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RESEARCH ARTICLE

Application of HEC-HMS Model and Satellite Precipitation Products to Restore Runoff in Laigiang River Basin in Vietnam

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Abstract. The Laigiang river basin in the South Central Coast of Vietnam plays an important role in the socio -economic development of Binhdinh Province. In recent decades, the region has experienced commonly flooding in vast areas. This research aims to simulate event-based rainfall-runoff modelling, a historical flood event in December 2016, by applying the HEC-HMS model and rainfall data from CHIRPS. The CHIRPS data is an acceptable potential data input of the hydrology model. These have been confirmed through reliable validation indexes: The peak flood flow rate of 2,542.6 m3/s corresponds to the flood frequency of 5%; NSE with the value at 0.95; R2 coefficient reached 0.87; PBIAS being around 0.45, and PFC being at 0.89. It shows better performance in the rainy season than in the dry season. Inclusive, the CHIRPS rainfall data set and the HEC model could be used for some operational purposes in weather forecasting, especially for flood warnings in river basins in the South Central Coast, Vietnam.

1. Introduction

Recently, flooding has happened more frequently in the South Central Coast of Vietnam, which needs to be seen continuously and systematically (Nghinh et al., 2014). The territorial space of the area is narrow, with terrain characteristics tending to be lower from West to East. Besides, the river density of the region is quite higher than the average density of Vietnam, and rivers often have the same shape (Son and Anh, 2015). The rapid and high flow of water causes flooding downstream during the rainy season. There have been only 19 measuring stations for water flows on 15 river basins in this region. The number of stations is too small compared to actual demands and uneven density distribution, resulting in high data scarcity in the region. For instance, limiting or lacking rainfall data is one of the main variables in the hydrological model that has deterred from estimating and predicting runoff to support local authorities in getting ready for flood risks.

Scientists have applied rainfall data from satellites in many studies worldwide to overcome the limitations. For instance, (Stampoulis et al., 2013) used satellite data to analyze heavy rainfall events over the Mediterranean, Janjai et al (2015) researched estimating long-term precipitation by employing satellite-based data, and recently, Fatkhuroyan et al (2018) evaluated the accuracy of Global Satellite Mapping of Rainfall data by consulting daily rain-gauged rainfall measurements across the Indonesian Maritime Continent. A similar approach, Libanda et al (2020) assessed the performance of satellite-based daily rainfall products in Zambia through utilizing satellite-based data to rain gauge data from meteorological, agrometeorological, and climatological stations. Satellite precipitation products have been used in many studies for various areas of Vietnam. Recent studies can be mentioned, such as the research of Bui et al., (2019). The authors used global satellite–gauge (GSMaP-Gauge) and satellite-only precipitation products (GSMaP-MVK) to evaluate and simulate streamflow. Study areas included three basins in Asian countries (Japan, Vietnam, and South Korea) in a wide range of latitudes and various climate features (Bui et al., 2019). The research by Trinh-Tuan et al (2019) evaluated the products of satellite precipitation datasets (included the Climate Prediction Center Morphing algorithm-CMORPH, Global Satellite Mapping of Precipitation-GSMaP Reanalysis, and Tropical Rainfall Measuring Mission multi-satellite precipitation analysis-TRMM through contrasting with the rain gauge-based Vietnam Gridded Precipitation (VnGP) in 10 years (from 2001 to 2010) for Central Vietnam (Trinh-Tuan et al., 2019).

A commonly accepted approach to predict rainfall-runoff has applied the hydrological models. This approach has been convenient because of its simplicity and essential input data requirements. Precipitation obtained from satellite precipitation products is the main input variable for a hydrological model, while its output is the series of flows for calibration and evaluation (Boufekane and Saighi, 2018). Many models have been used to restore data on the river flows currently. For instance, the hydrological NAM model originally developed at the Institute of Hydrodynamic and Hydraulic Engineering at the Technical University of Denmark has been applied to simulate the rainfall-runoff process at the watershed scale. Another model that has been widely used in many countries is the Tank model, proposed in 1956 by Dr. Masami Sugawara - a Japanese hydrologist (Ngoc et al., 2013). This model is also the basis for Nguyen Van Lai and Berndtsson R to construct The Linear tank-LTANK model, which has been applied in many studies in Vietnam (Quynh, 2017; Kiet, 2018). Additionally, the free model called HEC-HMS (Hydrologic Engineering Center-The Hydrologic Modeling System is widely and successfully used for small and medium catchments (15 km2 to less than 1,000 km2). HEC-HMS ensures simulation for river basins, including small basins, reservoirs, river branches, and other irrigation works such as pumping stations surges (Nguyen et al., 2013; Halwatura and Najim, 2013; Nghinh et al., 2014; Castro and Maidment, 2020; Natarajan and Radhakrishnan, 2020).

Laigiang river basin, the second-largest basin of Binhdinh Province (behind the Kon river basin), has a whole basin area is 1,466 km2, length 85 km, and plays an important role in socio-economic development in the North of the province (Kiet, 2018). Climate change effects and complicated extreme weather events have caused more unusual rain and floods in recent years. Late floods have appeared with greater frequency, and the number of floods has occurred more frequently in December (2-3 floods/month). However, only one flow monitoring station has been in the entire Laigiang basin (Anhoa hydrological station). This situation has caused many difficulties in determining the rainy and dry seasons flow. In fact, to improve flood forecasting accuracy, each river basin needs to ensure the number of flow monitoring stations and rain gauge stations. Therefore, intending to overcome the limitations related to the lack of flow measurement stations, it is necessary to apply rainfall data from satellite images combined with hydrological models to restore flow data as well as restore flood forecasting in order to limit the loss of life and property in the study area is very necessary. This paper introduces the integration and application of technologies of HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System), rainfall data of CHIRPS (the Climate Hazards Group Infrared Precipitation with Stations), and GIS (Geographic Information System) to simulate flood simulation, which is very useful, suitable and has been studied for typical applications in the Laigiang basin of the South Central Coast of Vietnam (Fig.1). Furthermore, the Laigiang river basin downstream is affected by climate change, urbanization, and land-use changes. Consequently, there is a need for a tool to quickly calculate the flow volume in the rainy season for forecast runoff and extreme events like floods for local authorities.

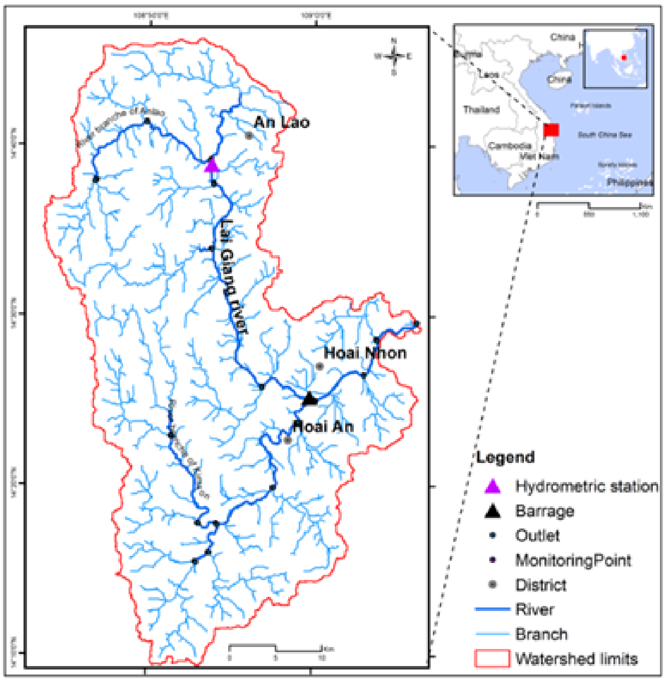

Figure 1. Schematic Location of Laigiang River Basin

2.Methods

Data

Ground data: The data, including rainfall, runoff, and the water level, was collected from An Hoa hydrological station for the year 2016 (from 1st to 31st in December), presented in Table 1. The data was obtained from Binhdinh Hydro-Meteorological Station, Vietnam.

Rainfall data from satellite imagery: The study has used satellite-based rainfall products of CHIRPS which are a quasi-global rainfall data (50°S-50°N) set with a relatively high spatial resolution (0.05°x0.05°) and long-term temporal coverage (from 1981 to near real-time). CHIRPS includes daily, pentad, and monthly precipitation datasets, in which daily rainfall data of this research was downloaded from the website: https://www.chc.ucsb.edu/data/chirps.

Digital Elevation Model data (DEM): The DEM of the Laigiang river basin were collected from radar satellite data named ALOS - PALSAR, with a spatial resolution of 12.5 m (collected on January 16, 2009, number "AP_18563_FBD_F0260_RT1.dem"). DEM data has been used to serve the division of basin and sub-basin of the Laigiang river.

Cross-sectional data of riverbed: There were 19 created sections from upstream to downstream of Laigiang river with a direct measurement method using the RTK GPS Trimble R4 (Fig.2).

Land use and land cover: Changes in both land use and land cover have a significant influence on hydro-ecological processes of catchments, including ecosystem productivity, evapotranspiration, and runoff (Reda et al., 2021; Afrin et al., 2019). Along with precipitation, therefore, land use and land cover are the considerable input data of hydrological modelling to estimate runoff (Khare et al., 2017). Based on the Landsat 8 satellite image (https://earthexplorer.usgs.gov/), the land use and land cover map of the Laigiang river basin for 2016 have been built with supporting of GIS technique. Various classes covering the study area's surface are forest (dense forest, open forest), vegetation by agriculture, bare land, built-up area (urban and rural), and body water. After classifying, the research has determined the accuracy of the classified image, with overall accuracy being at 80.5% (Fig.3).

Methods

GIS technique method: GIS can provide spatial analysis tools for various calculating features and carrying out geoprocessing activities. In this study, GIS has been applied to divide the Laigiang basin into tributaries and establish a network used as a mathematical model input from DEM data. It has also been a bare essential tool for spatial interpolating rainfall data, building, and editing maps.

QGIS 3.12 programming package has been used for planning spatial data, demanded as input data for the flow estimation.

Hydrological Model: HEC-HMS was a result of the US Army Corps of Engineers' innovative work program created by the Hydrologic Engineering Center (HEC) that could be used for simulating rainfall-runoff processes (USACE, 2000). The HEC-HMS model can be applied to analyze urban flooding, flood frequency, flood-loss reduction, flood-warning system planning, reservoir design, stream restoration, etc. (USACE, 2015). To simulate the flow by the hydrological modelling of the catchment, required data includes catchment and the sub-catchments area, daily rainfall data, daily river flow data, imperviousness, curve number, etc. (Halwatura and Najim, 2013). HEC-HMS 4.4.1 has been used to gauge the streamflow for the Laigiang basin.

Mathematical modelling method: To compute flow volumes over the Laigiang basin, the paper has had a pragmatic approach by simulating rainfall-runoff and combining it with mathematical modelling.

Mean-areal precipitation computation (X): Rainfall data measuring observations in or contiguous to the catchment has been used to calculate the average rainfall in the basin. There are many methods to calculate the average rainfall in the basin: Isohyetal Analysis, Thiessen polygonal, etc. The

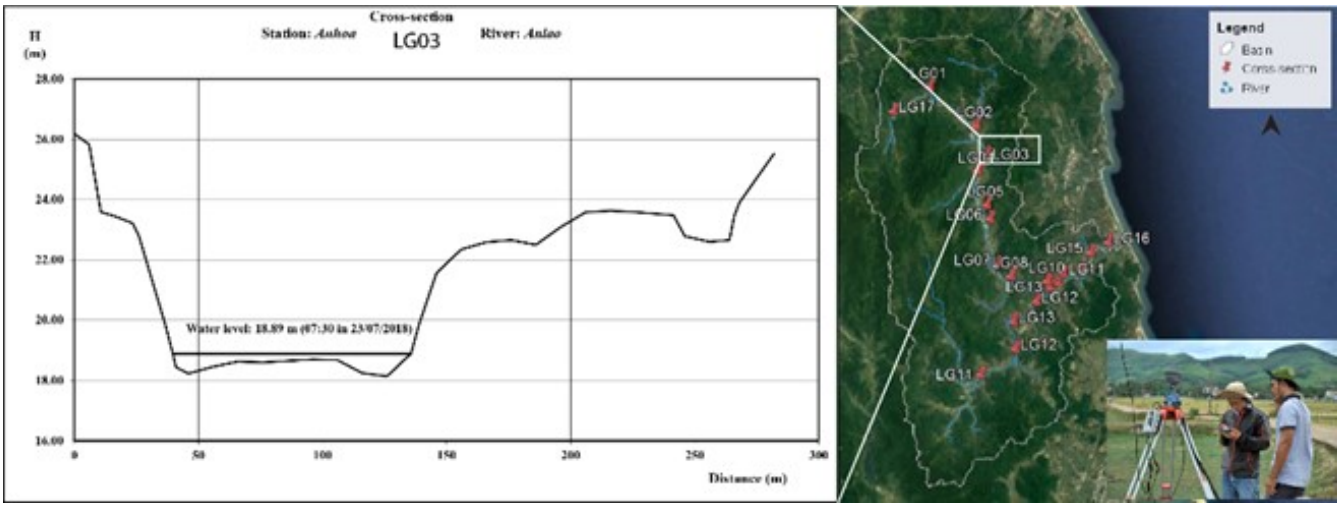

Figure 2. Measurement of a cross-section of the Laigiang riverbed at An Hoa station in 2018
Source: Photo by Tu Ngo Anh (2018)

Table 1. Obtained data at An Hoa station in December 2016 (14°34'39.81"N, 108°54'20.60"E)

Time (Date)	Data			Time (Date)	Data		
	Rainfall (mm)	Water level (m)	Flow rate (m^3/s)		Rainfall (mm)	Water level (m)	Flow rate (m^3/s)
1	256.40	22.52	837.00	17	28.00	21.83	479.00
2	137.00	22.02	564.00	18	11.20	21.27	293.00
3	42.40	21.56	379.00	19	19.90	21.21	276.00
4	43.20	21.64	406.00	20	0.50	20.93	213.00
5	85.00	21.69	426.00	21	0.00	20.75	177.00
6	134.70	22.39	756.00	22	4.60	20.60	151.00
7	111.60	22.05	574.00	23	26.00	20.56	142.00
8	121.00	22.14	664.00	24	14.80	20.54	139.00
9	0.90	21.25	289.00	25	0.50	20.40	119.00
10	0.00	20.96	219.00	26	0.00	20.31	105.00
11	7.40	20.80	186.00	27	8.50	20.24	96.10
12	79.80	21.20	281.00	28	4.10	20.17	86.60
13	80.70	21.31	315.00	29	4.00	20.12	80.00
14	108.20	21.31	306.00	30	16.20	20.11	79.40
15	800.80	22.83	1,020.00	31	36.70	20.36	112.00
16	195.10	23.05	1130.00				

Source: Binhdinh Hydro-Meteorological Station (2017)

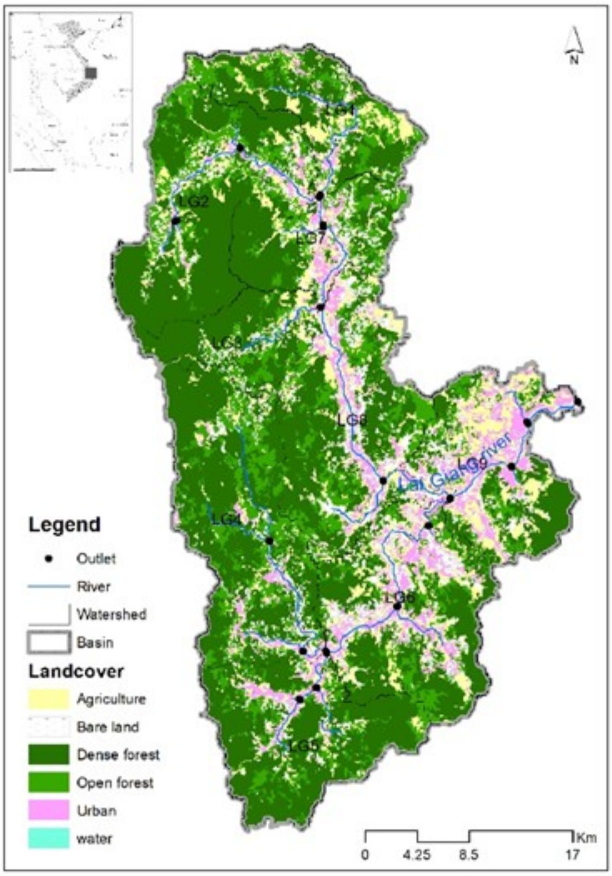

Figure 3. Land Use Land Cover Map of The Study Area

research has chosen the IDW-Inverse Distance Weighting, a deterministic spatial interpolation scheme first proposed by Shepard (1986), which appears to simulate mean-areal precipitation. Laigiang river basin has been divided into nine sub-basins, and mean-areal precipitation which has been calculated by the following formula (USACE, 2000):

$$X_{tb} = \frac{\sum_i (w_i \sum_i x_i(t))}{\sum_i x_i} \qquad (1.1)$$

Where X_{tb} = mean areal precipitation; xi(t) = precipitation measured at time t at station i; and wi = weighting factor assigned to station i.

Precipitation loss computation (): The loss is a consequence of precipitation absorbing by the surface cover, including plants in the watershed, and stored in the depression topography that eventually infiltrates or evaporates (Castro and Maidment, 2020). No runoff occurs until the accumulated precipitation on the previous area exceeds the initial loss volume (USACE, 2000).

The Soil Conservation Service (SCS) Curve Number (CN) models estimate precipitation excess, which was formed by USDA Soil Conservation Service in 1972—using the following equation (USACE, 2000).

$$Q = \frac{(R - I_a)^2}{R - I_a + S} \qquad (1.2)$$

Where Q = accumulated precipitation excess at time t (runoff); R = accumulated rainfall depth at time t (precipitation); Ia = the initial abstraction (or initial loss); and S = potential maximum retention.

Through many experimental consequents of the SCS, the relationship of Ia and S had determined: . Thus replacement gives:

$$Q = \frac{(R - 0.2)^2}{R + 0.8S} \qquad (1.3)$$

Besides, the maximum retention, S, are closely related to the curve number (commonly abbreviated CN) as (USACE, 2000):

$$S = \frac{25400 - 254CN}{CN} \qquad (1.4)$$

CN values vary from 0 to 100, CN=100 for waterproof surfaces or water bodies, CN <100 for natural surfaces (Deursen, 1995). The research area is absent of better information. Therefore, the study used estimates of infiltration rates for those soils published by Skaggs and Khaleel, 1982, as shown in Table 2.

Runoff transformation simulation (Y): To compute runoff transformation, the research has applied the Snyder Unit hydrograph model (USACE, 2000). The relevant parameters of this model include:

$$t_p = 0.75C_t(LL_c)^{0.3} \qquad (1.5)$$

Where tp: Basin lag time (defined as the time difference between the centroid of the excess rainfall time and the flood peak time); Ct: Basin coefficient (usually ranging from 1.8 to 2.2 (Bedient et al., 2008); L: Length of the mainstream from the outlet to the divide; Lc: Length along the mainstream from the outlet to a point nearest the watershed centroid; C: a conversion constant (0.75 for SI and 1.00 for foot-pound system).

Baseflow computation (qp): The study area has had a scarcity of information or data; therefore, to calculate groundwater flow, the constant monthly baseflow method being for each time step of the modelling has been applied. The study has consulted data about Laigiang river's constant monthly baseflow offered by Huong et al, (2005), detailed in Table 3.

Flow calculation (Qp): The Muskingum-Cunge method has been used to account for the flood wave movements across the river or reservoir section, based on the continuity equation and correlation between discharge and volume. The Muskingum-Cunge routing method is on the equations, followed by Miller and Cunge (1975).

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} = \mu\frac{\partial Q}{\partial x^2} + cq_L \qquad (1.6)$$

Where Q: inflow (m3/s), c: wave celerity (speed), μ: hydraulic diffusivity; = distance along the flow path/river, qL: lateral inflow.

The wave celerity and the hydraulic diffusivity are accounted as follows:

$$c = \frac{dQ}{dA} \quad \text{and} \quad \mu = \frac{Q}{2BS_0}$$

A: average cross-surface area, B: top width of the water surface, S0: friction slope (USACE, 2000).

Model calibration and validation: It is necessary to evaluate model performance for the range of its exactitude, consistency, and adaptability (Belayneh et al., 2020). Several statistical indices have been presented in the research for the performance assessment by determining the quality and reliability of simulation results, such as Correlation coefficient (R), Nash-Sutcliffe simulation efficiency (NSE), Percentage bias (PBIAS), Peak flow criterion (PFC). The equations, range, and excellent values of those indices are listed in Table 4.

3. Results and Discussion

Laigiang River Basin Delineation

The HEC-HMS has been used to simulate the hydrological processes in the catchment. The basin schematic, the flow direction data, location of hydrometric stations, and outlet in the Laigiang basin has been built. The represent schematic of the basin consists of many sub-basins, junctions, reaches, and the outlet.

The Laigiang river originates in the Northern mountainous region of the Anlao district. All over the basin has an average height of 300 m (fluctuates in approximately 400-825 m) and has an average slope of less than 22%. The Laigiang catchment is created by two sources, including the Anlao tributary and Kimson tributary, then they confluent at 1st Junction. All over this basin, there have been 9 sub-basins constructed to model the precipitation-runoff process of the Laigiang river (Fig.4).

The Average Rainfall Products of The Laigiang River Basin

The data of precipitation being input data in the study's model has been obtained from satellite-based rainfall estimation products, CHIRPS, during the date period in December 2016. Processing data through QGIS 3.12 has released the average precipitation result. The mean rainfall of this time from CHIRPS has been computed about 560.15 mm. In addition, the correlation coefficient has also been estimated to display the relationship between CHIRPS precipitation data and measured rainfall data in real-time at An Hoa station. As Figure 6 shows, with R2 being 0.85, there has been a significant correlation between the rainfall data of these two items. It shows better performance in rainfall data input for the HEC model.

Table 2. SCS soil groups and infiltration (loss) rates proposed by Skaggs and Khaleel (1982)

Soil Group	Description	Range of Loss Rates (cm/hr)
A	Deep sand, deep loess, aggregated silts	0.762 – 1.143
B	Shallow loess, sandy loam	0.381 – 0.762
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.127 – 0.381
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00 – 0.127

Table 3. Laigiang River's Constant Monthly Baseflow (Huong Nguyen Tan et al., 2005)

Month	1	2	3	4	5	6	7	8	9	10	11	12
q_p ($m^3.s^{-1}$)	15.3	10.2	6.59	5.2	6.12	5.75	4.75	4.3	8.07	46.2	58.8	28.6

Table 4. Indices Applied to Evaluate The Model Simulation Performance (Ji et al., 2020)

Statistical indices	Unit	Equation	Range	Perfect value
NSE	-	$NS = 1 - \frac{\sum_{i=1}^{n}(R_{0,i} - R_{m,i})^2}{\sum_{i=1}^{n}(R_{0,i} - \overline{R}_0)^2}$	-∞ ÷ 1	1
PBIAS	%	$PBIAS = \frac{\sum_{i=1}^{n}(R_{0,i} - R_{m,i})}{\sum_{i=1}^{n} R_{0,i}} X\ 100\%$	-∞ ÷ ∞	0
PFC	-	$PFC = \frac{(\sum_{i=1}^{np}(R_{0,i} - R_{m,i})^2 * R_{0,i}{}^2)^{0.25}}{(\sum_{i=1}^{n}(R_{0,i}))^{0.5}}$	-∞ ÷ ∞	0
R	%	$R = \frac{\sum_{i=1}^{n}(R_{0,i} - \overline{R}_0)(R_{m,i} - \overline{R}_m)}{\sqrt{\sum_{i=1}^{n}(R_{0,i} - R_o)^2 \sum_{i=1}^{n}(R_{m,i} - \overline{R}_m)^2}}$	-1 ÷ 1	1

Notation: n is the number of observations; Ro,i is observed streamflow, whereas Rm,i is the simulated streamflow, and Ro is the average value of Ro,i; np is the number of peak flows greater than one-third of the mean peak flow observed.

Losses by SCN CN

Based on equations from (1.2) to (1.4), flow loss estimated for the Laigiang river basin has been shown in Table 5. In sub-basins with high vegetation cover, such as Sub-basins of 1, 2, 3, 4 and 5, surface water capacity is much better than in sub-basins with little cover, mainly surface concrete surface of typical urban areas such as sub-basins 6 and 9. This shows that the role of the cover is very important in regulating flood flows.

Runoff Transformation Results

After calculating the precipitation losses, the Snyder Unit hydrograph method has been specified for transforming overland flow into surface runoff. Additionally, GIS technology has been used in conjunction to determine distances that have been the input parameters for estimating runoff volume (Table 6).

Table 6 shows that the time for the runoff transform in the sub-basins ranges from about 1.5h to 2.0h on average. In particular, sub-basin number 3 only reached 0.88h, and vice versa, sub-basin of 4 reached the largest 2.69h.

Flow Routing Results

Beds of Natural runoffs comprise unclassified sand, gravels, and rocks, so the bottom roughness of rivers is not uniform, affecting the water flow (Hubert Chanson, 2004). Hence, the Manning roughness coefficient-n has been determined for the research area by using Strickler's formula (K = 1/n). This empirical coefficient depends on many factors, including the surface roughness (nature of the vegetation cover and bare surfaces) and sinuosity (Tinkler, 1997; Hubert Chanson, 2004). Table 7 performs the range of values K. The value of n in the Laigiang river ranges from 0.025 to 0.065. Upstream of the river, the value of n is usually between 0.04 and 0.065, and in the lower part of the river, there is a system of the concrete embankment/ canal and average condition.

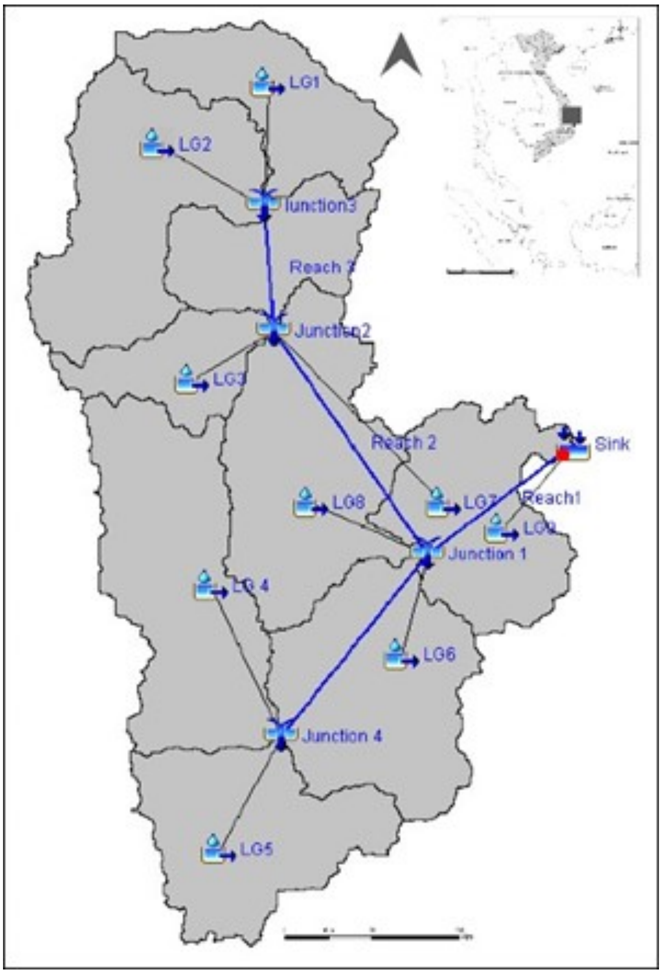

Figure 4. Schematic Model of Laigiang River Basin

It could be noticed that the tendency and shape of simulated and observed hydrographs have been closely similar. This result shows that the flood peak at An Hoa station has had a maximum flow volume reaching 2542.60 m3.s-1 was on December 15, 2016. This result has been practically verified by surveying and reconnoitring the peak flood time from 20:00 to 22:00 on the same day. Additionally, the figure for precipitation of situ gauge was about 800.80 mm; meanwhile, that for rainfall of CHIRPS satellite was marginally higher with just roughly 868.30 mm.

Model Validation

The model has been applied to run for December's daily rainfall-runoff data in 2016. The output of the simulated

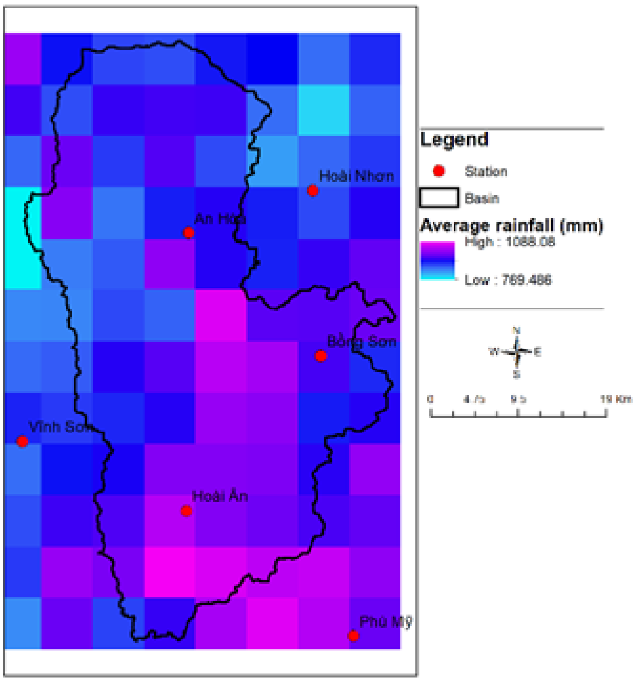

Figure 5. The Average Rainfall of The Laigiang River Basin in December 2016

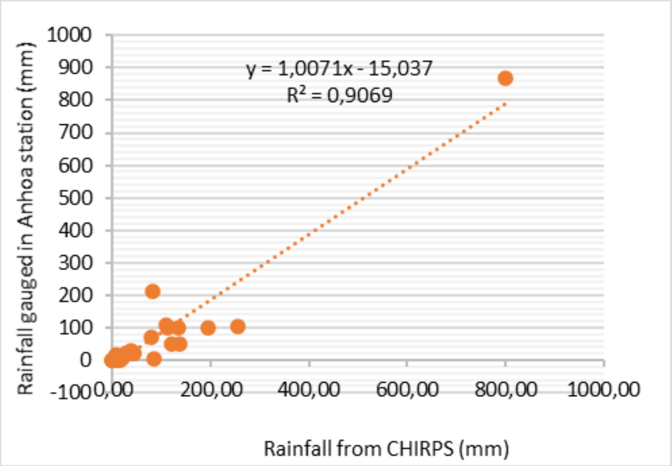

Figure 6. Correlation Between Average Values of Satellite Data and Gauge Values

Table 5. Input Parameters for Losses from The Rainfall Used in Modelling of the Laigiang River

Sub-basins	A_i (km^2)	CNi-Mean	Potential maximum retention-S	Initial loss-I_a
1	114.4	80	63.5	12.7
2	197.1	81	59.6	11.9
3	71.7	80	63.5	12.7
4	217.8	80	63.5	12.7
5	161.5	85	44.8	9.0
6	192.2	75	84.7	16.9
7	96.2	78	71.6	14.3
8	204.7	75	84.7	16.9
9	148.2	70	108.9	21.8

Table 6. Input Parameters for The Runoff Transform of The Laigiang River

Sub-basins	Parameters			
	L_{ci} (km)	L_i (km)	C_t	t_p (h)
1	7.60	10.08	0.70	1.93
2	10.00	20.27	0.60	2.21
3	5.00	1.84	0.60	0.88
4	12.40	18.60	0.70	2.69
5	7.60	5.89	0.60	1.41
6	10.40	25.76	0.40	1.61
7	5.70	11.73	0.50	1.32
8	10.10	25.18	0.40	1.58
9	8.00	15.89	0.40	1.28

Notation: L_i: Length of the mainstream from the divide to the outlet of sub-basin i; L_{ci}: Length along the mainstream from the

hydrograph has been validated by comparing the flow simulation results with the flow results observed at the Anhoa station is shown in Figure 8 and Figure 9.

The NSE and R2 have been 0.95 and 0.87, respectively. These results have indicated a high agreement between the data sets for the validated period. Other parameters have been determined, with PBIAS at 0.45 and PFC at 0.89 during validation periods. The model has apprehended well the daily time series of runoff and the trend during validation periods. Hence, it can be confirmed that the flood simulation results in the Laigiang river basin have been quite accurate in 2016.

Model Calibration

Table 8 provides calibrated model parameters values for loss, transform and base flow methods assumed in the HEC-HMS and run with precipitation data from CHIPRS. The optimization was tested at Anhoa hydrological station.

The calibrated model parameters from Table 8 was then used in the validation phase. The preliminary results indicate that the performance of the HEC-HMS model is satisfactory when the model is run with variable values of the optimized parameters. Figure 10 presents the observed and simulated hydrographs for the validation events in December 2016 of the Laigiang river basin.

The visual inspection of the simulated hydrographs (Fig. 10) shows that they fit well to the observer for the simulations based on CHIRPS data are used. In particular, the flood peaks between the simulation data are quite similar to the observed.

4. Conclusion

In this paper, the study has successfully applied the simulation conversion of precipitation and flow data to restore flood flow data at the Laigiang river basin in 2016, based on rainfall from CHIPRS source combined with HEC-HMS. The study results show that the flood process line has been relatively consistent with the actually measured results; the model validation has evaluated quite good results and is very satisfactory.

This shows the prospect of applicability satellites precipitation to restore flow data for other basins without rain-gauging and flow stations in Vietnam and can apply the

Table 7. Values of K coefficient (Tinkler, 1997; Sepaskhah and Bondar, 2002)

Flow characteristics	K coefficient ($m^{1/3}/s$)
The concrete embankment/canal, extreme smooth	75 ÷ 100
The concrete embankment/canal, average condition	50 ÷ 75
Soil canal	30 ÷ 50
River with pebble, straight and section uniform	40 ÷ 50
River with meander, sinuosity	30 ÷ 40
River with obstacles	20 ÷ 30

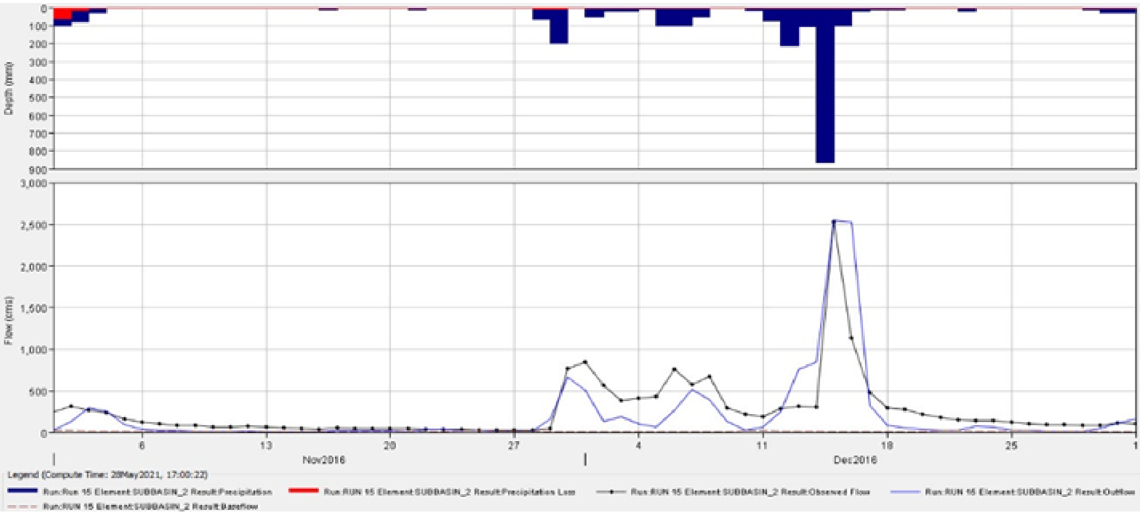

Figure 7. Observed Rainfall and Runoff Simulated Hydrograph at An Hoa Station (30/11 ÷ 31/12/2016)

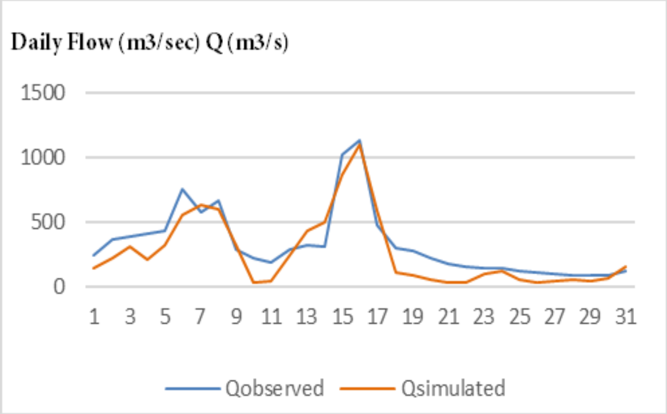

Figure 8. Comparison of Measured with Simulated Hydrograph for Validation from 1 to 31/12/2016

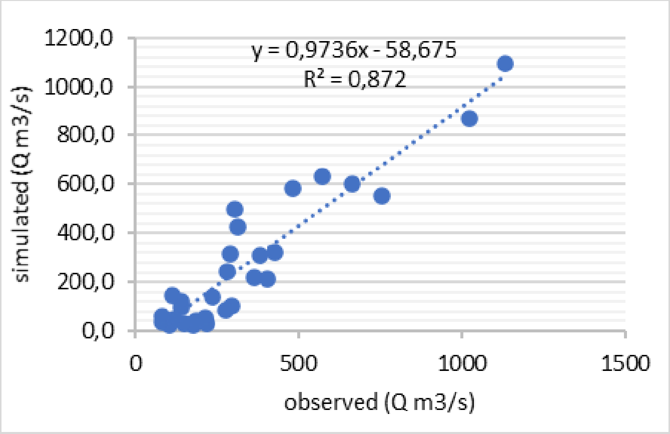

Figure 9. Correlation of Measured Real Flow with The Simulated Flow

results of this study to other basins in the World. In addition, the accuracy of the simulation is highly dependent on the input databases such as river bed cross-section density, base flow, ground cover, and especially topography that needs to be updated on a large scale.

The use of HEC-HMS to simulate the shape of the flooding process often depends on the shape of the designed rain process with each parameter of rain, watershed such as slope or vegetation cover for different rainfall patterns, and different flood peaks. The time from the appearance of the rain peak to the appearance of the flood peak is also affected.

Future research and development direction of this paper needs to integrate rain data of satellite images with rain data from ground monitoring stations to improve accuracy. In addition, the HEC-HMS model needs to combine early warning systems and water level monitoring technologies such as IoT.

Acknowledgements

The study results have been part of the Ministry-level scientific research topic, "Research and application of rainfall data from radar satellite images and mathematical models in flood risk prediction. Case study of Laigiang river basin, Binhdinh Province", with code being B2020-DQN-03 chaired by Quy Nhon University.

4.Conclusion

In this paper, the study has successfully applied the simulation conversion of precipitation and flow data to restore flood flow data at the Laigiang river basin in 2016, based on rainfall from CHIRPS source combined with HEC-HMS. The study results show that the flood process line has been relatively consistent with the actually measured results; the model validation has evaluated quite good results and is very satisfactory.

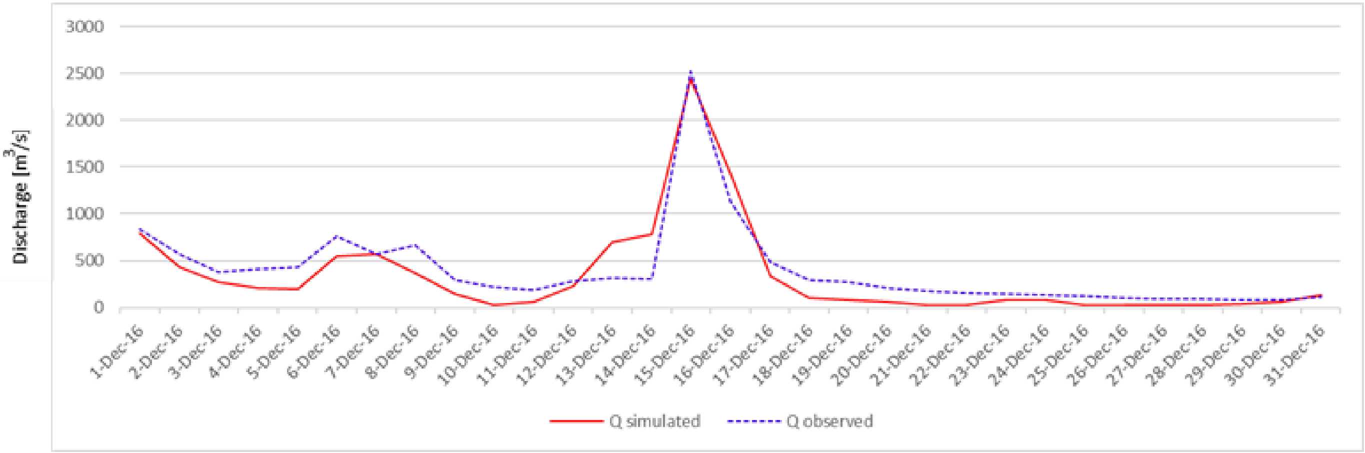

Figure 10. Comparison of Simulated and Observed Hydrographs for The Validation Events December 2016

This shows the prospect of applicability satellites precipitation to restore flow data for other basins without rain-gauging and flow stations in Vietnam and can apply the results of this study to other basins in the World. In addition, the accuracy of the simulation is highly dependent on the input databases such as river bed cross-section density, base flow, ground cover, and especially topography that needs to be updated on a large scale.

The use of HEC-HMS to simulate the shape of the flooding process often depends on the shape of the designed rain process with each parameter of rain, watershed such as slope or vegetation cover for different rainfall patterns, and different flood peaks. The time from the appearance of the rain peak to the appearance of the flood peak is also affected.

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