Study on the different type of hydrological input towards the accuracy of catchment discharge hydrograph

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Abstract. For hydrological applications, several rainfall measurement techniques are available, each with its own spatial and temporal resolution and errors. When these rainfall datasets are used as input for hydrological models, errors and uncertainties are propagated throughout the hydrological system. This research paper is using rainfall data from two different measurement tools namely rain gauge and radar. Using these two types of measurement tools, it is expected dissimilar output due to the different working principle. Arau catchment in Perlis were selected as the study area. The rainfall data used is in the unit of intensity with time interval 10 minutes for both instruments. Storm Water Management Model 5 (SWMM5) were used as model to simulate the discharge of catchment area. Sensitivity analysis is carried out in this study to determine the major parameters that influence to shape of hydrograph and peak flow. Then, calibration process using five (5) storm events have been performed using available information such as conduits lengths, shape of conduits, impervious and pervious surface using trial and error process. Good correlation between observed and simulated hydrograph on 18 September 2006 has been found to be the best Correlation coefficient (r) and Root mean square error (RMSE) equal to 0.92 and 0.14 respectively. The same parameter used for that storm event was chosen to be applied in validation event. Validation results also in the acceptable range with r is found more than 50% correlation. Next, using the rainfall data captured by radar that converted using equation \( Z=40R^{1.6} \) developed by researcher [1] for the similar date of storm event and similar catchment conditions, all the hydrograph shape shows significant drop. As a conclusion, different type of measurement tools for rainfall gives significant different to the catchment discharge and can be seen that rain gauge are better to use to simulate rainfall compared to the radar.

1. Introduction

Hydrologic cycle is a continuous cycle where water evaporates, travel into the air and become part of cloud, then fall down to the earth as precipitation or normally refer to rainfall. There are numerous types of hydrological input which can be used to capture rainfall. In this study, different type of hydrological input that have been use is rain gauge and radar. These two types of hydrological input are used to see
the different due to the river discharge. River discharge is the volume of water flowing through a river channel. This is the total volume of water flowing through a channel at any given point and is measured in cubic meters per second (cumecs) [2]. The discharge from a drainage basin generally influenced by precipitation, evapotranspiration and storage factors. In storm hydrology, an important consideration is the stream’s discharge hydrograph.

Simulating hydrologic runoff with computer model procedures is critical equipment for comprehending and explaining the hydrologic cycle in general. These models are used for crucial research concerning water management, water quality issue, flood inundation, and plenty of different forecasting applications. The Storm Water Management Model 5 (SWMM5) is a numerical model for simulating storm water runoff from a catchment. A model should be calibrated to reflect the observed hydrological conditions in the selected catchments to provide an understanding of the rainfall-runoff process. Thus, the process of calibration and validation are important to be done using SWMM5 model.

2. Materials and methods

2.1. Study area

Perlis was chosen as a research region because the climate in the area varies, with certain areas (Chuping) becoming Malaysia’s warmest [3]. There is also a dam in the North, and roughly half of Perlis used to be paddy land, with paddy farming being the main source of income. As a result, determining the impact of future climate change in this area will provide information on which to base suitable water resource management decisions. Arau catchment in Perlis were selected as the study area. Figure 1 and table 1 respectively display the details and locations of the rainfall stations. Water level station that was used in this study is station Sungai Arau, Ladang Tebu (6503401).

![Figure 1. Arau catchment](image)

| No  | Station No. | Station Name     | Longitude (E)   | Latitude (N)   |
|-----|-------------|------------------|-----------------|----------------|
| 1.  | 6402007     | Arau             | 100°16’15”     | 06°25’50”      |
| 2.  | 6403001     | Ulu Pauh         | 100°21’10”     | 06°27’30”      |
| 3.  | 6402006     | Guar Nangka      | 100°17’00”     | 06°28’30”      |
| 4.  | 6402008     | Ngolang          | 100°14’50”     | 06°28’30”      |
| 5.  | 6503001     | Ladang Perlis Selatan | 100°20’15” | 06°32’10”    |
2.2. Storm water management model 5 (SWMM5)

The Storm Water Management Model 5 (SWMM5) is a dynamic rainfall-runoff simulation model that can be used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. SWMM’s runoff component operates on a network of sub catchments areas that receive precipitation and produce runoff and pollutant loads. SWMM’s routing section transports this runoff through the system of pipes, channels, storage/treatment devices, pumps, and regulators.

2.3 Input parameter

There are three parameters that believed give high influence to shape of hydrograph and the rest parameter is recommended to be remain such as area of catchment (289m²), percentage of slope (0.5), manning’s n for impervious area (0.04), manning’s n for pervious area (0.4), and depression storage-pervious area (5.08mm). Table 2 shows three modified parameters used in the calibration process that influenced the shape of the hydrograph.

Table 2. Parameter use in each calibration event

| Event               | Percentage of impervious area | Catchment width (m) | Depression storage-impervious area |
|---------------------|------------------------------|---------------------|------------------------------------|
| 21 October 2006     | 90                           | 400                 | 2.0                                |
| 18 September 2006   | 10                           | 300                 | 2.54                               |
| 25 September 2006   | 30                           | 250                 | 2.3                                |
| 2 May 2007          | 85                           | 600                 | 1.8                                |
| 1 October 2007      | 65                           | 370                 | 1.6                                |

2.4 Methodology

According to [4], the first step before the calibration step is to identify the most important parameters, and therefore model components, with respect to the model’s performance. Insensitive parameters can be fixed to a suitable value to decrease the dimensionality of the calibration parameters. The second option is to perform a sensitivity analysis after the calibration step to estimate whether the parameters are identified well or poorly. Research methodology that been applied in this research shown in Figure 2.

Figure 2. Flowchart for research work
2.5 Calibration process
Calibration aims to reduce differences between field observations and model outcomes. Change model parameter values with the specified objective function during the calibration process to achieve a better fit and meet the calibration goals [5]. Five storm events were chosen to run the calibration process. The storm events were chosen because the events produced good discharge hydrograph. Five storm events were chosen for calibration process as listed.

1. 21 October 2006
2. 18 September 2006
3. 25 September 2006
4. 2 May 2007
5. 1 October 2007

2.6 Validation process
Validation is the process of gathering data to describe the behavior and characteristics of the urban watershed under a variety of conditions and adjusting the model to adequately replicate the watershed as depicted by these data. The most important process in establishing model credibility is probably validation. Two events were chosen for validation process as listed.

1. 1 October 2006
2. 7-10 September 2006

2.7 Radar rainfall simulation
After validation process performed and the result is acceptable, rainfall data from rain gauge were replaced with the rainfall data captured by radar. The rainfall data from the conversion of $Z=40R^{1.6}$ have been used in this study. All storm events with the similar catchment parameter that has been validated previously were simulated using the new rainfall data. The simulated hydrograph from the radar rainfall data were analyzed and compared to the observed hydrograph. These rainfall radar data were captured by Alor Setar Radar own by MetMalaysia.

3. Results and discussion
The acceptability of a model will be limited and doubtful unless it is thoroughly calibrated and validated [6]. There is no criterion for demonstrating model validity because models must be related to the systems they are designed to reflect.

3.1 Calibration process from rain gauge data
The percentage of impervious area, width of catchment and depression storage-impervious area were shown to have the biggest impact on the runoff depth through sensitivity analysis, while the sensitive parameter for peak flow is impervious area, catchment width and manning’s n for impervious area [7]. Sensitivity analysis is the process of defining model output sensitivity to changes of its input parameters [8]. The parameter influence to runoff depth and peak flow is shown in table 3.
Table 3. Parameter influence to runoff depth and peak flow

| Parameter                          | Influence to runoff depth | Influence to peak flow | Influence to runoff depth & peak flow |
|------------------------------------|---------------------------|------------------------|---------------------------------------|
| Percentage of impervious area      | √                         | √                      | √                                     |
| Catchment width                    | √                         | √                      |                                       |
| Depression storage-impervious area | √                         |                        |                                       |
| Manning’s n for impervious area    |                           |                        | √                                     |

Calibration result for the series of hydrograph are acceptable because the Root mean square error (RMSE) and Correlation coefficient (r) between observed and calibrated flow data shows a good correlation and small error as shown in table 4. Besides, the overall shape of hydrographs matches well in the visual comparison as shown in table 5. From the five storm events, one storm event with the best RMSE and r value will be identified. As a result, the catchment parameter that applies to this storm event will be used in the other specified process.

Table 4. Calibration result for peak flow

| Event                  | Observed peak flow | Calibrated peak flow | Correlation coefficient (r) | Root mean square (RMSE) |
|------------------------|--------------------|----------------------|-----------------------------|-------------------------|
| 21 October 2006        | 31.16              | 16.85                | 0.89                        | 12.08                   |
| 18 September 2006      | 0.48               | 0.38                 | 0.92                        | 0.14                    |
| 25 September 2006      | 3.69               | 2.05                 | 0.90                        | 0.99                    |
| 2 May 2007             | 6.45               | 5.86                 | 0.72                        | 2.10                    |
| 1 October 2007         | 7.71               | 6.33                 | 0.72                        | 2.08                    |

Table 5. Visual comparison of observed and simulated hydrograph in calibration process

![Image of observed and simulated hydrograph comparison]
### Table 5. Visual comparison of observed and simulated hydrograph in calibration process (continued)

| Parameter            | Hydrograph    |
|----------------------|---------------|
| **Subcatchment S1** | **18 September 2006** |
| Property             | Value         |
| Rain Gage            | R1            |
| Outlet               | J1            |
| Area                 | 289.232       |
| **Width**            | 250           |
| % Slope              | 0.5           |
| % Imperv             | 30            |
| N-Imperv             | 0.04          |
| N-Perv               | 0.4           |
| Distone-Imperv       | 25.4          |
| Distone-Perv         | 5.08          |
| %Zero-Imperv         | 25            |
| Percent of Impervious area (%) | OUTLET       |

| **Subcatchment S1** | **25 September 2006** |
| Property             | Value         |
| Rain Gage            | R1            |
| Outlet               | J1            |
| Area                 | 289.232       |
| **Width**            | 300           |
| % Slope              | 0.5           |
| % Imperv             | 30            |
| N-Imperv             | 0.04          |
| N-Perv               | 0.4           |
| Distone-Imperv       | 23.3          |
| Distone-Perv         | 5.08          |
| %Zero-Imperv         | 25            |
| Percent of Impervious area (%) | OUTLET       |

| **Subcatchment S1** | **2 May 2007** |
| Property             | Value         |
| Rain Gage            | R1            |
| Outlet               | J1            |
| Area                 | 289.232       |
| **Width**            | 600           |
| % Slope              | 0.5           |
| % Imperv             | 85            |
| N-Imperv             | 0.04          |
| N-Perv               | 0.4           |
| Distone-Imperv       | 1.8           |
| Distone-Perv         | 5.08          |
| %Zero-Imperv         | 25            |
| Percent of Impervious area (%) | OUTLET       |

Width of overland flow path (m)
From this result, the best $r$ and RMSE is found in the simulation of storm event on 18 September 2006 with $r$ and RMSE equal to 0.92 and 0.14 respectively. So, the three parameters that undergo the trial-and-error process in calibration namely width of catchment, percent of impervious area and impervious depression storage equal to 300, 10 and 2.54 respectively will be used as the catchment parameter in validation process. This process will validate either the model is really representing the condition of the study area or not. As seen, the best value of parameter for percent impervious area that was used in trial-and-error process was 10% impervious area. This parameter value really describes the state of Perlis because Perlis is a rural area that surrounded with paddy field.

Validation process were done for two storm events as stated in the methodology. Result for validation as shown in table 6 shows the good correlation and shape. Statistical analysis in table 7 also demonstrates the value of $r$ in the acceptable range with both of the events has more than 50% correlation. RMSE value also shows small error.
Table 6. Observed and validated hydrograph for two events

| Parameter | Hydrograph |
|-----------|------------|
| 1 October 2006 | ![Hydrograph](image) |
| 7-10 September 2006 | ![Hydrograph](image) |

Table 7. Statistical analysis for validated events

| Event              | Correlation coefficient (r) | Root mean square (RMSE) |
|--------------------|-----------------------------|-------------------------|
| 1 October 2006     | 0.77                        | 0.46                    |
| 7-10 September 2006| 0.61                        | 0.66                    |

As a conclusion from the result of calibration and validation process, SWMM5 was successfully simulated the parameter entered to mimic the observed hydrological conditions in the selected catchments. Now, this catchment parameters can be used for the next step of this study.

3.2 Simulation process from rainfall radar data

All five storm events in earlier calibration was simulated once again using rainfall data from radar Alor Setar and converted using $Z=40R^{1.6}$. Catchment parameter from the validated event were applied to see the shape of hydrograph simulated by SWMM5 as an output of rainfall from radar. From the visual comparison, it can be concluded that, hydrograph that simulated from rainfall radar data were obviously low than observed hydrograph. It can be seen from all the simulated events shown in table 8.
Table 8. Observed and simulated hydrograph for rainfall radar data

| Event           | Hydrograph                        |
|-----------------|-----------------------------------|
| 21 October 2006 | ![Graph](21_October_2006.png)    |
| 18 September 2006 | ![Graph](18_September_2006.png) |

Table 8. Observed and simulated hydrograph for rainfall radar data (continued)

| Event           | Hydrograph                        |
|-----------------|-----------------------------------|
| 25 September 2006 | ![Graph](25_September_2006.png) |
4. Conclusion
From the findings, the following conclusions regarding model calibration and validation can therefore be made:

i. Different shape for hydrograph obtained due to the observed radar data are lower than observed rain gauge data.

ii. The overall shape of the hydrograph for calibration and validation for rain gauge data shows a good match.

iii. The sensitivity analysis is similar like others researcher in another study such as Parameter estimation for urban runoff modelling study.

This study found that radar derived rainfall usually does not provide good correlation with rain gauge measurement. Errors and uncertainties come from lots of factors such as sampling error, sampling height and reflectivity to rainfall conversion errors. Given the probability of minor inaccuracies in the observed data, the model calibration for this rainfall event is deemed adequate. It also implies that SWMM is appropriate for managing water resources in humid tropic regions like Malaysia. It is suggested for future work, try include investigating runoff response in relation to rainfall dynamics, as well as implementing best management practices.
5. References
[1] Mahyun A W, Abdullah R, Abustan I, Adam M K M, and Nur Atiqah A A. 2012. The Radar-Rainfall Relationship for Northern Region of Peninsular Malaysia. International Journal of Innovation, Management and Technology.
[2] River Discharge – Storm Hydrograph. 2018, April 20. A Level Geography https://www.alevelgeography.com/river.
[3] Suhaila J, Deni S M, Zin W W and Jemain A A. 2010. Trends in peninsular Malaysia rainfall data during the southwest monsoon and northeast monsoon seasons: 1975–2004. Sains Malaysiana 39(4) 533-542.
[4] Wagener T, Gupta H V and Wheater H S. 2004. Rainfall Runoff Modelling in Gauged and Ungauged Catchment, Imperial College Press, London.
[5] Schumann A H, Acreman M C, Davis R, Marino M A, Rosbjerg D and Xia Jun. 2001. Regional Management of Water Resources, IAHS Publication, Centre of Ecology and Hydrology, Wallingford.
[6] Uncertainty Considerations in Calibration and Validation of Hydrologic and Water Quality Models. 2015. Transactions of the ASABE, 58(6), 1745–1762.
[7] Choi K S, and Ball J E. 2002. Parameter estimation for urban runoff modelling. Urban Water, 4(1), 31–41.
[8] Wainwright J and Mulligan M. 2004. Environmental Modelling: Finding Simplicity in Complexity, John Willey & Sons Ltd.