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Selecting the Best Set Value in Calibration Process for Validation of Hydrological Modeling (A Case Study on Kayu Ara River Basin, Malaysia)

Sina Alaghmand, Rozi bin Abdullah and Ismail Abustan
School of Civil Engineering, Universiti Sains Malysia (USM), Nibong Tebal, 14300, Penang, Malaysia

Corresponding Author: Sina Alaghmand, School of Civil Engineering, Universiti Sains Malaysia (USM), Nibong Tebal, 14300, Penang, Malaysia

ABSTRACT

This study describes a part of results of river flood risk modeling for Sungai Kayu Ara river basin which was conducted between January 2007 and January 2009 in which HEC-HMS3.1.0 was applied as hydrological model. The main aim of this study was evaluation of different sets of calibrated data to validate the hydrological model. In this regard, Nix method was utilized to establish and evaluate the credibility of the hydrological model. Kayu Ara river basin is located in Kuala-Lumpur, Malaysia and geographically surrounded within N 3° 6´ to N 3° 11´ and E 101° 35´ to E 101° 39´. After conducting of sensitivity analysis for HEC-HMS3.1, calibration process led to range of values for each parameter, in other words, it is possible to have different values for each parameter during calibration, even very near to each other; it makes a range of value. In this research, calibrated parameters were as follows; imperviousness, lag time and peaking flow coefficient. For selecting the best set among these values, average, median and mode were evaluated. The simulations were performed with 18 validation rainfall events re-ran according to average, median and mode values. Goodness-of-fit of results was compared according to the coefficient of determination R^2 of the simulation and observed stream flow hydrographs. The results show R^2 values of 0.8922, 0.8959 and 0.8678 for average, median and mode parameter values, respectively. According to this result, it can be concluded that average and median parameter values of calibration sets is more accurate and reliable for validation in comparison with mode of parameter values.

Key words: Sensitivity analysis, calibration, validation, HEC-HMS, Sungai Kayu Ara river basin

INTRODUCTION

Hydrological models are regarded as a powerful tool for predicting river basin response to rainfall events and assessment of impacts of various effective parameters such as land-use cover change on river basin hydrology (Whitehead and Robinson, 1993; Wang *et al.*, 2008, 2010; Li *et al.*, 2010; Kousari *et al.*, 2010; Zheng *et al.*, 2010; Cools *et al.*, 2010). Hydrological modeling is a powerful technique of hydrologic system investigation for both the research hydrologists and the practicing water resources engineers involved in the planning and development of integrated approach for management of water resources.

Schlesinger (1979) defined model calibration as the procedure of adjustment of parameter values of a model to reproduce the response of a river basin under study within the range of accuracy specified in the performance criteria. Also, he considers the model validation as substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model. It is important in this connection to assess the uncertainty in the estimation of model parameters, for example from sensitivity analysis. While, model validation involves conducting tests which document that the given site-specific model is capable of making sufficiently accurate predictions. This requires using the calibrated model, without changing the parameter values, to simulate the response for a period other than the calibration period. The model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits or to provide acceptable errors. In other words, validation is the testing of calibrated models with respect to additional set of field data preferably under different environmental conditions to further examine the validity of the model (Thomann, 1982). Validation testing is designed to confirm that, the calibrated model is applicable over the limited range of conditions defined by the calibration and validation data sets. Hence, it is important that collection of calibration and validation data must cover the range of conditions over which predictions are desired. The data should be such that, the calibration parameters are fully independent of the validation data (Himesh *et al*., 2000). One of the methods for establishment of the credibility of the model is method by Nix (1994); which is employed for hydrological modeling in Sungai Kayu Ara river basin.

CASE STUDY

Sungai Kayu Ara river basin is the case study in this research which is located in Kuala Lumpur, Malaysia. Sungai Kayu Ara river basin is geographically surrounded within N 3°6′ to N 3°11′ and E 101°35′ to E 101°39′, Figure 1a and b show the location Sungai Kayu Ara river basin in Malaysia, respectively. Sungai Kayu Ara river basin covers an area of 23.22 km^2. The main river of this river basin originates from the reserved highland area of Penchala and Segambut. The Sungai Kayu Ara river basin can be a suitable study river basin for this research because of some reasons such as follows: primarily, a large part of this river basin area is well developed urban area with different land use and also high population density that shows the importance of this river basin. Secondly, the availability of high density rainfall station network, whereby 10 rainfall stations and one water level station are available (Fig. 2) and also according to the area of Sungai Kayu Ara river basin, 23.22 km^2, the rainfall station network density is equal to 2.3 km^2/station, which justifies the minimum requirement of one station per 25 km^2 recommended by Linsely *et al*. (1975) in case of precipitation over small mountainous river basins. The third reason is the availability of stage discharge curve which has been developed by the DID, Malaysia. And finally, the availability of river basin digital topographic information which can be used in Geography Information System (GIS). This data has been produced by the Department of Survey and Mapping, Malaysia.

METHODOLOGY

HEC-HMS3.1.0 is a hydrological model developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers. In 1968, HEC released the HEC-1 computer model to aid engineers in hydrologic analysis. The window-based HEC-HMS3.1.0 software was released in 1998 (U.S. ACEHEC, 2006). The program simulates a rainfall-runoff response of a river basin system to a precipitation input by representing the entire river basin as an interconnected system of hydrologic and hydraulic components, which include river basins, streams and reservoirs

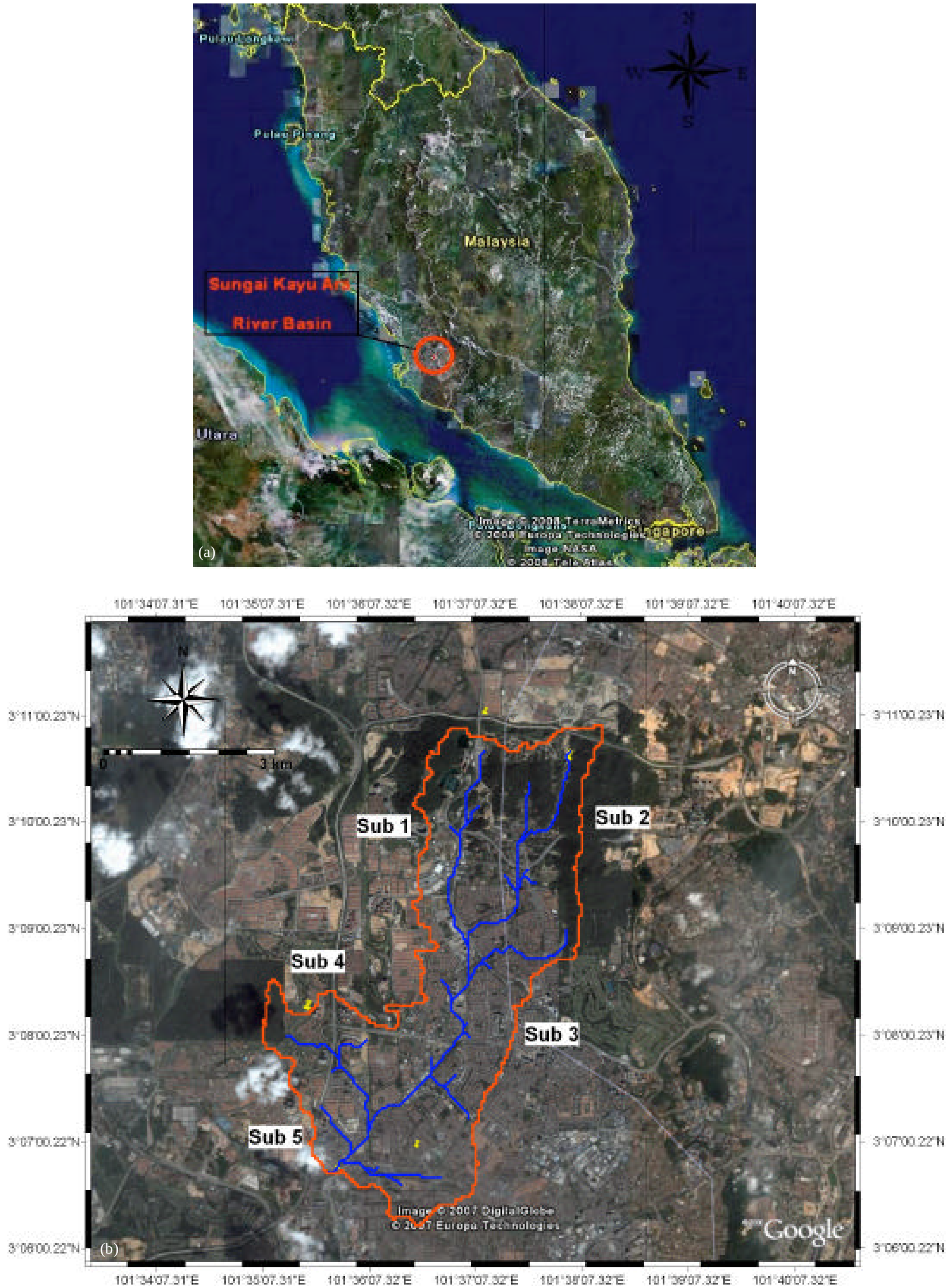


Fig. 1: (a, b) Location and base-map of Sungai Kayu Ara in Malaysia

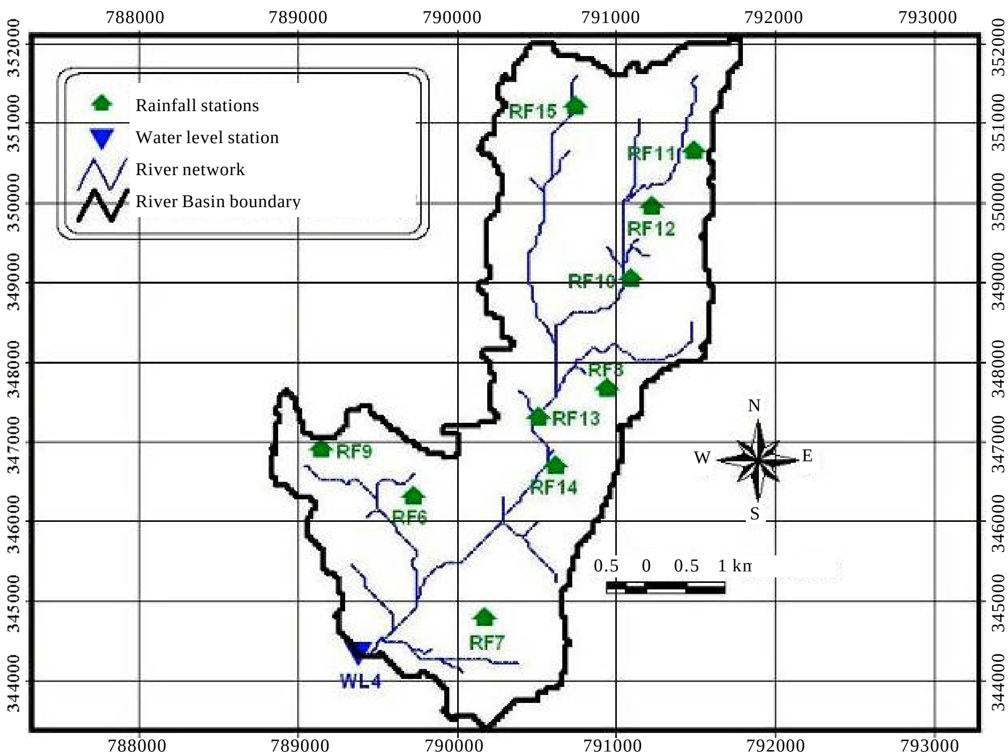


Fig. 2: Location of rainfall and water level stations in Sungai Kayu Ara Basin

(U.S. ACEHEC, 2006). HEC-HMS is a well-known hydrological computer model which is considered as one of the most utilized hydrological models in water cycle studies (Yawson *et al.*, 2005; Cunderlik and Simonovic, 2005; Stehr *et al.*, 2008; Ellouze *et al.*, 2009).

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package for use with the Arcview Geographic Information System. HEC-GeoHMS uses ArcviewGIS and Spatial Analyst to develop a number of hydrologic modeling inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities include the development of: grid-based data for linear quasi-distributed runoff transformation (ModClark), the HEC-HMS3.1.0 basin model, physical watershed and stream characteristics and background map file. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures and other control points. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS3.1.0, where simulation is performed. In this research, HEC-GeoHMS was utilized to extract some characteristics of the Sungai Kayu Ara river basin as input for hydrological modelling. Figure 3 shows characteristics of Sungai Kayu Ara river basin generated using HEC-GeoHMS.

Sensitivity analysis: Physically based models are used to simulate a wide range of complex processes in the river basin. Furthermore, there are long-term impacts that are difficult to calculate,

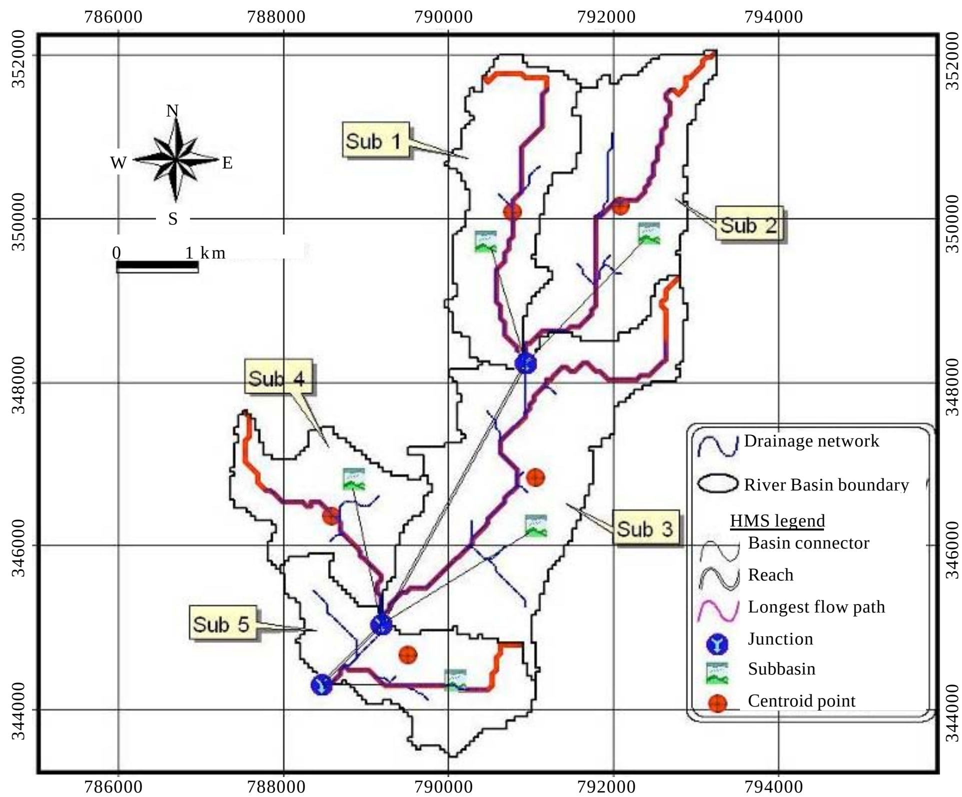


Fig. 3: Characteristics of Sungai Kayu Ara River Basin generated using HEC-GeoHMS

especially in ecological modeling. Using long data series, process-based deterministic models can compute the great number of calculations required to describe the complexity of a system (river basin). They can provide reliable information on the behavior of the system. Due to spatial variability, budget constraints or access difficulties, model input parameters always contain uncertainty to some extent.

In this research, 11 parameters were applicable for sensitivity analysis. In loss component in which Green-Ampt method was implemented, initial loss, moisture deficit, wetting front suction, saturated hydraulic conductivity and imperviousness were essential to consider. These five parameters which were used in Green-Ampt loss method in HEC-HMS for Sungai Kayu Ara river basin were involved in sensitivity analysis. The transformation component, applied Snyder UH method for Sungai Kayu Ara river basin which includes two parameters; lag time and peaking coefficient. For base-flow component of HEC-HMS, the recession method was used. In the recession method three parameters were implemented those were as follows: Initial Discharge, Recession Constant and Threshold Discharge. The last component which was applied in HEC-HMS for Sungai Kayu Ara river basin was routing procedure. Kinematic wave method was implemented for routing the flow in the river network. The kinematic wave method in HEC-HMS required the characteristics of the river, such as length of the river, slope of the river, width and the shape of the main river cross section and also Manning's n value. The length, slope, width and the shape of the main river cross section are measurable parameters those can be extracted via

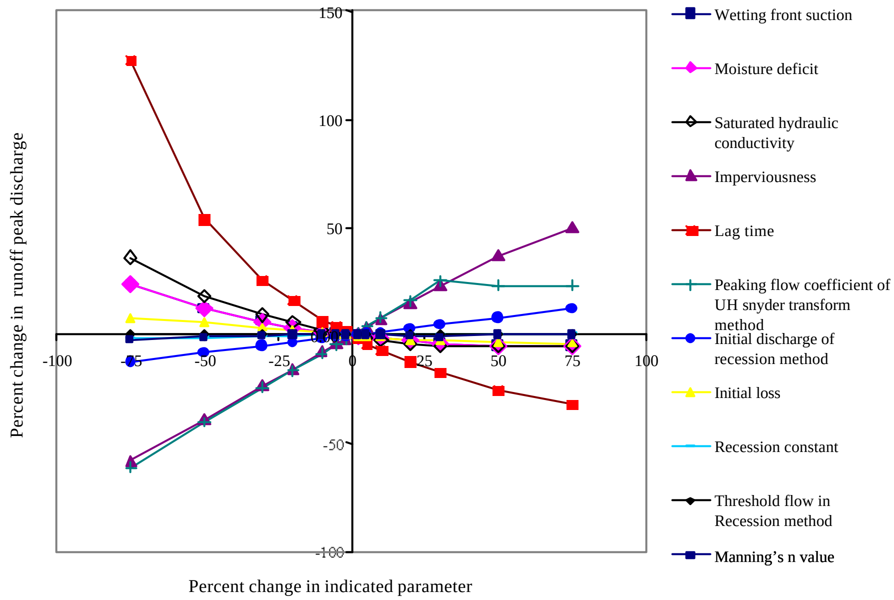


Fig. 4: Sensitivity analysis of HEC-HMS3.1.0 for Sungai Kayu Ara River Basin, runoff peak discharge

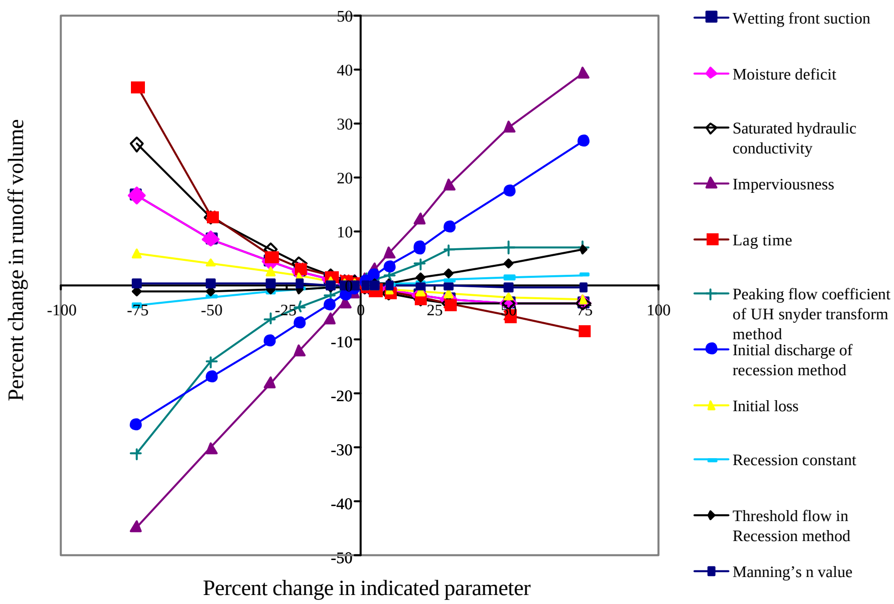


Fig. 5: Sensitivity analysis of HEC-HMS3.1.0 for Sungai Kayu Ara River Basin, runoff volume

HEC-GeoHMS. Hence, only sensitivity analysis was conducted on Manning's n value among kinematic wave method parameters.

For sensitivity analysis, each individual parameter was changed for ±5, ±10, ±20, ±30, ±50 and ±75% ranges and then simulated while the other parameters are constant, because the effect of each individual parameter on the outputs (runoff volume and runoff peak discharge) are intended. Figure 4 and 5 shows the results of the sensitivity analysis for HEC-HMS in Sungai Kayu Ara river basin.

According to Fig. 4 and 5, it can be concluded that, imperviousness, initial discharge of recession method, peak flow coefficient, lag-time, hydraulic conductivity, moisture deficit and wetting front suction were the most effective on the runoff volume (more than 5% changes). On the other hand, lag-time, imperviousness, peaking flow coefficient, hydraulic conductivity, moisture deficit, wetting front suction and initial discharge were more important parameters on the runoff peak discharge (more than 5% change). These parameters must be considered and focused during the hydrological modeling.

Calibration and validation: A total of 18 rainfall events which were occurred between the year 1996 and 2001 were selected for calibration process and 18 rainfall events between the years 2002 and 2004 were used for validation. Figure 6 and 7 show the detail and characteristics of the rainfall events for calibration and validation processes, respectively.

As Fig. 6 and 7 notice the basin mean areal rainfall depth for the 18 calibration and 18 validation rainfall events which were calculated with Thiessen method ranges between 7.14 and 58.93 mm, respectively. The maximum runoff peak discharge and runoff volume were observed on 10th February 1999 which are 220 m^3 sec^{-1} and 1190000 m^3, respectively.

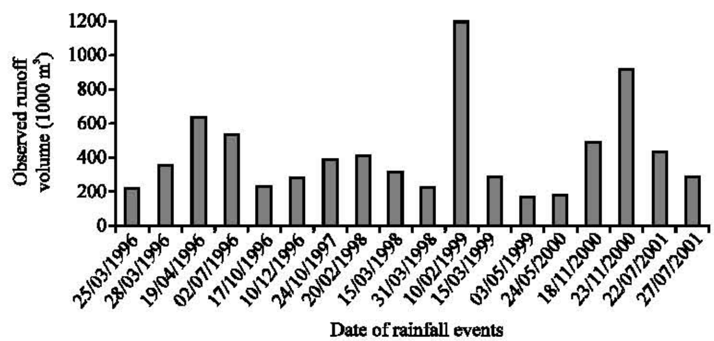


Fig. 6: Observed rainfall events for hydrologic model calibration of Sungai Kayu Ara River Basin hydrological model

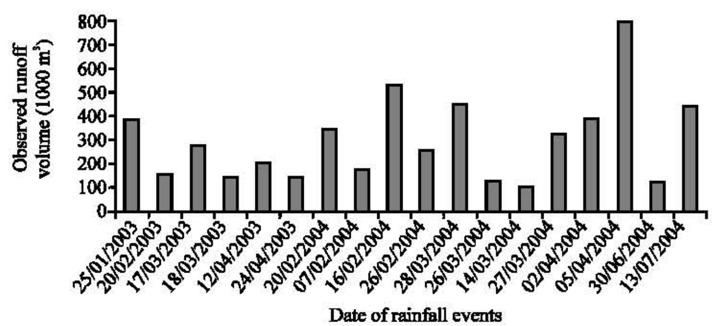
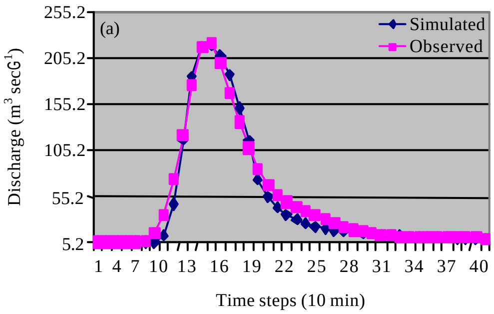


Fig. 7: Observed rainfall events for hydrologic model validation of Sungai Kayu Ara River Basin hydrological model



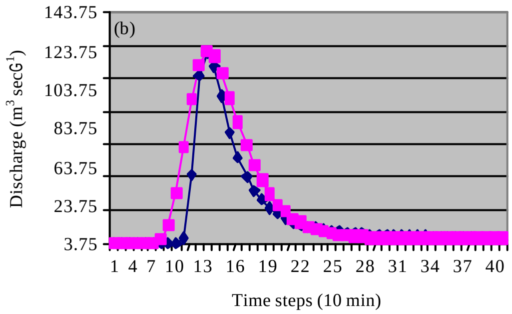


Fig. 8: (a, b) Calibration result for rainfall event 10/02/1999 and 19/04/1996

Figure 7 shows, the 18 selected rainfall events for validation of HEC-HMS for Sungai Kayu Ara river basin were observed between the years 2002 and 2004. The minimum and maximum validation events were observed on the 20th February 2003 and 5th April 2004. The minimum and maximum observed runoff peak discharges are 15.27 and 181 m^3 sec^{-1}, respectively, while the minimum and maximum observed runoff volumes are 158000 and 800000 m^3, respectively. Figure 6 and 7 represent the values of observed runoff peak discharge and runoff volume, respectively, of selected rainfall events for validation of HEC-HMS.

In this step, three factors of simulated hydrograph were considered, peak value, runoff volume and time of peak. During calibration procedure it was intended to gain the best simulation compare with observed data, to this aim in each run, three calibrated parameters which includes imperviousness, lag time and peak flow coefficient, were changing. According to the results of the calibration process for Sungai Kayu Ara river basin, the coefficient of determination (R^2) factor was more than 0.9 that shows the good correlation between simulated and observed data. Figure 8a and b show two of the results of the HEC-HMS3.1.0 calibration process for Sungai Kayu Ara river basin.

Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model adequately assesses the range of variables and conditions that are expected within the simulation. Although, there are several approaches to validating a model, perhaps the most effective procedure is to use different data set of the available record of observed values for calibration and validation. The rest is used for validation. Once final calibration parameters are developed, simulation is performed for the remaining period of observed values and the goodness-of- fit between recorded and simulated values is reassessed. Calibration process led to range of values for each parameter, in other words, it is possible to have different values for each parameter during calibration, even very near to each other, it makes a range of value. This is due to the dynamic characteristics of the river basin and rainfall event. In precise, a unique value for a specific river basin parameter never reflects the real situation of that parameter. Hence, in validation process a value must be selected which represents river basin condition more accurate. Table 1 shows the results of calibration process.

As denoted in Table 1, in the calibration process for imperviousness, lag time and peaking flow coefficient, a range of values were estimated. But for validation procedure only one set must be fixed. In this research, for selecting the best set among these, average, median and mode of values were evaluated. The simulations were performed with 18 validation rainfall events re-ran according to these parameter values. This means that three sets of parameter values (average, median and

Table 1: Results of calibration process for hydrologic model

Parameter	Statistical factor	River basin 1	River basin 2	River basin 3	River basin 4	River basin 5
Lag time (h)	Average	0.563	0.702	0.814	0.547	0.400
	Median	0.557	0.694	0.805	0.540	0.395
	Mode	0.596	0.742	0.861	0.578	0.423
Imperviousness (%)	Average	25.900	25.900	65.900	35.900	65.900
	Median	25.000	25.000	65.000	35.000	65.000
	Mode	25.000	25.000	65.000	35.000	65.000
Peaking flow coefficient	Average	0.610	0.610	0.610	0.610	0.610
	Median	0.610	0.610	0.610	0.610	0.610
	Mode	0.600	0.600	0.600	0.600	0.600

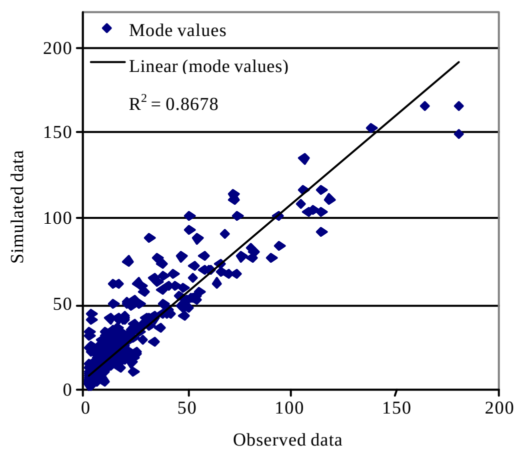


Fig. 9: Evaluation of calibrated values based on mode parameter values

mode of values range) applied for each 18 validation rainfall events. Goodness-of-fit of results was compared according to the coefficient of determination R^2 of the simulation and observed stream flow hydrographs. The calculation of coefficient of determination R^2 is based on the total of 18 rainfall events for the assessment. Figure 9-11 show R^2 values of 0.8922, 0.8959 and 0.8678 for average, median and mode parameter values, respectively. According to these results, it is appeared that average and median parameter values of calibration sets are more accurate and reliable for validation in comparison with mode parameter values. The median parameter values were closer as the HEC-HMS model for Sungai Kayu Ara river basin to generate design hydrographs.

According to the Fig. 9-11 it can be concluded that median of the calibrated values performs the best performance of the hydrological model. Hence, median of the calibrated values are implemented for hydrological model validation for Sungai Kayu Ara river basin. After selection of median values of calibrated parameters value, a total of 18 validation rainfall events were simulated in HEC-HMS for Sungai Kayu Ara river basin. In validation process all values were kept constant and output values for runoff volume and runoff peak discharge are evaluated and compared with observed runoff volume and runoff peak discharges. In fact, during validation process the reliability and credibility of the calibrated values were clarified. The results of the validation process for 18 rainfall events were shown in Fig. 12 and 13. The runoff peak discharge and runoff volume exhibit satisfactory R^2 values for the validation simulation. This shows that the

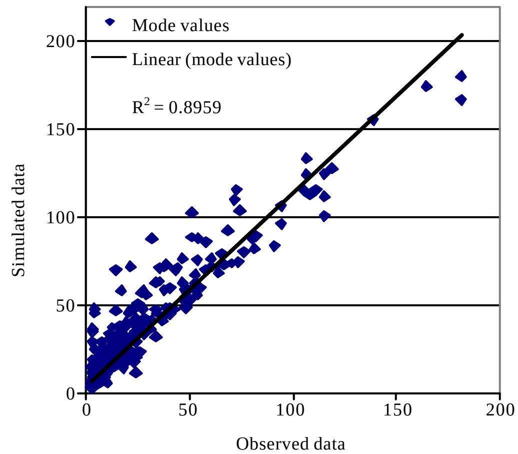


Fig. 10: Evaluation of calibrated values based on median parameter values

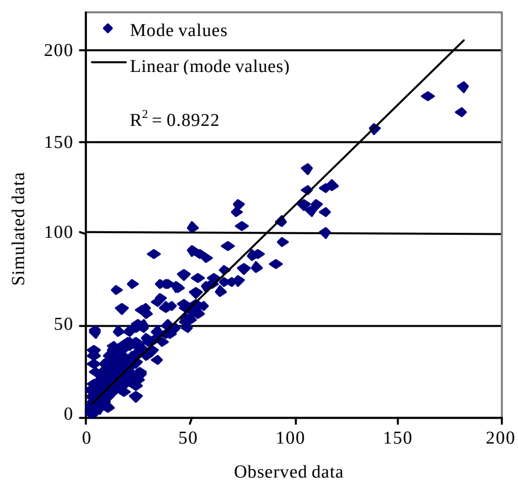


Fig. 11: Evaluation of calibrated values based on average parameter values

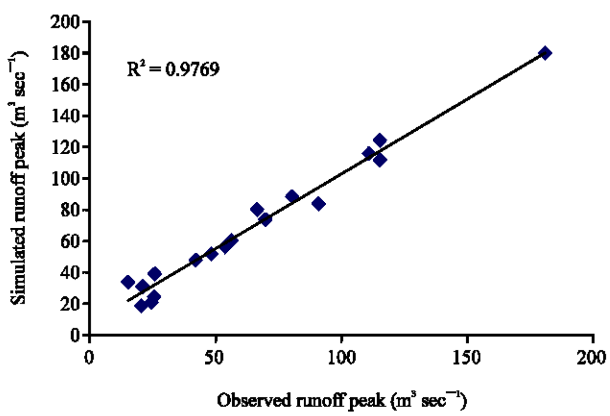


Fig. 12: Correlation of observed and simulated runoff peak discharge in validation process

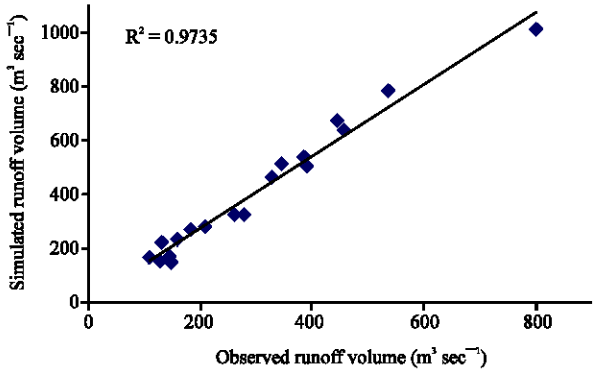


Fig. 13: Correlation of observed and simulated volume in validation process

Table 2: Final validated parameters value for of HEC-HMS Model for Sungai Kayu Ara River Basin

Component (method)	Parameters	Sub-river basin 1	Sub-river basin 2	Sub-river basin 3	Sub-river basin 4	Sub-river basin 5
Loss method	Initial loss (mm)	3.750	3.750	3.750	3.75	3.75
(Green and Ampt method)	Moisture deficit	0.190	0.190	0.190	0.19	0.19
	Wetting front suction (mm)	109.900	109.900	109.900	109.90	109.90
	Saturated hydraulic conductivity (mm h^{-1})	10.900	10.900	10.900	10.90	10.90
	Imperviousness (%)	25.000	25.000	65.000	35.00	65.000
Transform	Lag time (h)	0.557	0.694	0.805	0.54	0.395
(Snyder UH method)	Peaking flow coefficient	0.610	0.610	0.610	0.61	0.610
Baseflow (recession)	Initial discharge	Average of initial discharge in observed runoff hydrograph				
	Recession constant	0.300	0.300	0.300	0.30	0.30
	Threshold flow	Average of threshold flow in observed runoff hydrograph				

parameter values for HEC-HMS model have been adequately identified to represent Sungai Kayu Ara river basin. Table 2 indicates the final validated parameters value for of HEC-HMS model for Sungai Kayu Ara.

CONCLUSIONS

According to the results of this research, it can be concluded that average and median parameter values of calibration sets is more accurate and reliable for validation in comparison with mode of parameter values. The median parameter values are closer to the HEC-HMS model for Kayu Ara river basin to generate design hydrographs. Median of the calibrated values is recommended for validation of the hydrological models. It must be reminded, the difference between median and average of the calibrated values are negligible and so, there is no significant difference between average and median of the calibrated values.

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