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Forecasting The Future Drought in Bukit Merah Using HEC-HMS Software

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Abstract. Drought is a worldwide phenomenon caused by irregular rainfall patterns and rising temperatures. Malaysia, such as in Bukit Merah, has experienced floods and droughts due to climate change. Therefore, the objectives of this study were to calibrate and validate the rainfall-runoff of Bukit Merah and determine the future drought in HEC-HMS simulation. The Hydrologic Engineering Centre – Hydrologic Modelling System (HEC-HMS) is designed to simulate the rainfall-runoff of the basin. The study area's daily rainfall (mm) data were obtained from the Department of Irrigation and Drainage (DID) from 2010 to 2019. One rainfall streamflow station was the station was used in this study area. Previous data performed the different data from the hydrologic model of Bukit Merah for calibration and validation with the coefficient of $R^2 = 0.708$ and 0.574, respectively. The model was used to simulate the drought for the next thirty years (2020 – 2050) using SDSM's forecasted rainfall data. The modelling predicts over 30 years the lowest peak discharge is 1.06 m^3/s (01 Jan 2020; 00:00), 2.13 m^3/s (18 Feb 2021; 00:00), 1.98 m^3/s (24 Jan 2025; 00:00), 2.47 m^3/s (12 Mar 2025; 00:00) and 2.94 m^3/s (14 Feb 2049; 00:00). Therefore, the drought forecasting was done using the hydrologic model, HEC-HMS, as disaster prevention. The HEC-HMS will forecast the streamflow magnitude and date, allowing the government to plan ahead of time towards drought disaster. Also recommended is the continuous recording of rainfall and runoff data, recorded at intervals that correspond to one another in time. Install automatic recording stations for streamflow and rainfall at each river exit and ensure that these recording stations are kept in good working order at all times.

INTRODUCTION

Climate change threatens all living things with unpredictable weather and temperature [1]. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as a global phenomenon caused by natural or human activity over time. The least amount of rain and rising temperatures in the 21st century have increased aridity and drought. Peninsular Malaysia faces environmental issues such as droughts due to a lack of water to grow crops and drink [2]. Historically known as Malaysia Peninsula, Kelantan and Perak have suffered severe droughts before, with El Nino in 1997 and 1998 [3]. Not only that, Linggiu Reservoir in Johor (2019) and Bukit Merah dam (2016) has dropped to less than half their normal level because of extreme drought conditions brought on by El Nino. In this study, the Kurau river sub-basin was selected as the study area by using Hydrologic Engineering Centre– Hydrologic Modelling System (HEC-HMS). The HEC-HMS was used to stimulate the process of a complete hydrological system, including stimulating rainfall runoff [4]. The HEC-HMS model has superior simulated results in accuracy compared to traditional hydrological models [5]. The ability to model and run both short and long time events, as well as its ease of use, have made HEC-HMS particularly popular in hydrological investigations [6]. HEC-HMS hydrograph was developed to study urban drainage, water supply, the impact of future urbanization, flow forecasting, flood mitigation, flood regulation, and the operating system [7]. As a result, the rainfall-runoff data in the Bukit Merah basin was computed using the HEC-HMS modelling to forecast the future drought from 2020 – 2050.

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Malaysia, such as in Bukit Merah, has experienced floods and droughts due to climate change. Bukit Merah, located on the west coast of Peninsular Malaysia, was affected by drought. Kurau river basin near Bukit Merah was selected as the study area because it is important for Larut and Matang District, the State of Perak, which acts as the main water source (drinking water) and main supply of domestic water (drainage for paddy fields). The NST (2016) has reported almost 250,000 people in the area around the Bukit Merah dam will have to use less water if the level drops to 5.1 metres. Bukit Merah reservoir has less than 6m of water at its deepest point. It only has 14% left despite having a catchment area of 480 km^2. In the present dry condition Datuk Zainol Fadzi Paharudin, the Energy and Water Committee chairman, said the lake was losing a lot of water. It will only take 23 more days for the water level in the man-made lake to reach critical levels. Therefore, the hydrological model, HEC-HMS, was used to predict the future drought area of the Kurau river basin. So, the objectives of this study were to calibrate and validate the rainfall-runoff of Bukit Merah and determine the future drought in HEC-HMS simulation.

To achieve the objectives, several tasks were performed that selected the state of Perak in Malaysia suffering from natural disasters, especially during the dry season. Bukit Merah, Perak, was selected as the study area because the rainfall pattern was drastically changed compared to the previous study. In addition, historical data of daily rainfall (mm) at rain stations around the study area were obtained from the Department of Irrigation and Drainage (DID). Duration of historical data rainfall from 2010 to 2019. Data obtained was used for calibration and validation. Historical rainfall data was calibrated and validated to find relevant predictors before HEC-HMS forecasted future rainfall and drought. The forecasted data were obtained from SDSM and used to simulate the future drought (2020 – 2050). It is important because it gives the researcher an overview of whether it will experience a drought or not. If so, what is the magnitude of the drought? If the researchers can get this information before the disaster, it can help plan this problem situation as drought prevention.

MATERIALS AND METHOD

Study Area

The Kurau River basin in Perak, Malaysia, has been chosen in this study study because, downstream of a basin [8], it is located in a dam that serves as the primary drainage system for paddy fields and as a source of potable water. The basin is 322 km^2 in size and is located in northern Perak, Peninsular Malaysia (4° 51 - 5° 10 N and 100° 38 - 101° 01 E) [8]. The basin is a dominant part of Bukit Merah Reservoir, which is drained by two main rivers, the Kurau River and the Ara River. The two rivers meet at Pondok Tanjung town, Kurau. The upstream region also has rivers partly from the Star Range, and the Main Range is a steep and mountainous area. At the river's headwaters, the ground elevations are moderately high [9,10].

Hydrological Modelling (HEC-HMS)

The HEC-HMS stands for Hydrologic Engineering Center-Hydrologic Modeling System. It simulates rainfall-runoff in dendritic watershed systems. A big river basin, water supply, flood hydrology, and little urban or rural watershed runoff are some of the problems it is aimed to solve. Hydrographs created by the program are used directly or in conjunction with other tools for water availability studies, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation [4]

Data Collection

Brief description of the data used in the HEC-HMS rainfall-runoff model

i. Rainfall data
The Malaysian Department of Drainage and Irrigation (DID) provided rainfall data from 2010 to 2019. The rainfall station for this study was Ldg. Pondoland, Pondok Tanjung, because it was close to the inlet of Bukit Merah Reservoir.

ii. Forecasted future rainfall
SDSM has forecasted future rainfall data for 2020-2050. These data were used to simulate a 30-year drought in the Kurau River Sub-basin using HEC-HMS.

iii. Main morphological and cross-section data
Six sites of Kurau River were chosen for the main morphological and cross-section obtained from River Engineering and Urban Drainage Centre (REDAC), USM for detailed analysis and HEC-HMS channel parameter input.

HEC-HMS Setup

TABLE 1. The HEC-HMS simulation method.

Element	Method	Parameter
Sub-basin	Loss rate-SCS Curve Number Loss Transform-SCS Unit Hydrograph Base flow-Recession	Initial abstraction Curve Number Time Lag Base flow-Recession Initial discharge Recession constant Threshold type Threshold ratio
Reach	Muskingum Cunge	Length Slope Mannin's n Shape Bottom Width Side Slope (xH:1V)

A. Rainfall and discharge station: Pondok Tanjung Station (id no. 5007421)
B. Sub-basin
a) Loss rate – SCS Curve Number Loss
b) Transform method – SCS Unit Hydrograph
c) Baseflow method – Recession
C. Reach – Muskingum-Cunge Method
D. Meteorologic model – Thiessen polygon method

Calibration, Validation and Simulation Process

The model for the discharge stations at the Pondok Tanjung station was calibrated and validated using two different sets of data (id no. 5007421). The model was calibrated and validated using the daily interval rainfall event between November 01, 2014 (00:00 time) and November 14, 2014 (00:00 time). Daily interval rainfall events beginning on 01 December 2013 (00:00) and ending on 14 December 2013 (00:00) were used to validate. The coefficient of determination (R^2) determines the hydrological model's accuracy. If R^2 approaches 1, an accurate model is produced; if R^2 approaches 0, an inaccurate model is produced. Then, future rainfall data is specified as input. Simulate the model with data from January 1, 2020, to December 31, 2050.

RESULTS AND DISCUSSION

Calibration and Validation Results

Figures 1 and 2 illustrate the model calibration and validation findings for the Pondok Tanjung station (id no.5007421). Figures 1 and 2 shows simulated flow (blue line) vs observed flow (black line).

The calibration result for peak flow at R40 Pondok Tanjung was nearly close to what was measured at $R^2 = 0.708$, while the validation result is $R^2 = 0.574$. R^2 ranges from 0 to 1, with 0.5 being regarded good [8, 11, 12]. A close match between the simulated and observed flows in HEC-HMS, with a percentage difference of less than 10%, indicates that the model is validated and accepted. Also, the R^2 value is near to 1, proving the model's reliability and suitability for drought simulation.

Simulation of Future Drought

Based on the predicted simulation result, Table 3 shows the lower peak discharge for the next thirty years. The modelling predicts over thirty years, and the lowest peak discharge is 1.06, 1.98, 2.13, 2.47 and 2.94 m^3/s. This result shows that drought might occur around January, February and March because the peak discharge is lower than normal, around 12 m^3/s. According to DID, drought flow will be lower than normal within 2 to 20 years. Therefore, it is foreseen from the simulation that Bukit Merah is a drought-risk area that can easily become drought if there is an extreme lack of rainfall in that area. Hence, drought prediction using HEC-HMS can be used to tackle such events because it can predict them earlier. Due to the fact that climate change will almost certainly cause droughts to become more severe and more frequent [10, 11], the government and DID should be aware of those dates to keep the situation under control.

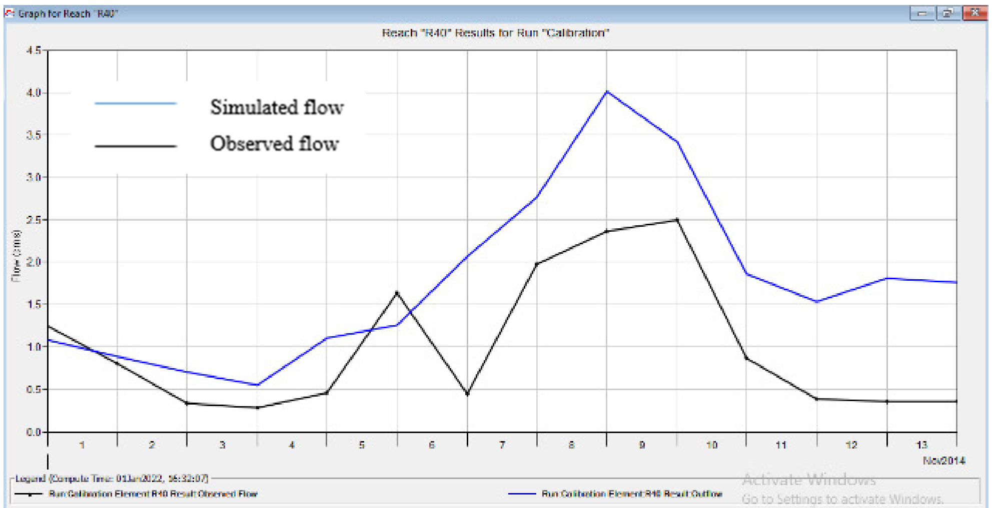

FIGURE 1. Calibration result

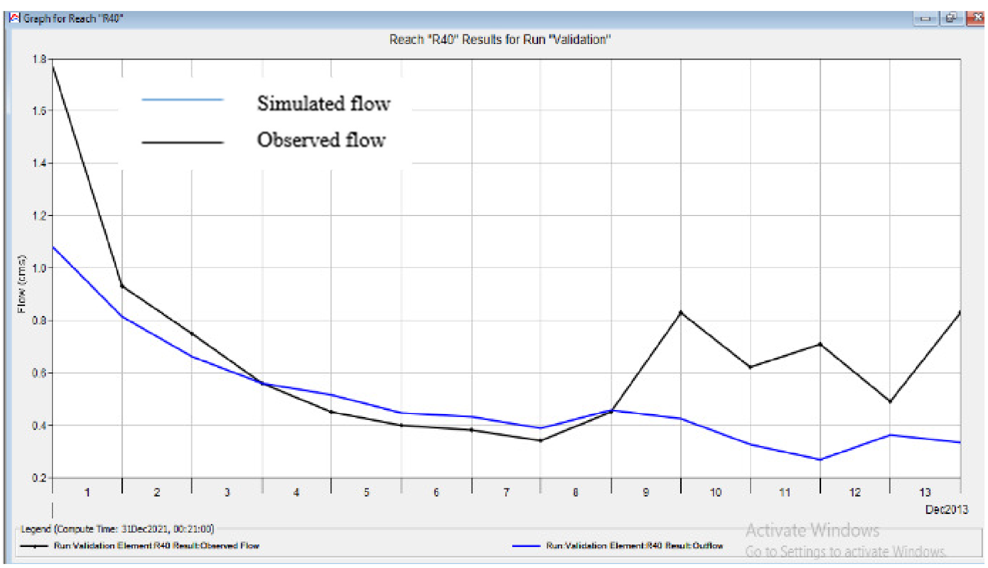

FIGURE 2. Validation result

TABLE 2. The summary calibration and validation results

Process	Observed	HEC-HMS	Differences	Percentage Different (%)
	Flow (m^3/s)	Flow (m^3/s)	Flow (m^3/s)	Flow (m^3/s)
Calibration	1.07	0.99	0.08	7.47
Validation	0.44	0.40	0.04	10

TABLE 3. The summary of low peak discharge results

Station	Date	Value (m^3/s)
Outlet	01 January 2020 (00:00)	1.06
	18 February 2021 (00:00)	2.13
	24 January 2024 (00:00)	1.98
	12 March 2045 (00:00)	2.47
	14 February 2049 (00:00)	2.94

CONCLUSION

This study used hydrologic model, HEC-HMS for Bukit Merah, Perak. The model forecasts drought in Bukit Merah, Perak from 2020 to 2050. The calibration and validation process affected the model's flow and coefficient of determination. The model was trusted since the simulated flow in HEC-HMS was close to the observed flow, with a flow differential of less than 10%. Moreover, the results of HEC-HMS perform well in terms of coefficient of determination (R^2) since the values for calibration and validation are near 1, 0.708 and 0.574, respectively. The modelling predicts over 30 years the lowest peak discharge is 1.06 m^3/s (01 Jan 2020; 00:00), 2.13 m^3/s (18 Feb 2021; 00:00), 1.98 m^3/s (24 Jan 2025; 00:00), 2.47 m^3/s (12 Mar 2025; 00:00) and 2.94 m^3/s (14 Feb 2049; 00:00).

In addition, the findings assist the hydrologic agencies in charge of basin management in making predictions and evaluating management options during planning for the catchment and future river basin studies. Also recommended is the continuous recording of rainfall and runoff data, which are recorded at intervals that correspond to one another in time. Install automatic recording stations for streamflow and rainfall at each river exit, and make it a point to check that these recording stations are always in a state of good repair and operational readiness.

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REFERENCES

1. M. K. Yener, a U. Sorman, and T. Gezgin, "Modeling studies with HEC-HMS and runoff scenarious in Yuvacik Basin, Turkiye," Int. Congr. River Basin Manag., no. June 2014, pp. 621–634 (2007).
2. H. H. Hasan, S. F. Mohd Razali, N. S. Muhammad, and A. Ahmad, "Hydrological Drought across Peninsular Malaysia: Implication of Drought Index," Nat. Hazards Earth Syst. Sci. Discuss., 28 (2021).
3. M. Hashim et al., "Satellite-based run-offmodel for monitoring drought in Peninsular Malaysia," Remote Sens., 8(8), 1–25 (2016).
4. A. N. A. Hamdan, S. Almuktar, and M. Scholz, "Rainfall-Runoff Modeling Using the HEC-HMS Model for the Al-Adhaim River Catchment, Northern Iraq," Hydrol. Res. 8(58), 17 (2021).
5. W. Yuan, M. Liu, and F. Wan, "Calculation of Critical Rainfall for Small-Watershed Flash Floods Based on the HEC-HMS Hydrological Model," Water Resour. Manag. 33(7), 2555–2575 (2019).
6. D. Halwatura and M. M. M. Najim, "Application of the HEC-HMS model for runoff simulation in a tropical catchment," Environ. Model. Softw. 46, 155–162 (2013).

7. US Army Corps of Engineers, "HEC-HMS User's Manual," US Army Corps Eng. Hydrol. Eng. Cent., no. December, 623 (2021).
8. M. N. M. Adib, M. K. Rowshon, M. A. Mojid, and I. Habibu, "Projected Streamflow in the Kurau River Basin of Western Malaysia under Future Climate Scenarios," Sci. Rep. 10(1), 1–16 (2020).
9. N. Hamidon et al., "Future Flood Forecasting in Bukit Merah Using HEC-HMS Software," 200, 183–189 (2021).
10. Z. Hassan and S. Harun, "Hydrological Response of a Catchment to Climate Change in the Kurau River Basin , Perak , Malaysia," 3rd Int. Conf. Manag. Rivers 21st Century Sustain. Solut. Glob. Cris. Flooding, Pollut. Water Scarcity, 216–225 (2011).
11. D. N. Moriasi, J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith, "Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations," Colomb. MedicaAmerican Soc. Agric. Biol. Eng. 0(3), 885–900 (2015).
12. F. Daide, R. Afgane, A. Lahrach, A.-A. Chaouni, M. Msaddek, and I. Elhasnaoui, "Application of the HEC-HMS Hydrological Model in the Beht Watershed (Morocco)," E3S Web Conf. 314, 05003 (2021).
13. M. Rodell et al., "Emerging Trends in Global Freshwater Availability," Nature, 557, 651–659 (2018).
14. S. Mukherjee, M. Ashfaq, and A. K. Mishra, "Compound Drought and Heatwaves at a Global Scale: The Role of Natural Climate Variability-Associated Synoptic Patterns and Land-Surface Energy Budget Anomalies," J. Geophys. Res. Atmos. 125, 19 (2020).