Mathematical Modeling Studies for Brahmani Delta Network from Talcher to Mangalgadi for Development of Inland Water Transport in the Proposed National Waterway-5, Odisha

Submitted to

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Executive Summary

Government of India has declared the National Waterway-5 (NW-5) in Mahanadi/Brahmani delta, Matai river and East Coast Canal (ECC) for total length of about 600 km. A policy decision has been taken initially to develop the commercially viable stretch between Talcher to Paradip and Dhamra for 332 km for providing the sustainable, economic and alternative mode of transport from the ports to mining area, industrial hubs. As a part of developing this project, Inland Waterway Authority of India (IWAI) has awarded consultancy to Indian Institute of Technology Guwahati (IIT Guwahati) for mathematical modeling of Brahmani river network in development of inland water transport.

The following points are the summary of various activities undertaken and recommendations suggested by IIT Guwahati for the proposed National Waterway

1. The reconnaissance survey was conducted in pre-monsoon season (July, 2015). This survey provided information on river morphology, flow pattern, inline structures, flood marks and existing embankments along the river route. It was observed that Jenapur weir on river Brahmani has been completely silted up and plays no role as weir and Sujanpur weir on river Tantigai is partially damaged.

2. Acoustic Doppler Current Profiler (ADCP) survey was conducted during both monsoon (August, 2015) and lean season (November, 2015) at all bifurcations to understand discharge distribution and to find active channels in the river network. ADCP survey confirms

Brahmani (Pankapal) - Kharsua (Jokadia) - Tantigai (Sujanpur)-Dudai (Erda)-Kani carries more discharge and has reasonably higher flow depths.

3. Hydrological data analysis is carried out for the daily discharge data available at Samal barrage, Brahmani (Pankapal) and Kharsua (Khanditar) gauging stations. The hydrological analysis performed in this study includes flow frequency analysis, 90% dependable flow, 100 year peak flood and flood distribution analysis. The findings in this study are

- Flow frequency analysis at Pankapal shows that on average 20 % of days in a year discharges less than 100 cumecs are observed.
- The 100 year flood computed at Pankapal is found to be around 13,000 cumecs.
- Based on flow distribution analysis 50 % this peak flood i.e. 6500 cumecs is distributed to Kharsua (Jokadia) to carry out 100-year flood simulations.

4. The bathymetry and topographic data from Talcher to Mangalgadi along the river network was provided by IWAI. The analysis of survey data between Talcher to Pankapal shows that there are artificial drops (around 2.0 m) for every 10.0 km. This is a result of very limited bench marking. This issue has been discussed in meeting with IWAI officials and subsequently, IWAI has suggested to conduct mathematical modeling studies for Pankapal to Padnipal stretch.

5. Mathematical modeling for Brahmani river network from Pankapal to Padnipal is carried out piece-wise with 100 m interval surveyed cross sections. Considering the lean season flow availability, the model is simulated for discharges of 50, 80 and 100 cumecs and proposed barrages accordingly. The losses such as evaporation and seepage are also considered in proposing design crest height of a barrage. The impact of reconstruction of existing weirs Jokadia and Sujanpur is studied and necessary revisions are suggested. The 100 year flood analysis is carried to predict flood levels for constructing /revising embankment heights in the proposed route. The map showing the tentative locations of the proposed/modified structures and notations followed for the structures is shown in Figure I. Table I summarizes the details of hydraulic structures proposed in the study area.

6. The height of Jokadia weir (W_1) is raised by 2.75 m and Sujanpur (W_3) by 2.60 m from existing level to provide suitable navigational depths throughout the reach in all seasons.

7. The new barrages W_2 *and* W_4 of 4.25 m and 5.25 m are proposed on Kharsua river, W_2 at 7 km upstream of Sujanpur weir and another W_4 after Budha-Kharsua confluence to store incoming flow and maintain depths required for navigation.

8. Check dams of 2.5 m high are proposed at Dudai and Bhogra rivers to divert complete lean season discharges to Dhaikia and also dredging along the proposed route is suggested for maintaining navigational depths.

9. The navigable depths in Kani river can be obtained either by dredging along with width reduction or providing 4.25 m rubber dam at downstream along with minor dredging. The feasibility of providing rubber dam in downstream of Kani river is studied and rubber dam (W_5) is suggested as an option against dredging.

10. In the stretch between Pankapal to Sujanpur majority of the river route is surrounded with embankments on both sides. The 100 years flood computed at Pankapal is distributed to downstream reaches and corresponding flood simulation analysis is carried out at upstream of weir locations assuming that barrage gates are completely opened during flood. The proposed structures in this route are Jokadia weir, intermediate weir (W_2), Sujanpur weir (W_3) and another weir (W_4). The 100 years flood shows submergence up to 1.70 m at locations where embankments are present and 3.0 m at locations where embankments are absent. Hence, embankments should be revised and/or constructed accordingly.

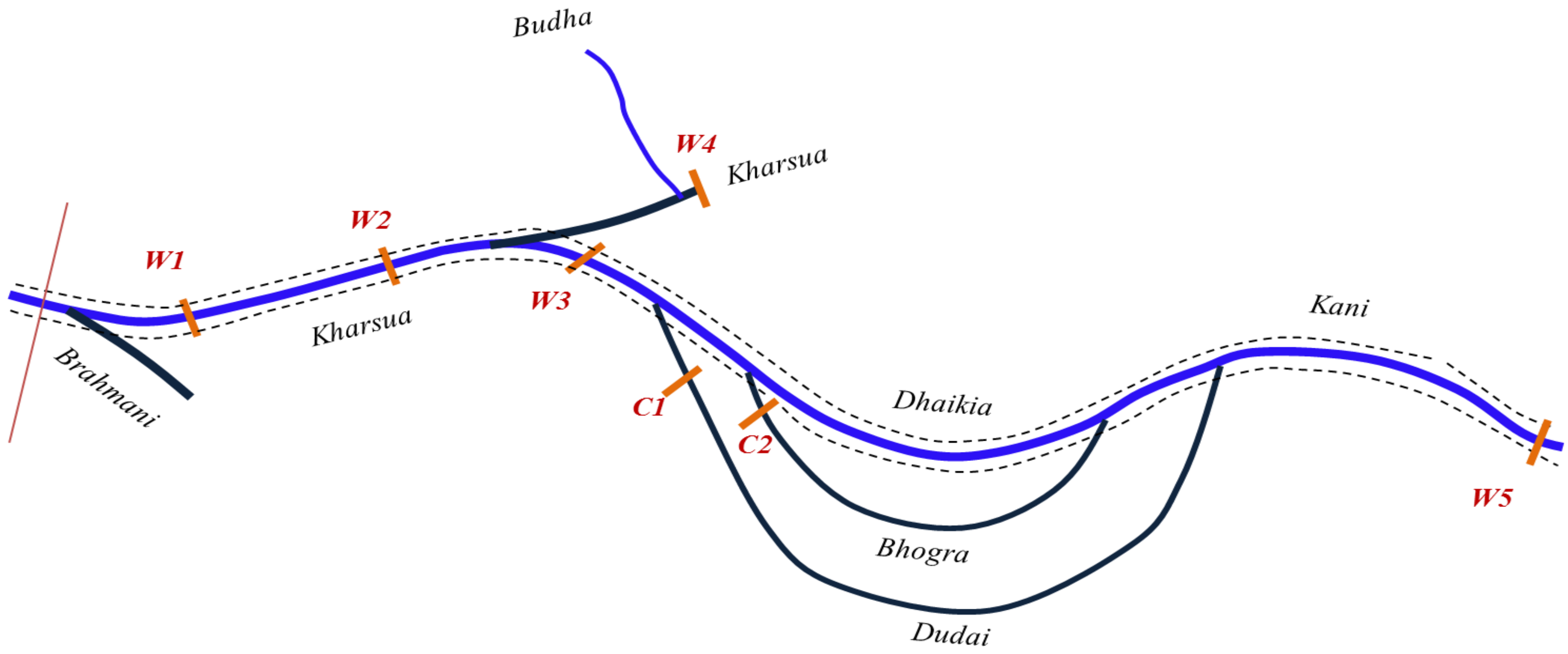
11. In the river route between Tantigai (Sujanpur) to Kani (Padnipal) via Dhaikia there are no embankments along the river route. The 100 year flood shows submergence up to 2.0 m above the banks. Hence, new embankments need to be constructed along the river route to accommodate 100 years flood.

12. In the study network, the inline structures are designed for minimum discharge of 50 cumecs to provide sufficient navigational depth and width. As per State Government's proposal if 16 cumecs of discharge is to be diverted for irrigation during Rabi season then as total 66 cumecs of discharge will be necessary at Pankapal for meeting both navigation and irrigation requirements.

Table I: Details of the hydraulic structures proposed in the National Waterway between Pankapal to Padnipal

Name of Weir	River name	Geographic Location	Weir Details/Levels			Max. WL @ 100 Years Flood MSL	Remarks
			Existing crest level MSL	Height of proposed weir (m)	Existing embankment level MSL		
Jokadia *(W₁)*	Kharsua	20°53'23.65"N 86° 6'35.85"E	14.78	2.75	20.70	23.38	Weir cum barrage with Navigational Lock
Intermediate (W₂)	Kharsua	20°49'53.52"N 86°15'40.89"E		4.25	17.69	19.56	Weir cum barrage with Navigational Lock
Sujanpur *(W₃)*	Tantigai	20°47'8.20"N 86°17'25.75"E	9.44	2.60	15.84	18.31	Weir cum barrage with Navigational Lock
Proposed *(W₄)*	Budha-Kharsua	20°46'29.84"N 86°19'26.59"E		5.25	16.06	18.49	Weir cum barrage
**Proposed* *(W₅)*	Kani	20°40'46.05"N 86°35'6.28"E		4.25	NA	3 m above banks	Rubber dam
Check dam 1	Dudai	20°43'53.64"N 86°20'38.13"E		2.50	NA	2 m above banks	Check Dam
Check dam 2	Bhogra	20°43'13.08"N 86°21'46.06"E		2.50	NA	2 m above banks	Check Dam

Note: 1. Proposed rubber dam (W_5) is optional against dredging; 2. NA: Not available



- W_1 : Revised Jokadia weir cum barrage with navigational lock
- W_2 : Newly Proposed weir cum barrage with navigational lock
- W_3 : Revised Sujanpur weir cum barrage with navigational lock
- W_4 : Weir cum barrage
- W_5 : Newly proposed rubber dam (Optional against dredging)
- C_1 *and* C_2 are Check Dams

Figure I: Proposed hydraulic structures between Pankapal and Padnipal

Chapter 1
Introduction

1.1 General

Brahmani River originates from Jharkhand, flows through heart of Odisha and has a fall out point at Bay of Bengal near Dhamra. The Brahmani River is formed by the confluence of the rivers South Koel and Sankh near the major industrial town of Rourkela. At about 480 km long, the Brahmani is the second longest river in Orissa after River Mahanadi and has a total catchment area of 39,033 km^2 up to Jenapur. Government of India declared the National waterway NW-5 in Mahanadi / Brahmani delta, Matai River and East Coast Canal (ECC) for total length of about 600 km. The stretch wise details of NW-5 are as given below

- Rivers Brahmani- Kharsua- Dhamra (Talcher- Dhamra) - 265 km
- Matai River (Charbatia- Dhamra) - 39 km
- Mahanadi delta rivers (Mangalgadi- Paradeep) - 67 km
- East Coast Canal (Geonkhali- Charbatia) - 217 km

A policy decision has been taken initially to develop the commercially viable stretch between Talcher to Paradip & Dhamra for 332 km for providing the sustainable and economically viable & alternative mode of transport from the ports to mining area, industrial hubs & vice versa. The Brahmani / Mahanadi river basins extending in Madhya Pradesh, Jharkhand and

Odisha have rich deposits of minerals, coal, iron ore and large production of various industrial and agricultural products. The likely commodities to be transported through proposed NW-5 mode could be divided into three groups namely Minerals (Coal, Iron Ore), Agricultural products (Paddy, Rice, Straw, Animal fodder, fish, Jute) and finished goods or manufactured products from Talcher Coal mines, Kalinganagar industries, textiles and forest. Therefore it is necessary to maintain navigable depth along the waterway in all the seasons for proper transport of goods. In this study mathematical modeling needs to be carried out to ascertain minimum discharge required to maintain navigable depth in the river system by including existing and required hydraulic structures. As a part of developing this project, Inland Waterway Authority of India (IWAI) has awarded consultancy to Indian Institute of Technology Guwahati (IIT Guwahati) on 15 April 2015 for mathematical modeling of Brahmani river network in development of inland water transport.

1.2 Terms of Reference

The following listed are the objectives in the present study

- River channel network model of Brahmani river delta will be developed comprising of major river channels like Kharsua, Tantigai/Kani, Hansua, Baitarani etc. to predict the flood levels/velocities/discharges along different river channels for different discharges.
- To assess the impact of raising crest level of Jenapur weir from E.L 17.41m to E.L 20.0 m on flood levels in the upstream reach and to assess discharge distribution in Kharsua, Brahmani and Tantigai rivers for range of flood discharges up to 100 years of flood.
- To assess the impact of reconstruction of Sujanpur weir on the distribution of flow in Kharsua and Tantigai rivers for ranges of discharges for monsoon and non- monsoon period.
- To assess the flow conditions in Kharsua, Tantigai and alternate channels on the east with and without proposed link at Budha.
- To assess the feasibility of development of a navigable channel of base width 50m, 3m depth LAD and 1:3 side slope , for movement of 2000 MT vessels from Talcher to

Pankapal/Jokadia up to Mangalgadi (no tidal stretch) and further up to Dhamra Port and Paradip Port.

Note: Salinity, sedimentation and morphological aspects not to be included in the studies.

1.3 Study area

The Brahmani River network from Pankapal / Jokadia to Padnipal through Kharsua-Tantigai-Bhogra-Kani is considered initially for the study. The river reach is nearly 76 km between these two stations and the width ranges from 500 m to 100 m along different routes of the network. The river distributes its flow along four major bifurcations in the study area viz. at Pankapal (as Brahmani and Kharsua), Sujanpur (as Kharsua and Tantigai), Erda (as Tantigai and Dudai) and Bhogra-Dhaikia. The rivers Dudai, Bhogra and Dhaikia rejoin further and flow as Kani River till Padnipal. A tributary of Baitarini (Budha) joins Kharsua and contributes considerable discharge to it during flood season. There are three structures at Jenapur (Brahmani), Jokadia (Kharsua) and Sujanpur (Tantigai) in the river network. The rivers Tantigai, Kani has no parallel embankments and, Kharsua has embankments at irregular intervals on both sides. The GIS map of the Brahmani River network showing bifurcations, embankment details and major interventions in study area is shown in appendix Figure A-1.

1.4 Organization of report

The report comprises of six chapters and one appendix. In the first chapter the general discussion on National Waterway-5, terms of reference and study area is discussed. Second chapter discusses briefly on hydrological analysis carried out for daily discharge data at various gauging stations. Third chapter discusses field surveys, bathymetry data analysis, ADCP survey and laboratory analysis of soil samples. The fourth chapter is about hydrodynamic modeling, procedure and model calibration aspects. Fifth and sixth chapters discusses about hydrodynamic model results, recommendations and conclusions.

Chapter 2
Hydrological Analysis

In order to carry out the hydrological data analysis, the daily discharge data at Samal barrage, Brahmani (Pankapal) and Kharsua (Khanditar) are utilized to understand the seasonal discharge pattern variations in the Brahmani river. The hydrological analysis carried in this study includes

a. Flow frequency analysis
b. 90 % dependable year flow analysis
c. 100 year flood analysis
d. Flood distribution analysis

Data Source and Period of Data:

- Daily discharge data from State Government Water Resources Department at Samal barrage from 2000 to 2014.
- Daily discharge data from State Government Water Resources Department at Khanditar gauging station on Kharsua from 1987 to 1997.
- Daily discharge data from India Water Resources Information System (IWRIS) at Pankapal gauging station on Brahmani from 1987 to 2012.

2.1 Flow Frequency Analysis

The analysis indicates frequency of different ranges of discharge observed in a year. In this study, flow availability in the river is carried out at two gauging stations (Samal and Pankapal) to understand release scenario from upstream. Through this analysis, the information on frequency of past droughts, floods and discharge availability during that period can also be obtained. The following data is used to carry out the analysis.

2.1.1 *Samal Gauging Station*

Available daily flow discharge series is categorized into seven groups based on discharge vales such as 0-50 cumecs, 50-80 cumecs, 80-100 cumecs, 100-150 cumecs, 150-300 cumecs, 300-500 cumecs and more than 500 cumecs to get past river flow system information. It is assumed that discharge values fall below 300 cumecs as lean flow and above 300 cumecs as monsoon flow. From Table 2.1, it is observed that the frequency of discharge less than 50 cumecs is 142 days in the year 2010. It is also observed that the frequencies of discharge of 50-80 cumecs and 80-100 cumecs are found to be 37.6 and 42.2 days respectively for the year 2010. From these observations, the year 2010 can be considered as drought year. It is further noticed that on an average the observed frequency are 34, 38 and 42 days for discharge less than 50 cumecs, 50-80 cumecs and 80-100 cumecs respectively. On an average 32% of days in a year discharges less than 100 cumecs are observed at Samal barrage.

2.1.2 Pankapal Gauging Station

For flow frequency analysis at Pankapal, similar observations are made as discussed above. From the Table 2.2, it is observed that the frequency of occurrence of discharge less than 50 cumecs is 30 days in the year 2010. It is also observed that the frequencies of occurrence of discharges of 50-80 cumecs and 80-100 cumecs are found to be 65 and 29 days respectively for the year 2010. From these observations, the year 2010 can be considered as drought year. It is further noticed that on an average the observed frequency of occurrence of discharges are 5, 37 and 32 days for discharge less than 50 cumecs, 50-80 cumecs and 80-100 cumecs respectively. On an average 20 % of days in a year discharges less than 100 cumecs are observed.

Table 2.1: Ranges of discharge and their frequency from 2000 -2014 at Samal barrage

Discharge (Cumecs)	<50	50-80	80-100	100-150	150-300	300-500	>500
Year	**No of Days During Lean Season**					**No of Days During Monsoon Season**	
2000	0	23	27	117	77	40	81
2001	0	79	64	23	64	37	98
2002	0	31	16	92	98	54	74
2003	0	55	11	13	83	55	148
2004	1	63	13	48	105	60	75
2005	0	10	2	21	188	60	84
2006	1	24	87	16	100	59	78
2007	0	28	95	7	58	36	141
2008	58	7	47	11	66	36	140
2009	4	40	114	1	101	29	76
2010	142	73	34	40	71	2	3
2011	76	54	17	14	68	47	89
2012	102	38	26	46	48	24	81
2013	56	16	23	46	87	49	88
2014	77	23	57	40	61	28	77
Average	34.5	37.6	42.2	35.7	85	41.1	88.9
Percentage	9.4	10.3	11.6	9.8	23.3	11.3	24.4

Table 2.2: Ranges of discharges and their frequency from 2000 -2014 at Pankapal

Discharge (Cumecs)	<50	50-80	80-100	100-150	150-300	300-500	>500
Year	**No of Days During Lean Season**					**No of Days During Monsoon Season**	
1998	0	1	17	23	103	80	140
1999	0	0	2	64	140	29	130
2000	0	17	11	67	153	27	91
2001	4	108	37	31	41	29	121
2002	2	47	60	80	45	40	91
2003	0	22	24	38	59	57	165
2004	0	26	49	55	104	33	99
2005	0	13	40	83	97	33	99
2006	1	44	57	67	71	31	94
2007	2	58	37	54	48	21	145
2008	16	30	32	83	50	37	118
2009	2	40	48	102	72	19	82
2010	30	65	29	56	138	40	7
2011	6	40	22	56	68	53	120
2012	13	48	12	52	102	47	92
Average	5.1	37.3	31.8	60.7	86.1	38.4	106.3
Percentage	1.4	10.2	8.7	16.6	23.5	10.5	29.1

2.2 90% Dependable Year Flow Analysis

Flow duration curve shows the percentage of time in a river flow can be expected or exceed a particular design discharge (e.g. 10 cumecs). If the probability of occurrence of the specified flow discharge in an annual flow series is 90%, then that specified discharge is assumed to be 90% dependable year flow. It is useful for the design of structures on dam. It can be identified by selecting the annual discharge in a water year with dependability closest to 90% using the Weibull formula.

$$P = \frac{m}{N+1}$$

where, P = Probability of occurrence of event,

m = Rank of observed discharge in ascending order of magnitude,

N = Number of observations.

2.2.1 Samal Gauging Station

From the available discharge flow series at Samal Gauging station, it is identified that the year 2009 as the 90% dependable flow year. Furthermore flow duration curve analysis is carried for that 90% dependable flow year 2009. The highest frequency of occurrence of discharge is found to be 154 days for the discharge of 50-100 cumecs and the lowest frequency of occurrence of discharge is found to be only one day for the discharge more than 4000 cumecs. Table 2.3 shows the flow frequency for 90% dependable year at Samal barrage. Figure 2.1 shows the flow duration curve for 90 % dependable year at Samal barrage.

2.2.2 Pankapal Gauging Station

From the available discharge flow series at Samal Gauging station, it is identified that the year 2002 as the 90% dependable flow year. Furthermore flow duration curve analysis is carried for that 90% dependable flow year 2002. The highest frequency of occurrence of discharge is found to be 114 days for the discharge of 50-100 cumecs and the lowest frequency of occurrence of discharge is found to be 25 days for the discharge 1000-4000 cumecs. Table 2.4 shows the flow frequency for 90% dependable year at Pankapal. Figure 2.2 shows the flow duration curve for 90 % dependable year at Pankapal.

Table 2.3: Flow frequency for 90% dependable year (2009) at Samal barrage

Flow (Cumecs)	No. of Days	Percentage
> 4000	1	0.2
1000-4000	10	2.7
500-1000	65	17.8
400-500	12	3.2
300-400	17	4.6
200-300	23	6.3
100-200	79	21.6
50-100	154	42.1
0-50	4	1

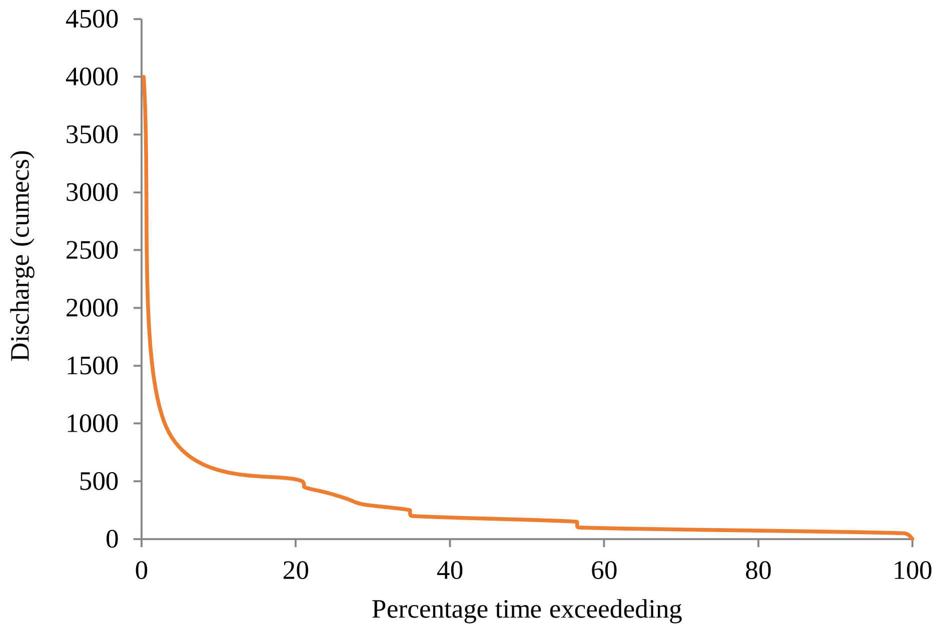


Figure 2.1: Flow duration curve for 90 % dependable year (2009) at Samal Barrage

Table 2.4: Flow frequency for 90% dependable year (2002) at Pankapal gauging location

Flow (Cumecs)	No. of Days	Percentage
> 4000	0	0.0
1000-4000	25	6.8
500-1000	66	18.1
400-500	25	6.8
300-400	15	4.1
200-300	11	3.0
100-200	114	31.2
50-100	107	29.3
0-50	2	0.5

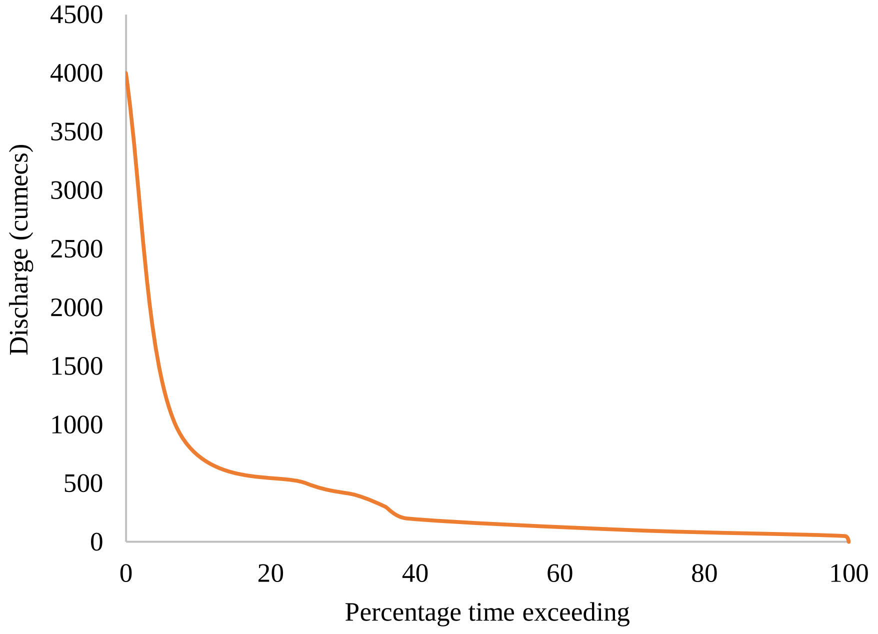


Figure 2.2: Flow duration curve for 90 % dependable year (2002) at Pankapal

2.3 100 Year Flood Analysis

Floods are extremely complex in nature and therefore it is very difficult to model analytically. In this study for prediction of flood flow statistical method of frequency analysis is adopted. For the calculation of flood magnitude for a specific return period, the most distribution function applicable in hydrological studies given by Chow (1951) is used. It can be expressed by the following equation 2.1.

$$X_T = \bar{X} + K\sigma \tag{2.1}$$

Where,

X_T = value of the variate X of random hydrologic series with a return period T

$\bar{X}$ = mean of the variate

σ = standard deviation of the variate

K = frequency factor which depends on return period, T and the assumed frequency distribution

For the present study Gumbel's extreme value distribution function proposed by Gumbel (1941) is used. It can be expressed as

$$y_T = -\left[0.834 + 2.303 \log\log\frac{T}{T-1}\right] \tag{2.2}$$

where,

y_T = reduced variate for a given T

T= Return period

Here, flood frequency analysis is carried out at Pankapal gauging station for return period of 10, 20, 50 and 100 years. The flood peak discharge for return periods 10, 20, 50 and 100 years are found to be 9,547 cumecs, 10,015 cumecs, 11,228 cumecs and 12,936 cumecs respectively.

Table 2.5: Peak flood discharge for different return periods

S. No	Return Period	Flood Discharge (cumecs)
1	10	9,547
2	20	10,015
3	50	11,228
4	100	12,936

2.4 Flood Distribution Analysis for Channel Network

The 100 year flood measured at Brahmani (Pankapal) is distributed to downstream reaches Brahmani (Jenapur) and Kharsua (Jokadia) by performing flood distribution analysis. The discharge data available from 1987 to 1997 at Brahmani (Pankapal) and Kharsua (Khanditar) is utilized for this analysis. The peak floods recorded at these gauging stations are used in evaluating flood distribution ratio obtained by dividing peak flood at Khanditar to Brahmani (Pankapal). It is found from the analysis that during peak floods 50% of the flow from Brahmani (Pankapal) is distributed to Kharsua and 50% of the flow to Brahmani (Jenapur). Table 2.6 shows recorded peak floods at Brahmani and Kharsua and corresponding flow distribution ratio.

Table 2.6: Flow distribution ratio analysis

Year	Peak Discharge at Pankapal (cumecs)	Peak Discharge at Khanditar (cumecs)	Flow distribution ratio
1987	4737.8	2449	0.52
1988	6216.8	2948.4	0.47
1989	4311.5	2245	0.52
1990	4595.2	2253	0.49
1991	9151	5101	0.55
1992	4892	2854.6	0.58
1993	3346	1718	0.51
1994	8952	4323	0.48
1995	3823	1645.3	0.43
1996	4652	2396.9	0.51
1997	7135	3549.9	0.49
		Average flow distribution ratio	**0.504**

Chapter 3
Field Investigations

3.1 Field Surveys

Detailed mathematical modeling study requires lot of field measured data such as bathymetry and topography data, flow and velocity distribution, particle size distribution of river bed and bank soils, daily water stage and discharge data etc. Hence before setting up of models, it is necessary to establish parameters, basic data required for the modeling. A series of field surveys were, therefore, conducted for setting and evaluation of mathematical model. Figures 3.1 to 3.14 shows the field photograph collected during lean and monsoon season. The details of the field surveys conducted are listed in table 3.1.

The preliminary investigations during the field visit shows that rivers Tantigai and Kani are relatively narrower and deeper than Kharsua. The Kharsua river is wider (300 m to 500 m), shallower and deposited in the reach between Sujanpur and Padnipal. The lean season survey at selective locations shows vertical stable banks up to 4 m high covered with different types of vegetation. It is also observed that Jenapur weir on River Brahmani has been completely silted up and plays no role as weir and the existing Sujanpur weir on River Tantigai is partially damaged.

Table 3.1: Details of field survey

Period of Survey	Flow Condition	Survey Particulars	Team
08 to 10 July 2015	Pre- Monsoon	• Collection of river bed and bank material soil samples • Field observations of study area	IWAI & IIT Guwahati
11 to 14 Aug. 2015	Monsoon Period	• ADCP survey at bifurcations for flow distribution • Collection of flood marks, bank features at different locations	IIT Guwahati & GMI Pvt. Ltd
07 to 08 Nov. 2015	Lean Season	• ADCP survey at bifurcations for flow distribution • Field observation of bank features, embankment heights at different locations	IIT Guwahati & GMI Pvt. Ltd

Source: Field Photograph **Name:** Pankapal Railway Bridge
Date: 13th August, 2015 **Location:** 20°52'48.72" N, 86°03'19.43" E

Figure 3.1: Brahmani river at Pankapal during monsoon season

Source: Field Photograph **Name:** Pankapal Railway Bridge
Date: 08th November, 2015 **Location:** 20°52'48.72" N, 86°03'19.43" E

Figure 3.2: Brahmani river at Pankapal during lean season

Source: Field Photograph **Name:** Brahmani river (Pankapal)
Date: 08th November, 2015 **Location:** 20°52'48.72" N, 86°03'19.43" E

Figure 3.3: Exposed sand char on Brahmani river at Pankapal

Source: Field Photograph **Name:** Brahmani river (Pankapal)
Date: 08th November, 2015 **Location:** 20°52'48.72" N, 86°03'19.43" E

Figure 3.4: Braiding pattern of Brahmani river at Pankapal

Source: Field Photograph **Name:** Jokadia Anicut
Date: 03rd July, 2015 **Location:** 20°53'24.67" N, 86°06'35.19" E

Figure 3.5: Kharsua river at Jokadia barrage during monsoon season

Source: Field Photograph **Name:** Jokadia Anicut
Date: 08th November, 2015 **Location:** 20°53'24.67" N, 86°06'35.19" E

Figure 3.6: Kharsua river at Jokadia barrage during lean season

Source: Field Photograph	**Name:** Kharsua river (D/S Jokadia)
Date: 08th November, 2015	**Location:**

Figure 3.7: Exposed sand char on Kharsua river during lean season

Source: Field Photograph	**Name:** Kharsua (U/S Sujanpur)
Date: 07th November, 2015	**Location:** 20°47'31.37"N, 86°17'17.72"E

Figure 3.8: High rise banks on Kharsua observed during lean season

Source: Field Photograph	Name: Kharsua river
Date: 07th November, 2015	**Location:** 20°47'50.79"N, 86°17'7.86"E

Figure 3.9: High rise banks of Kharsua observed during lean season

Source: Field Photograph	Name: Kharsua – Tantigai bifurcation
Date: 07th November, 2015	**Location:** 20°47'27.48" N, 86°17'09.85" E

Figure 3.10: Kharsua – Tantigai bifurcation during lean season

Source: Field Photograph | **Name:** Sujanpur Weir
Date: 03rd July, 2015 | **Location:** 20°47'08.13" N, 86°17'24.58" E

Figure 3.11: Tantigai river at Sujanpur weir during monsoon season

Source: Field Photograph | **Name:** Sujanpur Weir
Date: 07th November, 2015 | **Location:** 20°47'08.13" N, 86°17'24.58" E

Figure 3.12: Tantigai river at Sujanpur weir during lean season

Source: Field Photograph **Name:** Brahmani river (Jenapur)
Date: 03rd July, 2015 **Location:**

Figure 3.13: Jenapur weir on river Brahmani

Source: Field Photograph **Name:** Tantighai River
Date: 07th November, 2015 **Location:** 20°43'26.86" N, 86°21'15.75" E

Figure 3.14: Field photograph showing ADCP survey preparation on Tantigai river

3.2 Analysis of bathymetry data

The bathymetry survey conducted by GMI Pvt. Ltd during two different periods is used for the mathematical modeling. The period of survey for river Brahmani, Kharsua, Tantigai and Kani is in 2011 and Dhaikia and Bhogra in 2015. The post processed depth data referred from Charted Datum (m) is converted into MSL by using temporary bench marks established at various locations along the river. Figures A-2 to A-6 in appendix shows the bathymetry and topographic survey points along the waterway. The analysis of bathymetry data indicates Brahmani (after bifurcation) and Kharsua (after Sujanpur bifurcation) is highly deposited and has no defined cross section. In the proposed waterway the river follows straight and meandering paths before its confluence with Bay of Bengal. The longitudinal profile of the river between Pankapal to Padnipal is mostly gentle and at few locations it changes from mild to steep slope. The cross sections of the river are parabolic in shape and width varies wider to narrower from upstream to downstream along the proposed route. The highest depths are recorded in Kharsua (Jokadia), Tantigai, Dudai (Erda) and Kani rivers. Table 3.2 shows the details of the survey data used for piece-wise mathematical modeling. Figures 3.15 to 3.19 shows the longitudinal profiles of the river reach and sample cross sections along the proposed route.

Table 3.2: Details of the survey data used for hydrodynamic modelling

S. No	River reach	Stretch length (km)	No. of cross sections	Average bed slope	Figure showing survey points
1	Kharsua (Pankapal) to Kharsua (Jokadia)	3.9	39	0.00045	A-2
2	Kharsua (Jokadia) to upstream Sujanpur	21.6	216	0.00023	A-3
3	Kharsua – Tantigai (Sujanpur) bifurcation	6.3	63	0.00048	A-4
4	Tantigai (Sujanpur) –Tantigai- Dhaikia	17.4	174	0.00017	A-5
5	Kani river till Padnipal	24.5	245	0.00010	A-6

Note: Where A: Appendix

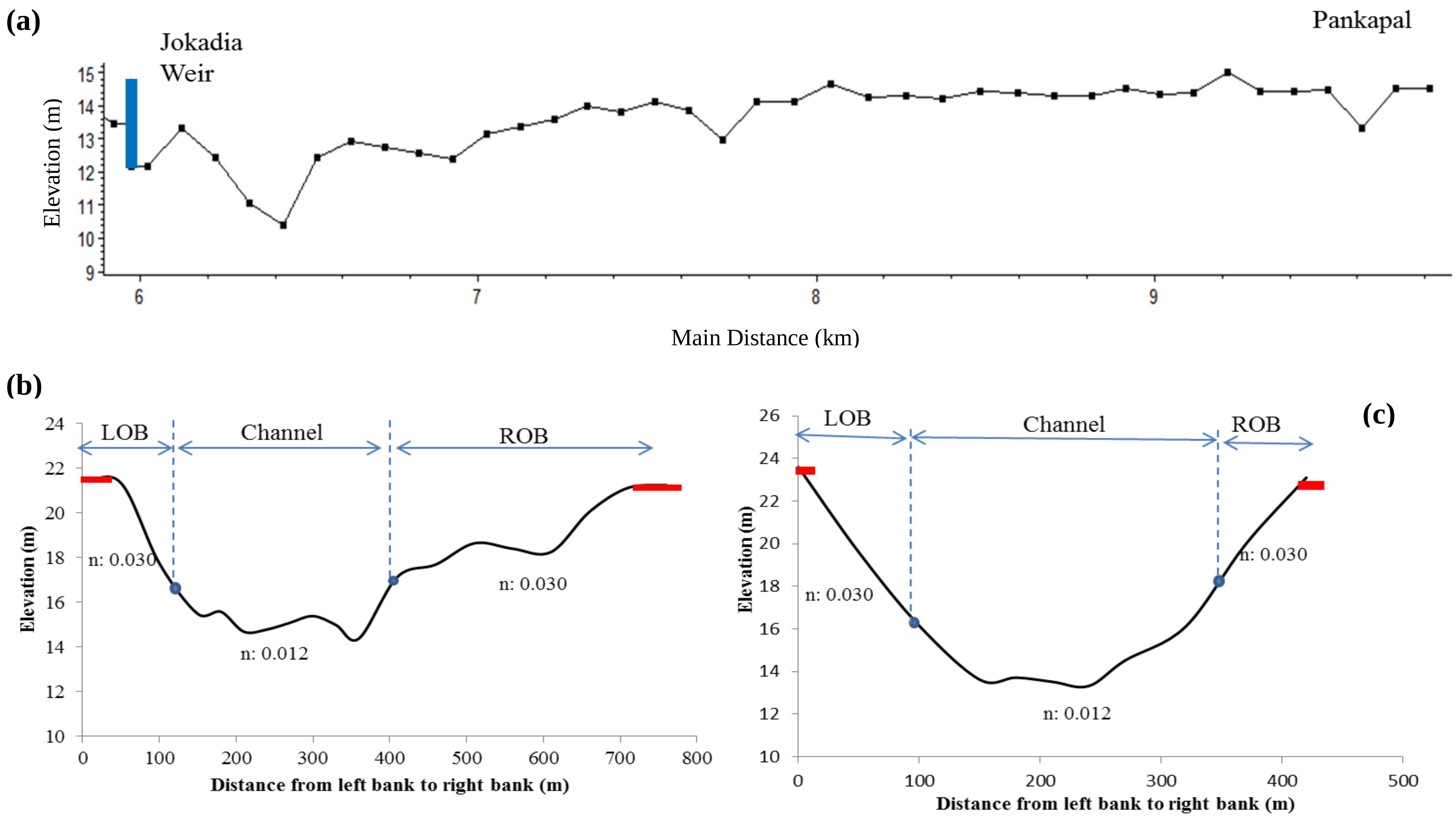
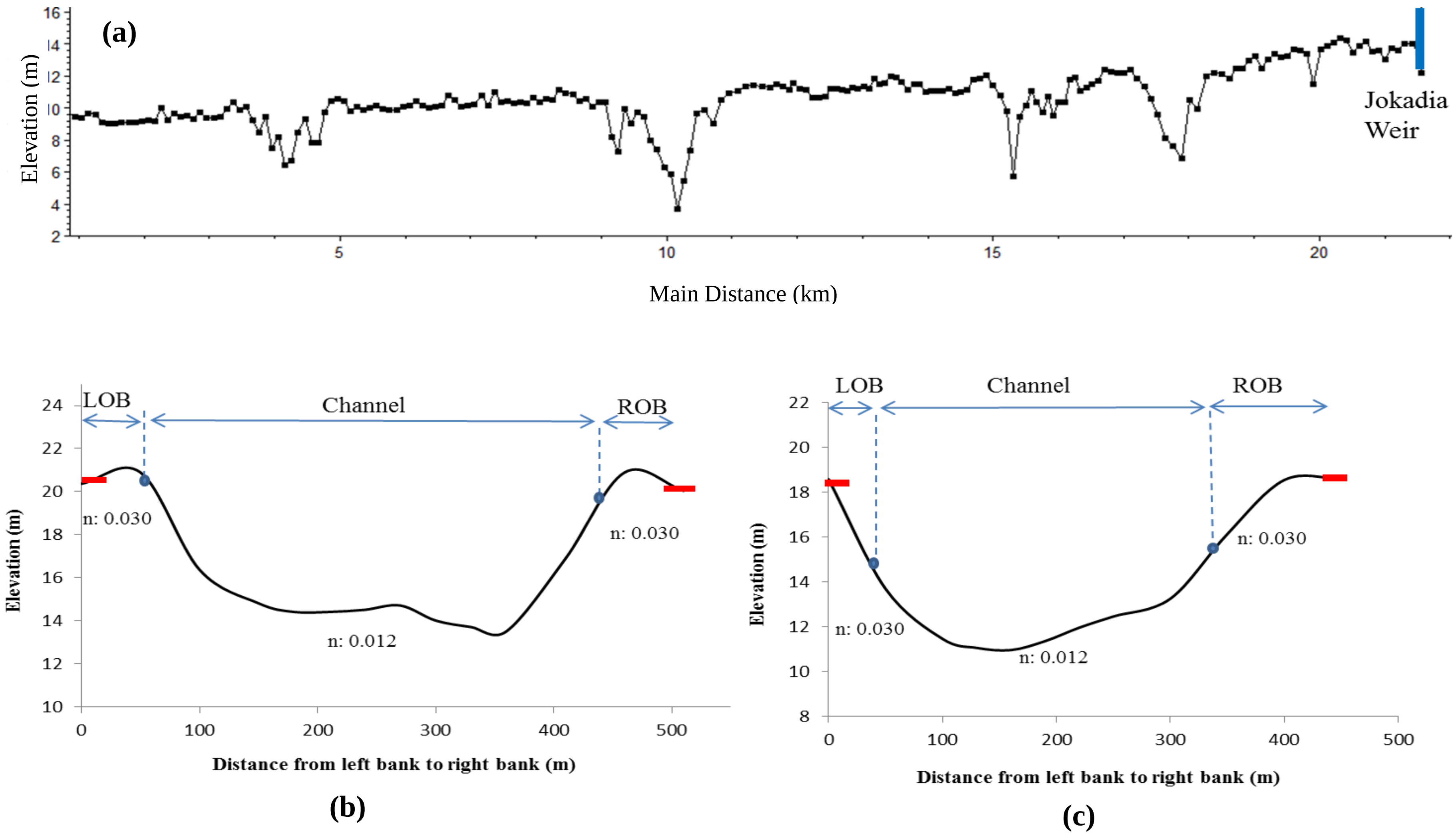


Figure 3.15: (a) Longitudinal profile of Kharsua river between Jokadia and Pankapal **(b)** Cross section of the Kharsua river at Pankapal **(c)** Cross section of the Kharsua river at Jokadia



Figures 3.16: (a) Longitudinal profile of the Kharsua river between Jokadia to 7 km upstream of Sujanpur **(b)** Cross section of Kharsua river at downstream of Jokadia **(c)** Cross section at upstream of Sujanpur

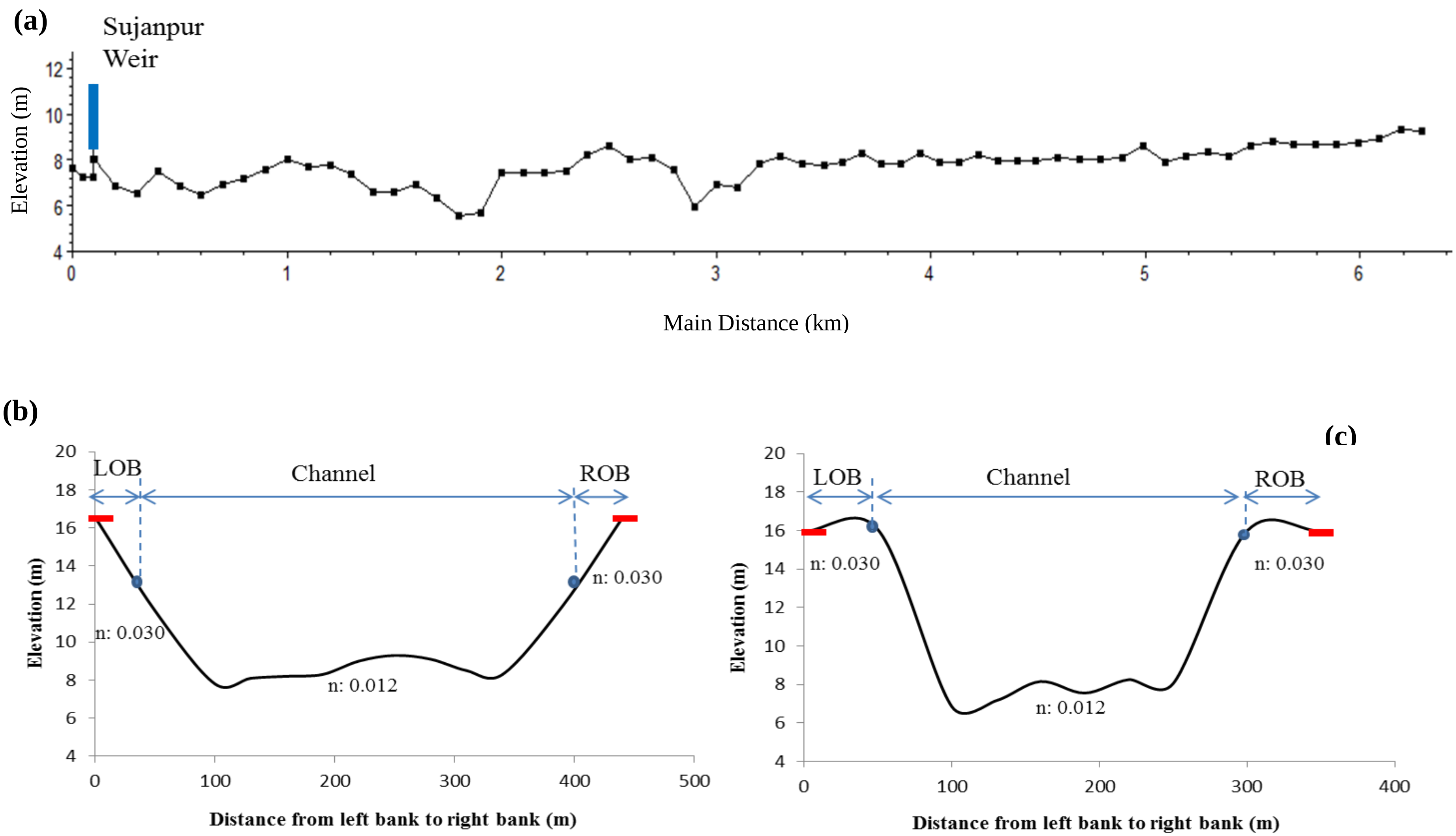


Figure 3.17: (a) Longitudinal profile of the Kharsua river at upstream of Sujanpur **(b)** Cross section of the Kharsua river at Kharsua – Tantigai bifurcation **(c)** Cross section of Tantigai river at Sujanpur

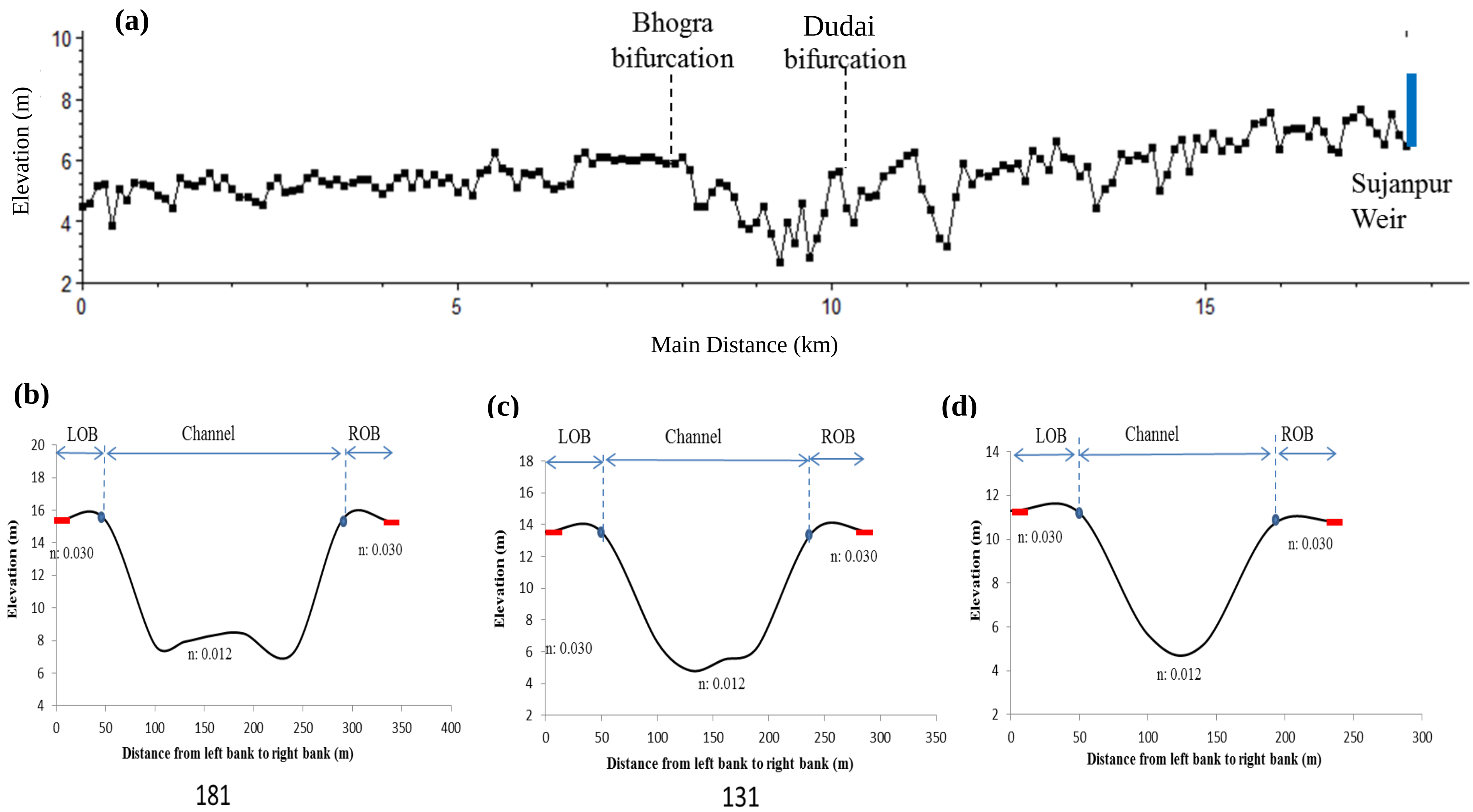


Figure 3.18: (a) Longitudinal profile of Tantigai – Dhaikia river **(b)** Cross section of Tantigai river downstream of Sujanpur **(c)** Cross section of Tantigai river at Tantigai – Dudai bifurcation **(d)** Cross section of the Dhaikia river

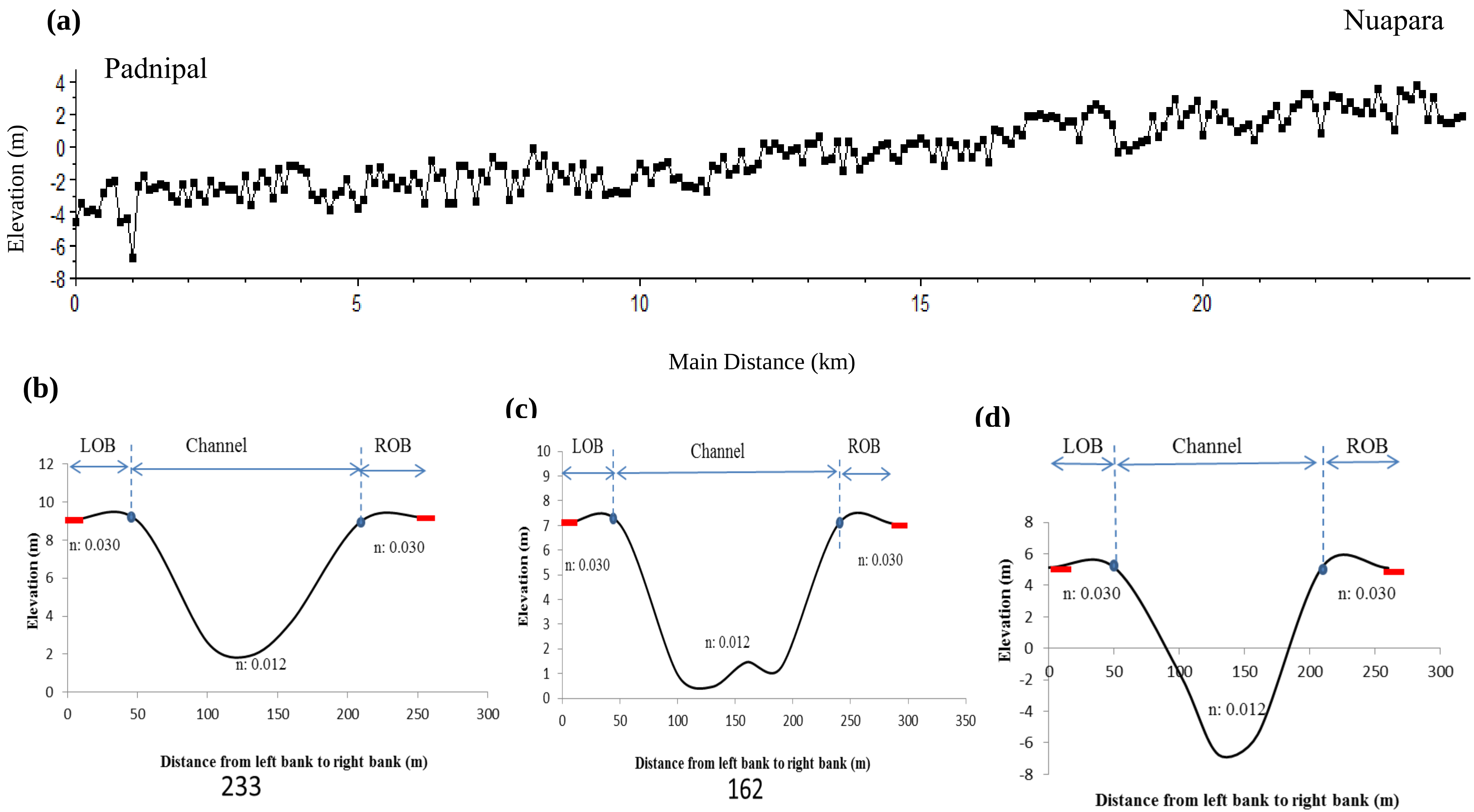


Figure 3.19 (a) Longitudinal profile of the Kani river **(b)** Cross section of Kani river at upstream **(c)** Cross section of Kani river **(d)** Cross section of Kani river at downstream

3.3 Acoustic Doppler Current Profiler (ADCP) Survey

ADCP survey was conducted during lean and flood season at all bifurcations in the study area to understand the velocity and discharge distribution and to find active channels in the river network. For this purpose SonTek river surveyor S_5 ADCP available with Civil Engineering Department IIT Guwahati was used. In total, 17 ADCP transects were made, at all the bifurcation locations (upstream and downstream of bifurcation) during monsoon and lean seasons. ADCP survey confirms that Brahmani (Pankapal)-Kharsua (Jokadia)-Tantigai (Sujanpur)-Dudai (Erda)-Kani carries more discharge and has reasonably high depths during lean and flood seasons. Flow chart showing discharge distribution along the different routes in Brahmani network during lean and monsoon season are shown in Figure 3.20 and 3.21. The ADCP survey transects at all locations are shown from Figures 3.22 to 3.38.

3.3.1 Velocity and Discharge variation during monsoon season

Brahmani-Kharsua Bifurcation

ADCP survey clearly shows that majority of Brahmani (Pankapal) flow is diverted towards Kharsua (Jokadia). During flood season out of 670 cumecs at Brahmani (Pankapal) 560 cumecs diverted towards Kharsua and 118 cumecs towards Brahmani (Jenapur). The velocity ranges between 0.2 to 1.2 m/sec at Pankapal, 0.1 to 1 m/sec at Brahmani (after bifurcation) and 0.5 to 1.5 m/sec in Kharsua.

Kharsua-Tantigai Bifurcation

From field observations and on referring to ADCP transect it is observed that large amount of flow is diverted towards River Tantigai. A discharge of 447 cumecs out of total 560 cumecs is flowing into this channel. As compared to Kharsua, Tantigai (Sujanpur) is relatively narrower, deeper having a depth up to 4.4 m and velocity ranges between 0.6 to 1.5 m/sec. The Kharsua river after bifurcation carried 113 cumecs with an average velocity of 1.018 m/sec.

Tantigai-Dudai Bifurcation

At this bifurcation, the discharge distribution is 220 cumecs towards Dudai and 223 cumecs towards Tantigai after bifurcation. The flow depths range up to 2.2 m in Dudai with average flow velocity of 0.63 m/sec. In Tantigai after bifurcation the same varied between 1.9 to 2.8 m and 0.73 m/sec.

Tantigai-Dhaikia-Bhogra Bifurcation

The rivers Dhaikia and Bhogra carried nearly equal amount of discharge after bifurcation. The discharge in Dhaikia is 113 cumecs and Bhogra is about 109 cumecs. The average flow velocity range is up to 0.6 m/sec in both these rivers.

3.3.2 Velocity and Discharge variation during lean season

Kharsua-Tantigai Bifurcation

ADCP survey conducted during lean season shows that, majority of lean season discharge is diverted towards Tantigai River after bifurcation. From a total 60 cumecs Kharsua discharge, 57 cumecs is flowing into Tantigai (Sujanpur) and 3 cumecs towards Kharsua (after bifurcation). The depths in Tantigai (Sujanpur) varied up to 3.1 m and average flow velocity is about 0.27 m/s.

Tantigai-Dudai Bifurcation

At this transect, the discharge distribution is higher towards Dudai than Tantigai river after bifurcation. Out of 57 cumecs, 37 cumecs is flowing into Dudai, in which depth ranges up to 1.5 m and average flow velocity is 0.5 m/s. Tantigai, after bifurcation is carrying 23 cumecs discharge for a flow velocity of 0.15 m/s and depth up to 0.95 m.

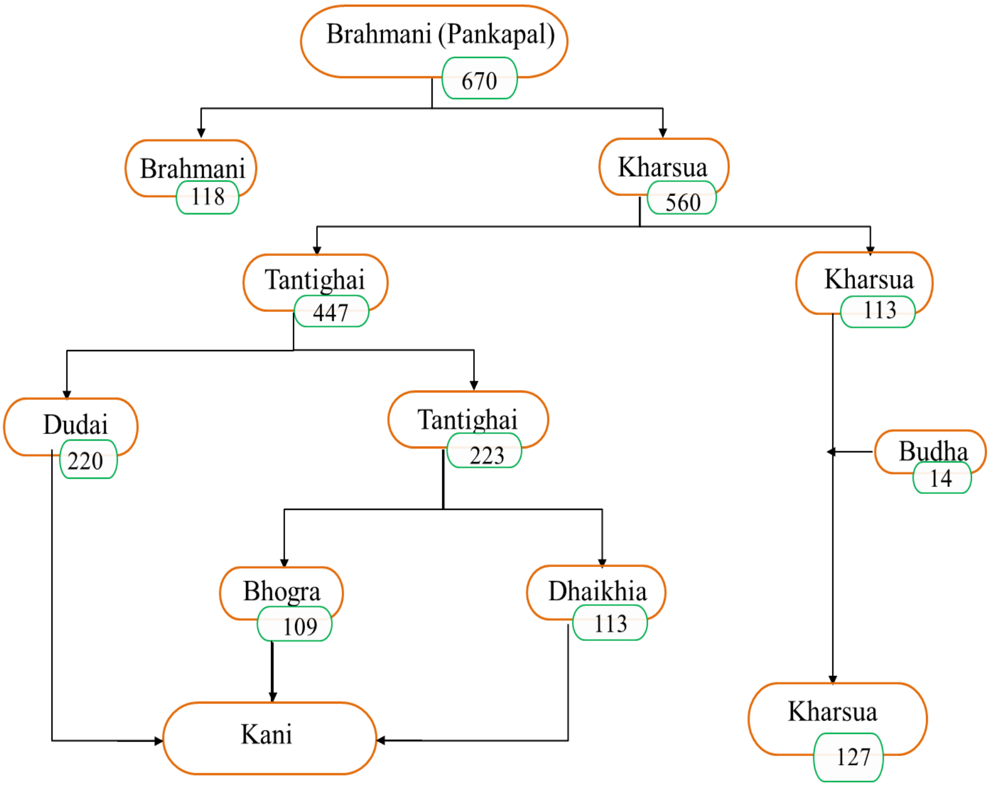


Figure 3.20: ADCP survey flow distribution during monsoon

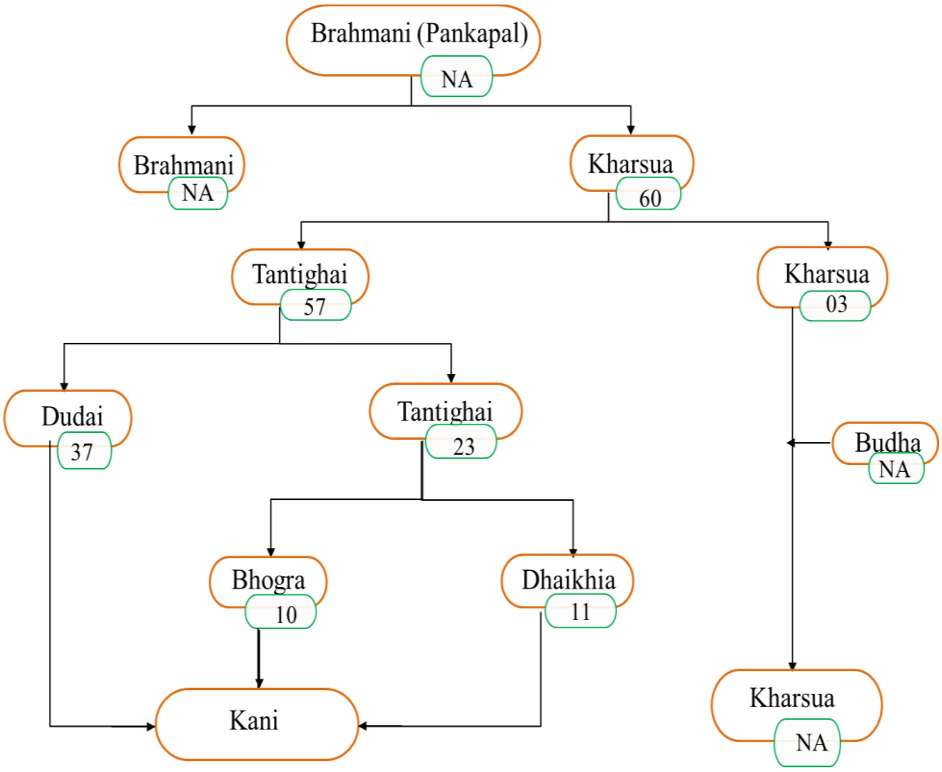
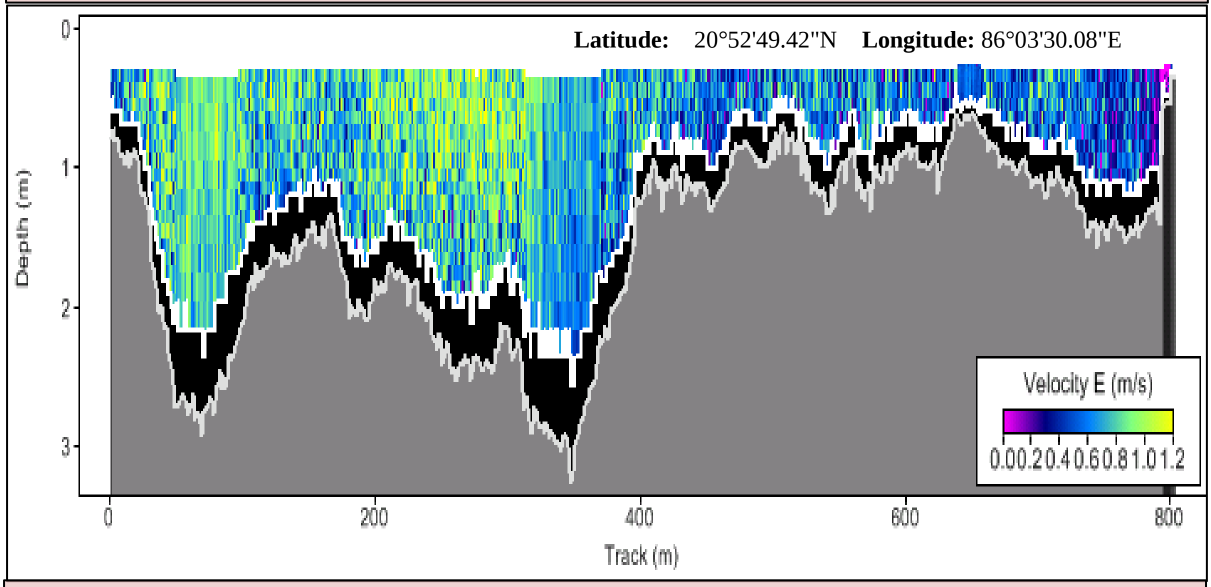


Figure 3.21: ADCP survey flow distribution during lean

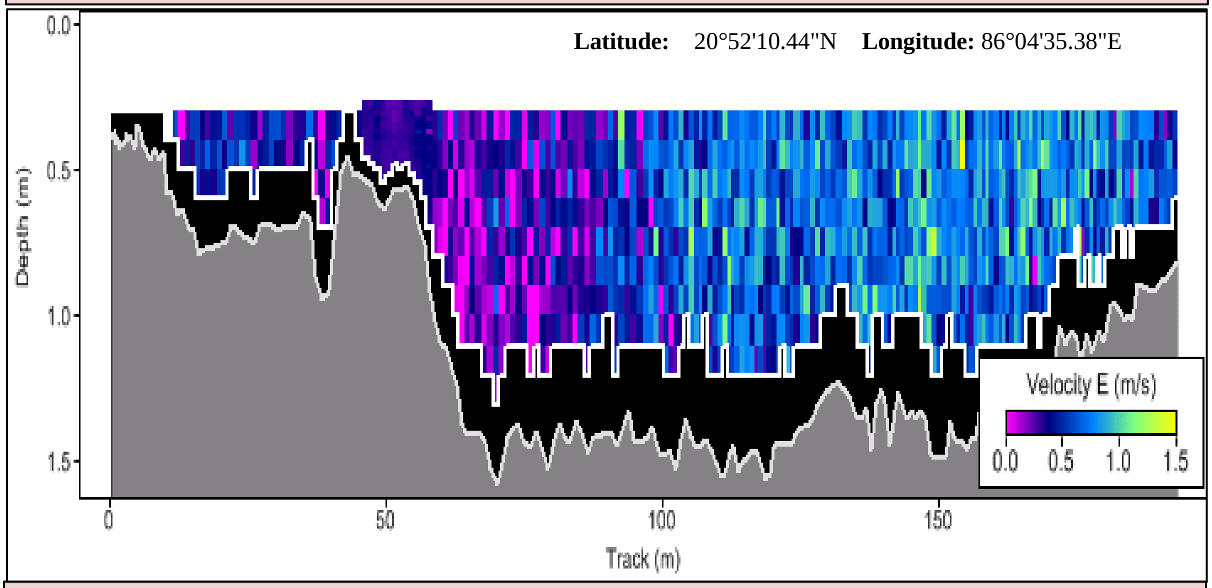
Name: Brahmani (Pankapal) **Date of ADCP survey:** 13th August, 2015



Q: 670.51 m^3/s V_{avg}: 0.242 m/s **D:** 0.6 to 3.2 m

Figure 3.22: ADCP survey transect showing velocity distribution of Brahmani river at Pankapal during monsoon

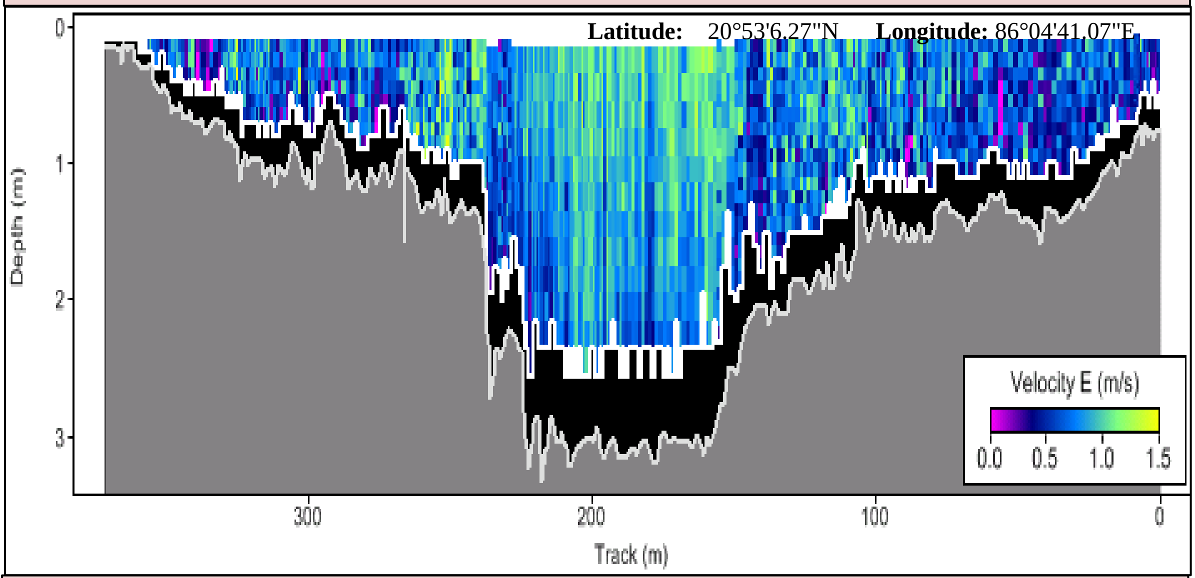
Name: Brahmani (Jenapur) **Date of ADCP survey:** 13th August, 2015



Q: 119.04 m^3/s V_{avg}: 0.636 m/s **D:** 0.4 to 1.6 m

Figure 3.23: ADCP survey transect showing velocity distribution of Brahmani river after bifurcation during monsoon

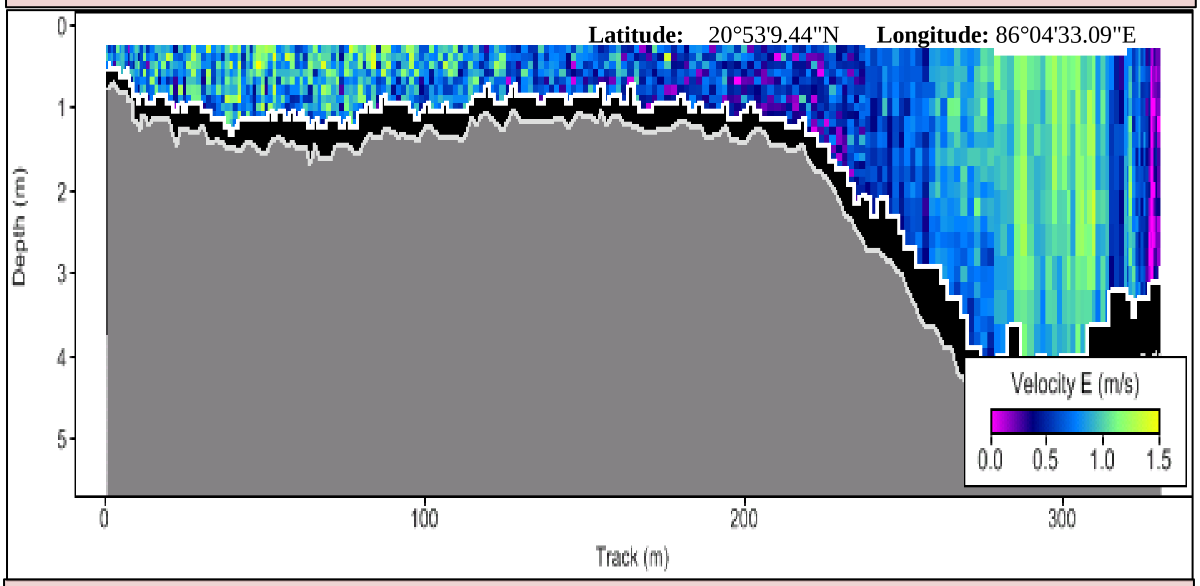
Name: Kharsua **Date of ADCP survey:** 13th August, 2015



Q: 566.10 m^3/s **V_{avg}:** 0.542 m/s **D:** 0.1 to 3.3 m

Figure 3.24: ADCP survey transect showing velocity distribution at Kharsua river during monsoon

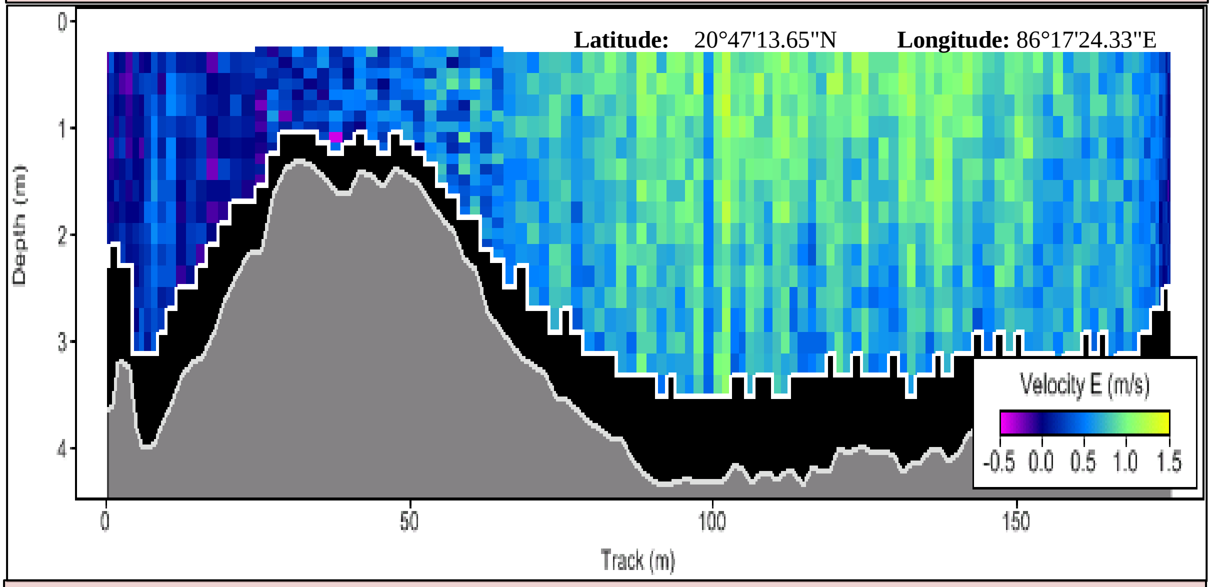
Name: Kharsua (Pankapal) **Date of ADCP survey:** 14th August, 2015



Q: 579.76 m^3/s **V_{avg}:** 0.136 m/s **D:** 0.8 to 5.5 m

Figure 3.25: ADCP survey transect showing velocity distribution of Kharsua river at Pankapal during monsoon

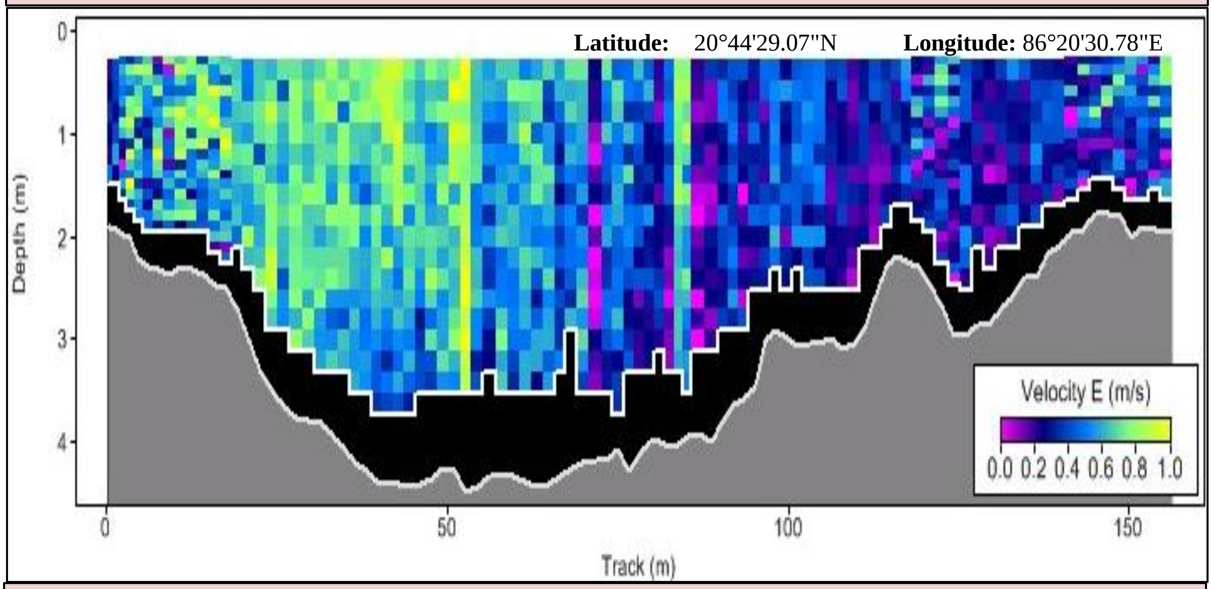
Name: Tantigai (Sujanpur) **Date of ADCP survey:** 14th August, 2015



Q: 453.31 m^3/s **V_{avg}:** 0.664 m/s **D:** 1.6 to 4.2 m

Figure 3.26: ADCP survey transect showing velocity distribution of Tantigai river at Sujanpur during monsoon

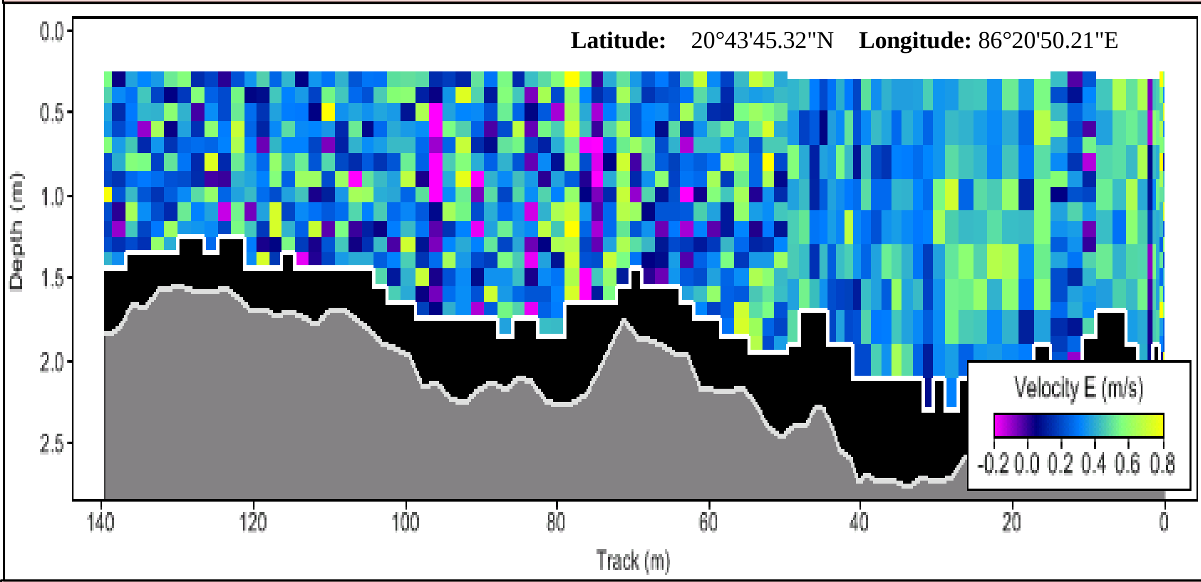
Name: Tantigai **Date of ADCP survey:** 14th August, 2015



Q: 447.0 m^3/s **V_{avg}:** 0.624 m/s **D:** 1.8 to 4.4 m

Figure 3.27: ADCP survey transect showing velocity distribution at Tantigai river during monsoon

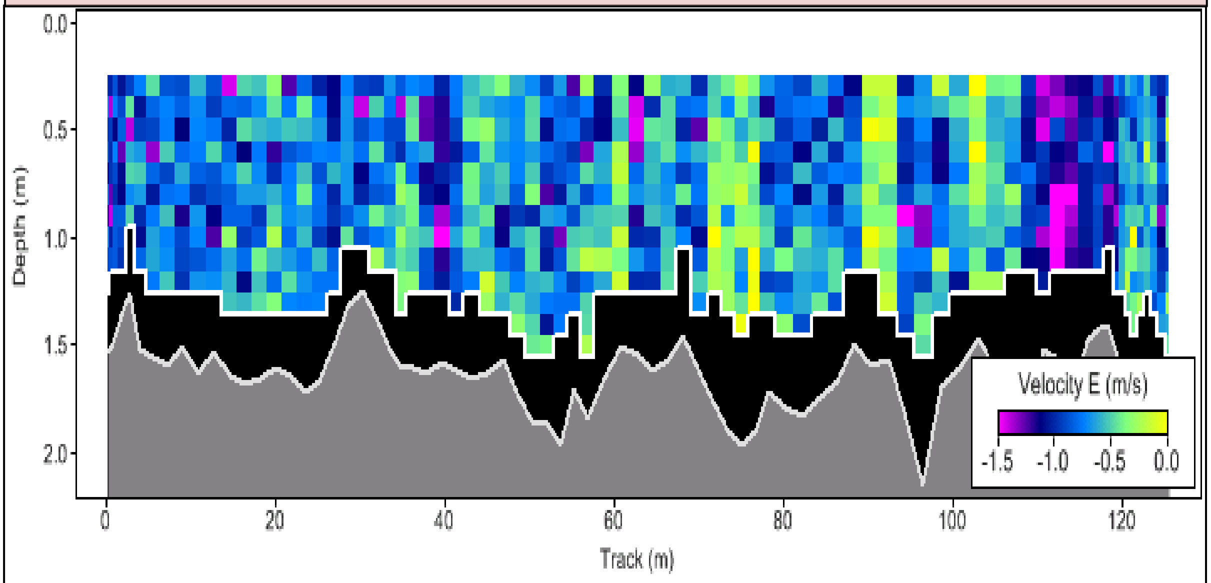
Name: Tantigai after Dudai bifurcation **Date of ADCP survey:** 14th August, 2015



Q: 222.50 m^3/s **V_{avg}:** 0.733 m/s **D:** 1.9 to 2.8 m

Figure 3.28: ADCP survey transect showing velocity distribution at Tantigai river after Dudai bifurcation during monsoon

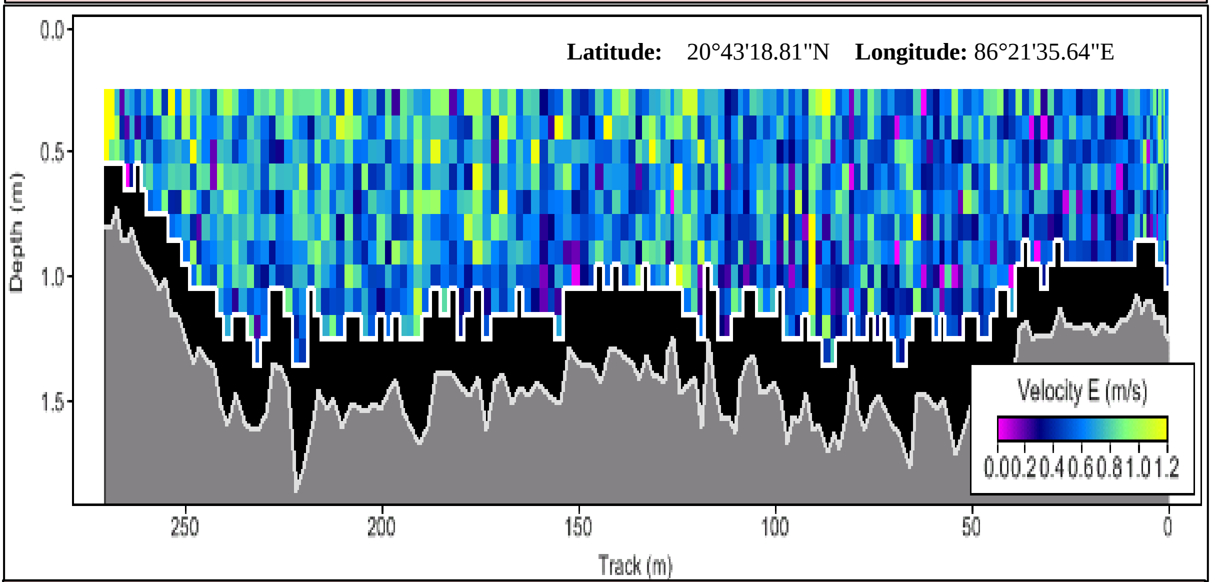
Name: Dudai (Erda) **Date of ADCP survey:** 14th August, 2015



Q: 220.95 m^3/s **V_{avg}:** 0.633 m/s **D:** 1.5 to 2.2 m

Figure 3.29: ADCP survey transect showing velocity distribution at Dudai (Erda) during monsoon

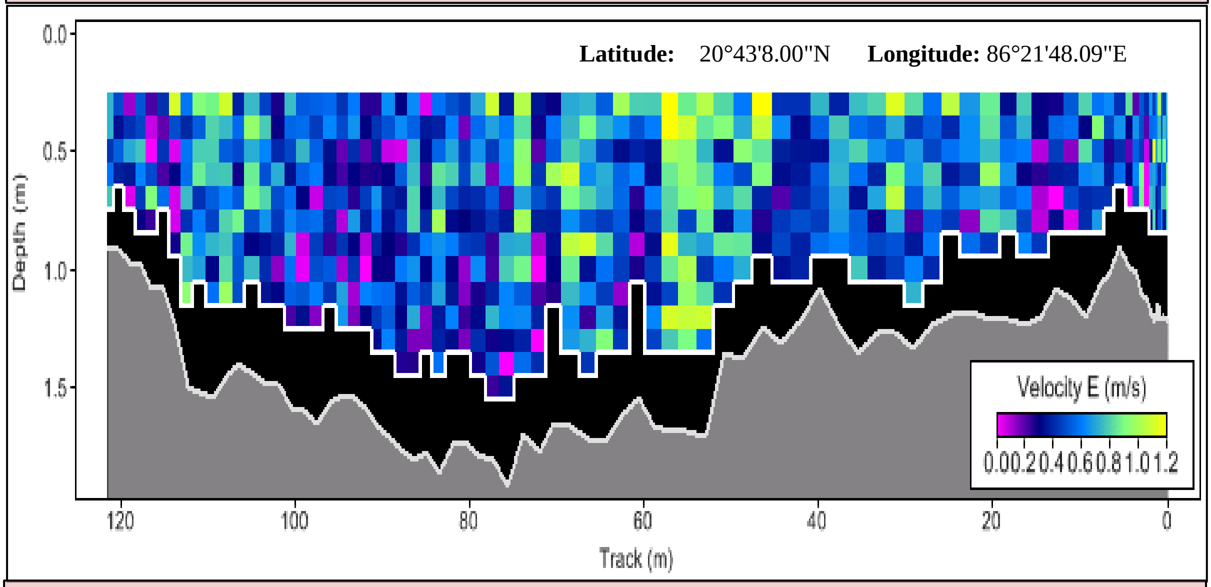
Name: Tantigai before Bhogra bifurcation **Date of ADCP survey:** 14th August,2015



Q: 230.42 m^3/s **V_{avg}:** 0.449 m/s **D:** 0.7 to 1.8 m

Figure 3.30: ADCP survey transect showing velocity distribution at Tantigai river before Bhogra bifurcation during monsoon

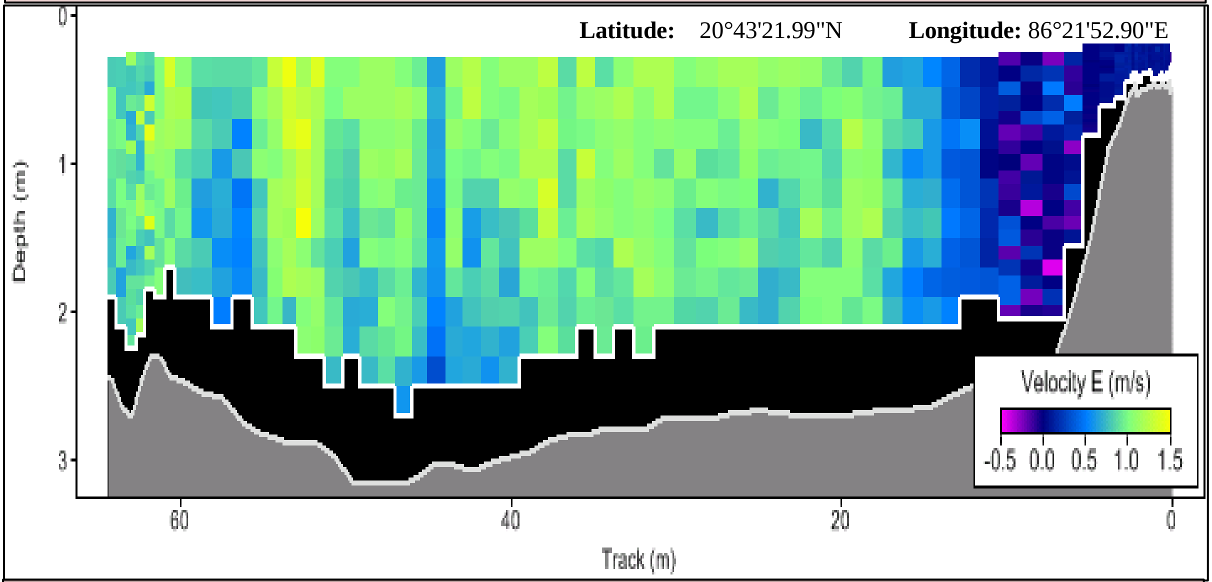
Name: Bhogra **Date of ADCP survey:** 14th August, 2015



Q: 113.91 m^3/s **V_{avg}:** 0.681 m/s **D:** 0.7 to 1.8 m

Figure 3.31: ADCP survey transect showing velocity distribution at Bhogra during monsoon

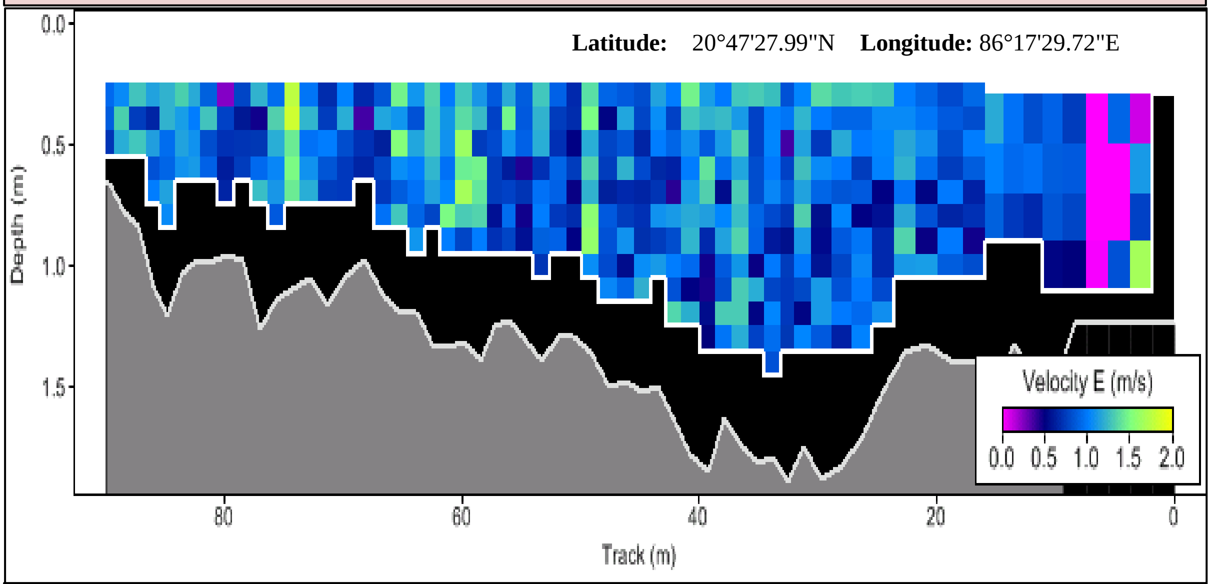
Name: Dhaikia **Date of ADCP survey:** 14th August, 2015



Q: 109.92 m^3/s **V_{avg}:** 0.603 m/s **D:** 2.4 to 3.1 m

Figure 3.32: ADCP survey transect showing velocity distribution at Dhaikia river during monsoon

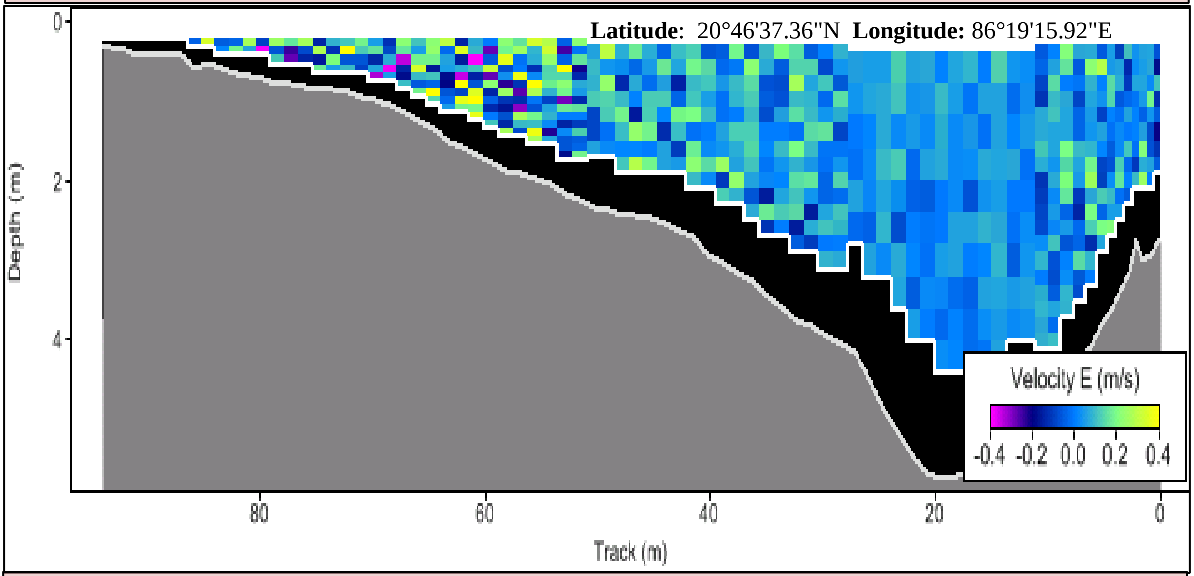
Name: Kharsua after Sujanpur **Date of ADCP survey:** 14th August, 2015



Q: 113.01 m^3/s **V_{avg}:** 1.018 m/s **D:** 0.6 to 2.0 m

Figure 3.33: ADCP survey transect showing velocity distribution at Kharsua river after bifurcation during monsoon

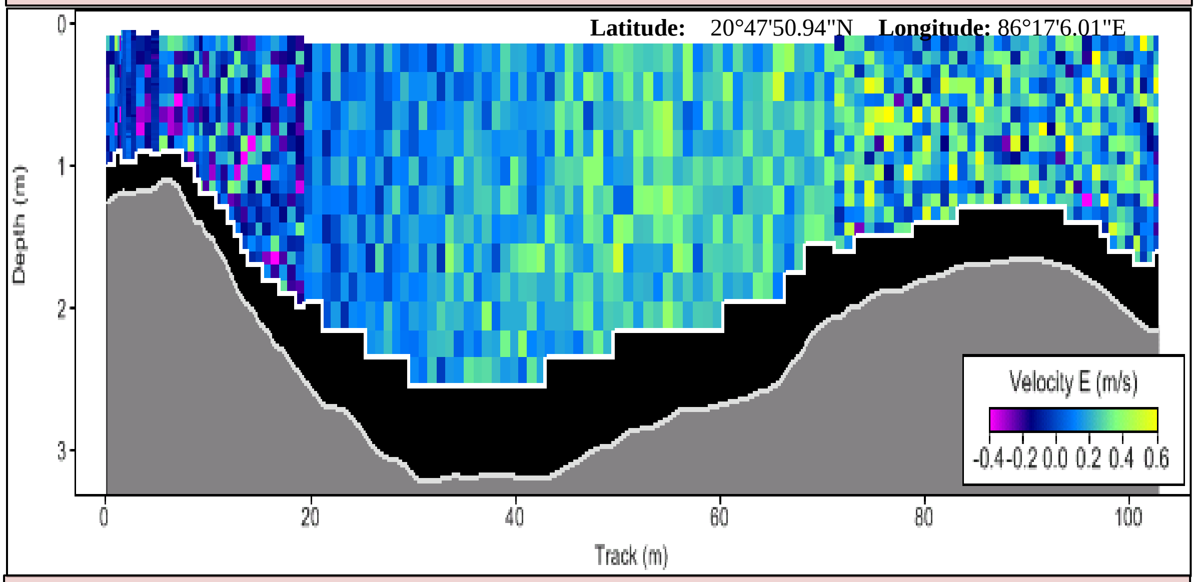
Name: Budha **Date of ADCP survey:** 14th August, 2015



Q: 14.19 m^3/s **V_{avg}:** 0.020 m/s **D:** 0.1 to 6.0 m

Figure 3.34: ADCP survey transect showing velocity distribution at Budha river during monsoon

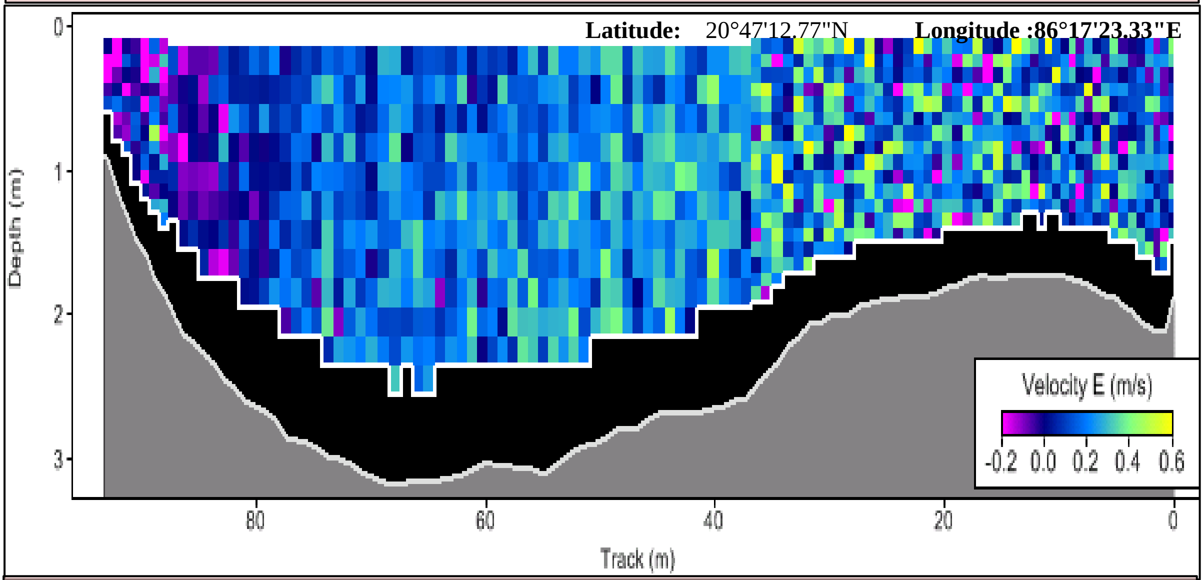
Name: Kharsua **Date of ADCP survey:** 12th November, 2015



Q: 60.74 m^3/s **V_{avg}:** 0.132 m/s **D:** 1.2 to 3.2 m

Figure 3.35: ADCP survey transect showing velocity distribution of Kharsua river at upstream of Kharsua- Tantigai bifurcation during lean

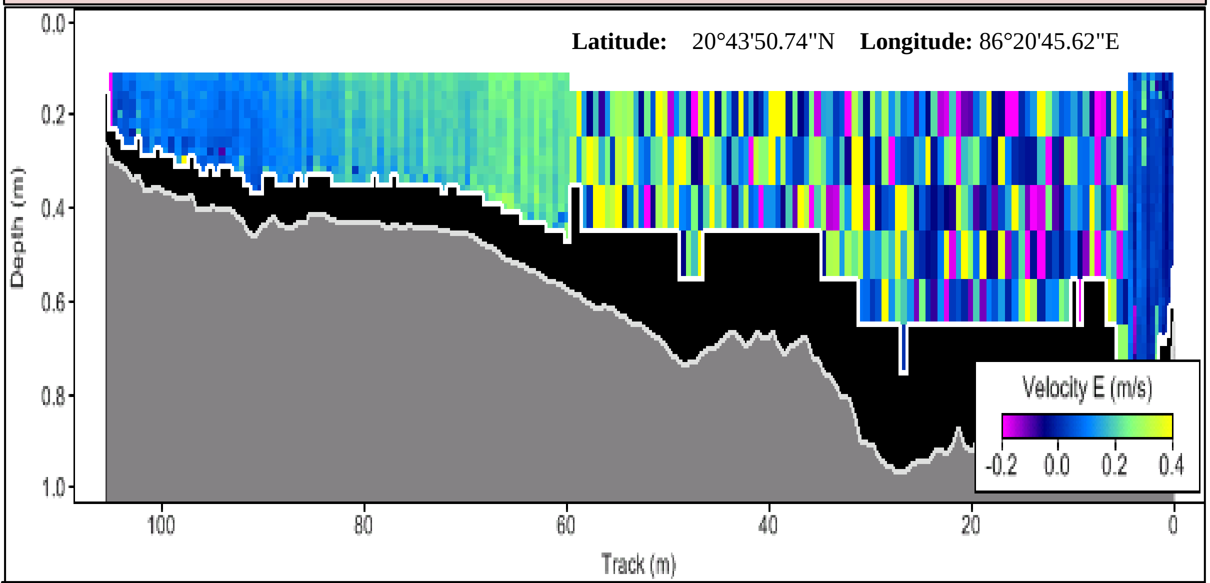
Name: Tantigai (Sujanpur) **Date of ADCP survey:** 12th November, 2015



Q: 57.22 m^3/s **V_{avg}:** 0.275 m/s **D:** 0.9 to 3.1 m

Figure 3.36: ADCP survey transect showing velocity distribution of Tantigai river at Sujanpur during lean

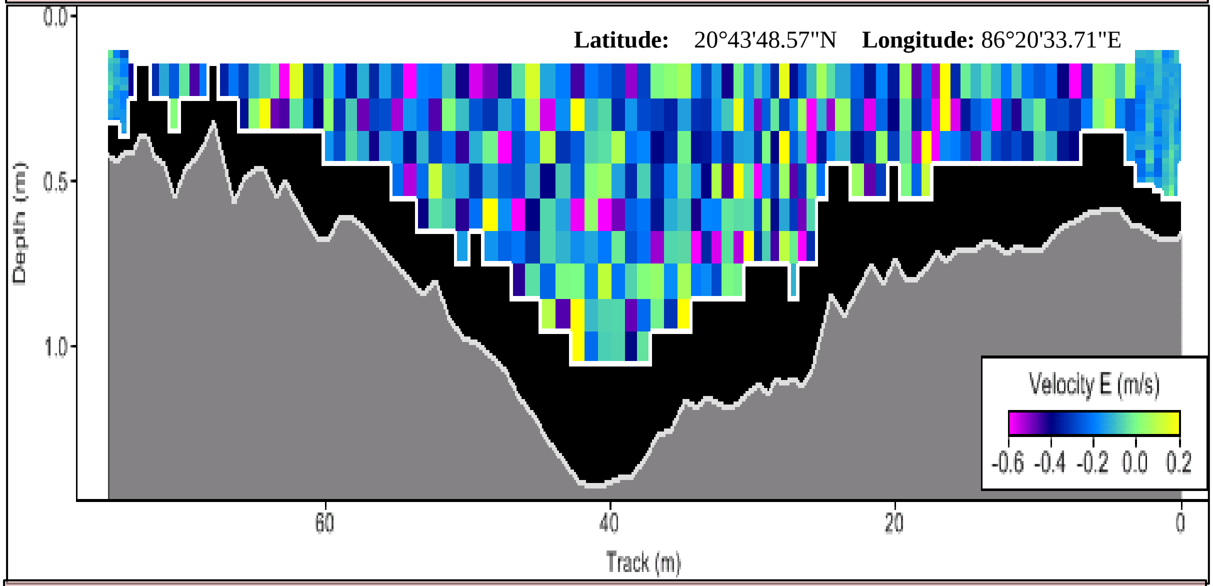
Name: Tantigai after Dudai bifurcation **Date of ADCP survey:** 12th November, 2015



Q: 22.86 m^3/s **V_{avg}:** 0.150 m/s **D:** 0.22 to 0.95 m

Figure 3.37: ADCP survey transect showing velocity distribution at Tantigai river after Dudai bifurcation during lean

Name: Dudai **Date of ADCP survey:** 12th November, 2015



Q: 37.26 m^3/s **V_{avg}:** 0.508 m/s **D:** 0.40 to 1.50 m

Figure 3.38: ADCP survey transect showing velocity distribution at Dudai river during lean season

***Note: Q:** Total Discharge, **V_{avg}:** Average velocity, **D:** Depth range

3.4 Analysis of soil and sediment samples

The soil samples from the river bed were collected at various locations of Brahmani river network. It is observed that the soil material is mostly composed of fine sand. The laboratory analysis of bed sample is carried out by performing sieve analysis. The particle size distribution curve of bed sample at Kharsua (Pankapal) is shown in Figure 3.39. Table 3.3.shows the representative diameter (d_{50}) and corresponding roughness parameters of bed samples collected at various locations of the river reach.

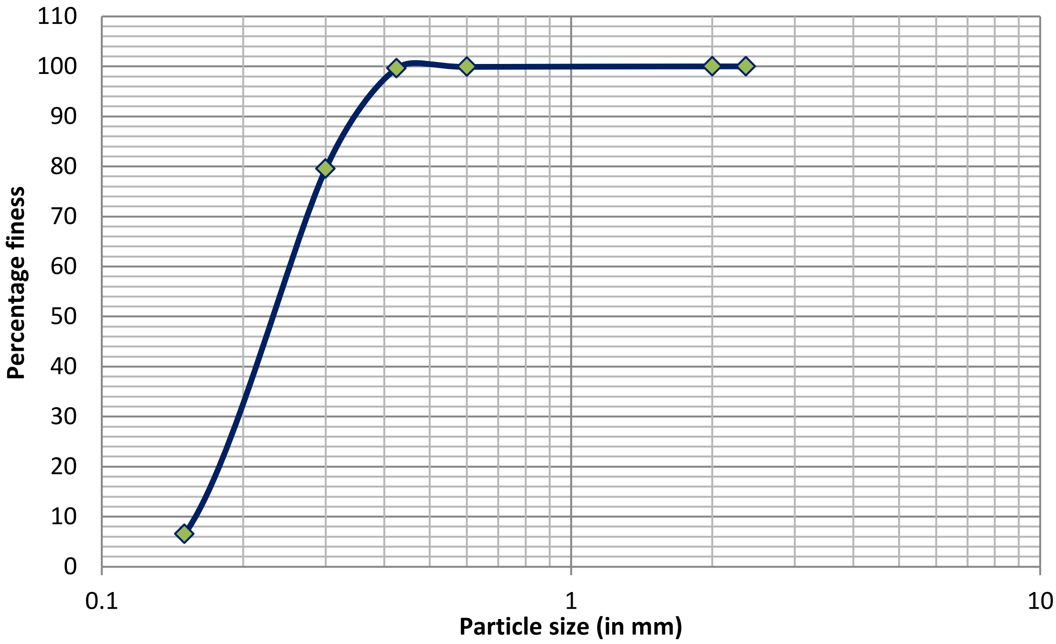


Figure 3.39: Particle size distribution curve of bed sample at Kharsua

Table 3.3 Laboratory analysis of bed samples and corresponding roughness parameters

S. No	Bed sample	Bed sample	
		D_{50} (mm)	Roughness parameter 'n'
1	Kharsua (Pankapal)	0.230	0.012
2	Kharsua (Jokadia)	0.200	0.012
3	Kharsua (Sujanpur)	0.210	0.012
4	Tantigai	0.225	0.012

3.5 Historical Flood Records

During the field visit to Jenapur and Jokadia weirs, there series of flood marks on the gauge level recorded at these locations were observed. There are two High Flood Levels (HFL) recorded at Jenapur weir, one is 72.10 (21.976 MSL) occurred in 2011 and other 70.50 (21.4884 MSL) occurred in 2006. Similarly at Jokadia weir there are three HFL values marked on gauge readings. First HFL recorded in 1894 was 69.10 (21.06 MSL), second was 70.0 (21.33 MSL) in 1897 and third HFL was 72.8 (22.18 MSL) observed in 1980. Figure 3.40 (a) and (b) shows the field photograph of gauge readings at Jenapur and Jokadia weir.

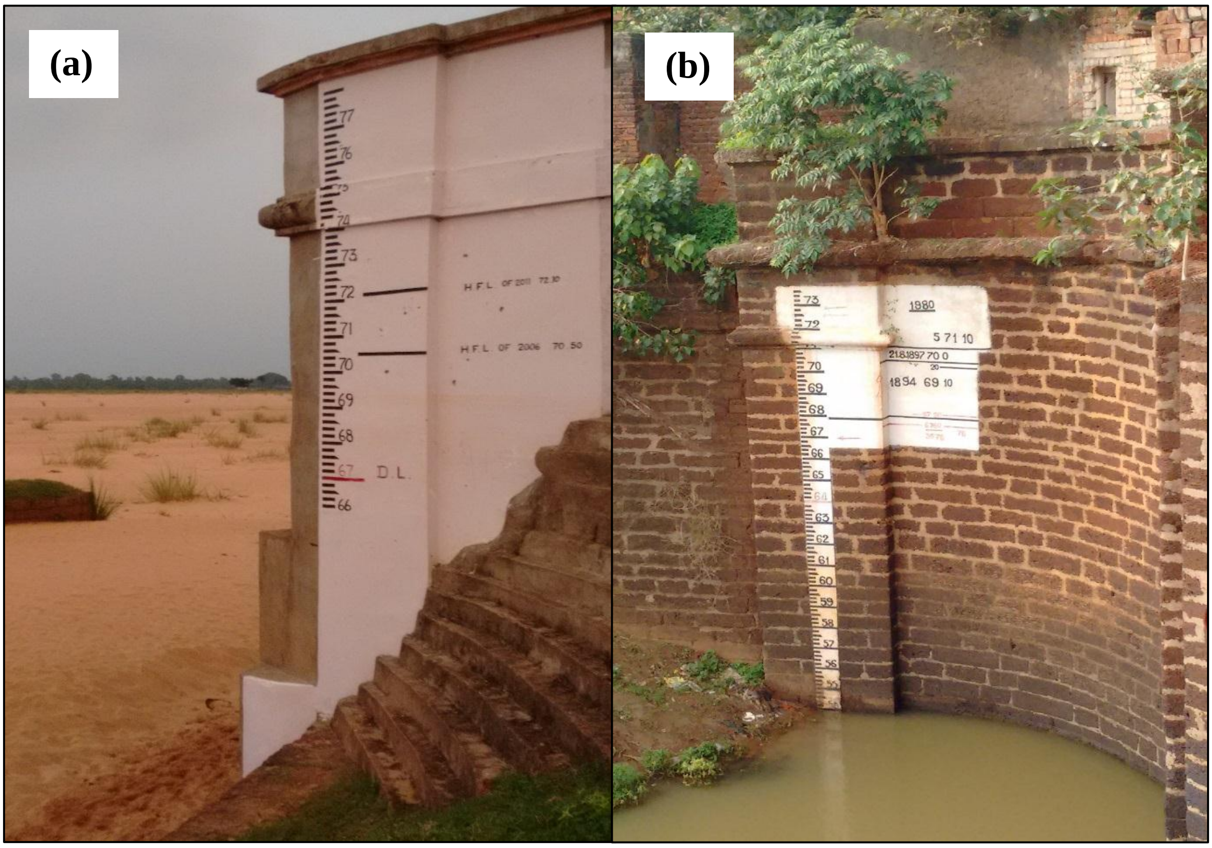


Figure 3.40: Historical flood marks at **(a)** Jenapur and **(b)** Jokadia

Chapter 4
Mathematical Modeling

4.1 HEC-RAS River Model

In this study 1D hydrodynamic model known as HEC-RAS, version 4.1 is used. HEC-RAS is developed by the Hydrologic Engineering Centre for the U.S. Army Corps of Engineers. HEC-RAS 4.1 allows user to perform one dimensional steady, unsteady flow analysis, movable sediment transport and water quality analysis. It is designed to perform one-dimensional hydraulic calculations for a combined network of natural and man-made channels. The model is capable of incorporating weirs, barrage, bridges and other structures along the river network. It numerically solves energy equation for steady flow analysis and the Saint-Venant equations for unsteady flow analysis for a complex river network. The model enables us to simulate sub-critical, super-critical and mixed flow regime calculations. In steady flow analysis the model computes water surface profiles using energy equation with iterative standard step procedure. The basic energy equation is

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_l \qquad (4.1)$$

Z_1, Z2 = elevation of main channel inverts

Y_1, Y_2 = depth of water at cross sections

V_1, V_2 = average velocities

h_l= energy head loss and α_1 α_2 = weighted velocity coefficients

In case of unsteady flow analysis the model computes water surface profiles by solving set of partial differential equations representing mass and momentum conservations at the control volume. The governing equations i.e. continuity and momentum equations are listed below

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0 \tag{4.2}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial Z}{\partial x} + S_f\right) = 0 \tag{4.3}$$

A=Total flow area

q_l=lateral flow per unit length

S_f= friction slope

4.2 Modeling Procedure

The bathymetry and topographic survey data of Brahmani river network provided by IWAI Noida are used in setting up HEC-RAS model. The model is set up piece wise for entire river network from Pankapal (Jokadia) to Padnipal with 100 m interval (c/c) cross sections along the reach. The piece wise setups along the Kharsua (Jokadia) - Tantigai (Sujanpur)-Dhaikia-Kani route include

a. Kharsua (Pankapal) to Kharsua (Jokadia)
b. Downstream of Kharsua (Jokadia) to 7 KM upstream of Sujanpur
c. Kharsua-Tantigai (Sujanpur) Bifurcation
d. Tantigai (Sujanpur)- Tantigai-Dhaikia
e. Kani river till Padnipal

The existing barrages (Jokadia and Sujanpur) and new structures (barrages and check dams) are incorporated in the model at different locations of the river. The roughness coefficients used at bed and bank are computed from grain size analysis (Section 4 e) and field observation study. The ADCP surveyed discharge data during lean and flood season at different bifurcations is used for setting initial and flow boundary conditions in the model.

Other boundary conditions like initial flow distribution, bed slope are incorporated for complete model preparation. Further the model set up is calibrated and validated with ADCP surveyed depths and velocity data to evaluate its performance. The calibrated model is then used for performing steady and unsteady flow analysis to simulate the effect of proposed weirs/barrages in the river network. The hydraulic parameters like flow depth, width and effect of weir along the reach are analyzed and then location and height of the weir is revised.

The model setups are also simulated for 100 years flood to study the impact of flooding and its effect on existing embankments. The 100 years flood computed for Brahmani (Pankapal) is distributed to downstream reaches based on flow bifurcation ratio (discussed in Chapter 2) and steady simulation is carried out. The maximum water level for 100 years flood at weir locations is compared with embankment levels and accordingly revision in existing height and/or raising new embankments along the proposed route is suggested. The detailed discussion on simulation results is presented in following chapter.

4.3 Evaporation and Seepage losses

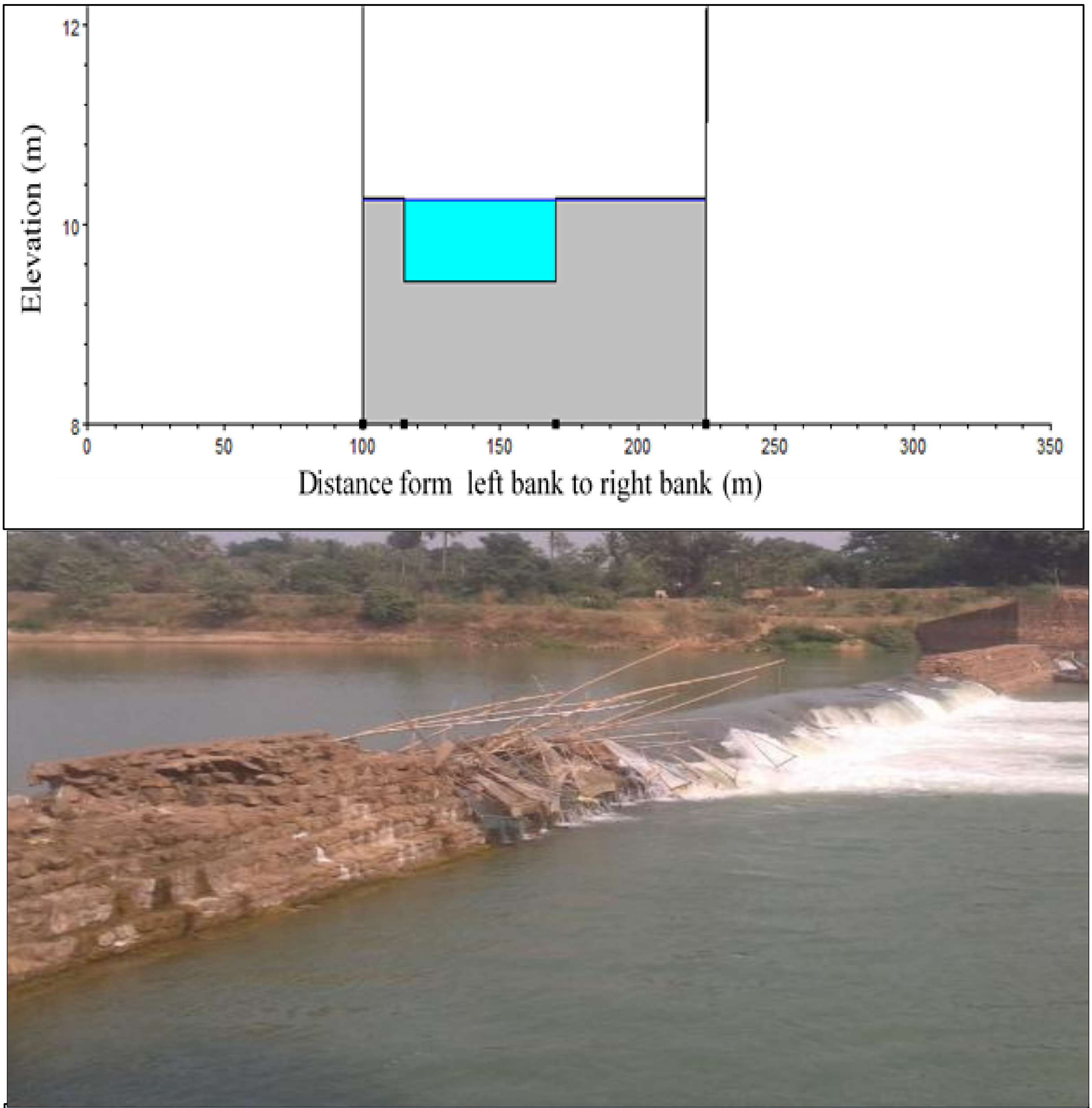
In tropical climate regions, evaporation and seepage loss play a major role in design of hydraulic structures. Evaporation loss occurs from pooling systems and seepage loss through bed and sides of channel. These losses significantly reduce the designed navigational depths above the barrage/weir. Therefore, these losses need to be accommodated in design of hydraulic structures used for pooling. In the present study, an additional height of 0.6 m for evaporation loss and 0.15 m for seepage loss is accounted for the proposed height of barrages. The evaporation loss is computed by taking average monthly pan evaporation at Hirakud Research station as reference.

4.4 HEC-RAS Model Calibration and Validation

The model calibration is carried out for natural river conditions without incorporating any proposed structures. The HEC-RAS model is setup with the required input data and simulated for steady discharges obtained during ADCP survey conducted in monsoon and lean period. The water depths and average velocity recorded at these transects are calibrated with the model simulated water depths and average velocity at the same locations by varying roughness parameter. Table 4.1 shows the details of the ADCP measured discharges, averaged observed and simulated (calibrated model) hydraulic parameters at different locations of the river network. It can be found that the simulated water depths and velocities are within the range of measured hydraulic parameters. Not only that, the model simulated flow depth over the existing Jokadia and Sujanpur weir are found to be in the similar range for the field observed depths at that locations. Therefore, the model set-up can be used for further analysis.

Table 4.1: Observed and Simulated water depths and velocities

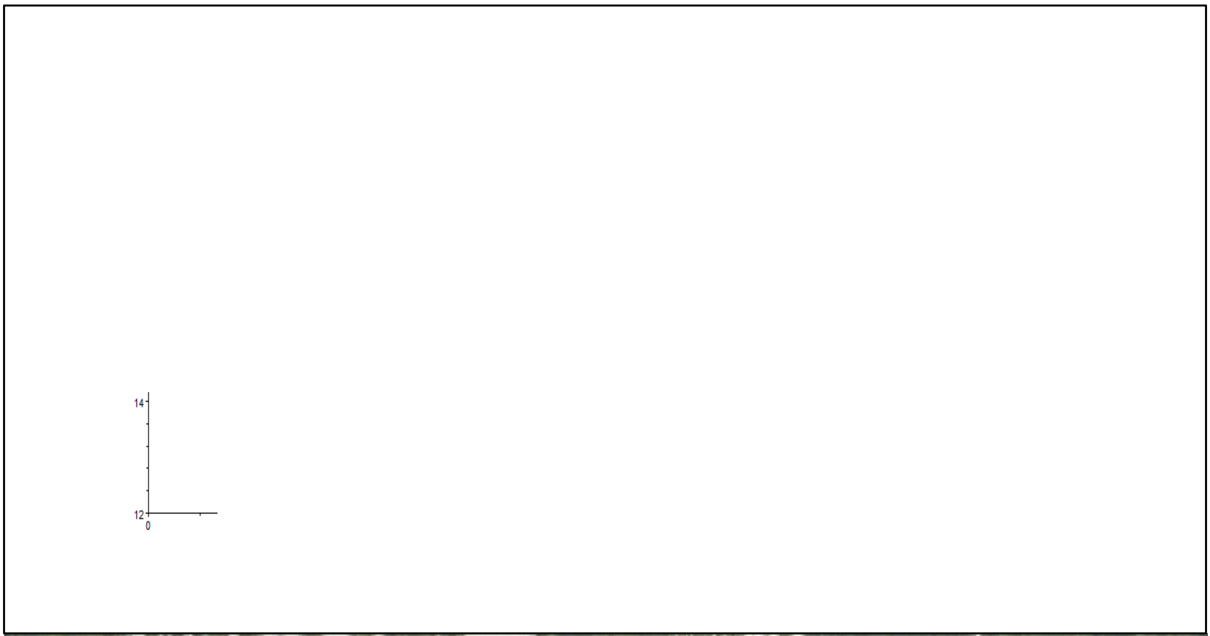
Transect	River Reach	Season	Discharge (cumecs)	Water Depths (m)		Average Velocity (m/sec)	
				Simulated	Observed	Simulated	Observed
1	Tantigai (Sujanpur)	Monsoon	447	3.15	2.9	0.59	0.66
2	Tantigai (Erda)	Monsoon	447	3.5	3.1	0.55	0.62
3	Kharsua	Lean	60	2.08	2.2	0.17	0.13
4	Tantigai (Erda)	Lean	22	1.5	1.2	0.12	0.15



Source: Field Photograph
Name: Sujanpur Weir

Location 20°47'08.13" N
86°17'24.58" E

Figure 4.1: HEC-RAS Model Calibration with Field Survey Data at Sujanpur Location on Tantigai River



Source: Field Photograph
Name: Jokadia Weir
Location: 20°53'24.67" N 86°06'35.19" E

Figure 4.2: HEC-RAS Model Calibration with Field Survey Data at Jokadia Location on Kharsua River

Chapter 5
Hydrodynamic Model Results

The bathymetry and topographic survey data of Brahmani river network is used in setting up HEC-RAS model. The model set up is carried out piece wise for entire river network from Pankapal (Jokadia) to Padnipal with 100 m interval (c/c) cross sections along the reach. The piece wise setups along the Kharsua (Jokadia) - Tantigai (Sujanpur)-Dhaikia- Kani route include

a. Kharsua (Pankapal) to Kharsua (Jokadia)
b. Kharsua (Jokadia) to 7 km upstream of Sujanpur
c. Kharsua-Tantigai (Sujanpur) Bifurcation
d. Tantigai (Sujanpur)- Tantigai-Dhaikia
e. Kani river till Padnipal

5.1 Kharsua (Pankapal) to Kharsua (Jokadia) segment

5.1.1 Rise of weir crest height at Jokadia

The impact of rising Jokadia barrage and its effect on flow depth and submergence is reported in this section. The stretch considered is Kharsua river from Jokadia barrage to Pankapal covering a total length of 4.0 km. The hydrodynamic model HEC-RAS is setup with total 40 surveyed cross sections with an average interval of 100 m c/c. Figure 5.1 shows the geometric network of the river reach prepared in the HEC-RAS for the present segment. In the model Jokadia barrage (W_1) is raised by 1.5 m, 2 m and 2.5 m from the existing crest level i.e. from 14.78 MSL to 16.28 MSL, 16.78 MSL and 17.28 MSL and the effect of weir on navigation depth availability is studied. It may be noted that as topographic survey is carried out till existing embankments in this reach, there is no further provision of lateral structure in the model. The flow analysis is carried out for discharges of 50 cumecs, 80 cumecs and 100 cumecs during lean season and 500 cumecs during monsoon season. Considering the hydraulic parameters (flow depth and width) along the reach for different cases, it is observed that 2 m rise in Jokadia barrage (W_1) is found to be appropriate in providing required navigational depth and width. Table 5.1 shows the details of variation in average flow parameters along the reach for different cases.

The analysis of the results showed that, 2 m rise in Jokadia barrage provided thalweg depths ranging from 4.5 m at Jokadia to 2.5 m at Pankapal for 50 cumecs of discharge. The same varied from 4.5 m to 2.7 m for 80 cumecs and 5.0 m to 3.0 m for 100 cumecs. During the monsoon season flow depths greater than 3.5 m are observed throughout the reach. The detailed plots showing the effect of weir for different LAD in the range of 2.2, 2.5, 3.0 and 3.5 m is presented in Figures 5.2 to 5.5. From the plots it can be observed that there is no significant variation in depths for lean season discharges ranging between 50-100 cumecs. To obtain depths greater than 3.0 m even during lean season minor dredging is necessary at selective locations of the river reach. In addition, there are some factors (evaporation and seepage) affecting storing capacity of the pooling system which needs to be accounted for, one such, evaporation losses which play a crucial role in tropical climate zones and other seepage losses together reduce the designed depths for a proposed barrage. Considering these losses the modified Jokadia barrage is further to be raised by another 0.75 m from the proposed height to prevent reduction in navigable depths. Hence, the Jokadia weir needs to be raised by 2.75 m from the existing level.

5.1.2 100 year flood analysis

It is assumed that the proposed 2.75 m raise of Jokadia weir from the existing level will be provided as barrage with navigational lock arrangement. As the barrage gates are completely opened during the flood period, the 100 year flood analysis is carried out for existing Jokadia weir height. The model is simulated for 6500 cumecs to study the impact of peak flood on existing embankments. It is found that the maximum water level for 100 years flood varied between 0.75 m to 1.50 m above existing embankments. Hence, to accommodate the peak flood and to prevent submergence, the existing embankments need to be raised from existing level to 100 year flood level including free board. Figure 5.6 shows the maximum water level for 100 years flood and existing embankment level along the reach.

Summary for the segment

- *Jokadia weir (W_1) to be raised by 2.75 m with the provision of navigational lock from existing crest level to provide suitable navigational depths throughout the reach in all seasons.*
- *100 years flood simulation for existing Jokadia weir shows submergence varied between 0.75 m to 1.50 m above embankments. The existing embankments should be modified by raising accordingly from the present level.*

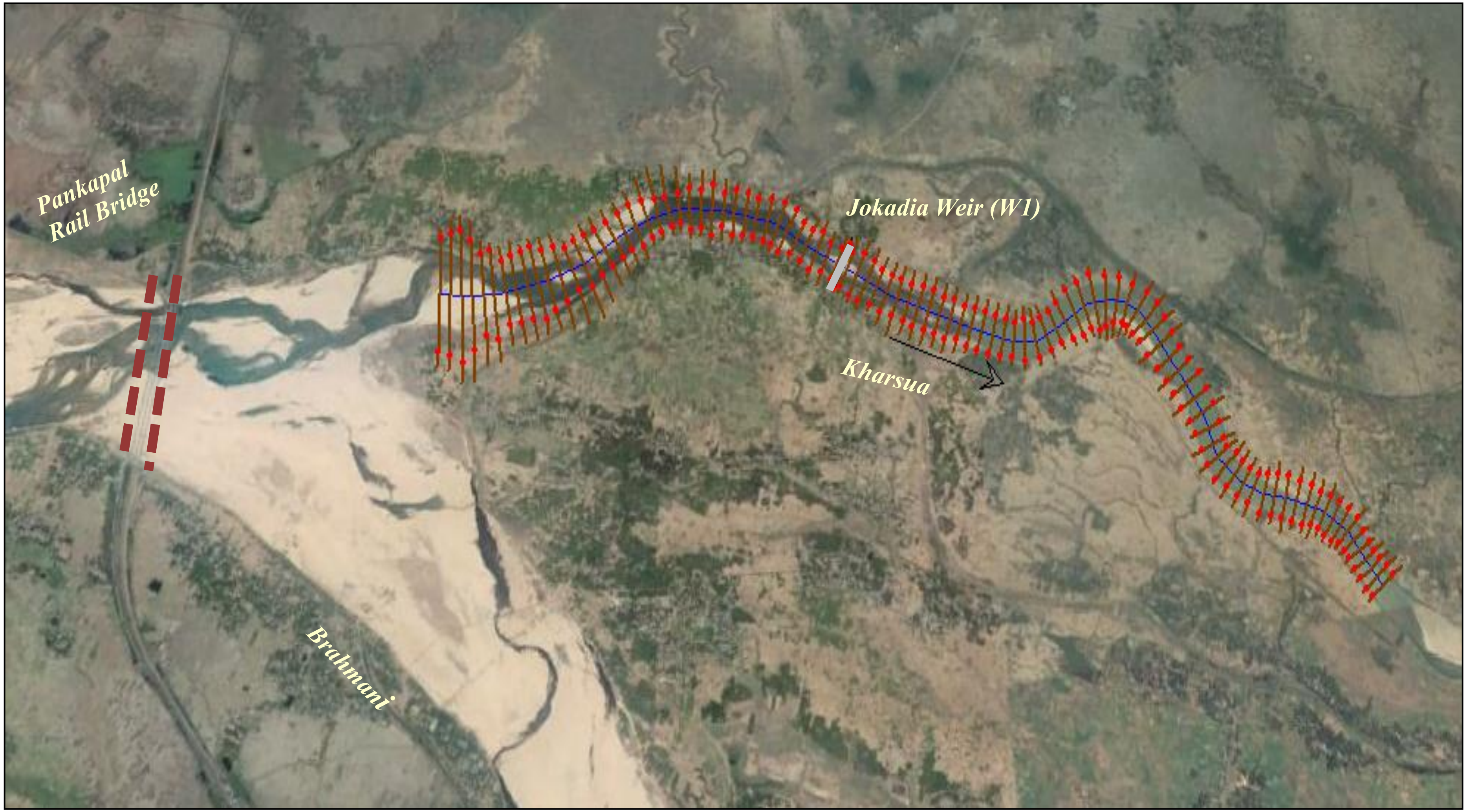


Figure 5.1: HEC-RAS Setup showing Geometric network of Kharsua Reach between Pankapal and Jokadia

Table 5.1: Variation in average hydraulic parameters for different cases of rising Jokadia weir (W_1)

S. No	Jokadia existing crest level MSL	Reach length (km)	Increased height (m)	*Lean season discharge*		*100 year flood*	
				Average Depth (m)	Average Top width (m)	Existing embankment level (m)	Max. water level MSL
1	14.78	3.9	1.5	3.05	317.4	20.70	Submergence varied between 1.5 m to 0.75 m along the existing embankments
*2	14.78	3.9	2.0	3.54	338.4	20.70	
3	14.78	3.9	2.5	4.04	370.7	20.70	

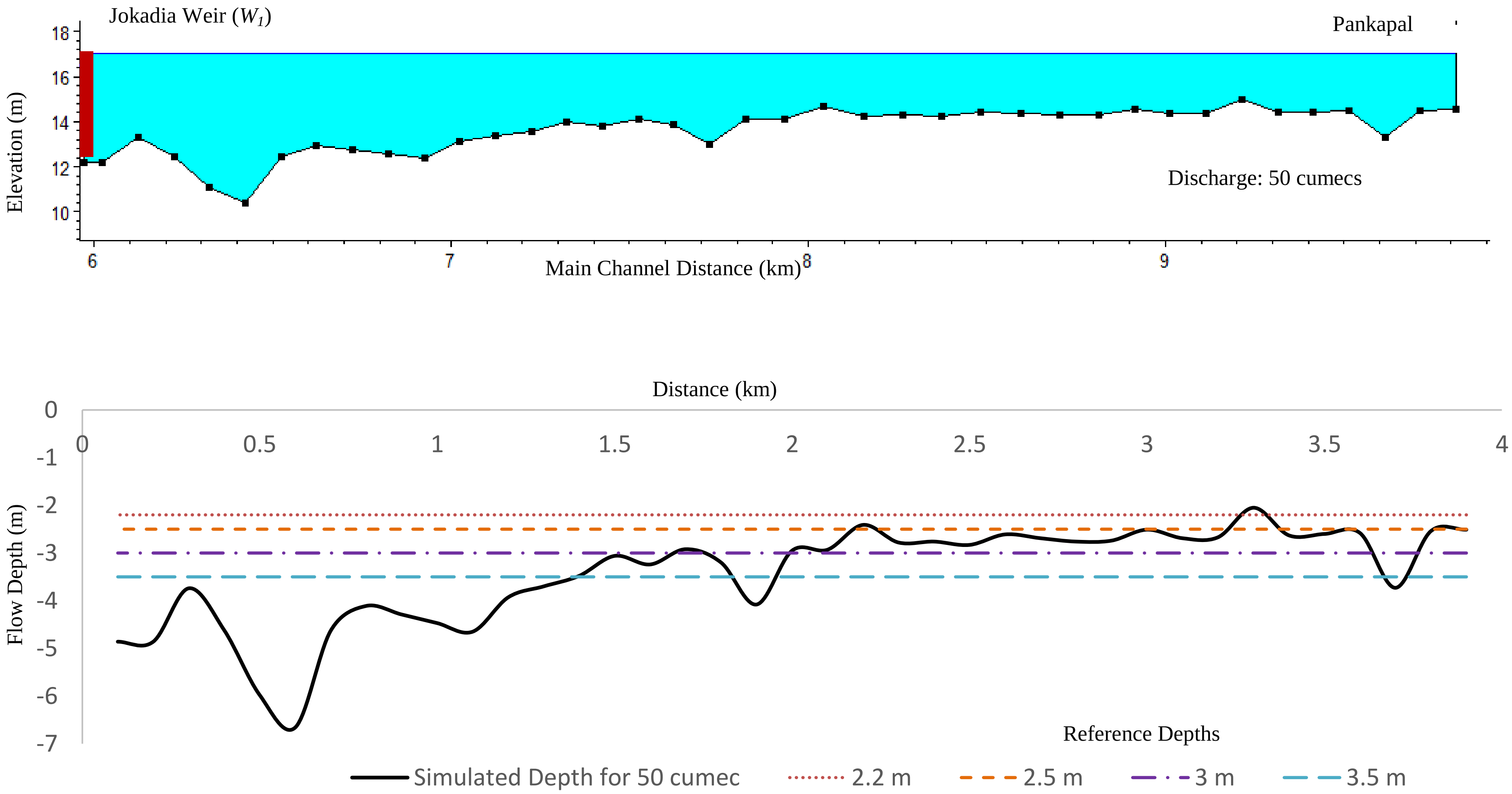


Figure 5.2: Effect of modified Jokadia Weir (W_1) on flow depth (50 cumecs) variations along the reach

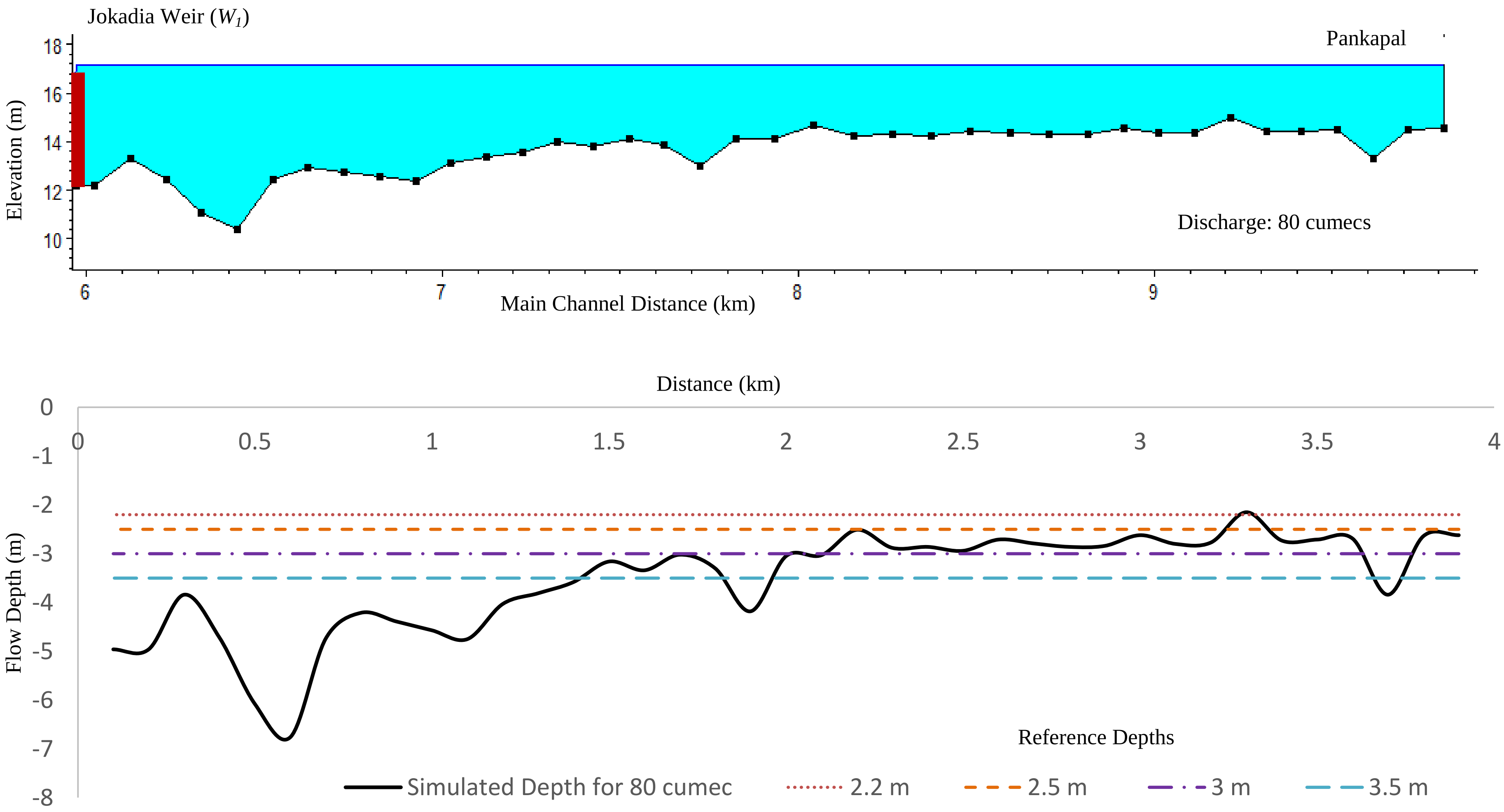


Figure 5.3: Effect of modified Jokadia Weir (W_1) on flow depths (80 cumecs) variation along the reach

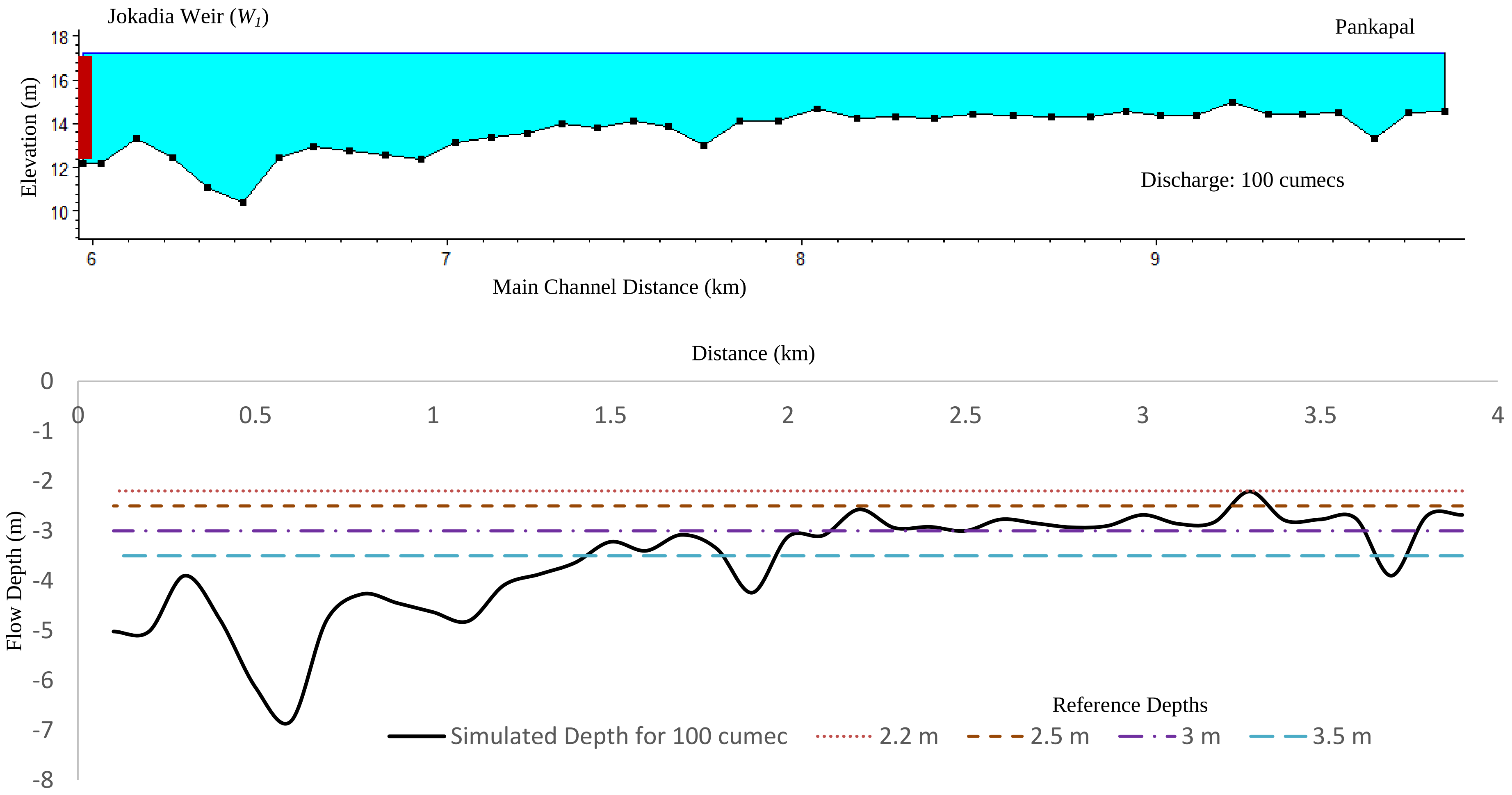
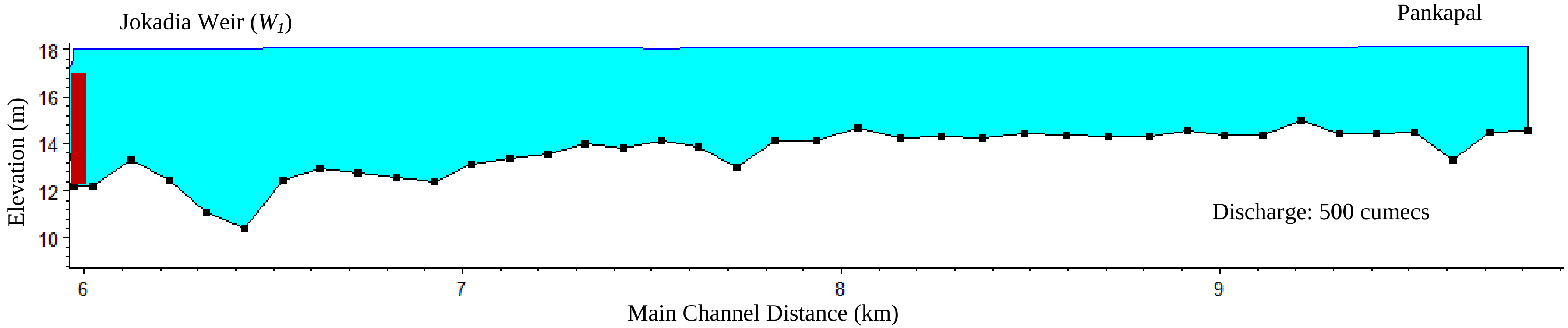


Figure 5.4: Effect of modified Jokadia Weir (W_1) on flow depth (100 cumecs) variation along the reach



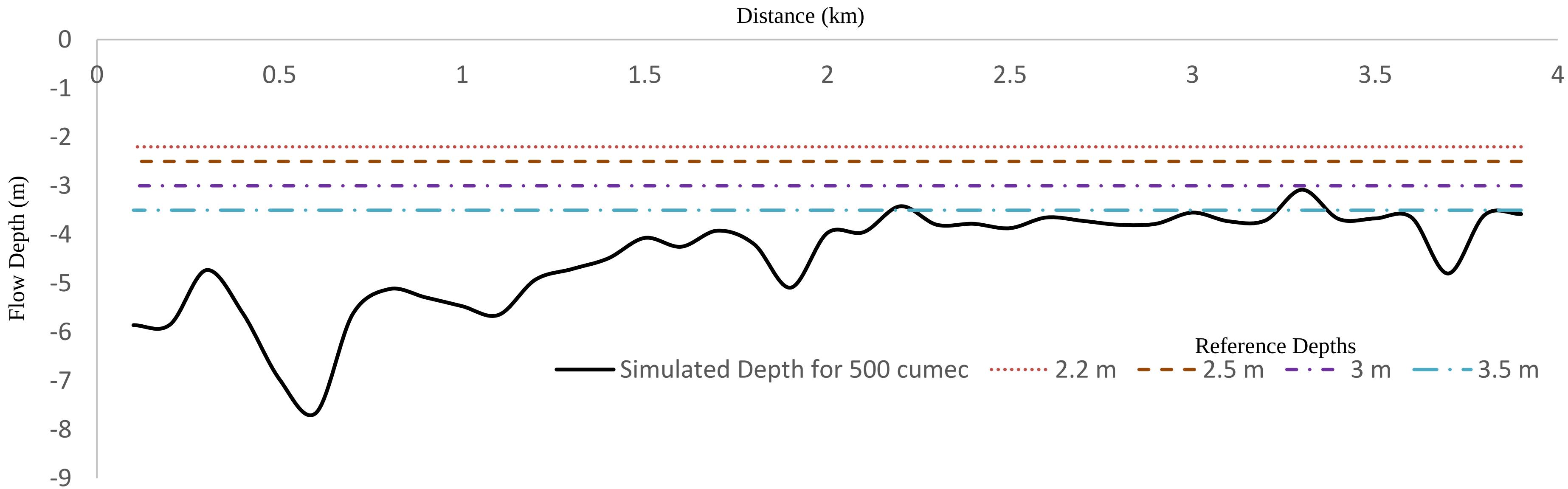


Figure 5.5: Effect of modified Jokadia Weir (W_1) on flow depth (500 cumecs) variation along the reach

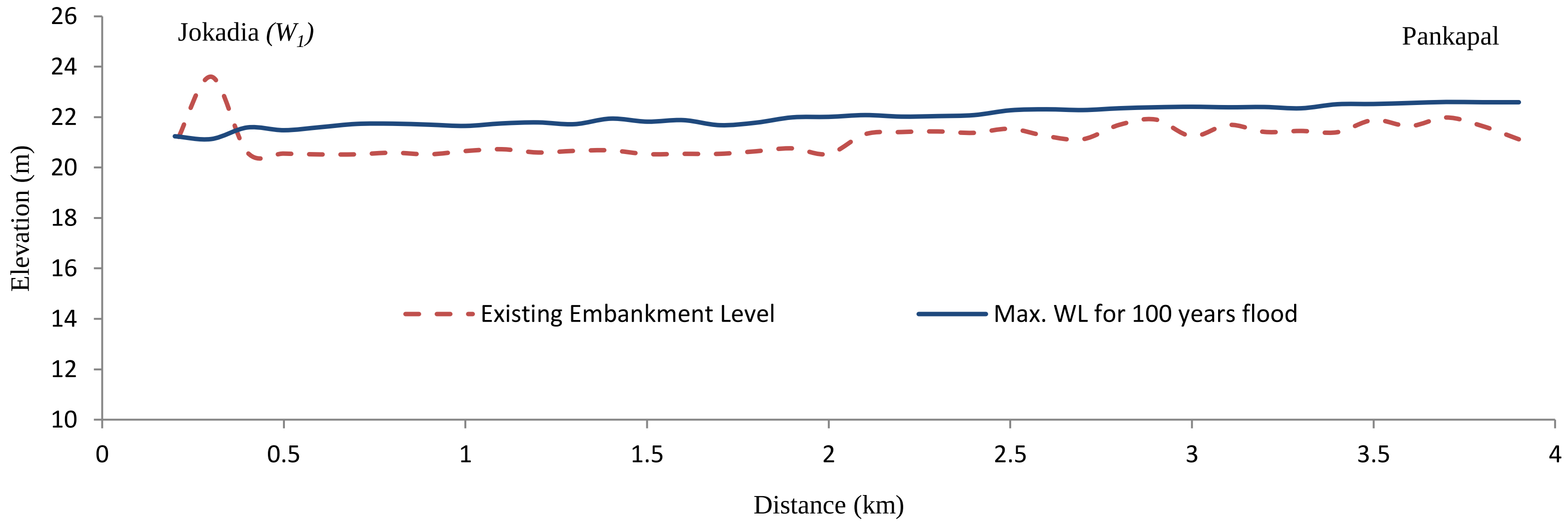


Figure 5.6: Maximum water level for 100 years flood and existing embankment height along the reach

5.2 Kharsua (Jokadia) to upstream of Sujanpur segment

5.2.1 Installation of new barrage with navigational lock

The present set up is from downstream of Jokadia barrage to 7 km upstream of Sujanpur covering a total distance of around 22 km. A total number of 216 surveyed cross sections each at 100 m interval are used in setting up the HEC-RAS model. Figure 5.7 shows the geometric network of river reach prepared in the HEC-RAS for the present segment. In this stretch an additional weir cum barrage (W_2) is proposed at the beginning of reach to store the incoming flow and maintain depths required for navigation. The flow analysis is carried out for steady lean (50, 80 and 100 cumecs) and monsoon (500 cumecs) discharges to study the effect of proposed structure. The inline structure of different height (2.5, 3.5 and 4.0 m) is incorporated in the model and their effect in providing required navigational parameters is examined. It is found that 3.5 m high structure (W_2) at beginning of reach is appropriate for obtaining consistent navigational depths for greater distance. Table 5.2 shows the details of variation in average flow parameters along the reach for different cases.

The simulation results showed that 3.5 m weir cum barrage (W_2) during lean season is significant in achieving thalweg depths greater than 2.5 m for 50-80 cumecs up to 18.0 km length. The effect of proposed barrage could not reach till end i.e. up to 22 km because of the steep slope for 4 km reach at downstream of Jokadia (W_1). This steep slope could be made gentle by dredging and necessary width controlling measures to be adopted for maintaining the navigable depths throughout year. In monsoon season, the effect of weir cum barrage is up to 18.0 km and the depths ranging from 5.0 m to 3.5 m. The detailed plots showing the effect of weir for different LAD in the range of 2.2, 2.5, 3.0 and 3.5 m is presented in Figures 5.8 to 5.11. From the plots it can be observed that there is no significant variation in depths for lean season discharges ranging between 50-100 cumecs. Considering losses due to evaporation and seepage the proposed barrage of 3.5 m needs to be further raised by 0.75 m for increasing storage capacity.

5.2.2 100 year flood analysis

It is assumed that the proposed weir cum barrage of 4.25 m is provided as 1 m weir and 3.25 m barrage with navigational lock arrangement. Therefore, the impact of flooding during 100 years flood is studied for 1 m height weir as the barrage gates are completely opened during flood. The results showed that the maximum water level for 100 years flood is varied between 0.5 m to 1.7 m above existing embankments. The analysis shows that the existing embankment needs to be raised up to 1.50 m for accommodating peak floods occurring in 100 years. It is also found that at the locations where embankments are not present the flooding is up to 3.0 m above banks. Hence, the embankments need to be raised accordingly. Figure 5.12 shows the maximum water level for 100 years flood and existing embankment level along the reach.

Summary of segment

- *A new weir cum barrage (W_2) of 4.25 m with navigational lock is proposed between Kharsua (Jokadia) and 7 km upstream of Sujanpur weir to maintain navigational depths for 22 km reach.*
- *Minor dredging work needs to be carried out for 4.0 km river reach downstream of Jokadia to make steep slope to gentle one. This helps to carry effect of proposed barrage for 4.0 km upstream.*
- *100 years flood simulation for 1 m height weir shows submergence varied between 0.5 m to 1.7 m above existing embankments and 3.0 m at no embankment locations. Hence, the existing embankments should be modified by raising accordingly from the present level and new embankments to be constructed 3.0 m high at locations where no embankments are present.*

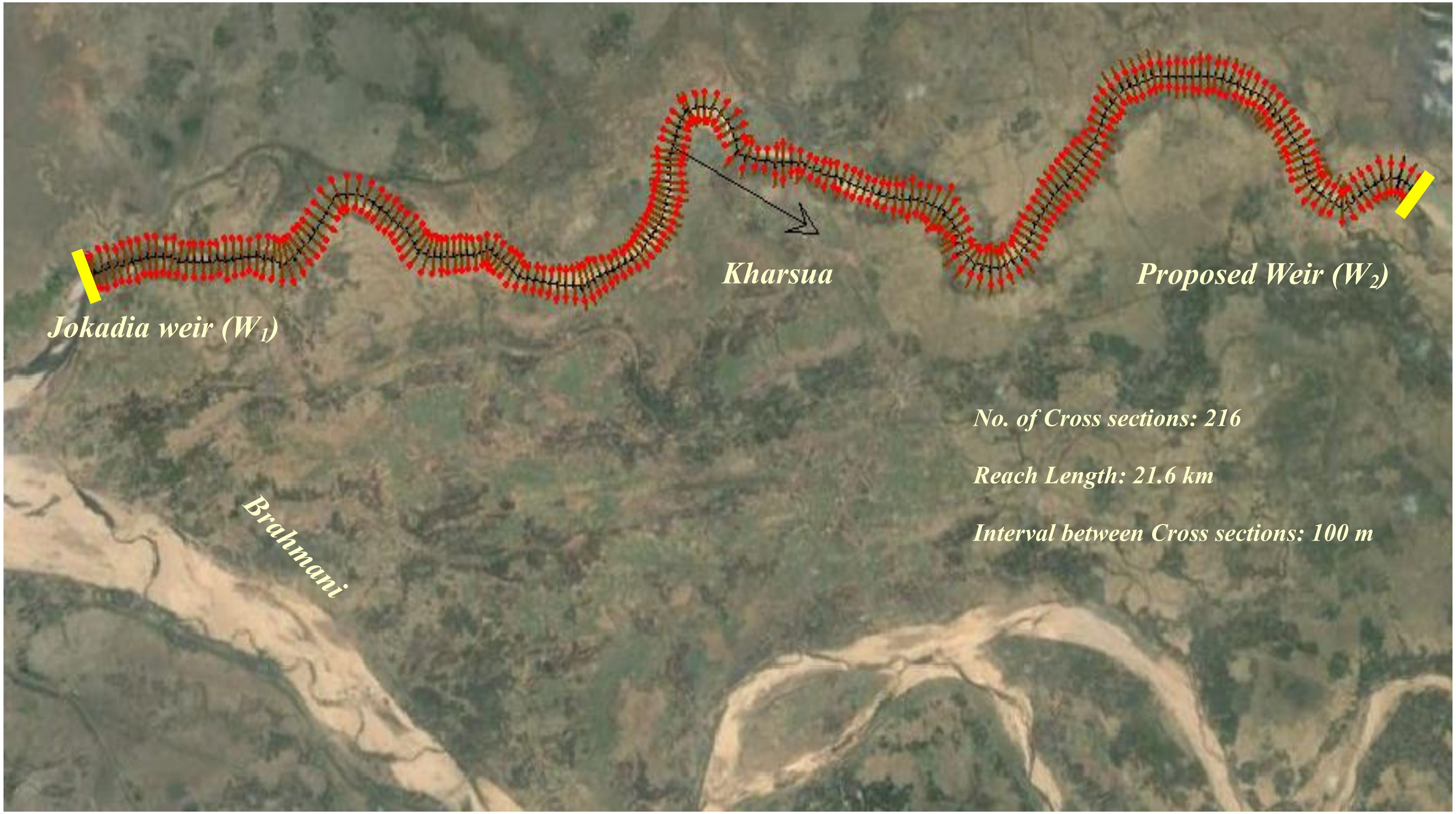
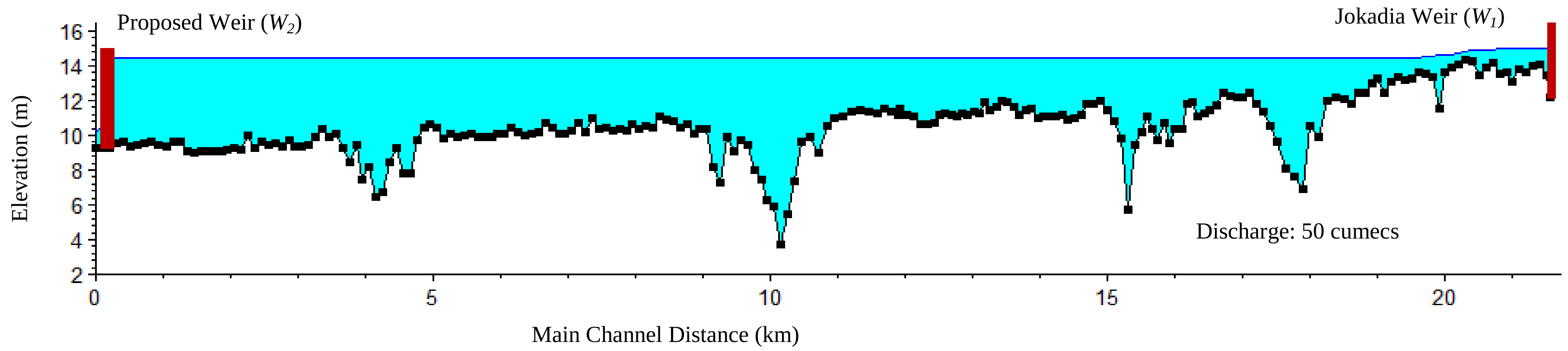


Figure 5.7: HEC-RAS Setup showing Geometric network of Kharsua reach between downstream of Jokadia and 7 km upstream of Sujanpur

Table 5.2: Variation in average hydraulic parameters for different cases of proposed Intermediate weir (W_2)

S. No	Intermediate weir proposed crest level MSL	Reach length (km)	Structure height (m)	*Lean season discharge*		*100 year flood*	
				Average Depth (m)	Average top width (m)	Existing embankment level (m)	Max. water level MSL
1	13.25	21.5	2.5	2.68	276	17.69	Submergence varied between 0.5 m to 1.7 m above existing embankments
* 2	14.25	21.5	3.5	3.47	312	17.69	
3	14.75	21.5	4.0	3.91	327	17.69	



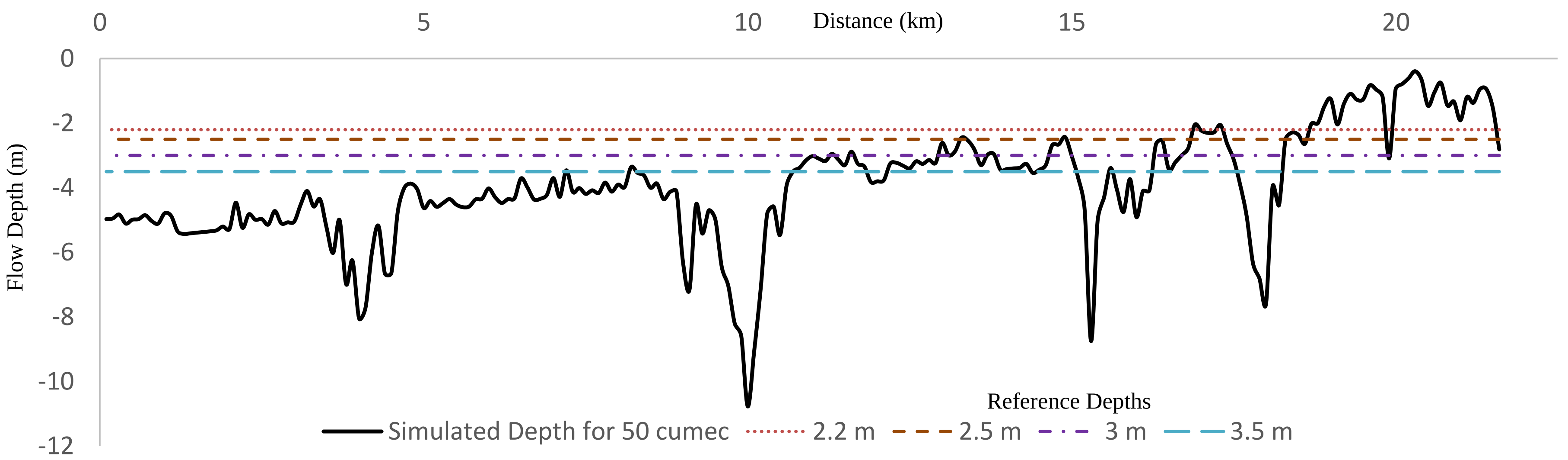


Figure 5.8: Effect of Proposed Barrage (W_2) on flow depth variations (50 cumecs) along the reach

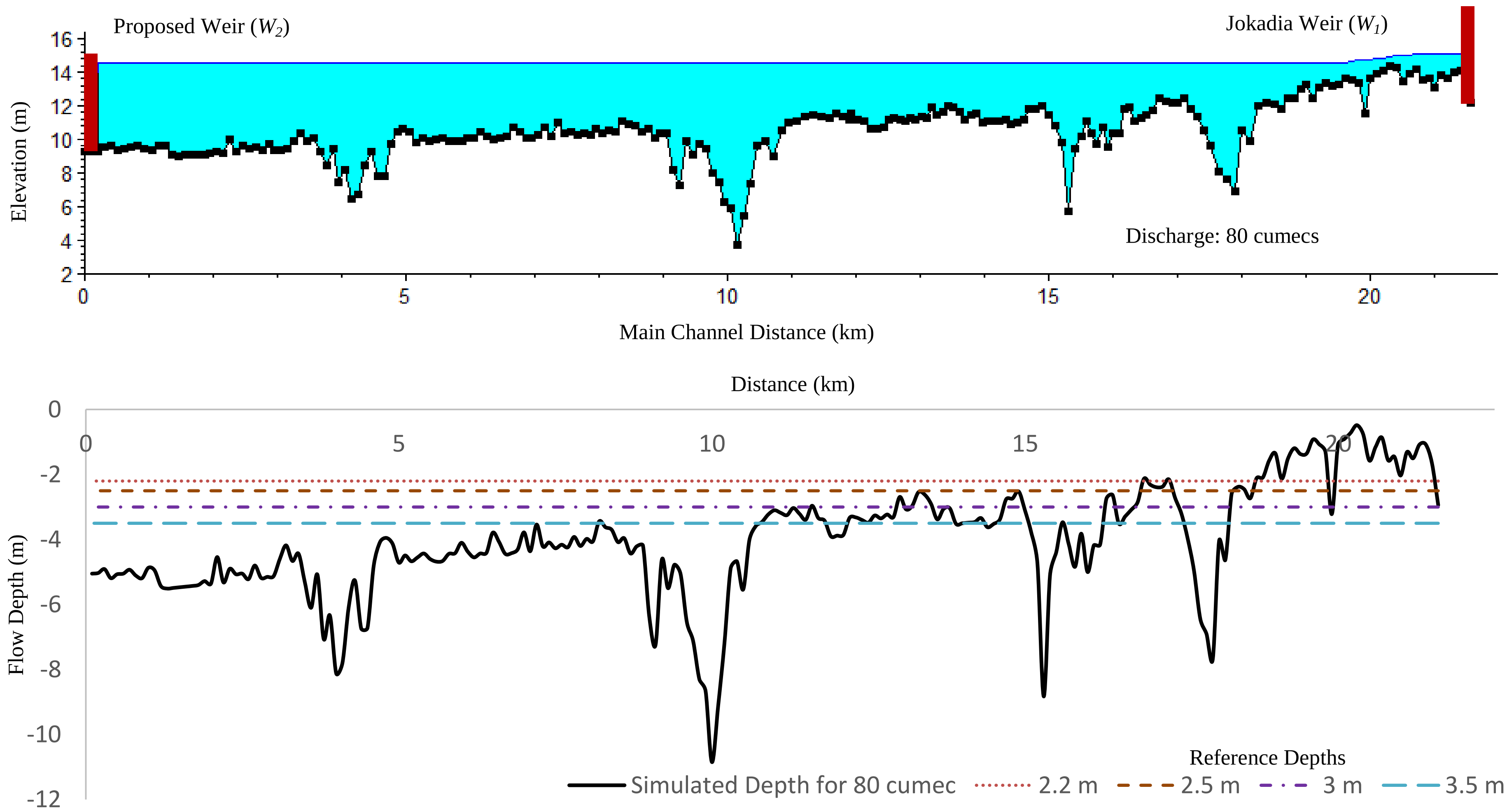


Figure 5.9: Effect of Proposed Barrage (W_2) on flow depth variations (80 cumecs) along the reach

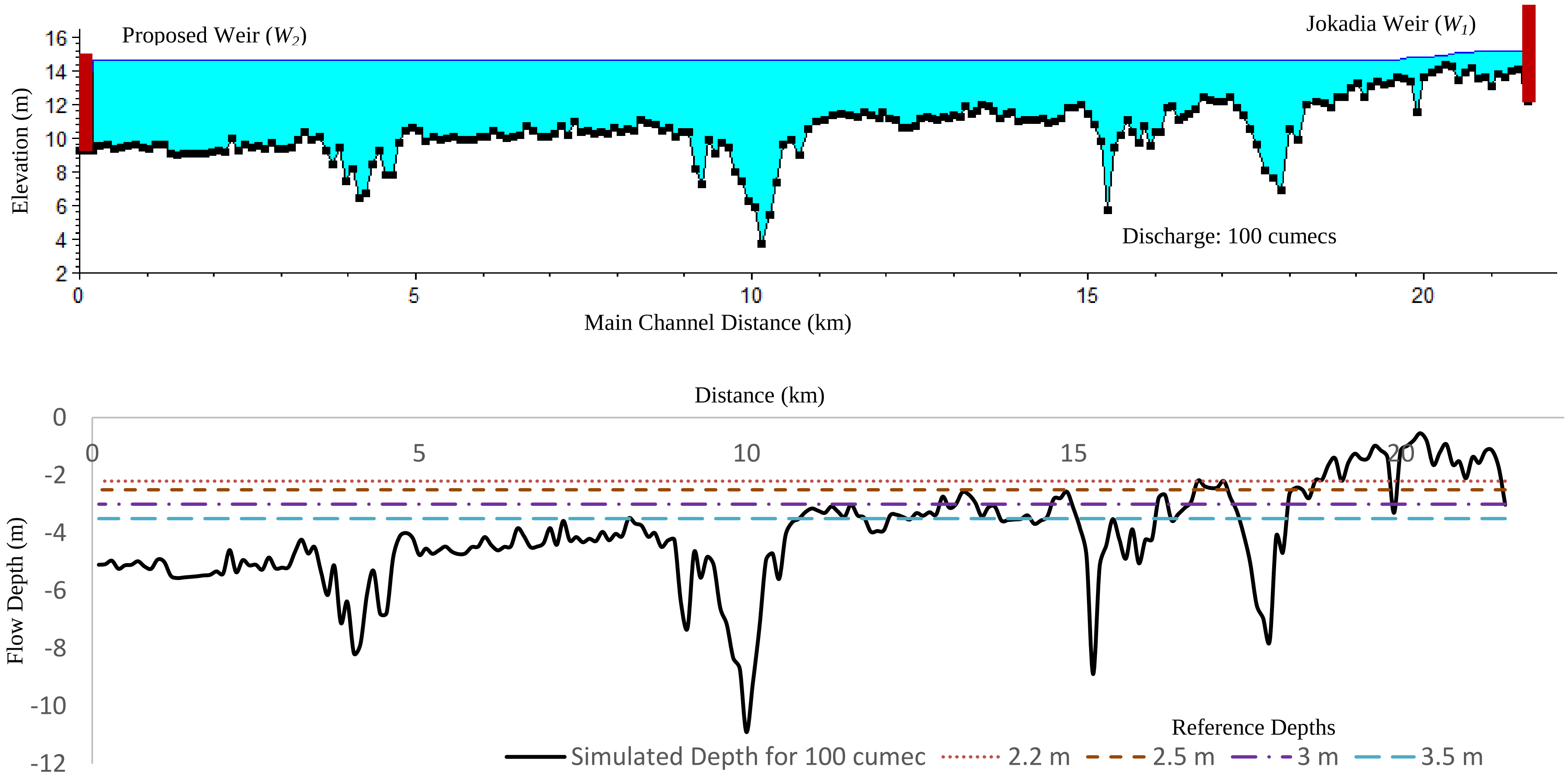


Figure 5.10: Effect of Proposed Barrage (W_2) on flow depth variations (100 cumecs) along the reach

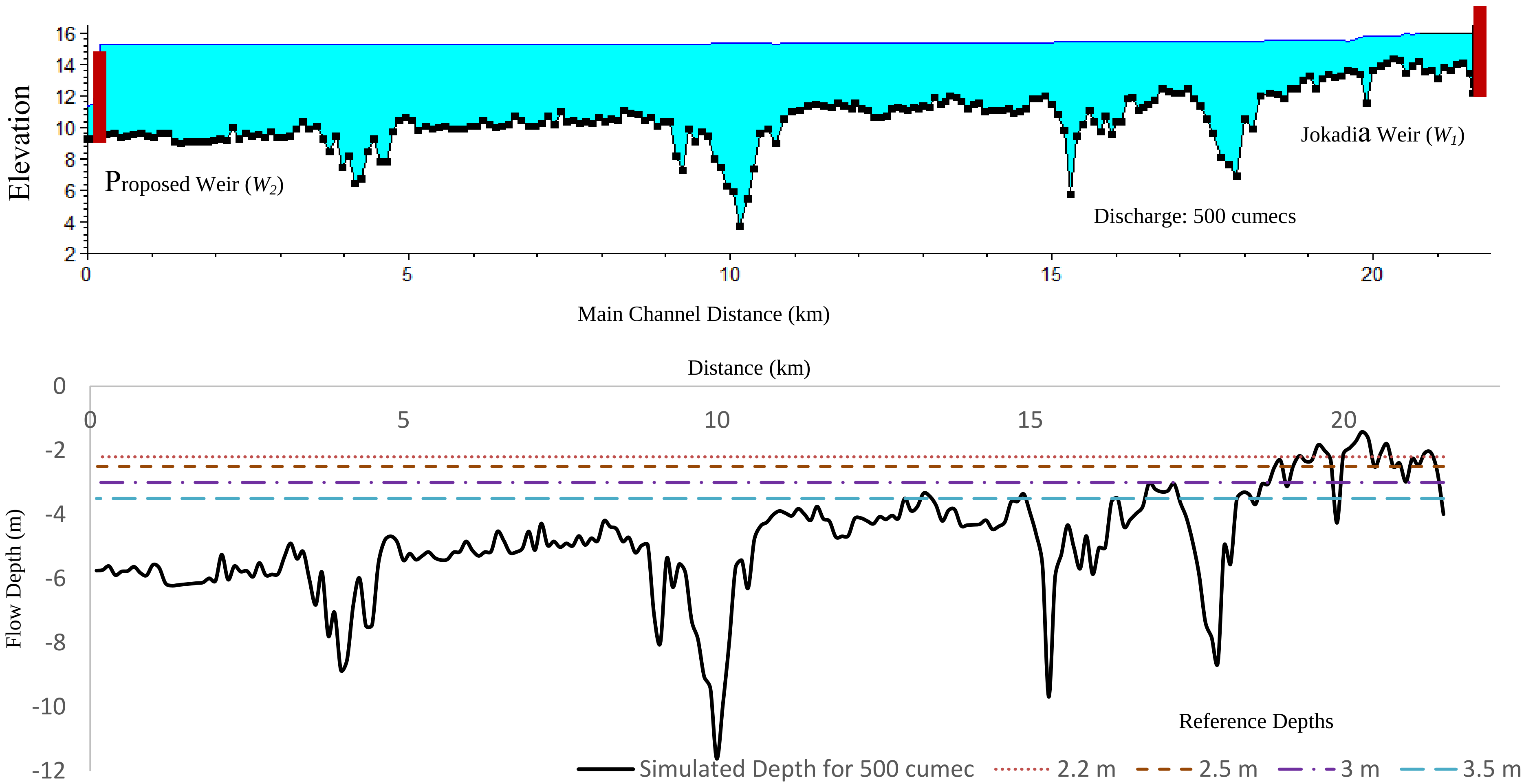


Figure 5.11: Effect of Proposed Barrage (W_2) on flow depth variations (500 cumecs) along the reach

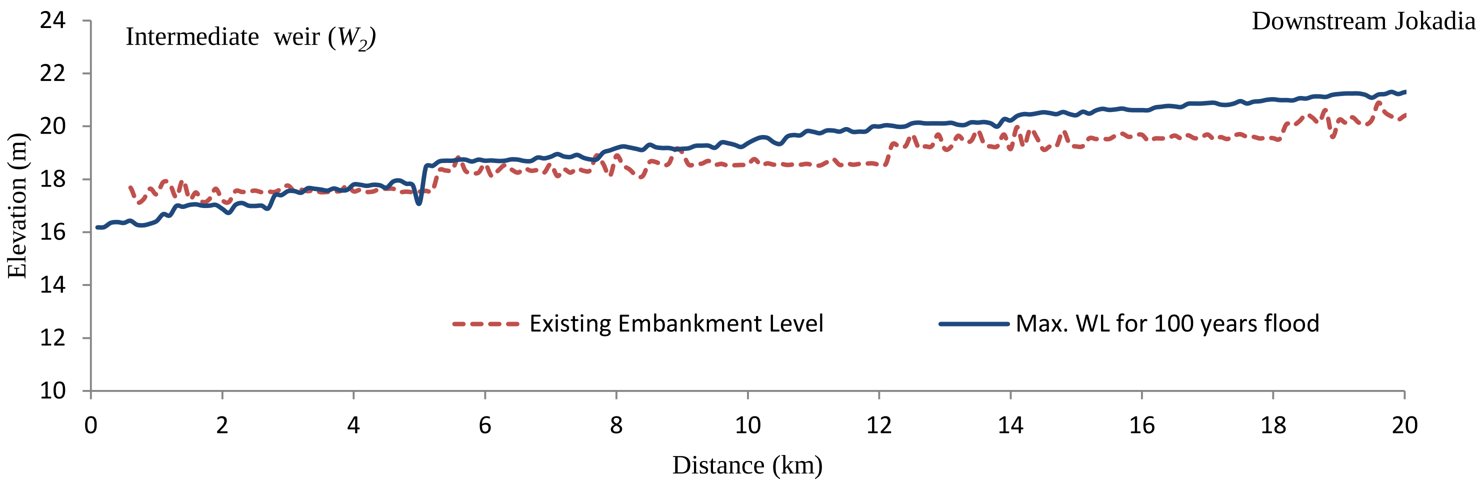


Figure 5.12: Maximum water level for 100 years flood and existing embankment height along the reach

5.3 Kharsua-Tantigai (Sujanpur) bifurcation segment

5.3.1 Rise of Sujanpur weir and additional structure on Kharsua

This section discusses effect of reconstructing Sujanpur weir and its impact on navigational parameters and flooding. The modeling stretch considered is from downstream of intermediate weir (W_2) to Kharsua-Budha confluence covering a length of around 11.3 km. Figure 5.13 shows the geometric network prepared in the HEC-RAS for the present segment. As rising Sujanpur weir alone has impact on to diverting the flow to Kharsua river (after bifurcation) and to capture flow from Budha river, an additional weir cum barrage (W_4) is proposed at downstream of Kharsua-Budha confluence. The Sujanpur weir on Tantigai and additional weir cum barrage on Kharsua (after Budha confluence) are raised for different heights and their effect is simulated by performing unsteady flow analysis. Table 5.3 shows the details of variation in average flow parameters along the reach for different cases of rising Sujanpur and additional weirs.

The simulation results showed that rising Sujanpur weir by 1.85 m i.e. from 9.44 MSL to 11.28 MSL and providing 4.5 m additional weir on Kharsua (after Budha confluence) is found to be effective in achieving navigational depth and width throughout the reach. The analysis showed that thalweg depths greater than 2.2 m for 50 cumecs and 2.5 m can be obtained for discharges ranging from 80-100 cumecs. During the monsoon season flow depths greater than 3.5 m are observed. The detailed plots showing the effect of weir for different LAD in the range of 2.2, 2.5, 3.0 and 3.5 m is presented in Figures 5.14 to 5.17. Considering the losses due to evaporation and seepage, Sujanpur weir and additional weir cum barrage on Kharsua need to be raised by another 0.75 m to prevent reduction in navigational depths.

5.3.2 100 year flood analysis

The 100 year flood simulation is carried out by performing steady flow analysis with a discharge of 6500 cumecs. It is assumed that the additional raise in Sujanpur weir is provided as barrage with navigational lock arrangement and proposed weir cum barrage of 5.25 m is provided as 1 m weir and 4.25 m barrage. Therefore, the impact of flooding during 100 years flood is studied by assuming barrage gates are completely opened during flood.

The analysis of peak flood water levels throughout the reach shows that in upstream (Kharsua river above Tantigai bifurcation) the submergence is up to 1.25 m above existing embankments and in downstream (Kharsua river after Tantigai bifurcation) the flood level is close to embankment level. Hence, the embankment needs to be revised from the existing level to accommodate peak flood discharge and prevent flooding in downstream reaches. Figure 5.18 shows the maximum water level for 100 years flood and existing embankment level along the reach.

Summary of segment

- *Sujanpur weir (W_3) is raised by 2.60 m from existing crest level and additional 5.25 m weir (W_4) at Budha-Kharsua confluence is proposed to capture water from Budha and maintain navigational depths throughout the reach in all seasons*
- *100 years flood simulation for 1 m height weir shows that in upstream (Kharsua river above Tantigai bifurcation) the submergence varied from 0.75 m to 1.25 m above embankments and in downstream (Kharsua river after Tantigai bifurcation) the submergence is close to embankment level. At the location where no embankments are present the submergence is up to 3.0 m. Hence, the existing embankments should be revised accordingly.*

Figure 5.13: HEC-RAS geometric network for Kharsua- Tantigai network

Table 5.3: Variation in average hydraulic parameters for different cases of rising Sujanpur weir (W_3)

S. No	Sujanpur weir Increased height (m)	Weir cum barrage at Kharsua-Budha confluence	Reach length (km)	*Lean season discharge*		*100 years flood*	
				Average Depth (m)	Average top width (m)	Existing embankment level (m)	Max. Water Level (m)
1	1.45	3.5	11.3	2.20	216	15.84	Submergence is close to embankment level in downstream and in upstream it is up to 1.25m
2	1.65	4.0	11.3	3.05	251	15.84	
*3	1.85	4.5	11.3	3.14	271	15.84	

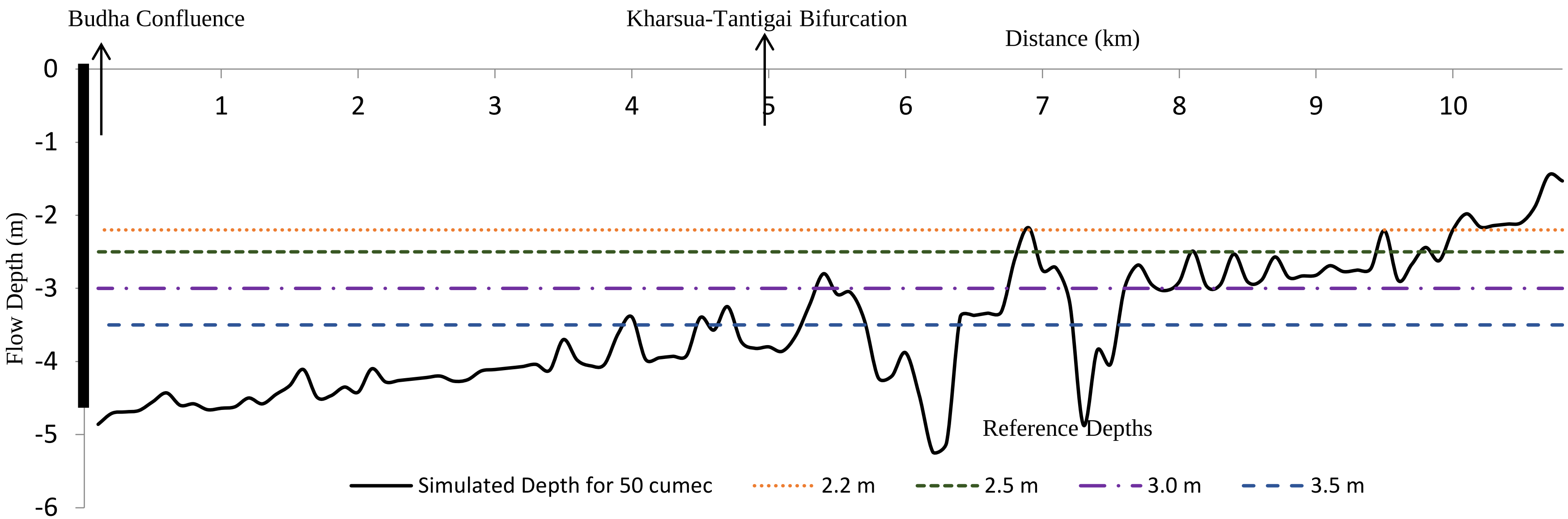


Figure 5.14: Effect of rising Sujanpur Weir (W_3) and additional weir (W_4) on flow depths (50 cumecs)

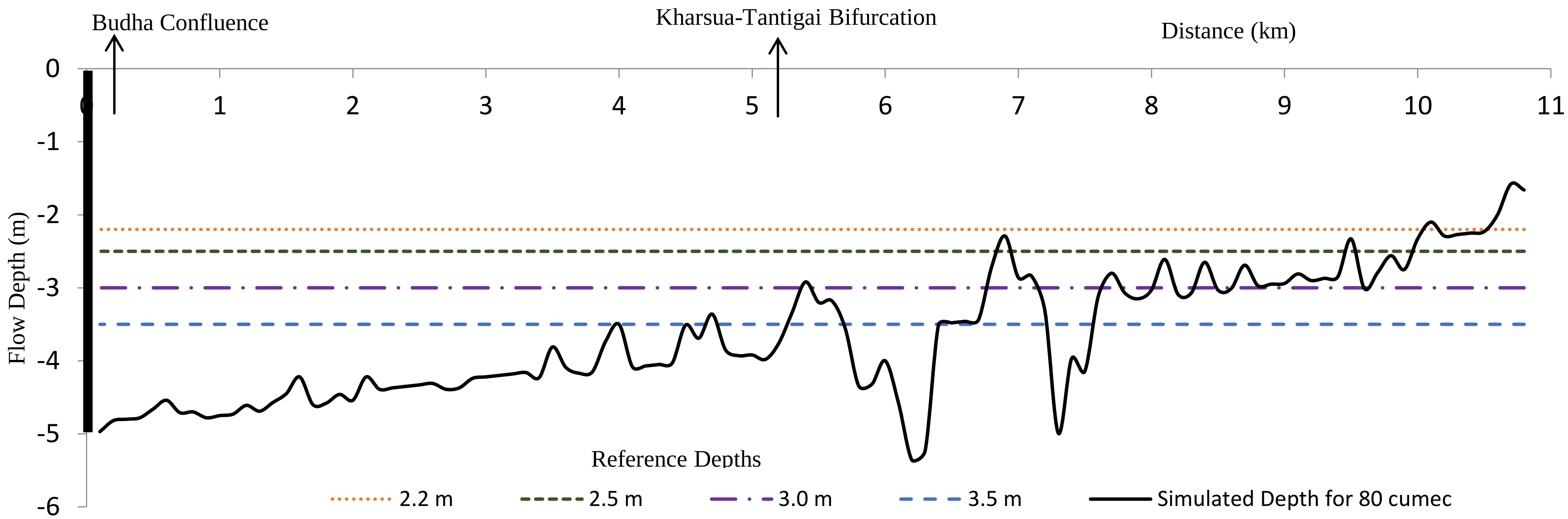


Figure 5.15: Effect of rising Sujanpur Weir (W_3) and additional weir (W_4) on flow depths (80 cumecs)

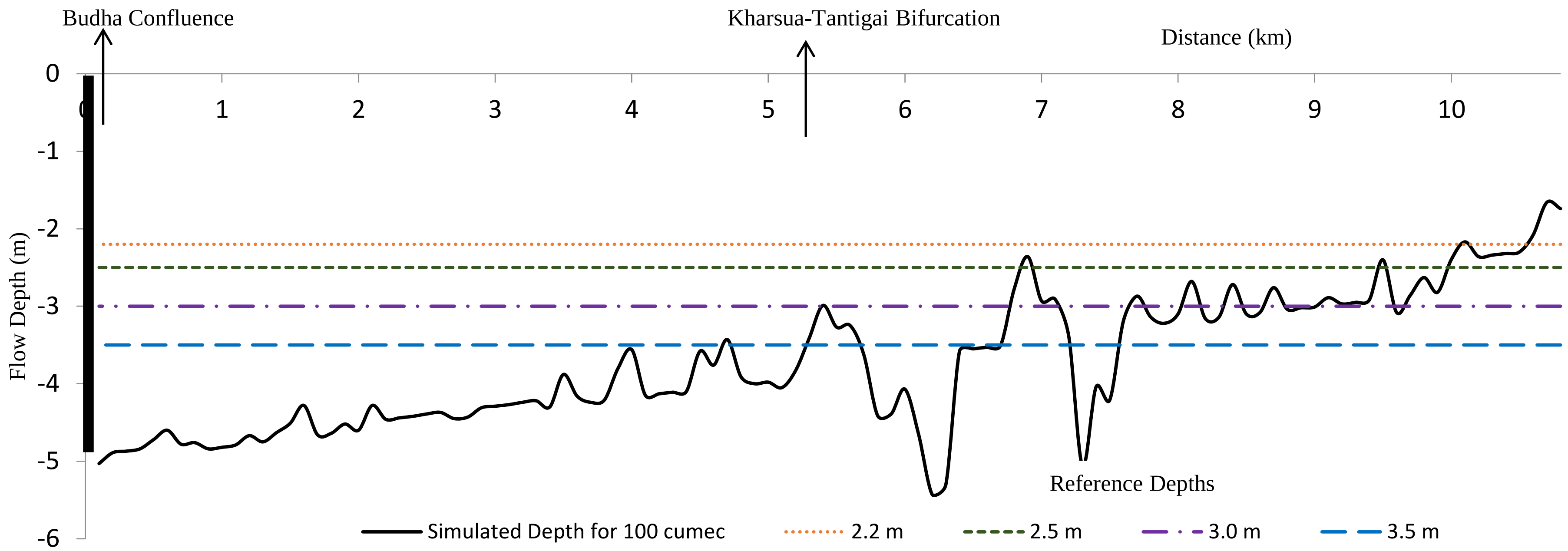


Figure 5.16: Effect of rising Sujanpur Weir (W_3) and additional weir (W_4) on flow depths (100 cumecs)

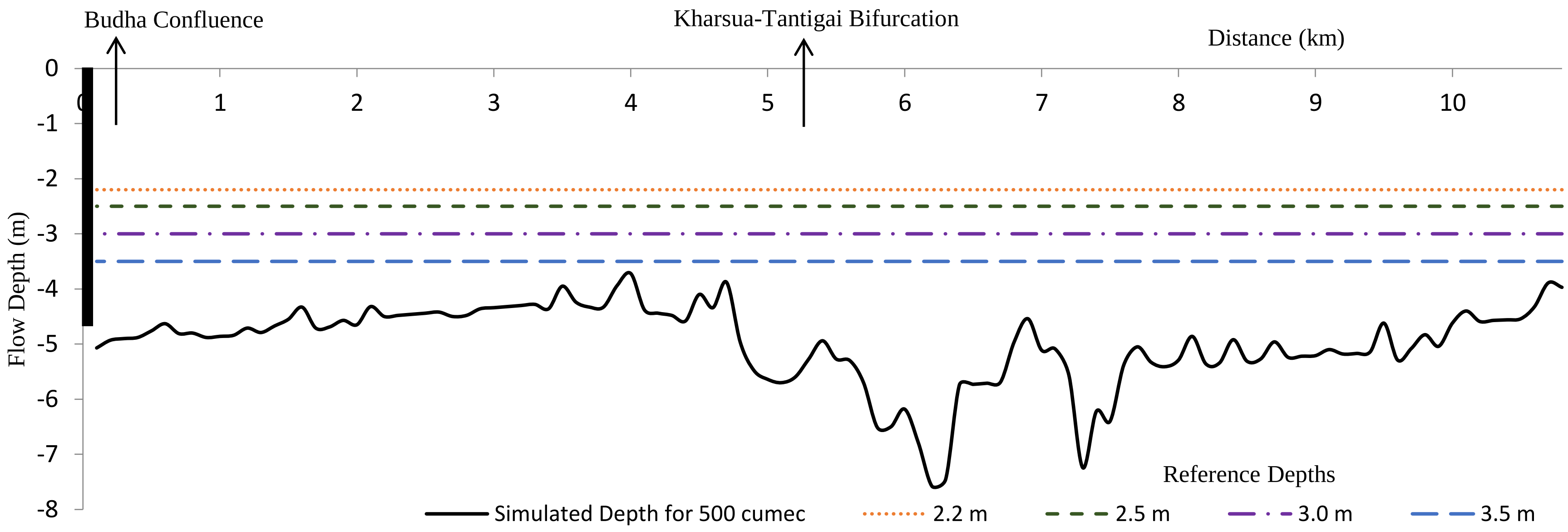


Figure 5.17: Effect of rising Sujanpur Weir (W_3) and additional weir (W_4) on flow depths (500 cumecs)

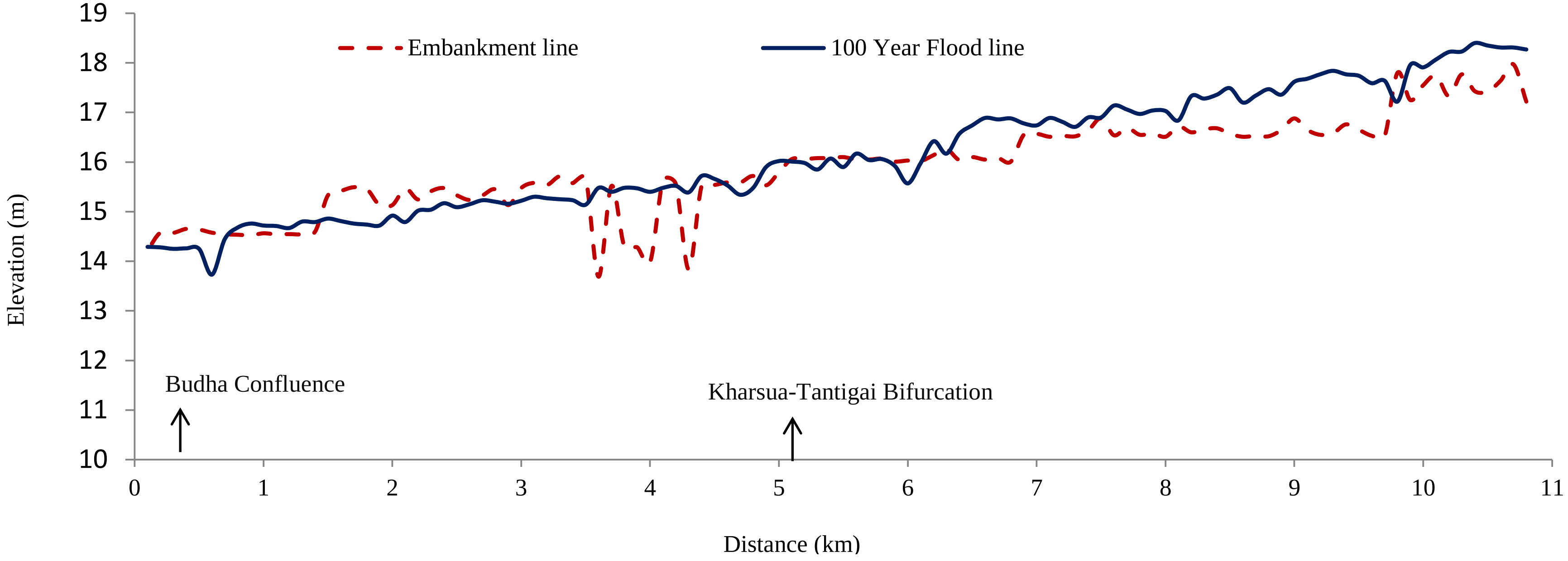


Figure 5.18: Maximum water level for 100 years flood and existing embankment height along the reach

5.4 Tantigai (Sujanpur) - Tantigai-Dhaikia segment

5.4.1 Blocking of Dudai and Bhogra

The river network in this stretch follows as Tantigai (Sujanpur) flowing for few kilometers and bifurcates into Tantigai (Erda) and Dudai (Erda). The river Tantigai (Erda) further travels downstream and bifurcates as Dhaikia and Bhogra. The multiple bifurcations in this stretch distribute the incoming flow and reduce flow depths through these channels. Hence, to avoid the flow distribution in this stretch check dams of 2.5 m height are proposed at Bhogra and Dudai to divert complete lean season discharge to Dhaikia for achieving sufficient navigational depths. The HEC-RAS model for this reach is set up with 174 cross sections covering a total length of 17.4 km. Figure 5.19 shows the geometric network prepared in the HEC-RAS for the present segment. The flow analysis is carried out for completely diverted discharges of 50 cumecs, 80 cumecs and 100 cumecs during lean season and 500 cumecs during monsoon season. The simulation results showed that thalweg depths in the range of 1.8 m are obtained for discharges between 50-80 cumecs. The same varied between 1.8 m to 2.0 m for 100 cumecs of discharge. To increase the flow depths in this reach, dredging and necessary width controlling measures to be adopted for achieving the navigational requirements. During the monsoon season consistent depths greater than 3.5 m are obtained throughout the reach. The detailed plots showing different LAD in the range of 2.2, 2.5, 3.0 and 3.5 m is presented in Figures 5.20 to 5.23.

5.4.2 100 year flood analysis

The 100 year flood analysis showed that for discharge of 3250 cumecs in Tantigai (before Dudai bifurcation), 1625 cumecs in Tantigai (after Dudai bifurcation) and 813 cumecs in Dhaikia, the submergence varied from 1.3 m to 2.0 m on either bank along these rivers. It is to be noted that the Tantigai has partial embankments and Dhaikia has no embankments. Hence, to accommodate the 100 years flood and to prevent submergence, embankments need to be constructed along the route rising to a height of 2.0 m from the banks excluding the free board.

Summary of segment

- *Check dams of 2.5 m are proposed at Dudai and Bhogra rivers to divert complete lean season discharges to Dhaikia and dredging along the proposed route is also suggested for maintaining navigational depths.*
- *100 years flood simulation shows submergence up to 2.0 m above banks. As there are no embankments in this route, the same needs to be constructed rising 2.0 m high from the banks.*

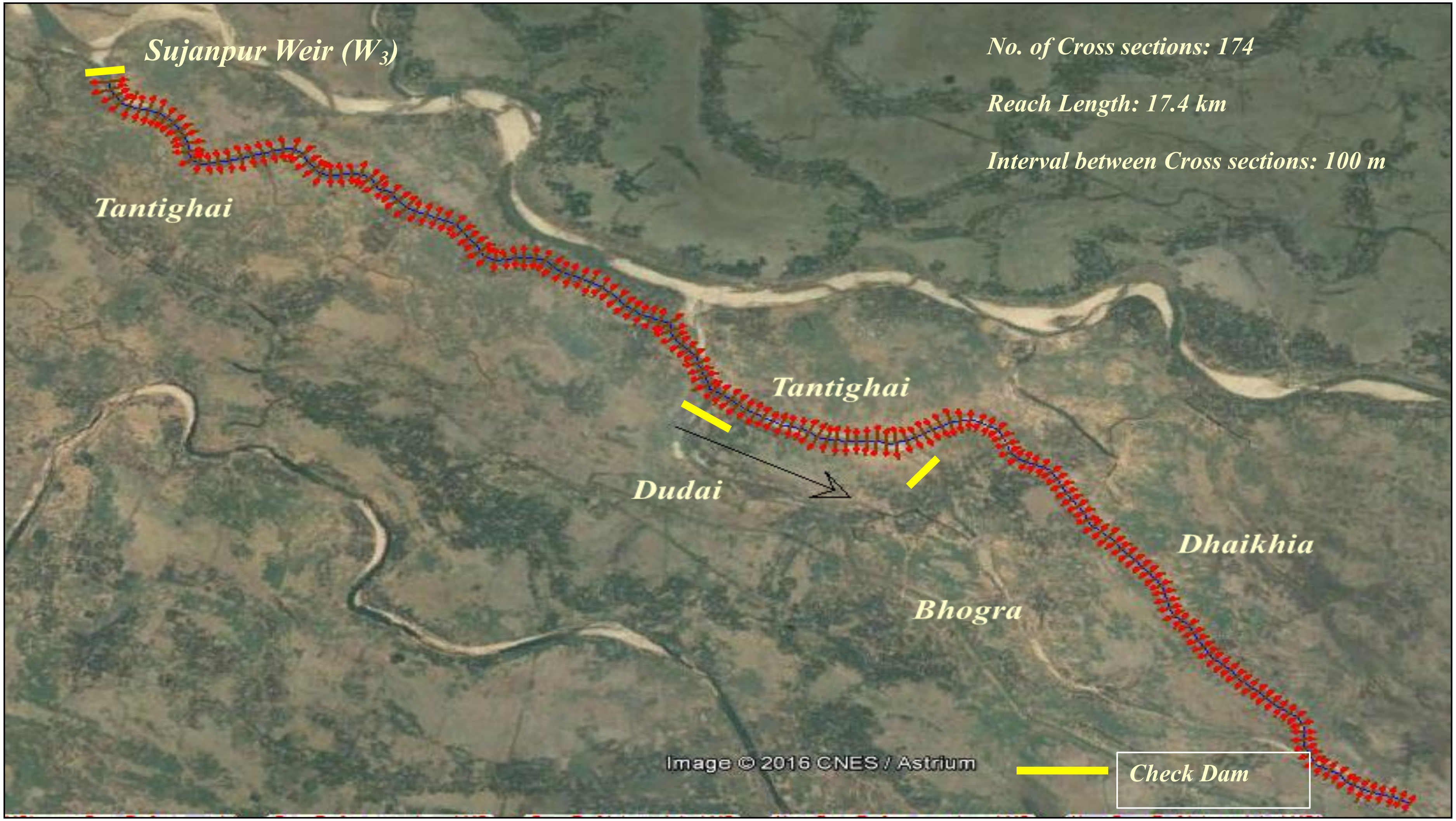
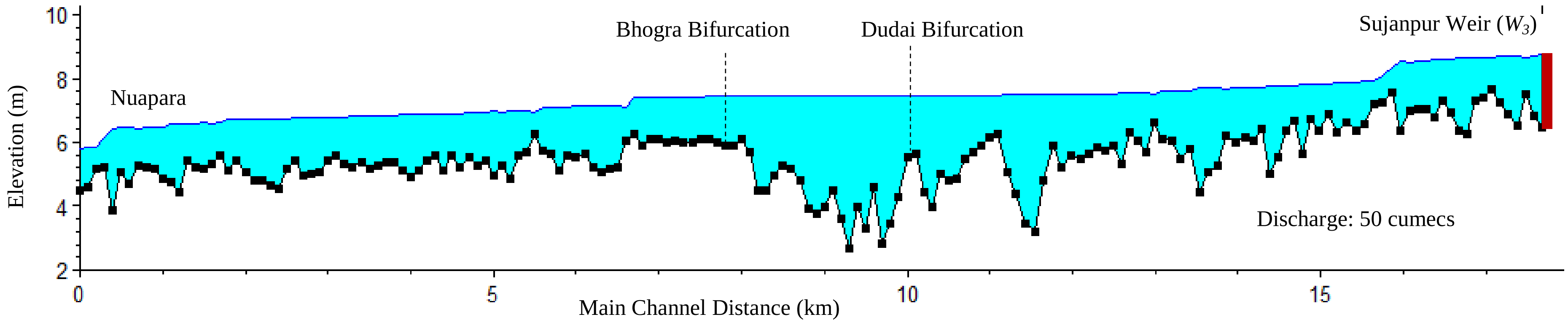


Figure 5.19: HEC-RAS geometric Setup from Tantigai (Sujanpur)- Tantigai - Dhaikia



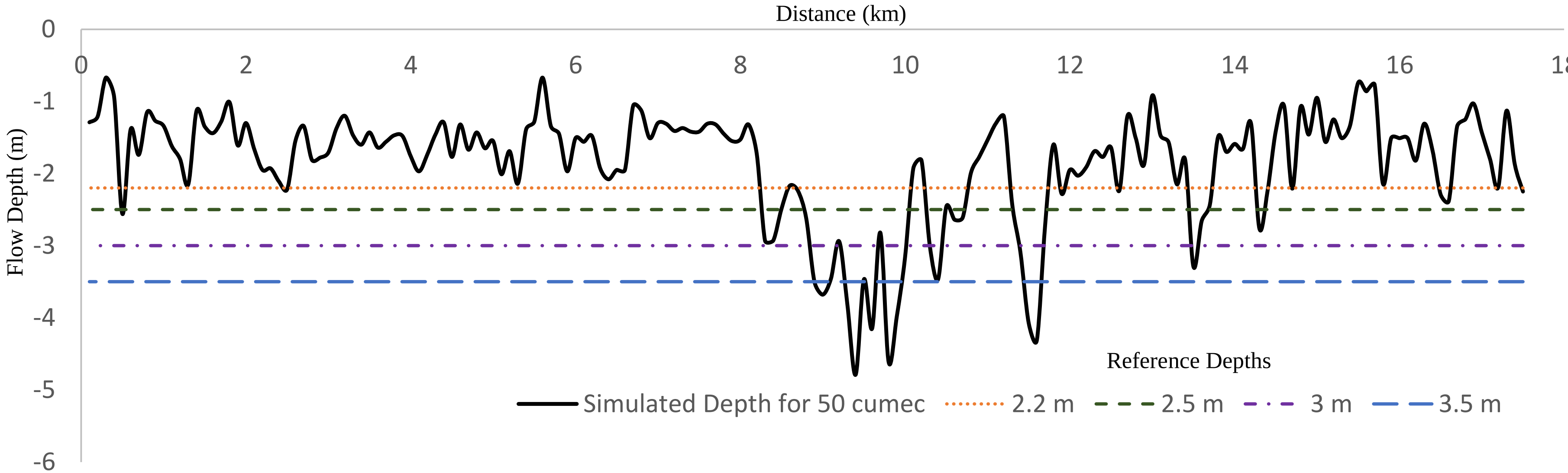


Figure 5.20: Flow variation along Tantigai (Sujanpur) - Tantigai- Dhaikia for 50 cumecs

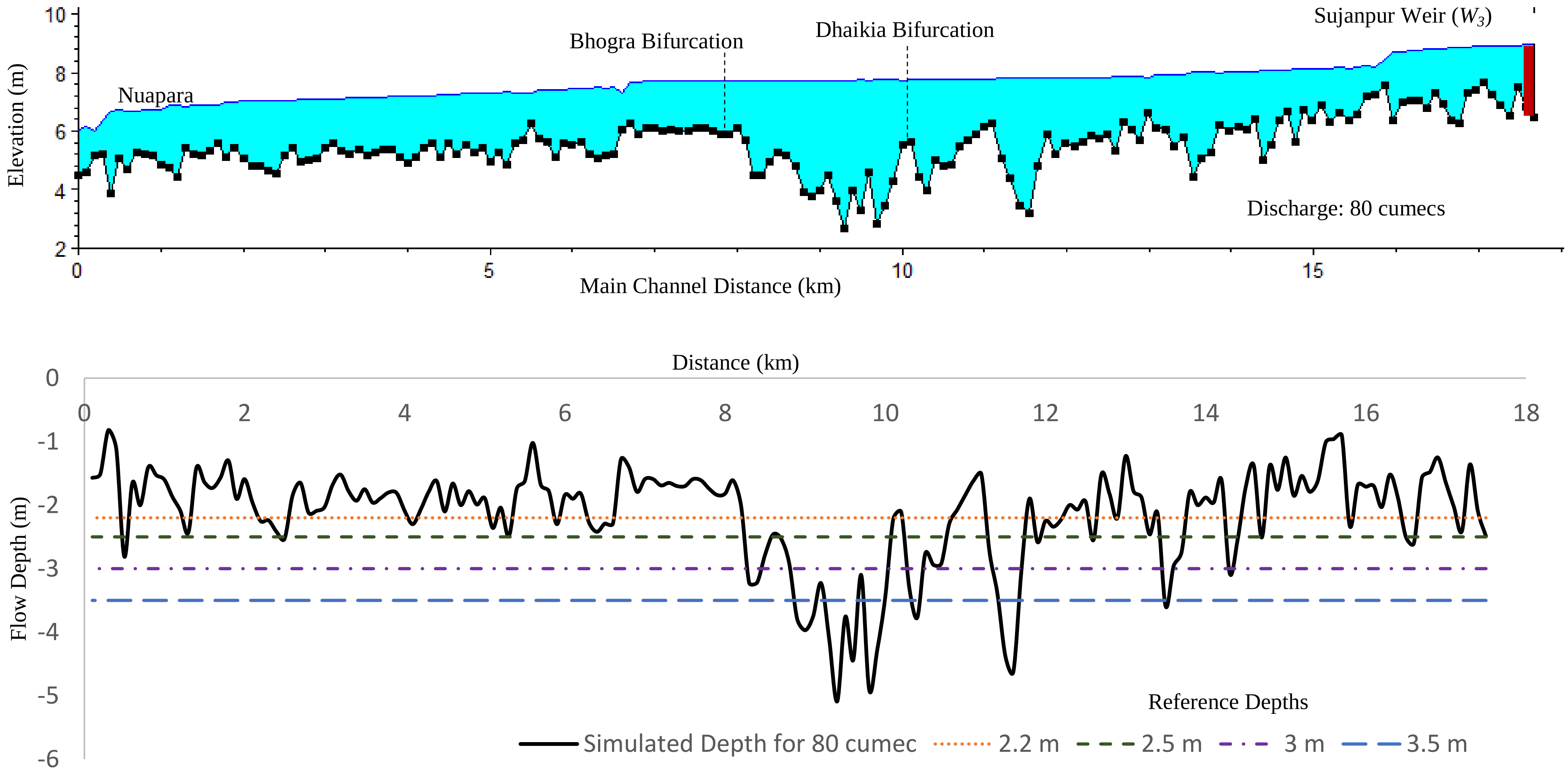


Figure 5.21: Flow variation along Tantigai (Sujanpur) - Tantigai- Dhaikia for 80 cumecs

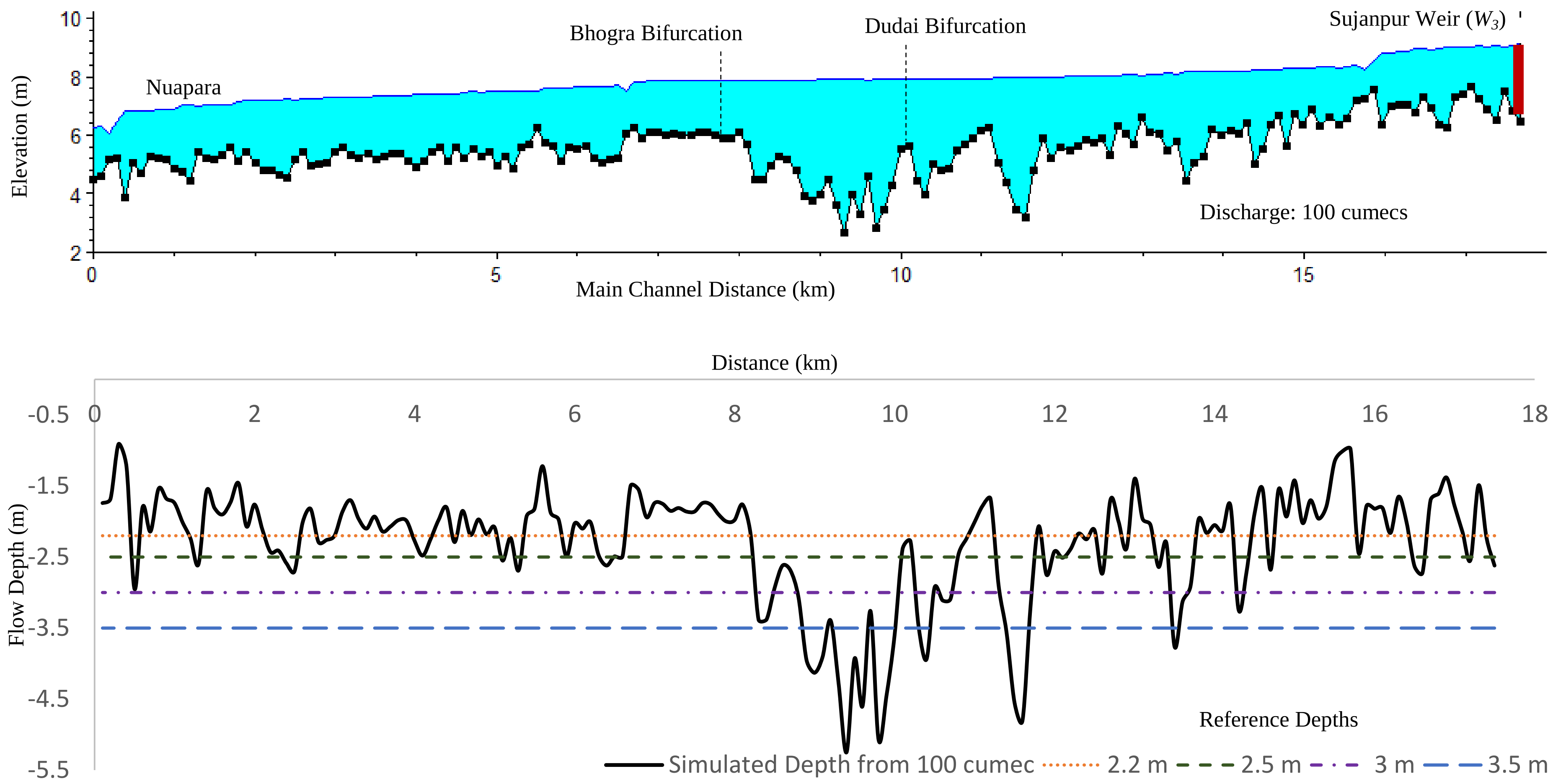


Figure 5.22: Flow variation along Tantigai (Sujanpur) - Tantigai- Dhaikia for 100 cumecs

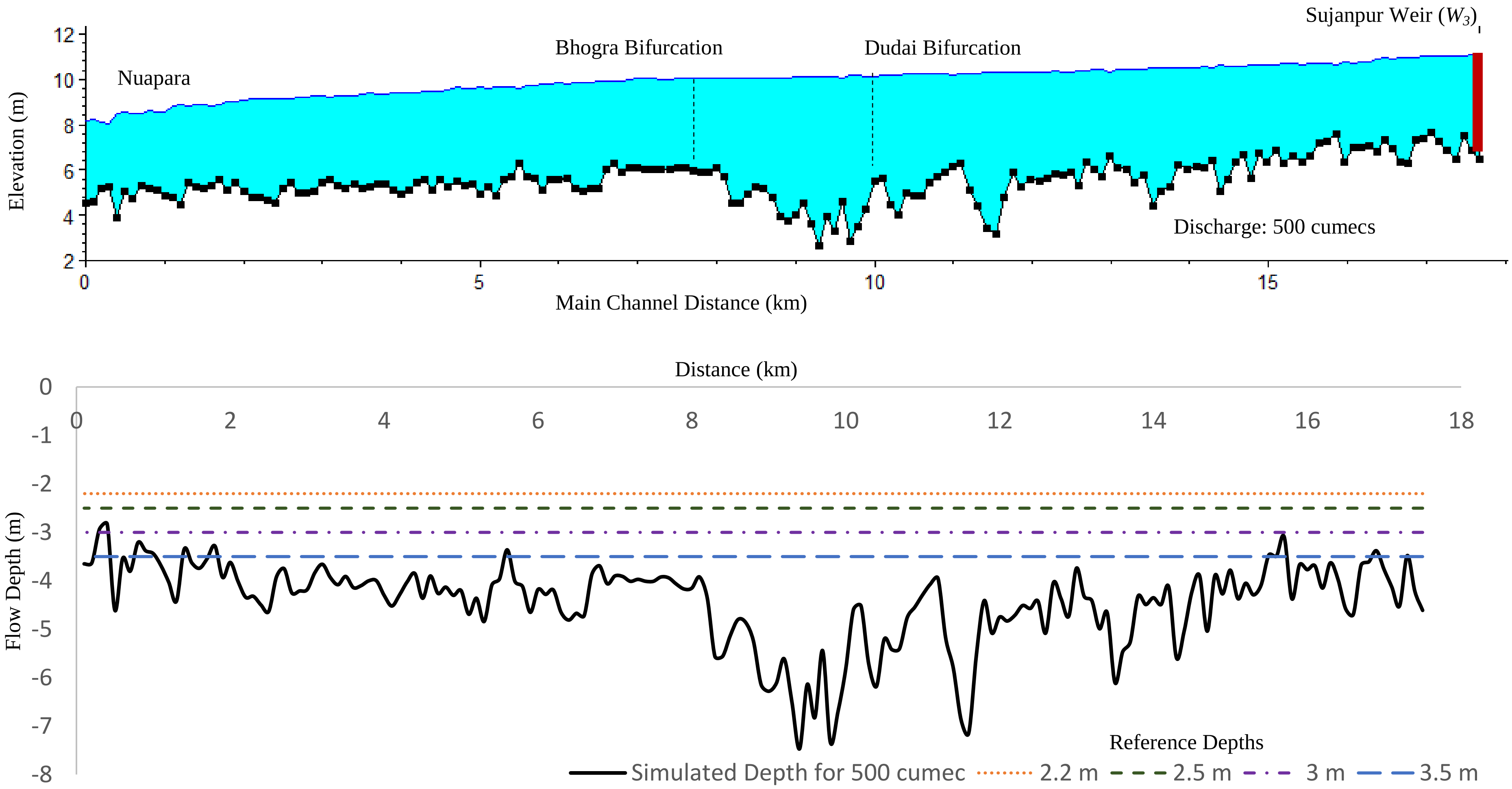


Figure 5.23: Flow variation along Tantigai (Sujanpur) - Tantigai- Dhaikia for 500 cumecs

5.5 Kani river till Padnipal

River Tantigai after multiple bifurcations as Dudai, Dhaikia and Bhogra rejoins further and flows as Kani till Padnipal. The Kani river reach covers 24.5 km in length through straight and meander paths before confluence with Kharsua in downstream. In this route the river embankments are partial and discontinuous with no proper alignment in it. The HEC-RAS model in this stretch is set up with 245 cross sections spacing at 100 m c/c covering a distance of around 24.5 km. Figure 5.24 shows the geometric network prepared in the HEC-RAS for the present segment. The flow analysis is carried out for discharges of 50 cumecs, 80 cumecs and 100 cumecs during lean season and 500 cumecs during monsoon season. The analysis of the bathymetry data indicates many local variations in longitudinal profile. Hence, obtaining the consistent depths throughout the reach could not be achieved for the lower discharges ranging from 50 – 100 cumecs. During the monsoon season as the discharges are higher the effect of local variations in profile is not significant in flow depths. The detailed plot showing flow depths for discharges of 50, 80 100 and 500 cumecs is shown in Figures 5.25 to 5.28. Hence, to obtain navigable depths in this reach either dredging or providing barrage at the downstream to carry its effect till upstream needs to be adopted.

5.5.1 Dredging

The bathymetric data analysis showed many local variations in bed profile from upstream to downstream. During lean season the variations in longitudinal profile has significant effect on flow depths required for navigation. Hence, to obtain the required navigational hydraulic parameters the reach can be dredged throughout along with reducing width. The hydraulic calculations for 30 m wide rectangular channel showed that 85 cumecs of discharge is required for obtaining 2.2 m flow depth.

5.5.2 Installation of Rubber Dam

A rubber dam of 3.5 m is proposed at the beginning of reach to store the incoming flow and maintain depths required for navigation. It is to be noted that the rubber dam will be inflated during lean season and deflated during flood period. The flow analysis is carried out for steady lean (50, 80 and 100 cumecs) and monsoon (500 cumecs) discharges to study the effect of proposed barrage. The simulation results showed that 3.5 m rubber dam during lean season is significant in achieving thalweg depths greater than 4.0 m up to 10.0 km length and depths between 2.5 m to 4.0 m for another 5 km for 50-80 cumecs. The effect of proposed rubber dam could not reach till end i.e. up to 23 km because of the steep slope for 8 km reach. This steep slope could be made gentle by dredging and necessary width controlling measures to be adopted for maintaining the navigable depths throughout. The detailed plot showing effect of rubber dam on flow depth variation for discharges of 50, 80, 100 and 500 cumecs is shown in Figures 5.29 to 5.32. In monsoon season the effect of rubber dam is up to 23.0 km with depths greater than 3.5 m. Considering the losses due to evaporation and seepage, the proposed weir need to be raised by another 0.75 m to prevent reduction in navigational depths.

5.5.3 100 year flood analysis

- The 100 year flood analysis for the present conditions showed that for discharge of 3250 cumecs the submergence is up to 2m on either bank along the river route. The maximum channel carrying capacity of Kani is 1200 cumecs and any discharge above causes flooding throughout the river line. Hence, to accommodate the 100 years flood and to prevent submergence embankments needs to be constructed along the route rising to a height of 2.0 m from the banks.
- As the rubber dam is deflated during flood season, the present case is similar to the no structure case. Hence, the analysis for the 100 years flood will be same as discussed above.

Summary

- *The flow depth ranges during lean season in the Kani river are lesser than depths required for navigation. The navigable depths in this reach could be obtained either by dredging along with reducing width or providing 4.25 m rubber dam at the downstream along with minor dredging in the upstream*

- *100 years flood simulation shows submergence up to 2.0 m above banks. The embankments need to be constructed along the route rising to a height of 2.0 m from the banks. It is to be noted that the rubber dam is deflated during the flood period and the 100 year flood analysis is same as no structure case.*

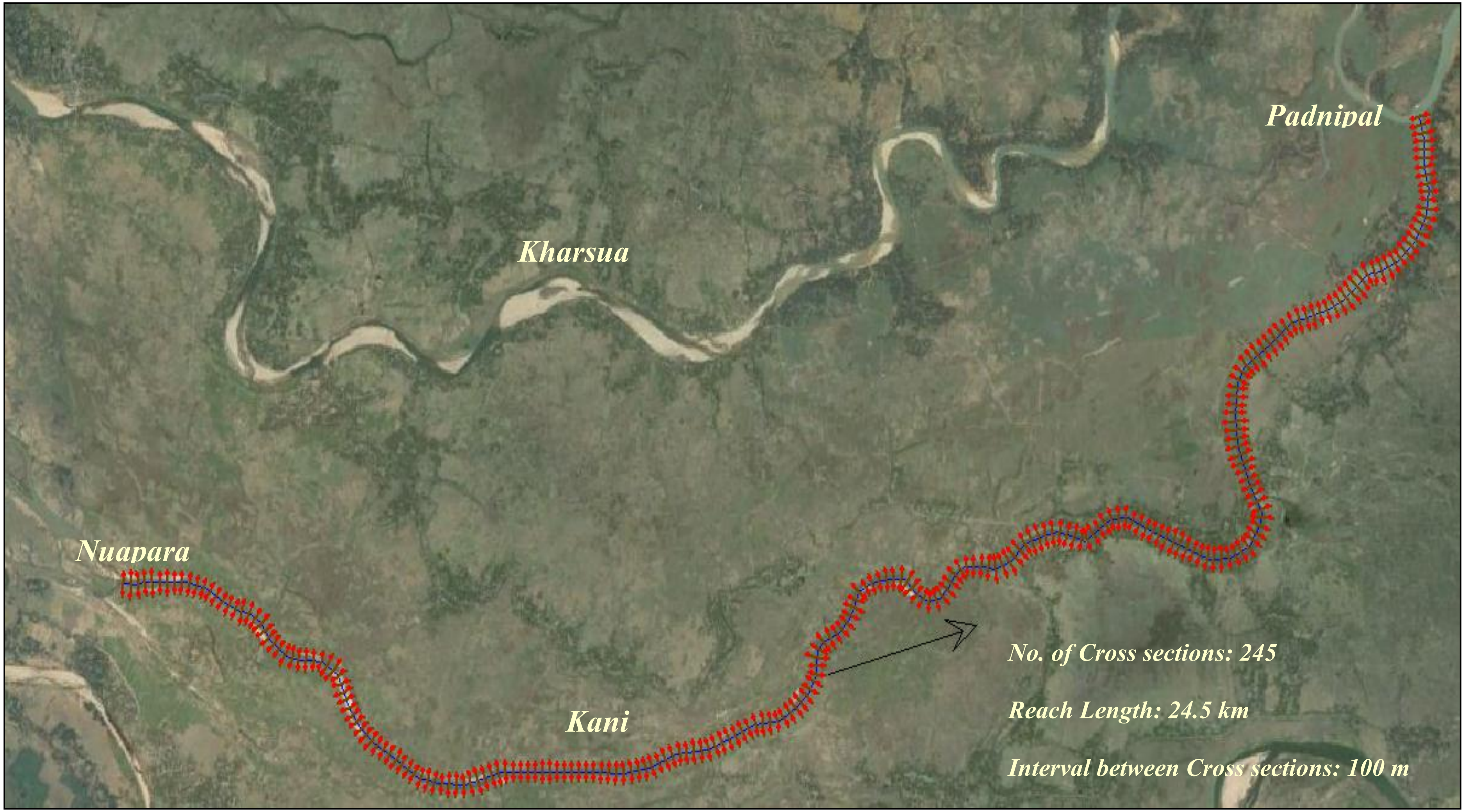


Figure 5.24: HEC-RAS geometric network for Kani Reach till Pankapal

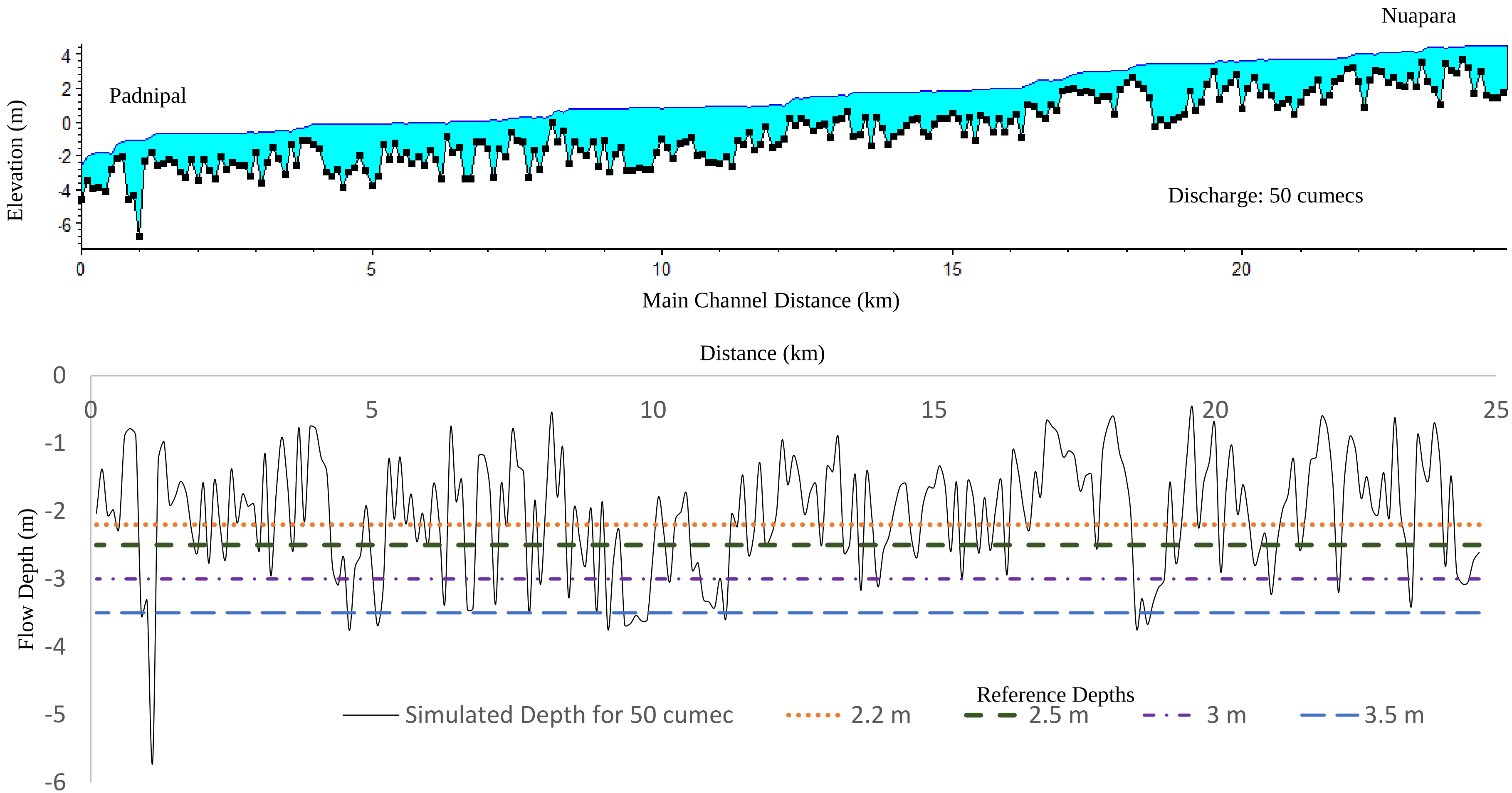


Figure 5.25: Flow variation along Kani River for 50 cumecs Discharge with natural condition

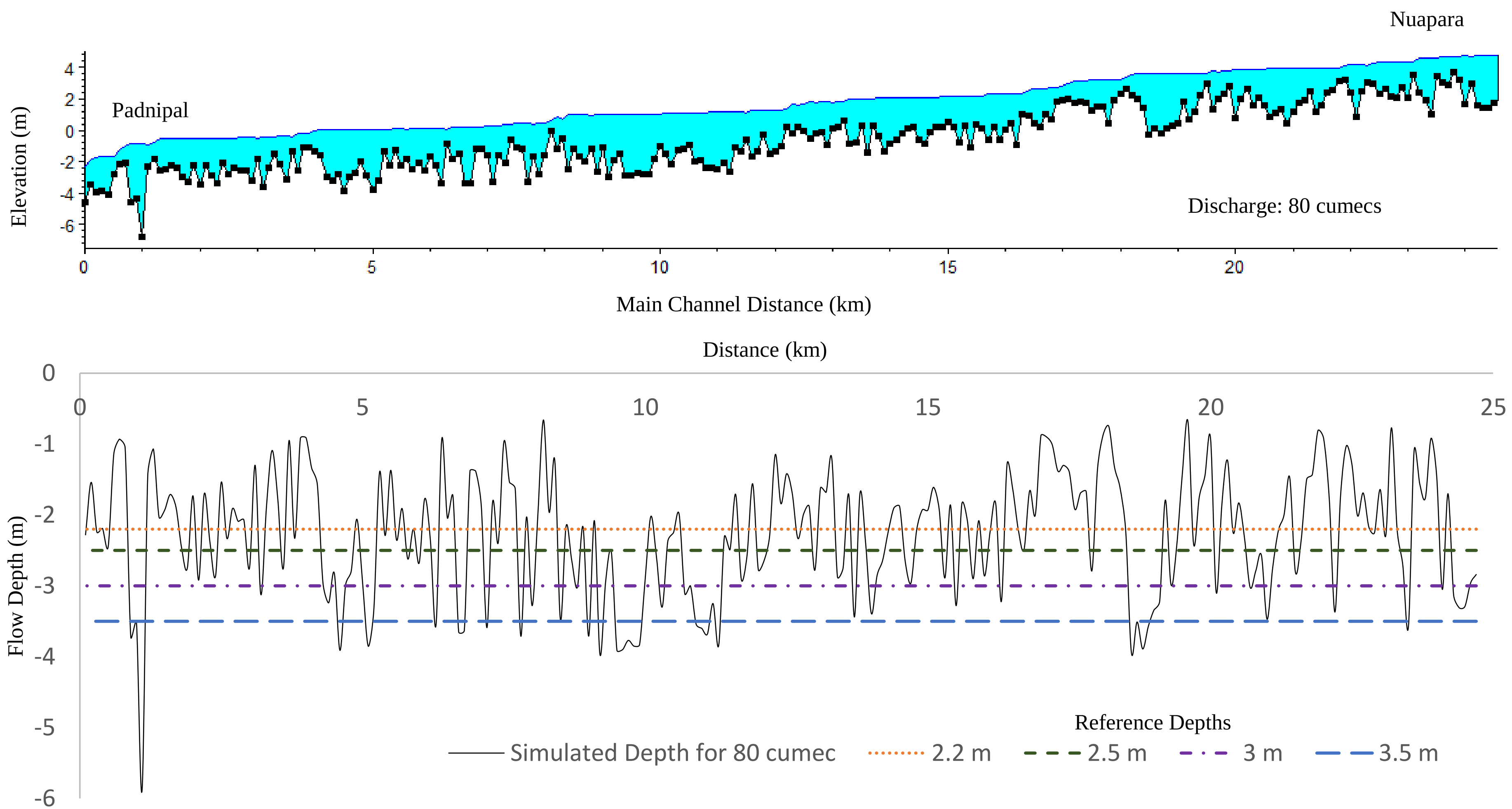


Figure 5.26: Flow variation along Kani River for 80 cumecs Discharge with natural condition

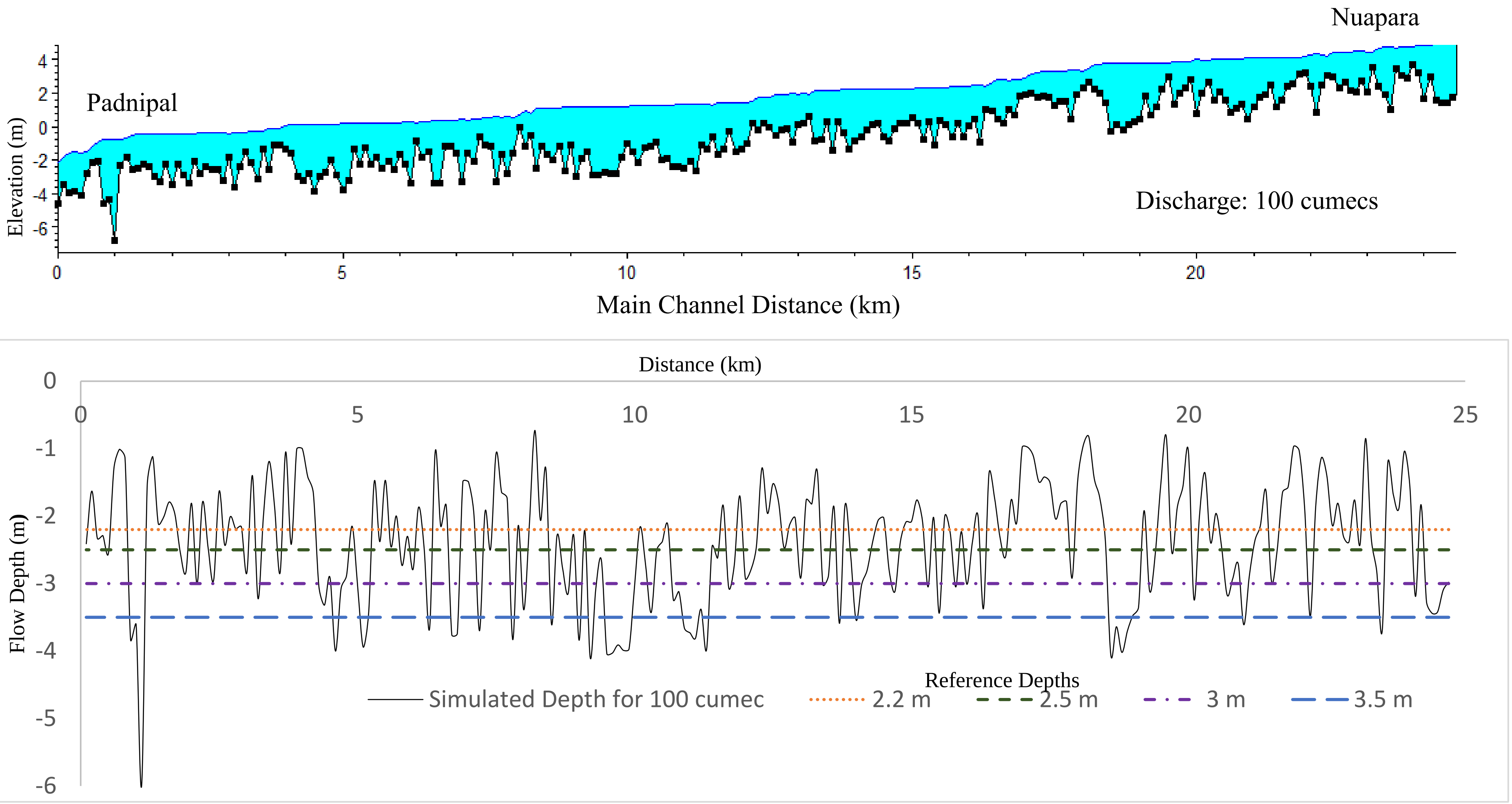


Figure 5.27: Flow variation along Kani River for 100 cumecs Discharge with natural condition

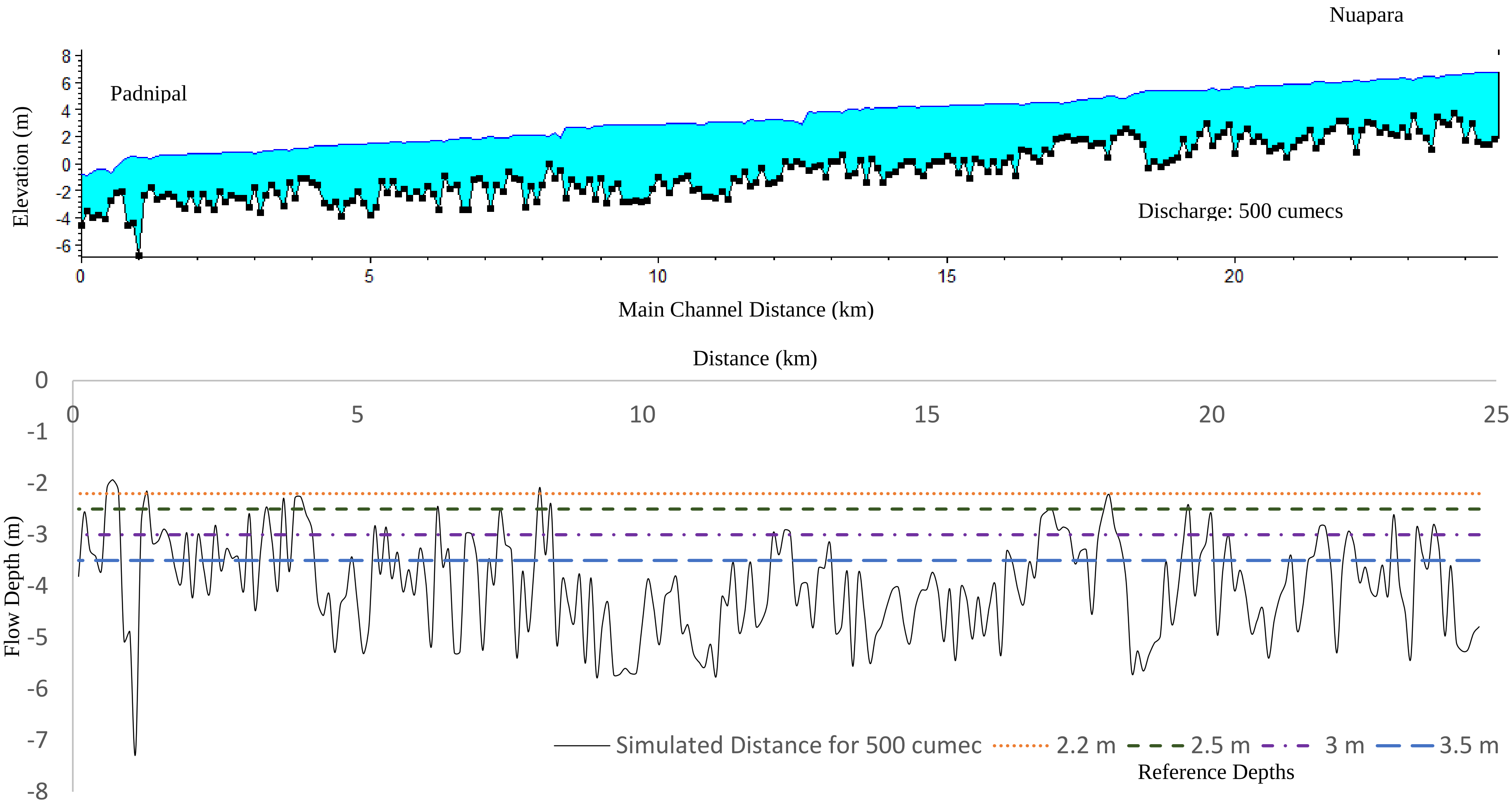


Figure 5.28: Flow variation along Kani River for 500 cumecs Discharge with natural condition

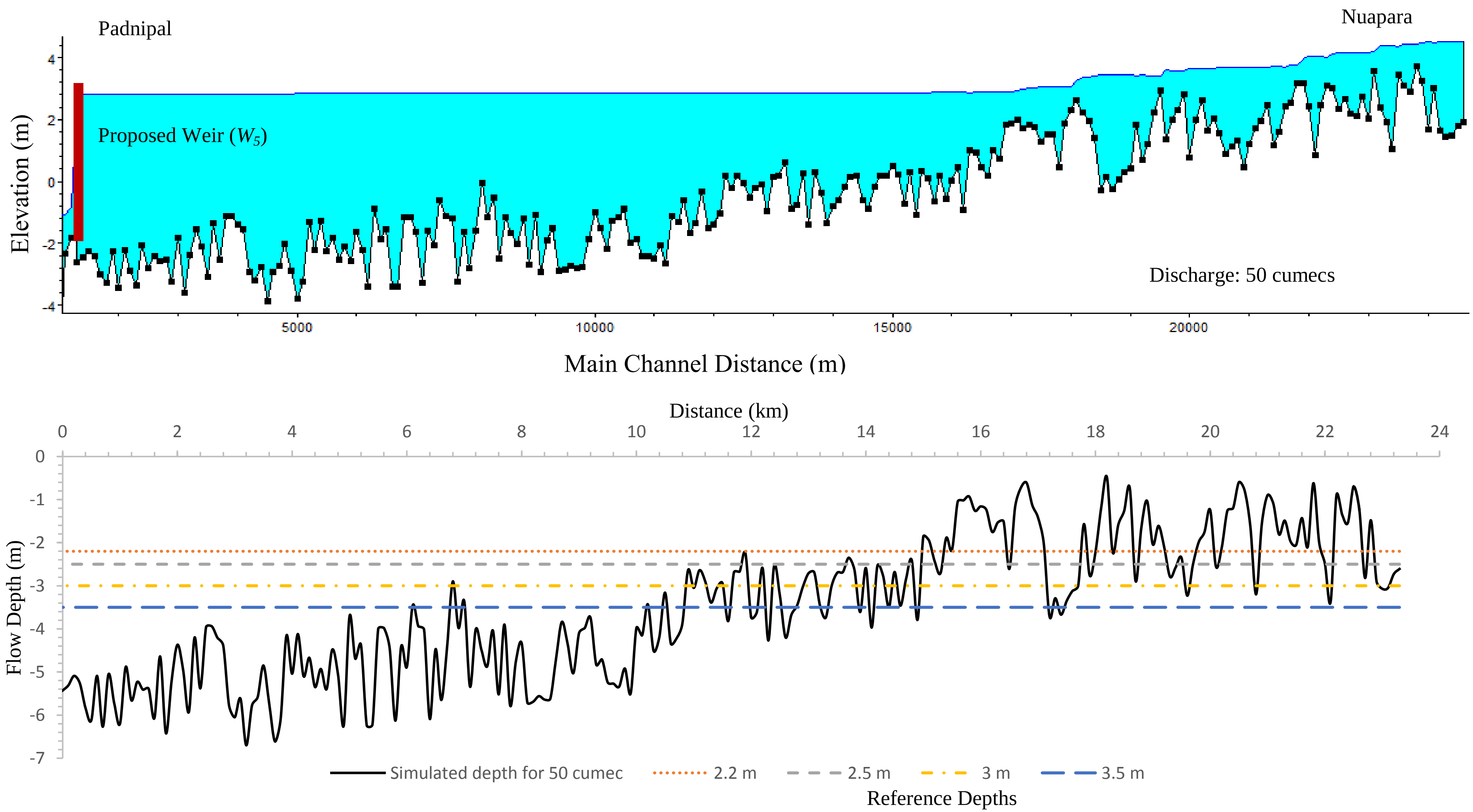


Figure 5.29: Flow variation along Kani River for 50 cumecs discharge with proposed rubber dam *(W_5)*

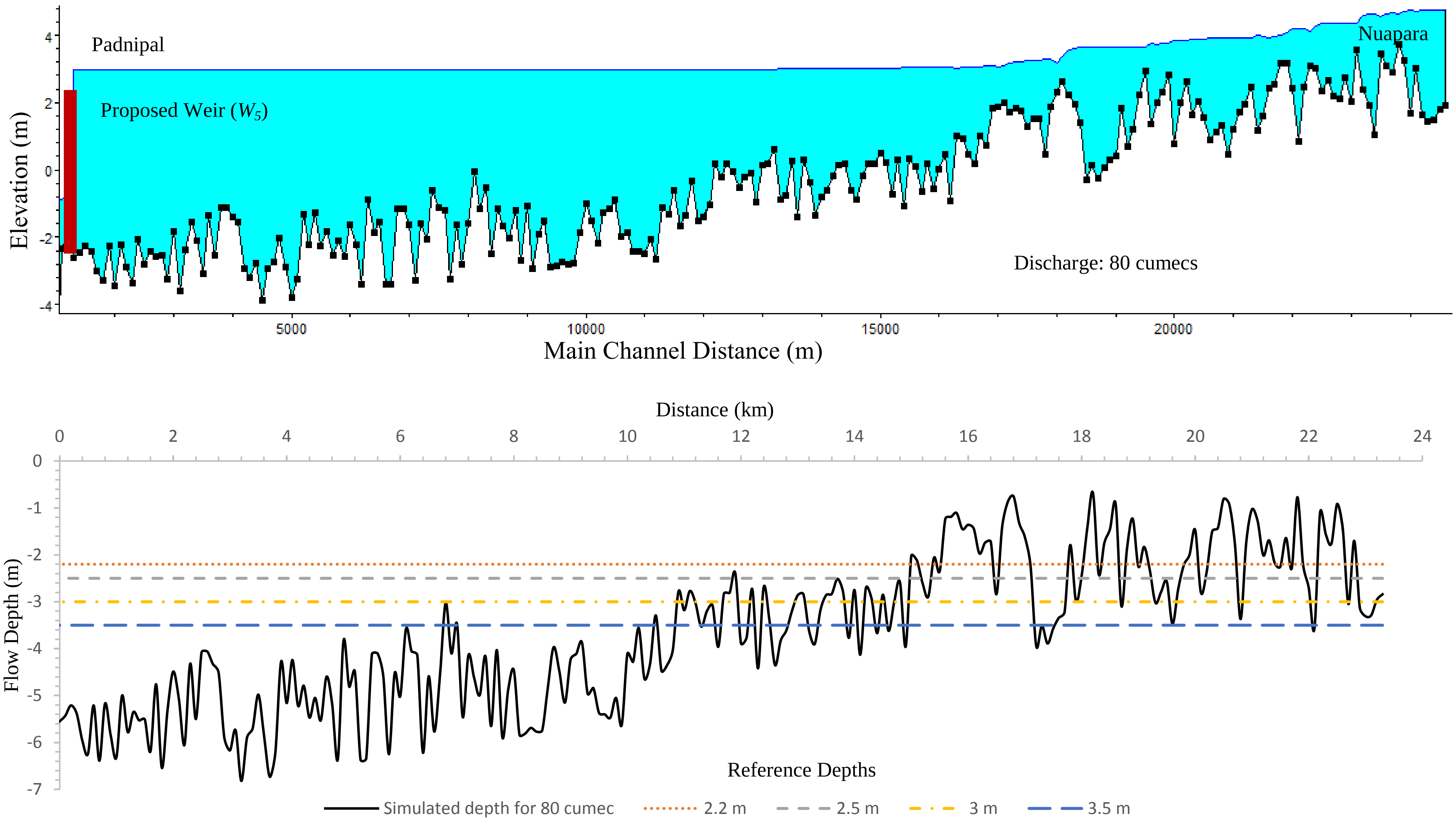


Figure 5.30: Flow variation along Kani River for 80 cumecs discharge with proposed rubber dam *(W_5)*

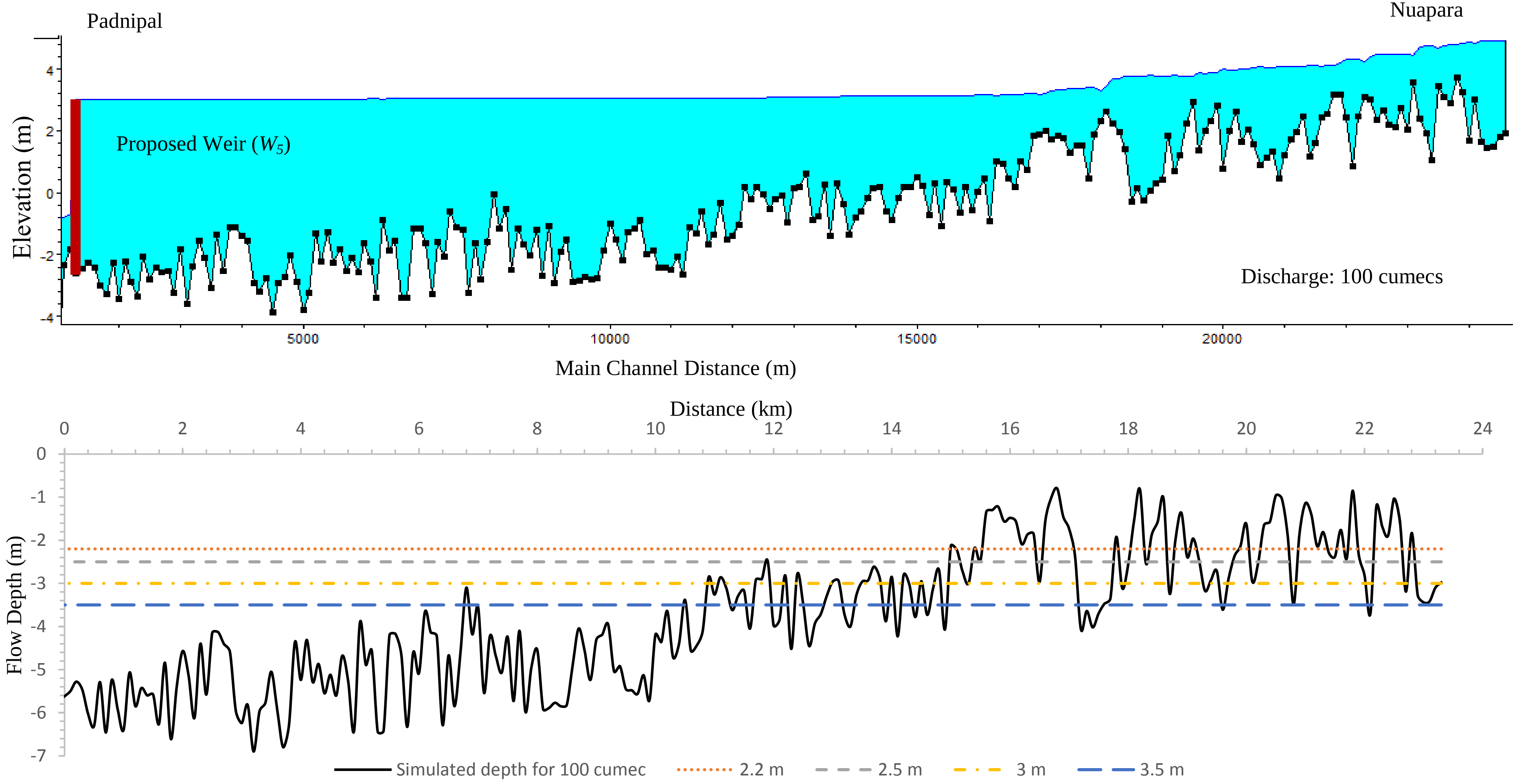


Figure 5.31: Flow variation along Kani River for 100 cumecs discharge with proposed rubber dam (W_5)

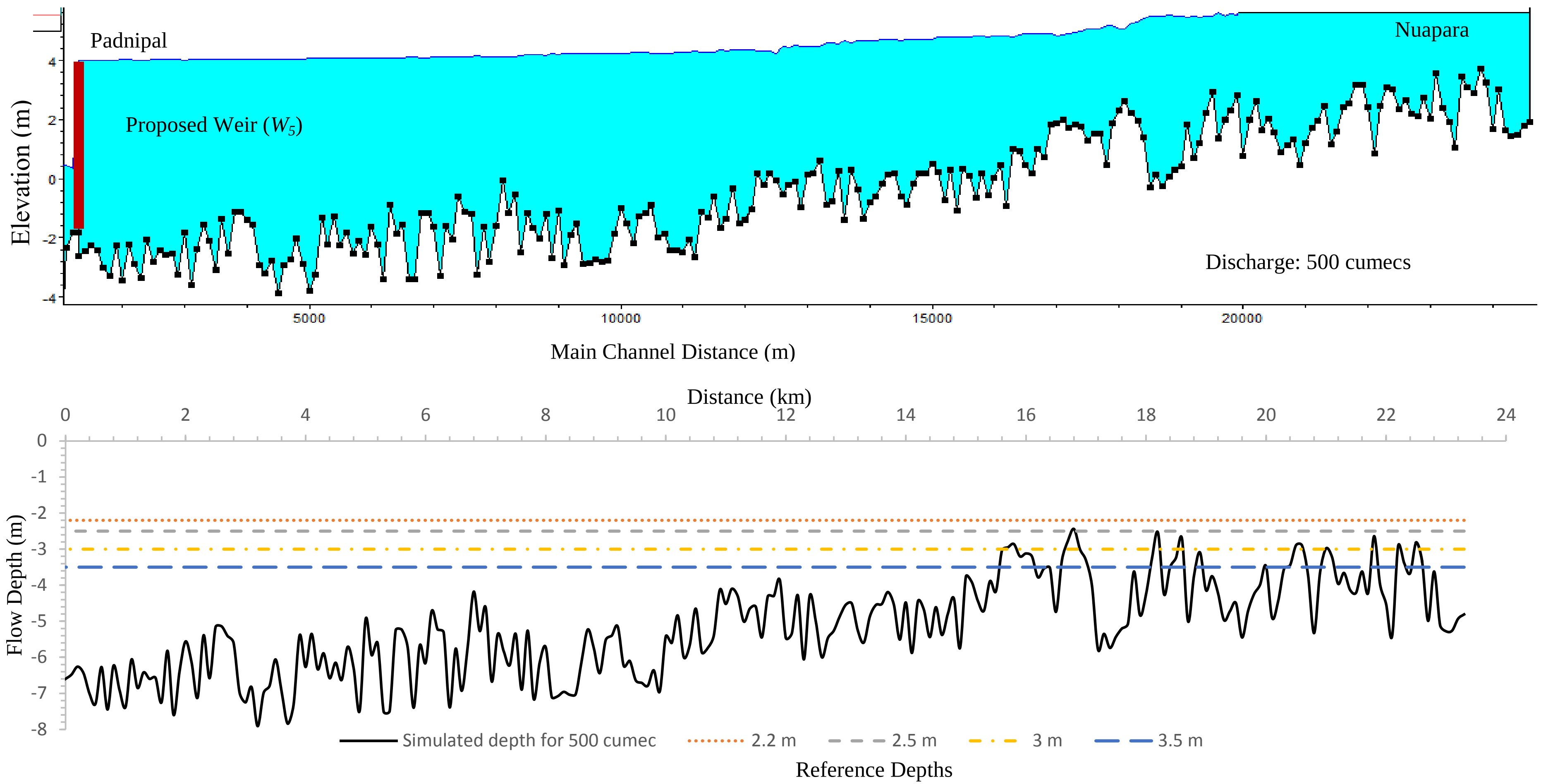


Figure 5.32: Flow variation along Kani River for 500 cumecs discharge with proposed rubber dam (W_5)

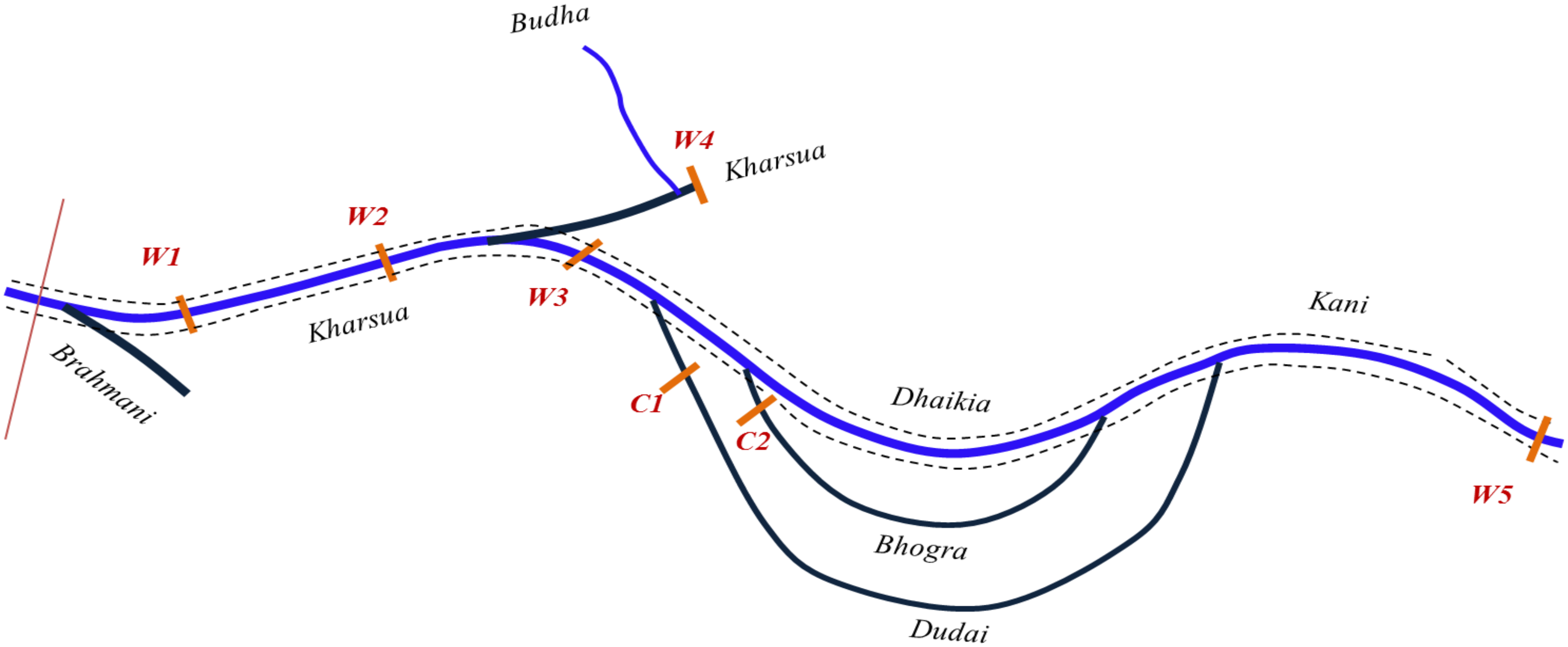
5.6 Hydraulic structures in the proposed Waterway

In the proposed waterway between Pankapal to Padnipal, suggestions for reconstruction of two existing structures, two new barrages, two check dams are proposed for maintaining navigational depth and widths throughout year. In addition another new structure (rubber dam) is proposed on river Kani which is given as an option against dredging. The index map showing the tentative locations of the proposed/modified structures and notations followed for the structures is shown in Figure 5.33. Table 5.4 summarizes the technical and geographic details of hydraulic structures proposed in the study area.

Table 5.4: Details of the hydraulic structures proposed in the National Waterway between Pankapal to Padnipal

Name of Weir	River name	Geographic Location	Weir Details/Levels			Max. WL @ 100 Years Flood MSL	Remarks
			Existing crest level MSL	Height of proposed weir (m)	Existing embankment level MSL		
Jokadia (W$_1$)	Kharsua	20°53'23.65"N 86° 6'35.85"E	14.78	2.75	20.70	23.38	Weir cum barrage with Navigational Lock
Intermediate (W$_2$)	Kharsua	20°49'53.52"N 86°15'40.89"E		4.25	17.69	19.56	Weir cum barrage with Navigational Lock
Sujanpur (W$_3$)	Tantigai	20°47'8.20"N 86°17'25.75"E	9.44	2.60	15.84	18.31	Weir cum barrage with Navigational Lock
Proposed (W$_4$)	Budha-Kharsua	20°46'29.84"N 86°19'26.59"E		5.25	16.06	18.49	Weir cum barrage
**Proposed (W$_5$)*	Kani	20°40'46.05"N 86°35'6.28"E		4.25	NA	3 m above banks	Rubber dam
Check dam 1	Dudai	20°43'53.64"N 86°20'38.13"E		2.50	NA	2 m above banks	Check Dam
Check dam 2	Bhogra	20°43'13.08"N 86°21'46.06"E		2.50	NA	2 m above banks	Check Dam

Note: 1. Proposed rubber dam (*W$_5$*) is optional against dredging; 2. NA: Not available



- W_1 : Revised Jokadia weir cum barrage with navigational lock
- W_2 : Newly Proposed weir cum barrage with navigational lock
- W_3 : Revised Sujanpur weir cum barrage with navigational lock
- W_4 : Weir cum barrage
- W_5 : Newly proposed rubber dam (Optional against dredging)
- C_1 *and* C_2 are Check Dams

Figure 5.33: Proposed hydraulic structures between Pankapal and Padnipal

Chapter 6

Recommendations and Conclusions

The Brahmani river network from Pankapal to Padnipal through Kharsua-Tantigai-Dhaikia- Kani is initially considered for the study. Mathematical modeling in this network is set up piece wise with 100 m interval surveyed cross sections. Considering the lean season flow availability the model is simulated for discharges of 50, 80 and 100 cumecs and proposed barrages accordingly. The impact of reconstruction of existing weirs Jokadia and Sujanpur is studied and necessary revisions are suggested. The 100 year flood analysis is carried out to predict flood levels for constructing/revising embankment heights in the proposed route.

6.1 Mathematical modeling studies between Pankapal to Padnipal

The following listed are major recommendations for the river network after thorough mathematical modeling studies

Kharsua (Pankapal) to Kharsua (Jokadia)

- Jokadia weir (W_1) to be raised by 2.75 m with the provision of navigational lock from existing crest level to provide suitable navigational depths throughout the reach in all seasons.

- 100 years flood simulation for existing Jokadia weir shows submergence varied between 0.75 m to 1.5 m above embankments. The existing embankments should be modified by raising accordingly from the present level.

Kharsua (Jokadia) to 7 km upstream of Sujanpur

- A new weir cum barrage (W_2) of 4.25 m with navigational lock is proposed between Kharsua (Jokadia) and 7 km upstream of Sujanpur weir to maintain navigational depths for 22 km reach.
- Minor dredging work needs to be carried out for 4.0 km river reach downstream of Jokadia to make steep slope to gentle one. This helps to carry effect of proposed barrage for 4.0 km upstream.
- 100 years flood simulation for 1 m height weir shows submergence varied between 0.5 m to 1.7 m above existing embankments and 3.0 m at no embankment locations. Hence, the existing embankments should be modified by raising accordingly from the present level and new embankments to be constructed 3.0 m high at locations where no embankments are present.

Kharsua-Tantigai (Sujanpur) bifurcation

- Sujanpur weir (W_3) is raised by 2.60 m from existing crest level and additional 5.25 m weir (W_4) at Budha-Kharsua confluence is proposed to capture water from Budha and maintain navigational depths throughout the reach in all seasons
- 100 years flood simulation for 1 m height weir shows that in upstream (Kharsua river above Tantigai bifurcation) the submergence varied from 0.75 m to 1.25 m above embankments and in downstream (Kharsua river after Tantigai bifurcation) the submergence is close to embankment level. At the location where no embankments are present the submergence is up to 3.0 m. Hence, the existing embankments should be revised accordingly.

Tantigai (Sujanpur)-Tantigai-Dhaikia

- Check dams of 2.5 m are proposed at Dudai and Bhogra rivers to divert complete lean season discharges to Dhaikia and dredging along the proposed route is also suggested for maintaining navigational depths.

- 100 years flood simulation shows submergence up to 2.0 m above banks. As there are no embankments in this route, the same need to be constructed rising 2.0 m high from the banks.

Kani River till Padnipal

- The flow depth ranges during lean season in the Kani river are lesser than depths required for navigation. The navigable depths in this reach could be obtained either by dredging along with reducing width or providing 4.25 m rubber dam at the downstream along with minor dredging in the upstream.
- 100 years flood simulation for present conditions shows submergence up to 2.0 m above banks. The embankments need to be constructed along the route rising to a height of 2.0 m from the banks.

6.2 Mathematical modeling studies between Talcher to Pankapal

The bathymetry and topography data provided by IWAI shows about 50 m relief between Talcher and Pankapal. The data was prepared w. r. t. charted datum (CD) with very limited benchmarks. Therefore, the bathymetry and topography data shows artificial drops between these two stations. Not only that, the river is braided in nature with multiple channels and sand bars, and the average width of the river is about 1 km in this stretch. In order to have appropriate bathymetry and topographic data set, new survey needs to be conducted with proper bench marking. The issue has been discussed in meeting with IWAI officials on 30 Nov. 2015. Subsequently, IWAI has suggested to conduct mathematical modeling studies for Pankapal to Padnipal stretch.

6.3 Modification of crest level of Jenapur weir

As discussed in field investigations of Chapter 3, the Jenapur weir on River Brahmani has been completely silted up and carries discharge only during flood period. In this study, the mathematical modeling of river network is carried out through Kharsua river. Therefore, the effect of raising the crest level of Jenapur weir will be addressed in the second phase of work between Talcher to Pankapal.

6.4. Supplementary provision for Irrigation

Department of Water Resources, Government of Odisha has a proposal to divert 16 cumecs of discharge through a canal located upstream of Jokadia weir. The design discharge for the inline structures proposed in the study network is 50 cumecs. If additional 16 cumecs of discharge is to be included for irrigation then as a total 66 cumecs of discharge will be necessary at Pankapal for both navigation and irrigation requirements.

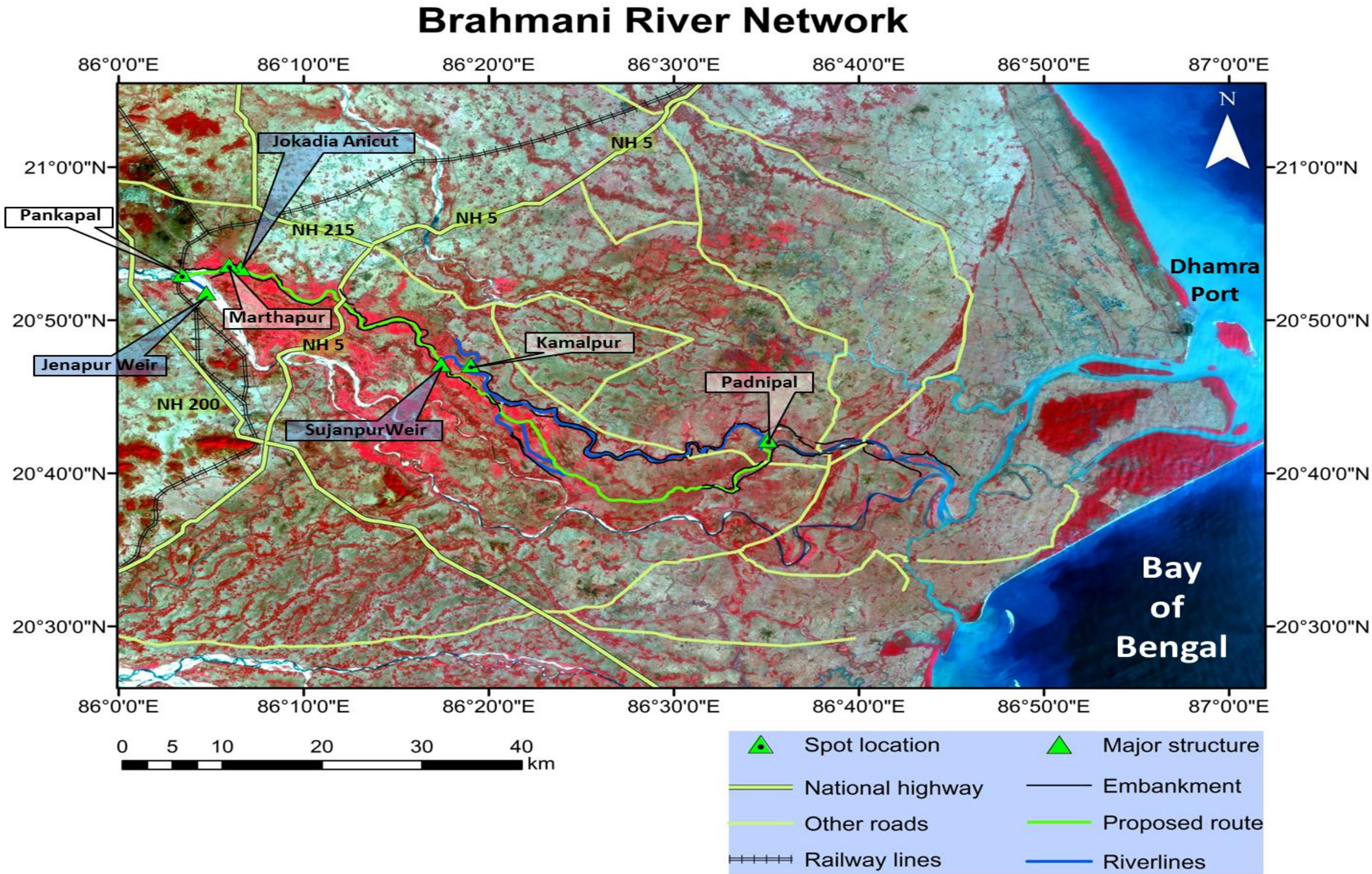


Figure A-1: Index map showing various geographic features along the Brahmani River network

Kharsua (Pankapal) to Kharsua (Jokadia)

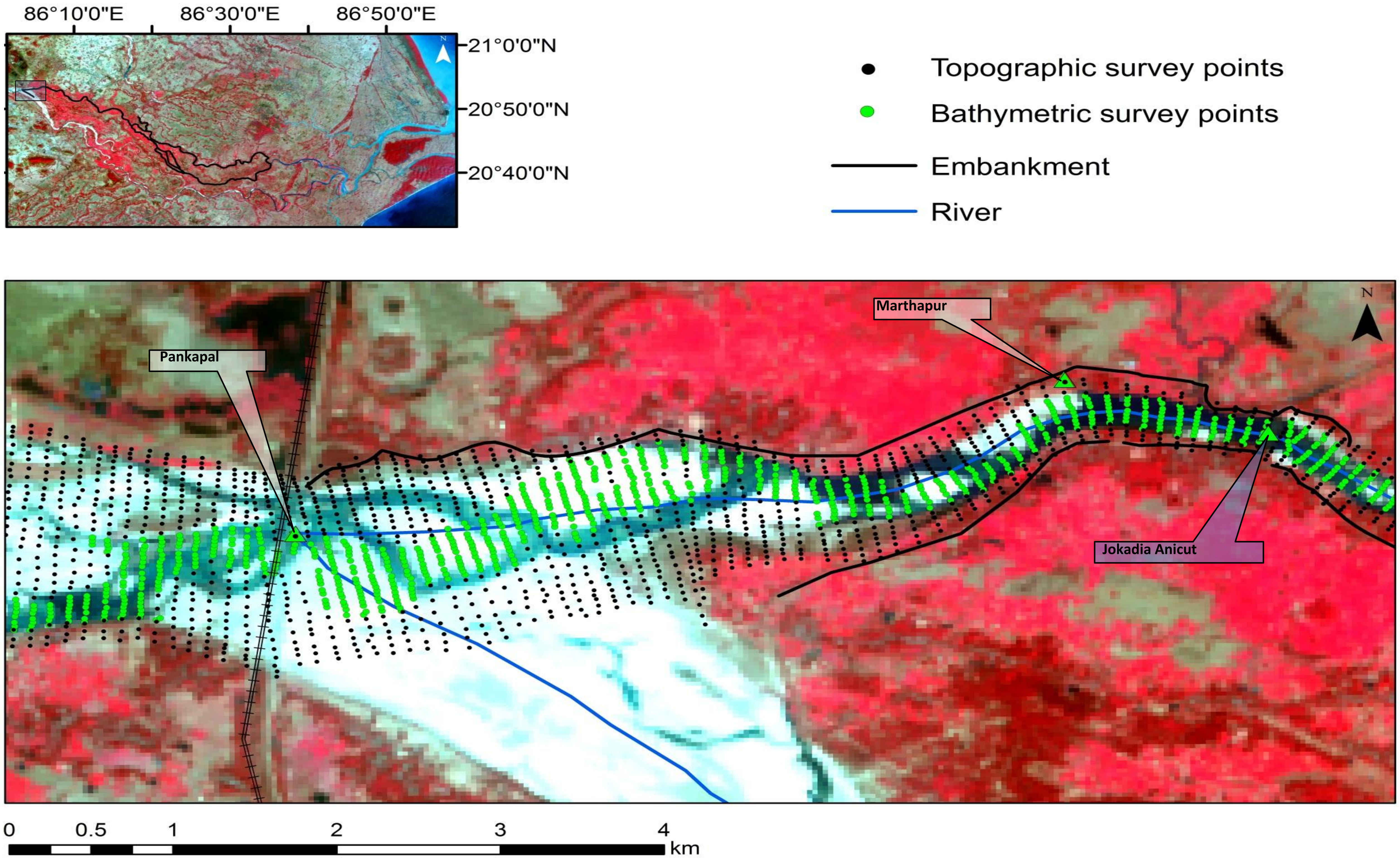


Figure A-2: Bathymetric and Topographic survey points from Kharsua (Pankapal) to Kharsua (Jokadia)

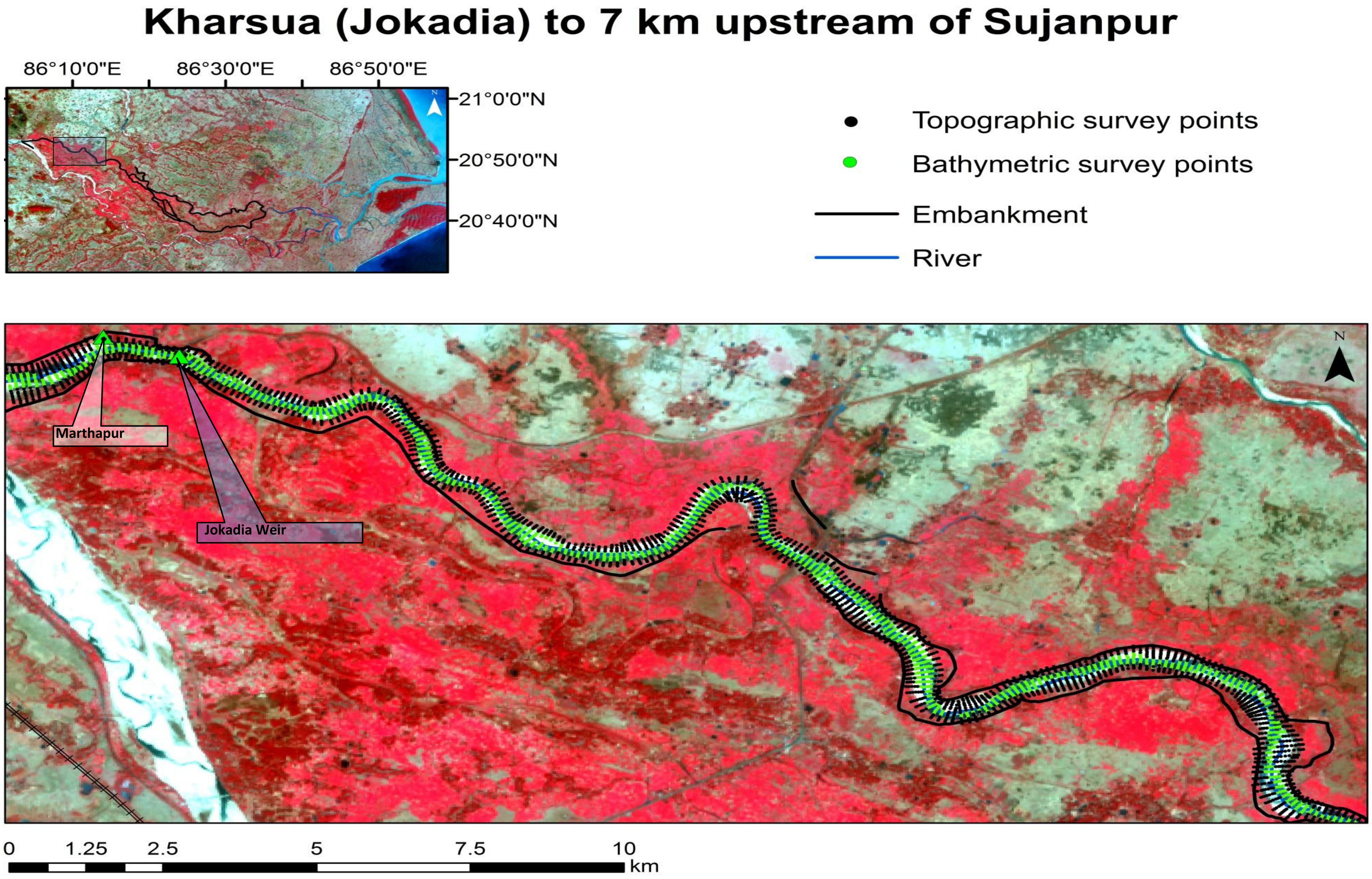


Figure A-3: Bathymetric and Topographic survey points from Kharsua (Jokadia) to 7 km upstream of Sujanpur

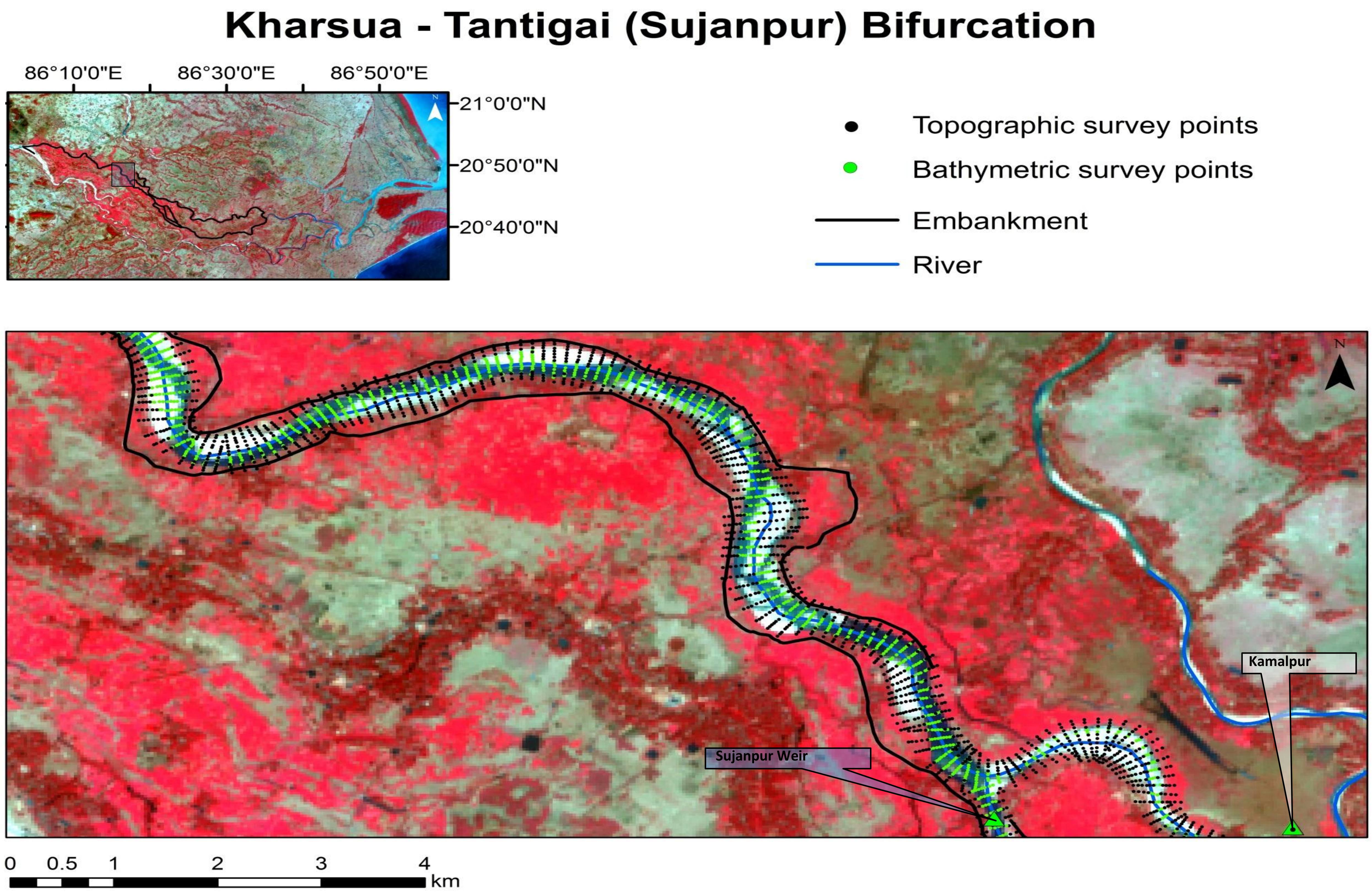


Figure A-4: Bathymetric and Topographic survey points for Kharsua – Tantigai (Sujanpur) bifurcation

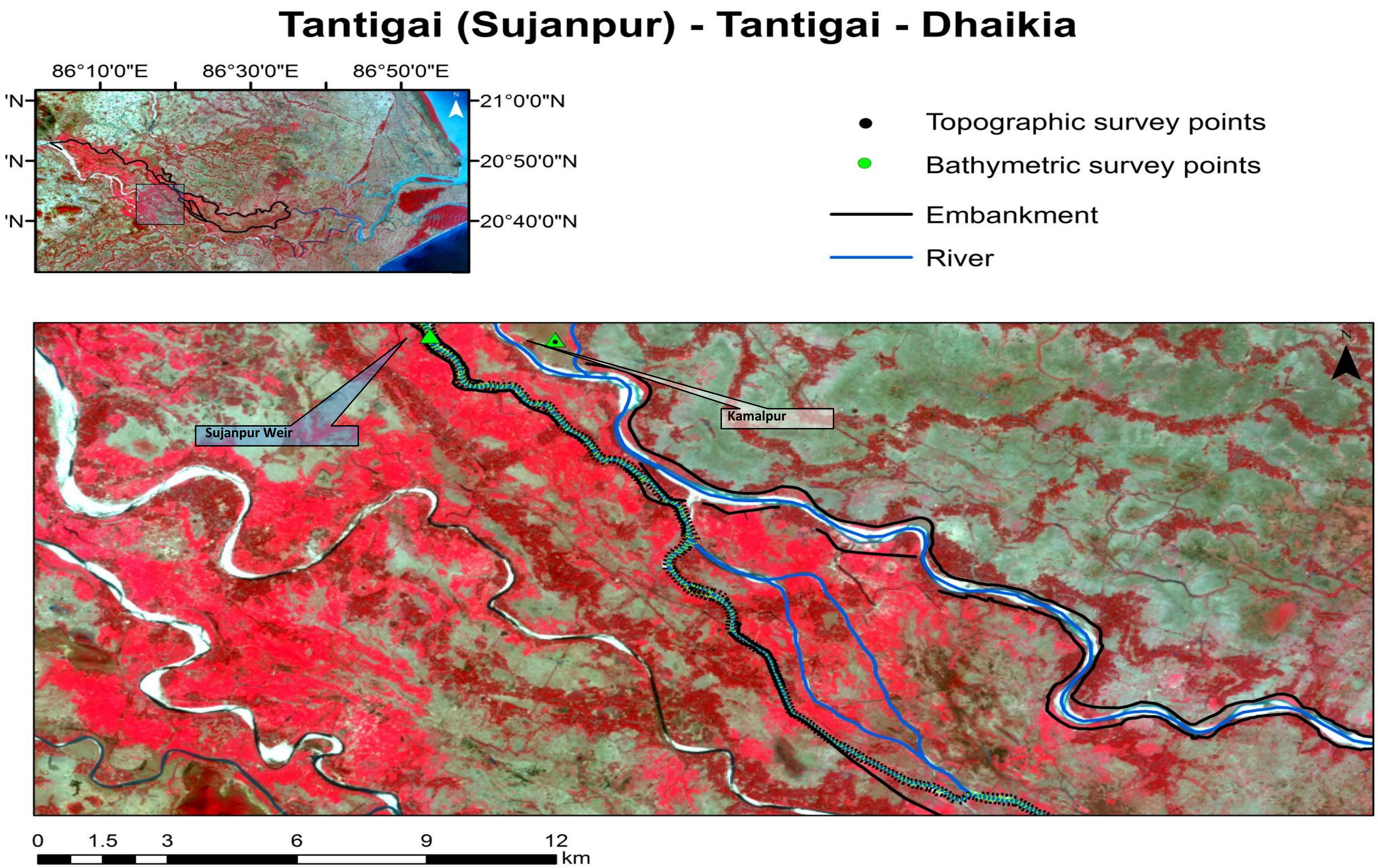


Figure A-5: Bathymetric and Topographic survey points for Tantigai (Sujanpur) – Tantigai – Dhaikia

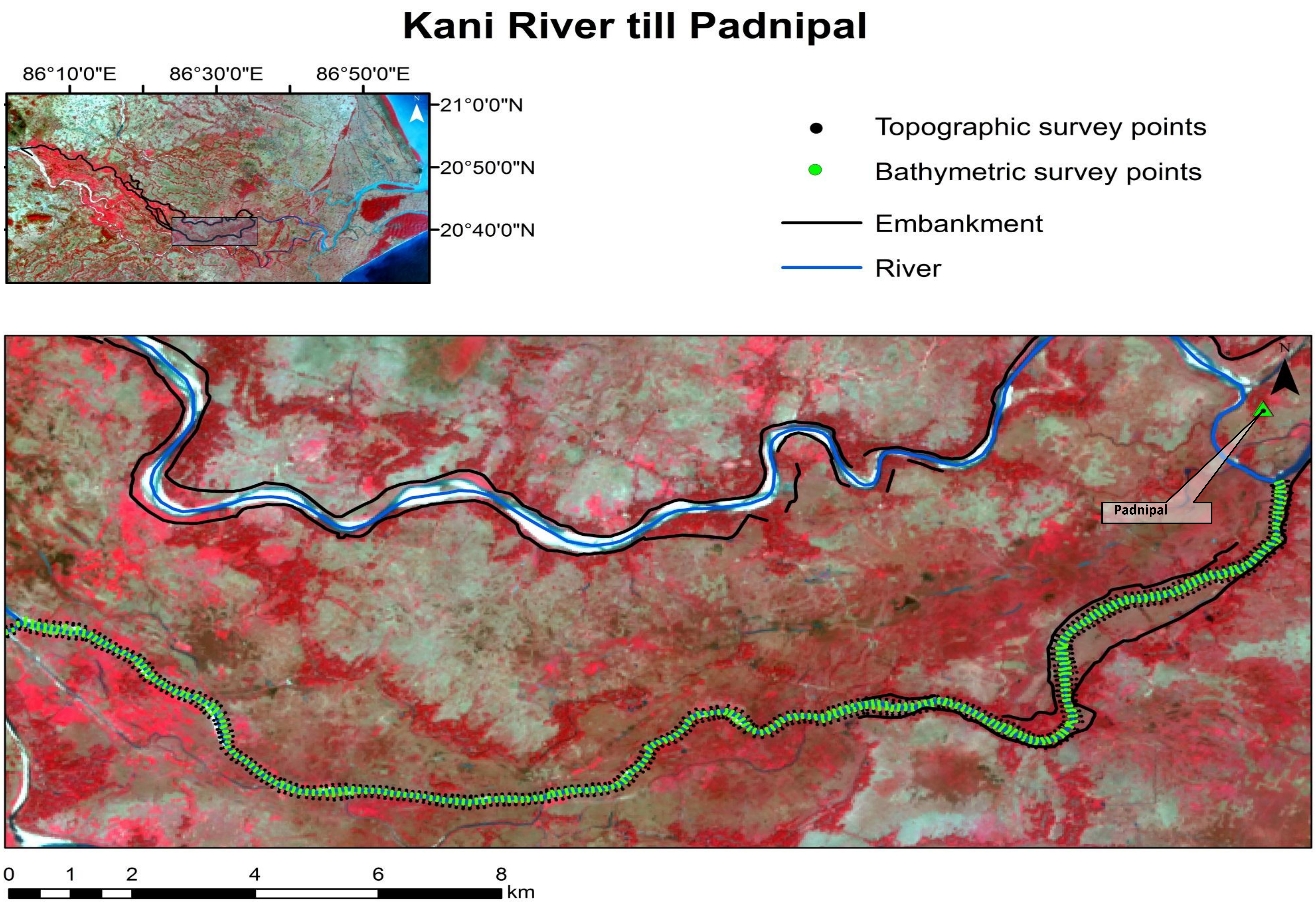


Figure A-6: Bathymetric and Topographic survey points for Kani river till Padnipal