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FLOOD INUNDATION MAPPING OF SHINGLA RIVER BASIN IN ASSAM USING A DISTRIBUTED HYDROLOGICAL MODEL

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ABSTRACT

Shingla river, a tributary of Barak river in Assam is severely affected by floods during the rainy season. Topographically, the Shingla basin is a long North-South oriented river valley that is constricted at the outlet on the northern end. Heavy rainfall in the upper catchment of the Shingla river periodically leads to serious flood situation in the basin, rendering thousands of people homeless and vast tracts of agricultural land submerged. This work aims to assess and predict rainfall run off in Shingla catchment using a distributed hydrological model V*flo*™. The simulations yield storm hydrographs and inundation maps, which are important indicators of flooding, for specific rainfall events. Climate variability scenarios can be used as inputs in the flood simulations to predict flood events more accurately. The procedures outlined in this paper have important implications for flood damage mitigation by providing an early warning system.

KEY WORDS
Hydrograph
Vflo
Flood Mapping
Shingla River Basin
Son Beel
Wetland

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INTRODUCTION

Flooding in a region is influenced by several factors and depending upon the topology of stream network, land-use conditions in the drainage basin and climate, the quantum and the outcome of the flood will vary. Several factors need to be considered in accurate flood hazard mapping under conditions of data and other material scarcities that typify the situation (Joy and Lu, 2006). The distributed hydrological model V*flo*™ (Vieux and Associates, Inc., 2004) was used in this study to simulate flooding in Shingla river basin. When analyzing runoff in hydrology, grid-based distributed rainfall-runoff model (Vflo™) is increasingly used because it enables more detailed examinations of spatial flux changes in the basin as compared to existing lumped hydrologic models (Noh *et al.,* 2012). Physical-based distributed model was first introduced by Freeze and Harlan (1969). Vieux, *et al.* (2004) evaluated the Vflo model for flash floods simulations.

In this study, ecologically significant Son Beel wetland (a potential Ramsar site), lying within the Shingla catchment finds special mention with regard to its dependence on river input from upstream regions, which is very important to sustain the wetland. To sustain the wetland against the threat of anthropogenic as well as climatic changes, the water availability to the wetland must be analyzed. The availability of water and its variability in the form of floods and droughts can be characterized by rainfall-runoff modelling. Storm hydrograph simulations are performed in the Shingla river basin to assess the flood potential of the basin. Landuse, soil and topography of the basin is taken into account and the response of the Shingla River is analysed based on hypothetical rainfall events.

Study area

The area of study (Fig. 1) is Shingla river basin including the Sonbil wetland located in the district of Karimganj, Assam. River Shingla originates from Mizoram and drops in Son Beel Haor (wetland). The river forms two separate streams, namely the Kachua and the Kakra, both of which are considered as the prime source of water in the region. Further downstream, there is another large lake known as Rata Beel, beyond which the river Shingla bifurcates into Kochua and Kakra. River Kakra joins river Longa which finally enters Bangladesh and meets river Surma and falls into Bay of Bengal. Kochua on the other hand moves in the north-east direction and joins river Barak which enters Bangladesh and falls into Bay of Bengal. The area undertaken for study is bounded within 24°47′54″ N, 92°27′04″ E and 24°09′40″ N, 92°24′5″ E and covers a catchment area of about 790 sq. km.

Data and tools

Data for the Shingla basin was downloaded from different websites. Soil map for the North East India was obtained from the European Digital Archive of Soil map (EuDASM) (Panagos *et al.,* 2011), at a scale of 1:500,000. SRTM (Shuttle Radar Topography Mission) Digital Elevation Model (Farr *et al.,* 2000) was downloaded from SRTM website (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1). SRTM DEM was used for the delineation of watershed, channel network, flow direction map, slope map.

High resolution satellite imagery in Google Earth was used to create land use/ land cover map along with the Landsat ETM+ satellite imagery (available on landsat.org).

SAGA (System for Automated Geoscientific Analysis) GIS has been used primarily for processing of the SRTM DEM, derivation of flow direction, channel network, catchment area, slope etc., as well as rasterisation of the land use shape files created in Google Earth. Google Earth was used for mapping present landuse scenario. Vflo (Vieux and Vieux, 2006), a distributed, finite element, physically based hydrological model, was used to simulate the rainfall runoff in Shingla catchment. Vflo's output is in the form of hydrographs at selected points, as well as inundation maps covering the watershed. Vflo input parameter maps were prepared in SAGA GIS and then imported into Vflo to setup the model.

MATERIALS AND METHODS

The distributed rainfall runoff model, Vflo, for the Shingla basin was parameterized using data from GIS thematic layers of soil, landuse and topography. Synthetic rainfall was used in the simulation. The SRTM DEM was initially processed to obtain a sink free DEM using the sink filling algorithm of Planchon & Darboux (2001) in SAGA GIS. The sink free DEM was then used to estimate flow directions at each grid cell of the DEM. The flow direction map provides the principal slope direction and defines the layout of finite elements forming the drainage network. The connectivity of these elements is used to assemble the finite elements. Using the flow direction map, the upstream area at the outlet of the Shingla basin was derived. The stream network was derived using upstream catchment area and slope as threshold.

The Vflo model simulates the runoff produced at each grid cell as a difference of the total water received over a time step minus the water lost due to infiltration. For the present study, evapotranspiration was neglected as the simulation period was relatively small (2 days). The total water received is a sum of the total rainfall over the grid cell plus the run-on from adjacent upstream cells.

Infiltration rate is the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches/hr or mms/hour. The rate decreases as the soil becomes saturated. If precipitation rate exceeds infiltration rate, runoff will usually occur unless there is some physical barrier. Hydraulic conductivity (K) is the ease with which water can move through pore spaces or fractures in soils/rocks. It depends on the intrinsic permeability of the material, the degree of saturation and on the density and viscosity of the fluid.

The infiltration was modeled using the Green-Ampt infiltration equation. The Green-Ampt method of infiltration estimation accounts for many variables like soil suction head, porosity, hydraulic conductivity and time. Green-Ampt equation is written as:

$$\int(t) = K_e[1 + \frac{\Psi_f \, \Delta\theta}{F(l)} \qquad (1)$$

Ø is wetting front soil suction head

Ψ is water content

K_e is Hydraulic conductivity

F is the total volume already infiltrated

The above infiltration properties are difficult to measure in the field, especially for a large basin. So, we use standard values (Table 1) of infiltration parameters for different soil types in the study area. This approach is fast and time & cost effective.

The surplus water in each grid cell is routed through the finite element network using the kinematic wave approximation Equation (2):

$$\frac{\partial h}{\partial t} + \frac{S_o^{1/2}}{n}\frac{\partial h^{5/3}}{\partial \chi} = R - I \qquad (2)$$

R = rainfall rate

I = infiltration rate

h = flow depth

S_o = bed slope or principal land surface slope

n = manning's hydraulic roughness coefficient

x = horizontal distance

t = time

The kinematic wave approximation uses the manning's hydraulic roughness coefficient, together with slope steepness and flow depth, to estimate the velocity of overland flow in each grid cell. Hydraulic roughness is the measure of the amount of frictional resistance water experiences when passing over land and channel features. One roughness coefficient is *Manning's n-value*. An increase in this n value will cause a decrease in the velocity of water flowing across a surface.

The parameters of the equation are obtained from the GIS themes of topography and landuse. Uniform rainfall is applied over the study area for a defined time interval. Infiltration is estimated using the Green-Ampt equation. Flow depth is a spatio-temporally dynamic parameter and is estimated from 'on the fly' in each grid cell. Channel bed slope/overland surface slope is estimated from the SRTM DEM. Manning's roughness coefficient is estimated based on the standard manning's roughness values for different landuse classes (Table. 2) in the study area.

The Vflo model can estimate the hourly discharge through each grid cell in the model domain. However, discharge estimation was run for the channel cells only to decrease computation time. Discharge time series can be obtained for each channel cell. Plotting the discharge against time gives the hydrograph for a specific rainfall event. Flood Inundation maps are also generated based on the flow accumulation in each grid cell during and after the rainfall event.

RESULTS AND DISCUSSION

The primary hydraulic interest in soil maps is the modeling of infiltration as a function of soil properties. Since infiltration is mainly controlled by soil properties, soil map (Fig. 2) is digitized to estimate the spatial variability of infiltration properties in the basin. The Green-Ampt model of infiltration estimation accounts for many variables like soil suction head, porosity,

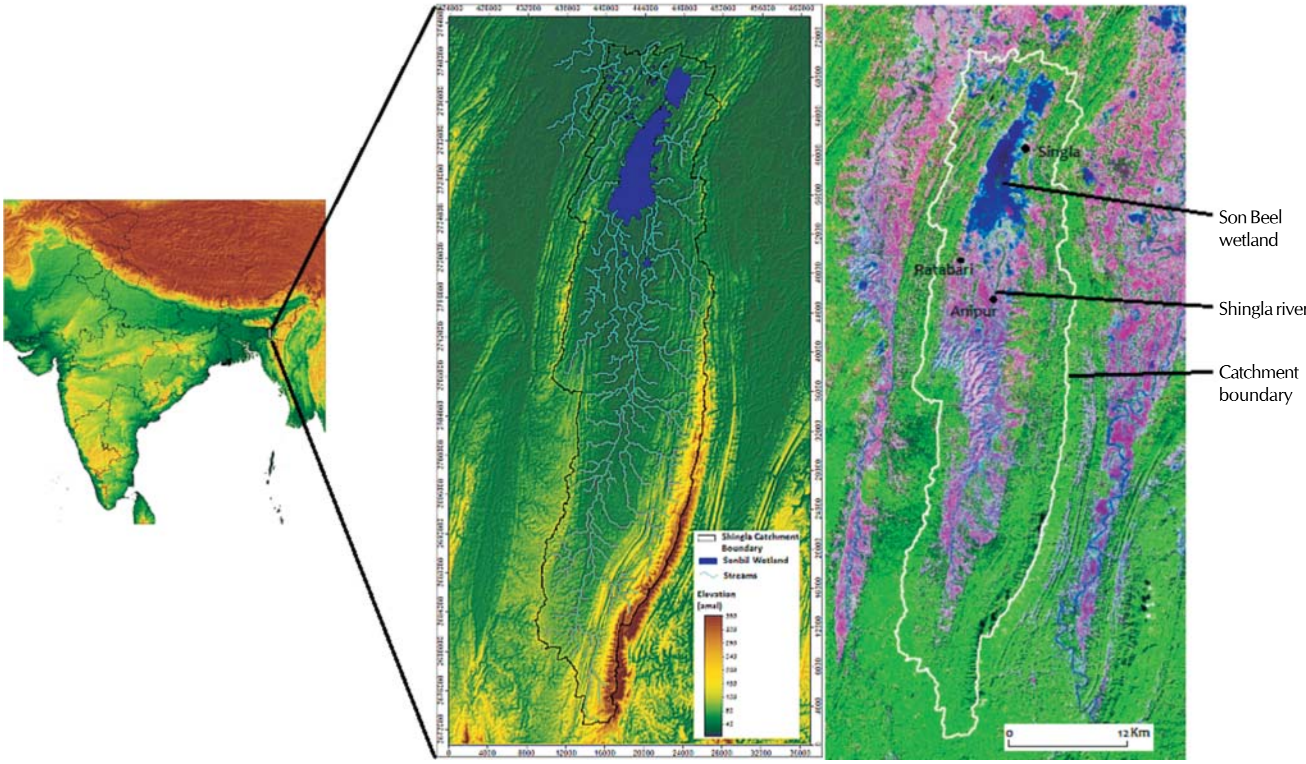

Figure 1: Location of the Shingla Basin. SRTM DEM (Digital Elevation Model) of the Shingla basin with main streams and Sonbil wetland overlaid (left) and Landsat ETM+ False Colour Composite of Shingla basin

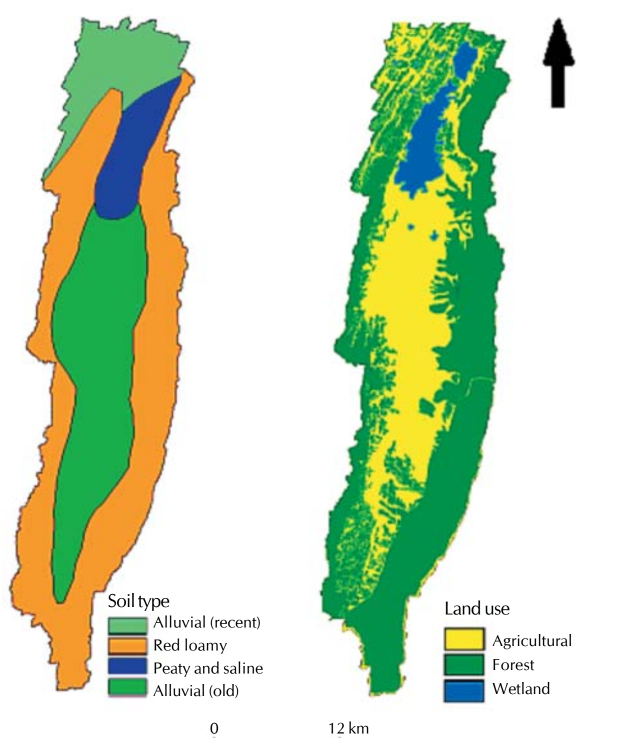

Figure 2: Soil Type and Land Use maps of the Shingla River Basin

hydraulic conductivity, all of which are estimated from the soil propertie. The soil map is reclassified into numerical values of the above three parameters using the table (Table. 1). Thus, we get three maps for each of these parameters, which are then fed to the model. The characteristic data structure associated with the original soil map carries forward into the hydraulic parameters used to simulate infiltration.

In the Shingla basin, younger alluvial soils are found in the downstream regions and are characterized by recent alluvial deposits. The color is generally gray to molted gray. Older alluvial soils are very deep with fine loams to coarse loams in texture. These are confined to the narrow zone along the piedmont zone (foothill zone).

Red loamy soils are confined to the hilly regions having greater forest cover and are characterized by higher infiltration rates. Peaty and saline soils are found in the vicinity of the Son Beel wetland. Peat forms in wetland conditions, where flooding obstructs flow of oxygen from the atmosphere, slowing rates of decomposition. Peaty soils have relatively poor infiltration rates.

Land use is an important parameter to quantify hydraulic roughness of a terrain surface. Land use is used here as a proxy for hydraulic roughness. The hydraulic roughness is a parameter that controls the rate of runoff over the land surface and therefore affects the peak discharge and timing of hydrograph in response to rainfall input. The landuse map was rasterised and recoded to give standard values of hydraulic roughness to each landuse class based on standard values (Table 2) derived empirically from a large number of observations by different workers. The landuse classes (Fig. 2) mapped are Wetlands, Agricultural land and Forests, each

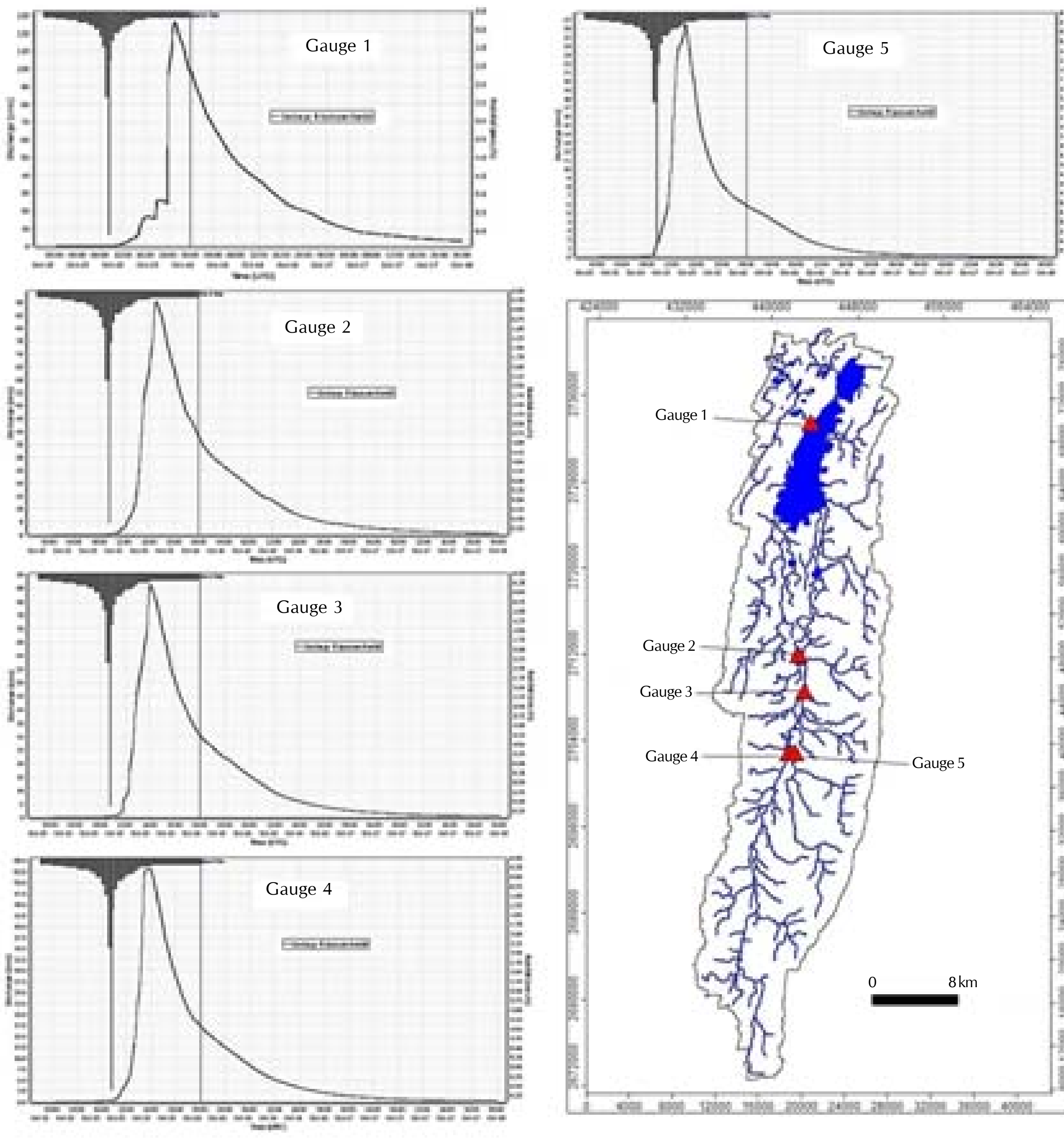

Figure 3: Location of gauging sites used for the simulation (right); stream hydrographs at selected gauging sites (left & top)

having different manning's roughness value or n-value.

Stream hydrograph simulation

Stream discharge was simulated at five gauging sites (Fig. 3) on river Shingla and its tributaries. Discharge is simulated for a uniformly distributed, temporally varying, cumulative rainfall of 10 cms over a period of 48 hours.

The simulation has duly accounted for all the controlling variables, as described in the methodology. In short, the discharge at a point is a function of the total upstream area drained by that point, the slope at that point, the landuse and the soil type.

Landuse controls the hydraulic roughness of the surface, which is given by Manning's number. Standard tables are available for Manning's roughness for different landuse types and these values were selected for corresponding landuse types in this study area. Soil type controls the amount and rate of infiltration at a point. Infiltration is modeled using the Green Ampt Model and it uses several variables like the saturated

Table 1: Limits for Green and Ampt infiltration parameters (from Chow *et al.,* 1988)

Soil Class	*water content (θ)*	*wetting front soil suction head ψ (cm)*	*Hydraulic conductivity K_e (cm/hr)*
Alluvial	0.412	11.01	1.09
Red Loamy	0.434	8.89	0.34
Peaty and Saline	0.423	29.22	0.05

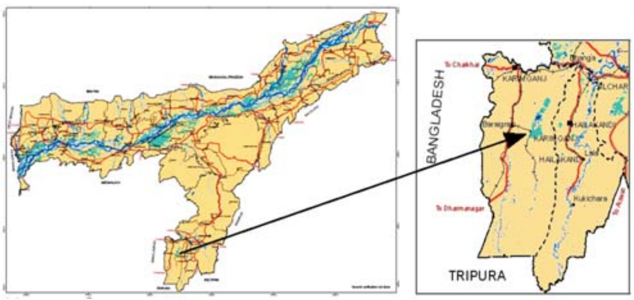

Figure 4: (Left) Flood inundation map of Assam based on the analysis of Radarsat-1 SAR data of 29-08-2012; (right) enlarged view of Barak valley showing the inundated parts of Sonbil and the adjoining areas

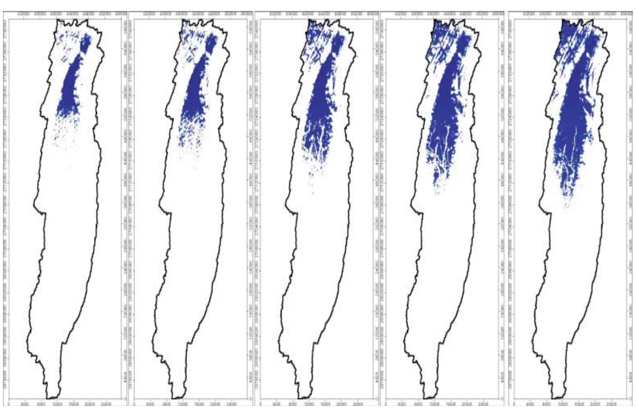

Figure 5: Simulated flood inundation map after a uniform total rainfall of 2, 4, 6, 8, and 10 cms (from left to right) for a period of twenty four hours

Table 2: Manning's roughness values for Landuse types in the basin (from Vieux 2005)

Land-Use	Manning's n value
Agricultural Land	.035
Forest	.100

hydraulic conductivity of the soil type, the suction head along the wetting front, the effective porosity, soil depth, etc.

The numerical values for these parameters are obtained from these standard tables and spatially distributed maps of the Green-Ampt parameters are prepared from which the cumulative infiltration for each grid cell is derived by the Vflo software. The slope is derived from the SRTM DEM. The total upstream area at each grid cell is calculated using the flow direction grid. All these parameters are integrated and flow is routed using the kinematic wave approximation to simulate the water volume over each grid cell at specified time steps, finally yielding a time series of discharge values at selected sites along the river and its tributaries.

The stream hydrograph (Fig. 3) at each site roughly corresponds, in volume, with the total basin area drained by that site, as expected. Gauge 1, however, shows two smaller peaks prior to the arrival of the actual flood peak. This is usually caused by the arrival of flood wave from the different sub-basins of the river at some time gap.

Flood Inundation maps

Flood inundation maps were simulated for different rainfall intensities. The model was run five times, each run specified by a different rainfall intensity, i.e. 2, 4, 6, 8, and 10 cms within 24 hours. Five inundation maps were generated corresponding to the five rainfall intensity inputs. Each inundation map shows progressively larger flooded area. The flooding, however, is focused around the Son Beel wetland, in the downstream part of the basin. The flood inundation from simulations was compared with the flood maps derived from the Radarsat SAR data available from NRSC. There is a good agreement between inundation extents derived from the two sources, confirming to the effectiveness of predicting flood inundation using Vflo model. Further work is required to integrate the outputs of Vflo to groundwater modeling tools to predict wetland extents during the dry season.

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