River Stage Prediction Using Hydrodynamic Modeling

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RIVER STAGE PREDICTION USING HYDRODYNAMIC MODELING

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KEYWORDS

Floods, HEC-RAS, Rainfall, Tapi River, Surat

ABSTRACT

Increasingly erratic climatic conditions cause sudden water surges from the Ukai dam in the river Tapi, flooding Surat City. There were disastrous floods in 1883, 1884, 1942, 1944, 1945, 1949, 1959, 1968, 1994, 1998, 2002, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013. The river's carrying capacity is estimated to be around 4.5 million cubic meters. Due to silting and encroachment caused by urbanization, the effective waterway of the river Tapi is shrinking in width and depth, reducing the river's carrying capacity. The Hydrologic Engineering Centres River Analysis System (HEC-RAS) software is used in this study to assess the carrying capacity of the Lower Tapi River reach, which is 12.25 km long, and to conduct an unsteady flow analysis for the tidal reach in order to understand the effects of high and low tides. As a study reach, the Tapi River reach was taken from Weir cum Causeway to Magdalla bridge. There are 49 cross-sections in the study's reach. The variations of water surface level due to upstream flow and high tidal backflow conditions in the channel reach are considered in the study. For the years 2010 and 2011 daily discharge data, unsteady flow analysis was performed using HEC-RAS, taking into account the tidal surges and backflow. To improvise the effect of minimum and maximum variations of tidal effect, two years of daily discharge data were considered and studied. The effect of changes in tidal level variations due to various peak discharges has been studied. The effects of the tidal effect on flooding are depicted in this study. To prevent flooding at various critical cross-sections levees are proposed to be constructed to store and mitigate the high inflow. This study may be used as a basis for disaster management, flood management, early warning systems, and infrastructure development decisions.

1. INTRODUCTION

Floods are one of the major causes of the loss of life and property and harm the economy across the globe [2,8,20]. With the rapid advancement in computational technology and research in numerical techniques, various one-dimensional (1D) hydrodynamic models, based on hydraulic routing, have been developed, calibrated, validated, and successfully applied for flood forecasting and inundation mapping [3,21]. It has been demonstrated that hydrodynamic models that replicate the hydraulic behavior of river channels are efficient tools for managing floodplains [1].

Flooding in coastal urban areas brought on by heavy rain and high tide is now a major concern, particularly in light of the anticipated effects of sea level rise and high-intensity rainfall on climate change [4]. Urban flooding disasters now cause many more annual disasters and economic losses than other disasters combined. For example, major cities in India have witnessed the loss of life and property, disruption to transport and power, and incidences of the epidemic during monsoons, most notable among them Mumbai in 2005, Surat in 2006, and Kolkata in 2007 [2,15].

The extent of inundation and water surface elevations at particular locations are among the crucial details from a flood event that is predicted using hydraulic modeling and flood inundation mapping. [5]. A hydraulic model essentially depicts the events that take place during a flood event. Many different simplifications and assumptions have been made to create models that can accurately represent compound channel flow while

being computationally efficient, raising questions about the processes that need to be modeled [6,22]. A compound channel is made up of the main river channel and the floodplains that are located on either side of it [7,9]. The flow expands into the comparatively flat floodplains when the depth of flow during a flood event exceeds the height of the main channel. [10,11].
The transition from low to high water (LW to HW) gets quicker and more abrupt as the tidal wave moves upstream. Since friction can only be felt when currents are flowing, friction and freshwater discharge are inextricably linked [12,13].
One-dimensional (1D) hydrodynamic models based on the Saint-Venant equations (the SVN model) have been extensively used for flow simulation in tidal rivers. In tidal rivers, the interaction of river flow and the tide is complicated [14, 18]. The tidal effect has a significant impact on flood routing, while tide propagation is also influenced by river discharge [17,19].
Rapid urbanization is contributing to an increase in flooding in urban basins. In-land drainage congestion and/or overbank river flow during a heavy rain event are the main causes of flooding. The rainfall-runoff phenomenon and the drainage system are both significantly changing as a result of rapid urbanization. Because of the enormous structural development, the overland flow pattern is becoming more complex, making it difficult to predict surface runoff [16].
The objective of the study is to analyze the carrying capacity of lower reach approximately 12.25km length of Tapi River between Weir cum causeway and Magdalla Bridge and to carry out unsteady flow analysis for the tidal reach to predict water level and understand the effect of high and low tides on predicted water levels.

2. STUDY AREA AND DATA COLLECTION

The river reaches approximately 12.25 km from Weir cum Causeway to Magdalla Bridge and is selected for study purposes. Unsteady flow analysis is carried out using flood events and tidal water levels in the HEC-RAS model. This report begins with studying existing channel cross-sections with high flood events and backwater effects by tides then an attempt has been made to identify various problems in the existing system with the unsteady flow. As already mentioned, a flow is high in the river with a high stage when water usually overflows from the banks, it inundates the adjoining areas and spreads over the flood plains and may cause loss of life and property and in a downstream condition the tides are affected in fresh water and both the freshwater, as well as tidewater, are meet and then the normal water level is increased. Surat is located in the western part of India in the state of Gujarat. The city is located on the river Tapi and has about a 6 km long coastal belt along the Arabian Sea. Surat is the second largest city in the state of Gujarat and it is also considered one of the cleanest cities in India. It is also known by several other names like “the silk city”, “the diamond city”, “the green city” etc. It is the city where the British first landed in India. The study analyses the existing level of service, and management and tries to solve the problems with different alternative solutions.

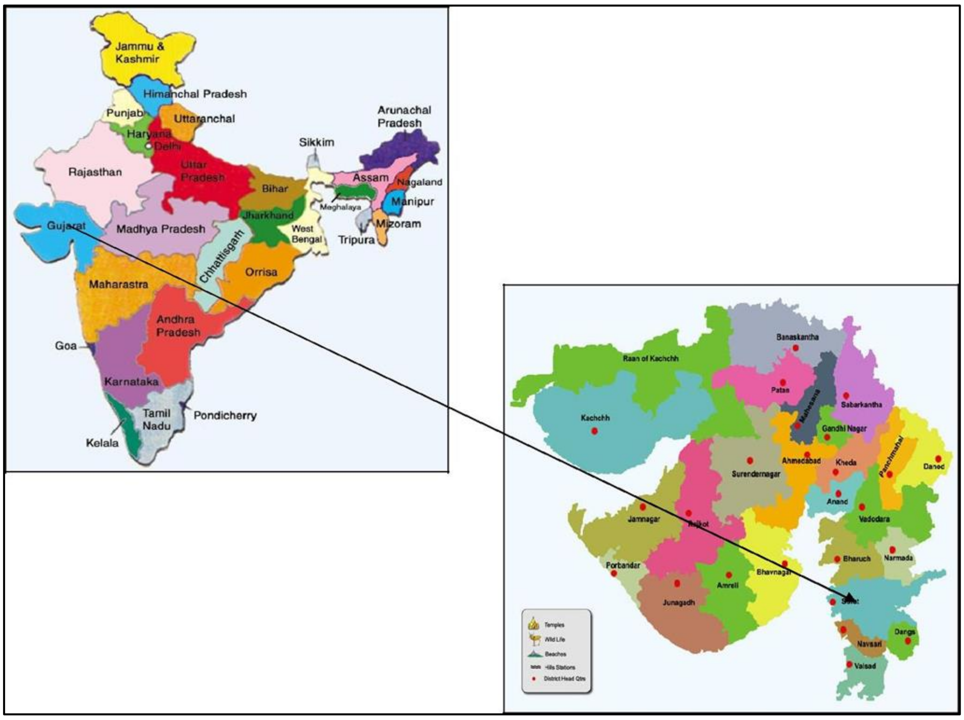

Figure 1 Map of India and Gujarat

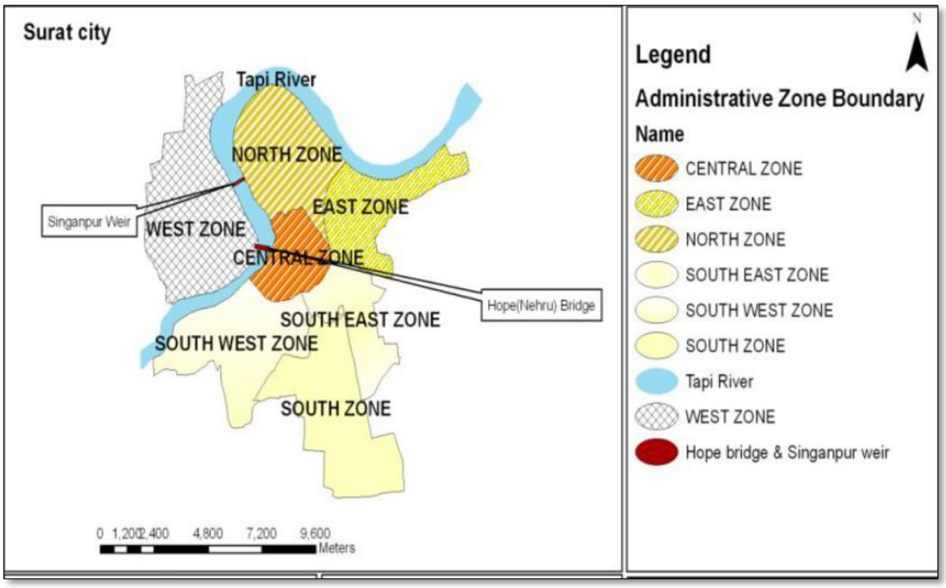

Figure 2 Surat City Administrative Zone Boundary

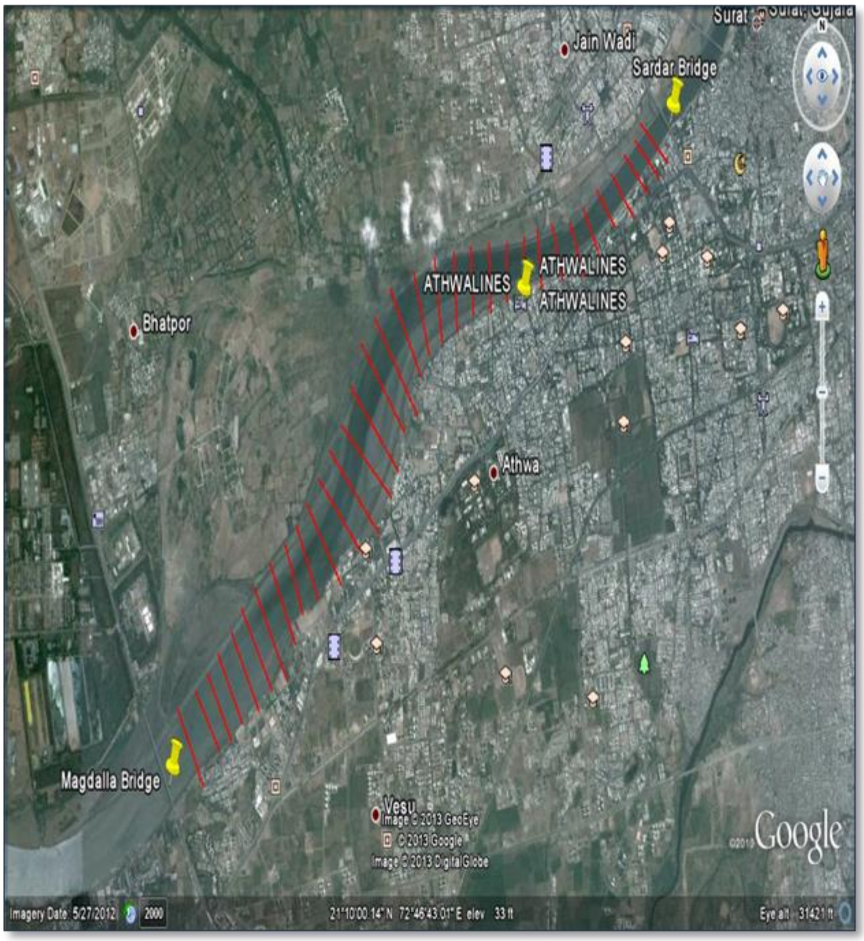

Figure 3 Google image showing the study area with cross-sectional details

Fig. 3 shows the study area i.e., Weir cum causeway to Magdalla Bridge. Following are the details of the Study area:

- There are a total of 49 nos. of cross-sections (CS). Upstream – CS-1 and Downstream – CS-49. As shown in the figure, the cross-sections are highlighted by a red color line.
- The length of the study reach is 12.25 km i.e., 12250metres
- The distance between one CS to another CS is approximately 200 to 250 meters.

Field data were collected from the Hydraulic Department of Surat Municipal Corporation. Surat Municipal Corporation has provided the topographic data of the study reach in the form of CAD-File, cross-sections at several locations in the study reach of the year 2009, and tidal level data. Central Water Commission provided the Daily discharge data for the Lower Tapi for 2008 & 2009 and the Flood data has been provided by Flood Cell Surat.

3. METHODOLOGY

3.1 Overview of HEC-RAS Software

HEC-RAS is designed and developed in 1995 by the United States Army Corps of Engineers. It is "software that allows you to perform one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport-mobile bed modeling, and water temperature analysis [14]". HEC-RAS was first released in 1995 and since that time there have been several major versions of HEC-RAS of which 6.0.0 is the latest version released in 2021.

3.1.1 HEC-RAS Parameters

Unsteady flow analysis is carried out using HEC-RAS software. The parameters that are required as input are discussed in the subsequent paragraphs.

3.1.1.1 Geometric Data

The first step for developing the HEC-RAS model is to prepare river reach using geometric data (collected from Surat Municipal Corporation). The basic geometric data consists of river reach details, cross-section numbers, cross sections details, and stream junctions' details of the study river reach.

3.1.1.2 Cross-section Geometry

The boundary geometry is defined in terms of cross sections for the analysis of river stream flow. Reach length is the measured distance between any two cross sections. The anticipated flow lines should be parallel to the cross sections. By entering the stations' elevations (x-y) data from left to right, the cross-section is described. The cross-section data editor shows all the necessary details.

3.1.1.3 Unsteady flow data

In this present study, evaluation of the tidal effect in maximum tidal level and minimum tidal level has been considered for the years 2010 & 2011, and comparing the water surface profile at the cross sections in maximum tide level and minimum tide level as a download boundary condition.

The following steps are followed to carry out the unsteady flow analysis using HEC-RAS are:

Step 1: Project Definition

Step 2: Boundary condition in unsteady flow analysis

For performing unsteady analysis, boundary conditions are to be entered. These boundary conditions are upstream and downstream. The upstream boundary condition should be a Flow hydrograph and the downstream boundary condition can be a Normal Depth, Flow hydrograph, Stage hydrograph, or Rating Curve. Mainly the downstream boundary condition Stage Series or stage hydro-graph is used during this work. For entering the upstream boundary condition, first, select the upstream section and flow hydrograph for Reach-A. After that enter Flow duration, Computation increment, and Flow corresponding to flow duration. For the downstream boundary condition, select the downstream section and stage hydrograph max tidal level and min tidal level. After that enter, the flow duration, computation increment, and the stage hydrograph corresponding to flow duration and the stage hydrograph (maximum tidal effect situation and minimum tidal effect situation) have been selected as downstream boundary conditions for the same upstream flow hydrograph.

Step 3: Initial Conditions for Unsteady flow analysis

Before carrying out unsteady flow analysis initial flow as input is given for Tapi (reach A).

Step 4: Results

To view results, in HEC-RAS main window click on view. When clicking on the view button; many options can be seen. Out of these options select Profile summary table and Stage and Flow hydrograph.

4. RESULTS AND DISCUSSION

Data analysis is an important tool for understanding the behavior of river sections under the influence of various flood events. The unsteady flow analysis over the 12.25 km range of the Tapi River considered daily flow data for the years 2010 & 2011. The survey area is affected by high tide and low tide. The scope of the survey is part of the confluence of the Tapi River and the Arabian Sea. Therefore, high and low tides affect the propagation of marine floods. Along with tidal conditions, surveys of river cross-section behavior under various flood flows will be carried out. The carrying capacity of the study reach section is accessed for five-year daily discharge data. For unsteady flow analysis, daily-discharge data for the years 2010 and 2011 have been taken as an upstream boundary condition along with the tidal data as a downstream boundary condition for the same. Unsteady flow analysis has been computed using HEC-RAS software.

4.1 Unsteady flow analysis for 2010 tidal data

Unsteady flow analysis is carried out for the daily discharge of the year 2010 as an upstream boundary condition and maximum as well as minimum tidal data as a downstream boundary condition. As a result, the maximum stage is simulated at each cross-section of the study reach, and the same is analyzed with the existing left bank as well as the right bank for the identification of critical sections.

Table 1 Comparison of existing bank level with maximum stage level (2010)

Sr. No.	Section	R.L. Of Left Bank	Computed Stage (Max.)	Critical Or not	R.L. Of Right Bank	Computed Stage (Max.)	Critical Or not
1	CS-1	25.078	5.21	NO	8.485	5.21	NO
2	CS-2	16.035	5.21	NO	7.23	5.21	NO
3	CS-3	15.143	5.2	NO	7.125	5.2	NO
4	CS-4	15.495	5.2	NO	8.5	5.2	NO
5	CS-5	15.59	5.19	NO	8.825	5.19	NO
6	CS-6	15.499	5.19	NO	14.919	5.19	NO
7	CS-7	15.853	5.19	NO	14.899	5.19	NO
8	CS-8	15.678	5.19	NO	13.55	5.19	NO
9	CS-9	16.05	5.19	NO	13.334	5.19	NO
10	CS-10	15.496	5.18	NO	10.34	5.18	NO
11	CS-11	4.45	5.18	YES	4.618	5.18	YES
12	CS-12	4.2	5.17	YES	10.23	5.17	NO
13	CS-13	4.369	5.17	YES	11.6	5.17	NO
14	CS-14	4.25	5.16	YES	12.628	5.16	NO
15	CS-15	5.87	5.16	NO	11.428	5.16	NO
16	CS-16	12.347	5.15	NO	11.45	5.15	NO
17	CS-17	12.33	5.15	NO	12.115	5.15	NO
18	CS-18	12.21	5.15	NO	12.097	5.15	NO
19	CS-19	12.227	5.15	NO	12.915	5.15	NO
20	CS-20	12.035	5.14	NO	11.827	5.14	NO

21	CS-21	11.78	5.14	NO	11.45	5.14	NO
22	CS-22	11.166	5.14	NO	11.522	5.14	NO
23	CS-23	11.76	5.14	NO	10.655	5.14	NO
24	CS-24	10.43	5.14	NO	6.85	5.14	NO
25	CS-25	10.215	5.14	NO	8.915	5.14	NO
26	CS-26	10.9	5.14	NO	10.45	5.14	NO
27	CS-27	10.275	5.14	NO	8.285	5.14	NO
28	CS-28	10.31	5.14	NO	8.621	5.14	NO
29	CS-29	10.125	5.14	NO	8.11	5.14	NO
30	CS-30	10.23	5.14	NO	8.8	5.14	NO
31	CS-31	9.78	5.14	NO	8.915	5.14	NO
32	CS-32	5.34	5.14	NO	5.784	5.14	NO
33	CS-33	5.9	5.14	NO	6.995	5.14	NO
34	CS-34	5.715	5.14	NO	5.715	5.14	NO
35	CS-35	6.62	5.14	NO	6.8	5.14	NO
36	CS-36	5.5	5.14	NO	6.95	5.14	NO
37	CS-37	6.91	5.14	NO	6.91	5.14	NO
38	CS-38	5.95	5.14	NO	7.5	5.14	NO
39	CS-39	6.985	5.14	NO	7.2	5.14	NO
40	CS-40	6.105	5.14	NO	7.005	5.14	NO
41	CS-41	5.707	5.14	NO	7.01	5.14	NO
42	CS-42	5.69	5.14	NO	6.915	5.14	NO
43	CS-43	4.52	5.14	YES	5.85	5.14	NO
44	CS-44	5.5	5.14	NO	4.175	5.14	YES
45	CS-45	4.855	5.14	YES	4.855	5.14	YES
46	CS-46	4.64	5.14	YES	4.64	5.14	YES
47	CS-47	4.3	5.14	YES	4.75	5.14	YES
48	CS-48	4.98	5.14	YES	4.715	5.14	YES
49	CS-49	4.15	5.14	YES	4.15	5.14	YES

Table 1 shows the comparison of the existing bank level with the maximum stage level. From the above table, it is observed that on the downstream side (Magdalla bridge) the cross-sections CS-43 to CS-49 are critical whereas on the upstream side (near Weir cum causeway) the cross-section CS-2, CS-3, CS-11 to CS-15 is critical.

Table 2 Comparison of existing bank level with minimum stage level for 2010

SR. NO.	SECTION	R.L. OF LEFT BANK	COMPUTED STAGE (MIN.)	CRITICAL OR NOT	R.L. OF RIGHT BANK	COMPUTED STAGE (MIN.)	CRITICAL OR NOT
1	CS-1	25.078	7.97	NO	8.485	7.97	NO
2	CS-2	16.035	7.89	NO	7.23	7.89	YES
3	CS-3	15.143	7.77	NO	7.125	7.77	YES
4	CS-4	15.495	7.8	NO	8.5	7.8	NO
5	CS-5	15.59	7.77	NO	8.825	7.77	NO
6	CS-6	15.499	7.74	NO	14.919	7.74	NO
7	CS-7	15.853	7.73	NO	14.899	7.73	NO
8	CS-8	15.678	7.71	NO	13.55	7.71	NO
9	CS-9	16.05	7.68	NO	13.334	7.68	NO

10	CS-10	15.496	7.6	NO	10.34	7.6	NO
11	CS-11	4.45	7.4	YES	4.618	7.4	YES
12	CS-12	4.2	7.25	YES	10.23	7.25	NO
13	CS-13	4.369	7.1	YES	11.6	7.1	NO
14	CS-14	4.25	6.97	YES	12.628	6.97	NO
15	CS-15	5.87	6.9	YES	11.428	6.9	NO
16	CS-16	12.347	6.68	NO	11.45	6.68	NO
17	CS-17	12.33	6.5	NO	12.115	6.5	NO
18	CS-18	12.21	6.35	NO	12.097	6.35	NO
19	CS-19	12.227	6.23	NO	12.915	6.23	NO
20	CS-20	12.035	6.03	NO	11.827	6.03	NO
21	CS-21	11.78	5.96	NO	11.45	5.96	NO
22	CS-22	11.166	5.92	NO	11.522	5.92	NO
23	CS-23	11.76	5.79	NO	10.655	5.79	NO
24	CS-24	10.43	5.55	NO	6.85	5.55	NO
25	CS-25	10.215	5.39	NO	8.915	5.39	NO
26	CS-26	10.9	5.25	NO	10.45	5.25	NO
27	CS-27	10.275	5.18	NO	8.285	5.18	NO
28	CS-28	10.31	5.07	NO	8.621	5.07	NO
29	CS-29	10.125	4.96	NO	8.11	4.96	NO
30	CS-30	10.23	4.57	NO	8.8	4.57	NO
31	CS-31	9.78	4.59	NO	8.915	4.59	NO
32	CS-32	5.34	4.55	NO	5.784	4.55	NO
33	CS-33	5.9	4.31	NO	6.995	4.31	NO
34	CS-34	5.715	4.2	NO	5.715	4.2	NO
35	CS-35	6.62	3.94	NO	6.8	3.94	NO
36	CS-36	5.5	3.87	NO	6.95	3.87	NO
37	CS-37	6.91	3.49	NO	6.91	3.49	NO
38	CS-38	5.95	3.25	NO	7.5	3.25	NO
39	CS-39	6.985	2.9	NO	7.2	2.9	NO
40	CS-40	6.105	2.79	NO	7.005	2.79	NO
41	CS-41	5.707	2.61	NO	7.01	2.61	NO
42	CS-42	5.69	2.62	NO	6.915	2.62	NO
43	CS-43	4.52	2.34	NO	5.85	2.34	NO
44	CS-44	5.5	2.04	NO	4.175	2.04	NO
45	CS-45	4.855	1.3	NO	4.855	1.3	NO
46	CS-46	4.64	1.18	NO	4.64	1.18	NO
47	CS-47	4.3	1.05	NO	4.75	1.05	NO
48	CS-48	4.98	0.93	NO	4.715	0.93	NO
49	CS-49	4.15	0.87	NO	4.15	0.87	NO

Table 2 shows the comparison of the existing bank level with the minimum stage level. From the above table, it is observed that on the downstream side, none of the cross-sections are critical whereas on the upstream side (near Weir cum causeway) the cross-section CS-2, CS-3, CS-11 to CS-15 is critical.

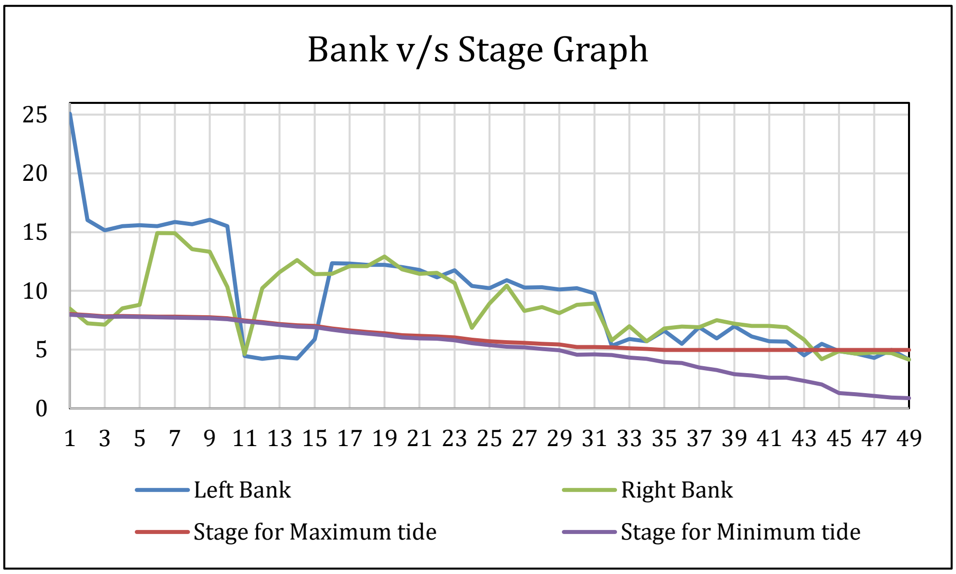

Figure 4 Graphical representation of bank v/s stage (2010)

Figure 4 shows the graphical representation of existing bank conditions with maximum and minimum stages for the year 2010 having discharge of 6238.367 cumecs.

4.2 Unsteady flow analysis for 2011 tidal data

Unsteady flow analysis is carried out for the daily discharge of the year 2011 as an upstream boundary condition and maximum as well as minimum tidal data as a downstream boundary condition. As a result, the maximum stage is simulated at each cross-section of the study reach, and the same is analyzed with the existing left bank as well as the right bank for the identification of critical sections.

Table 3 Comparison of existing bank level with maximum stage level (2011)

SR. NO.	SECTION	R.L. OF LEFT BANK	COMPUTED STAGE (MAX.)	CRITICAL OR NOT	R.L. OF RIGHT BANK	COMPUTE D STAGE (MAX.)	CRITICAL OR NOT
1	CS-1	25.078	8.23	NO	8.485	8.23	NO
2	CS-2	16.035	8.15	NO	7.23	8.15	YES
3	CS-3	15.143	8.03	NO	7.125	8.03	YES
4	CS-4	15.495	8.06	NO	8.5	8.06	NO
5	CS-5	15.59	8.04	NO	8.825	8.04	NO
6	CS-6	15.499	8.01	NO	14.919	8.01	NO
7	CS-7	15.853	8.01	NO	14.899	8.01	NO
8	CS-8	15.678	7.98	NO	13.55	7.98	NO
9	CS-9	16.05	7.95	NO	13.334	7.95	NO
10	CS-10	15.496	7.87	NO	10.34	7.87	NO
11	CS-11	4.45	7.67	YES	4.618	7.67	YES
12	CS-12	4.2	7.51	YES	10.23	7.51	NO
13	CS-13	4.369	7.37	YES	11.6	7.37	NO
14	CS-14	4.25	7.24	YES	12.628	7.24	NO
15	CS-15	5.87	7.18	YES	11.428	7.18	NO
16	CS-16	12.347	6.97	NO	11.45	6.97	NO
17	CS-17	12.33	6.78	NO	12.115	6.78	NO
18	CS-18	12.21	6.65	NO	12.097	6.65	NO
19	CS-19	12.227	6.54	NO	12.915	6.54	NO

20	CS-20	12.035	6.37	NO	11.827	6.37	NO
21	CS-21	11.78	6.31	NO	11.45	6.31	NO
22	CS-22	11.166	6.28	NO	11.522	6.28	NO
23	CS-23	11.76	6.17	NO	10.655	6.17	NO
24	CS-24	10.43	5.97	NO	6.85	5.97	NO
25	CS-25	10.215	5.85	NO	8.915	5.85	NO
26	CS-26	10.9	5.74	NO	10.45	5.74	NO
27	CS-27	10.275	5.69	NO	8.285	5.69	NO
28	CS-28	10.31	5.62	NO	8.621	5.62	NO
29	CS-29	10.125	5.655	NO	8.11	5.655	NO
30	CS-30	10.23	5.34	NO	8.8	5.34	NO
31	CS-31	9.78	5.34	NO	8.915	5.34	NO
32	CS-32	5.34	5.31	NO	5.784	5.31	NO
33	CS-33	5.9	5.2	NO	6.995	5.2	NO
34	CS-34	5.715	5.15	NO	5.715	5.15	NO
35	CS-35	6.62	5.03	NO	6.8	5.03	NO
36	CS-36	5.5	5.01	NO	6.95	5.01	NO
37	CS-37	6.91	5.01	NO	6.91	5.01	NO
38	CS-38	5.95	5.01	NO	7.5	5.01	NO
39	CS-39	6.985	5.01	NO	7.2	5.01	NO
40	CS-40	6.105	5.01	NO	7.005	5.01	NO
41	CS-41	5.707	5.01	NO	7.01	5.01	NO
42	CS-42	5.69	5.01	NO	6.915	5.01	NO
43	CS-43	4.52	5.01	YES	5.85	5.01	NO
44	CS-44	5.5	5.01	NO	4.175	5.01	YES
45	CS-45	4.855	5.01	YES	4.855	5.01	YES
46	CS-46	4.64	5.01	YES	4.64	5.01	YES
47	CS-47	4.3	5.01	YES	4.75	5.01	YES
48	CS-48	4.98	5.01	YES	4.715	5.01	YES
49	CS-49	4.15	5.01	YES	4.15	5.01	YES

Table 3 shows the comparison of the existing bank level with the maximum stage level. From the above table, it is observed that on the downstream side (Magdalla bridge) the cross sections CS-43 to CS-49 are critical whereas on the upstream side (near Weir cum causeway) the cross sections CS-2 and CS-3, CS-11 to CS-15 is critical.

Table 4 Comparison of existing bank level with minimum stage level (2011)

SR. NO.	SECTION	R.L. OF LEFT BANK	COMPUTED STAGE (MIN.)	CRITICAL OR NOT	R.L. OF RIGHT BANK	COMPUTED STAGE (MIN.)	CRITICAL OR NOT
1	CS-1	25.078	8.18	NO	8.485	8.18	NO
2	CS-2	16.035	8.09	NO	7.23	8.09	YES
3	CS-3	15.143	7.97	NO	7.125	7.97	YES
4	CS-4	15.495	8	NO	8.5	8	NO
5	CS-5	15.59	7.98	NO	8.825	7.98	NO
6	CS-6	15.499	7.95	NO	14.919	7.95	NO
7	CS-7	15.853	7.94	NO	14.899	7.94	NO
8	CS-8	15.678	7.92	NO	13.55	7.92	NO
9	CS-9	16.05	7.88	NO	13.334	7.88	NO

10	CS-10	15.496	7.8	NO	10.34	7.8	NO
11	CS-11	4.45	7.6	YES	4.618	7.6	YES
12	CS-12	4.2	7.43	YES	10.23	7.43	NO
13	CS-13	4.369	7.28	YES	11.6	7.28	NO
14	CS-14	4.25	7.15	YES	12.628	7.15	NO
15	CS-15	5.87	7.08	YES	11.428	7.08	NO
16	CS-16	12.347	6.85	NO	11.45	6.85	NO
17	CS-17	12.33	6.66	NO	12.115	6.66	NO
18	CS-18	12.21	6.51	NO	12.097	6.51	NO
19	CS-19	12.227	6.39	NO	12.915	6.39	NO
20	CS-20	12.035	6.19	NO	11.827	6.19	NO
21	CS-21	11.78	6.12	NO	11.45	6.12	NO
22	CS-22	11.166	6.08	NO	11.522	6.08	NO
23	CS-23	11.76	5.95	NO	10.655	5.95	NO
24	CS-24	10.43	5.7	NO	6.85	5.7	NO
25	CS-25	10.215	5.55	NO	8.915	5.55	NO
26	CS-26	10.9	5.4	NO	10.45	5.4	NO
27	CS-27	10.275	5.33	NO	8.285	5.33	NO
28	CS-28	10.31	5.23	NO	8.621	5.23	NO
29	CS-29	10.125	5.12	NO	8.11	5.12	NO
30	CS-30	10.23	4.74	NO	8.8	4.74	NO
31	CS-31	9.78	4.75	NO	8.915	4.75	NO
32	CS-32	5.34	4.71	NO	5.784	4.71	NO
33	CS-33	5.9	4.48	NO	6.995	4.48	NO
34	CS-34	5.715	4.37	NO	5.715	4.37	NO
35	CS-35	6.62	4.12	NO	6.8	4.12	NO
36	CS-36	5.5	4.04	NO	6.95	4.04	NO
37	CS-37	6.91	3.63	NO	6.91	3.63	NO
38	CS-38	5.95	3.38	NO	7.5	3.38	NO
39	CS-39	6.985	3.01	NO	7.2	3.01	NO
40	CS-40	6.105	2.9	NO	7.005	2.9	NO
41	CS-41	5.707	2.7	NO	7.01	2.7	NO
42	CS-42	5.69	2.74	NO	6.915	2.74	NO
43	CS-43	4.52	2.45	NO	5.85	2.45	NO
44	CS-44	5.5	2.13	NO	4.175	2.13	NO
45	CS-45	4.855	1.39	NO	4.855	1.39	NO
46	CS-46	4.64	1.26	NO	4.64	1.26	NO
47	CS-47	4.3	1.13	NO	4.75	1.13	NO
48	CS-48	4.98	1.07	NO	4.715	1.07	NO
49	CS-49	4.15	0.8	NO	4.15	0.8	NO

Table 4 shows the comparison of the existing bank level with the minimum stage level. From the above table, it is observed that on the downstream side, none of the cross-sections are critical whereas on the upstream side (near Weir cum causeway) the cross-section CS-2 and CS-3, CS-11 to CS-15 are critical

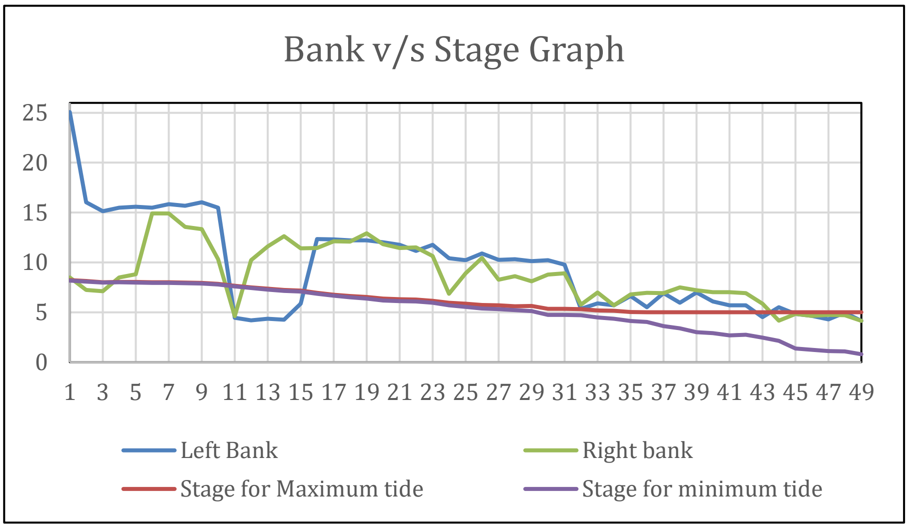

Figure 5 Graphical representation of bank v/s stage (2011)

Figure 5 shows the graphical representation of existing bank conditions with maximum and minimum stages for the year 2011 having a discharge of 231373 cumecs.

5. CONCLUSIONS

1. For the year 2010

- For the daily discharge and low tide conditions, seven (7) cross sections (CS-1, CS-2, and CS-11 to CS-15) are found to be critical along the study reach.
- For the daily discharge and high tide conditions, fourteen (14) cross sections (CS-1, CS-2, CS-11 to CS-15, and CS-43 to CS-49 are found to be critical along the study reach.

2. For the year 2011

- For the daily discharge and low tide conditions, seven (7) cross sections (CS-2, CS-3, and CS-11 to CS-15) are found to be critical along the study reach.
- For the daily discharge and high tide conditions, fourteen (14) cross sections (CS-2, CS-3, CS-11 to CS-15, and CS-43 to CS-49 are found to be critical along the study reach.

3. Though the discharge in the river is less than 4 lakh cusecs due to the effect of high tide and low tide, the surrounding region will be flooded at various locations over the study reach.
4. The critical area that is found on the upstream side needs to be protected by embankments to avoid flood hazards near the Adajan area and Bhatha village.
5. HEC-RAS is proved to be a useful tool for the analysis of unsteady flow when the daily discharge meets the low tide or high tide conditions co-incidentally, which leads to the flooding of the upstream areas on the river.

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