scope of network structure of Connectivity and Vessel Augmented networks, we have evaluated two network-level measures mentioned in section 4.3 which are the 'Clustering coefficient' and 'Average path length'. Our identification scope includes three complex network model theories described in section 4.4 – Random, Small-World, and Scale-free. Authors in a previous study analyzed the network model with connectivity network data [23] by evaluating the clustering coefficient and average path length measures. The authors concluded the model as a small-world for Bangladesh Inland Waterway Network. In this analysis, we recalculated the network-level properties by extending the analysis approach for both connectivity and vessel augmented networks. In this paper, for the same number of ports, we have generated these 3 networks and compared the network-level properties to identify which model shows the most accurate values as BIWN [13]. In Tables 6.2 & 6.3, different network-level properties for Connectivity & Vessel Augmented networks have been shown, respectively.

As found in Table 6.2, in a connectivity network for 31 ports, the average path length is 1.890 or nearly 2. This number describes the travel of container cargo within a given network by 2-4 steps, which is below the largest small-world 'six

SL	Properties	Connectivity	Random	Small-world	Scale-free
1	Nodes	31	31	31	31
2	Edges	274	46	289	61
3	Clustering Coefficient	0.502	0	0.618	0.150
4	Average Path Length	1.890	3.235	2.041	2.252

Table 6.2: Complex Network Model Calculation for Connectivity Network

SL	Properties	Vessel Augmented	Random	Small-world	Scale-free
1	Nodes	241	241	241	241
2	Edges	5636	2892	2323	2870
3	Clustering Coefficient	0.899	0.05	0.605	0.095
4	Average Path Length	5.216	2.479	5.523	2.385

Table 6.3: Complex Network Model Calculation for Vessel Augmented Network

degrees of separation'. We generated a random, small world, and scale-free network with the same size and found the average shortest path of our network is smaller than a random network (3.235) or a scale-free network (2.252). The average path length is closest to the value of a small-world network (2.041). The small average path length indicates that there is close connectivity among the adjacent ports. The average clustering coefficient of the connectivity network is 0.502. This implies that the neighboring ports are well connected [11]. Also, the measured value of the clustering coefficient (0.502) is larger than the clustering coefficient value of the random network (0) [10] or of scale-free networks (0.150) of similar size but closest to the small-world network value (0.618). The small average shortest path and the large clustering value indicate the connectivity network is a small world network [10].

By following the same analysis, we found that in the vessel augmented network for 241 ports, the average path length is 5.216 which exhibits the 'six degrees of separation' rule of a small-world network and also shows the closest value to small world network (5.523) among 3 complex network models as found in Table 6.3. Also, a high clustering coefficient (0.89) is found similar to small-world networks (0.605) of the same size compared to random and scale-free networks. Hence, we can conclude that both connectivity and vessel augmented networks show exhibits of small-world networks.

6.2 Identifying Major & Hub Ports

Our next scope is to identify major network ports of BIWN. This paper focuses on centrality index to identify major network ports. Centrality measures are used to identify relative importance of a node within a network [21]. Based on the five centrality measures calculation, overall top ranked ports has been listed in Table 6.4 for Connectivity and Vessel Augmented Networks.

As shown in Table 6.4, the topmost ranked port for both connectivity and vessel augmented network is Dhaka or Sadarghat Dhaka port. This port contains the highest centrality value in all our calculated centrality measures. Also, Dhaka acts as

SL	Connectivity Network	Vessel Augmented Network
1	Dhaka (1)	Dhaka (Sadarghat Dhaka) (1)
2	Chandpur (0.69)	Chandpur (0.79)
3	Barisal (0.61)	Mirkadim (0.55)
4	Shariatpur (0.58)	Fotulla (0.47)
5	Comilla (0.55)	Munshiganj (0.29)
6	Bhola (0.55)	Barisal (0.24)
7	Patuakhali (0.52)	Nomorhat (0.23)
8	Narayanganj (0.51)	Mohonpur (0.2)
9	Munshiganj (0.51)	Mridharhat (0.2)
10	Narsingdi (0.42)	Potti (0.17)

Table 6.4: Top Ranked Ports Based on Centrality Index

a bridging port for most of the other ports in different geographic distances and is closest to most ports over the network. The next important port after Dhaka is Chandpur as shown in Table 6.4. Following Dhaka and Chandpur, there are some differences in the major port rankings between Connectivity and Vessel Augmented networks. Other important ports noticed to be found in both networks top 10 lists are Barisal and Munshiganj. Barisal port neither acts as a bridging port like most of the other ports due to its geographical position nor does it have high connectivity with many ports across the network. Still, this port is ranked as an important port as it is surrounded by numerous river routes. So, the most influential ports within the networks are Dhaka, Chandpur, Barisal, and Munshiganj.

Traffic congestion can be measured by port connectivity and bridging conditions. To identify traffic congestion over Connectivity and Vessel Augmented networks, we have considered 'Betweenness Centrality' [21]. As per the conducted analysis, Dhaka port is considered as the most crucial node as all the waterway transportation routes are dependent primarily to this port. Dhaka has the highest betweenness centrality in both connectivity (0.296) and vessel augmented (0.366) networks. Dhaka port boasts the highest connectivity across the network, with the highest degree value indicating the highest outward and inward links. Among 241 ports in the vessel augmented network, 240 of the ports are connected to Dhaka, that is, 99% of the ports are connected to Dhaka. If any removal or damage is caused in this port, the whole waterway communication is supposed to be interrupted. Thus, Dhaka port creates a bottleneck in our analyzed networks. We suggest preventive measures to minimize load on Dhaka port and an improvement on other important ports i.e. Chandpur, Barisal, or Munshiganj.

6.3 Port Structure & Interconnections

In this section, we have analyzed the internal port structure and their connectivity for both connectivity and vessel augmented networks.

6.3.1 Overall Port Structure

In the connectivity network, 31 districts have ports with connectivity among them. Around 32% of the ports are hub ports. Most hub ports are clustered around the central part of Bangladesh. Their geographical location is surrounded by the main hub port Dhaka. 68% have non-hub ports. All the hub ports have 100% connectivity amongst each other. Among 31 ports, 23 of the ports are connected to the port of Dhaka directly, that is, 74% of the ports are connected to Dhaka.

In the vessel augmented network, we have observed that major ports are clustered centrally around Dhaka. Only one port, Barisal is situated at the southern part of Bangladesh. In total, there are 241 ports and 2% of the ports are hub ports. The rest 97% are non-hub ports. Since the ports are centrally distributed they have a higher degree of distribution with a higher frequency of vessels to and from the ports to other regions. These ports also act as major hub ports with high betweenness and closeness centrality. The ports that act as a bridging port in the vessel augmented network are Dhaka, Chandpur, Mirkadim, Munshiganj, Fotulla, Barisal, Mohonpur, Potti, Nomorhat, and Mridharhat. All the hub ports are located in the central and southern regions of Bangladesh and have 100% connectivity amongst each other.

6.3.2 Interconnectivity Pattern

To visualize the connectivity and clusters created among BIWN ports, we have calculated node-level measures for Connectivity and Vessel Augmented networks. We have conducted correlation analysis in two phases:

1. Degree vs. Clustering Coefficient
2. Degree vs. Betweenness Centrality

In degree vs clustering coefficient analysis, a structure has been observed between degree and clustering coefficient. As degree increases clustering coefficient gradually drops. Thus ports with high degree have crucial connections among distant ports resulting lower clustering coefficient. Fig. 6.1 plots the average clustering coefficient of nodes having degree k as a function of k. In the scatter plot, the dots represent the nodes which are the districts of Bangladesh present in the district based connectivity network. Fig. 6.2 plots the average clustering coefficient of nodes having degree k as a function of k. Here the nodes dots represent the nodes which are the ports present in the vessel augmented network connectivity, the clustering coefficient remains at a constant value close to unity for small k and then shows an almost power-law decay at larger values of k. This can be explained as follows. All ports are linked to form a clique in the vessel augmented network. The smaller ports (having low degrees) in this network are served by very few routes for connectivity, hence they are linked only to other ports. On the other hand, major ports (having high degrees) are served by a large number of connectivity, hence these ports are linked with other geographically distant ports in diverse parts of the country, which themselves do not tend to be connected, thus lowering the average clustering coefficient for nodes with higher degree.

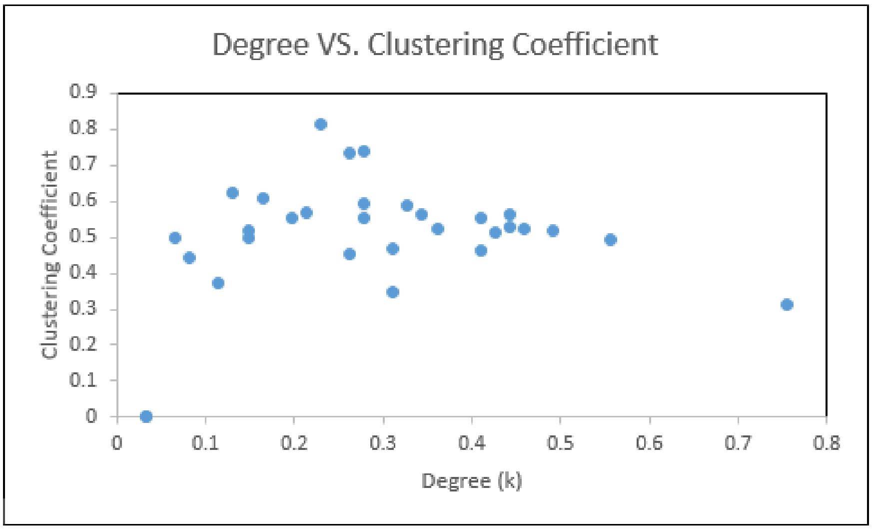


Figure 6.1: Degree vs. Clustering Coefficient of Connectivity Network

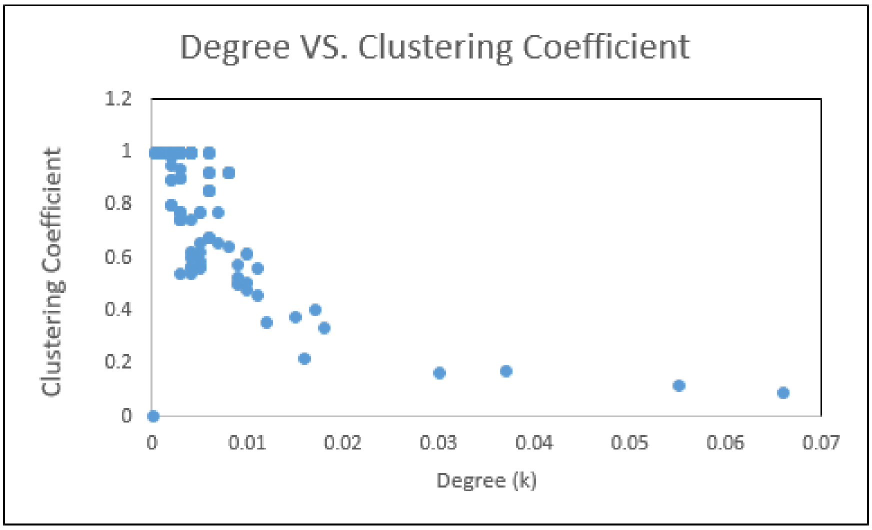


Figure 6.2: Degree vs. Clustering Coefficient of Vessel Augmented Network

Another correlation analysis that we have evaluated is degree vs. betweenness centrality. In both Fig. 6.3 and 6.4 of district-based connectivity and inland port connectivity, betweenness centrality increases along with degree. The betweenness centrality measure is used to identify the nodes with high congestion. Thus ports having higher degrees have more connectivity resulting in bottlenecks among major hub ports.

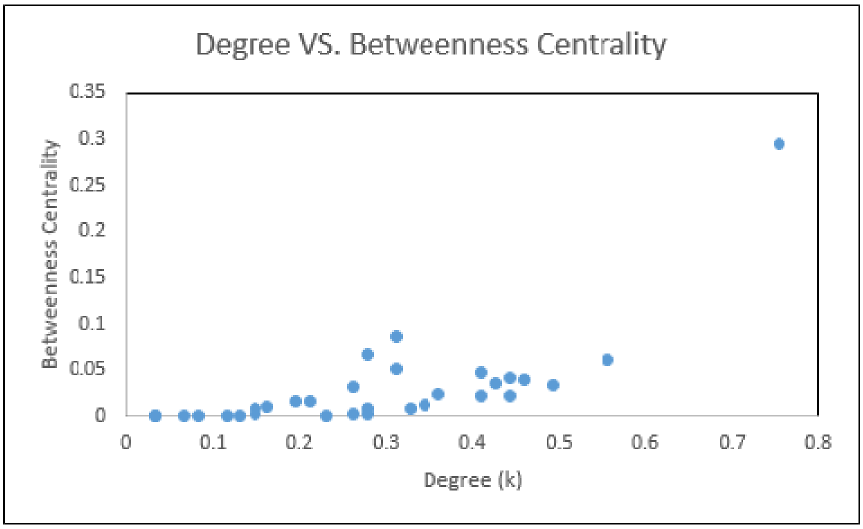


Figure 6.3: Degree vs. Betweenness Centrality of Connectivity Network

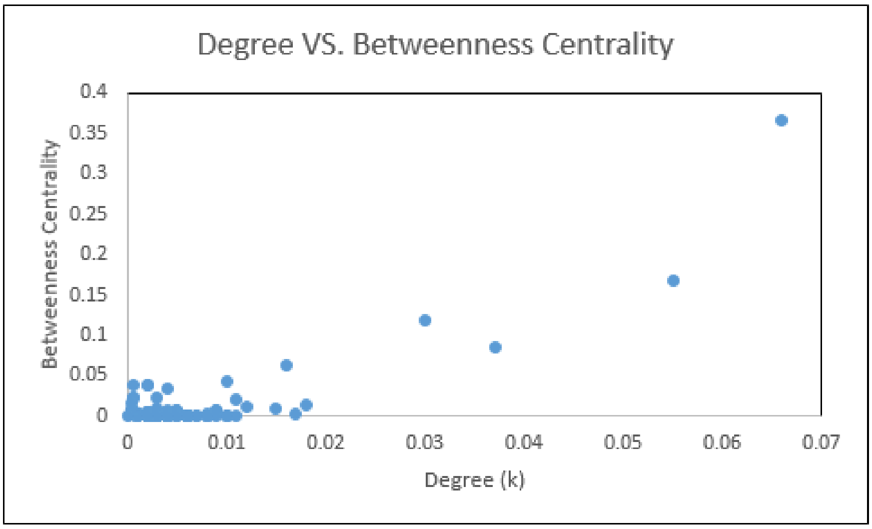


Figure 6.4: Degree vs. Betweenness Centrality of Vessel Augmented Network

6.4 Network Resilience & Next Important Ports

An important aspect of understanding network performance is to evaluate resilience and robustness [26]. A system's resilience is related to its capacity to withstand failures or disturbances while experiencing a tolerable drop in performance. A robustness analysis of the transportation network is predicated on the network's capacity, potential for failure, and the potential for user-provided path replacement.

Robustness is typically noticed following a failure, like the elimination of a node or edges. The study on major Asian airlines' network [24] robustness assesses the resilience of these carriers' networks and pinpoints the kinds of airports that affect it. In the robustness analysis, the criteria for node isolation are based on three measures of centrality: degree, betweenness, and closeness centrality. In order to evaluate network robustness of BIWN, we have followed the bottleneck port removal method.

In section 6.2, we have found Dhaka port creates heavy bottleneck. If we can visualize the clusters formed across this specific port, the dependencies can be understood better. For this analysis, we have considered Ego network. An ego-network is a subnetwork centered on a single ego node, with one-hop nodes called alters, and only directly connected nodes belong to this subnetwork [13]. So, the node dependencies can be better visualized in ego networks as shown in Figure 6.5 & 6.6 for connectivity and vessel augmented networks. It has been viewed in the generated ego-network that major clusters are formed across Dhaka and highest number of links (240) are connected with Dhaka among 5636 links in total. We calculated the properties by removing Dhaka from the network and generated ego network again to view whether the waterway network faces huge damage or not in Fig. 6.7 and 6.8 for connectivity and vessel augmented data, respectively. The result shows that most of the clusters are formed around Chandpur instead of Dhaka and highest number of links (196) are connected with Chandpur among 5156 links in total.

Figure 6.5: Ego Network generation of Connectivity Data Matrix by selecting 'Dhaka' port as sphere of influence

To observe the impact on port rankings, we have recalculated the centrality measures done in section 6.2 for connectivity and vessel augmented networks, but this time by removing Dhaka port. The top 10 ports based on overall centrality index has been shown in Table 6.5. As shown in Table 6.5, if 'Dhaka' port is removed from connectivity and vessel augmented networks, the next important port for both connectivity and vessel augmented networks is Chandpur. Other major hub ports are Chandpur, Barishal and Munshiganj. In comparison to our previous results

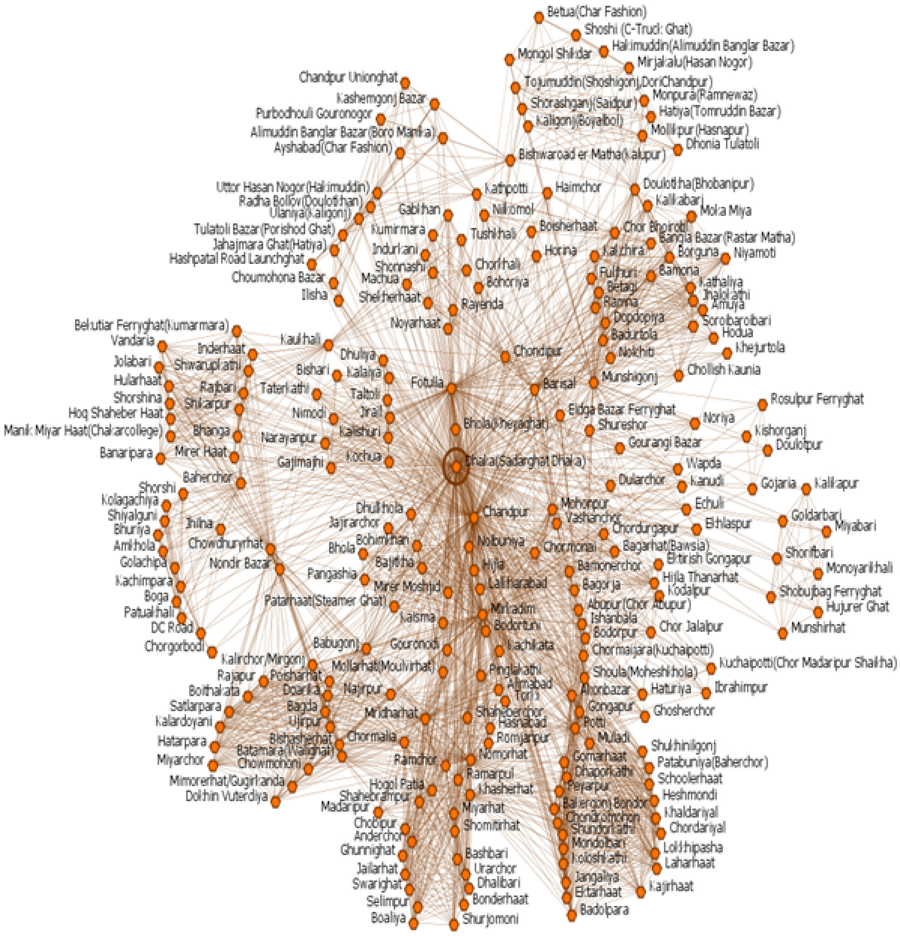


Figure 6.6: Ego Network generation of Vessel Augmented Data Matrix by selecting 'Dhaka' port as sphere of influence

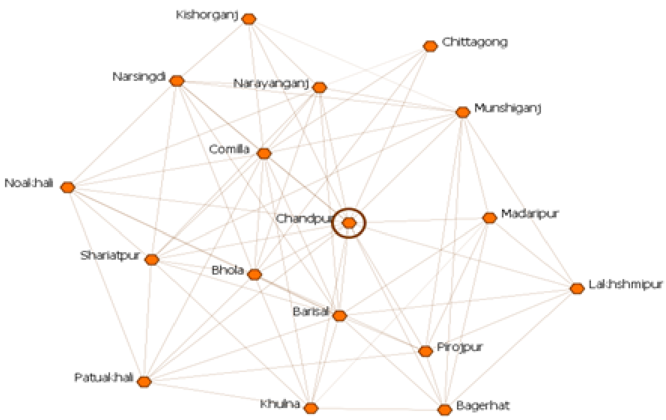


Figure 6.7: Ego Network generation of Connectivity Data Matrix by selecting 'Chandpur' port as sphere of influence

Figure 6.8: Ego Network generation of Connectivity Data Matrix by selecting 'Chandpur' port as sphere of influence

SL	Connectivity Network	Vessel Augmented Network
1	Chandpur (1)	Chandpur (1)
2	Shariatpur (0.86)	Mirkadim (0.75)
3	Barisal (0.86)	Fotulla (0.68)
4	Comilla (0.78)	Munshiganj (0.46)
5	Patuakhali (0.77)	Nomorhat (0.45)
6	Bhola (0.76)	Barisal (0.42)
7	Munshiganj (0.75)	Mridharhat (0.41)
8	Narayanganj (0.71)	Mohonpur (0.39)
9	Narsingdi (0.71)	Potti (0.37)
10	Pirojpur (0.55)	Chormalia (0.37)

Table 6.5: Top Ranked Ports Based on Centrality Index by Removing Highest Ranked Port

from Table 6.4, only 3% of the ports will be affected. The result shows, if we remove Dhaka port, both networks are still found to be robust as connectivity doesn't lose much across the whole network, rather port priorities are changed. But the port bottleneck is shifted from Dhaka to Chandpur for both networks. So, even if we optimize networks by removing one important port, instead of other ports from different regions having effective connectivity, the waterway communications are concentrated towards another major port

Chapter 7

Conclusion

Being a riverine country, it is important to study the structure of Bangladesh river way network so that maximum utilization is possible. Analyzing inland water port connectivity involves considering various aspects related to economic development, infrastructure development, environmental impact, risk mitigation, regional development, and trade competitiveness. To do so, we have followed Complex Network Analysis method in our study on Bangladesh Inland Waterway Network as well. We have collected data from Bangladesh Inland Waterways Transport Authority (BIWTA). From collected river data, we constructed two complex networks – Connectivity Vessel Augmented. Connectivity network represents port connectivity between districts. Vessel augmented network is constructed augmenting frequency of vessels traveling from one port to another. This network generation provides us clear visualization on BIWN port connectivity. We then applied Complex Network Analysis on connectivity and vessel augmented networks to identify our scopes. Our findings include identifying key nodes and hubs, quantifying connectivity and exploring network resilience and vulnerability of BIWN.

The study delved into identifying major network ports within the Bangladesh Inland Waterway Network (BIWN) through an analysis of centrality measures. Dhaka was identified as a crucial hub port, while Chandpur and Barisal were significant for connectivity and bridging capacity. Chandpur and Barisal also held considerable importance in both networks due to their strong connectivity and bridging capacities among distant ports. Geographical mapping revealed major ports were clustered around central regions, particularly around Dhaka. Understanding these port's connectivity patterns can help understand network dynamics and inform decision-making in network development and resource allocation.

The study analyzed degree vs. clustering coefficient and betweenness centrality to measure port connectivity. It found that degree and clustering coefficient were inversely related, with greater degrees of connectivity affecting the clustering coefficient. However, betweenness centrality showed a positive correlation, with higher connectivity causing more congestion. The study reveals that ports with lower connectivity tend to cluster more tightly, while major ports with higher connectivity may experience congestion problems.

Our study also aimed to identify bottlenecks within the Bangladesh Inland Waterway Network (BIWN) through the analysis of Betweenness Centrality, which assesses the critical nodes controlling information flow within the network. Dhaka emerged as the most crucial node, holding the highest Betweenness Centrality in both the Connectivity Network and the Vessel Augmented Network. This indicates Dhaka's critical role in facilitating waterway transportation routes, making it a potential bottleneck. The study proposed measures to alleviate pressure on Dhaka by enhancing other important ports such as Chandpur, Mirkadim, or Barisal.

Further analysis investigated network robustness by assessing the impact of removing Dhaka from the network and observing its effect on port connectivity and prioritization. Ego-networks centered on Dhaka highlighted the dependency of most ports on Dhaka, signifying its pivotal role in the network's overall communication. However, the study examined the impact of removing Dhaka from a network, revealing its dependency on port connectivity. Despite this, the network remained resilient, with clusters around Chandpur emerging as a bottleneck. The findings suggest that network dependencies should be distributed among major ports in different geographic distances to maintain overall robustness.

In summary, the research delves into understanding and optimizing the BIWN by evaluating network characteristics, identifying major ports, and assessing their implications for economic growth and structural development in Bangladesh. Our aim for this analysis is to provide a view on limitation and improvement scopes of Bangladesh inland waterway network. We hope this network analysis will give a way forward to design a more optimized and resilient port-connectivity network that can contribute largely to the sustainable economic growth of Bangladesh.

In future, we intend to conduct further network analysis for community detection and flow prediction. Community detection uses algorithms to identify port communities, while flow prediction uses dynamic network modeling and machine learning to optimize transportation routes. Another improvement that we aim to look into is automation of data preparation since the conversion process from manual data to digitized version takes a significant amount of time.

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