Applicability of HEC-RAS and Geospatial Tools for Inland Waterways Transportation Corridor Extension Study. Case Study of Ganga Basin, Bihar, India.

Abstract

Bihar has the largest networks of Rivers and drainage systems and most of them are perineal. Previously, north Bihar had active inland waterways transportation networks but these days the networks are not in use. Due to rapid urbanization and a hike in fuel prices, the transportation cost within the state has risen in the past few years. The demand for cheaper transportation systems is highly needed in these areas for goods transportation. Recently, the inland waterways authority of India has started a new shipping service in River Ganga only but a few more river networks can also be used for these kinds of activities. A study was conducted to find the inland waterways' potential for the development of a state river transportation corridor for North Bihar India. Various mathematical modeling tools such as HEC-RAS, HEC-HMS along with geospatial tools have been used for this study. The result obtained by the study indicates that the six more rivers of the states have the potential for inland waterways transportation along with suitable vessels for transportation. The methodology developed in the study is suitable for the development of waterways transportation corridors at various places. The study also emphasizes selecting the proper places for making the jetties which may be helpful for various activities such as disaster management, industrial fright services, logistic supply, etc.

Keywords- Inland Waterways Transportation, Disasters Management, Flood Modelling.

Introduction

In most of the developed countries the Inland waterways play an active role in the overall development of the nation (Dignan et al. 1991). The use of river networks for heavy and low-value goods transportation makes the supply chain more economical (Daniere et al. 1995) . A lot of nations have developed their transportation infrastructure and continuously expanding it to reduce the dependency on other means of transportation (Willems et al. 2018). India has also developed a large network of inland waterways transportation networks across various rivers such as Ganga, Brahmaputra, and a few other canal networks. The longest transportation network lies between Haldia to Prayagraj on River Ganga. In which West Bengal, Bihar, and Uttar Pradesh share is territories. In the past few decades, Bihar had its own inland waterways transportation networks but now these days most of them are not in function. Bihar is a landlocked state and also needs an economical transportation system to support various programs such as disaster relief operations, better connectivity between various districts for logistic supply, etc. **(Parks** et al 2012)**.**

A recent study indicates that more than two hundred rivers and drainage channels originate from the Himalayan foothills and confluence into River Ganga by associating with various tributaries (Jarman et al. 1993). These rivers are perineal and flow throughout the years. Previously, most of these river systems were deep enough to maintain the ecological flow for the vessel movements but now due to the construction of various engineering structures over the river Ganga and others, the flow area of various rivers has been restricted (Savoldi et al. 2024). A recent study indicates that more than seventy percent river networks of Bihar are either dead or filled with fine silt (Keli et al. 2008).

Navigation through a large vessel in these rivers is not possible. At present, few big rivers flowing in this region have the potential for inland waterways transportation. These rivers connect a large population that needs an economical transportation system (Sheng et al. 2024). The development of Inland waterways navigation corridors using these river systems may provide better connectivity along with economic trading between various districts and also nearest countries such as Nepal, Bhutan, and Bangladesh **(Li** et al. 2014**)**.

The inland waterways corridor may be helpful in the transportation of various types of logistics, farm products, disaster relief operations, medical emergencies, etc. (Cots et al. 2009). These systems will also serve various domestic and International supply chain demands using cargo, barge, or other supply containers. **(**Marsden et al. 2006**)**, **(**Walton et al. 2000**).** The government and other private agencies should invest in this system to reduce overburden in roadways, railways, and other transportation systems **(**Vilarinho et al. 2019**).** Furthermore, the local stakeholders, industries, startups, and small and marginal businesses need to be promoted to revive and reuse the inland waterways networks for multiple benefits. (Jaimurzina et al. 2017). At present various tools and techniques are being used for the planning, development, operation, and monitoring of inland waterways transportation corridors across the world **(***Puhar et al. 2022***)**. The application of hydrological models, geospatial tools, and other simulators plays a vital role in the operation and maintenance of waterways projects (Lin et al. 2020). In this study, the HEC- -RAS and other geospatial data and models have been used to develop a near real-time water level information system river for easy operation of inland waterways transportation system (Antunes et al 2024). The study also emphasizes the development of a local transportation corridor to connect various human settlements for disaster relief operations in north Bihar (Debnath et al. 2024). Which will be helpful in various disaster relief operations due to climate change and other natural activities **(**Tamiru et al 2023)**.** The methodology adopted in this study is highly useful for the development of inland waterways corridors at various locations across the world, especially for economically backward nations where mega inland waterways projects are not feasible due to various environmental and financial situations (Khan et al. 2021)**.** This type of project act as more economical and also essential for the sustainable development of the nation. (Tuan et al. 2011)**.** Furthermore, the entire system should be under a regional framework for the easy operation and maintenance of the transportation system **(Narayan et al. 2007).**

About Study Area.

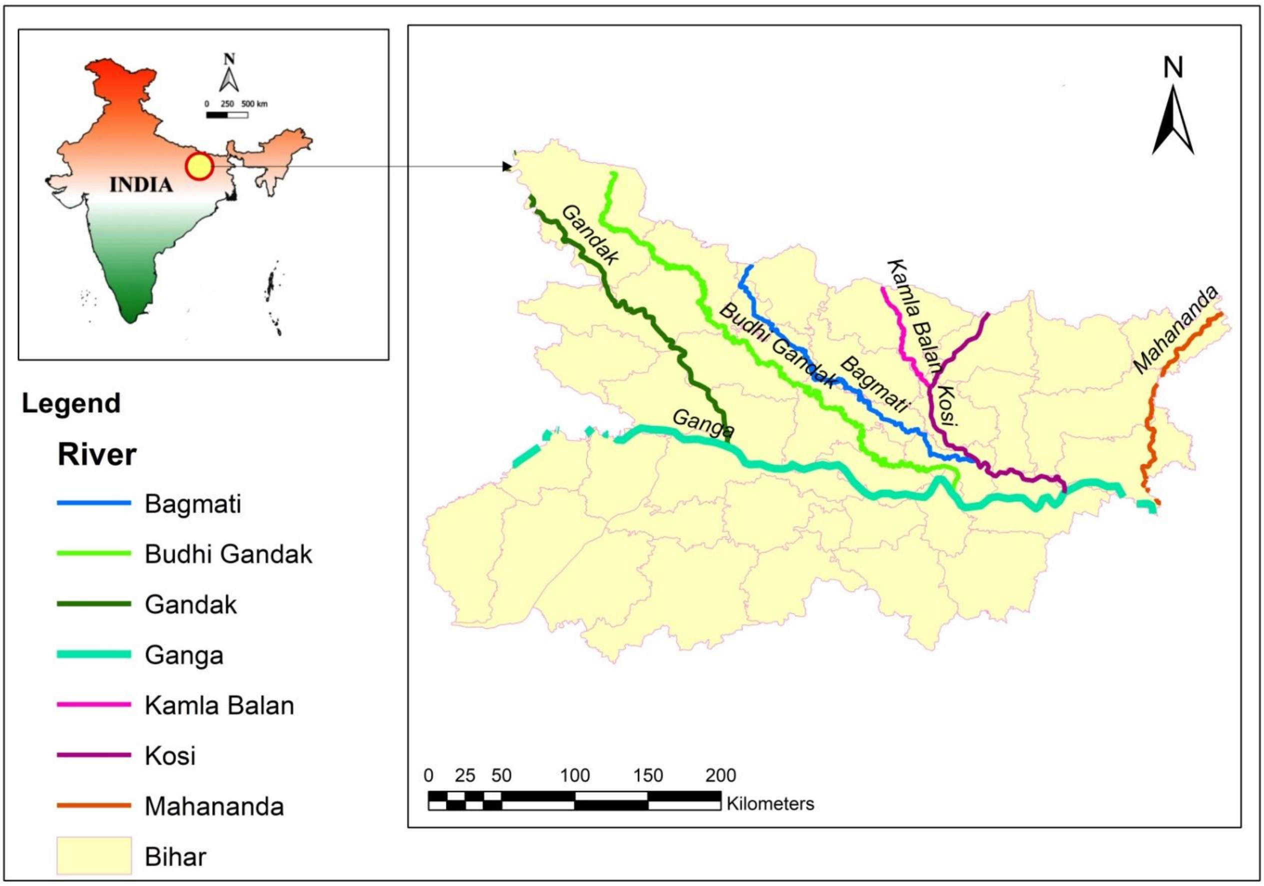


Fig.1: Location map of study area.

The study area is situated in the district of Bihar state of India. The state is rich in water resources having more than ten thousand rivers and drainage systems. Basically, the state is situated at the foothills of the Himalayas mountain. Approximately two hundred River and drainage channels originate from this area further small stream networks and other drainage networks make the count more in number. The River Ganga divides this state between two halves. i.e. south and north Bihar. The study area receives an annual rainfall of more than 1100 mm rainfall. The run-off generated in the catchment distributes the water into various micro watersheds and further, it is associated with more than six big rivers in (Fig. 01). During the monsoon, the high-intensity rainfall and run-off make this place a high flood-risk zone in India. The coordinate of this area lies between Latitude 27.433343° & Longitude 83.847583° to Latitude 24.574922° & Longitude 87.066147° During the summer the maximum temperature lies between 45 ºC to 50 ºC and in winter the lowest temperature lies between 7 ºC to 15º C.

Methodology

The methodology used for this study includes various steps and procedures such as stage-discharge modelling, selection of rivers for inland water corridor, development of a river discharge information system, and criteria for selection of sites for jetties locations. In this regard, few other basic information has been used such as available depth of water, width of the river, human settlements nearby, village cluster within 5 Km from the jetties, road networks connectivity, and least available depth.

Stage discharge modelling- Stage discharge modelling is useful to estimate the water level of the river at various discharges. In this study, it was necessary to know the stage of the River in which the inland waterways transportation was proposed. The river stage of these rivers is not the same throughout the year. The selection of vessels for the operation depends upon it. The detailed procedure for one-dimensional modelling has been taken from the paper **(Kumar et al.2017) (Kumar et al. 2020).**

Selection of rivers for inland water corridors- In this study area many rivers have the potential for inland waterways transportation. These rivers had sufficient width and depth for vessel transportation and also connected the populated areas along with local markets. The details of the state's active and proposed navigation route are listed in Table 1 (Ma et al. 2019).

Table 01. List of active and proposed Rivers in study area.

Sr. No	River Name	Average River Width in (m)	Transportation Status
1.	Ganga	1000	Active
2.	Gandak	700	Proposed
3.	Budhi Gandak	110	Proposed
4.	Bagmati	82	Proposed
5.	Kamla Balan	90	Proposed
6.	Kosi	600	Proposed
7.	Mahananda	140	Proposed

River stage information system- The river stage information system has been developed by using various discharge data such as (GFMS, and GLOFAS) and hydrological models such as HEC- RAS & HEC- HMS etc. The information system is rainfall run-off model output and used in the HEC RAS model on selected rivers of study area. The benefit of this method is it can predict the river discharge approximately three hours early in the event. The river stage information is useful in various applications such as disaster relief operations, vessel navigations, etc. In this study, the tools have been used for the identification of the depth of water at various locations for both inland waterways transportation systems and also jetties site selection.

Identification of sites for harbor or fixed RCC Jetty – It deals with the selection of suitable sites for the construction of a mini port or any related structures for operation and maintenance of the inland waterways transportation system. The Jetties will be used for various types of activities such as disaster relief operations, logistic supply, and other related activities. The selection criteria of the site for the construction of structures are described further.

Criteria for selection of stations Locations

It deals with the identification of potential sites for the construction of jetties along the bank lines of the rivers. The location must fulfill the basic and scientific criteria for its proper utility in disaster relief operations and other related applications. The criteria are helpful in the operation of vessels and other related ships or boats throughout the year.

Available depth of water – It refers to the perineal river in which the water flows throughout the year. The continuous flow occurs from the origin of the river to the confluence area without any obstructions such as structures, blockage, dunes, contraction of the river at several places, meandering, and bank erosion etc.

Width of the navigation route- The width of the navigational route varies at different places. According to the Indian waterways transportation system, the standard width of the river should be approximately 45 (m) and a straight stretch length up to 50 Km. to navigate commercial vessels.

Available Human Settlements within 100 m- The selection of the station location is an important part of this study because the services provided during the disasters suffer a lot due to the unavailability of skilled labour. The goods and other logistic carriage are highly affected due to the distance of human settlements from the jetties or harbour. So the maximum distance should not exceed more than a hundred meters from the settlements.

Village cluster within 5 Km from the jetties. The selection of station locations also depends upon the village hamlets in a radius of five kilometers. The advantage of having the village in the radius of 5 Km is that it provides the more relief during the disaster evacuation. The jetties' locations should be in the middle of the population in (Fig.03).

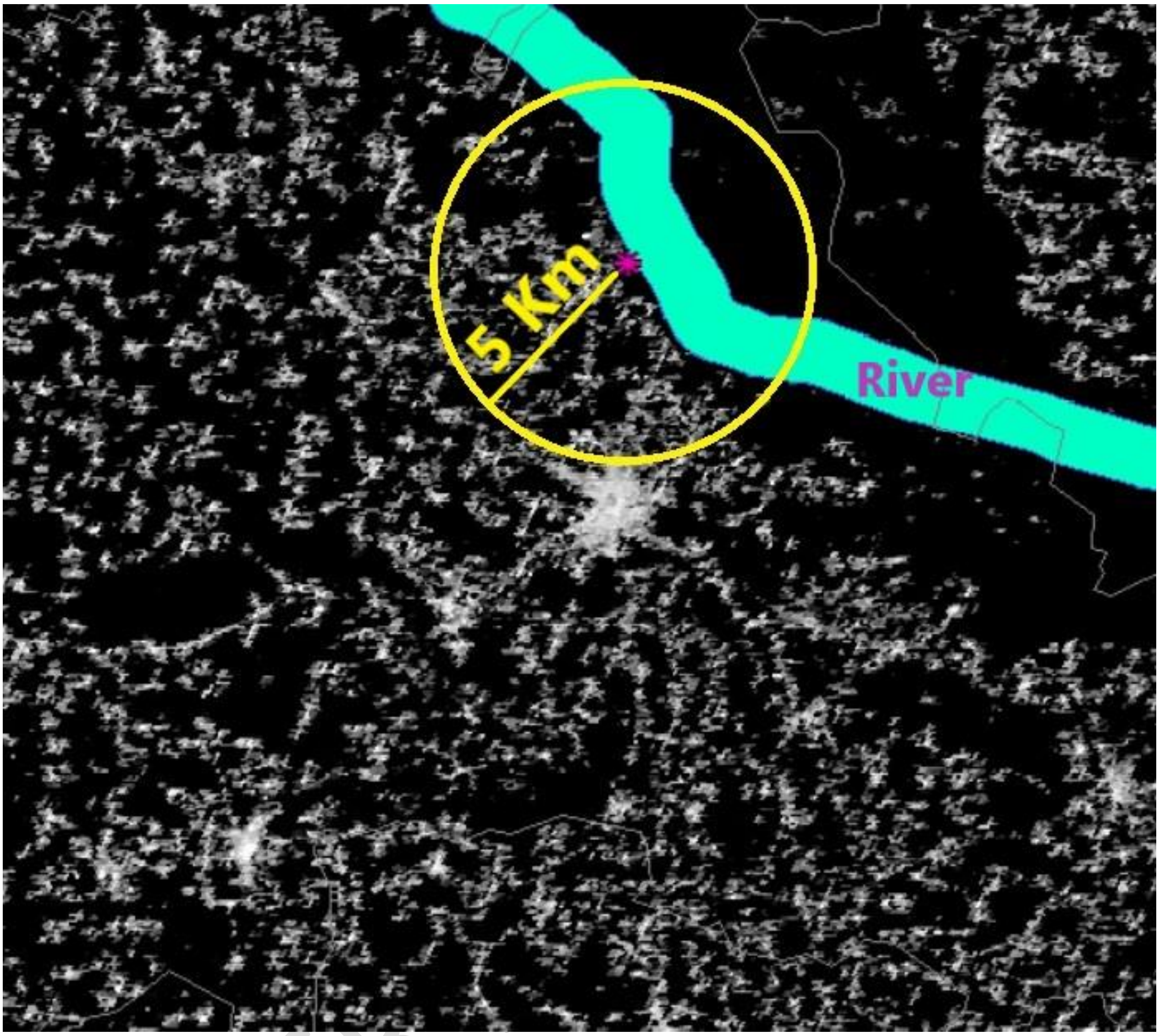


Fig.2: (GHSL) Village cluster within 5 Km from the river bank-lines.

Road network connectivity (Optional)- It is important to have the connectivity of road networks to the two hamlets because road connectivity helps in the identification of the obstacle-free path during disaster relief operations.

LAD -The least available depth of the river should not be less than 1.5 m for commercial vessels. The LAD of the river decides the operation of vessels at the different sections of the river throughout the year. It helps in planning the number of days for navigation along with the selection of vessels for transportation.

Result

The three major findings of this study are the identification of rivers for inland waterways corridor development. The second is the details of jetty construction sites along with a number of jetties on each river and the third is the available water surface elevation required for operation in the corridor along with suitable vessels. The details of the findings are elaborated below.

River Corridor detail - The state river corridor proposed in this study, is helpful in various activities such as disaster relief operations, logistic supply chain development, agriculture products supply, market and tourism development, river bank protection, etc. In this study, a total of six new rivers have been selected under the new inland water ways corridor development plan in (Fig. 03).The development of river corridors will help in connection with rural areas to inland waterways networks. It will also connect several other neighbouring states and countries near the corridor such as Nepal, Bhutan, and Bangladesh. The detail of the river length and operational length is listed in Table 2.

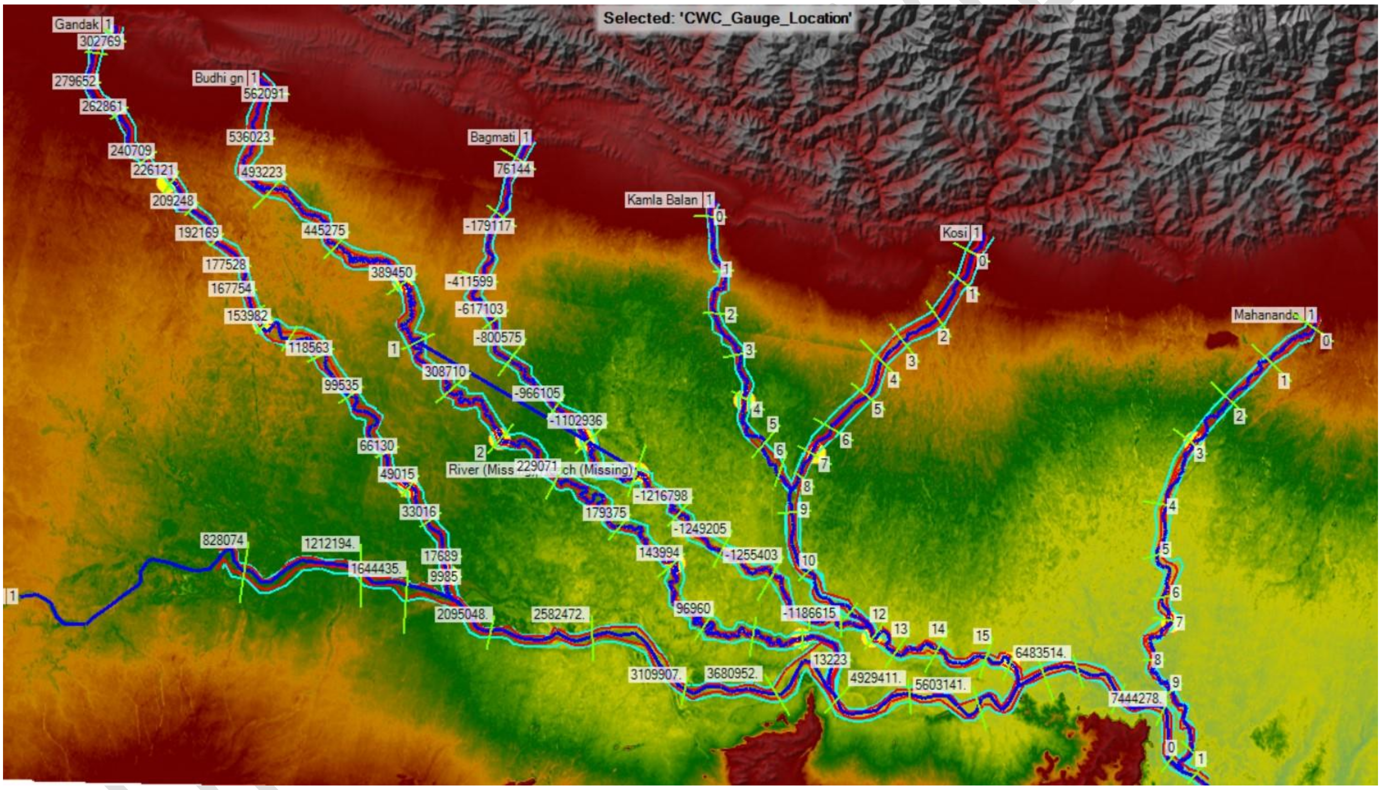


Figure 03: Route of New Inland Waterways Corridor for Bihar State.

Table No (02). The length of river with operational length in study area.

Sr No.	**River Name**	**Length of the River**	**Operational Length in (Km)**
1.	Gandak	306	258
2.	Budhi Gandak	568	568

3.	Bagmati	341	290
4.	Kamla Balan	132	88
5.	Kosi	274	250
6.	Mahananda	227	160

2- Location for Jetties – The study area is situated near the foothills of the Himalayas mountain and every year floods and a few other disasters are very common in these places. Another aspect is this the area is highly fertile and agricultural productive. The raw agriculture products need transportation facilities at a nominal cost. A large number of jetties and agricultural markets will involve the various farmers, and stakeholders to use the river corridor to expand their business near the river. The jetties near the bank will also help in disaster relief operations, local ferries, industrial goods transportation, etc. The details of the proposed location for jetty construction along the river bank lines are provided in Table 03.

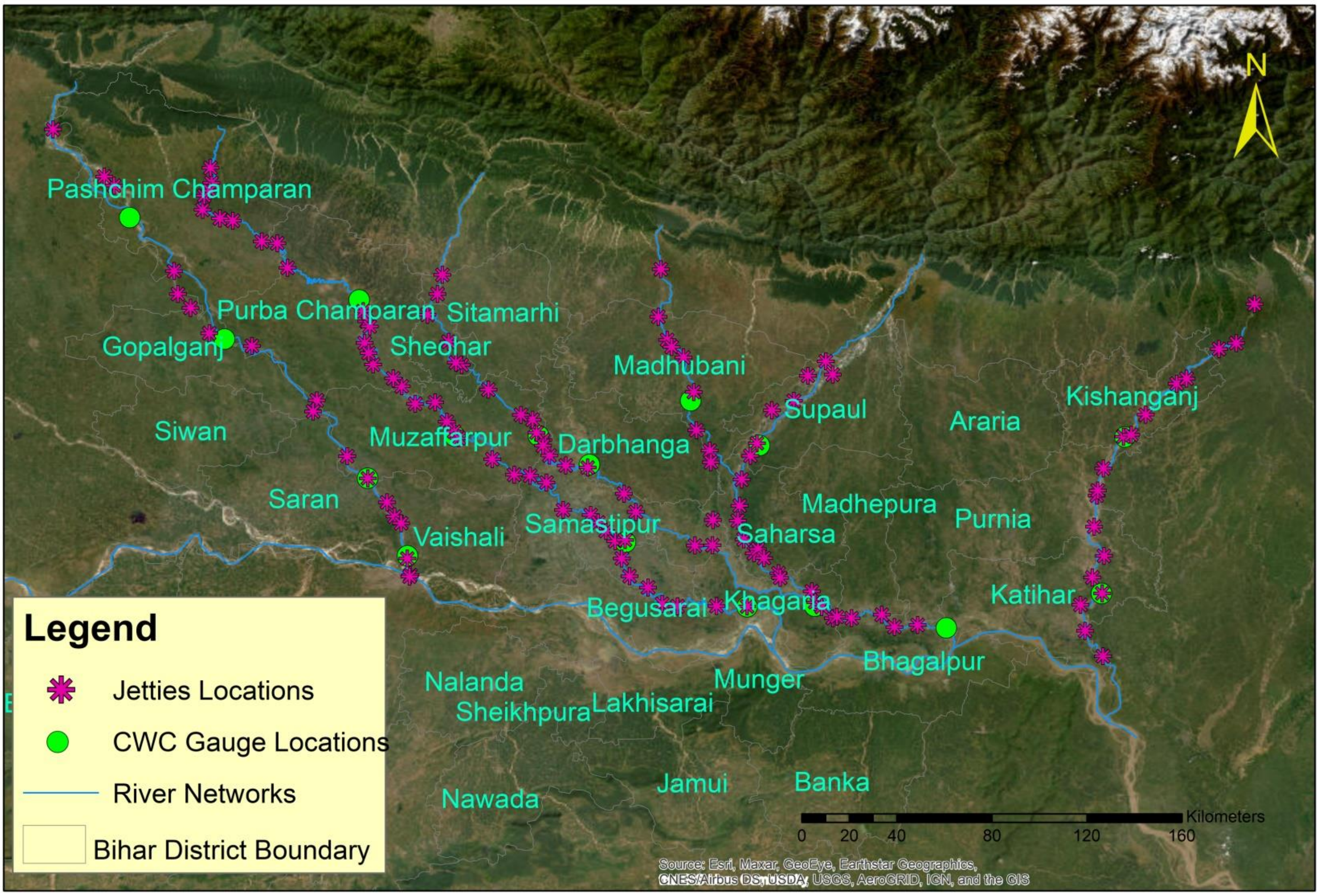


Figure 04 : Proposed Sites for Jetties.

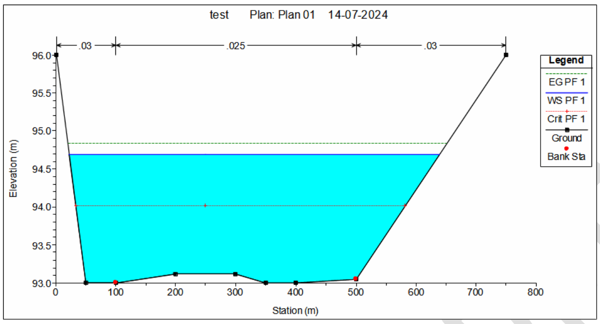
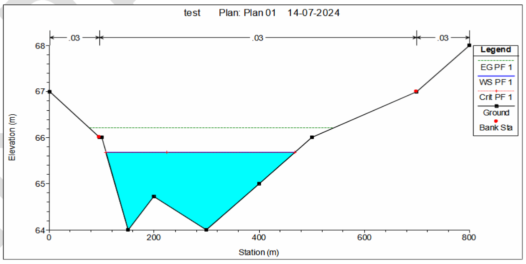
Table 03: River and associated Jetties

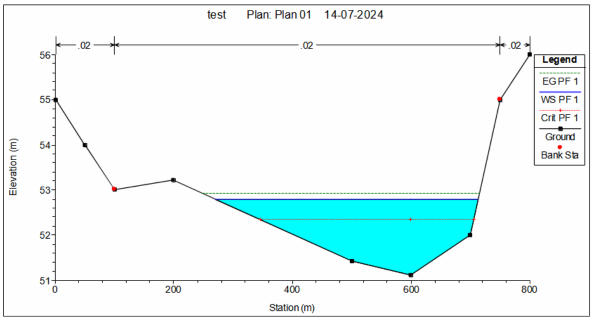
Sr No.	**River Name**	**District Associated**	**Number of Jetties**
1	Gandak	Paschim Champaran	3
		Purbi Champaran	2
		Gopalganj	1
		Muzaffarpur	1
		Saran	1
		Vaishali	2
2	Budhi Gandak	Paschim Champaran	8
		Purbi Champaran	9
		Muzaffarpur	8

		Samastipur	9
		Begusarai	4
		Khagaria	1
3	Bagmati	Sitamadhi	1
		Seohar	4
		Darbhanga	2
		Samastipur	4
		Muzaffarpur	6
4	Kamla Balan	Madhubani	5
		Darbhanga	1
5	Kosi	Supaul	3
		Saharsa	8
		Khagaria	4
		Madhepura	1
		Bhagalpur	3
6	Mahananda	Kisanganj	3
		Katihar	4
		Purnia	2

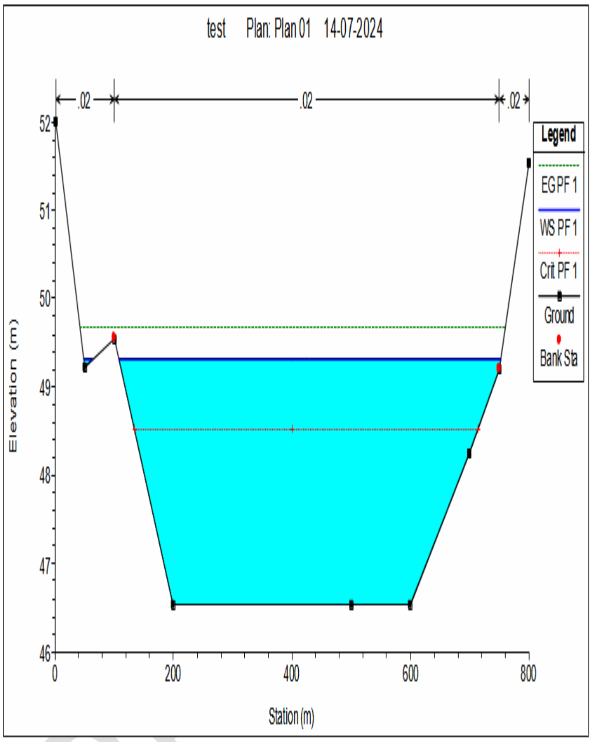
Corridor Operation Details- This refers to the number of days involved in the operation of inland waterways transportation in selected rivers. During the study, it was found that the number of days for operation or navigation of vessels will not affect throughout the year. The least available depth of all the rivers except Kamla Balan River lies near the allowable depth i.e. around 1.5 meters. It is the minimum water depth for any vessel movement. Apart from the big vessel navigation this study also suggests the various types of alternative ships and other related small boats for easy operations during the flood or any other disasters. The detail of the river LAD along with respected locations is described below.

Available Water Depth of River Gandak-The total length of Gandak River is 258 in the study area. The population density is high on both sides of the river banks. The operational depth of the inland waterways project for the big vessels is 1.5 m but other small vessels or boats can also navigate in the river. The entire river has sufficient water depth to support the small and marginal transportation system. The cross sections at several locations where sufficient depth of water is available are depicted in (Fig. 05)

	
Site : Khadda- Kushi	**Site :Chatia -Motihari**



Site :Rewaghat -Muzaffarnagar



Site :Vaishali - Hajipur

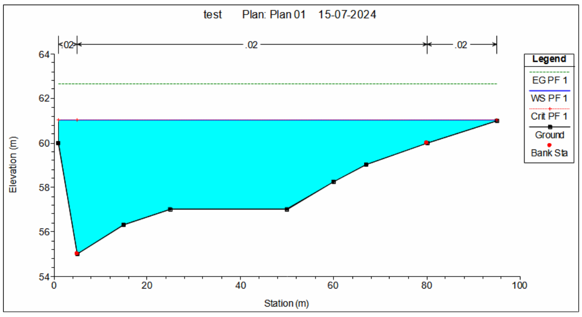
Figure 05: Cross- Section detail of River Gandak. Table 04: Water surface elevation at Gandak monitoring stations.

The information about the available water depth for navigation of the vessels at various places in the river Gandak was required. The purpose of this information was to estimate the depth of water for the overall planning of the transportation system in the Gandak River. The information indicates that sufficient water is available for navigation as well as jetty construction. The details of the depth and channel elevation are listed in Table 04.

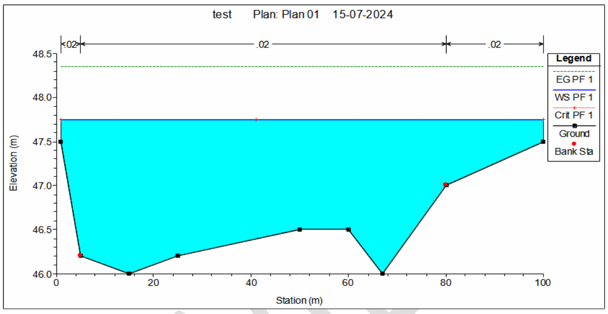
Table 04: Depth and Channel Elevation

Sr. No	**River Name**	**Station Location**	**Average Water Level (23) Years**	**Mean Channel Elevation**	Minimum Water Surface Elevation
1	Gandak	Khadda- Kushi Nagar	94.75	93.12	1.63
2	Gandak	Chatia -Motihari	65.88	64.72	1.16
3	Gandak	Rewaghat -Muzaffarnagar	52.91	51.42	1.49
4	Gandak	Vaishali -Hajipur	49.45	46.53	2.92

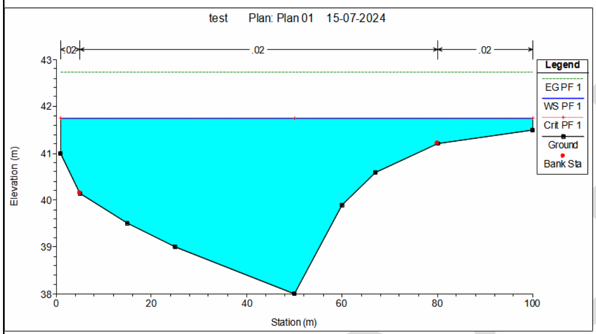
Available Water Depth of River Budhi Gandak- The cross-section of the River Budhi Gandak is shown in the (Fig. 06). The formation is needed to identify the depth of water at several locations where the jetties are needed. All four places where the jetties are proposed have sufficient depth of water and are also safe for construction.



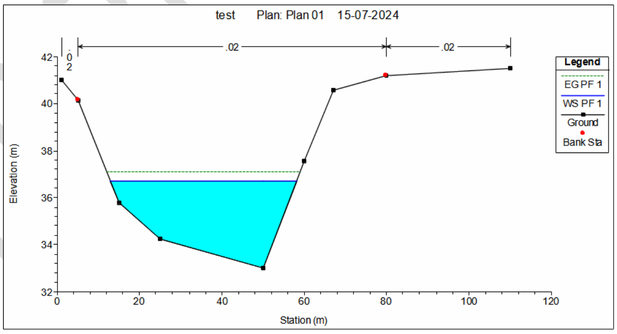
Site: Lalbegia Ghat - Motihari



Site: Sikandarpur -Muzaffarpur



Site: Rosera- Samastipur



Site: Khagaria- Khagaria

Figure 06: Cross Section details of River Budhi Gandak

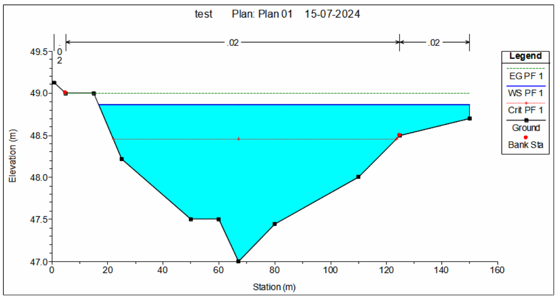
The information shows that average water level and mean channel elevation of the river Budhi Gandak. The difference in the water surface elevation indicates the depth of the water in the River is safe for various activities such as jetty construction and transportation. The detail information is listed in Table 05.

Table 05:Water surface elevation at Budhi Gandak monitoring stations.

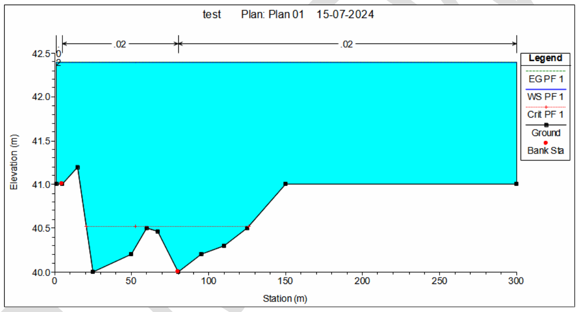
Sr. No	**River Name**	**Station Location**	**Average Water Level (20) Years**	**Mean Channel Elevation**	Minimum Water Surface Elevation
1	Budhi Gandak	Lalbegia Ghat - Motihari	60.94	58.26	2.68
2	Budhi	Sikandarpur -	47.57	46.5	1.07

	Gandak	Muzaffarpur			
3	Budhi Gandak	Rosera-Samastipur	41.9	39.9	2
4	Budhi Gandak	Khagaria-Khagaria	36.3	34.27	2.03

Available Water Depth of River Bagmati- The cross-section detail of river Bagmti has been shown in the (Fig.07) the cross-section indicates that the depth of water at various locations is more than 1.5 m. The average depth of water for the past twenty years has been used for the estimation of depth of water. The mean channel elevation is also indicated in cross-sectional details.



Site: Benibad- Muzaffarpur



Site:Hayaghat -Darbhanga

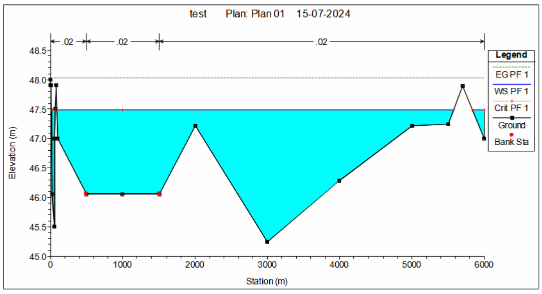
Figure 07: Cross- Section details of River Bagmati

The information provided in Table 06. deals with average water level of the river at various locations. The channel has sufficient depth of water for inland water ways transportation. The table also represent the mean channel elevation of the river at jetty sites.

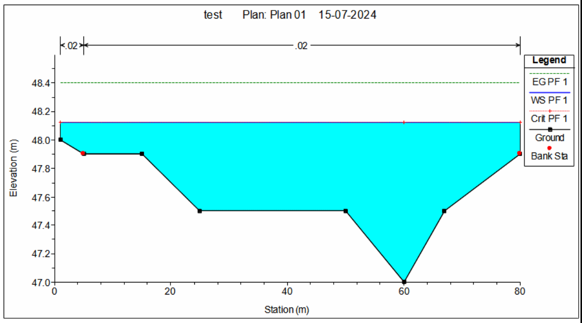
Table 06 :Water surface elevation at Bagmati monitoring stations.

Sr. No	River Name	Station Location	Average Water Level (20) Years	Mean Channel Elevation	Minimum Water Surface Elevation
1	Bagmati	Benibad-Muzaffarpur	48.60	47.05	1.55
2	Bagmati	Hayaghat -Darbhanga	42.39	40.46	1.93

Available Water Depth of River Kamla Balan -The cross-section profile of the River Kamla Balan is represented in the (Fig 08). It shows that the depth of water is not sufficient for big vessel transportation but small boats can be navigated in the channel and also it fulfils the requirement of jetty construction.



Site: Jhanjharpur



Site: Basua -Supaul (Kosi River)

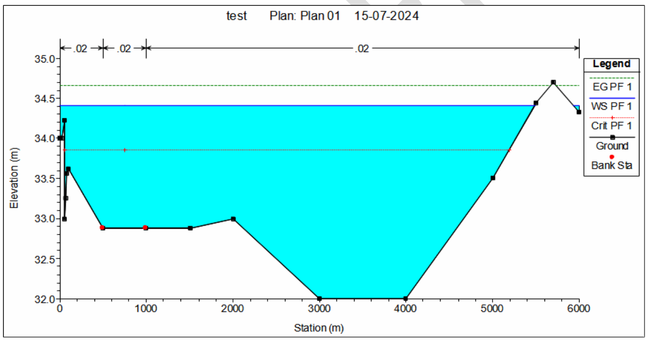
Figure 08: Cross- Section details of River Kamla Balan

The information provided in Table 07 represents the Kamla Balan River's water depth. The mean channel depth and the water level are also represented in this table. The maximum water surface elevation is 0.57 meters of the River.

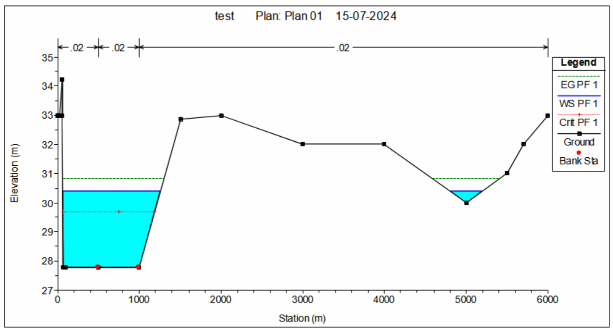
Table 07:Water surface elevation at Kamla Balan Monitoring Station.

Sr. No	**River Name**	**Station Location**	**Average Water Level (20) Years**	**Mean Channel Elevation**	Minimum Water Surface Elevation
1	Kamla Balan	Jhanjharpur	48.97	48.40	0.57

Available Water Depth of River Kosi - The information provided in (Fig. 09) represents the cross-section detail of River Kosi. The river flow is not in the centre, and during high discharge, it flows out of its bank for several hours. The cross-section has a sufficient depth of water for transportation activities in the river.



Site :Baltara - Khagaria



Site: Kursela - Katihar

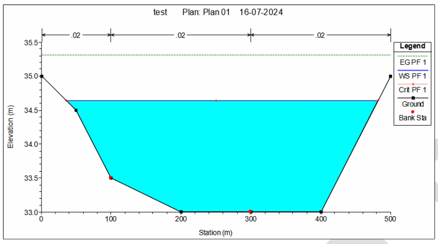
Figure 09: Cross- Section details of River Kosi.

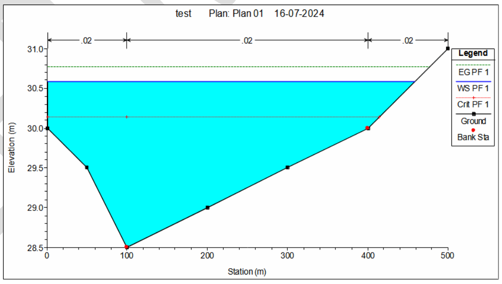
The details provided in the Table 08 represent the average depth of water at various locations along the flow area of the river. The river has sufficient depth of water for both inland waterways and also for jetty construction.

Table 08: Water surface elevation at Kosi Monitoring Station.

Sr. No	River Name	Station Location	Average Water Level (20) Years	Mean Channel Elevation	Minimum Water Surface Elevation
1	Kosi	Basua -Supaul	47.65	46.05	1.6
2	Kosi	Baltara - Khagaria	34.74	32.88	1.86
3	Kosi	Kursela - Katihar	30.19	27.78	2.41

Available Water Depth of River Mahananda- The cross-sectional detail of the river Mahananda is represented in (Fig. 10).The figure shows the average water surface elevation in the river at several places is sufficient for transportation activities.





Site : Dhengra ghat -Purnia **Site :Jhawa -Katihar**

Figure 10: Cross- Section details of River Kosi.

The information provided in the Table shows the depth of water at various places in the cross-section. The average water level of the river Mahananda is 34.87 on the upstream side and 30.58 on the downstream side. The information indicates that the it is safe for waterways activities as well as jetty construction.

Table 09: Water surface elevation at Mahananda Monitoring Station.

Sr. No	River Name	Station Location	Average Water Level (20) Years	Mean Channel Elevation	Minimum

					Water Surface Elevation
1	Mahananda	Dhengra ghat - Purnia	34.87	33.33	1.54
2	Mahananda	Jhawa -Katihar	30.58	29	1.58

Selection of suitable Vessels – The selection of suitable vessels and small boats is highly important to make the easy and successful operation under the proposed corridor. The following boats and ships can easily navigate the river throughout the year. The Average depth of water along with suitable types of boats are listed in Table (10).

Table 10 : Detail of boats for various river systems

Sr. No	**River Name**	**Average Depth of the River (m)**	**Suitable Type of Boat, Ships, Vessels**
1.	Gandak	1.8	Dinghy, Day Sailors, Catamarans
2.	Budhi Gandak	1.95	Dinghy, Sailors, Catamarans
3.	Bagmati	1.74	Dinghy, Sailors, Catamarans
4.	Kamla Balan	0.57	Dinghy.
5.	Kosi	1.96	Dinghy, Sailors, Catamarans
6.	Mahanandaa	1.56	Dinghy, Sailors, Catamarans

Conclusion

India and its few neighbouring countries such as Nepal, Bhutan, and Bangladesh are rich in the water resources sector. These countries also have a rich experience of trade using inland waterways transportation systems. In the past few decades due to the modernization of road and railway transportation systems, the inland waterways system has lost its popularity. In recent days the hike in fuel prices and more push towards sustainable development goals, the inland waterways transportation system is highly suitable for areas having large water networks available. Bihar state directly shares the borders with Nepal and also it is few rivers such as Ganga and Mahananda flow to Bangladesh and Bhutan. The inland waterways transportation system is a better and more economical transportation system between all these nations. Apart from that several other rivers such as Gandak, Budhi Gandak, Bagmati, Kamla Balan, and Kosi can be game changers during the disaster relief operation and also the local logistic supply system for Bihar state. The developed methodology in this study may be highly useful for operation and maintenance of marginal inland waterways transportation systems for developing countries.

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