Chapter 35
Numerical Modelling of Tidal Hydrodynamics Along River Tapi, Gujarat

R. Balaji, J. SatheeshKumar, R. Cornelius, R. Naveen, G. Prasantha, and T. Prince

Abstract Tapi, the second-largest westward draining river in India, originates at Multai reserve forest in Betul District, Madhya Pradesh, at 752 m. It runs westward for 724 km until discharging into the Arabian Sea via the Gulf of Khambhat. The basin is located between latitudes 20° 5' and 22° 3' north, and longitudes 72° 38' and 78° 17' east. The study aims to better understand the hydrodynamics of the tidally impacted river Tapi and estimate river discharge owing to rainfall at the ONGC bridge in Surat, which is about 14 km from the Arabian Sea. In order to achieve the goals, a two-dimensional hydrodynamic model was created using the Delft3D modelling scheme. The numerical model's offshore ocean boundary is forced with tidal constituents, while the upstream river boundary is forced with discharge estimated using HEC-HMS (hydrological modelling software). The model estimated tide-induced currents are validated using observed field datasets, and it shows a good correlation. The model results indicated the tidally varying hydrodynamic behaviour during the year's pre and post-monsoon seasons.

Keywords Tapi river · Discharge · Delft3D-FLOW · Tidal hydrodynamics · Numerical modelling

35.1 Introduction

The river is an essential factor in human civilization, which provides freshwater, inland transportation, hydro energy, and helps in recreational and tourism activities. However, several risk factors are linked to this due to the current abrupt change in climate, leading to flooding or drought. Increased flooding in the coastal and riverine flood plains and the degradation of coastal ecosystems like saltmarsh are all threats from climate change. These disasters cause significant and long-term damage to coastal communities, socioeconomic activities, and the environment. Cities situated along riverine and coastal floodplain banks are particularly vulnerable to this hazard

R. Balaji (✉) · J. SatheeshKumar · R. Cornelius · R. Naveen · G. Prasantha · T. Prince
Department of Civil Engineering, IIT Bombay, Mumbai 400076, India
e-mail: rbalaji@iitb.ac.in

(Adhikari et al. 2010). Moreover, the situation has worsened as the combination of flooding and high tide conditions in this region increases the probability of a disaster. Nowadays, numerical modelling is the most effective method for understanding this phenomenon all around the world (Cook and Merwade 2009; Gallegos et al. 2009; Mignot et al. 2006; Haider et al. 2003; Lindner and Miller 2012; Smith et al. 2005). Therefore, in the present work, the state-of-the-art Delft3D modelling system was used to understand the macro tidal river Tapi hydrodynamics, which runs along the Gujarat coast. The following sections discuss the details of the modelling and the outcomes.

35.2 Study Area

Tapi river is one of India's major rivers and originates from Madhya Pradesh in the Satpura range at 752 m above sea level. The river's total length is approximately 724 km, and it flows along the central part of India. The states through which the Tapi river flows include Maharashtra, Gujrat, and Madhya Pradesh. Apart from the Narmada river, Tapi is the only river that flows westward and merges into the Arabian Sea. Tapi basin is the second-largest in India with a total area of 65,145 km^2 and flows through major cities and discharge into the Arabian Sea about 16 km from Surat (Fig. 35.1). Therefore, Surat is frequently facing flooding problem due to river Tapi and its economy have been hit by several floods in the past few decades. During the floods, a significant portion of the city is submerged, creating a lot of damage in residential and industrial areas. Hence, it is essential to understand the hydrodynamics of the region.

35.3 Data and Methods

35.3.1 Delft3D

In the present study, the Delft3D modelling package (WL|Delft Hydraulics 2006) was used to simulate the hydrodynamics along the Tapi river. It is composed of multiple modules that work together to simulate processes like tidal hydrodynamics, wave transformation, water quality, sediment transport, and morphology. Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) modelling system that employs the finite-difference method to calculate non-steady flow and transport phenomena caused by tidal and meteorological forcing on a rectilinear or curvilinear boundary fitted grid with suitable initial and open boundary conditions (Lesser et al., 2004). It solves the Navier–Stokes equations for an incompressible fluid under the shallow water and Boussinesq assumptions, and it computes vertical velocities for 3D models using the continuity equation.

Fig. 35.1 View of study area (*Source* Google Earth)

35.3.2 Hydrological Model Setup

The Tapi river monsoon discharge was estimated using a hydrological model setup using HEC-HMS. The river discharge was calculated at a specific location near Magdala Bridge in Surat, at 21° 8′47.25″N and 72°44′48.78″E. Drainage to the Arabian Sea was restricted until the Ukai Dam in Gujarat. To extract basin properties, the model was created using ArcGIS 10.5 software and HEC-GeoHMS. As illustrated in Fig. 35.2, the Tapi river's drainage lines and catchment were identified using ArcGIS 10.5 and HEC-GeoHMS, followed by terrain pre-processing to obtain watershed delineation. HEC-Geo HMS basin processing was used to integrate relatively small sub-basins. The HEC-Geo HMS characteristic tool calculates river slope, river length, basin slope, longest flow path, and basin centroid. The basin was then modelled for rainfall-runoff using monsoon rainfall data and the transfer and loss method with suitable curve numbers to estimate river discharge.
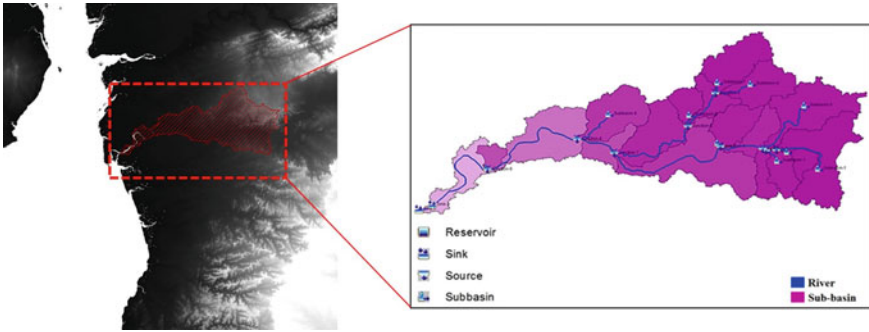
Fig. 35.2 View of river basin used for hydrologic model

35.3.3 Hydrodynamic Model Setup

The Delft3D computational model grid covers the entire Tapi river basin, as illustrated in Fig. 35.3. Admiralty charts (no. 1486 and 3460) were used to extract the river's bathymetry as well as nearshore coastal features such as inlets and estuaries in the region. A rectilinear grid system with a spatial resolution of 100 m was used for simulation throughout the domain. The open boundary of the model was set at 30 m of water depth, and it was forced with tidal astronomical elements from a TPXO7.1 global tidal model (Egbert et al. 1994). The HEC-HMS model was used to estimate river discharge values, which were then imposed on the upstream side of the boundary.
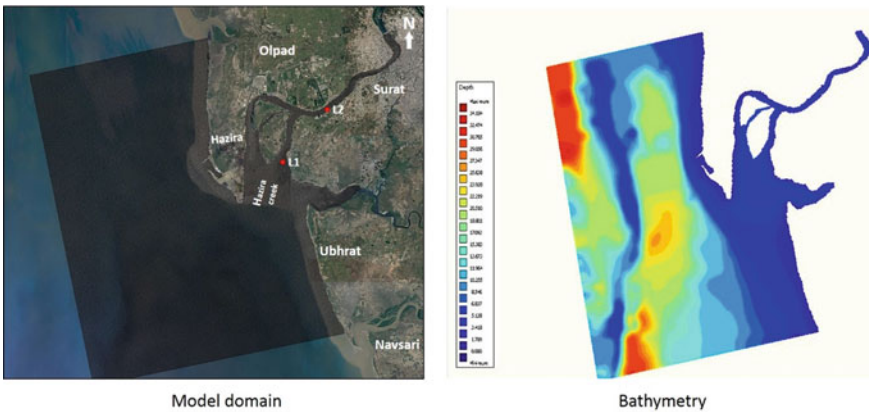

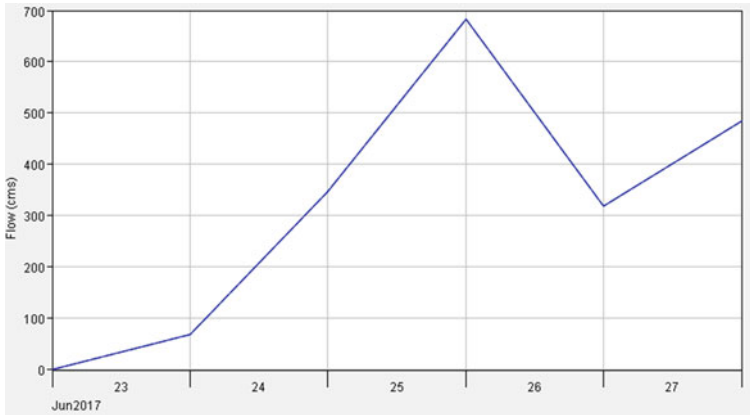**Fig. 35.3** View of study domain and bathymetry

Fig. 35.4 Discharge hydrograph at Magdala Bridge, Tapi river

35.4 Results and Discussion

35.4.1 Hydrological Model Results

The rainfall data were obtained from GSDMA, Gujarat, for six days from 23 Jun 2017 to 28 Jun 2017, and it was observed that the peak discharge and the volume are 5.9*107 m^3/day and 1.4*105 mm, respectively, at the specified discharge location. The estimated discharge was shown in Fig. 35.4.

35.4.2 Simulated Tidal Levels and Currents

The hydrodynamic model was simulated for ten days, from 12 November to 22 November 2017. The model-simulated results are validated with the in situ field dataset carried out on 19 November 2017, to test the model's performance in the below section. The model extracted water level and velocity are shown in Fig. 35.5. It is observed that the developed model was able to simulate hydrodynamics well in the river. The observed maximum water level and velocity are 2.2 m and 1.79 m/s, respectively. Figure 35.6 depicts contour plots of water level variation.

35.4.3 Comparison of Measured Versus Modelled Data

On 19 November 2017, field measurements were taken to estimate the water level and flow velocity using a total station and GPS Drifters. The measured water level
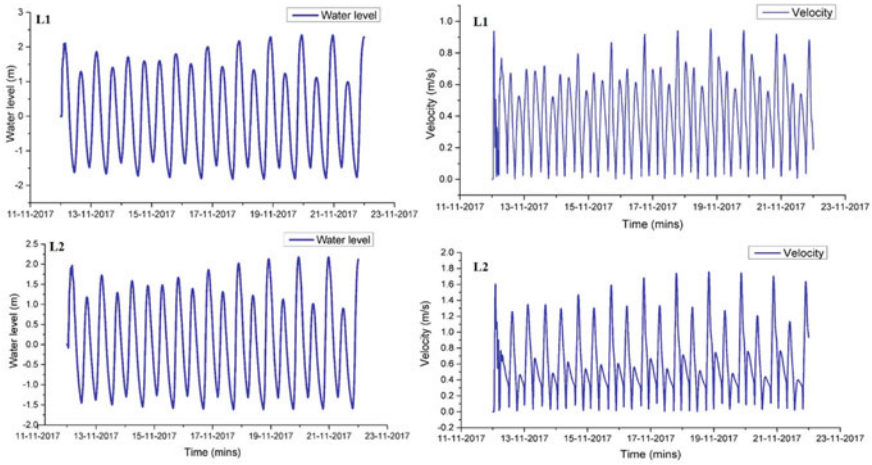
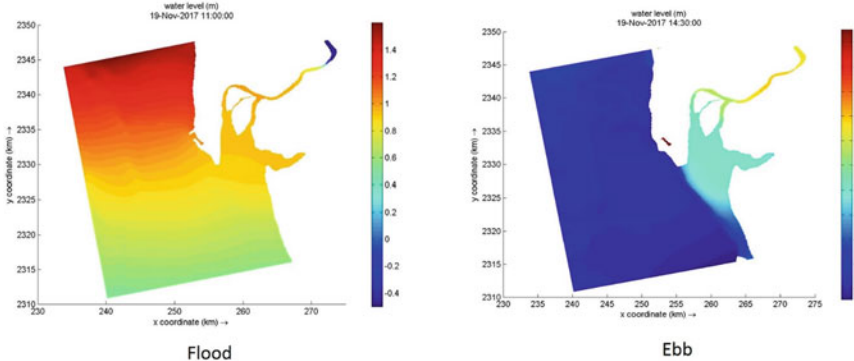**Fig. 35.5** Time series of simulated water level and velocity

Fig. 35.6 Typical view of water level variation during flood and ebb

and velocity ranges are compared with the model outputs to validate the model successfully. The time-series comparison of measured and modelled water levels at river Tapi is presented in Fig. 35.7, and the qualitative comparison is shown in Table 35.1. Figures 35.8 and 35.9 illustrate the measured and modelled drifter velocity, and Table 35.2 provides a quantitative comparison.

35.5   Conclusion

The two-dimensional shallow water-based finite different model has been utilized to understand the hydrodynamics of Tapi river, Gujarat. The estimated peak discharge and water volume are $5.9*107$ m^3/day and $1.4*105$ mm at the specified discharge
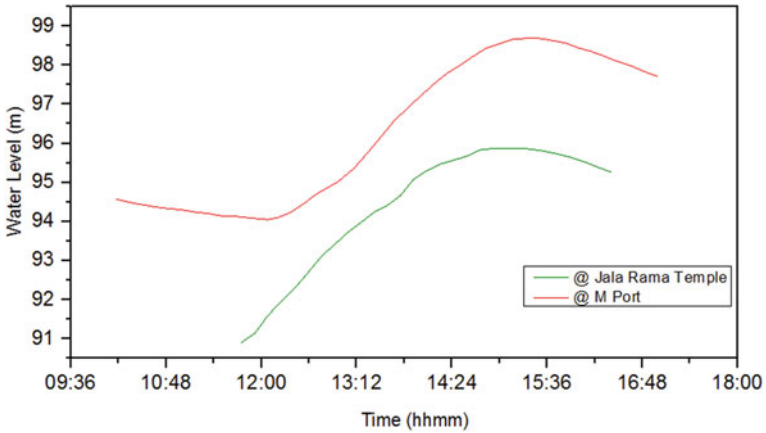
Fig. 35.7 Measured water level at two locations in Tapi river

Table 35.1 Comparison of measured versus modelled water level values

Location	Measured range (m)	Modelled range (m)
L1-joining	4.6	4.1
L2-at site	4.5	3.5

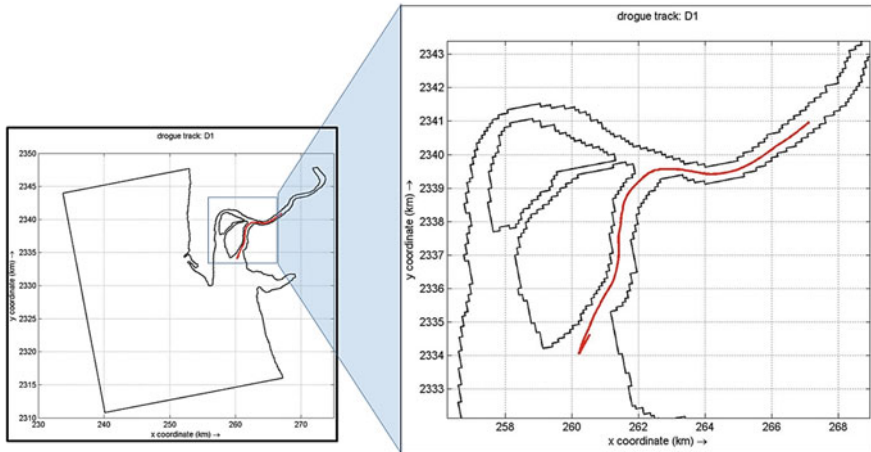**Fig. 35.8** Measured GPS drifter trajectories

Fig. 35.9 View of model-simulated trajectories

Table 35.2 Comparison of measured versus modelled drifter's surface velocity

Latitude	Longitude	Measured (m/s)	Modelled (m/s)
21.107458	72.702114	1.6	1.22
21.139184	72.711927	1.0	0.80
21.140485	72.724300	1.4	1.25

location through HEC-HMS hydrological modelling study. The tidal hydrodynamic model was forced with the estimated discharge value of different scenarios (monsoon and non-monsoon) to calculate extreme water levels and flooding. The simulated results were successfully validated against the limited available field measured data. It was further used to reproduce the spatially varying hydrodynamic characteristics such as water level and current velocity throughout the model area. It is concluded from this study, the maximum water level and velocity reach up to 2.2 m and 1.79 m/s, respectively, in the combination of spring tide and extreme discharge scenario.

References

Adhikari Y, Osti R, Noro T (2010) Flood-related disaster vulnerability: an impending crisis of megacities in Asia. J Flood Risk Manage 3(3):185–191

Cook A, Merwade V (2009) Effect of topographic data, geometric configuration and modeling approach on flood inundation mapping. J Hydrol 377(1–2):131–142

Egbert GD, Bennett AF, Foreman MGG (1994) Topex/Poseidon tides estimated using global inverse model. J Geophys 99:24821–24852

Gallegos HA, Schubert JE, Sanders BF (2009) Two dimensional, high-resolution modeling of urban dam-break flooding: a case study of Baldwin Hills, California. Adv Water Res 32(8):1323–1335

Haider S, Paquier A, Morel R, Champagne J-Y (2003) Urban flood modelling using computational fluid dynamics. In: Proceedings of ICE, Water Maritime Engineering 156(2):129–135
Lesser GR, Roelvink JA, van Kester JATM, Stelling GS (2004) Development and validation of a three-dimensional morphological model. Coast Eng 51:883–915
Lindner GA, Miller AJ (2012) Numerical modeling of stagedischarge relationship in urban streams. J Hydraul Eng 59:590–596
Mignot E, Paquier A, Haider S (2006) Modeling floods in a dense urban area using 2D shallow water equations. J Hydrol 327(1–2):186–199
Smith JA, Miller AJ, Baeck ML, Nelson PA, Fisher GT, Meierdiercks KL (2005) Extraordinary flood response of a small urban watershed to short-duration convective rainfall. J Hydrometeorol 6(5):599–617
WL|Delft Hydraulics (2006) Delft3D-FLOW User manual