Determination Number of Tanks for Tank Model at Southern Region of Sarawak

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The average rainfall for Sarawak, Malaysia is 3282 mm. With such heavy rainfall plus expected rise in population coupled with rapid development, flood occurrences are found to be more frequent as more lands are developed and more pervious grounds become impervious. Therefore, Tank model is adapted as flood forecasting system to provide early warning for the southern region of Sarawak. Tank model is selected because it requires only rainfall and runoff data. Despite the simple structure and computation, Tank model has proven its reliability to forecast the runoff accurately. However, there are a few configurations of Tank model. The current study investigates 3-Tank, 4-Tank and 5-Tank models for determining the most appropriate Tank model configuration for southern region of Sarawak. Three river basins located at southern region of Sarawak were selected for model calibration and validation. These three river basins are Bedup, subbasin of Sadong, Batu Gong, subbasin of Samarahan and Rayu, subbasin of Sarawak. Each model for three river basins is calibrated with trial and error method with an independent single storm event. The optimal parameters obtained will be validated with three independent single storm events. The models performance is evaluated using coefficient of correlation (R), Nash Sutcliffe coefficient (E^2) and peak error. Most of the results revealed that the three river basins produce the best runoff forecasting result using the 4-Tank model. Hence, the best number of tanks for southern region of Sarawak is four.

Keywords: Tank model, Rainfall-runoff model, Flood forecasting

Introduction

Sarawak, located at East Malaysia receives an annual average rainfall of 3282 mm. With such heavy rainfall, flood remains a major threat to the nation, as it causes great socioeconomic losses. It was estimated that at least 29,000 km^2 or 9% of Malaysia's land

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area is flood prone and more than 2.7 million people or 18% of Malaysia's population are affected by flood (Flood Preparedness Guidelines 2009).

Therefore, there is a need to develop a flood forecasting model, as a warning system to reduce damages. Early warning will provide sufficient time for residents to evacuate. The current study utilized Tank model, as flood forecasting system for southern region of Sarawak. Tank model was first introduced by Sugawara and Funiyuki in 1956. It composed of simple structure and computation, but has proven its ability to simulate reliable and accurate simulation results using only rainfall and runoff data.

Previous research showed that Tank model was successfully adopted to model rainfall-runoff at various locations. Chen and Pi (2004) applied the diffusive tank model to analyze the rainfall-runoff process of upland fields in Taiwan. Xiong *et al.* (2010) applied multi-tank model to simulate rainfall and infiltration processes in the slope and used the dual ensemble Kalman filter approach for slope water table forecasting. Tingsanchali and Gautam (2000) proclaimed that the calibrated Tank model is able to produce comparable results with neural network model. Mizumura (1995) also used recession curves of a catchment runoff hydrograph together with simple tank model to predict runoff in both small and large catchment areas. Besides, Villafana *et al.* (2008) also coupled Tank model with an ANNs model, that control six tank model parameters and adjust them along time to improve model efficiency. The experiment results showed that the combinations and configurations of Tank Model are different from catchment to catchment. Therefore, there is a need to determine the best number of tanks for the Tank model to be used in the southern region of Sarawak, a tropical humid region.

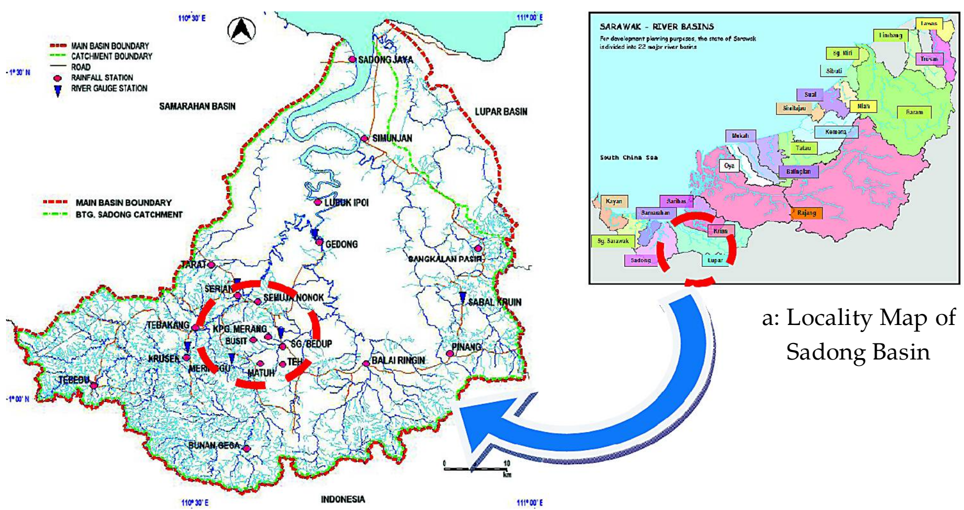
This study is conducted to determine the best tank combination to be applied in southern of Sarawak. The study area covered three river basins located at southern region of Sarawak, named as Sungai Rayu, Sungai Bedup and Sungai Batu Gong, which are subbasin of Sarawak Basin, Sadong Basin and Samarahan Basin respectively.

Study Area

This study concentrates on three catchments that are located within the region of Southern Sarawak, namely, Bedup basin, a subbasin of Sadong basin (Figure 1), Batu Gong basin, a subbasin of Samarahan basin (Figure 2), Rayu basin, a subbasin of Sg. Sarawak River (Figure 3). The general characteristics of these three rural catchments are steep and continuous observation of the areas show that there are no significant changes on its land use for the last few decades.

The land area of Sadong basin is 3,543 km^2 and its main river stretches for a total of 150 km. Its subbasin, the Bedup river basin is situated in the rural areas of Samarahan Division within 1° 50' 10" northern latitudes and 110° 37' 50" eastern longitudes with the catchment area of 45.0 km^2 (DID, 2007). The elevation around the basin varies from 8 m to 686 msl (JUPEM, 1975). The Bedup basin receives an annual mean precipitation of 3,550 mm and is characterized as a dendrite type of channel system. The maximum stream length is measured approximately 10 km from the most remote point of the stream to the basin outlet. As shown in Figure 1, there is one water level station and five rainfall gauge stations in this basin. The hourly water level data is obtained from the Bedup water level station situated at the outlet of the basin. The rainfall gauging stations are Teb River, Bukit Matuh, Merang River, Busit River and Semuja Nonok.

Figure 1: Locality Map of Bedup Basin, Subbasin of Sadong Basin, Sarawak



a: Locality Map of Sadong Basin

b: Sadong Basin and River Networks

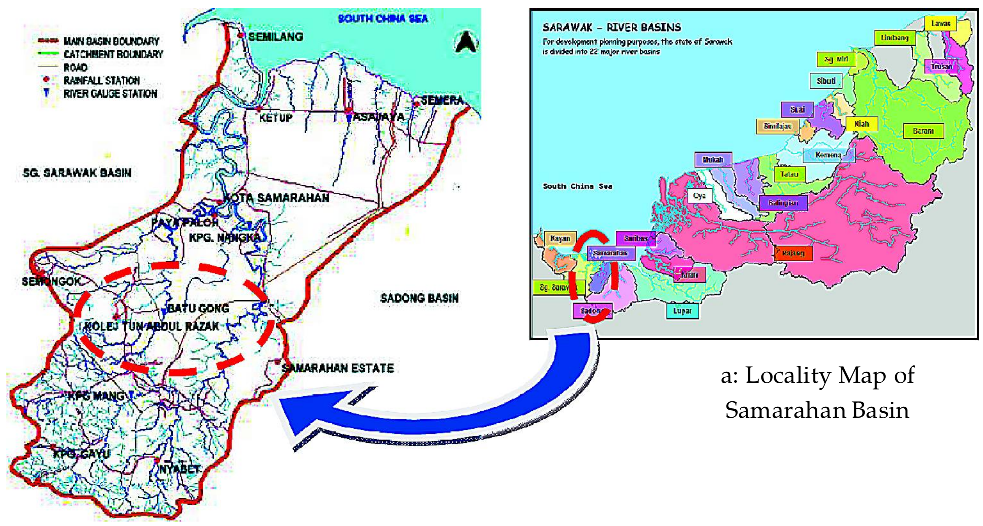
Batu Gong River (Figure 2) is located at coordinates between 1° 22' 00" northern latitudes and 110° 25' 60" eastern longitudes in the rural area of Samarahan division, Sarawak. The catchment consists of an area approximately 52.5 km^2, about 7.2 km from Siburan town in Kuching Division. The stream length is approximately 15 km to the basin outlet and annual mean precipitation is measured at 4,107 mm.

Rayu River, Sarawak is a small scale catchment with 26.71 km^2, as shown in Figure 3. This catchment basin is located at coordinates 1° 39' 00" northern latitudes and 110° 09' 00" eastern longitudes. Its stream length is measured approximately 0.6 km to the basin outlet. Meanwhile, Kampung Rayu is situated around 28 km from Kuching International Airport.

Data Acquisition

The performance of the flood forecasting model is undermined by the availability of hydrological data in terms of its quality and quantity. Rainfall and water level are acquired

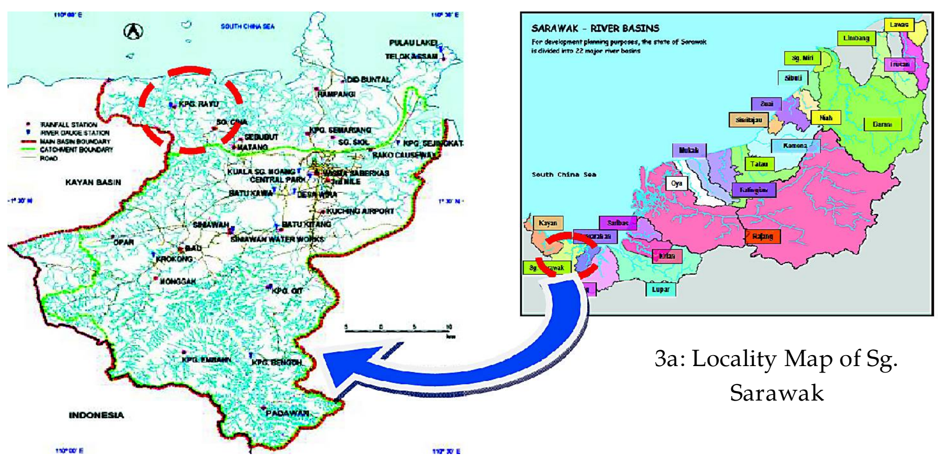
Figure 2: Locality Map of Batu Gong Basin, Subbasin of Samarahan Basin, Sarawak



a: Locality Map of Samarahan Basin

b: Batu Gong Basin, Subasin of Samarahan Basin

Figure 3: Locality Map of Rayu Basin, Subbasin of Sg. Sarawak Basin, Sarawak



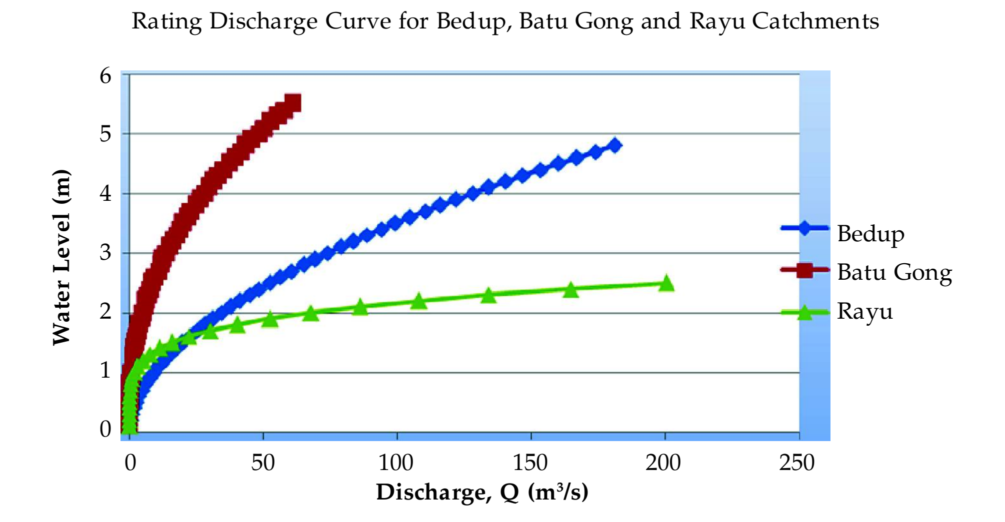
3a: Locality Map of Sg. Sarawak

3b: Rayu Basin, Subbasin of Sg. Sarawak Basin

from Department of Irrigation and Drainage (DID) Sarawak data bank, that were generated and stored in HYSYS software and updated only once a month. Currently, instantaneous or real time data are not available, as telemetric stations still not exist yet for the three river basins.

To convert the water level to discharge for model calibration, the rating discharge curves are obtained from DID. They are defined in Equations 1, 2 and 3 (DID, 2007) and the curves are presented in Figure 4.

Figure 4: Rating Curves for Bedup, Batu Gong and Rayu Catchments



For Bedup catchment, the equation of rating discharge rate is derived as:

$$Q = 9.19\ (H)^{1.9} \qquad ...(1)$$

For Batu Gong catchment, the rating discharge rate is given as:

$$Q = 1\ (H - 0.04)^{2.42} \qquad ...(2)$$

For Rayu catchment, the rating discharge rate is given as:

$$Q = 5.82\ (H - 0.24)^{4.34} \qquad ....(3)$$

where Q is the discharge (m^3/s) and H is the stage discharge (m).

Tank Model

Tank model was selected due to its simple structure and computation. Using only rainfall and runoff data, Tank model that is interconnected with a set of linear storages either in series or parallel is able to simulate hydrological processes that occurs naturally within a catchment using simple mathematical equations.

Each tank basically represents one soil layer. The uppermost tank models the hydrological process that occurs on the top layer of the soil that consists of rainfall, surface runoff, evaporation, and infiltration between the top soil and subsoil layer. The first tank governed the simulated discharge since most of the discharge in a river is contributed by the surface runoff. The same principle applies to the subsequent tanks that model infiltration, water storage and groundwater discharge of subsoil layers. The last tank models the base flow, which flows in the subsoil just above the layer of impermeable bedrock that will stop infiltration process.

There are two outlets from Tank model, named as bottom outlet and side outlet. Outlets on the bottom represent water infiltration into the soil and side outlets represent discharges into the river.

3-Tank, 4-Tank and 5-Tank models consist of different set of parameters. The parameters calibrated for 3-Tank model are C1, C2, C3, C4, C5, C6, X1, X2, X3, X4, EV, EV1, EV2. For 4-Tank model, parameters calibrated are C1, C2, C3, C4, C5, C6, C7, C8, X1, X2, X3, X4, X5, EV, EV1, EV2 and EV3, whereas parameters calibrated for 5-Tank model are C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, X1, X2, X3, X4, X5, X6, EV, EV1, EV2, EV3 and EV4. The schematic diagram for 3-Tank, 4-Tank and 5-Tank models are presented in Figure 5. Table 1 explains all the parameters calibrated for 3-Tank, 4-Tank and 5-Tank models.

Figure 5: Schematic Diagram for 3-Tank, 4-Tank and 5-Tank Models

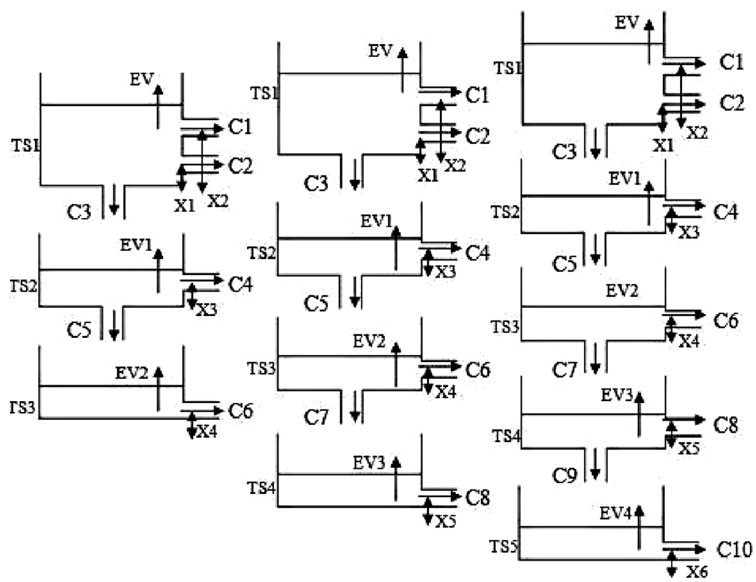


Table 1: Description of Parameters for 3-Tank, 4-Tank and 5-Tank Models

Parameter	Description	Parameter	Description	Parameter	Description
C1	First outlet coefficient for tank 1	C9	Infiltration coefficient from tank 4 to tank 5	EV	Amount of water evaporated from tank 1
C2	Second outlet coefficient for tank 1	C10	Sixth outlet coefficient for tank 5	EV1	Amount of water evaporated from tank 2
C3	Infiltration coefficient from tank 1 to tank 2	X1	Height of bottom side outlet to base of tank 1	EV2	Amount of water evaporated from tank 3
C4	Third outlet coefficient for tank 2	X2	Height of top side outlet to base of tank 1	EV3	Amount of water evaporated from tank 4
C5	Infiltration coefficient from tank 2 to tank 3	X3	Height of side outlet to base of tank 2	EV4	Amount of water evaporated from tank 5

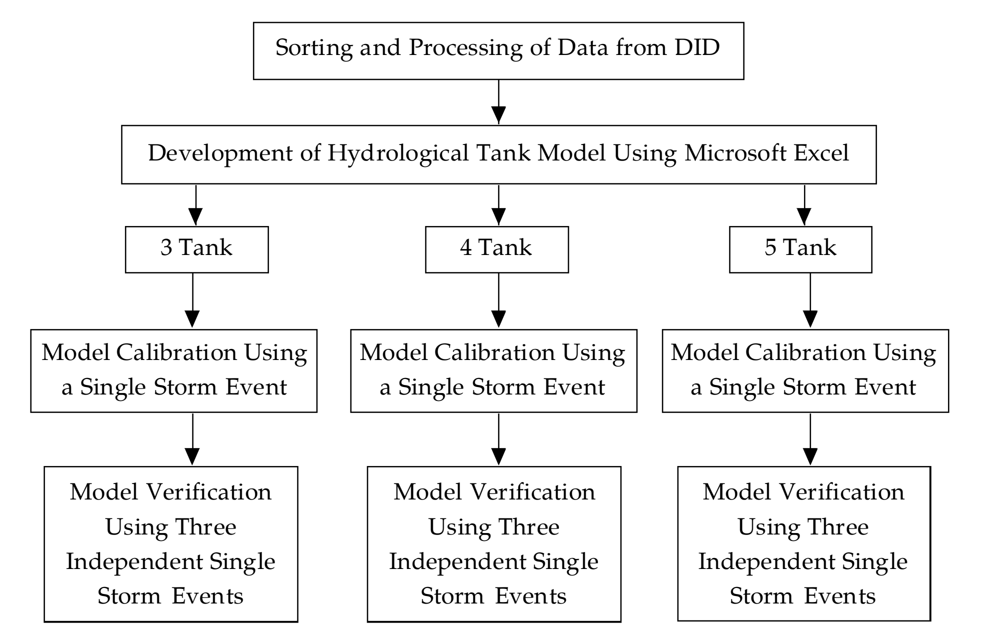
Table 1 (Cont.)

Parameter	Description	Parameter	Description	Parameter	Description
C6	Fourth outlet coefficient for tank 3	X4	Height of side outlet to base of tank 3		
C7	Infiltration coefficient from tank 3 to tank 4	X5	Height of side outlet to base of tank 4		
C8	Fifth outlet coefficient for tank 4	X6	Height of side outlet to base of tank 5		

Research Methodology

The study is generally divided into three major parts which are the model development, calibration and verification. Model development includes collection of hydrological data from DID Sarawak and development of the 3-Tank, 4-Tank and 5-Tank model. The subsequent part is the calibration process, where the model parameters are fine tuned to ensure the optimum performance of the model. A single storm event, each from the Bedup basin, Batu Gong basin and Rayu basin is identified as the basis of calibration using trial and error method. The model's performance is evaluated using Coefficient of Correlation (R), Nash-Sutcliffe Coefficient (E^2) and peak error. The final part is the model verification where the parameters will be verified by three independent single storm events for each river basin. The chronological order of model development, calibration and verification processes is simplified in Figure 6.

Figure 6: Chronological Order of Model Development, Calibration and Verification Processes



Model Calibration and Verification

To produce a good and accurate forecasting result, Tank model needs to be calibrated with historical storm events to obtain the closest fit between the simulated and observed hydrographs. A single storm event is selected for model calibration and three independent single storm storms are chosen for model verification for each river basin. Table 2 presents the respective storm events selected for the study.

Table 2: Storm Events Selected for Model Calibration and Validation

Bedup Basin		Batu Gong Basin		Rayu Basin	
Calibration	Verification	Calibration	Verification	Calibration	Verification
18-21 Feb 2001	5-9 Apr 2000 11-15 Feb 1999 21-25 Oct 1999	16-20 Mar 1998	6-9 Jul 1999 12-15 Oct 1998 3-7 May 1998	20-21 Jan 1998	11-13 Dec 1998 4-6 Oct 1999 25-27 Nov 1999

Model Performance Evaluation

The simulated hydrograph is evaluated with three chosen performance criteria, named as coefficient of Correlation (R), Nash-Sutcliffe Coefficient (E^2) and peak error, as presented in Equations 4, 5 and 6.

$$R = \frac{\Sigma(obs - \overline{obs})(pred - \overline{pred})}{\sqrt{\Sigma(obs - \overline{obs})^2 \, \Sigma(pred - \overline{pred})^2}} \qquad ...(4)$$

$$E^2 = 1 - \frac{\Sigma(obs - pred)^2}{\Sigma(obs - \overline{obs})^2} \qquad ...(5)$$

Peak error = (obs peak – pred peak)/obs peak) × 100% ...(6)

Author pl chk: J is not cited in the above equations

where obs = observed value, pred = predicted value, $\overline{obs}$ = mean observed value, $\overline{pred}$ = mean predicted values and J = number of values.

For R and E^2 values, the closer the model efficiency to 1, the more accurate the model is. In contrast, the higher the value of peak error, the more inaccurate the model is.

Results and Discussion

After calibrating the simulated hydrograph against the observed data, one set of parameters that provides the best hydrograph fitting, highest model efficiency and the least mean absolute error is obtained from each Tank model in all the three investigated basins. The sets of optimal calibrated parameters obtained are shown in Tables 3, 4 and 5 for Bedup, Rayu and Batu Gong basins respectively.

Table 3: Optimal Calibrated Parameters for Bedup Basin				
		Bedup Basin		
		3-Tank Model	**4-Tank Model**	**5-Tank Model**
Parameters	C1	0.01	0.01	0.001
	C2	0.002	0.002	0.002
	C3	0.1	0.1	0.1
	C4	0.01	0.01	0.01
	C5	0.08	0.08	0.08
	C6	0.04	0.04	0.04
	C7	-	0.008	0.008
	C8	-	0.07	0.07
	C9	-	-	1.6
	C10	-	-	1.2
	X1 (mm)	10	10	10
	X2 (mm)	40	40	40
	X3 (mm)	0	0	0
	X4 (mm)	0	0	0
	X5 (mm)	-	0	0
	X6 (mm)	-	-	0
	EV (mm)	0	0	0
	EV1 (mm)	0	0	0
	EV2 (mm)	0	0	0
	EV3 (mm)	-	0	0
	EV4 (mm)	-	-	0
	Baseflow (m^3/s)	0	0	0
	Area (km^2)	3543		

Table 4: Optimal Calibrated Parameters for Rayu Basin				
		Rayu Basin		
		3-Tank Model	**4-Tank Model**	**5-Tank Model**
Parameters	C1	0.0105	0.01	0.01
	C2	0.01	0.01	0.01
	C3	0.08	0.14	0.14
	C4	0.01	0.01	0.01
	C5	0.06	0.16	0.16
	C6	0.0001	0.2	0.2
	C7	-	0.79	0.79

Table 4 (Cont).

		Rayu Basin		
		3-Tank Model	4-Tank Model	5-Tank Model
Parameters	C8	-	0.0001	0.0001
	C9	-	-	0.0001
	C10	-	-	0.0001
	X1 (mm)	10	10	15
	X2 (mm)	40	40	25
	X3 (mm)	0	0	0
	X4 (mm)	0	0	0
	X5 (mm)	-	0	0
	X6 (mm)	-	-	0
	EV (mm)	0.05	0	0.1
	EV1 (mm)	0	0	0
	EV2 (mm)	0	0	0
	EV3 (mm)	-	0	0
	EV4 (mm)	-	-	0
	Baseflow (m^3/s)	1	1	1
	Area (km^2)	26.71		

Table 5: Optimal Calibrated Parameters for Batu Gong Basin

		Batu Gong Basin		
		3-Tank Model	4-Tank Model	5-Tank Model
Parameters	C1	0.01	0.01	0.01
	C2	0.02	0.02	0.02
	C3	0.2	0.13	0.13
	C4	0.09	0.1	0.1
	C5	0.001	0.02	0.02
	C6	0.01	0.01	0.01
	C7	-	0.6	0.6
	C8	-	0.2	0.2
	C9	-	-	0.0001
	C10	-	-	0.0001
	X1 (mm)	10	10	15
	X2 (mm)	35	25	25
	X3 (mm)	0	0	0
	X4 (mm)	0	0	0
	X5 (mm)	-	0	0

Table 5 (Cont.)

		Batu Gong Basin		
		3-Tank Model	4-Tank Model	5-Tank Model
Parameters	X6 (mm)	-	-	0
	EV (mm)	0.05	0	0
	EV1 (mm)	0	0	0
	EV2 (mm)	0	0	0
	EV3 (mm)	-	0	0
	EV4 (mm)	-	-	0
	Baseflow (m^3/s)	1	1	1
	Area (km^2)	52.5		

The values of R, E^2 and peak error of all the calibrated and validated hydrographs using 3-Tank, 4-Tank and 5-Tank models for Bedup, Rayu and Batu Gong basins are presented in Tables 6, 7 and 8 respectively.

Table 6: Average R, E^2 and Peak Error of 3-Tank, 4-Tank and 5-Tank Models for Bedup Basin

		3-Tank Model			4-Tank Model			5-Tank Model		
		R	E^2	Peak Error (%)	R	E^2	Peak Error (%)	R	E^2	Peak Error (%)
Bedup Basin	Feb2001	0.9358	0.9157	5.00	0.9671	0.9788	1.00	0.9320	0.968	10.00
	Oct 1999	0.9203	0.8938	12.00	0.9270	0.8036	29.00	0.8964	0.9040	3.00
	Apr 2000	0.9466	0.9294	7.00	0.9488	0.8940	5.00	0.9209	0.8989	3.00
	Jun 2000	0.9469	0.9605	4.67	0.9476	0.9635	1.06	0.9471	0.9635	0.80
	Average	**0.9374**	**0.9249**	**7.17**	**0.9476**	**0.9100**	**9.02**	**0.9241**	**0.9336**	**4.2**

Table 7: Average R, E^2 and Peak Error of 3-Tank, 4-Tank and 5-Tank Models for Rayu Basin

		3-Tank Model			4-Tank Model			5-Tank Model		
		R	E^2	Peak Error (%)	R	E^2	Peak Error (%)	R	E^2	Peak Error (%)
Rayu Basin	Jan 1998	0.9238	0.9751	4.00	0.9260	0.9607	0.25	0.9289	0.9658	12.89
	Dec 1998	0.7886	0.2375	6.00	0.8511	0.5368	0.36	0.8198	0.5279	1.71
	Oct 1999	0.8806	0.7843	24.61	0.9238	0.8425	32.59	0.9583	0.8622	13.13
	Nov 1999	0.8609	0.9256	4.99	0.8473	0.9255	2.68	0.8160	0.8227	16.18
	Average	**0.8635**	**0.7306**	**9.9**	**0.8871**	**0.8164**	**8.97**	**0.8808**	**0.7947**	**10.98**

For Bedup basin, 5-Tank model generates an average peak error of 4.2%, as compared to 7.17% and 9.02% by 3-Tank and 4-Tank models respectively. Meanwhile, the average E^2 obtained for 5-Tank model is 0.9336 compared with 0.9249 and 0.9100 by 3-Tank and

Table 8: Average R, E^2 and Peak Error of 3-Tank, 4-Tank and 5-Tank Models for Batu Gong Basin										
		3-Tank Model			4-Tank Model			5-Tank Model		
		R	E^2	Peak Error (%)	R	E^2	Peak Error (%)	R	E^2	Peak Error (%)
Batu Gong Basin	Mar 1998	0.8459	0.8314	2.34	0.9615	0.9103	1.87	0.9645	0.8739	6.07
	July 1999	0.8547	0.9125	29.15	0.9217	0.9605	15.83	0.8674	0.9616	8.31
	May 1998	0.3097	0.0196	11.93	0.4373	0.0411	1.68	0.2909	0.1241	5.88
	Oct 1998	0.9838	0.8621	17.16	0.9794	0.9523	5.64	0.9798	0.9517	5.64
	Average	**0.7485**	**0.6564**	**15.15**	**0.8250**	**0.7161**	**6.26**	**0.7757**	**0.7278**	**6.48**

4-Tank models respectively. However, based on R performance criteria, the average R obtained for 4-Tank model is 0.9476, which is slightly higher than 3-Tank model (average R = 0.9374) and 5-Tank model (average R = 0.9241). The results revealed that the Tank model performed the best with 5-Tank for Bedup basin.

In Rayu basin, 4-Tank model generates an average peak error of 8.97%, as compared to 9.90% and 10.98% by 3-Tank and 5-Tank models respectively. Average E^2 value also yielded to 0.8164 for 4-Tank model. Meanwhile, average E^2 for 3-Tank and 5-Tank models are found to be 0.7306 and 0.7947 respectively. Besides, 4-Tank model also yielded the average R to 0.8871, that is, slightly higher than average R = 0.8635 and average R = 0.8808 produced by 3-Tank and 5-Tank models, respectively. Therefore, 4-Tank Model is found to be the best for simulating runoff at Rayu Basin.

A similar scenario happened for Batu Gong basin. 4-Tank model generates an average peak error of 6.26%, as compared to 15.15% and 6.48% by 3-Tank and 5-Tank models, respectively. The average R for 4-Tank model is 0.8250, that is, slightly higher than the average R = 0.7485 and average R = 0.7757 obtained using 3-Tank and 5-Tank models, respectively. When evaluating the model performance with E^2, it was found 5-Tank model generates an average E^2 of 0.7278, which is slightly better than the average E^2=0.7161 and average E^2=0.6564 obtained by 4-Tank and 3-Tank models, respectively. However, 4-Tank Model is still found to be the best for Batu Gong basin.

The results revealed that 4-Tank and 5-Tank models are performing accurately in predicting and simulating runoff for Bedup, Rayu and Batu Gong basins compared with 3-Tank. 5-Tank model performed the best for Bedup basin. 4-Tank model performed the best for Rayu and Batu Gong basins.

Although 5-Tank model is performing slightly better than 4-Tank model for Bedup basin, it was observed that 5-Tank model needs to calibrate 22 parameters compared to 18 parameters for 4-Tank model. More parameters required more time for model calibration, and thus make the calibration processes become complicated. Therefore, the best number of tank for simulating hourly runoff at southern region of Sarawak is four.

Conclusion

The results showed that all the investigated 3-Tank, 4-Tank and 5-Tank models are able to simulate the hourly runoff accurately for southern region of Sarawak. However, the best number of Tank is found to be four even though the analytical results showed that 5-Tank is performing slightly better than 4-Tank in certain scenarios. This is because the more number of tanks involve, the more complicated the calibration process. In this study, 22 parameters are calibrated for 5-Tank model, whereas 4-Tank model involves only 18 parameters. Besides, the parameter values obtained include C9, C10, X6 and EV4 for 5-Tank model are very small (near to zero) and do not have any significant impact to the model accuracy. Hence, it can be concluded that the best number of tank for southern region of Sarawak is four.

The results of the study confirmed that Tank model can be utilized as a real-time flood forecasting model for these three catchments if the model is incorporated into the telemetry system. Calibration and application of Tank model for Bedup, Batu Gong and Rayu basins are stepping stones for further expansion for various river basins in Sarawak, Malaysia.

References

1. Chen R S and Pi L C (2004), "Diffusive Tank Model Application in Rainfall-runoff Analysis of Upland Fields in Taiwan", *Agricultural Water Management*, Vol. 70, No. 1, pp. 39-50.
2. DID (2007), *Hydrological Year Book 2007,* Department of Irrigation and Drainage, Sarawak.
3. Flood Preparedness Guidelines (2009), *Jabatan Pengairan dan Saliran Malaysia*, http://www.water.gov.my/index.php?option=com_content& task=view&id=55& Itemid=308
4. JUPEM (1975), *Jabatan Ukur dan Pemetaan Malaysia*, Scale 1:50,000.
5. Mizumura K (1995), "Runoff Prediction by Simple Tank Model Using Recession Curves", *Journal of Hydraulic Engineering*, Vol. 121, No. 11, pp. 812-818, http://cedb.asce.org/cgi/WWWdisplay.cgi?9505888.
6. Tingsanchali T and Gautam M R (2000), "Application of Tank, NAM, ARMA and Neural Network Models to Flood Forecasting", *Hydrological Processes*, Vol. 14, No. 14, pp. 2473-2487.
7. Villafana C, Ledesma-Orozco G S and Gonzalez R (2008), "Tank Model Coupled with an Artificial Neural Network", *Computer Science*, Springer Berlin.
8. Xiong J, Koyama T, Nisiyama S, Ohnishi Y and Takahashi K (2010), "Real-time Slope Water Table Forecasting by Multi-tank Model Combined with Dual Ensemble Kalman Filter", *Landslides*, Springer Berlin.

Reference # 63J-2011-11-xx-01