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# Review of Development and Applications of Integrated Flood Analysis System (IFAS) for Flood Forecasting in Insufficiently-Gauged Catchments

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**Abstract:** Flooding problem is becoming more frequent, intense and less predictable in the last century as a consequence of changing climate conditions including shifts in precipitation, soil moisture and land uses. Lack of hydrological data and catchment information has becomes great challenges for the local authorities to set up the flood early warning system in many developing countries. Thus, Integrated Flood Analysis System (IFAS) is developed to forecast the flood event in insufficiently gauged catchments. IFAS Software is able to improve the accuracy of lead time of flood forecast and thus reduce the vulnerability to flood disaster. IFAS can automatically collect the geographical data, soil type, land uses and satellite rainfall data to set up the river basin model for flood simulations. This study reviews the development and applications of IFAS at several river basins with different catchment characteristics in Asian countries.

**Key words:** Flood forecasting, flood early warning system, insufficiently gauged catchment, satellite rainfall

## INTRODUCTION

Flooding problem is becoming a big challenge for many Asian countries in the recent decades due to the climate change and uncontrolled urban developments (Bormudoi *et al*., 2011; Sugiura *et al*., 2014a, b). Severe flood events had occurred in the past in countries like Myanmar in 2008, Philippines in 2009, Pakistan in 2010, Thailand in 2011, Philippines in 2013 and Malaysia in 2014. Huge economic losses due to damage of infrastructures and even human life losses are burdening the responsibility of the country government. Since, it is almost impossible to prevent from flood hazards completely with sufficient structural measures due to its high cost, implementation of flood forecasting and early warning system becomes the main strategy for the authorities to reduce the vulnerability against flood risk (Sugiura *et al*., 2014a, b). However, the problems of flood forecasting system installation in poorly-gauged river basins are including difficulty to get real time hydrological data in the upstream of a transboundary river basin, insufficient of implementation and maintenance of ground-based real time hydrological observation stations such as rain gauge and river discharge gauging station with data transmission system; lack of the data required for creation of a flood forecasting model such as altitude, land use and river channel network, etc., lack of budget for flood forecasting system installation and insufficient framework to enhance the technical capabilities (Fukami *et al*., 2006; Miyamoto *et al*., 2014; Sugiura *et al*., 2014a, b). Therefore, there is a great need for developing a flood forecasting system that able to acquire the necessary information in un-gauged river basin for efficient and accurate flood prediction. As such, Integrated Flood Analysis System (IFAS) is developed by ICHARM (International Center for Water Hazard and Risk Management) and Public Works Research Institute (PWRI) of Japan as an advanced technology to forecast the flood event using satellite rainfall data and Geographic Information System (GIS). The objective of this study is to review the development and applications of IFAS for flood simulation at several river basins with different catchment characteristics in Asian countries.

**Integrated Flood Analysis System (IFAS):** The aim of IFAS is to create flood forecasting for river basins with insufficient hydrological data in order to reduce its vulnerability to flooding disasters. The Public Works Research Institute Distributed Hydrological Model (PDHM) is employed in IFAS Software as its runoff

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simulation model. The structure of PDHM is consists of surface tank model, subsurface tank model, aquifer tank model and river tank model. The IFAS Software is capable to import satellite-based rainfall data such as GSMaP and 3B42RT for insufficient ground observation river basin (ICHARM, 2011).

## MATERIALS AND METHODS

**Model structures:** The structures of IFAS can be classified to four main components: input rainfall, basin model, runoff calculation engine and results display interfaces (Fig. 1).

**Input rainfall data:** The input rainfall data for IFAS can be obtained either from ground based rain gauges or satellite rainfall data. The global satellite rainfall datasets provided by National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), USA and Japan Aerospace Exploration Agency (JAXA) offer different spatial and temporal resolutions and time of delay.

**Basin model:** The IFAS runoff basin model can be developed by utilizing global GIS data. The GIS tool kits were used to obtain the geophysical data and construct the river basin model. The imported global GIS data includes catchment elevation, land use/land cover, soil type and geology. The topography map and river channel network for the modelled catchment can be constructed by using Digital Elevation Model (DEM) data provided by United States Geological Survey (USGS). The land use data can be downloaded from the Global Land Cover Characterization (GLCC) database provided by USGS. Meanwhile, the soil type and geology data can be acquired through database provided by United Nations Environment Programme (UNEP) and Commission for the Geological Map of the World (CGMW), respectively. All these data are used to estimate the hydrological parameters for runoff simulation model in IFAS. Since, all data can be obtained from global GIS databases and satellites, it is possible for IFAS to simulate the rainfall runoff at an ungauged catchment where no or limited hydrological information (Fig. 2).

**Parameter setting:** The coefficient and parameter values for each cell in the runoff model can be setup automatically based on the GIS data. Default values have been recommended for all surface, subsurface, aquifer and river course tanks in IFAS Model. This standard guideline allows the IFAS user to set the parameter values without the past hydrological information. The calibration for IFAS Model simulation can be carried out by tuning these parameters in order to match with the observed results. The parameters are tuned and set by using trial and error method (Fig. 3).

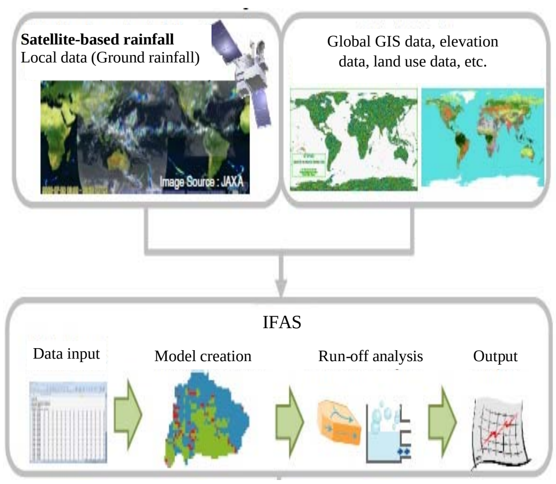


Fig. 1: Model structures of Integrated Flood Analysis System (IFAS)

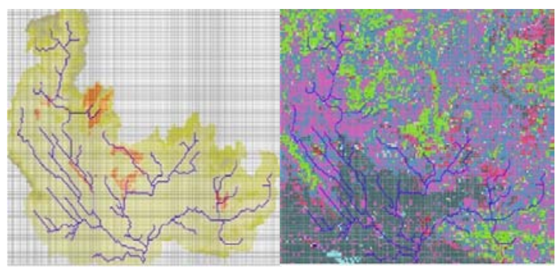

Fig. 2: River channel network and land use map in IFAS basin model

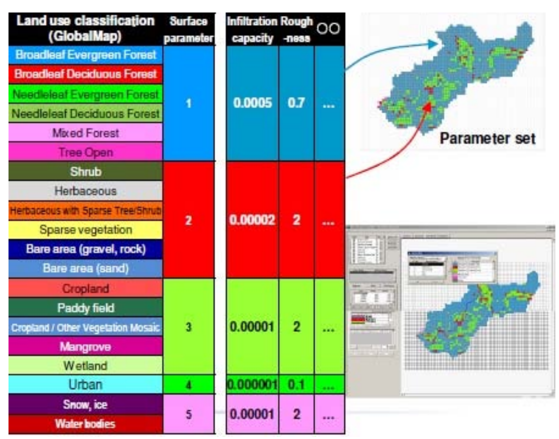


Fig. 3: Parameter setting function in IFAS basin model

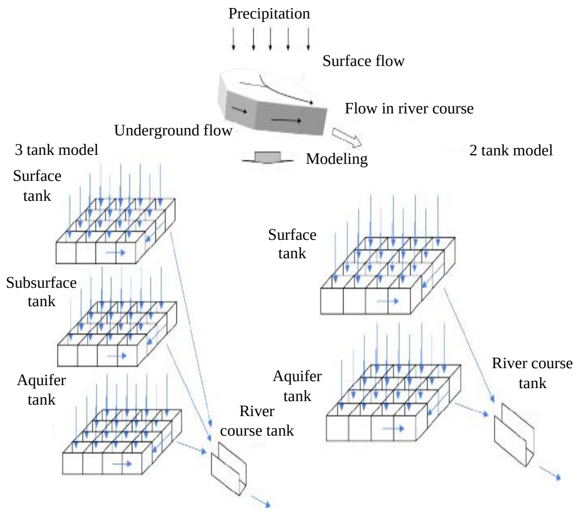


Fig. 4: Conceptual structure of runoff simulation engine for IFAS

**Runoff simulation:** The runoff simulation engine for IFAS is Public Works Research Institute (PWRI) distributed hydrological model. The PWRI distributed hydrological model is configured as three or four tank models which are surface, unsaturated if 3 layers, aquifer and river course tanks. The conceptual structures of IFAS runoff simulation model is represented in Fig. 4. The times taken for executing the runoff simulation may vary from several minutes to few hours which it depends on the number of calculation cell sizes, simulation period and the computer capability.

**Surface tank model:** The surface tank model separates the rainfall into surface, rapid intermediate and ground infiltration flows. The input parameters for surface tank model includes vertical hydraulic conductivity ($f_0$), maximum water height ($S_{f2}$), height where rapid unsaturated subsurface flow occurs ($S_{f1}$), minimum height for infiltration to start ($S_{f0}$), surface roughness coefficient (N), mesh Length (L), rapid unsaturated subsurface flow regulation coefficient ($\alpha_n$) and initial water height (Fig. 5).

**Subsurface tank model:** The subsurface tank model is used to simulate the low flow conditions as well as long term periods. The input parameters for subsurface tank model includes tank height (D), horizontal saturated hydraulic conductivity ($K_{sx}$), vertical saturated hydraulic conductivity ($K_{sz}$), saturated moisture content ($\theta_s$), moisture content at field capacity ($\theta_{FC}$), vertical hydraulic conductivity at field capacity (KFC_z) and initial water height (Fig. 6).

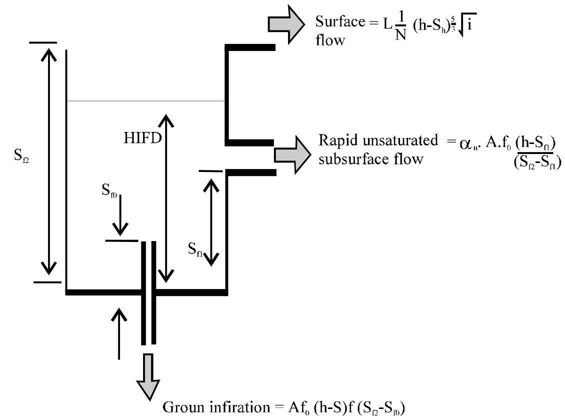


Fig. 5: Schematic representation of surface tank

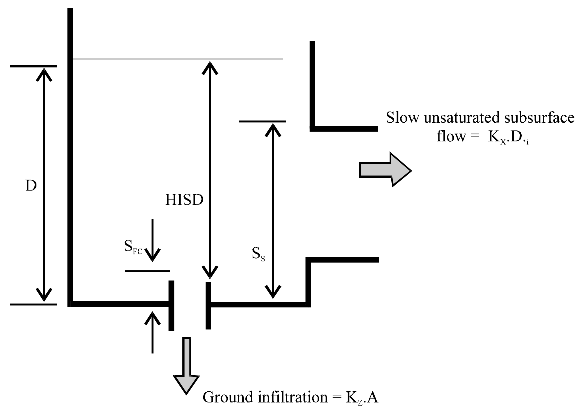


Fig. 6: Schematic representation of subsurface tank

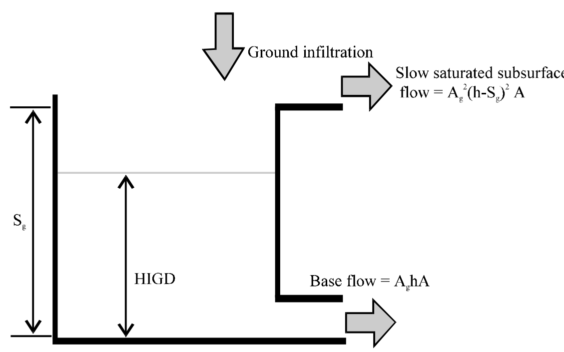


Fig. 7: Schematic representation of aquifer tank

**Aquifer tank model:** The configuration of aquifer model is shown. The input parameters for aquifer tank are slow unsaturated subsurface flow regulation coefficient (Au), base flow coefficient (Ag), water height where the slow unsaturated subsurface flow occurs (Sg), initial water height and coefficient for unaccountable aquifer loss ($\alpha_{GW}$) (Fig. 7).

**River course tank model:** For river discharge calculation, the equations used differ according to the cell type. The input parameters for river course tank model includes breadth of river course, coefficient of the resume law: c, coefficient of the resume law: s, Manning's roughness coefficient, initial water level in the river course, infiltration from river tank to the aquifer tank, coefficient for cross section shape and meander coefficient (Fig. 8).

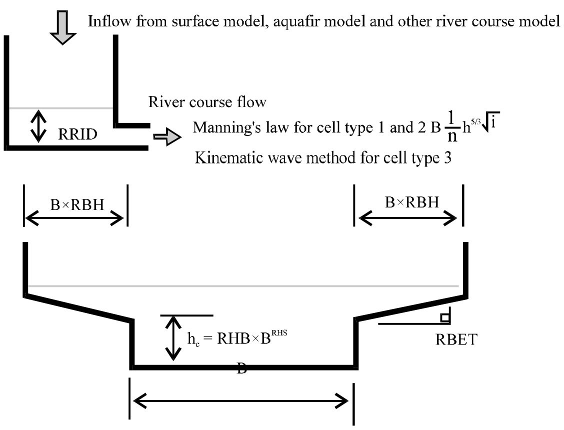


Fig. 8: Schematic representation of river course tank

## RESULTS AND DISCUSSION

**Interface display of simulation results:** The hydrological simulation results can be displayed in terms of hydrograph, plan view, table and animation (Fig. 9 and 10). It is also possible to display the setting parameters, rainfall data, discharges and water level in each tank and

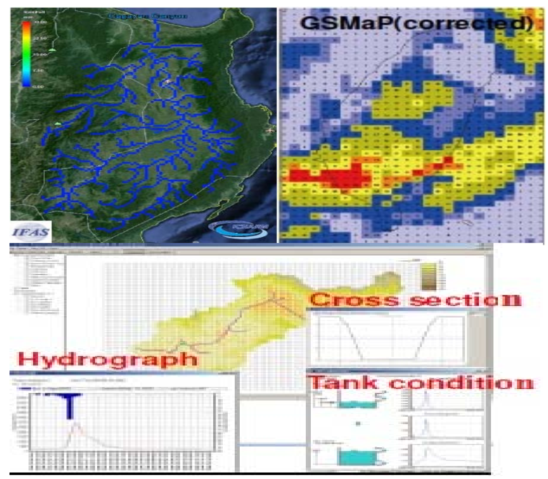


Fig. 9: Interface displays of simulation results

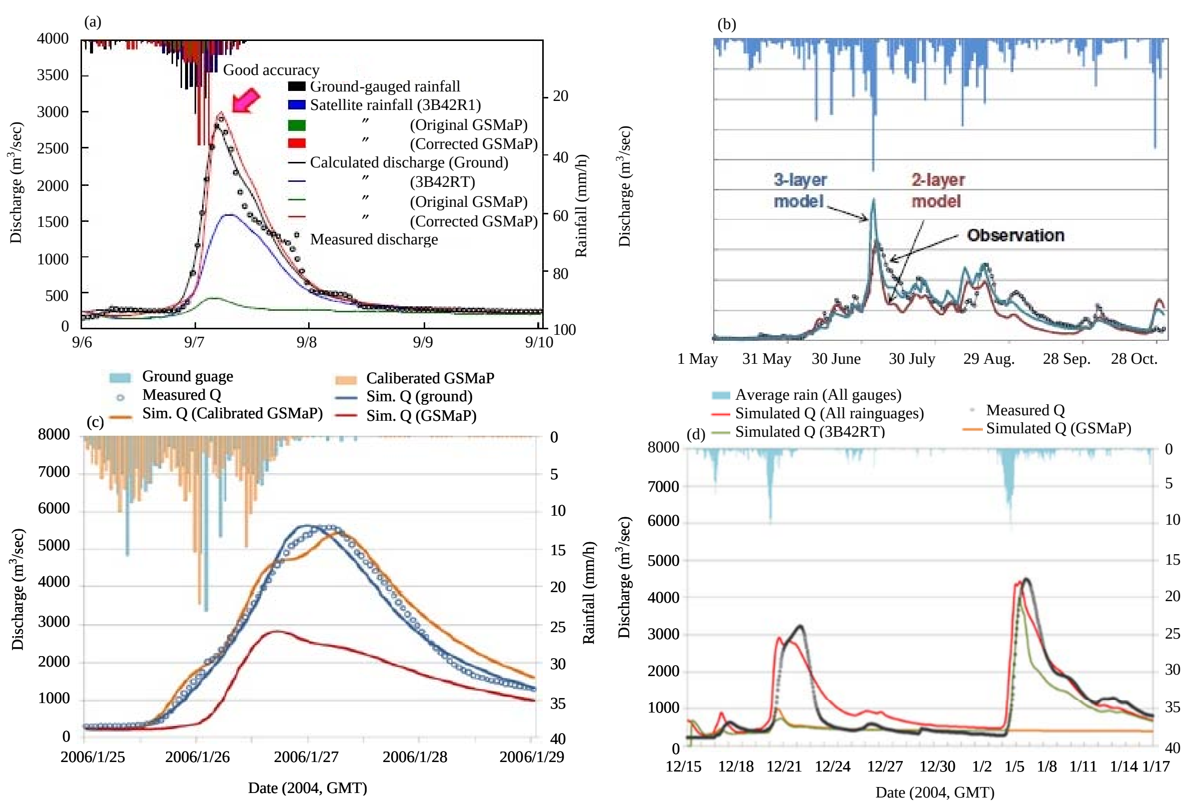


Fig. 10: Continue

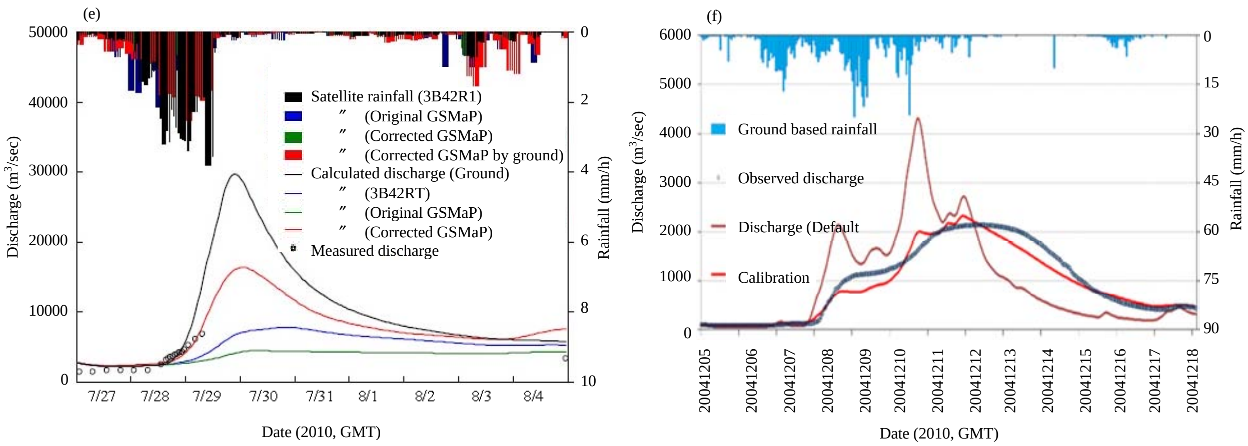


Fig. 10: Flood simulation results using observed and satellite rainfall in: a) Sendai, Japan; b) Chindwin, Myanmar; c) Kabul, Pakistan; d) Dungun, Malaysia; e) Cagayan, Philippines and f) Kelantan, Malaysia

river cross sectional results. It is also possible to display simulation results of two or more locations simultaneously and in different conditions.

**Case studies of IFAS applications:** IFAS Model has been applied for flood analysis and forecast at several river basins in different countries. A flood event simulation at Sendai river basin in Japan was accurately reproduced by IFAS using self-corrected satellite-based rainfall data without any in-situ ground based rainfall data. Flood simulation by IFAS Model was also carried out at Chindwin River basin in Myanmar. The 2 tank model showed that able to simulate the 1st major flood peak well and other major flood peak timing wel but under estimated the low flows. Meanwhile, the 3 tank model reproduced both major flood peaks (timing and level) and the river discharges better. The IFAS Model is also applied for flood simulations at river basins in Pakistan (Aziz and Tanaka, 2011), Malaysia (Hafiz *et al*., 2013, 2014), Indonesia (Bormudoi *et al*., 2011), Vietnam, Philippines (Miyamoto *et al*., 2014) and Thailand (Chuenchooklin and Pangnakorn, 2015). The simulation errors for timing and magnitude of flood peak flows in all these studies are averagely below 20%. The IFAS Model was proved that it is possible to simulate the flood peak flow and duration accurately by using satellite rainfall data and global GIS data at different river basins with various catchment characteristics. This study also showed that flood forecasting with calibrated satellite rainfall data performed higher reproducibility than satellite rainfall without calibration particularly beginning and peak of hydrograph.

## CONCLUSION

Integrated Flood Analysis System (IFAS) is able to integrate the satellite-based rainfall data and global GIS data for simulating the flood event. The results indicated that the calibrated satellite rainfall data is performs well in flood simulation, although, improvement still needed for increasing the model simulation accuracy. The estimated catchment physical parameters from GIS data are representable and The IFAS Model is proved that it has high potential and efficient for forecasting the flood event, especially in poorly gauged river basins. IFAS Model can be widely used as a tool for flood early warning system in developing countries where the available and access to hydrological data is limited.

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