



# Hydrodynamic flood modeling of Dikrong River in Arunachal Pradesh, India: a simplified approach using HEC-RAS 6.1

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Received: 23 May 2022 / Accepted: 13 August 2022 / Published online: 27 August 2022  
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## Abstract

An attempt has been made in this study to simplify the conventional approach of hydrodynamic modeling using HEC-RAS 6.1. Conventionally, the ArcGIS extension HEC-GeoRAS has been used to perform hydrodynamic modeling for HEC-RAS application. However, the new tool RAS Mapper, available with the latest version of HEC-RAS 6.1 has been found to be capable of performing complex hydrodynamic modeling. In this study, the flood inundation maps are generated using the RAS Mapper rather than the widely used HEC-GeoRAS. To assess the accuracy of the simplified approach, velocities, and water surface elevations at the return periods of 25 years, 50 years, and 100 years are stimulated using DEM and compared with the results obtained using total station data. The comparison of results shows that the coefficient of correlation ranges between 92 to 94 percent for velocity and 96 to 98 percent for water surface elevation. The flood inundation map for the return periods of 25 years, 50 years, and 100 years reveals There is an increase in channel depth as well as the extent of inundation as the return period of flood even increases. Furthermore, the simplified technique is demonstrated to be effective and reliable for hydrodynamic flood modeling. As per the findings, the two most vulnerable locations in the study area are Banderdewa and Harmuty. As a result, the government of Arunachal Pradesh has recommended building sheet pile spurs on the river's right bank long with earthen embankments on both banks to mitigate the flood problems in the study area.

**Keywords** HEC-RAS · RAS mapper · Flood · Flood inundation map · Hydrodynamic model

## Introduction

Flood is one of nature's most catastrophic natural disasters, wreaking havoc on people's lives, economies, and infrastructure. Every year, devastating floods kill millions of people and destroy vast amounts of property. The scenario is even more dangerous for countries for developing and underdeveloped countries. Flooding is growing increasingly widespread

throughout the world, which is a serious concern. A better understanding of flood inundation, as well as the execution of mitigation measures, are required to reduce flood risk (Ficchi and Stephens 2019; Hounkpe et al. 2022). Ray et al. (2019) studied three different flood events in India, namely, the Uttarakhand flood of 2013, the Jammu and Kashmir flood of 2014, and the Gujrat-Rajasthan flood of 2017, and found that climate change has been one of the major factors causing excess surface runoff and flooding. In the Uttarakhand flood of 2013, heavy rainfall and snow melt intensified surface run-off towards Kedarnath and the downstream region. In the Jammu and Kashmir flood of 2014, a five-day period of exceptionally high rainfall in the first week of September 2014 triggered devastating floods in the northern region of the state. In July 2017, unexpected monsoon rainstorms caused flooding in Rajasthan and Gujarat. The Himalayas are the source of several of India's major river systems including the Brahmaputra and the Barak. Further, Gupta (2003), Sanayanbi et al. (2014), and Sharma et al. (2021) have studied the flood problems of the Brahmaputra in Assam and found that the North-east states

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are more vulnerable to water-induced disasters due to its location, fragile geo-environmental ecosystem, slowly growing economy, and rapid growth on floodplains along with inadequate water management. Keeping in view the severe flood problems in northeastern states of India, the present study highlights the flood problems of the Dikrong river in Arunachal Pradesh, India, and identifies the flood inundation and vulnerability of the study area.

The issue becomes worse due to the lack of advanced flood modeling methodologies. HEC-RAS is one of the widely used public domain software for flood mitigation studies. The Hydrologic Engineering Centre (HEC) of the USA has developed the River Analysis System (RAS) (<https://www.hec.usace.army.mil/software/hec-ras/downloads.aspx>) to assist hydraulic engineers in river flow analysis and floodplain mapping (US Army Corps of Engineers (USACE) 2010). It includes numerous data entry capabilities, hydraulic analysis components, data management capabilities, and graphing capabilities (US Army Corps of Engineers (USACE) 1998). In most studies, HEC-RAS has been used in conjunction with other GIS software, such as ArcGIS or the Hec-GeoRAS extension (Tate et al. 2002; Mehta et al. 2014; Rangari et al. 2019; Ezzine et al. 2020). These modeling methodologies are viewed as essential tools for urban and municipal development, disaster response strategies, flood control, and environmental research. In the case of flood plain mapping, software must have the capacity to anticipate the behavior of water resources for different intervals. It should also be capable of performing a strategic evaluation of inundation size. The above clarification is included in the revised manuscript (Baldassarre et al. 2010). The HEC-RAS model offers a method for analyzing floods accompanied by other relevant hydrological parameters and their consequences. The outcomes of this study can play a significant role in predicting flood potential along with determining future Water Surface Elevation (WSE) and velocity to plan the flood protection work for a city located on the bank of a river.

Some of the relevant literature using HEC-RAS are presented in the following paragraphs. Goodell and Warren (2006) compared the flood of 1 year return period with the flood of a 100-year return period. The study concluded that HEC-RAS software is unique and capable of computing the WSE for each cross-section. Similarly, Adams et al. (2010) have discussed the Ohio River community HEC-RAS Model consisting of 2800 cross-sections of the modeled reach. They observed HEC-RAS is capable of performing complex hydrological modeling with large datasets. Prata et al. (2011) used bathymetric data to perform hydrodynamic modeling in the Taquaraçu river of Brazil. They suggested different intervention techniques to mitigate the flood. Khalil and Khan (2015) used HEC-RAS, ArcGIS, and its extension HEC-GeoRAS for hydraulic modeling and flood plain

mapping. They calculated the peak flows and estimated the lag time between intake and outflow. They have also applied to map for the calculation of flood zone depth and flooded area of reach. Gawade et al. (2015) created flood maps of the Yamuna River in Delhi, India, using HEC-RAS, remote sensing (RS), and geographic information system (GIS). They found the water depth, velocity maps, and flood inundated areas. Kumar et al. (2017) and Kumar et al. (2020) used 1D and 2D HEC-RAS modeling coupled with the Global Flood Monitoring System to calculate flood episodes and High Flood Level (HFL) in the river Yamuna in Allahabad, Uttar Pradesh, India. The findings indicate that a larger region around the study area is in a high-risk zone, necessitating the creation of a safety management plan. Khalfallah and Saidi (2018) employed HEC-GeoRAS to evaluate flood occurrences in the Medjerda basin of North Africa in 2015. They found that there is an increase in the extent of flooding as the return periods increase. Pilotti et al. (2020) studied the Cancano-I dam in northern Italy. They discovered that HEC-RAS could properly describe the spread of impulsive floods even on highly steep and rough terrain. Desalegn and Mulu (2021) advised that the regions prone to a 100-year flood return period should not be used for agricultural operations, infrastructure construction, or other investment projects during the rainy season. They added that in flood-prone locations, proper land use planning methods should be considered to avoid flood tragedies. Pathan and Agnihotri (2021) used the HEC-RAS v5 for 1D hydrodynamic flood modeling of the Purna river at Navasari city, Gujarat, India. They discovered that geospatial techniques coupled with HEC-RAS can provide a reliable and accurate methodology for 1D hydrodynamic flood modeling. Tamiru and Wagari (2021) developed a flood inundation mapping approach that incorporates machine learning and HEC-RAS in the Baro River Basin (Ethiopia). The HEC-RAS model was calibrated and verified using LANDSAT 8 data and a water body was defined using the normalized difference water index based on historical flood occurrences of 2005 and 2008. Recently, Namara et al. (2021) prepared a flood inundation map using HEC-RAS for Awash Bello flood plain, Upper Awash River basin, Ethiopia. Venkatcharyulu and Viswanadh (2021) conducted a study that included a runoff model that incorporates GIS and a hydrological model. The authors suggested that the digital model aided in predicting flood volume and estimating runoff in the Medigadda Barrage.

The Digital Elevation Model (DEM) is a three-dimensional (3D) depiction of a terrain's surface generated using elevation data. It is often constructed utilizing data obtained through remote sensing techniques, although it can also be constructed using field surveying (Brunner, 2013). Pallavi and Ravikumar (2021) discovered that the HEC-RAS model in conjunction with remotely sensed data is critical for the geospatial study of the hydrologic cycle, such as inundation

mapping, watershed delineation, and flood plain delineation. Patel and Yadav (2019) advocated using the software's data to predict future flood disasters of various magnitudes. However they reported to use GIS applications with greater accuracy, flood maps must be upgraded.

Khattak et al. (2016) created a floodplain mapping of the Kabul River and computed the water surface profiles of historical flood occurrences as well as the inundation area. They identified the calibration of Manning's coefficient as a research drawback. Using HEC-RAS, Parsa et al. (2016) generated flood zone mapping for various return periods of the Johor River-Kota Tinggi area. Changes in the roughness coefficient are shown to be the most sensitive issue on the water surface profile. They also discovered that the primary source of increasing flood damage was excessive use of flood plain areas or embankment areas along the river. Husain et al. (2018) performed a study to examine the vulnerability of several hydraulic infrastructures in Delhi between Wazirabad and Okhla Barrage of the river Yamuna. They found that the proposed model may be used to predict future flooding in the Yamuna basin, assisting in the development of policies to mitigate the negative effects of floods in the area. Tamiru and Dinka (2021) found that an integrated Artificial Neural Network (ANN) method and HEC-RAS model for flood inundation mapping is a useful tool for flood risk management and early warning systems. Ahmad et al. (2016) conducted a field study on the usage of the HEC-RAS Model for flood studies in the Jhelum River of Kashmir valley. The findings of their study reveal that the extent of inundated area for the study region is more with floods of 50 and 100 years return periods. The 1D steady flow analysis also indicated that the majority of the existing bunds will be overflowed by floods with return periods of 50 and 100 years. The authors highlighted the need for engineering structures such as dykes and levees along the Jhelum River channel to mitigate the flood.

The above-mentioned examination of the literature shows that numerous attempts have been made globally for floodplain modeling in various river basins utilizing HEC-RAS integrated with ArcGIS, HEC-Geo RAS, ANN, and other technology. In contrast, the primary goal of the study is to perform a 1D steady flow analysis using the latest feature 'RAS mapper' in HEC-RAS 6.1 and to compare the DEM simulated results against the total station (TS) simulated results. The goal was met by comparing DEM and TS simulations for channel velocity and WSE performed with the RAS Mapper tool included in the newest version of HEC-RAS 6.1. This manuscript also highlights inundation flood mapping generated during the evaluation of the simplified technique.

## Methodology

The Dikrong river basin is located in western Arunachal Pradesh, India. It is situated between latitudes of 27°00' and 27°25' N, and longitudes of 93°00' and 94°15' E. The catchment area totals 1,556 km<sup>2</sup>, of which 1,278 km<sup>2</sup> is in Arunachal Pradesh and the remainder is in Assam. Every monsoon, the river Dikrong transports a massive amount of sediments consisting of silt, gravel, and relatively small boulders. This causes flash floods in some sections of the basin (Bhadra et al. 2011). The study has been carried out on a 2-km length of the Dikrong River (Fig. 1 a). The stretch was chosen based on its geographical significance, population density, and socioeconomic conditions in the area.

The methodology uses HEC-RAS 6.1 which is a Hydraulic modeling software developed by the US Department of Defence, the Army Corps of Engineers. The 1D hydraulic models compute cross-sectional average WSE and velocity at discrete cross-sections using 1D Saint–Venant equations solved using the implicit finite difference method (Kowalczyk et al. 2018; Lai and Khan 2018).

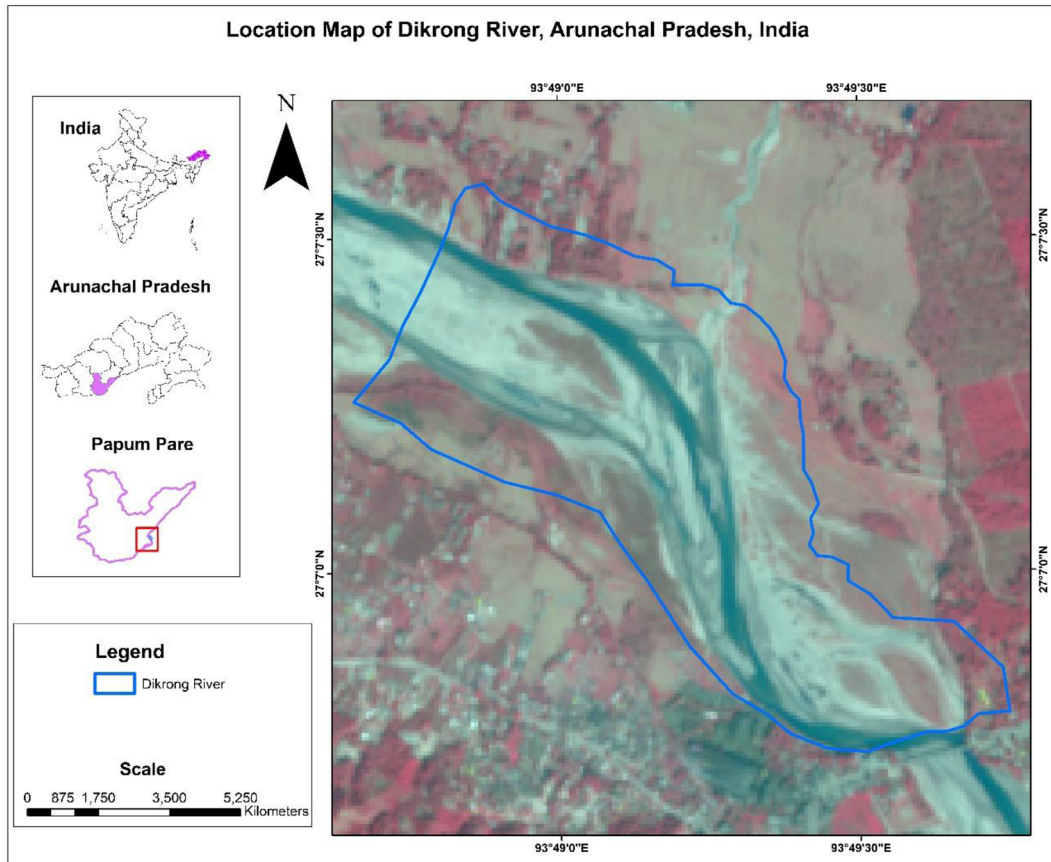
$$\frac{\delta A}{\delta t} + \left( \frac{\delta \phi Q}{x_c} \right) + \frac{\delta(1 - \phi)Q}{\delta x_f} = 0 \quad (1)$$

$$\begin{aligned} \frac{\delta Q}{\delta t} + \frac{\delta}{\delta x_c} \left( \frac{\delta \phi^2 Q^2}{A_c} \right) + \frac{\delta}{\delta x_f} \left( \frac{(1 - \phi)^2 Q^2}{A_f} \right) + gA_c \left( \frac{\delta z}{\delta x_c} + S_c \right) \\ + gA_f \left( \frac{\delta z}{\delta x_f} + S_f \right) = 0 \end{aligned} \quad (2)$$

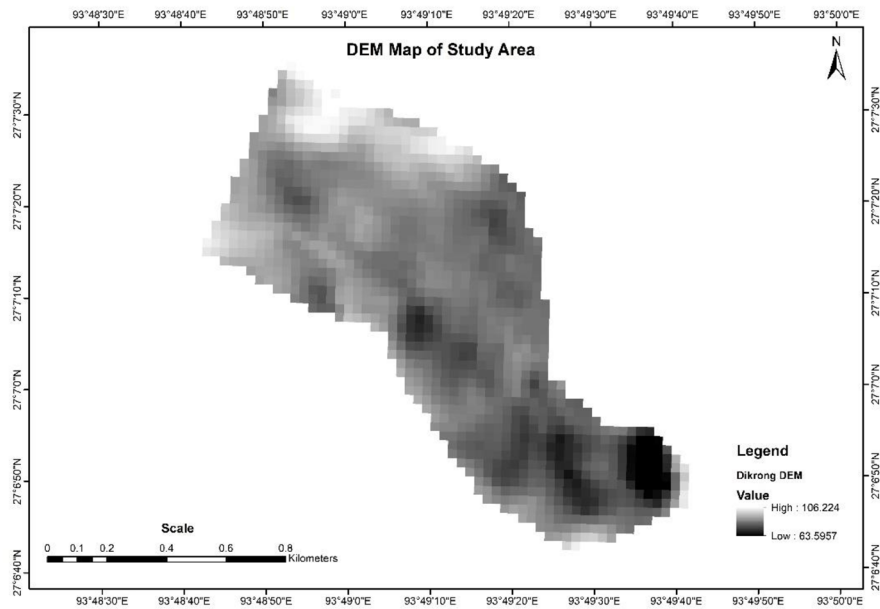
where  $A$  is the: cross-sectional area,  $Q$  is Discharge,  $S$  is the frictional slope,  $z$  is water depth,  $x$  is the distance along with the flow,  $S_f$  is the friction slope,  $S_c$  is the bed slope,  $\phi$  is the fraction to determine channel versus floodplain discharge, and  $t$  is time. Equation 1 is a continuity equation whereas Eq. 2 is a momentum equation. These equations are used to perform the 1D hydrodynamic computations in the HEC-RAS software.

The software has geospatial capabilities for digitizing bank lines, river centrelines, cross-sections, and channel flow lines (river geometry data) directly from the RAS-mapper tool with the pre-observed data. The Cartosat-1 satellite imagery with 30 m resolution is used in this study and river geometry is extracted from the DEM (Fig. 1b). This digitization process had been earlier performed in ArcGIS with HEC-GeoRAS extension. This modeling application allows to perform both 1-D and 2-D hydraulic modeling. The steps used to perform hydrological modeling using the RAS mapper in HEC-RAS 6.1 are shown as a flowchart in Fig. 2 and are further explained as follows.

To perform the 1D hydrological modeling, HEC-RAS 6.1 is downloaded from its official website (<https://www.hec.usace.army.mil/software/hec-ras/>). The terrain data

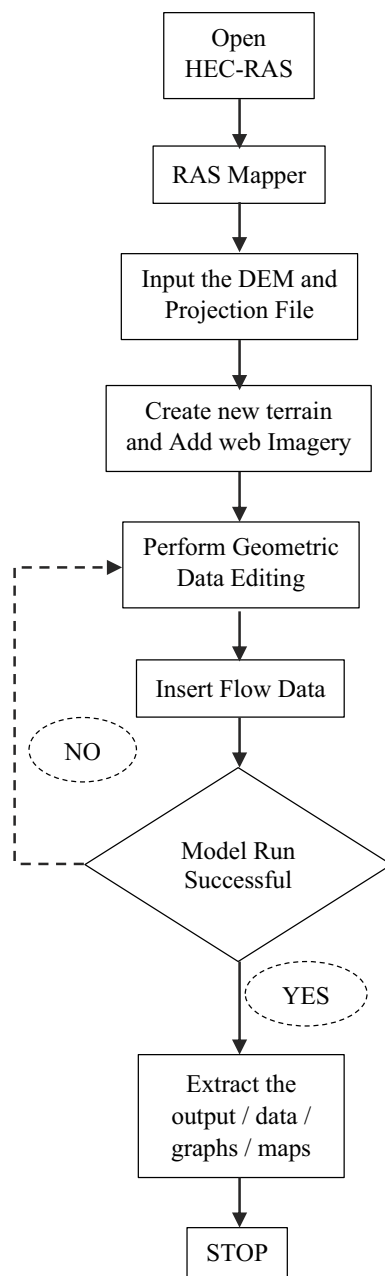


(a)



(b)

**Fig. 1** a Location Map of the study area b DEM of the study area



**Fig. 2** Flow chart of the methodology

of the study area is downloaded from the earth data provided by NASA (<https://search.earthdata.nasa.gov/search>), followed by downloading the projection file of the DEM from the spatial reference website (<https://spatialreference.org/ref/sr-org/4691/>). Using these files as input files in the RAS mapper a new terrain is created by clicking the 'create new terrain' option available under the 'Project' menu in the RAS mapper window. Similarly, using the georeferencing tool 'Add Web Imagery' available under the 'Project' menu, a 2-km section of the Dikrong River is located over the input files. By using this feature, the

DEM is linked with the Google Satellite Image, and then the DEM is accurately incorporated with the study area.

The model needs the other essential data to construct the appropriate steady-state model of a river in HEC-RAS. The geometry data for the study area is processed utilizing the following tools: stream centreline, stream banks, flow track lines, and cross-sections. These tools give key geometric data such as the river reach, left and right over bank, flow path river station, cross-sections, and main channel bank stations (Fig. 3). The river stationing is then drawn downstream to upstream locations. The river system can also be modified by adding new points or shifting existing ones within the river's reach. After drawing the river system, the cross-section data for the stationing points are added to a system editor, (cross-sections are ordered within a reach from the first upstream station to the last downstream station as shown in Fig. 3). The ability to interpolate the cross-sections in the river reach or between two successive cross-sections is a critical capability that aids in the building of realistic models in HEC-RAS 6.1. When the area is large, the model can be simplified by including interpolated cross-sections, allowing for the creation of an accurate model of the investigated river.

To simulate the model, steady-flow data along with the number of flow profiles are entered. The flow from upstream to downstream for the selected river stretch is defined. The probable discharge for return periods of 25, 50, and 100 years are 2051 m<sup>3</sup>/sec, 2221 m<sup>3</sup>/sec, and 2385 m<sup>3</sup>/sec, respectively, calculated using Gumbel's Method (Al-Mashidani et al. 2009). The possible types of boundaries which can be used in the HEC-RAS environment are (i) known water surface elevations, (ii) critical depth, (iii) normal depth, and (iv) rating curve. The boundary conditions are critical in determining the beginning water surface at either end of the simulated river system. For a supercritical flow regime, boundary conditions must be established only at the upstream ends of the river system and for a subcritical flow regime, the downstream boundary conditions are required. Whereas boundary conditions must be set at all ends of the river system for a mixed flow regime. In the present study, the boundary condition is selected as the critical depth at the downstream side of the river. In the study, Manning's roughness coefficient value of 0.03 is used as applicable to this case (Chow et al. 1988). Once all the required information is provided to the software, the model is ready for simulation. The simulated model provides velocity, WSE, and other important parameters such as cross-sections, water surface profiles, general profile plots, rating curves, X–Y–Z perspective plots, stage and flow hydrographs, and hydraulic property plots. Flood inundation maps are generated for the 25, 50, and 100-years return flood period as shown in Fig. 4.

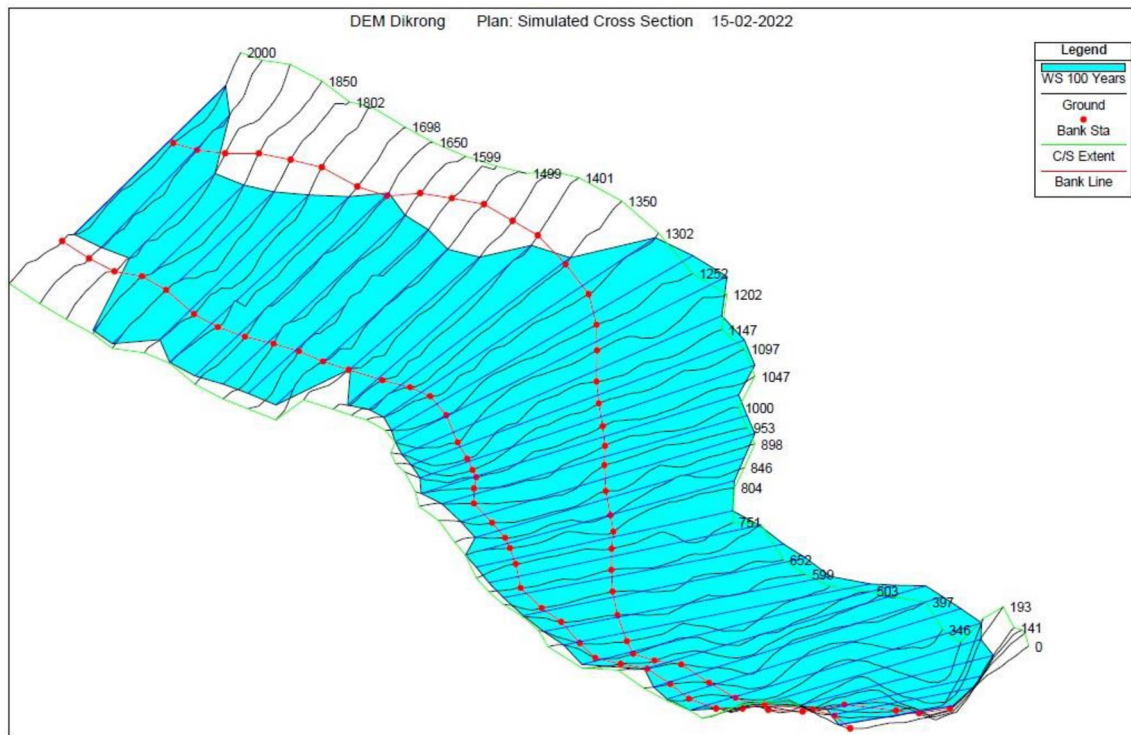


Fig. 3. 3D view of Ras-mapper plot

## Results and Discussions

### Cross-sectional details of the Dikrong river in the study area

The first river station, station zero has been positioned with respect to an identifiable location on the river. Following the identification of the first river station, the other stations for the 2000-m length were spaced 250 m apart. The geometry of eight cross sections was observed to be irregular and distinctive. However, the 0-river station at the starting appears to be U-shaped. For this station, the channel depth ranges from 20 to 25 m in the DEM simulated results. Whereas in TS simulated results it ranges from 6 to 8 m. in the same station, a gradual drop is observed in DEM simulated results in contrast to TS simulated results. The center of the catchment lies between 150 to 300 m away from the start of the river. Further, the channel depth in the remaining cross-sections ranges between 10 to 20 m. The center of the catchment is observed at 250 m to 350 m away from the start of the river.

### WSE obtained using HEC-RAS Model

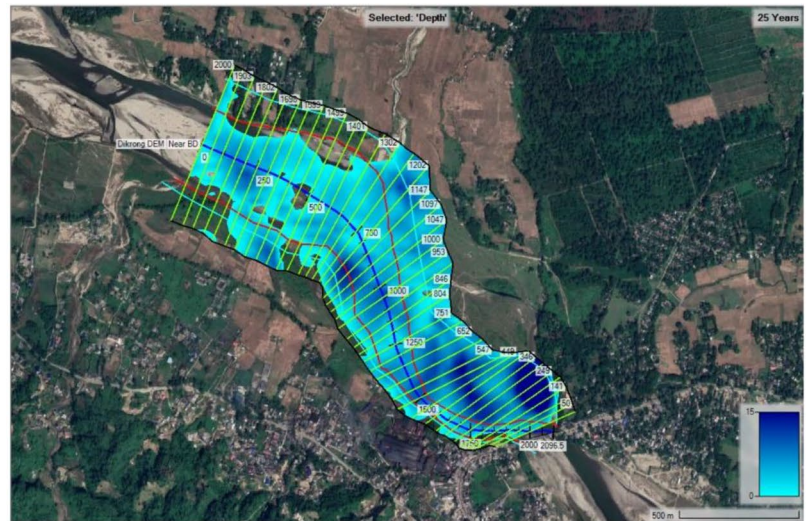
Table 1 shows the simulated velocity and WSE using DEM and TS datasets for 25 years, 50 years, and 100 years flood return period. The table shows that the channel velocity and

WSE increase with the return period for both the TS and DEM simulation. Figure 5 a and b show the WSE using DEM and TS for 25 year return period. Similarly, Fig. 6 a and b show the WSE using DEM and TS for 50 year return period, and Fig. 7 a and b show the WSE using DEM and TS for 100 year return period. These WSE profiles are taken from upstream to downstream, located along the channel section. As observed, the WSE at the upstream location is at a higher elevation, which decreases along the channel section in the downstream direction. The water surface profiles along the cross sections are found to be irregular at different stationing points. This may be due to the real nature of the flow along the hilly region. The channel velocity decreases gradually from upstream of the river to downstream of the river. However, there is a significant increase at the 0-stationing point. This is due to the relatively narrow channel section around the 0-stationing point.

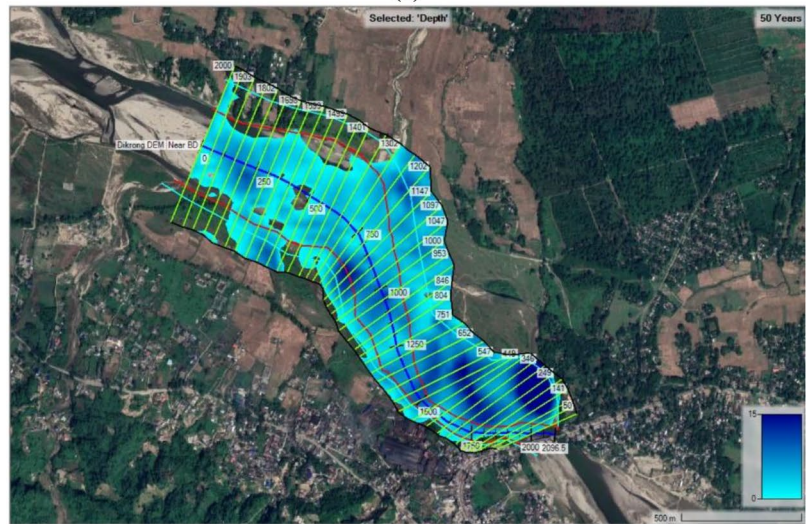
### Comparison of WSE and channel velocity

Figure 8 a, b, and c show the simulated velocity using the DEM and TS data for floods of return periods 25, 50, and 100 years, respectively. The figure shows that the coefficient of correlation for the velocity varies between 92 to 94 percent. Similarly, Fig. 9 a, b, and c show the simulated WSE using the DEM and TS data for floods of

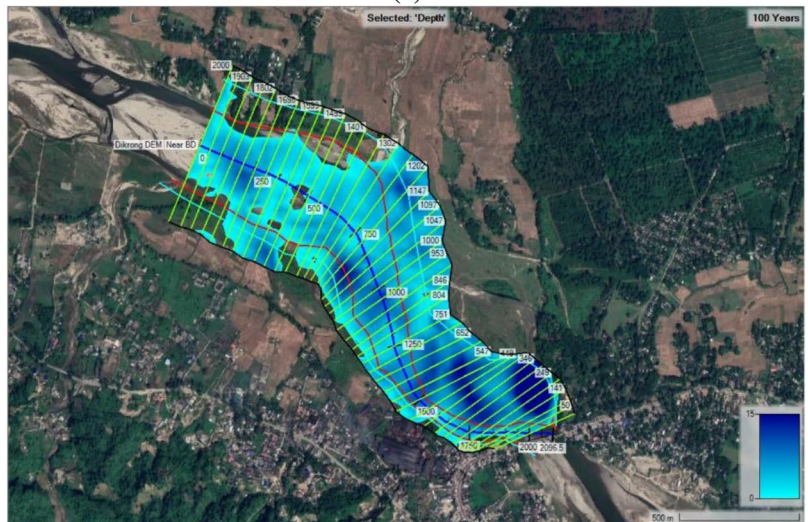
**Fig. 4** Flood Inundation Map for **a** 25 years **b** 50 years **c** 100 years return period



(a)



(b)



(c)

**Table 1** DEM and Total Station simulated results

River Station	Simulated from Total Station Data		Simulated from DEM	
	Channel Velocity (m/s)	WSE (m)	Channel Velocity (m/s)	WSE (m)
<i>25 Year return period</i>				
2000	2.17	100.47	1.36	93.36
1750	1.93	100.19	1.24	91.15
1500	1.49	100.06	2.44	90.23
1250	1.37	99.96	0.57	89.96
1000	1.88	99.73	0.85	89.94
750	1.7	99.54	0.91	89.78
500	1.94	99.22	0.55	89.82
250	1.7	98.97	0.2	89.82
0	4.33	97.59	4.94	88.42
<i>50 Year return period</i>				
2000	2.23	100.58	1.42	93.47
1750	1.98	100.3	1.3	91.26
1500	1.54	100.18	2.51	90.34
1250	1.42	100.08	0.6	90.16
1000	1.94	99.84	0.88	90.14
750	1.75	99.65	0.96	89.98
500	1.96	99.34	0.58	90.02
250	1.73	99.1	0.21	90.02
0	4.43	97.69	5.06	88.55
<i>100 Year return period</i>				
2000	2.29	100.69	1.48	93.58
1750	2.03	100.41	1.36	91.37
1500	1.58	100.29	2.61	90.43
1250	1.47	100.19	0.63	90.35
1000	2	99.94	0.91	90.33
750	1.8	99.76	1	90.17
500	1.98	99.46	0.6	90.21
250	1.76	99.23	0.23	90.21
0	4.52	97.79	5.16	88.69

return periods 25, 50, and 100 years, respectively. From the figure, it is observed that the coefficient of correlation varies between 96 to 98 percent. The variation in the results of DEM and TS is due to minor misalignment in the process of locating the exact river stations in HEC-RAS while using TS datasets. Moreover, the presence of outliers in the simulated result is another reason for the differences. The variance in the cross-section is mainly caused due to nonavailability of the latest DEM. The TS data was recorded in 2021 by the water resources department, Government of Arunachal Pradesh, India, whereas the available DEM was recorded in 2015.

## Estimation of flood-prone area

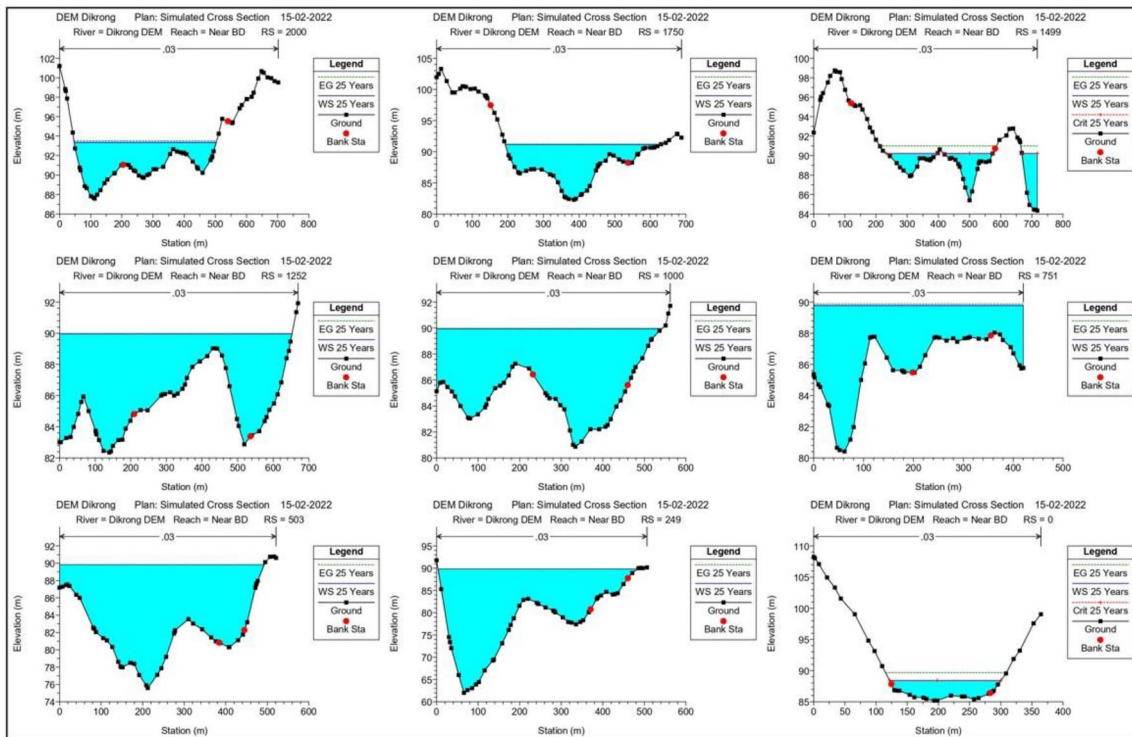
From the study, it is observed that in the two-kilometer stretch of the study area, there are multiple locations where the depth and extent of inundation increase with the increase in flood return periods. This might be due to the shallow bed in this section. The study site has geographical significance as it is located in the Arunachal Pradesh – Assam boundary containing multiple government offices and markets. The socioeconomic advancement makes the area densely populated. Banderdewa and Harmutty are the most vulnerable to flash floods, with areas of 1.24 km<sup>2</sup> and 2.81 km<sup>2</sup>, respectively (Fig. 10). This necessitates the construction of engineering structures to mitigate the flood. Based on the study following mitigation measures are being undertaken by the Government of Arunachal Pradesh.

1. For solving the flooding and erosion problem on the right bank, construction of steel sheet piles and sheet pile spurs are suggested.
2. Dredging of braided channels in the middle portion of the river course is proposed to reduce the flood risk in this section.
3. Earthen embankment behind sheet pile and with filling is proposed to restore the damaged land.

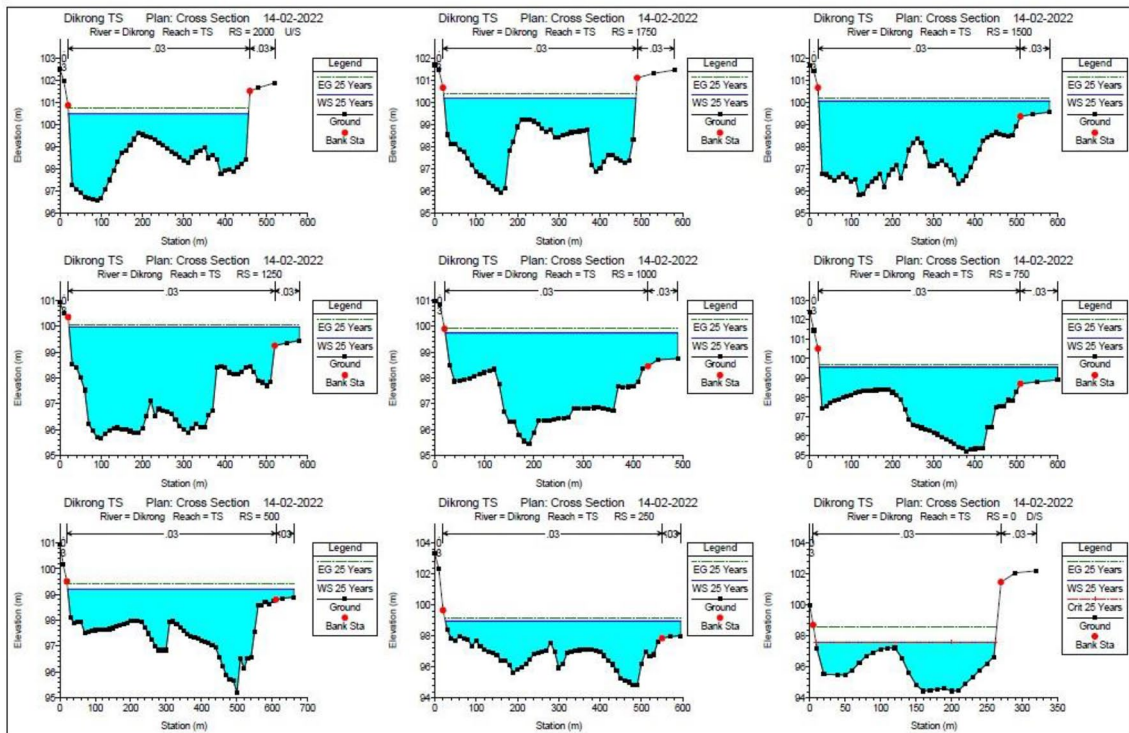
## Conclusion

In this study, the proposed simplified approach of Hydrodynamic modeling, HEC-RAS 6.1 is applied to the Dikrong River of Arunachal Pradesh, India. It is found that the simplified approach successfully simulates the hydrological modeling. The results attained with the simplified approach indicate that the RAS-mapper may be used to determine hydrodynamic parameters for various return periods. Overall, the simplified approach was found to be reasonably robust and cost-effective. Although HEC-RAS 6.1 is available on an open platform and is free to use, traditional approaches require users to have skills and knowledge of other supporting platforms. In traditional approaches, hydrodynamic modeling is performed with complex procedures, whereas the presented simplified approach is easy to adopt. Therefore it is found that the simplified approach is efficient for hydrodynamic modeling of the Dikrong River in Arunachal Pradesh and the preparation of flood inundation maps of the study area. A comparison of DEM simulated and TS simulated velocity profiles reveal the simulation patterns with correlation coefficients ranging from 92 to 94 percent. Whereas, the coefficients of correlation for the WSE of different return periods ranges from 96 to 98 percent. It is further found that the increase in return periods increases the depth of



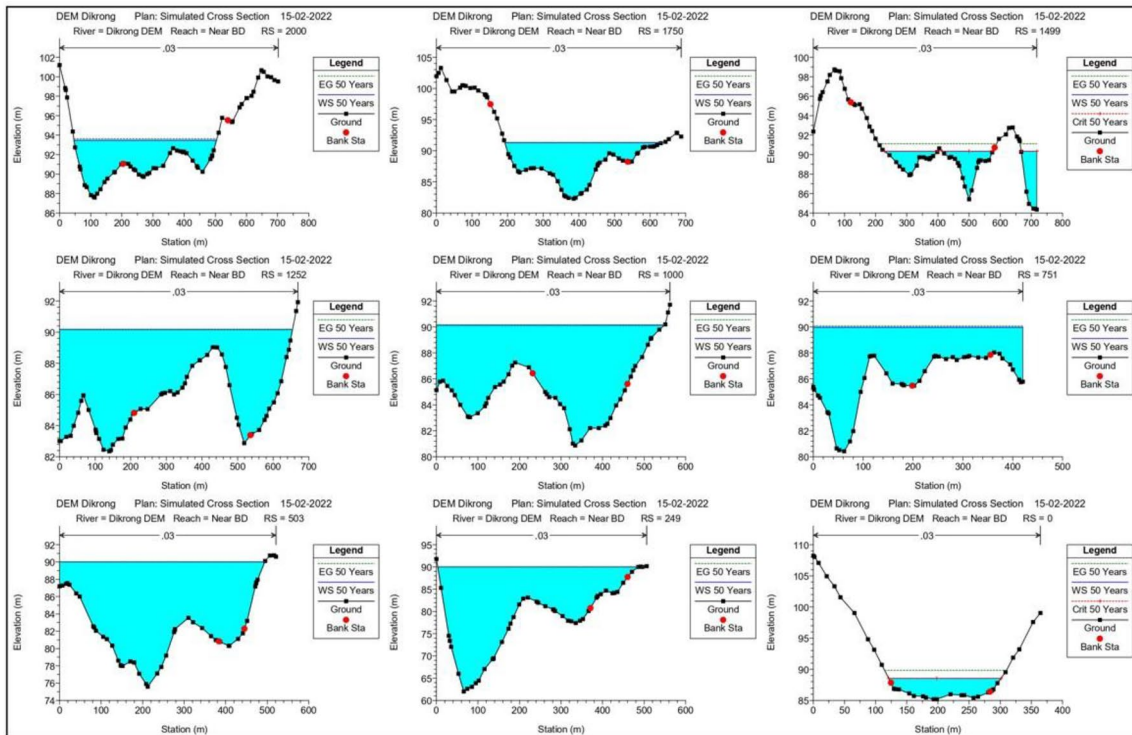


(a)

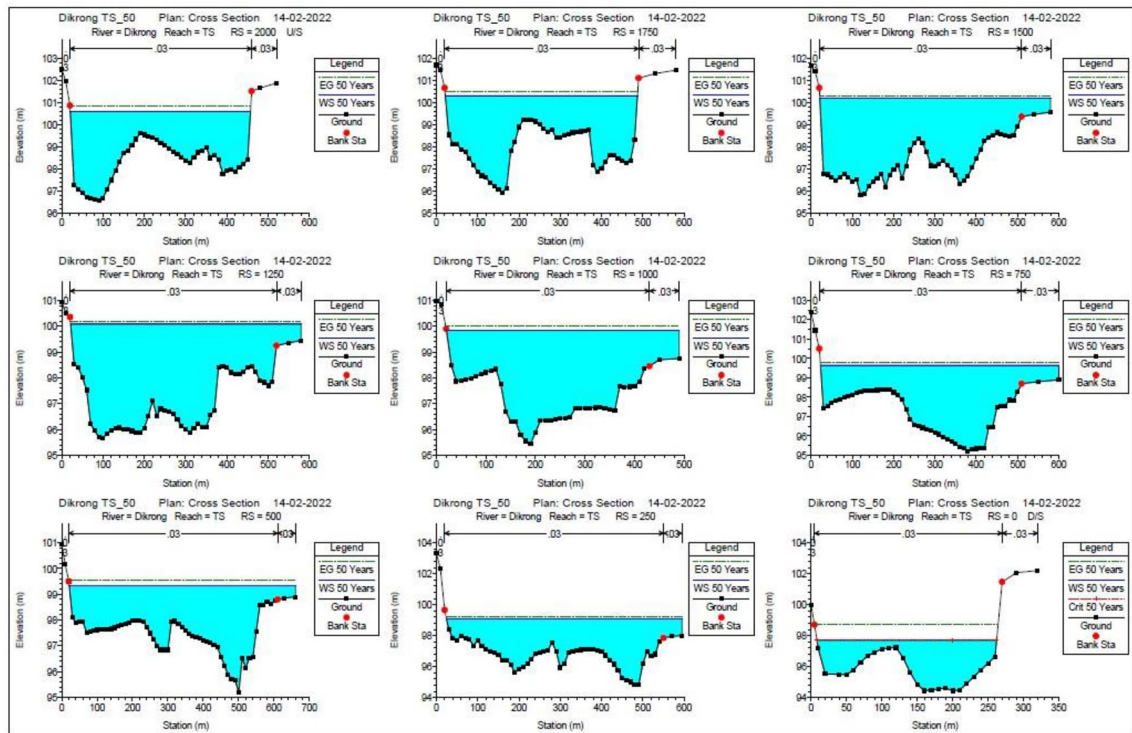


(b)

Fig. 5 Cross-section for 25 years return period a DEM simulated b Total Station simulated

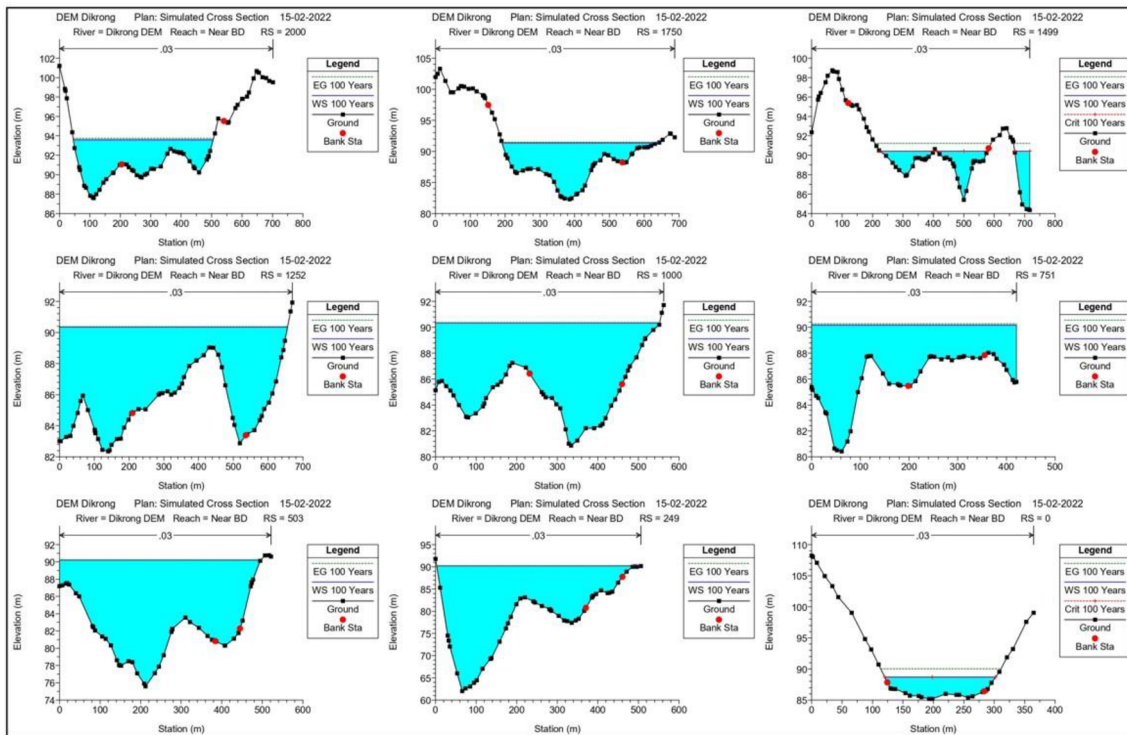


(a)

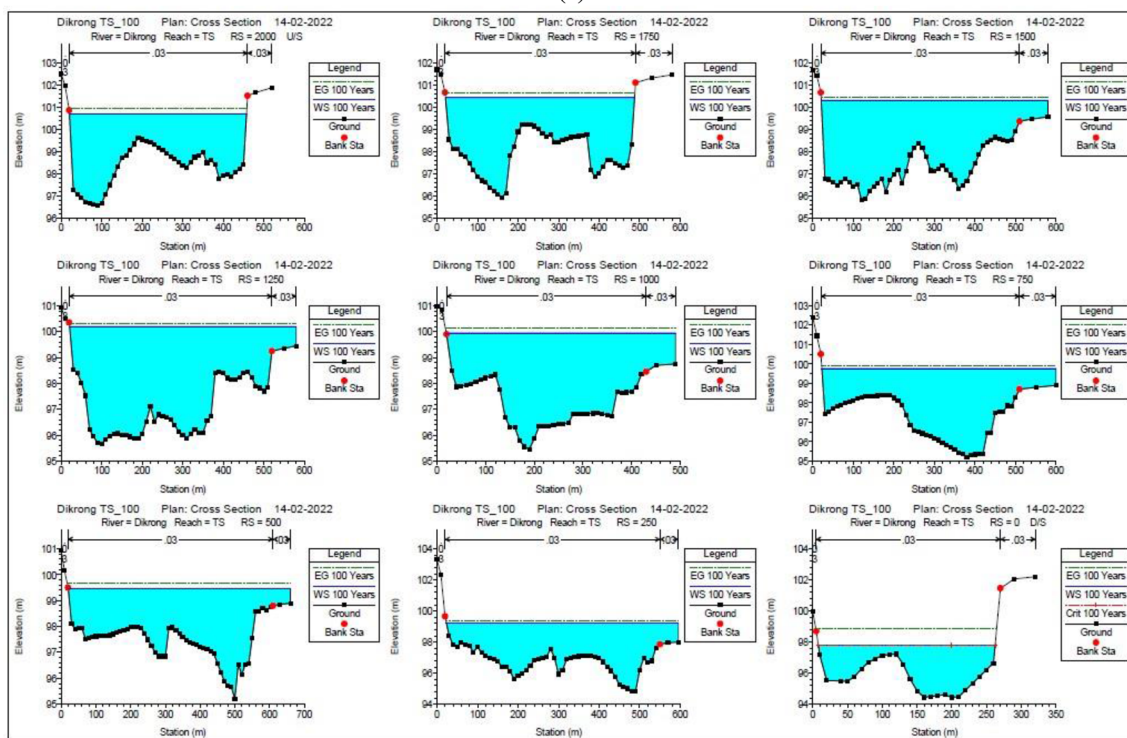


(b)

Fig. 6 Cross-section for 50 years return period a DEM simulated b Total Station simulated



(a)



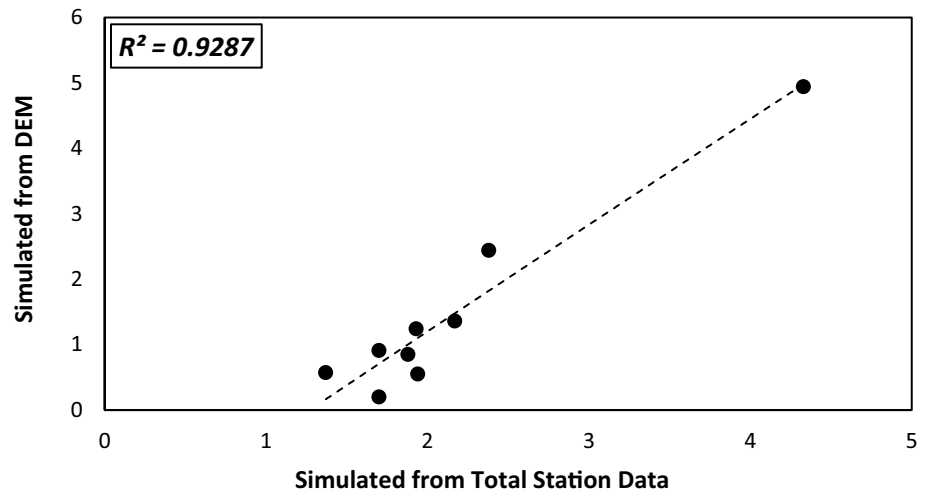
(b)

**Fig. 7** Cross-section for 100 years return period **a** DEM simulated **b** Total Station simulated

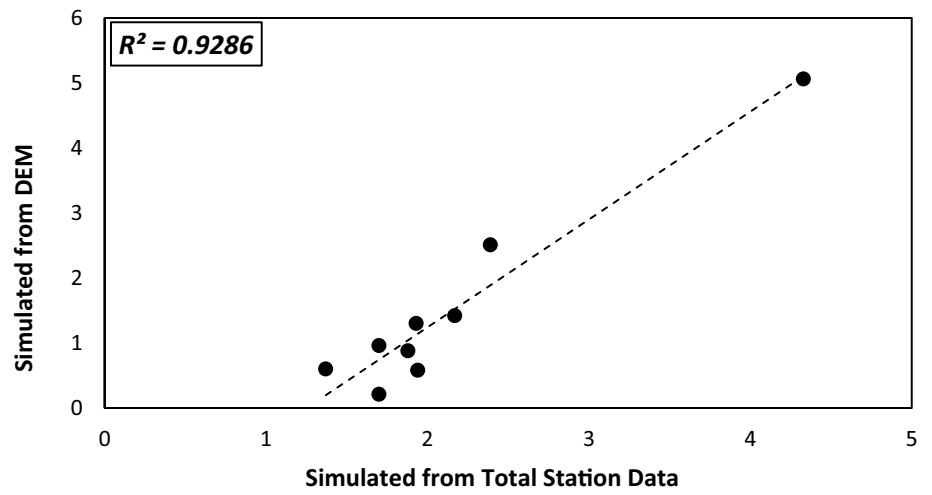
flow in the channel as well as the extent of inundation. In the study area, Banderdewa and Harmutty are found to be most vulnerable to flash floods. Further, it can also

be asserted that with the availability of the recent DEM, precise inundation maps of the study area can be generated, which could be very valuable for flood prevention

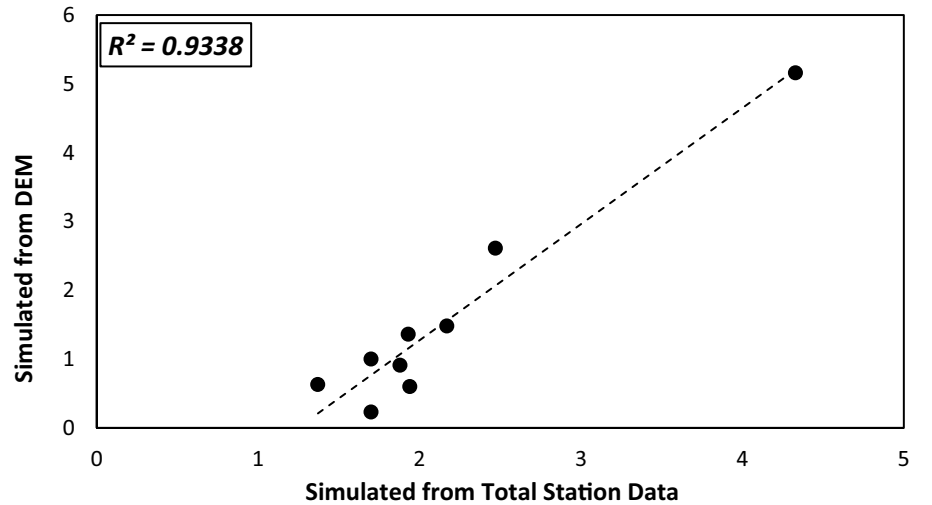
**Fig. 8** Comparison of velocity obtained by simulating DEM data and Total Station Data for **a** 25 years **b** 50 years **c** 100 years



(a)

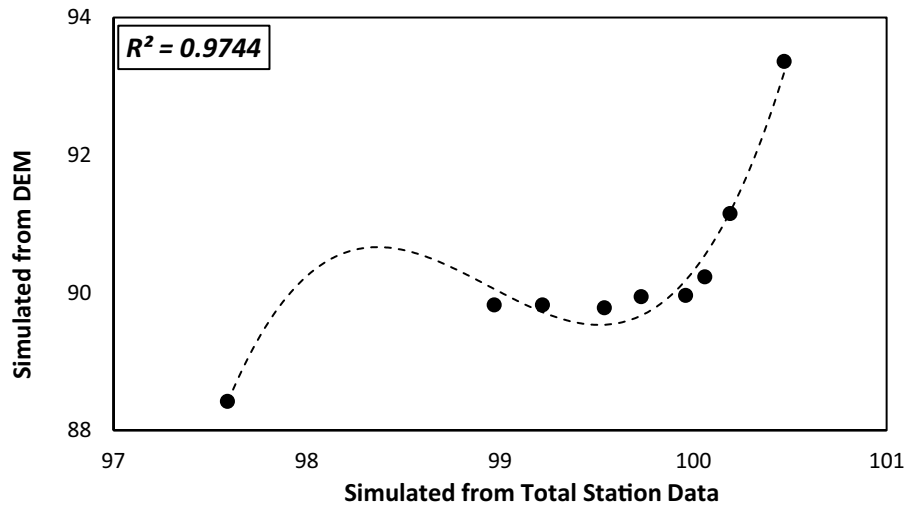


(b)

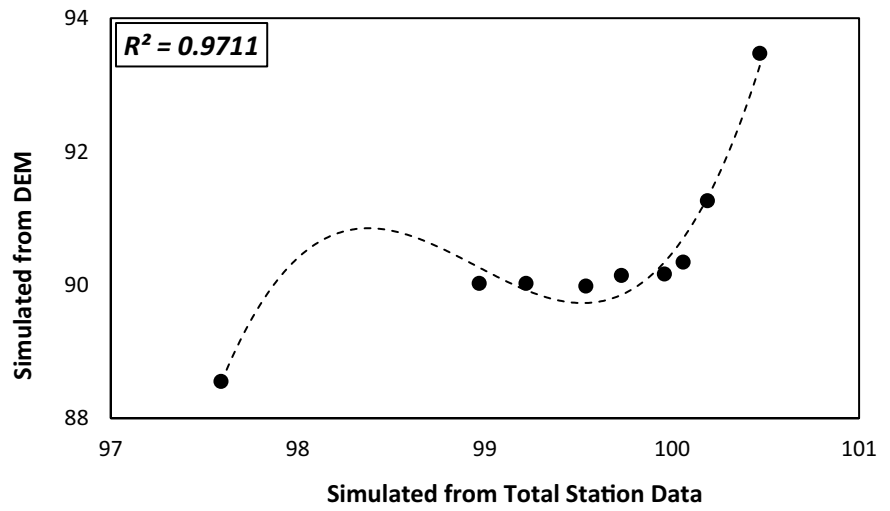


(c)

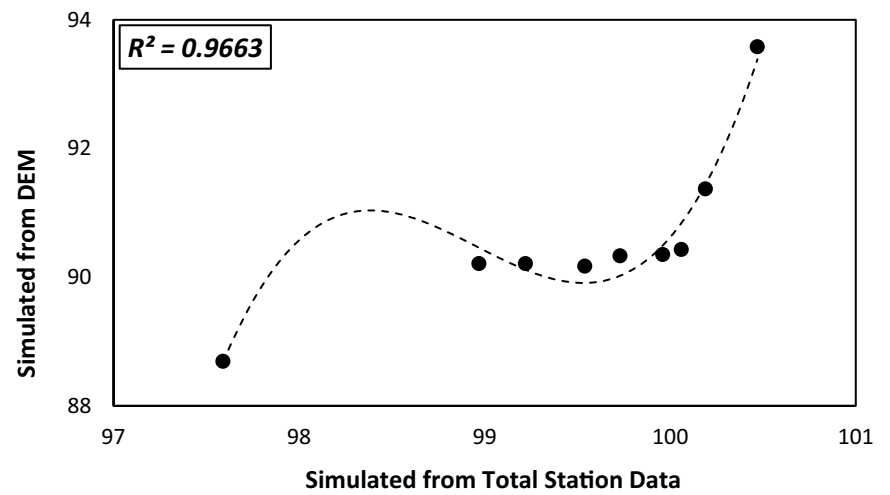
**Fig. 9** Comparison of WSE obtained by simulating DEM data and Total Station Data for **a** 25 years **b** 50 years **c** 100 years



(a)



(b)



(c)



**Fig. 10** Map of vulnerable locations in the study area

and mitigation efforts on real-time bases. However, based on this study, it is recommended that engineered structures such as steel sheet piles and sheet pile spurs need to be built on the right bank to reduce flooding and soil erosion. Construction of earthen embankments along both banks of the river stretch together with dredging the center section of the river channel may also serve as a significant mitigation measure against floods in the area.

**Acknowledgements** The authors thankfully acknowledge the Department of Science and Technology, Ministry of Science and Technology, Government of India for providing financial support. Infrastructural support to carry out the investigation was provided by the North Eastern Regional Institute of Science and Technology, Arunachal Pradesh, India.

**Author contribution** Conceptualization, G.G. and R.K.P; methodology, G.G. and R.K.P; software, G.G. and D. K; validation, G.G. and R.K.P; formal analysis, G.G.; investigation, G.G. and R.K.P; resources, G.G. and R.K.P; data curation, G.G.; writing—original draft preparation, G.G. and D. K.; writing—review and editing, R.K.P; visualization, G.G. and R.K.P; supervision, R.K.P; project administration, R.K.P.

**Funding** Funding for this research was received from the Department of Science and Technology, Ministry of Science and Technology, Government of India.

**Data availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

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