Flood Forecasting Using Tank Model and Weather Surveillance Radar (WSR) Input for Sg Gombak Catchment.

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Abstract-- A modified Tank model was developed and calibrated for Sg. Gombak catchment. The Tank model uses hydrological and meteorological data such as rainfall, stream flow, and water level as an input to develop the model. A trial and error method was used to calibrate this tank model with a set of parameters that suit the tank configuration. The average Mean Absolute Error (MAE) and Root Mean Square Error (RMS) for the tank model are 0.025 m and 0.065 m while the Nash-Sutcliffe Efficiency is 96.3% after the autoregressive corrections to improve the simulated flood level at Jalan Tun Razak. The research also investigated the use of WSR data as rainfall input to the Tank model.

Index Term-- Tank Model, Weather Surveillance Radar, Sg Gombak Catchment, Flood forecasting

I. INTRODUCTION
Flooding is a significant natural hazard that affects 2.7 million people within the 29,000 km² of flood prone area in Malaysia [1]. A significant measure to reduce damages and protect lives from the hazards of flood is by issuing early flood warnings. A timely and accurate flood forecasting and warning system can reduce loss of lives and properties and disruption to socio-economic development as well as assisting the authority in flood rescue operations [2]. Residents and businesses have greater chances to relocate to safer places and secure properties with a reliable operational flood forecasting and warning system.

Flood forecasting and warning systems operated based on river level forecasts, have been in operation for Malaysian rivers since as early as in 1900’s. Among the systems are the Stage-Correlation Method (SCM), the Sacramento Model, the Tank Model, the Multivariate Non-linear Regression technique, the Linear Transfer Model [3] and Flood Watch [4]. Wardah et.al [5] had researched on improving the performance of flood forecasting system for upper Klang River Basin by coupling a rainfall-runoff model with satellite based quantitative precipitation forecast.

In flood forecasting system, the radar rainfall can become the input data and potentially able to improve the precision of the flood prediction [6]. The weather radar offers high resolution rainfall estimates to monitor the spatial distribution of precipitation area [7]. It also has been widely adapted in many developed countries such as Japan and Netherlands. In this study, Sg. Gombak River Basin was selected as a case study for the development of flood forecasting model using the Tank Model. Sg. Gombak River Basin was located at the upper catchment of Klang River Basin and one of the flood prone areas. It was also selected due to the frequently floods occurrence in the River Basin.

II. TANK MODEL
Tank hydrological model [8], [9] consists of four tanks with the first tank is considered as surface discharge, the second tank as intermediate discharge, the third tank as sub-base discharge and the fourth tank as base discharge.
The components may be considered to correspond to the zonal structure of underground water as shown in Figure 1. For this study, Modified Tank Model is used to promote a better performance of the model and to minimize errors.

Conceptually, tank storages in the Tank Model are analogous to storages in the real Gombak River Basin in term of the runoff mechanism. These storages are gradually depleted as water stored evaporates or flows into the river system. Tank storage increases due to rainfall input and decreases as water stored flow out through the outlets of the tank.

**Calibration**

The objective of the calibration was to obtain a close fitting of hydrograph between the observed and simulated streamflow data at Sg. Gombak flow station at Jalan Tun Razak. All storm events were calibrated simultaneously by referring to the same set of Tank model parameters. This process is tedious because of the trial and error method used to obtain the closest results compared to the real situation. Figure 2 describes the calibration procedure applied in this study by using the Modified Tank model.

Validation process is conducted to run and check the reliability of calibrated modified Tank Model parameters and the average Autoregressive Analysis coefficient (AR). It is important in determining whether the Tank Model has achieved the required efficiency.

**Autoregressive Analysis**

The Autoregressive Analysis (AR) has been carried out in this study to simulate the observed hydrographs more accurately by adjusting the computed hydrograph. It was applied with the aim to make an effective adjustment to improve the forecast capability of the modified Tank Model.

**Model Evaluation**

The Tank model calibrated was checked numerically for its Mean Absolute Error (MAE), Root Mean Square Error (RMS) and the Nash-Sutcliffe Efficiency (E) to determine the best set of parameters.

### III. RESULTS AND ANALYSIS

A set of parameters were produced for this Tank Model which are shown in Table I. The best fit of calibrated parameters was given a high percentage of the efficiency by using the same set of parameters. The calibration results are shown in Table II.

#### Table I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV1</td>
<td>0.5 mm</td>
<td>C1</td>
<td>0.08</td>
<td>TS1</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>EV2</td>
<td>0 mm</td>
<td>C2</td>
<td>0.02</td>
<td>TS2</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>EV3</td>
<td>0 mm</td>
<td>C3</td>
<td>0.2</td>
<td>TS3</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>X1</td>
<td>15 mm</td>
<td>C4</td>
<td>0.17</td>
<td>TS4</td>
<td>10 mm</td>
</tr>
<tr>
<td>X2</td>
<td>20 mm</td>
<td>C5</td>
<td>0.25</td>
<td>TS5</td>
<td>2x10^6 mm</td>
</tr>
<tr>
<td>X3</td>
<td>0 mm</td>
<td>C6</td>
<td>0.05</td>
<td>K</td>
<td>0.015</td>
</tr>
<tr>
<td>X4</td>
<td>0 mm</td>
<td>C7</td>
<td>0.5</td>
<td>M</td>
<td>1.15</td>
</tr>
<tr>
<td>X5</td>
<td>0 mm</td>
<td>C8</td>
<td>0.005</td>
<td>Area</td>
<td>119.2 km²</td>
</tr>
</tbody>
</table>

#### Table II

<table>
<thead>
<tr>
<th>No.</th>
<th>Year</th>
<th>Date</th>
<th>Nash-Sutcliffe Efficiency (%)</th>
<th>Efficiency Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2007</td>
<td>3-Jun</td>
<td>89</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>2008</td>
<td>8-Jul</td>
<td>95</td>
<td>Excellent</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3-Jul</td>
<td>40</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>14-Jul</td>
<td>70</td>
<td>Very Good</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>22-Aug</td>
<td>55</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>27-Nov</td>
<td>35</td>
<td>Sufficient</td>
</tr>
<tr>
<td>7</td>
<td>2009</td>
<td>21-Jul</td>
<td>63</td>
<td>Very Good</td>
</tr>
<tr>
<td>8</td>
<td>2010</td>
<td>7-Jul</td>
<td>30</td>
<td>Sufficient</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>26-Sep</td>
<td>27</td>
<td>Sufficient</td>
</tr>
</tbody>
</table>

**Model Validation Result**

In this process, the latest storm event is used to check the reliability of calibrated modified Tank Model parameters. Comparison was made for both discharge values between observed and simulated hydrographs. This validation result using the calibrated parameters is shown in Figure 3.
Figure 3 shows that the Nash-Sutcliffe efficiency (E) for this validation process is 0.78 or 78%. The Mean Absolute Error (MAE) for this validation process is 0.13 m while the Root Mean Square Error (RMS) is 0.38 m. It can be inferred from the results that the calibrated parameters for this Tank Model were reliable to be used for flood simulation.

**Autoregressive Analysis (AR)**

Autoregressive analysis (AR) was carried out to determine the average of AR coefficient between observed and simulated hydrographs. The results were summarized in Table III.

The average autoregressive analysis coefficient for AR1, AR2, AR3 and AR4 are then applied to the entire storm event to check the reliability between observed and adjusted hydrograph for 15 minutes, 30 minutes, 45 minutes and 1 hour forecast.

**Model Evaluation**

The error improvement after adaptive adjustment for 15 minutes, 30 minutes, 45 minutes and 1 hour on validation hydrograph by calculating the Mean Absolute Error (MAE), Root Mean Square Error (RMS) and the Nash-Sutcliffe Efficiency (E) were shown in Table IV.

**IV. USE OF WSR DATA AS RAINFALL INPUT**

An effort to use the WSR data as alternative to gauged rainfall data were made for three storm events dated 8 July 2007 and 21 July 2009. The two events were selected based on radar data availability. Figure 4 shows a radar display dated 2nd February, 2003 from the WSR located at Subang which is the closest radar station to Sg Gombak catchment.
Though the closest radar station to the Sg Gombak catchment is Subang radar, no data is available on the dates due to the upgrading work at Subang radar station (upgrading to Doppler radar). Therefore, this study can only consider the radar data from the nearest stations which are Kluang and Butterworth radar stations. Figure 5 shows the location of the four radar stations in Peninsular Malaysia (beside the KLIA Doppler radar and Alor Setar WSR) whose radar rainfall data are managed by the Malaysian Meteorological Department (MMD).

Butterworth station to Gombak catchment with average distance of 288 km. The only available radar data are from Kluang station.

The simulation process using the Kluang radar data shown that the result for Nash-Sutcliffe is -0.34 or -34% which is considered as a poor result for the flood forecasting model. The Mean Absolute Error (MAE) and Root Mean Square Error (RMS) for this simulation are 10 m$^3$/s and 23.8 m$^3$/s which are higher compared to rain gauge station simulations which are 3.43 m$^3$/s and 5.71 m$^3$/s. Figure 6 show the result of the Tank Model simulation using the WSR data and gauged rain.

Event Simulation on 8th July 2007

Investigation on the record shows that radar data from the Butterworth WSR station does not record any value of rainfall over Gombak catchment on this date. The reason could be due to the limitation range coverage from Butterworth station to Gombak catchment with average distance of 288 km. The only available radar data are from Kluang station.

Event Simulation on 21st July 2009

For this storm event, the record also shows that the Butterworth radar station had not captured any data over Sg. Gombak catchment. From the result it shows that the Nash-Sutcliffe Efficiency for this storm event is -0.39 or -39%. While for a Mean Absolute Error (MAE) and Root Mean Square Error (RMS) are 9.07 m$^3$/s and 17.45 m$^3$/s which are higher compared to rain gauge station simulations which are 4.96 m$^3$/s and 9.13 m$^3$/s.

Discussion on WSR input

The Tank model calibration work had been initiated by choosing best selected events for several years as shown in Table III and IV. Effort to use WSR data as input to the Tank model for the same dates of events, were not very successful due to the unavailability of Subang radar data. Attempts were made to retrieve the closest radar data to Sg Gombak catchment that is from Butterworth, Kluang or Kuantan.
The analysis on the recorded radar data revealed that Kuantan and Butterworth radar did not capture most of the wanted events. The reason could be due to the beam blockage (due to mountainous region in the midst of Peninsular Malaysia as shown in Figure 5) or limited range coverage. Therefore the only radar data that can be used in this study is from the Kluang radar station. However, the results show that quality of the Kluang radar data were very poor during the events.

V. CONCLUSION

After the simulation, calibration and validation processes, it has been shown that the development of the Tank model for Sg Gombak catchment was successful and was able to provide a reliable water level forecast at Jalan Tun Razak. With adaptive adjustment (AR) in this model, the average simulation errors for the average Mean Square Error (MAE) and Root Mean Square Error (RMS) are reduced from 0.13 m and 0.384 m to 0.025 m and 0.065 m while the average of Nash-Sutcliffe Efficiency (E) resulted from this Tank Model is 0.963 or 96.3% which is in excellent range. It was also found that the flood wave travel times from upper catchment of Gombak River Basin to forecast point at Jalan Tun Razak ranges from 15 to 30 minutes.

The varying results between input of gauged rain and WSR rainfall show that there are much work need to be done to improve the radar rainfall application in the country. The fact that currently the MMD is upgrading all conventional radar to Doppler type indicates the ongoing improvement work.

Recent study on the correlation between Doppler radar rainfall estimates and gauged rainfall for Klang River Basin indicates that there is a positive good correlation (r² = 0.66) between the two rainfall measurement. About 20 rain events that are fairly uniform throughout the catchment were investigated to provide 441 radar-gage pairs as shown in Figure 7 [10].

In the study, optimization technique was applied to obtain improved Z-R relationship. The overall results from the study indicated that the radar error had been reduced if using the improved Z-R relations, with the best performance is for category low rain and southwest monsoon.

The on-going study on radar error and application for rainfall estimation and forecasting will help in improving the performance of flood forecasting in Malaysia.

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REFERENCES


Fig. 7. Radar rainfall estimates using the TDR versus gauged rain for Klang River Basin [10].

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