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Development of 1D hydrodynamic Analysis in Data Scarce Region by Comparing Two Digital Elevation Models

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Abstract: Fluvial floods are the most prevalent type of flood worldwide. To create a hydrodynamic model in the Hydrologic Engineering Centre-River Analysis System (HEC-RAS), among the different accessible software, open-source software HEC-RAS is the most popular and widely used worldwide. This review intends to investigate the many applications of HEC-RAS software for the building of a one-dimensional hydrodynamic model for study in the Shetrunji River, for which geometric data is the primary input into the software. The primary goal of this work is to investigate and compare the effectiveness of open-source DEM. Every river hydraulic model that models water level and discharge employs river cross sections as its major input. River cross-section measurements in the field are time-consuming and costly. The river cross-sections obtained by both DEMs were used to simulate the severity of a flood in the Saurashtra area of Gujarat's downstream Shetrunji river basin. The outcome of the simulation will be used to assess various hydrological parameters. Hydrological modeling is being conducted to demonstrate the feasibility of flooding, which will ultimately lead to the development of an action plan and the transmission of information to local authorities in the surrounding areas.

Keywords: Hydrodynamic Model, DEM, ALOS JAXA, Shetrunji river, Cross-section Delineation.

I. INTRODUCTION

A flood is a type of natural disaster where a vast area of normally dry land is covered in water. Fluvial floods are the most frequent type of flooding worldwide, out of several different varieties including coastal, pluvial, fluvial, groundwater, and sewer flooding. Fluvial floods happen when a river's water level rises above its banks, and they are typically brought on by heavy, prolonged rain. Losses of human and animal life, destruction of infrastructure, harm to properties and the environment, and a detrimental influence on socioeconomic growth are the main effects of floods. Bridge abutments, bank lines, sewage lines, and other structures inside the floodway may sustain structural damage as a result of flooding. Many engineering projects that can be classified into one of two groups are typically included in flood management techniques. A hard engineering project is one that involves building man-made barriers to stop rivers from flooding. The opposite is true as well: soft engineering initiatives make use of local knowledge of the river and natural resources to lessen the risk of flooding. Afforestation, river restoration, wetland restoration, and floodplain zoning are a few examples of soft engineering strategies for managing floods. Undoubtedly, one of the most useful tools for managing and mapping floods is hydrological modeling.

A successful model needs enough representational data and precise parameter descriptions. In order to effectively estimate the river flow size and water levels along the river reach, a river flood model also needs appropriate data on the river channel and floodplain geometries, coupled with an accurate description of the river flood model parameters. To extract spatial elements from topographical data sources that are helpful for hydraulic models, computer software tools are being updated and developed in both a GIS environment and a non-GIS context. To get topographical information for each river basin under consideration, however, requires a time-consuming and expensive survey campaign, as well as meticulous post-processing of the survey data Many field investigations have been conducted in an effort to address the lack of topographical data in river flood models. While others attempt to use data assimilation techniques to identify a synthetic cross-section that is hydraulically equivalent to the actual river geometry, the majority

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of topographical data depend heavily on the integration of GIS with digital elevation models (DEMs) obtained from earth observation satellites or other globally accessible data sets

This study uses two methods to extract river cross sections from two separate sources and prepares 1D geometry for the HEC-RAS model using each of the cross sections. The following primary duties were completed:

Using DEMs, a river cross section has been identified. In order to prepare 1D river geometry, the exported sections were loaded into the HEC-RAS model. The entire cross-section delineation process was carried out using computerized approaches. For the purpose of creating river geometry for 1D HEC-RAS modeling, the demarcated sections have been generated in the RAS Mapper tool of the HEC-RAS program. The hydrograph from 2015 was taken into consideration for the upstream boundary, while normal depth was taken into consideration for the downstream boundary.

II. STUDY AREA

One of the 71 river basins in Gujarat state, India's Saurashtra area, is the Shetrunji. It is located near the village of Nani Rajasthali, about 10 kilometers from Palitana taluka and district Bhavnagar. The Shetrunji, the second-largest river in the Saurashtra region, flows through Bhavnagar, Amreli, and Junagadh, which have total areas that are, respectively, 53.44%, 45.21%, and 1.35% of Saurashtra. The Chchai Hills in the Gir Forest of the Junagadh District are where the Shetrunji River's source is located. The river flows east from there. The longest length of the Shetrunji River is 227 kilometers, and its catchment area is 5,636 square kilometers. The Khodiyar and Shetrunji dams are located, respectively, 55 and 160 kilometers from the river's source, on opposing sides of the Shetrunji River.

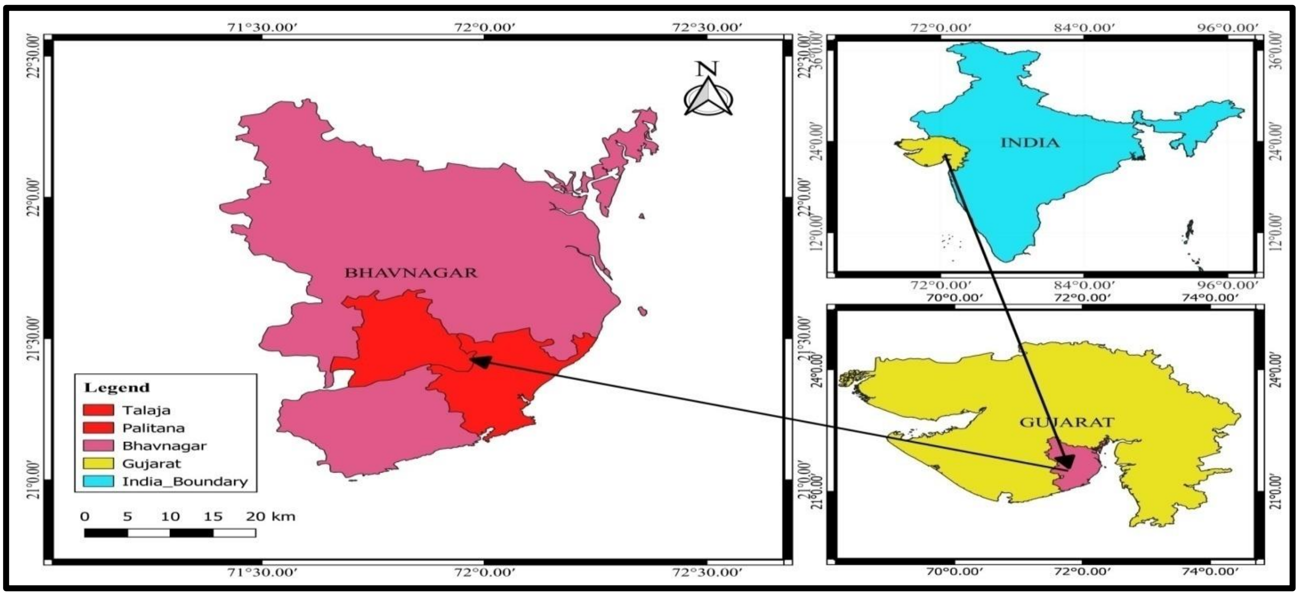

Fig. 1 Study Area Map

The current research area is situated in the Talaja and Palitana talukas of Gujarat's Bhavnagar district, which is downstream of the Shetrunji dam. The downstream river extends 33 km from the Shetrunji dam, of which a 21.57 m patch is taken into consideration for this study.

III. DATA COLLECTION

Geometric and hydrologic data constitute the majority of the fundamental data needed for the hydrologic model. The Bhavnagar Irrigation Department provides hydrological information such as historical flood statistics, river discharge, gauge readings, and water surface level for Shetrunji Bridge. Two different types of DEMs were obtained to create the geometry of the river in HEC-RAS.

TABLE 1: DATA COLLECTION

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Type of Data	Details	Source of Data	Application
Digital Elevation Models	30 m SRTM	USGS Earth Explorer(USGS 2011)	Terrain file creation
	12.5 m ALOS JAXA	JAXA website (JAXA 2008)	Terrain file creation
Stream Flow Data (1 hr frequency)	Shetrunji damsite (2015)	Bhavnagar Irrigation Department	Input parameter
Water surface Elevation Data	Shetrunji Bridge, Talaja.	Bhavnagar Irrigation Department	Manning's Coefficient Validation
Manning's roughness Coefficient	0.02 – 0.04	Chow's Table	Calibration

IV. OVERVIEW OF HEC-RAS SOFTWARE

The United States Army Corps of Engineers Hydrologic Engineering Centre's River Analysis System (HEC-RAS) is an open-source software tool that was created in 1995. 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." Water surface profiles are calculated using Saint-Venant equations in an HEC-RAS unsteady state simulation, which aids in locating the 1-D hydrodynamic model.

Continuity equation
$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \qquad (1)$$

Momentum equation
$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_0 - S_f) = 0 \qquad (2)$$

Q= discharge through the channel
A= area of cross-section of flow
y = depth of flow
S0 = channel bottom slope
Sf = Friction slope

V. METHODOLOGY

The geometry of the river is a crucial input for the simulation of an effective hydrodynamic model. It has been noted that practically all of the geometry for 1D modeling has been created using openly accessible DEMs. The process of creating the geometry using a surveyed cross-section takes time and labor. Additionally, modeling requires intense concentration; otherwise, there is a risk of producing inaccurate geometry. The length of the research region, 21.57 km, has had elevation data retrieved using RAS mapper 30 m and 12.5 m grid SRTM and ALOS JAXA DEM, as indicated in the methodology flow chart in Fig 2. Several RAS layers are formed, including cross-section cut lines, bank lines, flow route lines, and stream centerlines. Each layer has been given the appropriate properties and reach code. According to the table, cross-section cut lines are automatically determined by assigning a 200 m interval and 800 m width while taking into account the maximum width of the river reach.

TABLE 2: CROSS-SECTION DETAILS

DEM	Avg. Distance	No. of C/S	Series of Cross-sections
SRTM	**200 m**	**110**	**21200 to 200**
ALOS JAXA	200 m	107	21400 to 200

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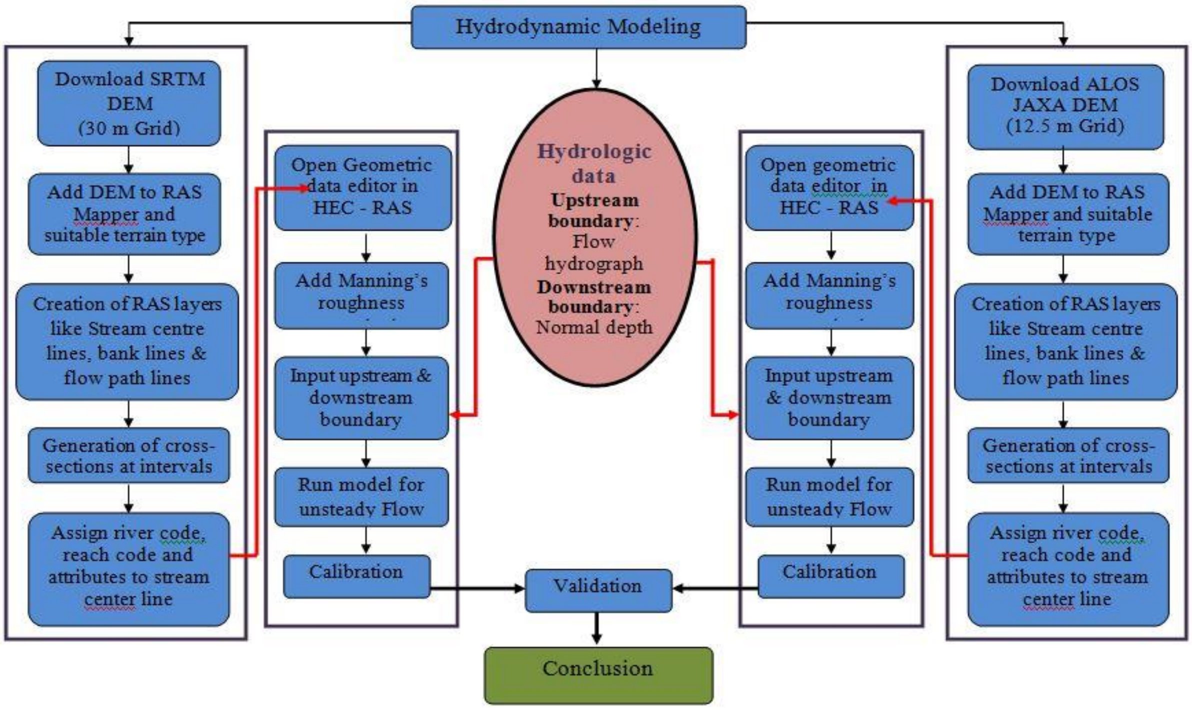

Fig. 2 Flow chart of a method implemented in the entire research

According to HEC-RAS, the upstream and downstream conditions are the flow hydrograph at Shetrunji Dam and the normal depth at Shetrunji Bridge in Talaja, respectively. For trial-and-error purposes, Manning's value between 0.020 and 0.040 is used to validate water surface height. In order to simulate the 1D HEC-RAS model for the entire channel, Manning's value of 0.030 comes quite close to the observed value of stages in Medha and Royal villages. The study reach, which is 21.57 kilometers long, slopes fairly gently. The influence of meandering has been ignored because no sharp curves have been seen; hence, the expansion and contraction coefficients have been set at 0.3 and 0.1, respectively. When a model is simulated in an unstable environment, the results are expressed in terms of the water surface elevation, discharge, velocity, flow area, and energy gradient slope. River stages have been taken into consideration among all simulated parameters and compared to observed values at the Medha and Royal villages sites for investigation since data was frequently accessible.

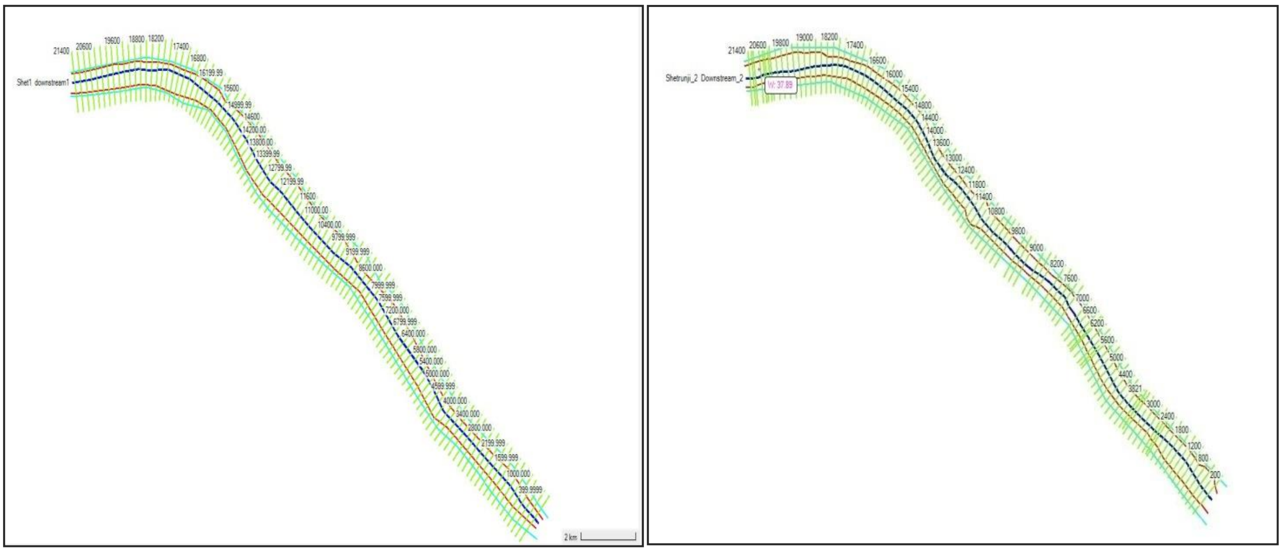

Fig.3 Geometry from SRTM DEM and ALOS JAXA DEM

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VI. RESULT & DISCUSSION

Using open-source HEC-RAS 6.3.1, floods from the year 2015 were simulated. For the upstream and downstream boundary conditions, respectively, the flow hydrograph of the corresponding year at Shetrunji Dam and the normal depth at Shetrunji Bridge at Talaja have been taken into consideration. By choosing the one-minute computational time step in HEC-RAS, the flow is simulated under unstable conditions. According to Chow's (1959) recommendations, Manning's n has been determined to be 0.030 for the entire Shetrunji River patch, which spans a total of 21.57 km, including both sides of the river. After simulation, HEC-RAS outputs different hydraulic properties such as water surface elevation, flow velocity, discharge, flow area, and energy gradient.

TABLE 4 CO-EFFICIENT OF DETERMINATION (R^2)

Village	Medha		Royal	
DEM	**SRTM**	**ALOS JAXA**	**SRTM**	**ALOS JAXA**
R^2	0.7676	0.7033	0.8380	0.7463

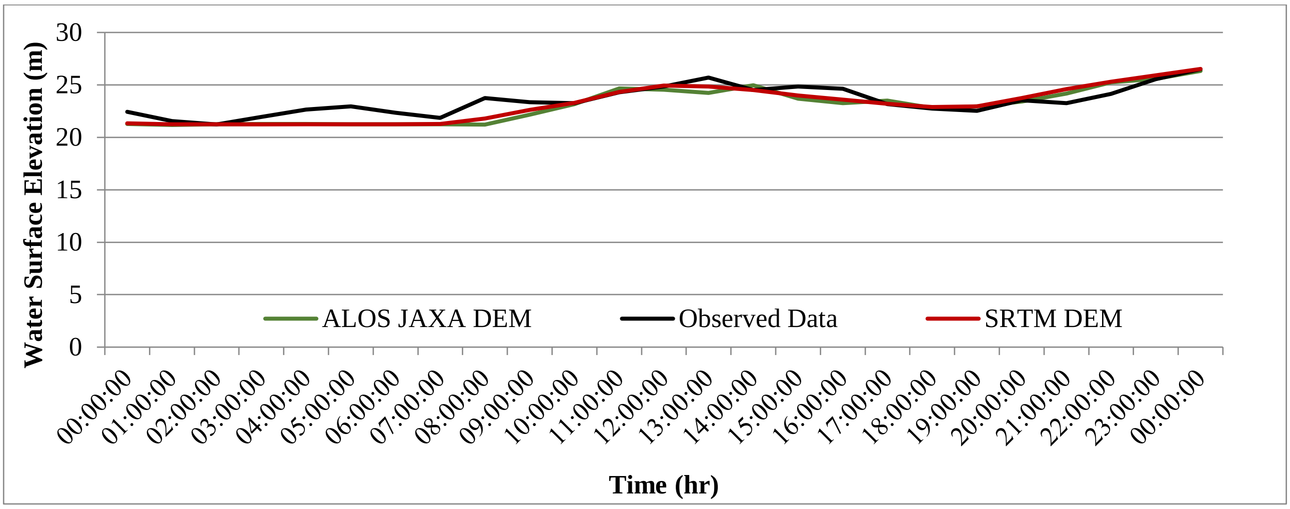
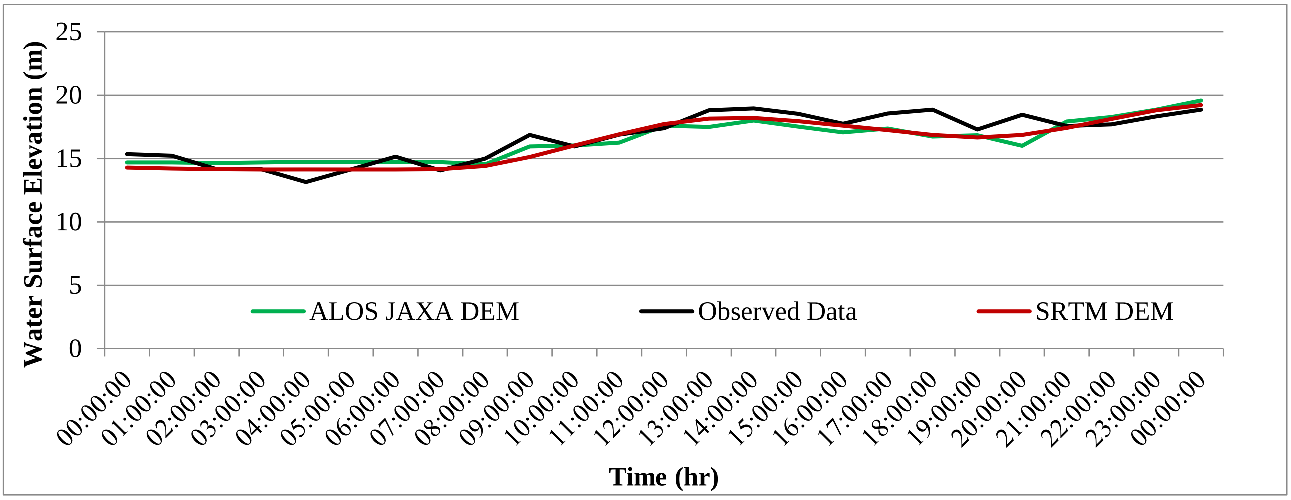


Fig. 4 Comparison of observed and simulated stages hydrographs at Medha village



From a validation standpoint, the year 2015 is considered the year when all other comparable polls were carried out. Here is a comparison of water surface elevation for flooding duration and a study of cross-sectional inundation. The exact manning value for fitting is shown in both DEMs. For this time span, the coefficient of determination (R^2) is studied. The matching values for SRTM and ALOS are presented in table 4. SRTM results improve the value of an observed dataset with a Manning value of 0.03 by calibration.

Fig. 5Comparison of observed and simulated stage hydrograph at Royal village

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A. Water surface elevation study

Water surface elevation studies were conducted in two locations (Medha and Royal villages). Both sites are 10.3 km and 17.6 km away from the inflow point, respectively. These locations were not chosen for Manning coefficient validation due to a lack of data availability, as recorded data is only available during particular hours. The data chart illustrates the elevation of the water surface for both DEMs and observed levels. The graphic depicts the water surface elevation (m) of Medha and Royal villages for both DEMs, as well as the distance between them from upstream to downstream. Local officials measured the data sets near the two villages indicated to check the model's capability. Data from water surface indicators was utilized to compare.

R^2 values for both DEMs show that the SRTM has better agreement than the ALOS. According to the model configuration, water is distributed effectively. Both tributaries responded to water distribution and observed and simulated flow elevation values were compared.

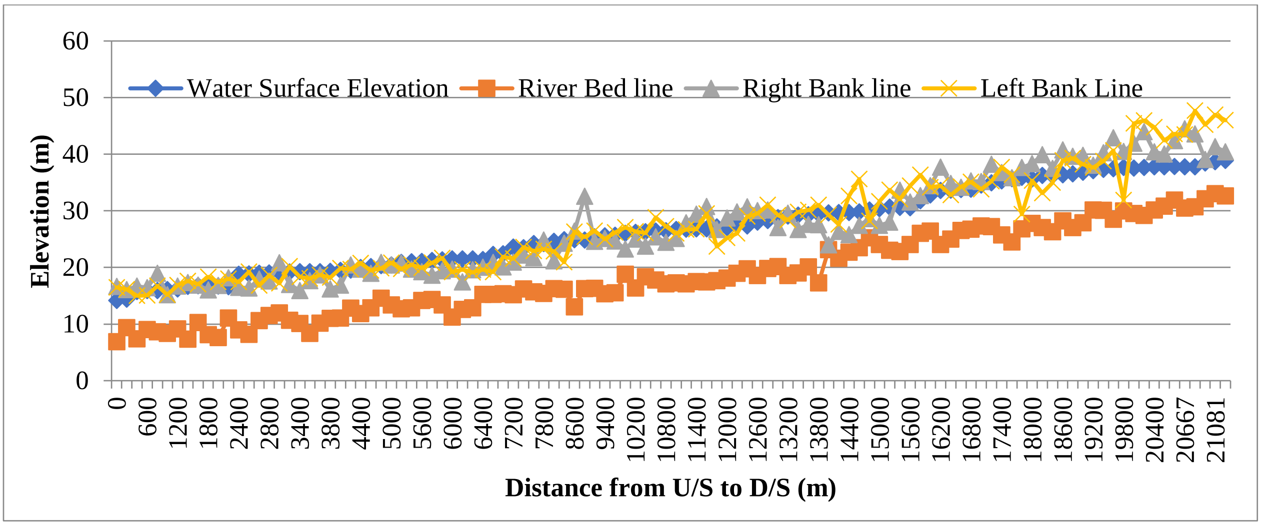

Fig. 6 Comparison of riverbed and bank profiles for SRTM DEM

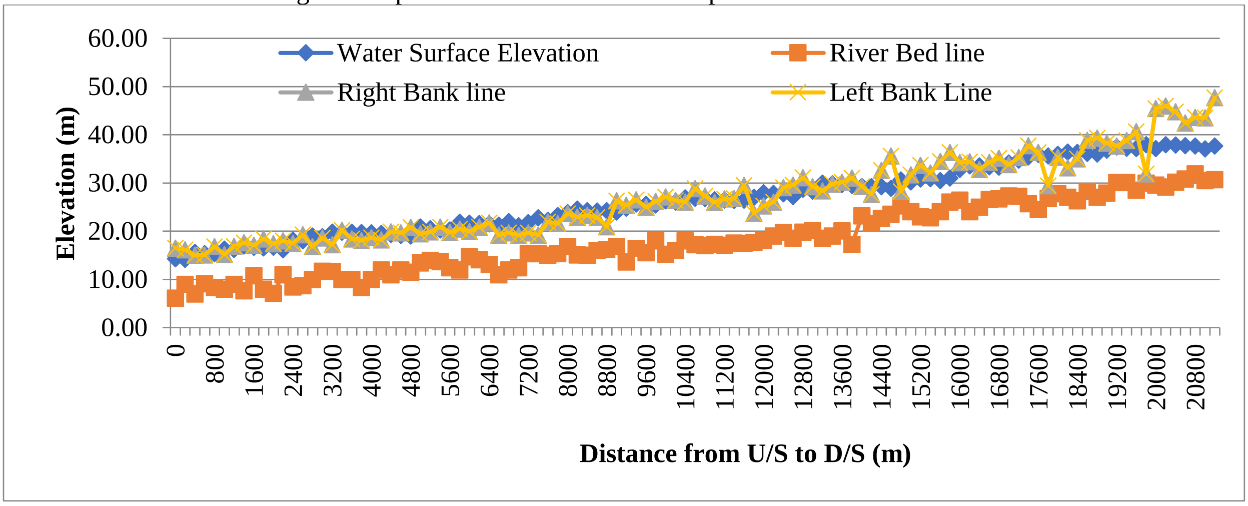

Fig. 7 Comparison of riverbed bank profiles for ALOS JAXA DEM

B. Cross-section inundation study

Simulated 1-D model results for both DEMs were compared to field observations and a questionnaire survey of residents of a nearby river valley. The 1D model output shows numerous inundated cross-sections along all three river lengths, which can be compared to the observed data. The difference in cross-section inundation for the same river and

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reach is seen in Table 5. It occurred as a result of discrepancies in cross-section placement and actual observations based on cross-section position, which differed for both DEMs.

A cross-sectional inundation study was carried out so that if the model indicated flooding for a certain cross-section, it was compared with field observation and a questionnaire survey. This criterion requires additional time to investigate the ground situation. Table 4 shows the coefficients of determination (R^2) for each of the two villages for both DEMs. A greater value of R2 suggests better model fitting; an average value of R^2 for Medha and Royal is 0.7676 and 0.8380, respectively, which corresponds to SRTM DEM. When compared to ALOS, SRTM takes the lead.

TABLE 5: INUNDATION OF CROSS-SECTIONS

DEM	**SRTM**		**ALOS JAXA**	
SIDE	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**
No. of c/s	51	46	67	62
% of c/s	46.36 %	42,89 %	60.90 %	57.94 %

C. Discussion

1D modeling is essential to research for DEM comparison that has been carried out using a limited data set. However, a decision-making mechanism has been created and is vulnerable. In terms of overbank discharge, locations are recognized. Discussions are taking place here about the future boundaries of comprehensive research in the Shetrunji River basin.

Copernicus GLO, TanDEM-X DEM, ASTER, SRTM, ALOS, IKONOS, LiDAR, and MOLA are among the many open-source DEMs available. The hydrodynamic analysis in this paper is solely compared between SRTM and ALOS. This study should be expanded to include 2D hydraulic modeling using these DEMs to make a more exact comparison. It benefits the global community of academics, researchers, and water resource managers.

DEM-generated cross-sections were utilized to evaluate the 1D modeling of the Shetrunji River basin. Numerous studies, however, show that the results from the surveyed cross-sections outperform those from the DEM. A lack of funds and human resources has an impact on flood modeling conclusions, which can be corrected by supporting physical surveys and satellite data using cutting-edge techniques.

The impact of a change in land use or land cover on the fluvial cross-section of the river was not taken into account when assessing flooding in the research region

VII. .CONCLUSION

The comparative research of hydrodynamic analysis using open-source data is successful in data-constrained regions.Areas that are likely to flood for matching upstream discharge for semi-arid zones are shown by results from comparing different river stages by both DEM corresponding bank levels. Decision-makers may utilize the results of the 1D unsteady hydrodynamic simulations to artistically predict a likely percentage of the area that will be submerged on the left and right banks of the river. A 1D hydrodynamic model that was validated close to the settlements of Medha and Royal displays both DEMs. The coefficient of determination (R^2) indicates that an SRTM combination is preferable to an ALOS combination. Geometry studies, observations on the ground, and model results show that the LOB is more vulnerable than the ROB in the case of bank discharge; although SRTM is still a reasonable option for determining the vertical components, ALOS DEM has superior compatibility in the horizontal direction. The water spills out of this site as a result and travels a large distance before reaching the residential and agricultural sectors.

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