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FLOOD FORECASTING MODEL USING EMPIRICAL METHOD FOR A SMALL CATCHMENT AREA

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Abstract

The two most destructive natural disasters in Malaysia are monsoonal and flash floods. Malaysia is located in the tropical area and received on average, around 2800 mm of rainfall every year. Due to this high amount, a reliable and timely flood forecasting system is necessary to provide early warning to minimize the destruction caused by flash flood. This study developed and checked the adaptability and adequacy of the flood forecasting model for 93 km^2 catchment area, Kampung Kasipillay, in Kuala Lumpur. The Empirical Unit Hydrograph Model was used in this study and past rainfall data, water level and stage-discharge curve were used as inputs. A Rainfall-Runoff Model (RRM) which transforms the rainfall to runoff hydrograph, was developed using excel. Since some data, such as properties of the watershed, are not always complete and precise, some model parameters were calibrated through trial and error processes to fine-tune the parameters of the model to get reliable estimation. The simulated unit hydrograph model was computed in prior runs of the flood forecasting model to estimate the model parameters. These calibrated parameters are used as constant variables for flood forecasting model when the runoff hydrograph was regenerated. The comparison between the observed and simulated hydrograph was investigated for the selected flood events and performance error was determined. The performance error achieved in this study of 15 flood events ranged from -2.06% to 5.82%.e.

Keywords: Flood Forecasting, Empirical Unit Hydrograph Model, Rainfall-Runoff Model (RRM)

1. Introduction

Flood is one of the most powerful forces on earth and extreme floods can have severe consequences for society and mankind. People around the world have suffered greatly in term of properties destruction and loss of lives due to the great flood in the last few decades [1]. This resulted in many efforts to improve availability and reliability of flood forecasting system and flood warning system. This study focused on reassessment of flood forecasting system available and measuring the uncertainty and reliability of the system in flood forecasting. Flood forecasting and warning systems help in estimating the extent of the eventual flooding and allow safety measures to be taken at an earlier time. Provision of flood forecasting and warning system is vital, practical and low cost toward reducing flood losses. If the coming big flood is forecasted early, it allows for people who live in the area to move to other place and protect some of their movable belongings.

Empirical Modelling allows a better understanding on how the local hydrologic system works by relating a series of inputs to a series of outputs. This is an event-based modelling, usually at a catchment scale, without making many references to physical or hydrological process. Because of this, the model is also called as the black box modelling.

Flood forecasting is one of the most important applications of rainfall-runoff modelling. It requires decisions to be made and the model predictions occurred as the event happens in “real time”. The requirement is for those forecasts and warnings to be made as accurately as possible and as early as possible. Therefore, a good forecasting models must be suited with parameters that has been calibrated based on past event data

The empirical unit hydrograph model will be used for simulation of runoff into Kampung Kasipillay effective catchment, and will be used as flood forecasting tool. Hydrologists have tried to classify rainfall-runoff models according to their specific approach as well as their characteristics [2-6]. Flood forecasting model can be categorized into three main groups [6]:

- Physically based (or theoretical, white box) model. This model is based on physical laws that included a set of conservation equations of mass, momentum, energy and specific case entropy to describe the real world physics that governed the nature.
- Conceptually based (grey box) model. This model considers physical laws but in a simplified form that is able to explain the hydrologic behaviour by empirical expression.Example of this approach are Tank [7], Sacramento [8], TOPMODEL [9], HVB [10].
- Empirically based (black box) model. This model contains parameters that may have physical chracteristics that allow the modelling of input-output patterns based on empirism. Examples of this approach are Unit Hydrograph, rational method, etc. which are well described by Singh [5].

Empirical methods for rainfall runoff modelling typically involve the fitting and application of simple equations that relate runoff response to flow at the catchment outlet.

2. Study Area

Sentul River station commands a total catchment area of about 145 km^2. Batu Dam is located upstream of the catchment and has been mitigating the storm runoff from the upstream catchment of 52 km^2 from flowing down to the Kasipillay area. Thus, the effective catchment area that contributes flood runoff to Kampung Kasipillay is about 93 km^2. Figure 1 shows the catchment area of Kampung Kasipillay, Kuala Lumpur.

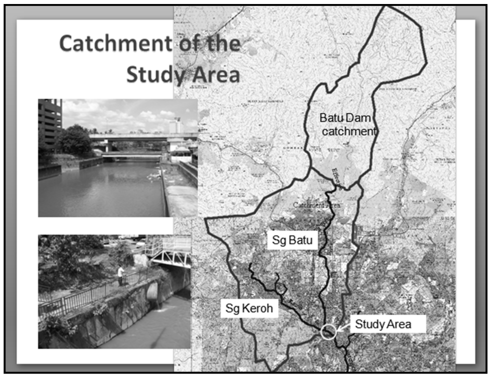

Fig. 1. Kampung Kasipillay catchment area, Kuala Lumpur.

In this study, rainfall data for selected past flood events act as the main input for the simulated flood forecasting model. There are three rainfall stations in the effective catchment area which are Empangan Batu, Jinjang and Ladang Edinburgh. The water level station is located at 870 m from the junction of Sungai Batu and Sungai Keroh. The station is labelled as Sungai Batu @ Sentul and is circled in Figure 1. The station's role is to detect rising water levels at Sungai Batu. Weighting factors for each rainfall station is calculated based on Thiessen Polygon method. Figure 2 shows the location of the three rainfall stations and one water level station. Table 1 show the coordinates of the four stations.

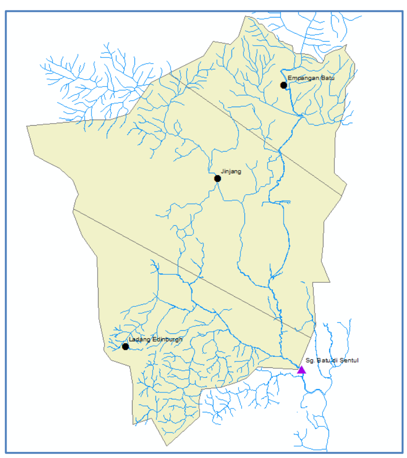

Fig. 2. Location of three rainfall stations and a water level station.

Table 1. Location of three rainfall stations and one water level station.

Rainfall Station	**Station Name**	Location	Area Occupied (km^2)
3116006	Ladang Edinburgh	3’11’00 N, 101’38’00E	17.8
3216064	Jinjang	3’14’6.4N, 101’39’41.8E	28.1
3216005	Empangan Batu	3’15’50’N, 101’40’55E	47.8
			Total area= 93.7
Water Level Station	**Station Name**	**Location**	
3116434	Sungai Batu @ Sentul	3’10’35N,101’41’15E	

3. Methodology

The simulation of unit hydrograph in the rainfall-runoff model was done to estimate the values of runoff coefficients and coefficients for rainfall stations. Once all parameters were obtained, the calibration process was carried out to fit them in a systematic manner for flood forecasting model. Comparison between the simulated runoff hydrograph with the actual runoff hydrograph was then made. Thiessen Polygon for the effective catchment area was computed using ArcGIS 10.2. The catchment boundary data, which includes the related river basin, rainfall station and water level station, act as inputs data in ArcGIS. The input data was analysed to obtain the weighting factor for all the three rainfall stations delineated by Thiessen Polygon method. 15 past flood events from year 2008 to year 2013, where water level exceeded the alert level of 32 m, were identified. The differences are lumped together by a certain percentage of total rainfall and are represented by an arbitrary runoff-rainfall coefficient (RC).

The flood forecasting part runs after the simulation of unit hydrograph rainfall-runoff model. This is to calibrate all the model parameters. For flood forecasting model, the surface runoff hydrograph for each time step was regenerated by multiplying the excess rainfall with calibrated unit hydrograph ordinates. Then, using the discreet de-convolution equation, the surface runoff unit hydrographs will be derived. The generated surface runoff hydrographs of each rainfall station for each time step were then superimposed to generate the surface runoff hydrograph for the entire catchment. Through a fixed amount of runoff as base flow to the surface runoff hydrograph, total surface runoff hydrograph was produced. The De-convolution equation used is as below:

$$\text{Direct Runoff DR} = (\text{UH x ECA x } 1000) / (15 \text{ min time step x}60\text{sec}) \tag{1}$$

Where ECA denotes Effective Catchment Area and UH denotes Unit Hydrograph

4. Result and Discussion

4.1. Simulation of model

A total 15 past-events were selected for model calibration and validation. The criterion for selecting event is that the Water Level (WL) exceeded the alert level, which is 32m, as recorded at the water level station of Sg Batu at Sentul. For flood forecasting, this empirical Rainfall-Runoff Model (RRM) simulated the runoff hydrograph from the real time rainfall data and converted the discharge simulation to the WL using the stage-discharge curve. The general model with its initial parameters was adjusted during the optimization process so that the simulated hydrograph matches the observed one from the Sg Batu at Sentul Station. Model parameters are calibrated using the data from all selected events and the selected event was run again for model validation in the flood forecasting part. The results computed from flood forecasting model includes Simulated Discharge (Q), Simulated Water Level (WL), Time-to-peak Q, WL and Effective Rainfall. Figure 3 shows a sample of comparison of total runoff hydrograph between the observed data and the simulated data for rainfall event, on 10th October 2013. The figure shows that the observed peak discharge was 234.67 m^3/s, occurred at 17:15 hours, while the simulated peak discharge was 300 m^3/s occurred at 17:00 hours. Table 2 shows the results for all 15 rainfall events computed by the produced model. The observed water level and observed time to peak were compared to the related simulated data. Performance errors for each of the 15 rainfall events were also calculated and the values obtained ranged from -2.06% to 5.82%.

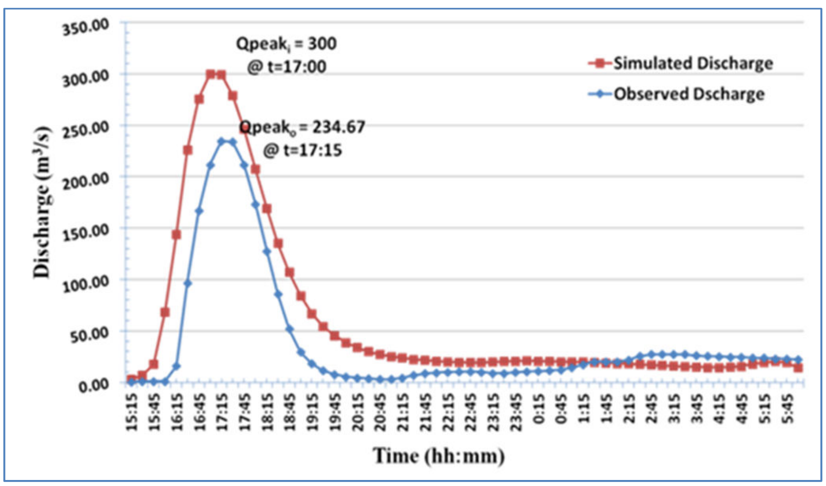

Fig. 3. Simulated hydrograph for a rainfall event on 10th October 2014.

Table 2. Result computed from flood forecasting model.

Empirical Unit Hydrograph Model						
Event	***Time to Peak Observed WL (hh:mm:ss)**	**Observed WL (m)**	**Time to Peak Simulated WL (hh:mm:ss)**	**Simulated WL (m)**	**Time Difference (hh:mm:ss)**	**Performance Error (%)**
10-Oct-13	17:15:00	33.67	17:00:00	34.45	00:15:00	2.32
13-Sep-13	16:45:00	32.03	16:30:00	32.65	00:15:00	1.94
3-May-13	19:45:00	32.45	19:30:00	33.63	00:15:00	3.63
24-Apr-13	17:45:00	32.36	17:45:00	32.67	00:00:00	0.97
10-Apr-13	19:00:00	33.61	19:00:00	33.72	00:00:00	0.33
29-Apr-10	19:00:00	32.24	19:00:00	32.64	00:00:00	1.24
22-Apr-10	05:15:00	32.42	05:15:00	32.21	00:00:00	-0.66
12-Nov-09	18:15:00	32.14	18:15:00	32.56	00:00:00	1.31
28-Oct-09	14:45:00	32.54	14:45:00	32.22	00:00:00	-1.00
11-Mar-09	16:15:00	32.25	16:30:00	32.43	-	0.56
3-Feb-09	18:15:00	33.31	18:00:00	33.08	00:15:00	-0.70
29-Jan-09	20:00:00	32.43	19:15:00	34.32	00:45:00	5.82
10-Oct-08	19:15:00	32.55	19:15:00	32.09	00:00:00	-1.43
21-Sep-08	15:30:00	32.2	15:30:00	31.54	00:00:00	-2.06
14-Jul-08	18:15:00	32.03	16:30:00	31.71	01:45:00	-0.99

* Time to Peak for both observed Q and WL are similar as WL was computed from the stage-discharge curve

4.2. Performance evaluation

The objective of this study is to evaluate the effectiveness of the simulated runoff in approaching the observed peak. Error between observed peak and simulated peak values is calculated by Eq. 2.

$$Error = (simulated\ peak - observed\ peak) \times 100\% \,/\, (observed\ peak) \quad (2)$$

The simulated results obtained are evaluated to determine the differences between observed and predicted values. The accuracy of model performance is measured by the overall differences of "time to peak discharge" between observed and estimated flow values. In this study, the flood forecasting part predicted flood water levels for all flood events and the lag times for are within the range of 0.75 hours to 1.25 hours. Lag time is the time for floods to occur in the catchment area from the time rainfall begin to produce streamflow at the outlet point of watershed. An important feature of models used for real-time forecasting is the ability to update the modelled flows in such a way to improve the accuracy of forecast flows. To achieve this, correction of model states or prediction model errors can be accommodated within the calibration process.

4.3. Calibration of model

The method used to calibrate the empirical model is by adjusting the values of the parameters to achieve the best match between the model prediction and the observation of the actual catchment response. The objective of the calibration, which is to obtain a close fitting of hydrograph between the observed and simulated streamflow data at station of Sungai Batu at Sentul, was achieved. 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.

5. Conclusions

The advantage of this flood forecasting model is that it has a stronger empirical base that is more consistent with the results of the record rainfall and runoff. The model is also practical, easy to be implemented and can provide results related to the hydrological processes. It also uses simple equation and appropriate application. From the results that have been simulated, the empirical method is able to develop a flood forecasting model for the study area using the unit hydrograph produced from telemetric rainfall and water level data for selected flood events.

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