SENSITIVITY FOR HYDROLOGIC SIMULATION FROM TOPOGRAPHIC DATA IN KULSI RIVER BASIN, INDIA

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ABSTRACT

Rainfall-Runoff-Inundation (RRI) hydrological model was used in this study to simulate discharge and inundation extent for the flood events in 2007 and 2008 for Kulsi River basin, India. The objectives of the study were a) to evaluate the sensitivity on hydrologic simulation using SRTM (Shuttle Radar Topography Mission), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and CARTO (CARTOSAT-1) DEM and b) to evaluate the impact of smoothing of DEM using low pass filter, enhanced lee filter and denoising filters on discharge and flood inundation extent. RRI model was found to be sensitive to - first Manning's n values of flood plain, second source of DEM and third soil depth among the input parameters. Combination of ASTER DEM with denoising algorithm performed better hydrologic simulations of discharge and inundation extent among all other input combinations for Kulsi River basin.

Keywords: DEM, SENSITIVITY, FILTERING, RRI

INTRODUCTION

IWRM is a process which promotes the coordinated development and management of water, land and related resources (Global Water Partnership, 1999). Centre for Flood Management Studies, National Institute of Hydrology, India has selected Kulsi River basin for undertaking Pilot Basin Study (PBS) as a component of Integrated Water Resource Management (IWRM). The Kulsi River basin, a part of the Brahmaputra sub-basin, is situated on the south bank of the mighty Brahmaputra River. The Kulsi River drains out a total area of 2806 sq. km. within the Kamrup District of Assam as well as west Khasi hills and Ri Bhoi district of Meghalaya. The selected basin is ideal to develop flood inundation maps due to its strategic location encompassing two states in the north-east coupled with the fact that the region experiences maximum floods.

Topography plays a major role in determining the accuracy of hydraulic modeling and flood inundation mapping (Brandt, 2005). Digital Elevation Model (DEM) is a raster dataset containing information about the topography of a region and is used as a prerequisite to hydraulic modeling. Different sources of Digital Elevation Model (DEM) characterizing the topography are available online. Considerable variation is observed among the different DEM spatial resolution, vertical precision and accuracy (Vaze et al., 2010). When used as an input to hydraulic modelling,

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the differences in the quality of each DEM subsequently result in differences in model output performance. One of the biggest problems faced while analysing digital elevation models (DEM) produced using photogrammetry, is to avoid pits and peaks in DEM. Smoothing filters preserves sharp features in the DEM, while removing noise.

This study assesses on the suitability different DEM on hydrodynamic simulations. DEM preprocessing plays an important role in the final simulations, and the impact of DEM smoothing on flood inundation mapping is considered in this study. Specifically, the objectives of the study are : 1) To generate flood inundation maps using RRI Model with different topographic data: SRTM, ASTER, and CARTO DEM of Kulsi River basin and 2) To evaluate the impact of smoothing using low pass filter, enhanced lee filter, and denoising algorithms on flood inundation maps of Kulsi River basin.

DATA AND METHODOLOGY

Daily rainfall data of twenty years from 1991 to 2011 were collected from India Meteorological Department for five rain gauges in and around Kulsi River Basin. Daily discharge data is recorded at Kulsi Bazzar location which is at the outlet of the Kulsi River Basin. The daily discharge data from 1991 to 2011 was collected from Brahmaputra Board, Guwahati.

SRTM DEM of 90 m x 90 m spatial resolution was downloaded from URL (http://hydrosheds.cr.usgs.gov)

ASTER DEM of 30 m x 30 m spatial resolution was downloaded from URL (http://www.jspacesystems.or.jp/ersdac/GDEM/E/index.html).

CARTO DEM is a National DEM developed by the Indian Space Research Organization (ISRO). The DEM of 30 m x 30 m was downloaded from (www.nrsc.gov.in). The soil data for the study has been obtained from the Harmonized World Soil Database v 1.2 of the FAO soil portal.

Moderate Imaging Spectroradiometer Images (MODIS) for the study area were downloaded from (http://modis-land.gsfc.nasa.gov/MODLAND_grid.html).

Elevation values were measured at fifty locations along the Kulsi River using Differential Global Positioning System (DGPS). The measurements were part of water quality experiment conducted by NIH in 2012. The flowchart of methodology adopted in this study is shown in figure 1.

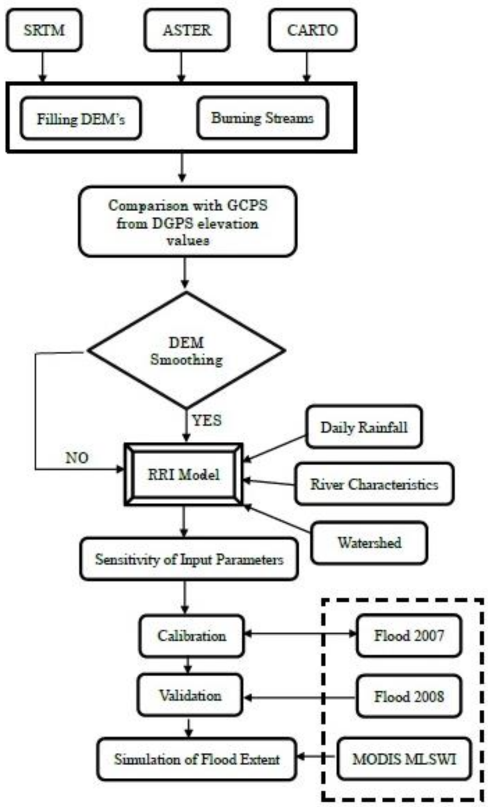

Figure 1: Flowchart of methodology

The topographic data consisting of SRTM, ASTER and CARTO DEM were processed using ArcGIS Software. The accuracy of DEM was compared with elevation values of Ground Control Points (GCPs) obtained from DGPS. DEM smoothing was carried out using low pass filter, enhanced lee filter (window size = 3), enhanced lee filter (window size =5) and denoising algorithm. Flow direction and flow accumulation were computed from the processed DEM. Elevation, flow direction and flow accumulation grids were exported into ASCII format to be used as input in RRI model.

Rainfall – Runoff data corresponding to the flood event observed in the study area for the year 2007 were selected for calibrating the RRI model. RRI model was set up to simulate the flow of Kulsi River at Kulsi Bazzar. Scenarios of sensitivity check were performed with RRI input parameters in order to study their influence on hydrologic simulations. Validation of RRI model was performed by executing the RRI model with the calibrated parameters for the year 2008.

The RRI model performance was quantified using three indices i.e. coefficient of correlation (r2), Nash Sutcliffe Model Efficiency (NSE) and Root Mean Square Error (RMSE).

Remote sensing images from MODIS were used to determine the flood inundation extent in Kulsi River Basin. Modified Land Surface Water Index (MLSWI) was used to identify the flooded areas. MLSWI was calculated using equation 1 as:

$$\text{MLSWI} = \frac{1-R_{NIR}-R_{SWIR}}{1-R_{NIR}+R_{SWIR}} \qquad (1)$$

Where, NIR: near infrared reflectance; SWIR: short wave infrared reflectance. R_{NIR} and R_{SWIR} are reflectance values (R) of MODIS bands 2 and 6 or 7, respectively. An optimal threshold of MLSWI was selected as 0.64 to separate water bodies from other land-cover features based on the spectral characteristics (Kwak et al, 2014). The flood extent determined from MLSWI were used to access the accuracy of RRI model simulations based on different DEM, with and without smoothing.

RESULTS AND DISCUSSIONS

Fig 2 shows the differences in elevation values observed for the flood plains from different DEM sources when compared with DGPS elevations. Based on the computed error analysis (Table 1) it was found that SRTM DEM produces the least RMSE and MAE of the flood plains i.e. 1.88 m and 1.73 m

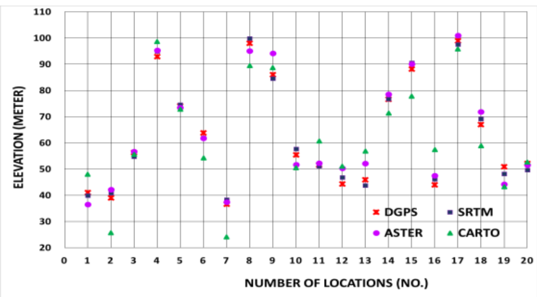

Figure 2: Comparison of elevation of DGPS points with elevation of SRTM, ASTER and CARTO DEM for flood plain

Table 1: Comparison of SRTM, ASTER and CARTO DEM with elevation of DGPS

Source of DEM	Flood Plain		Forest and Hills	
	RMSE (m)	MAE (m)	RMSE (m)	MAE (m)
SRTM	1.88	1.73	9.53	8.82
ASTER	3.85	3.15	6.95	5.94
CARTO	8.08	7.08	8.81	10.46

respectively, however for the remaining study area the best results of RMSE and MAE were obtained from ASTER DEM i.e. 6.95 m and 5.94 m respectively.

Manning's n values were varied between the highest and lowest values prescribed by RRI manual in order to observe the impact on discharge and inundation area simulated by RRI model. Figure 3 shows the variation in simulated discharge from RRI model by varying n from 0.15 to 1.0 for ASTER DEM.

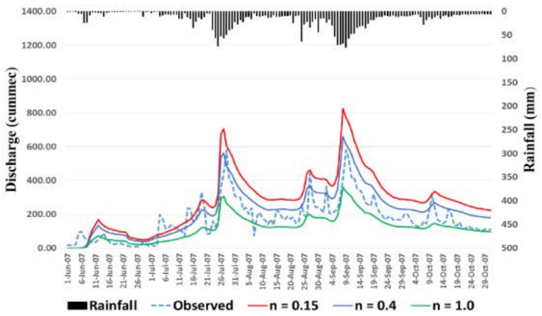

Figure 3: Sensitivity of Manning's n values on discharge at outlet for ASTER DEM

Table 2: Performance of RRI model for different n values using ASTER DEM

	n = 0.15	**n = 0.4**	**n = 1.0**
NSE	-0.3536	0.5464	0.5313
r^2	0.8936	0.8939	0.8938
RMSE (m^3/sec)	135.5275	78.4546	79.7525
Inundation Area (km^2)	859.5120	547.3170	209.2680

From the figure it can be observed that decreasing n values result in increase in discharge values. Flood peaks show higher rate of change due to changes in manning's n values compared to intermediate discharge values. Generally it was observed that a five percent decrease in values resulted in increasing the flood peaks by 2.05 %. Table 2 shows the performance indices of simulated discharge and inundation area for different n values.

After fixing the manning's n values, soil depth parameter in RRI model was varied based on the specification from RRI manual (figure 4). The soil type selected was clay as it yielded the best performance among all the other soil types. Changing the values of soil depth by 5 % results in variation of discharge peaks by 1.7 % for ASTER DEM.

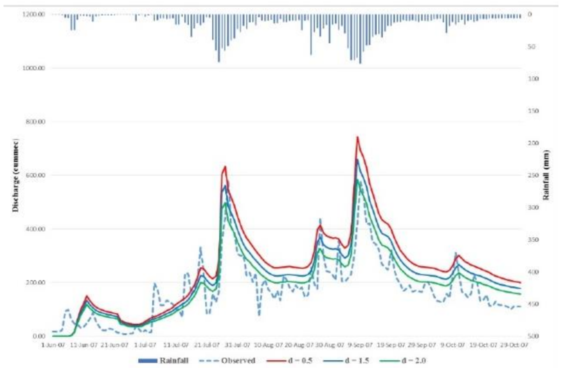

Figure 4: Sensitivity of soil depth values on discharge at outlet for ASTER DEM

Table 3: Performance of RRI model for different soil depth values using ASTER DEM

	d = 0.5 m	**d = 1.5 m**	**d = 2.0 m**
NSE	0.1778	0.5464	0.3753
r^2	0.8937	0.8939	0.7939
RMSE (m^3/sec)	105.6225	78.4546	89.6779
Inundation Area (km^2)	696.6678	547.317	506.1732

Table 3 shows the performance indices of simulated discharge and inundation area for different soil depth values for ASTER DEM. The values of NSE were observed to vary from 0.1778 (d = 0.5 m) to 0.5464 m (d = 1.5 m). Simulated flood inundated area by RRI model was found to vary from 7.2 % to 27.8 %.

After calibrating RRI model with manning's n values and soil depth parameter, the effect of different smoothing filters of DEM on hydrologic simulations were observed. Four types of filters i.e. low pass filter, enhanced lee filter (window size = 3), enhanced lee filter (window size = 5) and denoising algorithms were applied to SRTM, ASTER and CARTO DEM respectively.

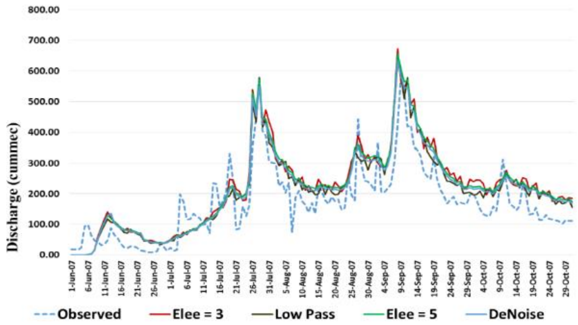

Figure 5: Sensitivity of smoothing of ASTER DEM on discharge at outlet

Table 4: Performance of RRI model for smoothing of ASTER DEM

	Low Pass Filter	**Lee Filter (window size = 3)**
NSE	0.5615	0.6290
r^2	0.8886	0.8921
RMSE (m^3/sec)	77.1397	70.4515
	Lee Filter (window size = 5)	**Denoising Algorithm**
NSE	0.5448	0.6342
r^2	0.8916	0.9023
RMSE (m^3/sec)	78.5875	67.3880

Figure 5 shows the variation in simulated discharge from RRI model by using different smoothing filters for ASTER DEM. Low pass filter generally resulted in simulation of lower discharge values. Enhanced lee filter with window size 3 produced the highest peak and variation of simulated discharge. Denoising algorithm resulted in simulation of lowest discharge values closer to the observed hydrograph. Table 4 shows the performance indices of simulated discharge for different smoothing filters for ASTER DEM. NSE values were observed to increase by 16% and RMSE values decreased by 14 % on comparison of performance of ASTER DEM with and without smoothing filters.

Inundation area for 28-07-2007 was computed using RRI model for DEM with and without smoothing and results compared with MLSWI derived from MODIS Imagery. Table 5 shows the comparison of inundation area simulated by RRI model. Inundation area derived from MODIS imagery for the period was calculated to be 746.83 km^2.

Table 5 :Comparison of simulated flood extent with MODIS imagery for 2007 flood

Source of DEM	**Inundation Area (km^2)**				
	Without Smoothing	**Low Pass Filter**	**Lee Filter (size = 3)**	**Lee Filter (size = 5)**	**Denoising Algorithm**
SRTM	418.57	429.36	429.57	436.15	485.55
ASTER	547.31	556.04	574.77	596.45	615.86
CARTO	453.68	455.57	463.43	484.41	509.51

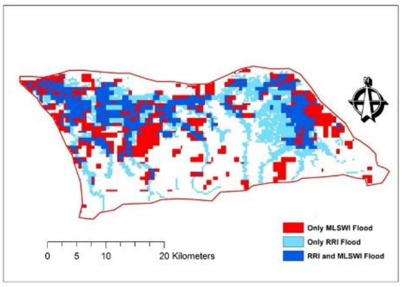

Figure 6 : Comparison of the RRI model (ASTER DEM + Denoising algorithm) with MODIS derived MLSWI

Comparison of inundation area shows that RRI model using ASTER DEM were closer to those derived from MODIS imagery. Inundation area simulated using RRI model with SRTM DEM showed the least extent among DEM. CSI between RRI model and MODIS imagery produced a value of 0.47, 0.57 and 0.51 respectively for SRTM, ASTER and CARTO DEM respectively. It is observed that RRI model generally underestimated the simulated flood extent compared to MODIS imagery. The combination of denoising algorithm with ASTER DEM produced inundation area of 615.86 km^2, which was closest to flood extent derived from MODIS imagery (Figure 6)

RECOMMENDATIONS

The future scope of this study is to evaluate the relative accuracy of DEM using high resolution topographic maps. One such data is available from Advanced Land Observing Satellite (ALOS) of 5 m by 5 m spatial resolution obtaining from Japan Aerospace Exploration Agency (JAXA). Improving the best fitting parameters of smoothing filters for different resolution of on hydrologic simulation will be useful in determining the best fitting parameters required to adequately characterize the catchment behavior. Since spatial resolution of remote sensing data is one of the important factors in detecting flood waters, comparison of inundated flood areas with indices derived from LANDSAT imagery (30 m x 30 m spatial resolution) will increase the reliability of RRI model simulations.

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