

## Experimental flood early warning system in parts of Beas Basin using integration of weather forecasting, hydrological and hydrodynamic models

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### ABSTRACT:

The flood early warning for any country is very important due to possible saving of human life, minimizing economic losses and devising mitigation strategies. The present work highlights the experimental flood early warning study in parts of Beas Basin, India for the monsoon season of 2015. The entire flood early warning was done in three parts. In first part, rainfall forecast for every three days in double nested Weather Research and Forecasting (WRF) domain (9km for outer domain and 3 km for inner domain) was done for North Western Himalaya NWH using National Centres for Environmental Prediction (NCEP) Global Forecasting System (GFS) 0.25 degree data as initialization state. Rainfall forecast was validated using Indian Meteorological Department (IMD) data, the simulation accuracy of WRF in rainfall prediction above 100 mm is about 60%. Rainfall induced flood event of August 05-08, 2015 in Sone River (tributary of Beas River) Basin, near Dharampur, Mandi district of Himachal Pradesh caused very high damages. This event was picked three days in advance by WRF model based rainfall forecast. In second part, mean rainfall at sub-basin scale for hydrological model (HEC-HMS) was estimated from forecasted rainfall at every three hours in netcdf format using python script and flood hydrographs were generated. In third part, flood inundation map was generated using Hydrodynamic (HD) model (MIKE 11) with flood hydrographs as boundary condition to see the probable areas of inundation.

### 1. INTRODUCTION

Floods are one of the most common and damaging disasters of India. Early warning of floods is most critical for minimizing the losses due to reoccurring floods in many parts of India. North West Himalaya (NWH) is one of the most vulnerable areas in terms of overall natural hazards. The area is susceptible to flash floods, earthquakes, snow avalanches, forest fires, mudflows and landslides. In last few years, numbers of flash floods, cloud burst or extreme rainfall events and floods due to glacier lake outburst have increased in frequency. The flash floods of Leh-2010 (Kumar et al., 2012; Thayyen et al., 2013), Uttarkashi floods-2012 (Gupta et al., 2013), Manali cloud burst induced flash flood-1995 and 2012 (Thakur et al., 2010), Ukhimath floods 2012 (Rana et al., 2012; DMMC, 2012), Uttarakhand floods-2013 (Dobhal et al., 2013), Kedarnath floods and GLOF 2013 (Dobhal et al., 2013; Rao et al., 2013; Kumar et al., 2015), Sirmor, Himachal Pradesh flash floods-2014, Srinagar, Kashmir flood -2014 (Bhatt et al., 2016) are few of examples of recent flood disasters in NWH states of India. Traditionally, remote sensing has been used on regular and operational basis for many applications of hydrology and water resources management (Bhavsar, 1984; Rao et al., 2013). In case of floods, frequently used data during and post flood time is Synthetic Aperture Radar (SAR) and cloud free optical datasets (Rao et al., 2011; Aggarwal et al. 2009) for flood inundation mapping and flood models calibration/validation activities (Rao et al., 2013). Use of remote sensing data before and after flood event is mainly done in creating updated base maps having geo-located layers of elevation, infrastructure and Land Use Land Cover (LULC). In addition to this, time series of historical flood inundation maps are used to create flood hazards maps at various scales.

Flood early warning activities are mainly part of pre-flood management plans. The flood early warning is now becoming

one of most important task of many disaster support and management agencies, academia and space agencies globally. Many countries, disaster management agencies and river basins authorities have initiated and setup the flood early warning centres systems (Jorgensen et al. 1997; Thielen et al. 2009; Navalgund, 2014). National Water Model (NWM) framework have been made operational across US in 2016 to translate streamflow forecast into flood inundations maps (<http://water.noaa.gov/about/nwm>). In India, near real time streamflow forecast system has been developed for Bhakra-Beas Basin and Bhima Basin under Hydrology Project II (RT-DSS 2015). Results of the developed systems depends on the accuracy of near real time meteorological data used in hydrological models. Despite new inventions, converting generated hydrographs into time varying flood inundations maps with speed and reasonable accuracy is a challenge.

In all the flood early warning studies, accurate prediction of rainfall remains most important task (Mukhopadhyay, 2015), other important factors are parameterization of hydrological models, accuracy and resolution of Digital Elevation Models (DEM) (Alemseged and Rientjes, 2005), scale and details of LULC and soil map. Rainfall events have increased in there frequency as well in their intensity. In this study attempt has been made to establish flood early warning system using integration of weather forecasting, hydrological and hydrodynamic models.

### 2. MATERIALS AND METHODS

Study area of this work is Sone River Basin, Himachal Pradesh (HP), India as shown in Figure 1. Sone River is a tributary of Beas River having catchment area of 230 km<sup>2</sup> with outlet at Kandhapatan, Mandi district, HP. It is the region where the

hydrology dominates due to high rainfall and faces high flood situation in every monsoon.

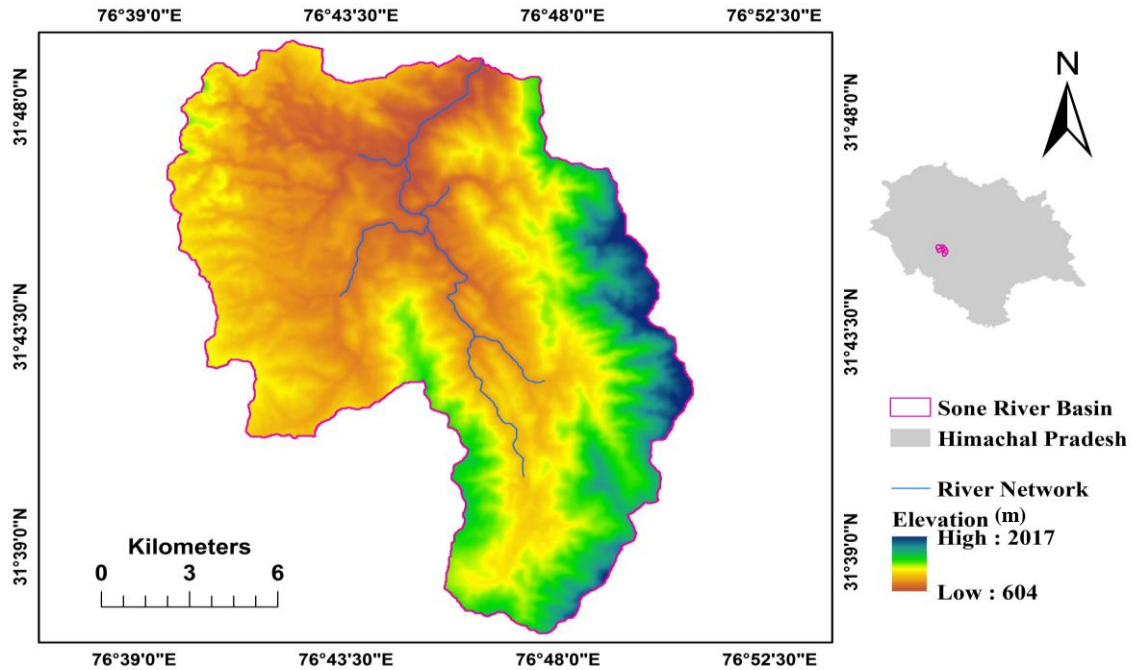


Figure 1. Study Area: Sone River Basin and River Network

The overall methodology adopted in the study is shown in Figure 2. The flood early warning system is divided into three parts. In the first part, precipitation forecast for every three days in a double-nested WRF domain (9 km for outer domain and 3 km for inner domain, as shown in Figure 3) was done for NWH using NCEP GFS 0.25 degree data as initialization state. The listing of physics options used in WRF for weather forecast are given in Table 1. In the second part, the forecasted precipitation of selected hours in netcdf format was used in python-based codes to get zonal statistics of mean rainfall at sub-basin scale. NCEP's GFS downscaled rainfall data at 3 km from WRF simulation, IMD (Indian Meteorological Department) grid of 50 km resolution, INSAT 3D IMR data at 0.5 degree and CPC daily rainfall inputs were the different rainfall datasets analysed for hydrological modelling. Out of all the mentioned datasets, only WRF's 3-day forecasted rainfall and IMD's district-wise five-day ensemble forecast were used for flood hydrograph prediction using HEC-HMS model (HEC, 2000). ASTER GDEM of 30m resolution was used for the delineation of the catchments and rivers. Hydrological model was established using SCS method for initial loss estimation, SCS unit hydrograph as runoff transformation, Muskingum-Cunge method as channel routing and constant base flow. In the third part, flood inundation scenarios were generated using MIKE 11 based HD modelling (DHL, 2014). Cross-sections were generated using SRTM-X band 30m DEM and roughness coefficients were estimated based on ISRO-IGBP LULC map (NRSC, 2008: Indian Space Research Organisation-International Geosphere Biosphere Programme, Land use land cover). Hydrographs generated using hydrological modelling were used as boundary conditions in MIKE 11 HD modelling to see the probable areas in the vicinity of the river which may inundate.

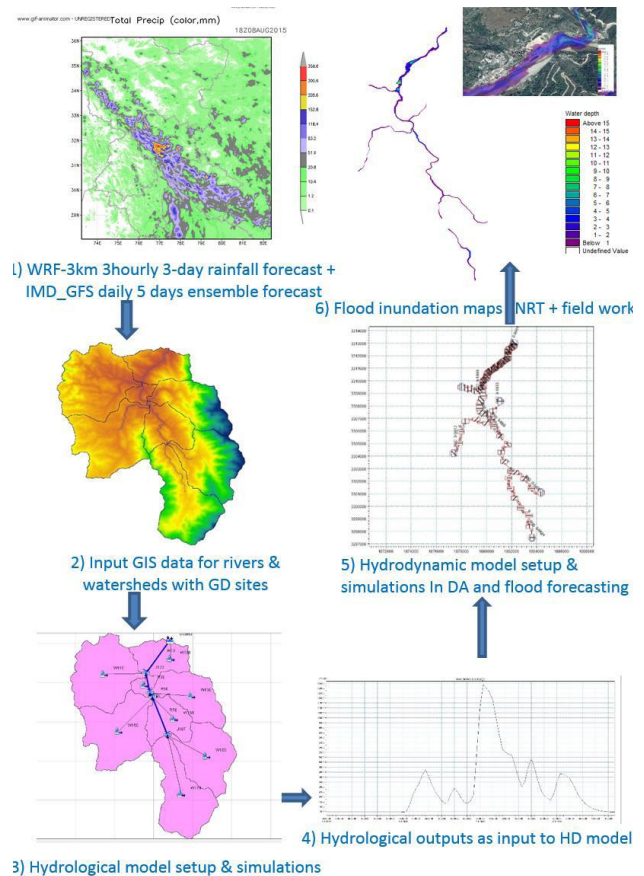


Figure 2. Overall methodology pictorial flowchart

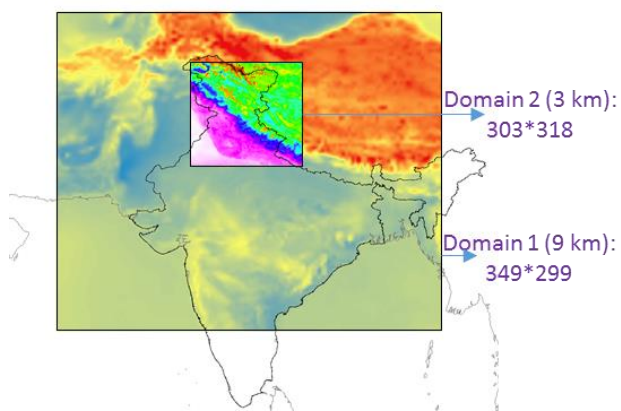


Figure 3: Domains for WRF simulations

Table 1: WRF physics schemes used for simulations

Code	Physics Option	Used scheme/algorithm
6	Microphysics (mp_physics)	WRF Single-Moment 6-class scheme: A scheme with ice, snow and graupel processes suitable for high-resolution simulations
1	Longwave Radiation (ra_lw_physics)	RRTM scheme: Rapid Radiative Transfer Model. An accurate scheme using lookup tables for efficiency. Accounts for multiple bands, trace gases, & microphysics Species
1	Shortwave Radiation (ra_sw_physics)	Dudhia scheme: Simple downward integration allowing efficiently for clouds and clear-sky absorption and scattering
2	Land Surface (sf_surface_physics)	Noah Land Surface Model: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics.
2	Cumulus Parameterization (cu_physics)	Betts-Miller-Janjic scheme, Operational Eta scheme. Column moist adjustment scheme relaxing towards a well-mixed profile

### 3.0 RESULTS AND DISCUSSION

The first output of given methodology for flood early warning is WRF-ARW model based rainfall forecast. Rainfall forecast was done for entire monsoon in 2015 at every three days. An example of very heavy rainfall (Aug 05-08, 2018) in Mandi district, HP forecasted in three days advance is shown in Figure 4. WRF based rainfall forecast was validated with IMD 0.5 degree daily data as reference and using the Model Evaluation Tools (MET) model (Brown et al., 2009). Figure 5 shows results of validation, WRF model was able to pick most of the rainfall events above 100 mm (accuracy > 60 %) but pixel to pixel correlation between forecasted rain and IMD grid was very poor, with  $R^2$  (coefficient of determination) less than 0.3.

Heavy rainfall during Aug 05-08, 2015 resulted in flood disaster at Sone River Basin near Dharampur, HP. This event was used to highlight the overall approach of flood early warning system. Hydrograph generated using HEC-HMS for the mentioned heavy rainfall event at outlet is shown in Figure 6a. Dynamic flood inundation maps were generated using MIKE 11 with boundary conditions based on hydrological model hydrographs, maximum flood extent is shown in Figure 6b. The flood inundation map generated from HD model has correctly shown flood inundation in most of parts. However, data gaps were seen in main river channel and points of river curvature (Figures 6c & d).

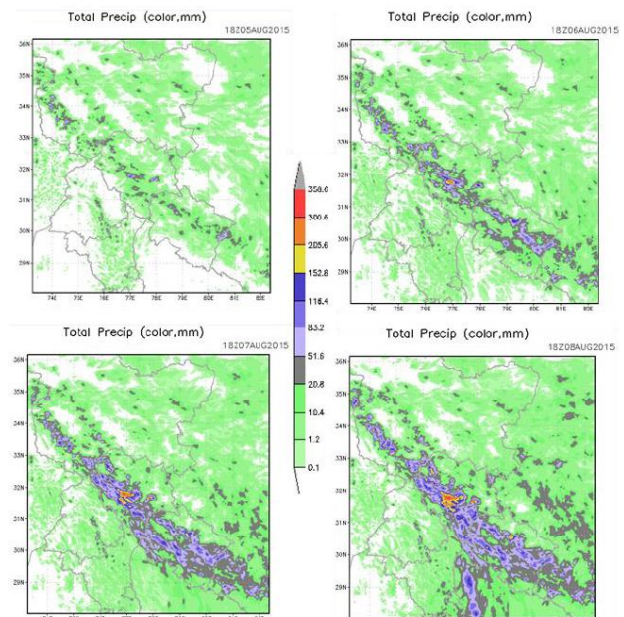


Figure 4. Forecasted rainfall on dated Aug 05, 2015 for Aug 05-08, 2018, showing very heavy rainfall in Mandi district, HP

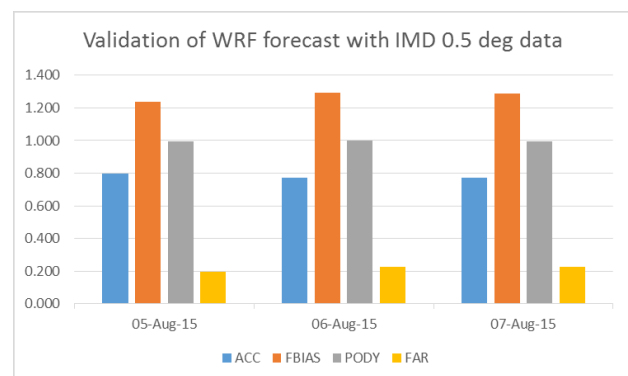
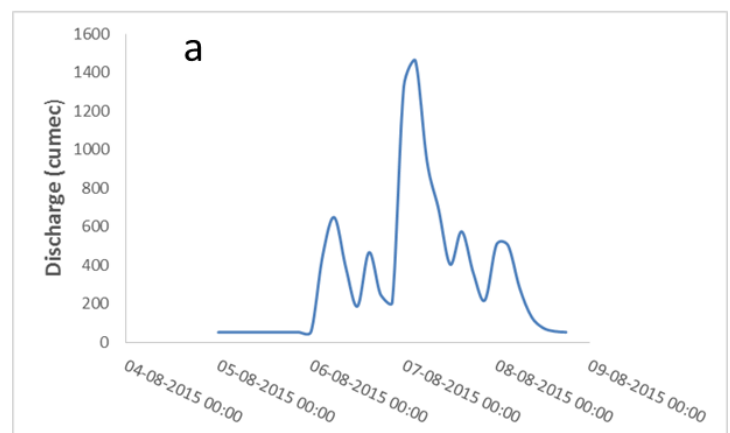


Figure 5. Rainfall prediction above 100 mm statistical outputs from MET tool (ACC: accuracy; FBIAS: frequency of bias; PODY: probability of detection; FAR: False Alarm Ratio)



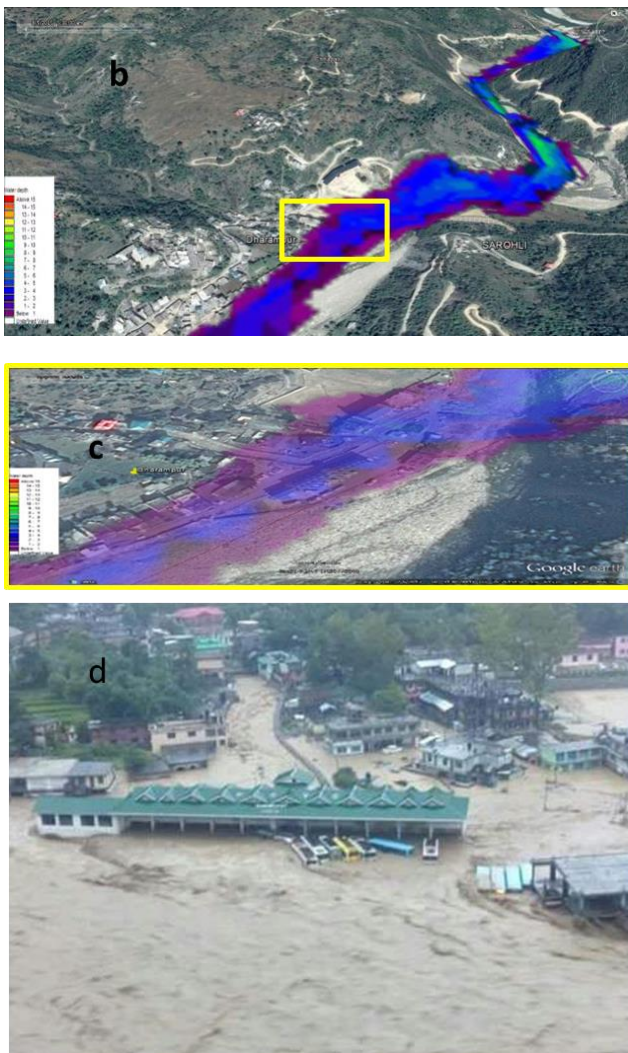


Figure 6. Results of heavy rainfall events and subsequent simulated and actual floods in Dharampur, Mandi, H.P. a) Flood hydrograph using HEC-HMS b) Simulated flood inundation using MIKE 11 c & d) Simulated and actual flood inundation situation near Bus stand, Dharampur, Mandi district.

## 2. CONCLUSIONS AND LIMITATIONS

The current work highlights the flood early warning system using integration of weather forecast, hydrological and hydrodynamic models for complex terrain of NWH. Forecasted rainfall ensemble with IMD data was used for hydrographs generation using hydrological modelling. HD model was established to simulated flood inundation using produced hydrographs as boundary condition. Based on visual inspection there was good agreement between simulated and actual flood extent near Dharampur, HP. However, there are certain limitations of the study as explained below.

The study showed that, although overall accuracy of weather forecast model, WRF-ARW in this case is able to correctly pick the high rainfall events having more than 100 mm rainfall at medium time range of 3 days, but comparison with IMD rainfall data product showed a poor pixel to pixel correlation as well as time lag of few hours in picking heavy rainfall. The WRF rainfall forecast can improved by running simulations at daily

interval instead of once in every three days. The current study was done without calibration and validation of hydrological/hydrodynamic models due non availability of gauging data for Sone River. Results can improved using stable models (calibrated and validated). The accuracy of flood inundation map is highly dependent on flow hydrographs as well as input DEM. The actual river cross section data is also needed to improve results of flow routing and flood inundation.

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