

River Geometry Extraction from Cartosat-1 DEM for 1D Hydrodynamic Flood Modeling Using HEC-RAS—A Case of Navsari City, Gujarat, India



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Abstract Flooding is a worldwide phenomenon that occurs in casualties, property destruction, and it is possibly the most destructive, severe, and recurrent natural catastrophe. The main input parameter for any hydrodynamic modeling is river geometry. A discussion of a method to create river geometry by using the Cartosat-1 Digital Elevation Model (DEM) has been carried out. Many difficulties in distinguishing arise in hydraulic features, which requires pre-processing of the datasets before using it in the HEC-RAS model. The extracted geometry has been utilized in the Hydrological engineering Center-River Analysis System (HEC-RAS) mapper/GeoRAS to perform a 1D hydrodynamic flood modeling approach on the river Purna, Navsari, India. Earlier the river geometry was extracted with the HEC-GeoRAS extension tools available in ARC-GIS. The new HEC-RAS version 5 has been utilized in this study. The geometry of the river includes river centerline, bank lines, flow path lines, and cross-section cut lines which have been digitized in HEC-RAS mapper tool without ARC-GIS being used in the current study. The R^2 value of the Cartosat-1 DEM was 0.7166 which showed the best match with the observed values. The model output was promising and demonstrated the strong potential to extract the river geometry using Cartosat-1 DEM especially in the data scarce regions.

Keywords Cartosat-1 DEM · River geometry · HEC-RAS · Modeling · Purna River

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1 Introduction

Flooding is undoubtedly regarded as the world's most destructive cause of natural catastrophes. During rainy seasons (June–September), the Himalayan Rivers cause flooding in 80% of the total flood-affected region in India. In many states of India such as Gujarat, Maharashtra, Andhra Pradesh, West Bengal, and Orissa extreme flooding is witnessed mostly annually during the monsoon season, affecting a tremendous loss in properties and lives. The primary causes of flooding in India are inadequate water systems particularly in the low land depositional area of the basins, inadequate river carrying capacity due to sedimentation, and inadequate flood management techniques. To minimize flood losses, appropriate flood management practices are needed, which in turn requires space-time flux flow variation in 1-D as well as 2-D. Few researchers have conducted studies on the hydrodynamic flood modeling with the integration of GIS of the Indian basin river floods [1–3].

An effective model of the river flood includes a proper river bed representation and the floodplains geometry, with a precise explanation of the model input parameters, for forecasting the magnitude of flow and the flood water level along the river path precisely [4]. At present, software techniques have been created and are now being modified to extract river geometry features, which are effective for hydrodynamic modeling based on the GIS database [5, 6]. Several studies have been conducted which attempt to address bathymetric data shortages in river flood modeling which highly depend on Digital Elevation Model (DEM) GIS integration obtained from remote sensing satellites or other data sets available globally [7–9]. Also, data assimilation techniques are used to recognize synthetic cross-sections similar to river geometry [10].

With the advent of the latest computers, 1D hydrodynamic flood inundation modeling has become simpler. Numerous studies have been performed in the past 20 years on different aspects of river hydraulics. The theory of hydraulic river flow routing was added to numerous river basins across the globe [11, 12]. The integrated approach of the hydraulic model such as Water RIDE, Mike 11, and HEC-RAS with Geographic Information Systems (GIS) are the latest advancement in flood modeling [7, 13, 14]. The Digital Elevation Model (DEM) is used for the HEC-RAS model extension with a GIS database to extract the river geometry for flood modeling [15]. Pathan and Agnihotri [16] have extracted the river cross-section by using the latest HEC-RAS mapper tools for 1D hydrodynamic modeling.

In the present study, the 1D hydrodynamic approach has been carried out using the latest HEC-RAS version 5. Cartosat-1 DEM is downloaded free of cost from the ISRO BHUVAN web portal. RAS mapper tool available in HEC-RAS was utilized to extract the river geometry such as center line of the river, bank lines, flow path lines, and cross-section lines. This research demonstrates the utility of DEM in flood modeling with the integration of GIS. This approach is the advancement of the 1D hydrodynamic flood modeling in the data-scarce region.

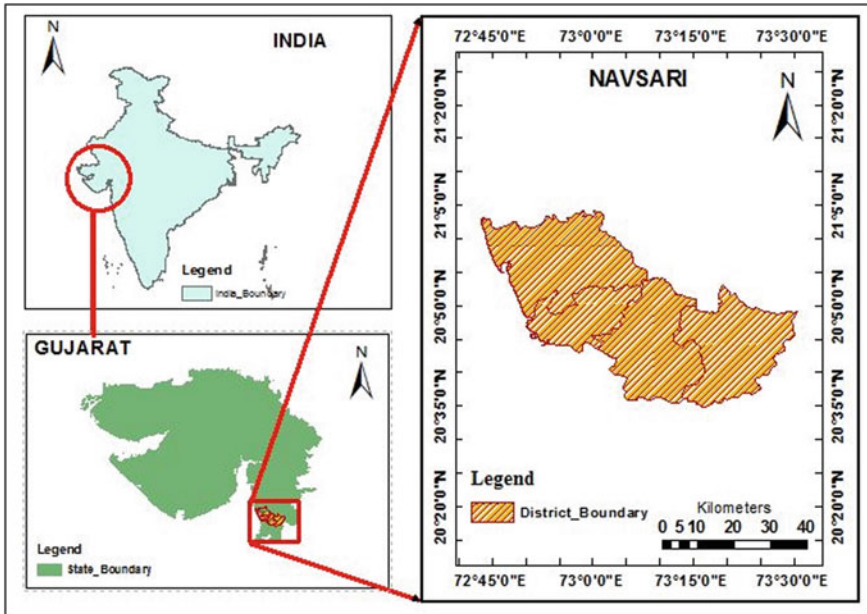


Fig. 1 Study area map

2 Study Area and Data

2.1 Study Area

Navsari city is situated on the coastal part of Gujarat near the Arabian Sea. The city is at $20^{\circ} 32'$ and $21^{\circ} 05'$ north latitude and $72^{\circ} 42'$ and $73^{\circ} 30'$ east longitude. The topographical area of the city is about 2210.97 km^2 . The study area map is illustrated in Fig. 1. Due to heavy precipitation, the water level may rise in the study area and the surrounding area gets inundated annually in monsoon. There is no setup provided by the government in this region to reduce the impact of the floods.

2.2 Data

The river flow data of the last 2 decades were obtained from the Navsari irrigation department. The two major flooding events which took place in the city of Navsari for the years 1968 and 2004. Cartosat-1 DEM was utilized for the extraction of river geometry which is freely available (www.bhuvan.nrsc.gov.in). The spatial projection needs to be set in Arc-GIS for coordinate systems used in HEC-RAS [17]. The 2004 year flood data is required for validating the model.

3 Methodology

RAS Mapper is a GIS function capable of collecting GIS datasets such as the center-line of the river, bank lines, flow direction lines, and cross-section lines by river digitalization. The following are presented input parameters for 1D hydrodynamic flood modeling in the HEC-RAS mapper. The flow chart of the region of study is illustrated in Fig. 2.

3.1 Extracting River Geometry

To build the river alignment within the river reach, a light blue marked line which shows the river center line is shown in Fig. 3, which flows from upstream to downstream. To separate the primary river from the left and right banks of the floodplain, the red marked lines shows the river bank lines. To regulate the flow of the river, flow path lines were digitized presented by the red marked shown in Fig. 3. The Green marked line shows the elevation data which was extracted from DEM, which is perpendicular to river flow.

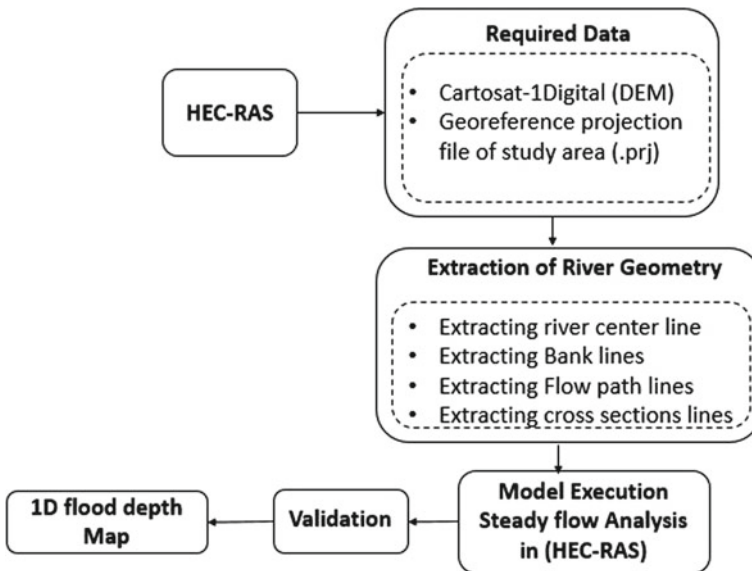


Fig. 2 Flowchart of methodology

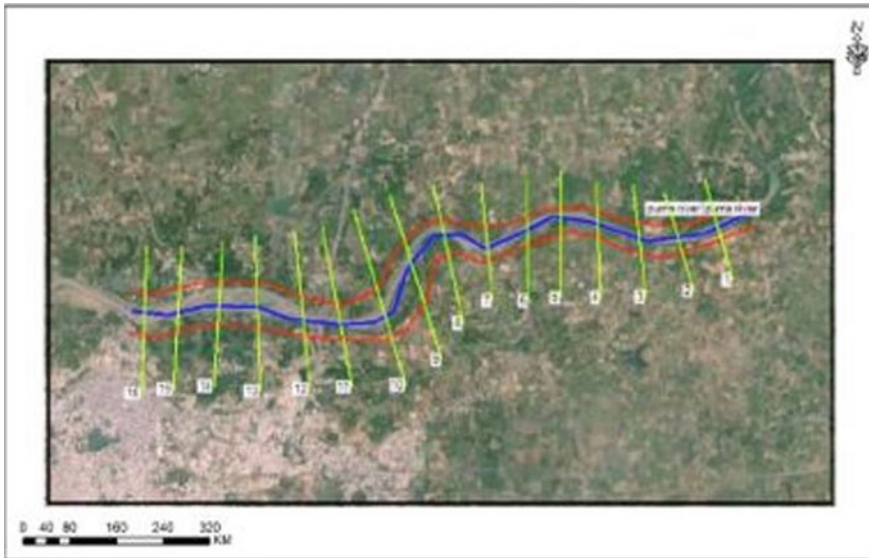


Fig. 3 Extraction of River geometry

3.2 *Hydrodynamic Flood Modeling Using HEC-RAS (Hydrological Engineering Center-River Analysis System)*

HEC-RAS is a software that describes water hydraulics flowing through common rivers and other channels. It is a computer-based modeling program for water moving through open channel systems and calculating profiles of water surfaces. HEC-RAS identifies specific applications viable in floodplain mitigation measures [18, 19]. Saint Venant’s equation is utilized in HEC-RAS to solve the energy equation for one-dimensional hydrodynamic flood modeling [20] expressed as,

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \tag{1}$$

where, Y_1, Y_2 indicates the water depth at cross-sections, Z_1, Z_2 expressed as the elevation of the main river channel, α_1, α_2 demonstrates the velocity weighting coefficients, V_1, V_2 shows the average velocities, g indicates the acceleration due to gravity, and h_e expresses it as energy head loss.

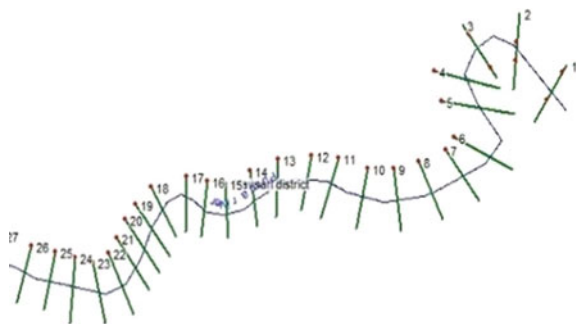
3.3 Model Execution in HEC-RAS

Cartosat-1 Dem was downloaded from the ISRO BHUVAN portal for the digitization of river geometry such as river centerline, river bank lines, flow path lines, and cross-section lines with the arrangement of the spatial coordinate system in HEC-RAS through the RAS mapper window along with Google map as shown in Fig. 4. The extraction of the cross-sections presents the station-elevation data through a geometric data window as illustrated in Figs. 5 and 6 represents river geometry in HEC-RAS. River maximum discharge of the 2004 year flood was used as an upstream condition and the normal depth of the Purna river was utilized as a downstream condition in HEC-RAS, the rugosity coefficient is taken as per [21], and steady flow analysis was carried out for flood modeling.



Fig. 4 Extraction of River geometry in RAS mapper with google base map

Fig. 5 Extracted river geometry in HEC-RAS



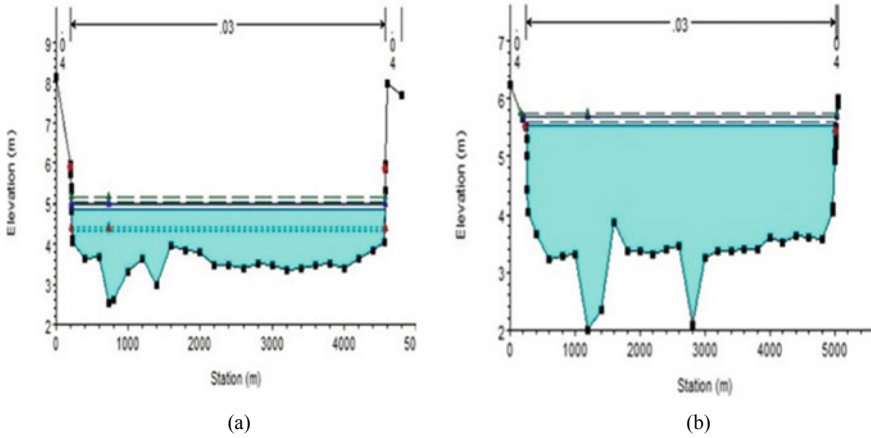


Fig. 6 a Water level at CS-1; b water level at CS-2

4 Results

This study is being performed in the lower part of the city. Discharge data for the 2004 year flood events has been used to simulate steady flow analysis. Due to data scarcity in the study area and only one gauging site is available, it is mandatory to simulate only 2004 year flood events to verify model accuracy. Cross-sections were extracted from DEM provides good results in the data deficient region. Flood modeling approach in such region would be effective during peak flood events [6, 17]. The results from the model for the present study indicate the depth of water at each cross-section. The discharge was measured from the gauge station near Kurel village about 1.5 km away from the downstream side. The depth of water was measured corresponding to the discharge of 8836 m³/s for 1D hydrodynamic flood modeling. Results obtained from the simulation indicated that the cross-section number 1 and 2 were quite affected during peak discharge, and cross-sections 19 and 20 close to Navsari city were more affected by the flood event. The results which were simulated show that the water level at cross-section one and cross-section twenty (Fig. 6). The water level at the downstream part of the study area demonstrates that the people surrounding cross-section number twenty were suffered more during peak discharge and there were lots of property and lives casualties during the 2004 year flood events. Figure 7 indicates simulated the one-dimensional flood depth map for the 2004 year flood event. 1D hydrodynamic flood modeling would be advantageous for the region where the flash flood is frequently occurring phenomenon annually (Fig. 8) [9].



Fig. 7 Simulated flood depth for the 2004 years flood event

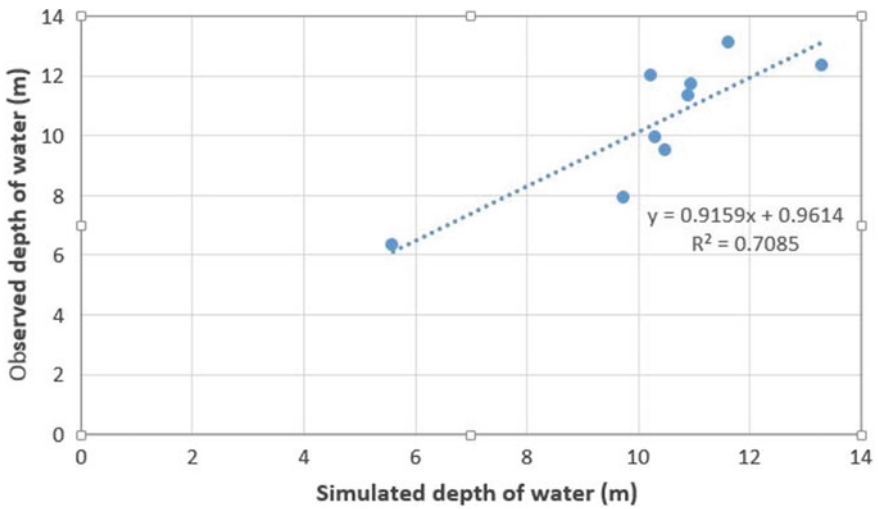


Fig. 8 Regression analysis

4.1 Error Analysis of Cartosat-1 DEM

The error analysis of Cartosat-1 DEM was determined by the comparative analysis of GPS elevation and DEMs grid height at 6 locations of the study area. The scatter plot of GPS elevation and DEM grid elevation is shown in Fig. 9. The linear regression analysis indicates a clear significant correlation between the elevation given by Cartosat-1 DEM and the GPS measured elevation at six locations. Additionally, the R^2 value of the Cartosat-1 was 0.7166, which illustrates the accurate correlation. The gradient value of the regression line shown in Fig. 9 indicates that the value is near 1. The error was evaluated by the difference of the elevation grid of DEM and the GPS elevation of the six locations in the study area. The propagation of error corresponding to the elevation of the Cartosat-1 is shown in Fig. 10. It is noted that the negative errors were observed at two locations, which indicates that the elevation of the Cartosat-1 DEM is higher than the elevation of GPS points. Figure 11 shows the profile comparison between the GPS elevation and Cartosat-1 elevation. It is observed that the major elevation difference was found at GPS locations number two, five, and six. The selection of DEM will have been a great influence on flood modeling. From the output of the model, it is noted that the river geometry extraction from the Cartosat-1 DEM was promising and effective because the availability of DEM data is open source. Further research would be on 2D modeling with the use of different DEMs and comparative analysis would be required for the accuracy of the model.

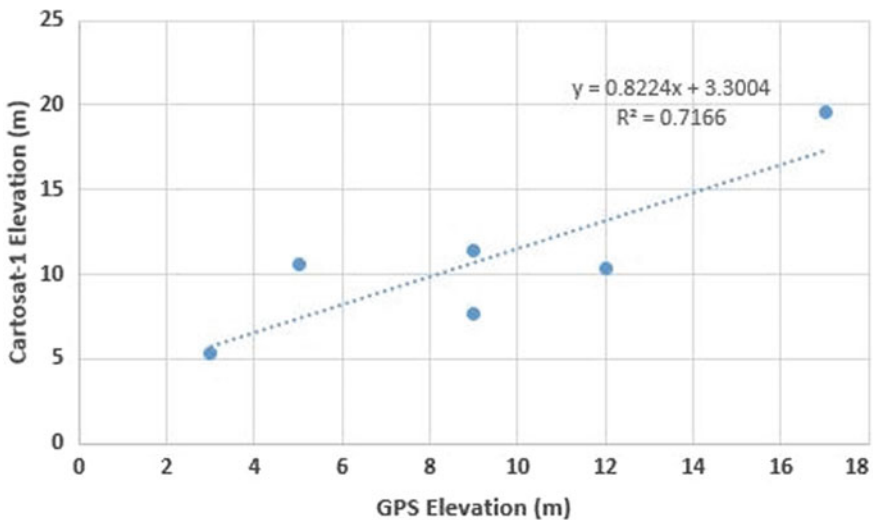


Fig. 9 Scatter plot of Cartosat-1 DEM elevation versus GPS elevation

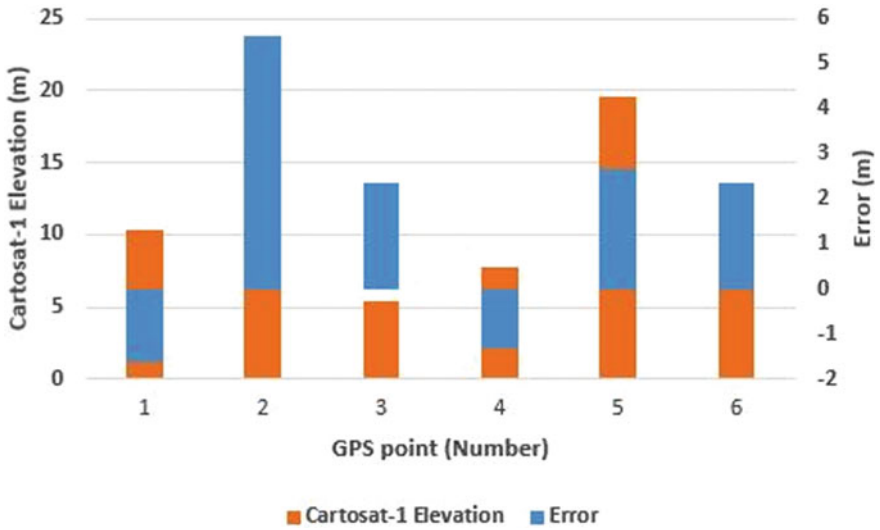


Fig. 10 Error propogation in Cartosat-1 DEM

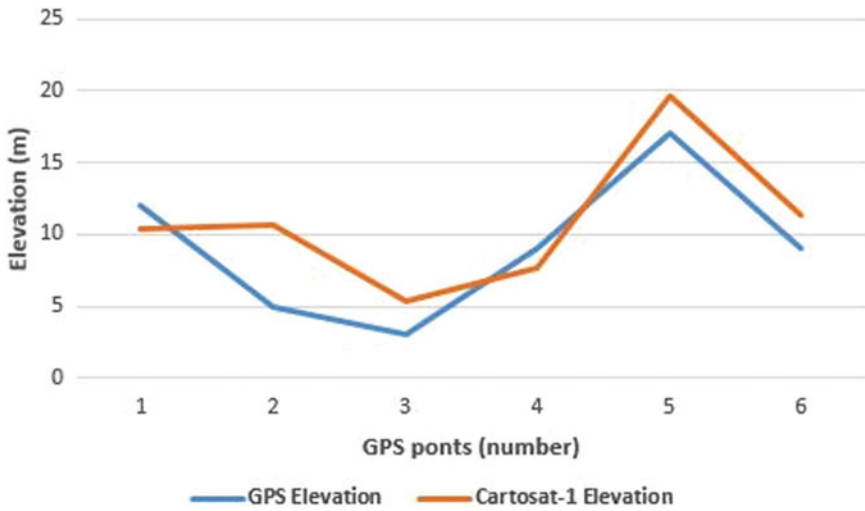


Fig. 11 Profile comparison between GPS elevation and Cartosat-1 Elevation

5 Discussion

The main objective of the study was to show the applicability of Cartosat-1 DEM to extract the river geometry and perform 1D hydrodynamic modeling using HEC-RAS. Newly released HEC-RAS version 5 can extract the GIS data from the DEM, which

indicates the advancement of the approach we have performed in the present study [22]. 30 m resolution DEM was used for 1D hydrodynamic modeling in the study. The 2004 year flood event is simulated and steady flow analysis was performed in the present study. Error analysis of the Cartosat-1 DEM demonstrated the scientific approach to the study. The present study showed the comparative analysis of the observed and simulated water depth. Improvement of the existing cross-section with the modification of error could be the research gap of the study [23, 24]. It is assumed that the precipitation, infiltration process were assumed to be neglected in the HEC-RAS. Due to the scarcity of data in the study region, less observed data were identified. The study would be more accurate if more data can be collected in the future. 2D model should be well recognized the flood extent, which was a limitation of the present study. The flooded cross-sections work were located in the HEC-RAS model was based on the base map as a google earth image. However, GPS surveys could be required to find the actual position of cross-sections.

6 Validation

The limitation of data in the study region was a major concern. The river geometry approach presented in the study is the advancement of geospatial techniques in flood modeling. Moreover, Only one gauging site is available near Kurel village, Navsari for validation of simulated results for the 2004 year flood event. Table 1 depicts the comparison between observed and simulated water depth at the gauging site, which indicates valued and efficient results as far as accuracy is concerned. The regression analysis of observed and simulated datasets at the gauging sites is shown in Fig. 8.

Table 1 Differences between observed and simulated water depth at Gauge station

Satellite	Years	Observed depth of water (m)	Simulated depth of water (m)	Difference (m)
Cartosat-1	2001	10.9	11.3	0.01
	2002	10.23	12	0.27
	2003	10.32	9.92	-0.22
	2004	11.64	13.1	1.6
	2005	13.3	12.32	0.92
	2006	10.5	9.5	0.37
	2007	10.96	11.69	-1.1
	2008	9.75	7.89	0.02
	2009	5.61	6.3	0.13
	2010	10.9	11.3	-0.06
	2011	10.23	12	0.02
	2012	13.8	13.79	0.01

7 Summary and Conclusions

The present study shows the applicability of the HEC-RAS for river geometry extraction with the application of geospatial techniques (HEC-RAS mapper tool). A 1D hydrodynamic flood modeling approach was presented using Cartosat-1 DEM on the Purna river, Navsari, Gujarat, India. The new version of HEC-RAS version 5 was utilized in the present study for GIS applications in flood modeling. River geometry includes: river centerline, bank lines, flow path lines, cross-section cut lines were digitized in RAS mapper tools without ARC-GIS being used in the present study. The error analysis of Cartosat-1 DEM was performed, in which vertical differences were evaluated between GPS elevation and Cartosat-1 elevation. The R^2 value of the Cartosat-1 was found to be 0.7166, which indicates good results. The Validation of the model is being carried out by comparing the observed water depth with the simulated water depth at the location of the gauging site. The output of the model was promising and demonstrates strong potential in the area of data scarcity for using the suggested method. The applicability of open-source datasets would be an effective worldwide approach in flood modeling.

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References

1. Kale VS (1997) Flood studies in India: A brief review. J Geol Soc India (Online archive from Vol 1 to Vol 78), 49(4):359–370
2. Vijay R, Sargoankar A, Gupta A (2007) Hydrodynamic simulation of River Yamuna for riverbed assessment: a case study of Delhi Region, vol 130, no 1–3. Springer, pp 381–387. <https://doi.org/10.1007/s10661-006-9405-4>
3. Pathan AKI, Agnihotri PG (2020) 2-D unsteady flow modelling and inundation mapping for lower region of Purna Basin using HEC-RAS. Nat Environ Pollut Technol 19(1):277–285
4. Merwade V, Cook A, Coonrod J (2008) GIS techniques for creating river terrain models for hydrodynamic modeling and flood inundation mapping. Environ Model Softw 23(10–11):1300–1311. <https://doi.org/10.1016/j.envsoft.2008.03.005>
5. Schwanghart W, Kuhn NJ (2010) TopoToolbox: a set of Matlab functions for topographic analysis. Environml Model Softw 25(6):770–781
6. Tesfa TK, Tarboton DG, Watson DW, Schreuders KA, Baker ME, Wallace RM (2011) Extraction of hydrological proximity measures from DEMs using parallel processing. Environ Model Softw 26(12):1696–1709
7. Abdulkareem JH, Pradhan B, Sulaiman WNA, Jamil NR (2018) Review of studies on hydrological modelling in Malaysia. Model Earth Syst Environ 4(4):1577–1605

8. Pathan AI, Agnihotri PG (2019) A combined approach for 1-D hydrodynamic flood modeling by using Arc-Gis, Hec-Georas, Hec-Ras Interface-a case study on Purna River of Navsari City, Gujarat. *IJRTE*, 8(1):1410–1417
9. Maharjan LB, Shakya NM (2016) Comparative study of one dimensional and two dimensional steady surface flow analysis. *J Adv Coll Eng Manage* 2(c):15. <https://doi.org/10.3126/jacem.v2i0.16095>
10. Roux H, Dartus D (2008) Sensitivity analysis and predictive uncertainty using inundation observations for parameter estimation in open-channel inverse problem. *J Hydraul Eng* 134(5):541–549
11. Finaud-Guyot P, Delenne C, Guinot V, Llovel C (2011) 1D-2D coupling for river flow modeling. *Comptes Rendus - Mecanique* 339(4):226–234. <https://doi.org/10.1016/j.crme.2011.02.001>
12. Teng J, Jakeman AJ, Vaze J, Croke BFW, Dutta D, Kim S (2017) Flood inundation modelling: a review of methods, recent advances and uncertainty analysis. *Environ Model Softw* 90:201–216. <https://doi.org/10.1016/j.envsoft.2017.01.006>
13. Pathan AI, Gandhi PJ, Agnihotri PG, Scholar R (2019) Integrated approach for flood modeling using Arc-GIS, HEC-GeoRAS—A case study on Purna River of Navsari District of Gujarat State
14. Pathan AI, Agnihotri PG (2020) Use of computing techniques for flood management in a coastal region of South Gujarat—A case study of Navsari District. *Adv Intell Syst Comput* 1072:108–117. https://doi.org/10.1007/978-3-030-33585-4_11
15. Gichamo TZ, Popescu I, Jonoski A, Solomatine D (2012) River cross-section extraction from the ASTER global DEM for flood modeling. *Environ Model Softw* 31:37–46
16. Pathan AI, Agnihotri PG (2021) Application of new HEC-RAS version 5 for 1D hydrodynamic flood modeling with special reference through geospatial techniques: a case of River Purna at Navsari, Gujarat, India. *Modeling Earth Systems and Environ* 7(2):1133–1144. <https://doi.org/10.1007/s40808-020-00961-0>
17. Gichamo TZ, Popescu I, Jonoski A, Solomatine D (2012) River cross-section extraction from the ASTER global DEM for flood modeling. *Environ Model Softw* 31:37–46. <https://doi.org/10.1016/j.envsoft.2011.12.003>
18. Ouma YO, Tateishi R (2014) Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. *Water (Switzerland)* 6(6):1515–1545. <https://doi.org/10.3390/w6061515>
19. Ahmad HF, Alam A, Bhat MS, Ahmad S (2016) One dimensional steady flow analysis using HECRAS—A case of River Jhelum, Jammu and Kashmir. *Eur Sci J* 12:340–350
20. Brunner G (1995) HEC-RAS River analysis system. hydraulic reference manual. Version 1.0. <https://apps.dtic.mil/docs/citations/ADA311952>
21. Chow V, Maidment D, Og Mays LW (1988) Applied hydrology. International edition. McGraw-Hill, New York
22. Kumar N, Lal D, Sherring A, Issac RK (2017) Applicability of HEC-RAS & GFMS tool for 1D water surface elevation/flood modeling of the river: a Case Study of River Yamuna at Allahabad (Sangam), India. *Model Earth Systems and Environ* 3(4):1463–1475. <https://doi.org/10.1007/s40808-017-0390-0>
23. Bhuyian MNM, Kalyanapu AJ, Nardi F (2015) Approach to digital elevation model correction by improving channel conveyance. *J Hydrol Eng* 20(5):1–10. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001020](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001020)
24. Pathan AI, Agnihotri PG, Patel DP, Eslamian S (2021) Comparative analysis of 1D hydrodynamic flood model using globally available DEMs a case of the coastal region. *Int J Hydrol Sci Technol* 1(1):1. <https://doi.org/10.1504/IJHST.2021.10034760>