Evaluation of Parameter Regionalization Methods for Flood Simulations in Kelantan River Basin

M.F. Chow, M.M. Jamil, F. Che Ros, M.A.M. Yuzir, M.S. Hossain

Abstract*: *Parameter regionalization techniques are widely used to estimate the parameters for calibrating the hydrological models in ungauged catchments. This study is aimed to compare global average and regression regionalization method for estimating input parameters for Integrated Flood Analysis System (IFAS) model in Kelantan River basin. The calibrated IFAS parameters were obtained from a number of gauged catchments. The model performances obtained using both methods were evaluated using Nash-Sutcliffe coefficient for peak flow, runoff volume and wave shape for flood event during period Dec 2006 – Jan 2007. The regression-based technique performed better than global averaged technique, with the Nash-Sutcliffe model efficiency coefficient values obtained were greater than 0.7 (indicating good model performance) compared to 0.4 for global averaged technique. The results suggest that it is possible to estimate the IFAS parameters using regression-based techniques for flood simulation.

Index Terms*: *flood simulation, hydrological modeling, parameter regionalization, ungauged catchment

I. INTRODUCTION

Reliable estimates for the occurrence of flood event are important for developing control measures for flood reduction and prevention at the early stage. There is an urgent need for such estimates especially on the catchment drainage area within 1000 km^2, following the aftermath of the 2014 serious flood event in Kelantan [1,2]. Usually, flood with various recurrence intervals in catchments with long gauge records can be estimated by using extreme value statistics. However, the results for flood estimation are noticely influenced by many factors, such as the selection of theoretical extreme value distribution function, parameter estimation techniques and ignorance of processes governing individual flood events [3,4]. Other than that, short record or absent of local runoff data that used for calibrating model parameters would become the main challenge on flood estimation in ungauged catchments [5,6,7,8,9].

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For solving this problem, parameter regionalization method is widely used to estimate the parameters for calibrating the hydrological models [10,11,12,13,14]. In parameter regionalization, parameter values in ungauged catchments are normally extrapolated using calibrated values obtained from gauged catchments by applying different regionalization techniques.

The successful of regional model calibration is mainly depends on the robustness of model parameters obtained from gauged catchments that are used in parameter estimation. The more robust parameters are contributing to the reduction of runoff simulation uncertainty when transposing them to ungauged catchments. Typically, the regression models are used to relate the model parameters with catchment attributes and climatic variables to determine the regionalized parameter values [15,16,17]. Other commonly used methods are including global average [18]; average based on expected similarities in catchment hydrologic responses [19] and kriging [20].

In this study, we compare two regionalization methods (namely, global average and regression) for estimating the input parameters for Integrated Flood Analysis System (IFAS) model. The main objective of this study is to predict the river flow hydrographs for any Kelantan catchment without field discharge data. Thus, the relevant flood conditions can be estimated from these predicted river flow hydrographs.

II. METHODOLOGY

A. Study Site

The studied catchment is Kelantan River basin (latitudes 4° 40' and 6° 12' North, while longitudes 101° 20' and 102° 20' East) which located in the north eastern part of Peninsular Malaysia. The Kelantan river has four main tributaries, namely Galas, Lebir, Nenggiri and Pergau Rivers and occupying more than 85% of the State of Kelantan. The Kelantan River originates from the central mountain range (Main Range) and finally discharging into the South China Sea. The Kelantan River basin is mostly formed by steep mountainous area which covered with virgin jungle and rubber and some paddy are planted in the lowlands. The soil type within the catchment area is categorized as a mixture of fine to coarse sand and clay with fine sandy loam soil found in the lower part of the basin. The characteristics of Kelantan River basin is summarized in Table 1.

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Table. 1 Characteristics of Kelantan river basin

Item	Value
Catchment area	13,100 km^2
Maximum length of catchment	150 km
Maximum breadth of catchment	140 km
Length of Kelantan river	248 km
Soil type	fine to coarse sand and clay
Annual rainfall	2,500 mm
mean flow	557.5 m^3/s

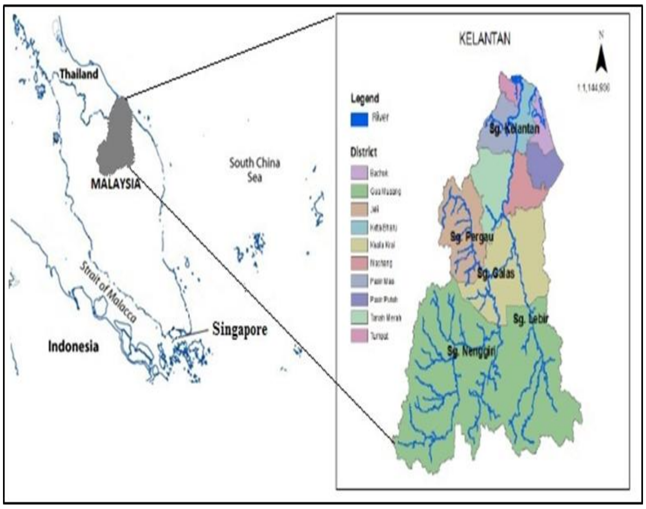

Fig. 1 Location of Kelantan River basin

B. Integrated Flood Analysis System (IFAS)

IFAS is a deterministic model which developed by ICHARM (International Center for Water Hazard and Risk Management) of Japan for flood modeling on river basin. The aim of IFAS is to create flood forecasting for river basins with insufficient hydrological data. The Public Works Research Institute Distributed Hydrological Model (PDHM) is employed in IFAS as its runoff simulation model. The structure of PDHM is consists of surface tank model, subsurface tank model, aquifer tank model and river tank model. The IFAS software is capable to import satellite-based rainfall data such as GSMaP and 3B42RT for insufficient ground observation river basin.

C. Regionalization methods

Regionalization 1: Global average-based parameter regionalization

The global average parameters were determined by calculating the average of each parameter from selected gauged catchments as listed in Tables 2 and 3. The parameter value will be reset to the maximum value of range if any mean value exceeding the reasonable range for the parameter. These parameter values were then inserted into their respective model input files for the tested river basin. The IFAS model was then run using the mean parameter values obtained from global average regionalization method for generating the corresponding river hydrographs.

Table. 2 Catchment characteristics considered in parameter regionalization

	Catchment					
Characteristics	Kelantan	Dungun	Cagayan	Upper Indus	Kabul	Solo
Size (km2)	11,099	30,207	27,700	467,136	92,605	16,100
% Forest	85.95	45	42.3	49.84	1.4	24
% Shrub	0.13	35	24.1	38.52	90.7	17.2
% Agriculture	13.42	20	30.1	11.16	6.3	34.4
% Urban	0.49	-	2.3	0.14	0.4	23.8
% Water bodies	-	-	1.2	0.34	1.2	-

Table. 3 IFAS model parameters used in regionalization

Surface tank model		*Parameter value*						
	Parameter description	Final infiltation capacity	Maximum storage height	Rapid intermediate flow	Height where ground infiltration occurs	Surface roughness coeffiecient	Rapid intermediate flow regulation coefficient	Initial storage height
	Symbol	SKF	HFMXD	HFMND	HFOD	SNF	FALFX	HIFD
Catchment	Kelantan	0.005	0.1	0.02	0.005	0.7	0.8	0
	Dungun	0.00014	0.35	0.01	0.005	0.78	0.8	0
	Philippines	0.0015	0.35	0.01	0.005	0.6	0.8	0
	Upper Indus	0.00001	0.06	0.01	0.002	1	0.15	0
	Pakistan	0.00001	0.06	0.01	0.002	1	0.15	0
	Indonesia	0.0025	0.06	0.01	0.002	1	0.15	0

Aquifer tank parameter		*Parameter value*			
	Parameter description	Runoff coefficient of unconfined aquifer	Runoff coefficient of confined aquifer	Height where the unconfined aquifer runoff	Initial water height
	Symbol	AUD	AGD	HCGD	HIGD
Catchment	Kelantan	0.100	0.003	2.000	2.000
	Dungun	0.100	0.006	2.000	2.000
	Philippines	0.125	0.005	2.020	2.000
	Upper Indus	0.200	0.000	2.000	2.000
	Pakistan	0.200	0.000	2.000	2.000
	Indonesia	0.500	0.001	2.000	2.000

River tank model		*Parameter value*									
	Parameter description	Constant of the Resume Law	Constant of the Resume Law	Manning roughness coefficient	Initial water table of river channel	Infitration of Aquifer tank	Coefficient of cross shape	Coefficient of cross shape	Coefficient of cross shape	Coefficient of cross shape	Coefficient of cross shape
	Symbol	RBW	RBS	RNS	RRID	RGWD	RHW	RHS	RBH	RBET	RLCOF
Catchment	Kelantan	7.000	0.500	0.035	0.200	0.000	9999.000	1.000	0.500	0.050	1.400
	Dungun	7.000	0.300	0.035	0.200	0.000	9999.000	1.000	0.500	0.050	1.400
	Philippines	7.000	0.300	0.035	0.150	0.000	9999.000	1.000	0.500	0.050	2.000
	Upper Indus	7.000	0.500	0.038	0.200	0.000	9999.000	1.000	0.500	0.050	1.400
	Pakistan	7.000	0.500	0.038	0.200	0.000	9999.000	1.000	0.500	0.050	1.400
	Indonesia	7.000	0.500	0.038	0.200	0.000	9999.000	1.000	0.500	0.050	1.400

Regionalization 2: Regression

The model input parameters are related directly to selected catchment attributes in the regression regionalization technique. In this approach, each of the model parameter is estimated using a linear regression model which containing n attributes (attribj) as shown in Equation (1).

$$param = a_i + \sum_{j=1}^{n} (b_{i.j} \, . \, attrib_j) \tag{1}$$

A linear regression model is developed for each tuned-able parameter, which consists of several catchment attributes that show the highest correlation with the respective parameter. The estimated parameter set for the ungauged catchment was then checked for plausibility: Values which exceed or fall short of the range of parameter values realized in calibration are determined as the threshold of respective parameter value. This is to avoid the unreasonable parameter values in model.

D. Model efficiency

The performance of model is determined by using the Nash-Sutcliffe coefficient (NS) value (as show in equation 2) for peak flow, runoff volume and wave shape. The NS coefficient is a measure of model efficiency that compares the simulated results to the corresponding actual field results:

$$NS = 1 - \left(\frac{\sum_{i=1}^{n} (Q_i - Q_i')^2}{\sum_{i=1}^{n} (Q_i - \bar{Q})^2} \right) \tag{2}$$

Where,
Qi = Measured value
Qi' = Simulated value
Q¯ = Average measured value
n = Number of data points.

The NS value can range from −∞ to 1; the ideal model performance is indicated as NS value approaches 1, while NS value of zero indicates that model performed lower than the mean of measured results. Normally, a NS value which greater than 0.5 is considered acceptable for hydrological modeling results [21,22,23]. According to the study by Van Liew and Garbrecht [24], NS values greater than 0.75 indicate that the model performs the simulation results that quite match with the observed values. Nevertheless, The model performance still acceptable if the NS values range between 0.36 and 0.75. Rammanarayanan et al. [25] stated that NS values that higher than 0.4 still can be considered as acceptable model performance. Donigan and Love [26] stated that NS values range 0.65 and 0.75 as fair performance, and range 0.75 and 0.85 as good performance while NS values above 0.85 is considered as very good model performance. Often, the acceptance level of model performance is depend on the model and nature of the application, thus what is considered acceptable will vary among projects. These general guidelines were used in further evaluating the IFAS model performance.

III. RESULTS AND DISCUSSION

Performance analysis of parameter regionalization methods

The calibrated IFAS parameter values are obtained from gauged catchments in Dungun catchment (Terengganu), Upper Indus basin (Pakistan), Kabul river basin (Pakistan), Cagayan river basin (Philippines) and Solo river basin (Indonesia). The global average values for each parameter in IFAS model were calculated and summarized in Table 4. Slightly difference was observed for surface roughness coefficient with a percentage of different of 21.4%.

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However, global average values for vertical hydraulic conductivity, maximum water height, rapid intermediate flow regulation coefficient and runoff coefficient of unconfined aquifer are

exhibiting higher magnitude of different with percentage of 200%, 60%, -40% and 104%, respectively.

The global average parameter values in Table 4 were inserted into the IFAS model for simulating the historical flood event (December 2016 – January 2017) in Kelantan river basin. The model simulation performance was determined using Nash-Sutcliffe value for parameters obtained using global averaging method. The model performance statistics were then compared to default and calibrated models for the Kelantan River basin for the period December 2006 – Jan 2007. Generally, the IFAS model performance was poor compared to calibrated model when global average parameters were used. For the flood event during period December 2006 – January 2007, we obtained the NS value of 0.4 by using global averaging technique. Meanwhile, the NS value of model performance is 0.8 that obtained through calibration process.

The IFAS model performance for parameters obtained using regression regionalization technique was also shown in Table 5. The NS values range between 0.68 and 0.73 which are considered as good. In general, the model performance was comparable to that obtained through calibration process when regression-based parameters were used. The regression-based technique for parameter estimation for IFAS simulation is consistently outperformed the default model outputs in the tested flood event.

Table. 4 Model parameter values obtained using global averaging

Parameter description	Symbol	Notation	unit	Default	Global average
Vertical hydraulic conductivity	f_0	SKF	cm/s	0.0005	0.0015
Maximum water height	S_{f2}	HFMXD	m	0.1	0.16
Rapid intermediate flow	S_{f1}	HFMND	m	0.01	0.012
Height where ground infiltration occurs	S_{f0}	HFOD	m	0.005	0.004
Surface roughness coeffiecient	N	SNF	$m^{-1/3}/s$	0.7	0.85
Rapid intermediate flow regulation coeffiecient	a_n	FALFX	Non-dimensional	0.8	0.48
Initial water height	-	HIFD	m	0	0
Runoff coefficient of unconfined aquifer	A_u	AUD	$(1/mm/day)^{1/2}$	0.1	0.204
Runoff coefficient of confined aquifer	A_g	AGD	1/day	0.003	0.003
Height where the unconfined aquifer runoff	S_g	HCGD	m	2	2.003
Initial water height	-	HIGD	m	2	2.00
Coefficient of the Resume Law	c	RBW	Non-dimensional	7	7.0
Coefficient of the Resume Law	s	RBS	Non-dimensional	0.5	0.433
Manning roughness coeffiecient	n	RNS	$m^{-1/3}/s$	0.035	0.037
Initial water level of river channel	-	RRID	m	0.2	0.192
Infitration of Aquifer tank	-	RGWD	1/day	0	0.00
Coeffiecient of cross section shape	-	RHW	Non-dimensional	9999	9999
Coeffiecient of cross shape	-	RHS	Non-dimensional	1	1.0
Coeffiecient of cross shape	-	RBH	Non-dimensional	0.5	0.5
Coeffiecient of cross shape	-	RBET	Non-dimensional	0.05	0.05
Meander coefficient	-	RLCOF	Non-dimensional	1.4	1.5

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Table. 5 Comparison of model performance statistics

		Nash-Sutcliffe Coefficient			
Time period	**Items**	**Default**	**Calibration**	**Global average**	**Regression**
Dec. 2006 – Jan 2007	Peak flow	0.45	0.80	0.40	0.70
	Runoff volume	0.50	0.77	0.56	0.68
	Wave shape	0.60	0.74	0.60	0.73

IV. CONCLUSION

This study had evaluated the two parameter regionalization methods: global average and regression-based as an alternative method for obtaining IFAS model parameters in ungauged mesoscale catchments. The model performance results obtained using regression-based parameters was comparable to that obtained through calibration. The Nash-Sutcliffe efficiencies for predicting the peak flow using global averaged and regression-based parameters are 0.40 and 0.70, respectively. The result of regression-based technique is comparable with value of 0.80 obtained through calibration. In general, these findings proved that it is better to estimate the IFAS parameter values using regression-based technique compared to global averaged technique.

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