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Application of a rainfall-runoff model for flood generation in the Huai Sangka catchment, Thailand

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Abstract

Estimation of the rainfall-runoff relationship is essential for solving and managing water resources. This paper presents the use of an event-based rainfall-runoff model built with HEC-HMS version 4.3 to simulate runoff in the Huai Sangka catchment (193 km^2), a small agricultural watershed. The rainfall-runoff model was conducted by a semi-distributed modelling approach, where parameter values of sub-basins were estimated based on spatial and temporal data such as topography, land use, soil and climatic variables. The modelling approach includes Soil Conservation Service (SCS) Curve Number, SCS unit hydrograph and Muskingum routing methods for simulating losses, runoff transformation, and routing in the rainfall-runoff system, respectively. The rainfall-runoff model was used to simulate runoff with corresponding to four extreme rainstorm events (in September 2007, September 2008, August 2011 and July 2017). The present study aimed at testing the applicability of the modelling approach to ungauged basins. Thus, only travel time parameter K of the Muskingum routing method was adjusted to achieve reasonable reproductions of major flood hydrographs. The other parameters, which were initially estimated from the spatial data, were remained constant. On the basis of event-based runoff simulation results, the largest percentage error in peak was 12.96%, considered satisfactory. The comparison of the observed and simulated hydrographs confirmed the reliable performances of the rainfall-runoff model with NSE values, ranging between 0.61 and 0.74 and with RSR values, ranging between 0.51 and 0.57 for the selected rainstorm events. Thus, the model was considered suitable for flood simulations in the study catchment. Furthermore, it was found that the travel time parameter K is strongly related to physical characteristics of channels. In summary, the modelling approach is applicable to ungauged watersheds since model parameters can be estimated on the basis of physical characteristics.

Keywords: Flood, HEC-HMS, Hydrological model, Muskingum routing, SCS Curve number method, Ungauged basin

1. Introduction

Runoff information is one of the most important hydrological elements used for water resources planning and management. In some regions where runoff information has been regularly measured, runoff variables such as runoff volume and discharge can be simply estimated by using water level-discharge relationships [1]. However, in the regions where runoff information remains insufficiency, the estimation of the runoff variables is a challenging task and requires an adequate understanding of rainfall-runoff systems [2].

Over recent decades, hydrological models have gained some advantage from remote sensing (RS) and geographic information systems (GIS) [3]. The RS plays a fundamental role in providing spatial and temporal information for the models such as elevation, land use, vegetation, soil and climatic variables. This information can be stored as a georeferenced database and analysed by GIS tools. The integrated RS and GIS applications enhance the capability of capturing and managing a quantitative amount of data. By applying RS and GIS techniques, spatial and temporal information on hydrological variables can be served as input into hydrological models. Therefore, hydrological models have been extensively used for various research and management purposes [4, 5].

According to Beven [6], the existing hydrological models for runoff simulation are classified into two basic categories: lumped and distributed models. Lumped models remain a reliable tool for flood forecast and simulation because of the simplified structure, computational efficiency and low data requirements. However, they are not suitable for application in complex basins due to their coarse resolution, which physiographical conditions over a watershed are assumed to be uniform distribution [5]. Thus, some lumped models have been extended to provide the facilities and capabilities for taking in account the spatial parameters as input. An extended version of a lumped model is now considered as a semi-distributed or distributed hydrological model [7]. Distributed hydrological models divide the entire basin into a large number of elements with diverse hydrological response units. One of them represents the uniqueness of combined land use, soil properties and topography [8]. As a result, distributed hydrological models can account for spatial variability of hydrological and physiographical characteristics within a sub-basin.

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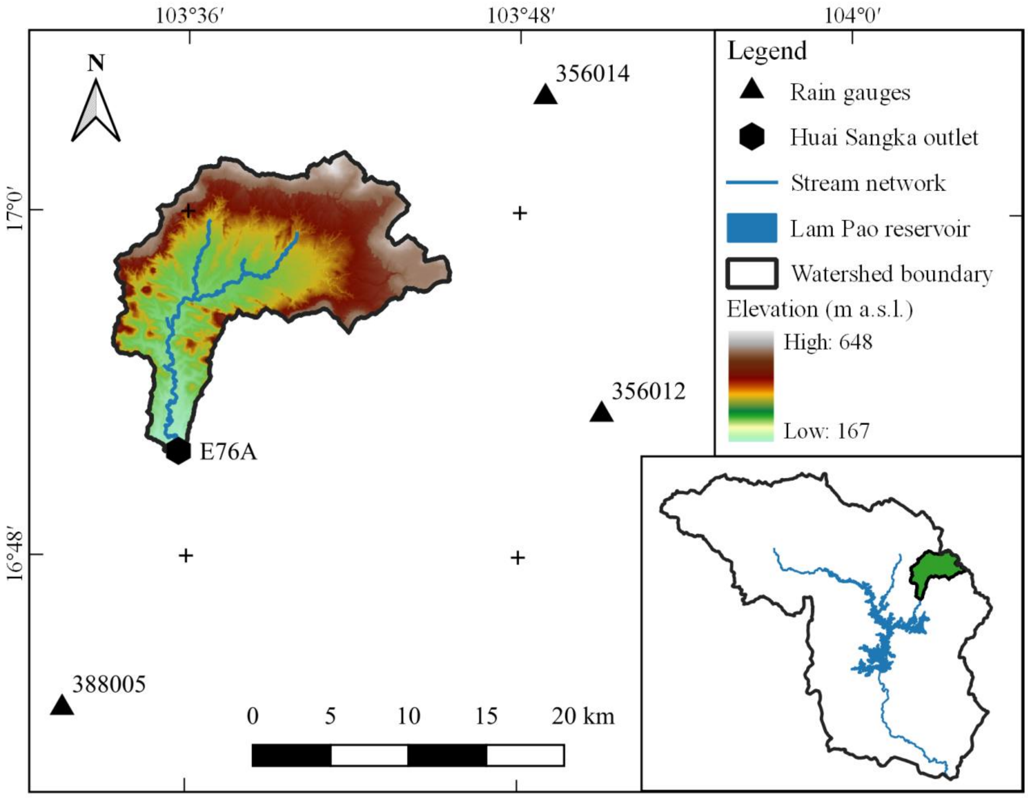

Figure 1 Location of Huai Sangka catchment with rain gauge stations

The suitability of a model in handling a specific task is based on data availability, process complexity and study objectives. Deciding whether a model is reliable may be based upon calibration and validation results [4]. In data-spare conditions such as missing runoff data, Moore et al. [9] claimed that the physically-based distributed models may provide more reasonable results than the lumped models. In contrast, less complex conceptual lumped models are often used in gauged and ungauged basins since they have shown to be equally reliable to the complex ones [6, 7, 10]. Hence, it remains unclear that whether the application of more complex models for flood prediction in ungauged basins has much advantage over the application of simplified models [7, 11].

In the context of flood prediction, several hydrological models have been applied [12]. One of these models, which notably applied in various parts of the world, is the HEC-HMS developed by the US Army Corps of Engineers Hydrologic Engineering Centre [13]. In addition, the HEC-HMS model has been tested for flood simulation in diverse geographical areas, for instance, large river basins and small agricultural or urban catchments [14, 15]. The HEC-HMS model appears to be the most popular tool due to its capacity in runoff simulation both in short and long time events, the use of many common hydrological methods, and the use of different approaches for modelling. The approaches implemented into the HEC-HMS model are lumped and distributed modelling systems, which can be chosen on the basis of research objectives [13].

Results of the HEC-HMS model are based a combination of hydrological methods, which can consist of the loss methods, transform methods, baseflow separation approaches, and channel routing techniques. According to the study by Nadalal and Ratmayake [16], for instance, a combination of initial and constant-rate, Clarks unit hydrograph, recession, and lag and Muskingum routing methods provided reasonable results, which was able to simulate flood peaks at the Kalu-Ganga River basin, Sri Lanka. Another example is the application of the HEC-HMS model to tropical regions by Halwatura and Najim [15]. They obtained satisfactory results using a combination of deficit and constant loss, Snyder unit hydrograph to generate long time flow in the Attanagalu Oya catchment. Moreover, many recent studies (e.g. [14, 17]) have gotten reliable results from a combination of the Soil Conservation Service (now Natural Resources Conservation Service (NRCS)) Curve Number (SCS-CN) loss, SCS unit hydrograph and Muskingum routing methods.

Though the HEC-HMS model has been applied and evaluated worldwide, little effort has been made to investigate rain-induced flood events in small catchments of Thailand. The Huai Sangka catchment, a small sub-basin of the Lam Pao basin, has extensive agricultural practices and unpredicted flood events. An accurate estimation of flood peaks and their arrival is vital in issuing flood warnings to the public and taking effective flood defence.

This study is mainly conducted to develop a rainfall-runoff model by using the HEC-HMS version 4.3 and evaluate its applicability to runoff prediction in the Huai Sangka catchment. This catchment was selected because there is a gauging station located at its outlet, which has been used for flood monitoring in the Lam Pao basin. The gauging station operated by the Royal Thai Department (RID) has recorded streamflow information on an hourly basis, which is useful for flood modelling studies in small basins. To develop the rainfall-runoff model, the HEC-HMS model was performed by using a semi-distributed modelling approach, where parameter values can be estimated based upon physiographical characteristics of sub-catchments and channel sections. The methodology developed for this study can be adopted for accomplishing similar kinds of studies in future.

2. Materials and methods

2.1 Study area description

The Huai Sangka catchment selected for this study is a headwater of Lam Pao watershed located in the northeastern region of Thailand (Figure 1). The selected study area extends between 16° 51′ N and 17° 2′ N latitudes and 103° 33′ E and 103°

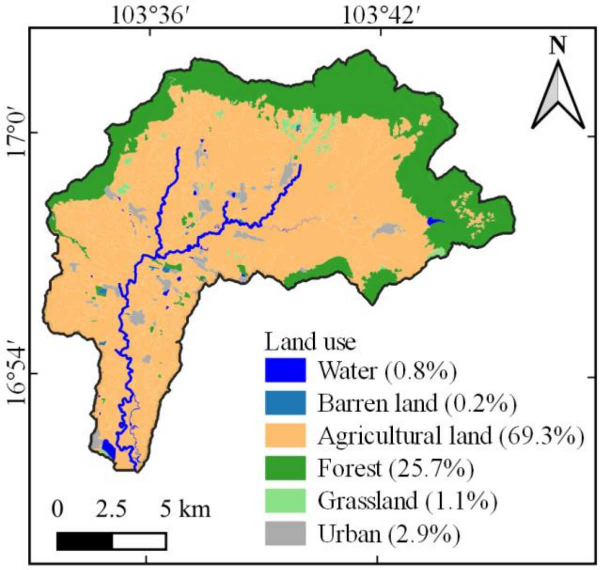

Figure 2 Land use map of Huai Sangka catchment

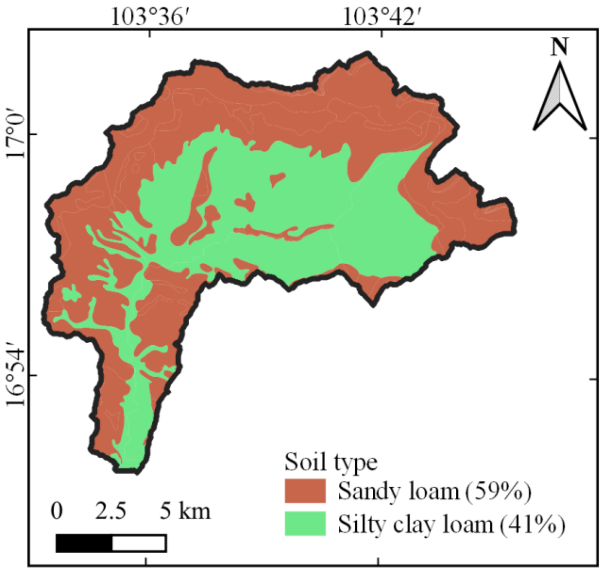

Figure 3 Soil map of Huai Sangka catchment

45′ E longitudes, which covers an area of approximately 193 km^2. The predominant land use is agricultural land, which accounted for 69.3% of the total catchment area. The other land use types are forest areas (25.7%), urban areas (2.9%), grassland (1.1%), water surface (0.8%) and barren land (0.2%) in the catchment as shown in Figure 2. Soils of the catchment are characterized by sandy loam (59%) and silty clay loam (41%) textures (Figure 3). The downstream areas of this catchment have gentle slopes (< 7%), while the upstream part has a rugged topography. The altitude ranges from 167 m to 648 m above sea level (a.s.l.). The main stream is Huai Sangka, which runs from North-East to South, and drains into Lam Pao River. The length of the main stream is about 22 km. According to rainfall observations of the Thai Meteorological Department (TMD), the Huai Sangka catchment has a tropical climate with average annual rainfall of 1290 mm (1998-2017), more than 85% of which falls in the rainy season (May to September).

The Huai Sangka catchment was chosen because it is a small basin, which can have a high potential for flash flood occurrence [18]. If such an event happens, it can cause loss of life and damage to buildings because of the short time for warning and reacting [7]. In developing and emerging countries, runoff data at small basins are often not recorded. However, observed hourly runoff information has been available since 1999 at the Kham Muang gaging station (E76A) located at the outlet of the Huai Sangka catchment. Therefore, this catchment can be a useful case study for imitating rainfall-runoff generation process for the small basins.

2.2 Data collection

Daily rainfall data from the January 1, 2007 to the December 31, 2017 were collected from the three rain gauge stations, namely Sang Kho (356012), Kut Bak (356014), and Sahatsakhan (388005), which were in the vicinity of Huai Sanka catchment as shown in Figure 1 and Table 1. These stations have been monitored by the TMD. Water level observations at the Kham Muang gauging station (E76A) obtained from the RID were recorded at hourly intervals. These water level observations can be used to estimate discharge hydrographs by using the local rating curves.

Spatial data required to construct the rainfall-runoff model were digital elevation model (DEM), land use and soil type maps collected from the Land Development Department (LDD) in Thailand. The DEM has a spatial resolution of 30 m. The land use and soil type maps were available on a scale of 1:50,000.

2.3 Spatial data analysis and preparation

Prior the application of the rainfall-runoff model, pre-processing of the temporal and spatial data was performed by Quantum geographic information system (QGIS). The temporal data were daily rainfall observations collected from the three rain gauges. Some of their missing data were filled by taking the average of rainfall data from neighbouring stations. The rainfall data were averaged based on the inverse distance weighting method and then were used to fill the missing data of the three rain gauges. Owing to the lack of a rain gauge in each sub-basin of the Huai Sangka catchment, spatial variation of rainfall data was estimated by using the Thiessen Polygon method in the QGIS from the three rain gauges.

The spatial data used in this study consisted of the DEM data, land use map and soil type map. The DEM data were spatially analysed by the QGIS in order to compute physiographical characteristics of the Huai Sangka catchment. The area of this catchment was subdivided into 15 sub-basins as shown in Figure 4. These sub-basins were linked by seven routing reaches, which represent the longitudinal sections of the main channel. Afterwards, the physiographical characteristics of these sub-basins such as stream network, river slope, sub-basin boundaries and basin slope were created.

In addition, the gridded runoff curve number (CN) information was spatially calculated based on land use types and hydrological soil groups [13, 19]. Soils of the Huai Sangka catchment were classified into four hydrological soil groups based on infiltration rates and other characteristics. In the calculation of CN, the land use map and the hydrological soil groups were combined and then the gridded runoff CN map was produced as shown in Figure 5. Afterwards, the averaged CN values of the sub-basins were addressed.

In the following processes, the physiographical characteristics and the averaged CN information were used to estimate hydrological parameters of the Huai Sangka catchment for rainfall-runoff modelling.

2.4 Rainfall-runoff modelling

HEC-HMS (Hydrologic Engineering Center-Hydrologic Modelling System) developed by US Army Corps of Engineers was selected for rainfall-runoff modelling of the study catchment. It is a physically-based and conceptually semi-distributed model,

Table 1 Data inputs for the HEC-HMS model in this study (note: Thai Meteorological Department (TMD), Royal Thai Department (RID) and Land Development Department (LDD))

Data type	Resolution	Description	Source
Rainfall	Daily	Rainfall data observed at 3 stations (Sang Kho, Kut Bak, Sahatsakhan) between 2007 and 2017	TMD
Streamflow	Hourly	Water level data observed at the E76A station between 2007 and 2017	RID
DEM	30 m x 30 m	Digital elevation model in 2015	LDD
Land use	1:50,000	Land use in 2015	LDD
Soil	1:50,000	Soil type classification in 2015	LDD

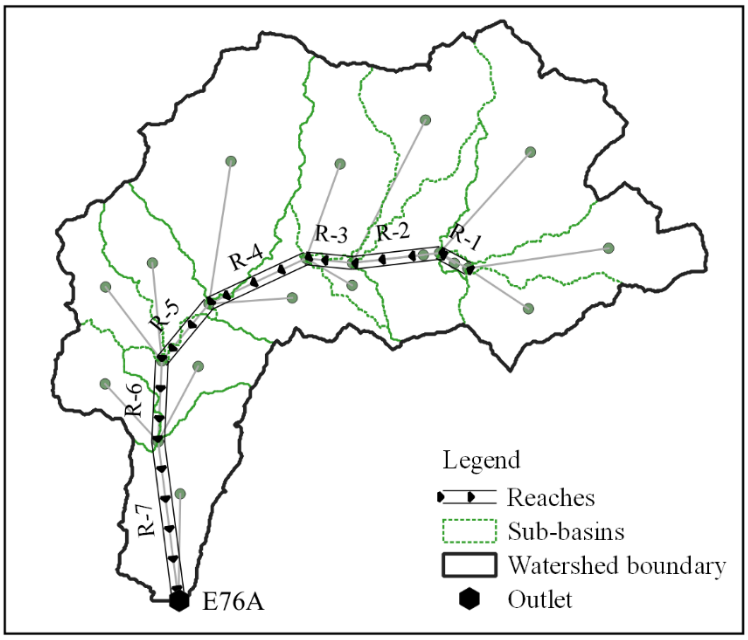

Figure 4 Basin model of Huai Sangka catchment

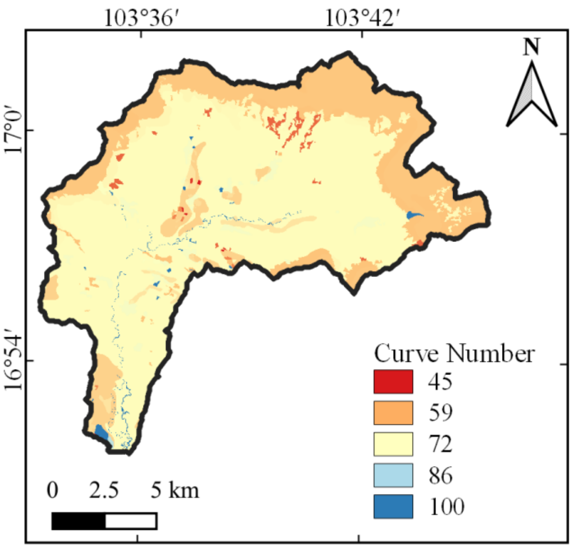

Figure 5 Curve Number map of Huai Sangka catchment

which has been widely applied in a wide range of geographic and climatic regions (e.g. [14, 17, 20]).

The HEC-HMS model computes runoff volume through several components of runoff generation which include losses, runoff transform and runoff routing from the precipitation. In the HEC-HMS software, there are different loss methods, namely initial and constant-rate, deficit and constant rate, SCS curve number, Green and Ampt, Smith Parlange, and Soil Moisture Accounting models, which can be chosen for estimating losses. The HEC-HMS model also has an assortment of runoff transform methods, for instance, Clark UH, kinematic wave, ModClark model, SCS UH, Synder UH, user-specified graph, and user-specified UH. Several methods, which are incorporated as routing runoff to basin outlets, are kinematic wave, lag, modified Puls, Muskingum, Muskingum-Cunge, normal depth, and Straddle Stagger models [13].

2.4.1 Selection of rainfall-runoff methods

To construct the rainfall-runoff model for simulating runoff hydrographs, we considered three main components of runoff generation, which can be estimated by loss, runoff transform, and runoff routing methods implemented in the HEC-HMS model.

1) Loss method

SCS curve number (SCS-CN) method was chosen for determining the hydrologic loss rate because the computation of its parameters is a straightforward procedure based upon land use and hydrological soil group maps. The SCS-CN method assumes that the excess precipitation is a function of cumulative precipitation, soil, land use, and previous moisture conditions. The depth of excess precipitation or direct runoff can be estimated in the following empirical equation:

$$Q = \frac{(P - I_a)^2}{P - I_a + S_r} \quad (1)$$

where Q is excess precipitation or direct runoff [mm]; P is accumulated precipitation [mm]; I_a is the initial abstraction [mm]; and S_r is potential maximum retention [mm].

According to the Natural Resources Conservation Service [19], the maximum retention and curve number are related by

$$S_r = \frac{25400}{CN} - 254 \quad (2)$$

in which CN is runoff curve number ranging from 100 for water bodies to about 30 for permeable soil with high infiltration rates.

In addition, the initial abstraction was found to be approximately 20% of the potential maximum retention for small watersheds [19].

2) Runoff transform method

The transformation in the HEC-HMS software is referred to the process, where excess precipitation is converted into direct runoff on a watershed. In this study, this transformation was accomplished using the SCS UH method. It is based on the average unit hydrographs derived from gauged rainfall and runoff information of many large and small rural watersheds [19]. The reason of selecting the SCS UH method was that it required only the lag time parameter as input. This parameter is defined as the time period between the centroid of precipitation mass and the peak of the runoff hydrograph. For ungauged and small watersheds, the Natural Resources Conservation Service suggests that the lag time (T_{lag}) may be empirically related to time of concentration (T_c) by

$$T_{lag} = 0.6T_c \quad (3)$$

where T_{lag} and T_c are in minute.

The time of concentration was estimated by using Kirpich's formula, which was derived based on physiographical characteristics of small agricultural watersheds [1]. The Kirpich's formula can be expressed as follows:

$$T_c = 0.0195 \times L^{0.77} \times S^{-0.385} \quad (4)$$

where T_c is the time of concentration [min]; L is the length of the main stream [m]; and S is the average slope of the main stream [m/m].

3) Runoff routing method

Runoff routing methods can be used to predict the temporal and spatial variations of a flood wave through channel reaches. The Muskingum method, a lumped system model developed by McCarthy [1], was chosen in this study because it has been widely used in gauged and ungauged watersheds [17].

The Muskingum method is on the basis of the continuity equation and a storage relationship between inflow and outflow in the channel reach [1]. This method assumes that the channel storage volume of the flow is linearly related to the discharge at the section. The linear relationship between the volume of storage and the discharge can be expressed as

$$W = K[XI + (1 - X)Q] \quad (5)$$

in which W is the total storage of water [m^3]; K is the travel time constant of the flood wave through routing reach [hr]; X is dimensionless weight, which varies from 0 to 0.5 for a given reach [-]; I is inflow [cms]; and Q is outflow [cms].

In this study, the dimensionless weight (X) of the Muskingum routing model was set to 0.2 suggested by Subramanya [1] for natural streams. The travel time of the flood wave, here called the travel time parameter K, was obtained by applying both manual and automated calibration techniques [13].

2.4.2 Sensitivity analysis of model parameters

A sensitivity analysis is necessary process to determine which model parameters have the greatest impact on the simulation results. The understanding of sensitive parameters is useful in model calibration where we attempt to fit the simulation results with observed data [17]. In the rainfall-runoff model of this study, there were six main parameters, namely initial abstraction, CN, impervious areas, lag time, the dimensionless weight (X) of the Muskingum routing model and the travel time parameter K. In the sensitivity analysis, four of them, which were initial abstraction, lag time, the dimensionless weight (X) and the travel time parameter K, were chosen because of the following reason. This study aimed not only to develop the rainfall-runoff model for runoff prediction in the Huai Sangka catchment, but also to propose the modelling approach for estimating runoff in ungauged basins. The parameter CN and impervious areas depend on land use and soil types, which are normally different from one area to another. To estimate values of the parameter CN, the relationships between land use types and hydrological soil groups, which were developed from many regions, have been frequently used [1, 19]. As aforementioned, attempts made in this study to improve the modelling approach for ungauged basins. Therefore, values of these two parameters were obtained from the local land use and soil types in order to reduce the complexity of the model [10]. The other parameters (initial abstraction, lag time, the dimensionless weight (X) and the travel time parameter K) were considered in the sensitivity analysis.

In the present study, the local sensitivity analysis, which individually evaluates the effect of each input parameter by keeping other parameters constant, was conducted. The values of the four model parameters, namely initial abstraction, lag time, the dimensionless weight (X) and the travel time parameter K, were changed in the range of 15% with a 5% interval and their effects on peak discharge were analysed.

2.4.3 Model calibration and validation

Calibration and validation are necessary to make sure that the rainfall-runoff model is reliable for simulating runoff and its components. Parameters for each hydrologic method of the model should be entered as input values. Some of the parameters may be computed from physiographical characteristics of basins and channel reaches, but some of them can only be estimated by using trial-and-error methods or optimization techniques due to the lack of measurement. In this study, parameters for each sub-basin such as initial abstraction, curve number, impervious areas and lag time were estimated and extracted from its physiographical characteristics. Values of these parameters were fixed throughout the calibration and validation procedures. For the routing parameters of the channel reaches, the value of 0.2 was selected for the dimensionless weight and values of the travel time of the flood wave were adjusted to produce a best fit between simulated and observed hydrographs. In this study, two flood events that occurred in September 2007 and 2008 were selected for a calibration purpose. Another two flood events that occurred in August 2011 and July 2017 were chosen for validating the rainfall-runoff model. The events were chosen for calibration and validation because they are the four largest (highest peak discharge) events observed at the E76A gauging station during the period 2007-2017.

The rainfall-runoff model was applied in a mode of event-based simulations. Therefore, rainfall events were separately analysed and used to compute runoff hydrographs. During calibration and validation, observed daily rainfall data were transformed by the model into simulated runoff hydrographs. The performance of the model was evaluated by statistically comparing the relation between the simulated and observed runoff hydrographs in hour intervals.

2.5 Criteria for model evaluation

From the scientific point of view, a combination of different statistical indices is recommended for the model performance evaluation [21]. Multiple statistical indices used in this study were based on Nash-Sutcliffe Efficiency (NSE), RMSE-observations Standard deviation Ratio (RSR) [22] and the percent error in peak (PEP) [13]:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(SIM_i - OBS_i)^2}{\sum_{i=1}^{n}(OBS_i - \overline{OBS})^2} \quad (6)$$

$$RSR = \frac{RMSE}{STDEV_{OBS}} = \frac{\sqrt{\sum_{i=1}^{n}(OBS_i - SIM_i)^2}}{\sum_{i=1}^{n}(OBS_i - \overline{SIM})^2} \quad (7)$$

$$PEP = \frac{(OBS_{peak} - SIM_{peak})}{OBS_{peak}} \times 100\% \quad (8)$$

where OBS_i is the observed discharge at time i [cms]; $\overline{OBS}$ is the mean of observed discharge [cms]; SIM_i is the simulated discharge at time i [cms]; $\overline{SIM}$ is the mean of simulated discharge [cms]; n is the length of the time series; $RMSE$ is root mean square error [cms]; $STDEV_{OBS}$ is the standard deviation of observed discharge [cms].

Since peak flow was the main focus in the present study, the percent error in peak was used as a major objective function during model calibration and validation. The simulation results of the model are satisfactory when the absolute values of PEP are less than 20% [23]. In addition, model performance was evaluated based on NSE and RSR. Performance evaluation criteria of these statistical indices are presented in Table 2.

3. Results and discussion

3.1 Sensitivity analysis

The sensitivity analysis of the rainfall-runoff model was performed on the four model parameters, namely initial abstraction, lag time, the dimensionless weight (*X*) and the travel time parameter *K* as described in Section 2.4. The effect of each input parameter on peak discharge at the catchment outlet was separately assessed by changing values of the parameter and keeping other parameters constant. The values of the four model parameters were changed from -15% to 15% with a 5% interval. Figure 6 shows how the values of peak discharge change with corresponding to the different parameters, which are initial abstraction (I_a), lag time, the dimensionless weight (*X*) and the travel time parameter *K*. For example, the zero change in the parameter lag time corresponds to the initial values in the model, which were computed using empirical equations as previously explained in Section 2.4. From the chart, it is apparent that the travel time parameter *K* is the most sensitive parameter, which was considered as the key parameter for model calibration in the present study.

3.2 Calibration and validation

The successful application of any conceptual rainfall-runoff model is dependent on the quality of data, the selection of methods and accuracy of calibration and verification processes. In the present study, the rainfall-runoff model built with HEC-HMS was calibrated for the event-based simulation. As previously mentioned, this study was designed to develop a rainfall-runoff modelling approach that can be applied to gauge and ungauged catchments. Prior studies have noted that uncertainties on model simulations can be decreased by a reduction of the number of model parameters [11]. Therefore, a combination of simplified and well-known approaches, namely the SCS curve number loss, SCS unit hydrograph and Muskingum routing methods, was chosen for flood simulations. In the present study, only the travel time parameter *K* was calibrated since it was found to have greatest impact on simulated peak discharges of the model during the sensitivity analysis. The other parameters were initially estimated from the physiographical characteristics of the study basin as described in Section 2.4. Thus, estimated values of these parameters were not changed during the calibration.

Table 2 Performance evaluation criteria [22]

Evaluation statistic	Performance evaluation criteria			
	Very good	**Good**	**Satisfactory**	**Unsatisfactory**
NSE	NSE > 0.8	0.7 < NSE ≤ 0.8	0.5 < NSE ≤ 0.7	NSE ≤ 0.5
RSR	0.0 ≤ RSR ≤ 0.5	0.5 < RSR ≤ 0.6	0.6 < RSR ≤ 0.7	RSR > 0.7

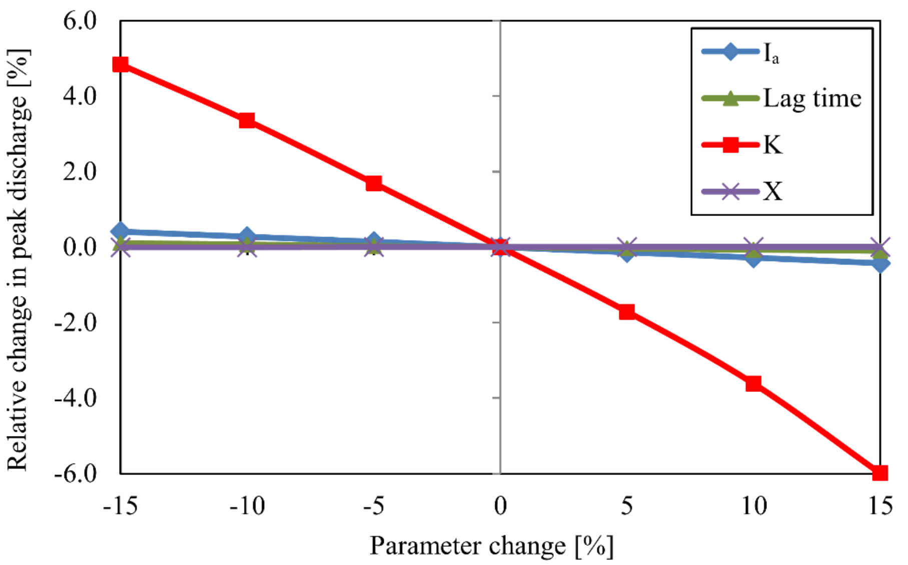

Figure 6 Effect of model parameters on peak discharges

Table 3 Lengths and slopes of channel reaches and their calibrated values of the travel time parameter *K*

Reach code	R-1	R-2	R-3	R-4	R-5	R-6	R-7
Length [km]	1.28	4.09	2.08	4.71	3.49	3.29	8.02
Slope [-]	0.00148	0.00138	0.00123	0.00089	0.00077	0.00105	0.00122
K [hr]	0.26	6.58	1.37	14.24	10.35	5.36	17.68

Table 4 Comparisons of observed and simulated peak discharges and evaluations of the model performance for the selected rainstorm events

Events	Peak discharge [cms]		*NSE* [-]	*RSR* [-]	*PEP* [%]	Period
	Observed	Simulated				
20070905	125.5	127.9	0.74	0.51	1.90	Calibration
20080915	130.2	135.2	0.61	0.57	3.79	
20110820	133.6	121.8	0.73	0.51	8.92	Validation
20170729	141.7	123.4	0.71	0.54	12.96	

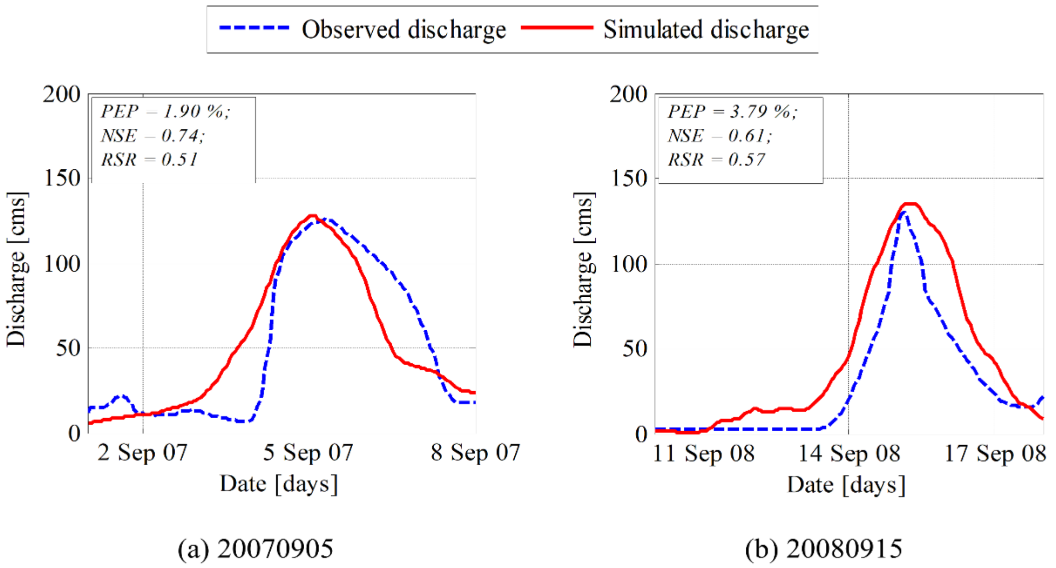

Figure 7 Comparison of observed and simulated hydrographs during calibration for at the station (E76A) of the Huai Sangka catchment: (a) hydrographs for the 20070905 event and (b) hydrographs for the 20080915 event.

Calibration and validation procedures were undertaken for the rainfall-runoff model to the Kham Muang gauging station (E76A) that acts as the outlet of the Huai Sangka catchment. Observed runoff hydrographs at this station were estimated by using the local rating curves from water level records. For model calibration purpose, two historical flood events occurred on the September 5, 2007 (20070905 event) and September 15, 2008 (20080915 event) were selected. As a result of the model calibration, the values of the travel time parameter *K* for the seven channel reaches were obtained (Table 3). Other two historical flood events occurred on the August 20, 2011 (20110820 event) and the July 29, 2017 (20170729 event) were considered for model validation purpose.

Figure 7a shows the observed and simulated runoff hydrographs for the 20070905 event, which was based on the rainfall events between the September 1 and 8, 2007. The dashed and solid lines represent observed and simulated hydrographs, respectively. This figure illustrates that the simulated peak discharge is slightly higher than the observed peak discharge. This difference is measured by using the percent error in peak (PEP). As can be seen in Table 4, the error is relatively small for the flood event with a PEP value of 1.90%. In addition, the relative model fit of the model simulations was quantified by the Nash-Sutcliffe efficiency index (NSE) and RMSE-observations Standard deviation Ratio (RSR). One the basis of the statistical analysis results for the 20070905, the rainfall-runoff model was performed “good” for NSE ($0.7 < NSE \leq 0.8$) and RSR ($0.5 < RSR \leq 0.6$) [22].

The results of the other calibration period (the 20080915 event) based on the rainstorm events, which occurred between September 11 and 18, 2008, are shown in Figure 7b. The rainfall-runoff model seemed to produce a larger volume of discharge comparing to the observed discharge during the 20080915 event. This comparison was evaluated by NSE with a value of 0.61. Moreover, the simulated peak discharge was relatively higher than the observed discharge approximately 3.8%. According to Moriasi et al. [22], the calibration results for those two events were considered as satisfactory since their NSE values were greater than 0.5. Moreover, the PEP values obtained during the calibration were smaller than 20%, which indicated that the rainfall-runoff model provided reasonable results in terms of peak magnitude [23].

Afterwards, the set of the model parameters obtained from the calibration was validated using the rainstorm events occurring between August 15 and 23, 2011, which caused the peak flow on the August 20, 2011 (20110820 event). In addition, the rainstorm events that occurred during the July 24 and August 3, 2017, which caused the peak flow on the July 29, 2017 (20170729 event) were selected for validating the set of the model parameters as well. Figures 8a and 8b show the comparison of the observed and simulated hydrographs at the gauging station E76A for the 20110820 and 20170729 events, respectively. During the validation average of NSE and RSR was 0.72 and 0.52, respectively. Furthermore, the rainfall-runoff model underestimated the peak discharge by PEP with values of 8.92% and 12.96% relatively compared with the peak discharge

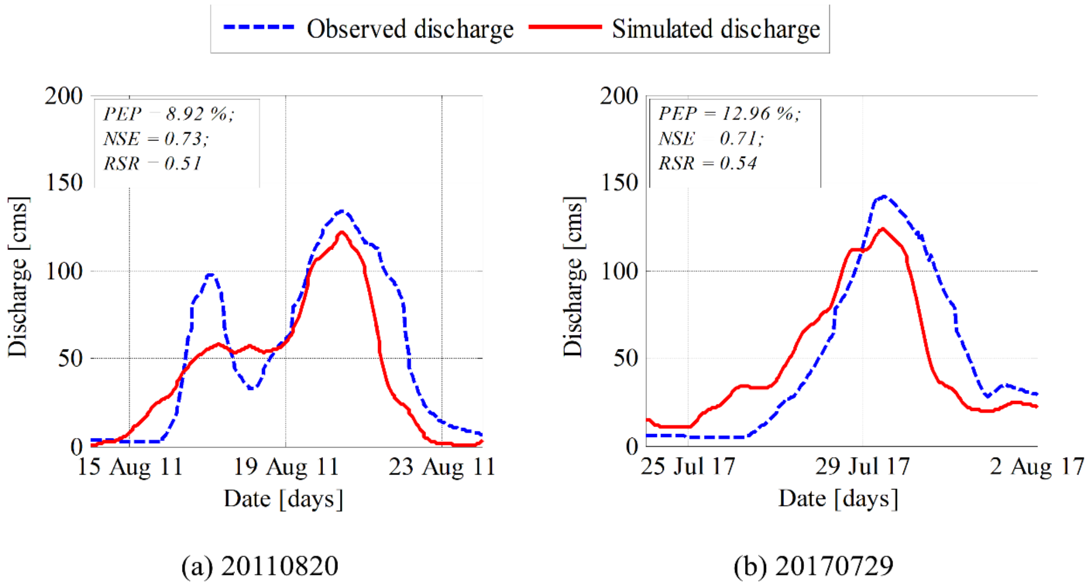

Figure 8 Comparison of observed and simulated hydrographs during validation for at the station (E76A) of the Huai Sangka catchment: (a) hydrographs for the 20110820 event and (b) hydrographs for the 20170729 event.

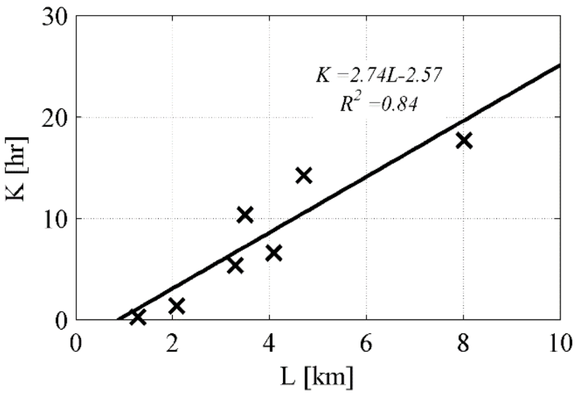

Figure 9 Scatter plot between lengths of channel reaches and values of the travel time parameter *K*

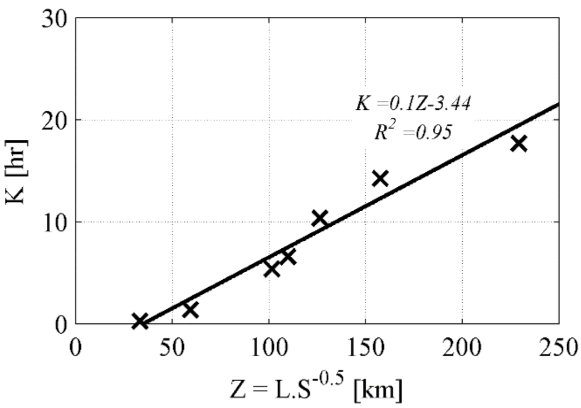

Figure 10 Scatter plot between the coefficient *Z* of channel reaches and values of the travel time parameter *K*

observed during the 20110820 and 20170729 events, respectively. These findings may be somewhat limited by coarse spatial and temporal resolutions of rainfall data used in the present study. Spatial variation of rainfall data was estimated using the Thiessen Polygon method from the three rain gauges located in the vicinity of the study area.

The test was successful as the rainfall-runoff model was able to reproduce peak discharges based on the combination of the different statistical indices (NSE, RSR and PEP). However, improvements can be made by using rainfall from different sources (ground gauges, weather radars and satellite-based precipitation estimates). There are still many unanswered questions about the use of finer spatial and temporal resolutions of rainfall observations in flood simulations [7]. Sub-daily rainfall data such as hourly time series from rain gauges may improve the model performance and flood simulation [24]. Normally, sub-daily rainfall data observed by ground gauges are rarely available, particularly for small basins. Satellite-based precipitation estimate (SPE) datasets can be alternative sources. However, the bias in SPE datasets has been recognized as a major issue. Thus, the comparison between SPE datasets and rainfall data observed by ground gauges should be performed and a bias correction are recommended in order to improve the performance of runoff simulations [25].

3.3 Analysis of Muskingum parameters

The variations of model simulation such travel time and peak discharge were found to be most sensitive to changes in the travel time parameter *K* of the Muskingum routing method. Therefore, the calibration in this study was based on changes in values of the travel time parameter *K*. These values were adjusted by using manual and automated approaches. However, the other parameters, namely curve number, the percentage of impervious areas, lag time, were estimated by the QGIS techniques from the DEM, land use, and soil database as previously described in Section 2. The estimated values of the parameters were remained constant throughout the model computations.

On the basis of the selected rainstorm events, calibrated values of the travel time parameter *K* for the channel reaches were found to be linearly correlated to with the length of their channel reaches, as shown in Figure 9. This finding is consistent with that of Fread [26] who showed that the travel time parameter *K* can be approximated from the linear relations between the channel length and flood wave velocity [19]. In addition, the finding corroborates the ideas of Yoo et al. [27], who suggested that the travel time parameter *K* had good linear relationships to the coefficient *Z*, which represents the ratio between the channel reach lengths and the square root of the channel reach slopes, as shown in Figure 10. In accordance with the present results, previous studies (e.g. [20, 28]) have demonstrated that the Muskingum model parameters are strongly related to physical characteristics of channels. Thus, their relationships developed in gauged catchments may be meaningful to the flood routing models in ungauged catchments.

The overall simulation results for the selected rainstorm events proved the applicability of the rainfall-runoff model built with HEC-HMS in predicting peak discharge. This HEC-HMS model was constructed based on a combination of the SCS curve number loss, SCS unit hydrograph and Muskingum routing methods. Similar studies by Zelelew and Melesse [14] and Tassew et al. [17] obtained reasonable simulation results of peak flood in the HEC-HMS model involving a combination of the selected loss, unit hydrograph transform and routing methods. Although, the statistical evaluation criteria indicated a good performance of the HEC-HMS model used in the present study, its performance in simulating the peak flow can be improved by: (i) determining the actual CN values from regional studies instead of using the tabulated standardized CN values and (ii) developing regional unit hydrographs instead of using synthetic unit hydrographs. This was also recommended in Yu et al. [23] and Tassew et al. [17].

It has been demonstrated that a reliable rainfall-runoff model can provide useful information on flood peak and arrival times generated in the catchment from the corresponding rainfall events. This information is usually necessary for the planning and designing of different water resources activities. The findings of this study suggest that the rainfall-runoff modelling approach can also be useful for ungauged catchments. These is abundant room for further progress in transferring the values of the calibrated parameters from gauged catchments to the near-by ungauged catchments through regionalization and other techniques described in Rosbjerg et al [29].

4. Conclusions

This paper has sought to examine the applicability of the rainfall-runoff model built with HEC-HMS for runoff simulation in the Hual Sangka catchment, a small headwater catchment in the Lam Pao watershed. Observed spatial data such topography, land use and soil type of the study catchment were analysed using QGIS and were used to estimate hydrological characteristics and initial values for starting the model calibration. As previously mentioned, this study also attempted to improve the modelling approach for ungauged basins. Thus, the parameter CN and impervious areas were computed from land use and soil types and their values were remained constant during the local sensitivity analysis. This was because these land use and soil types are normally different from one area to another. As a result, the four model parameters, namely initial abstraction, lag time, the dimensionless weight (X) and the travel time parameter K, were considered in the local sensitivity analysis. On the basis of the sensitivity analysis, it was found that simulation results were sensitive to changes in values of the travel time parameter K. Therefore, this travel time parameter K was calibrated in order to fit simulated hydrographs with the observed ones. According to the statistical evaluation criteria, the rainfall-runoff modelling approach is considered suitable for the simulation of peak discharges at the outlet of the study catchment. The approach is based on event-based rainfall-runoff modelling and consists of simple hydrological methods. Therefore, it can be a powerful tool for flood monitoring due to the effective computation time. In conclusion, the methodology developed in this study can be applied to other ungauged catchments where have hydrological similarity. Future work should investigate the applicability of the HEC-HMS model, which contains other loss and transform methods in the similar climate zones and catchment sizes. Moreover, it will be important to explore the potential use of satellite-based precipitation estimate datasets for improving flood forecasting.

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