Research the applicability of IFAS model in flood analysis (Pilot at Bang Giang river basin in Cao Bang Province)

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Abstract

In climate change context, the increase of seriousness of natural disasters including flood is considerable. Thus, flood monitoring has been used to understand its rule and increase human subjective sensitivity on this catastrophe, in order to find management solution. However, this is not an easy job at national, regional and organizational levels because of lack of monitoring equipment, operational fund or lack of reliable data.

To solve this problem, IFAS (Integrated Flood Analysis System) model was built. By using the input data which can be downloaded completely free for research, such as land use, elevation, especially rainfall data - this is completely new method comparing to current hydrological models. In this study, IFAS model is implemented at Bang Giang river in northeastern Vietnam. Through the algorithms of model, outputs are water level and discharge of surface, subsurface, aquifer, river course and vertical seepage in 3 forms: map, chart and table, showing the detailed information related to the flood. Assessing accuracy of the flow simulation model by relative error of the peak of flood (ΔQ) and Nash–Sutcliffe coefficient (R) shows that the flow simulation model achieves high accuracy in large rivers (ΔQ= -13.63%, R=0.93) and low accuracy in small river branches (ΔQ=+57.64%, R=0.44).

1. Introduction

Flood is considered as the most dangerous disaster in Vietnam – an agricultural country. There are about 7 storms per year, occurs mostly from July to October, brings large volume of runoff to the relatively large catchment areas and causes damage to people and property.

Common hydrological models in Vietnam includes: Rational, HEC-HMS, TANK, SSARR, NAM, VRSAP, DHM, etc. These models are tested at many different rivers in Vietnam e.g. Tuy Loan, Hong, Thai Binh, Thu Bon rivers [1, 2, 4, 6] to solve problems of flood forecasting and analysis, and obtained helpful results. However, most of them faced difficulty in providing input data (due to poor data, especially high and rural areas where don’t have observation stations). IFAS model solves this problem by using satellite data which are available on the Internet. Thus, it can work for anywhere and anytime (satellite data has range from 2003 to present)

Bang Giang river is the main river in Cao Bang province, located in northeastern Vietnam where has the annual rainfall over 1500mm, focus from June to October. This river flows from Ha Quang district, passes through Hoa An district, Cao Bang city, Luc Hoa district (Vietnam) and finally comes to Quang Tay province (China). Its length is 108 km and total of basin area of approximately 4,200 km^2.

Aims of study:

(1) Apply IFAS model flood analysis in Bang Giang river basin, Vietnam

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(2) Assess accuracy of the satellite rainfall data and accuracy of the flow simulation model

(3) Assess applicability of IFAS in small scaled river basin

2. Material and Methodology

2.1. Material

IFAS is a deterministic model, founded by ICHARM (International Center for Water Hazard and Risk Management) of Japan for analysis flood on the basin river. It calculates flows basing on the amount of rainfall similar to tank principles of TANK and NAM models.

Input data of IFAS are base map and satellite rainfall data, which are available on the Internet.

- Background map are derived from Global Map[4] - Digital geographic information in 1 km resolution covering the earth's surface with standardized specification and available to everyone at marginal cost. Global Map data have 8 layers: Boundaries, Drainage, Transportation, Population Centers, Elevation, Land use, Land Use, and Vegetation. Two layers which are used in IFAS, are Elevation and Land use.
- Global rainfall information observed by satellite is free for downloading on the Internet. The products called 3B42RT (provided by satellites TRMM/TMI, SSMI, IR of NASA) and GSMaP (provided by satellites TRMM/TMI, Aqua/AMSR E, ADEOS II/AMSR, DMSP/SSMI) are such rainfall data set.

After setting coordinates of study area and importing input data, boundary, river course and parameters will be created. Time scale is from 07/01/2009 to 07/15/2009.

2.2. Methodology

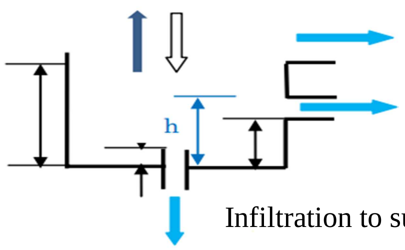
To simulate flood process, IFAS uses the theoretical of tank model and Manning's law, Darcy's law and kinematic wave method.

When the horizontal and vertical flows are formed, IFAS divides them into 4 types of model: Surface tank, Subsurface tank, Aquifer tank, River tank.

2.2.1. Model outlines [5]

a) Surface tank model

The surface tank model is a model used to divide the rainfall to surface, rapid intermediate, and ground infiltration flows.



Surface flow (Mainning's law): $Q_{sf} = L\frac{1}{N}(h - S_{f2})^{5/3}\sqrt{i}$

Rapid unsaturated subsurface flow:

$Q_{ri} = a_n.A.f_0\frac{h-S_{f1}}{S_{f2}-S_{f1}}$

Infiltration to subsurface tank

$Q_0 = A.f_0\frac{h-S_{f0}}{S_{f2}-S_{f0}}$

Figure 1: Flows in surface tank model

With:

[4] See http://www.iscgm.org

R: rainfall

Eps: Evapotranspiration

Q0: infiltration to lower tank

Qsf: surface flow

Qri: rapid unsaturated subsurface flow

h: water height for the tank

Sf2: height from which surface flow occurs

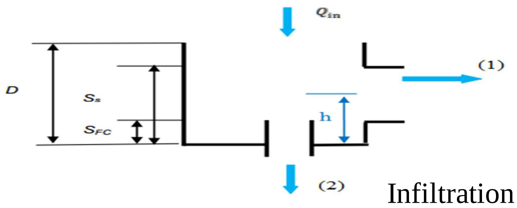
Sf1: height from which rapid unsaturated subsurface flow occurs

Sf0: height where ground infiltration occurs

A = L*L : mesh area with L, mesh length

b) Subsurface tank model

The subsurface tank model makes it possible to simulate low flow conditions as well as long-term periods.



Slow unsaturated subsurface flow (Darcy's law): $Q_{s1} = K_x.D.L.i$

Infiltration to aquifer (Darcy's law): $Q_{s2} = K_z . A$

Figure 2: Flows in subsurface tank model

If h≥S_S, then the subsequent flow is considered coming out from the surface tank as rapid unsaturated subsurface flow.

With:

Eps: Evapotranspiration

Qin : flow entering the subsurface tank

QS1: slow unsaturated subsurface lateral flow

QS2: slow unsaturated subsurface vertical flow

D: maximum water height for subsurface tank

h: water height for this tank

i: slope with the adjacent cell

A: mesh area.

SS: height when θ=θS, soil moisture is equal to soil moisture at saturation and θS=SS/D

SFC: height when θ=θFC, soil moisture is equal to soil moisture at wilting point and θFC=SFC/D

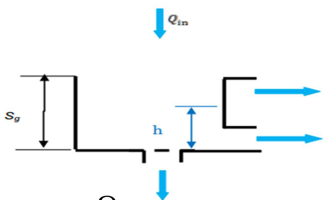
θ: soil moisture content (=h/D)

KX: horizontal hydraulic conductivity at θ

KZ: vertical hydraulic conductivity at θ

c) Aquifer tank model

The configure ration of aquifer model is shown as the Figure below. The top right and bottom right orifices represent the unconfined and confined aquifer outflows, respectively. Outflow of ground water is considered as a fraction of confined aquifer to h, and of unconfined aquifer to h^2. These relationships were determined experimentally.



$Q_{g1} = A_u^2(h-S_g)^2.A$

$Q_{g2} = A_g hA$

$Q_{g\_loss} = a_{g\_loss} Q$

Figure 3: Flows in aquifer tank model

With:

Q_{in}: inflow to the aquifer tank

h: water height of model

Q_{g2}:base flow

Q_{g_loss}: unaccountable aquifer loss

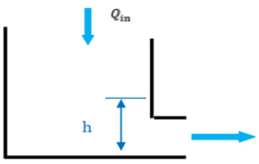
Q_{g1}:slow saturated subsurface flow

S_g: height from which slow saturated subsurface flow

d) River course tank model

For river discharge calculation, the equations used differ according to the cell type.

River discharge calculation for cell type 1 and 2: Outflow from the river course tank is based on Manning equation for cell type 1 and 2.



$$Q_r = B\frac{1}{n}h^{5/3}\sqrt{i}$$

$$LB\frac{\partial h}{\partial t} = Q_{in} - Q_r$$

Figure 4: Flow in river course tank model

With:

Q_{in}: flow entering the river course tank

Q_r: outflow from river course

L: length of river course

B: breadth of river course

The river course breadth is calculated according to the Resume Law:

$B = cA^s$ (c and s are constants, generally s<1).

Because the model is considering runoff, the influence on the river course outflow is omitted

For river course tank in cell type 3, the river routing method is the kinematic wave method using the difference method:

$$\frac{\partial Q}{\partial t} + C\frac{\partial Q}{\partial x} = 0 \qquad \text{With } C = \frac{dQ}{dA}$$

C: the kinematic wave celerity

2.2.2. Assessing method

Accuracy of the model is assessed basing on satellite rainfall and discharge of river.

Satellite rainfall	Discharge of river
Correlation coefficient: $r_{xy} = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}.\sqrt{n(\sum y^2) - (\sum y)^2}}$ y is the measured rainfall x is the satellite rainfall n is the number of measurements And difference in total rainfall d(%) = $\frac{\sum y - \sum x}{\sum x}$	Relative error of the peak of flood $\Delta Q\ (\%) = \frac{Q_{model} - Q_{\max measured)}}{Q_{\max measured}} \%\Delta;$ Using Nash–Sutcliffe coefficient [3]: $R^2 = 1 - \frac{\sum_{i=1}^{n}\left[Q_{obs,i} - Q_{sim,i}\right]^2}{\sum_{i=1}^{n}\left[Q_{obs,i} - \bar{Q}_{obs}\right]^2}$ where $Q_{obs,i}$: flow measured at the time of the i^{th}

	$Q_{sim,i}$: flow calculated at the time of the i^{th} $\overline{Q}_{obs}$: Average measured flow all time
If r_{xy} > 0,6 and |d| < 30%, the satellite-based rainfall data is usable.	If R > 0,7 and |ΔQ| < 30%, simulation model is acceptable.

3. Results and Discussion

3.1. Results

Parameters such as initial water height, surface roughness coefficient, saturated moisture content, moisture content at field capacity, etc., are calibrated to suit with characteristics of study area.

Figure 6 shows simulated hydrograph before and after calibration compared with measured base on heavy rain in August 2008.

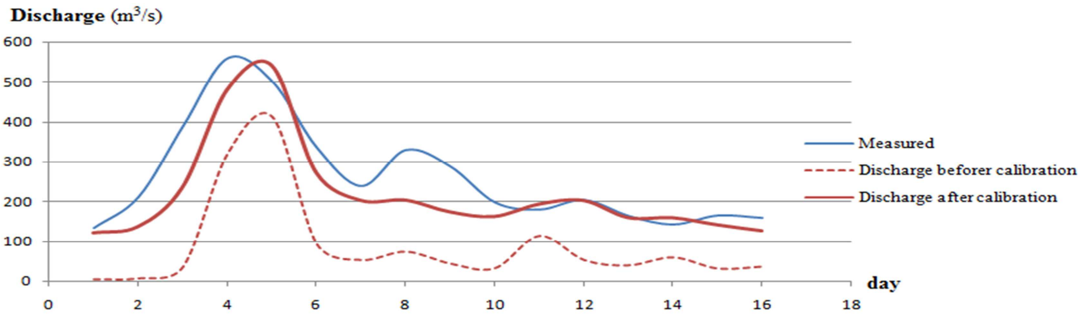


Figure 5: Simulated hydrograph before and after calibration (8/01/2008 to 8/16/2008)

By using parameters calibrated and the calculations mentioned above, IFAS model gives results in 3 formats: map (which can be exported to Google Earth), chart and table for each hour and each cell. Output information is water level and discharge of surface, subsurface, aquifer, river course and vertical seepage.

Results with image format

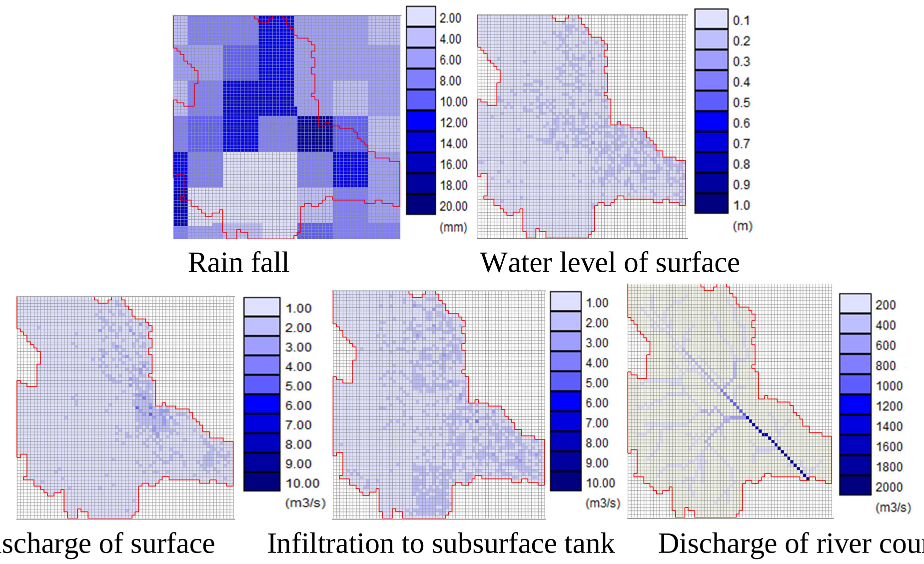


Figure 6: Result images at 18:00 07/03/2009

Figure 7: Discharge of river course is exported to Google Earth

Exporting results to Google Earth supports observations more exactly.

Results in table and graph

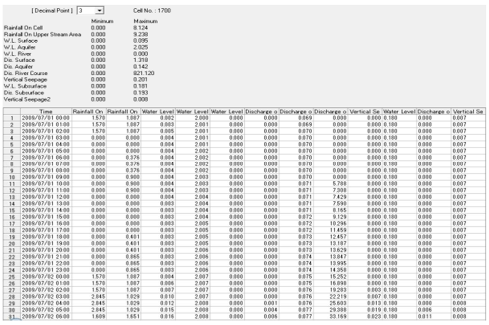


Figure 8: Result table in Cao Bang city

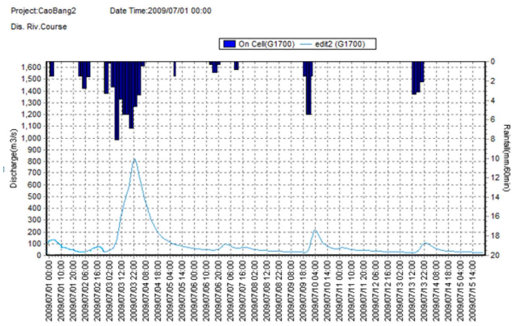


Figure 9: Result graph in Cao Bang city

The results show that there was a big rain from 2009/07/03 02:00 to 2009/07/04 08:00. It made water level of surface in some monitoring points increased by 0.2m and discharge of river course in the upstream up to over 2000 m^3/s at 18:00 07/03/2009 (Fig 6). In Cao Bang city, discharge of river course is lower with the peak of it 800 m^3/s at 22:00 07/03/2009 (Fig 9).

3.2. Assessing the model

3.2.1. Assessing the accuracy of the Satellite-based rainfall data

Satellite-based rainfall data is compared with measured rainfall at 2 observation stations: Cao Bang city (106°16' E, 22°39' N) and An Lai (106°19' E, 22°43 N).

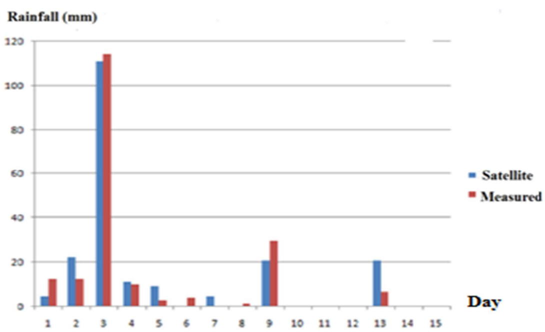


Figure 10: Graph of satellite rainfall and measured rainfall in Cao Bang

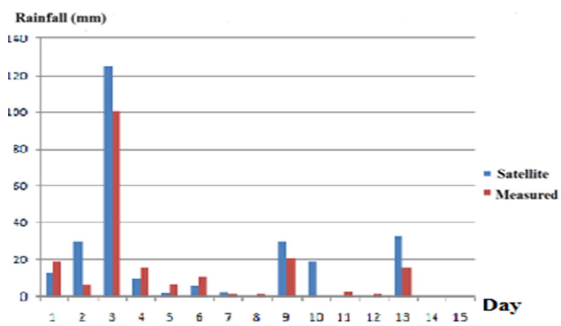


Figure 11: Graph of satellite rainfall and measured rainfall in An Lai

d = +6.2% ;

r_{xy} = 0,978 ;

d = +25.76%

r_{xy}= 0.95

The result of correlation coefficient showed that satellite-based rainfall reliable for calculation.

3.2.2. Assessing the accuracy of the flow simulation model

Discharge of river of model is compared with discharge of river measured at 2 observation stations: Cao Bang city (106°16' E, 22°39' N) and Duc Thong (106°15' 0" E, 22°30 N).

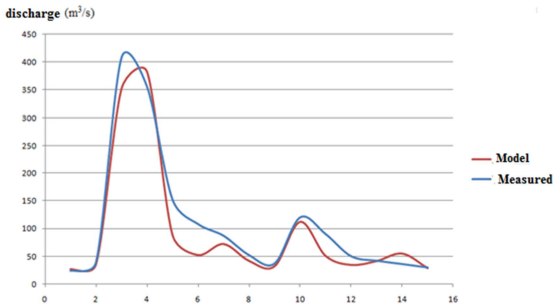


Figure 12: Discharge of river of model and measured in Cao Bang

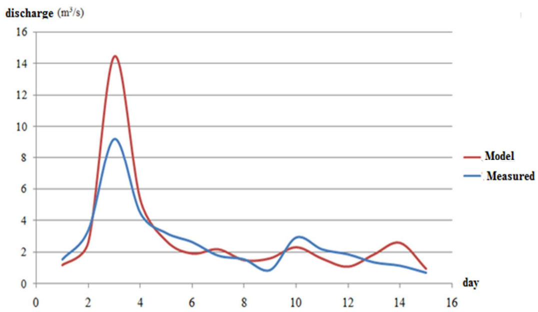


Figure 13: Discharge of river of model and measured in Duc Thong

ΔQ = -13.63%;
R = 0.93;
→ Simulation model is acceptable

ΔQ = +57.64%
R = 0.44
→ In this situation, simulation model is not acceptable.

Through the test at Cao Bang and Duc Thong, the results show the ability of flow simulation model achieve has high accuracy in large rivers and low accuracy in small river branches.

4. Conclusion

(1) With using the input data available on internet, including: satellite rainfall data, elevation, land use, parameters and the algorithm: Manning, Dancy, kinematic wave method, IFAS model calculate to give results in 3 formats: map (be able to connect with Google Earth), chart and table for each hour and each mesh. Output information are water level of surface, discharge of surface, water level of subsurface, discharge of subsurface, water level of aquifer, discharge of aquifer, vertical seepage, discharge of river course.

Results show that discharge of river course went to peak rapidly only after an hour rainfall got max (Fig 9). People in Cao Bang need to prevent before it is rain. In addition, most of water level and discharges are high in the southeast of river basin (Fig 6). Therefore, managers should pay attention to this area.

(2) Assessing accuracy of the satellite-based rainfall data by correlation coefficient and difference in total rainfall show that satellite-based rainfall data is completely reliable.

(3) Assessing accuracy of the flow simulation model by relative error of the peak of flood and Nash–Sutcliffe coefficient show that the ability of flow simulation model achieve has high accuracy in large rivers and low accuracy in small river branches. The large size of pixel (1km) can be reason for this. Model should be improved by decreasing the size of pixel. Besides, adding Soil layer and Geology layer to background map (now only Elevation layer and Land use layer) is necessary for IFAS to increase accuracy.

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