Progress in Engineering Application and Technology Vol. 1 No. 1 (2020) 96–103
© Universiti Tun Hussein Onn Malaysia Publisher's Office

PEAT

Homepage: https://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 0000-0000

Prediction of Future Streamflow for Kurau River Sub-Basin by Using Hydrological Modeling, HEC-HMS

Fegi Jahira Fakaruddin[1], Nur Aini Mohd Arish[1]*, Nuramidah Hamidon[1]

[1]Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Education Hub, 84600, Johor, MALAYSIA.

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat.2020.01.01.012
Received 23 September Month 2020; Accepted 09 November 2020; Available online 02 December 2020

Abstract: Climate change can lead to changes in the global hydrological cycle through rising surface temperatures, evaporation rates and increasing precipitation rates in some continents. Due to these changes, the flow regimes will affected by altering the magnitude and timing of the streamflow. The objectives of this study are to develop hydrological model for Kurau River Sub-basin and predict the streamflow for next 30 years (2020-2050) by using predicted future rainfall data using Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS). Different of data sets were performed for the calibration and validation process. A performance assessment of the developed hydrological model derived using HEC-HMS yields a correlation coefficient R^2 near to 1.It showed that the HEC-HMS was reliable model to predict the hydrological changes. The simulated peak discharge was 113.7 m^3/s. The scenarios of excess rainfall and extremely lack of rainfall were simulated and it showed the peak discharge of Kurau River Sub-Basin decreased by 79.33 % while for the excess rainfall scenario, the peak discharge was increased by 379.00 %. Hence, this paper outlined that the climate change has the biggest impact on the magnitude of streamflow. Further research has to be continued in order to identify the cause of peak flood risk in the Kurau River catchment.

Keywords: Climate Change, Hydrological model, HEC-HMS, streamflow, Kurau River

1. Introduction

Climate changes has gained significant recognition and has been extensively discussed around the world [1]. Climate change refers to long-term (usually decades or more) changes in global climate or population which are statistically important. .According to natural forces on Earth, external pressures or continuous anthropogenic shifts in air quality and land use, climate change may occur [2]. The changes in rainfall quantity and intensity influenced flood and drought severity, as well as streamflow.

*Corresponding author: nuraini@uthm.edu.my

A rapid streamflow loss may have a significant adverse impact on shipping and irrigation [3]. Furthermore, the significant increase in rainfall would result in flood hazards that severely endanger life and properties. Extreme drought conditions in the context of climate change have happened even more often than ever and a great deal of attention has been paid to these conditions.

In Malaysia, the climate change phenomenon stemming from human activity was started to be felt. In the past few years, Malaysia has experienced heavy rainfall and severe flooding events, such as the floods in Penang on November 2017, where rainfall averages of 15 hours of rain reached 1.5 times the normal monthly rainfall (JPS, 20 I 7) as well as extreme hot weather conditions such as prolonged drought in Selangor and Lembah Klang on 2014, which have caused water shortages (Mat Awai et al., 2019). Natural disasters are rising in frequency and magnitude as a result of these extreme weather events and both of these contribute to hjgh losses and damages. Kurau River, Perak was selected because it is one of the states that involved in climate change especially in flood occurrence. It has been reported that on TheStar (2017), Kurau River Sub-basin has contributed into flash flood at Batu Kurau after heavy rain that cause approximately sixty houses surrounding Semambu River, Titi Kasai and Anak Kurau were flooded about 0.6 meter to 0.9 meter depth. The upstream of the confluence of Kurau River is a Bukit Merah Reservoir that used to store the rainfall water.

Therefore, provided the above and the extent of the damage done by extreme events, a hydrological model must be developed to simulate the area's streamflow magnitude. The purpose of this study were to develop hydrological model and predict the future streamflow in the next thirty years (2020-2050) in Kurau River Sub-basin by using HEC-HMS. This is relevant because in future this provides researchers with an overview, whether it will suffer from the flood or not. If so, what is the magnitude of the streamflow causing the flood? If this information can be obtained before the disaster, the researchers can help to plan flood mitigation measures and minimize damage to floods.

1.1 Study Area

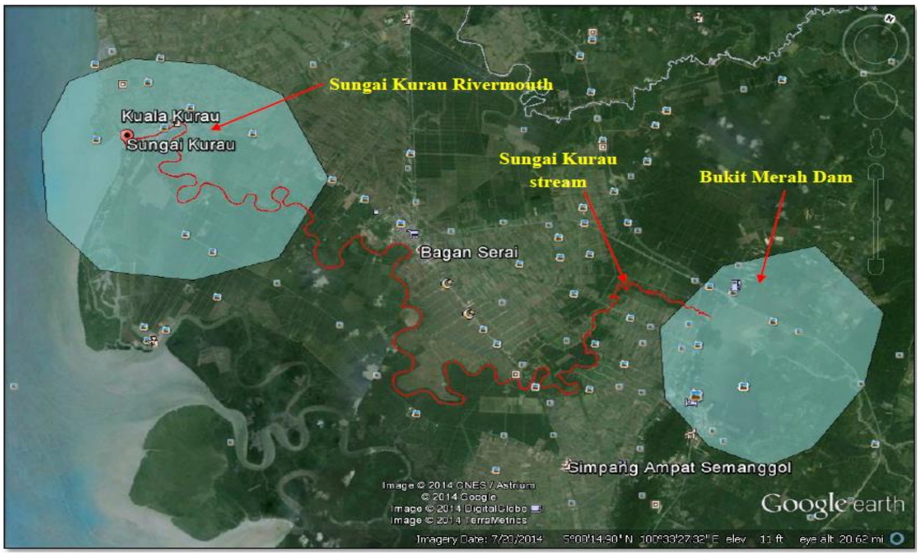

Figure 1: Satellite image of Kurau River and Bukit Merah Reservoir

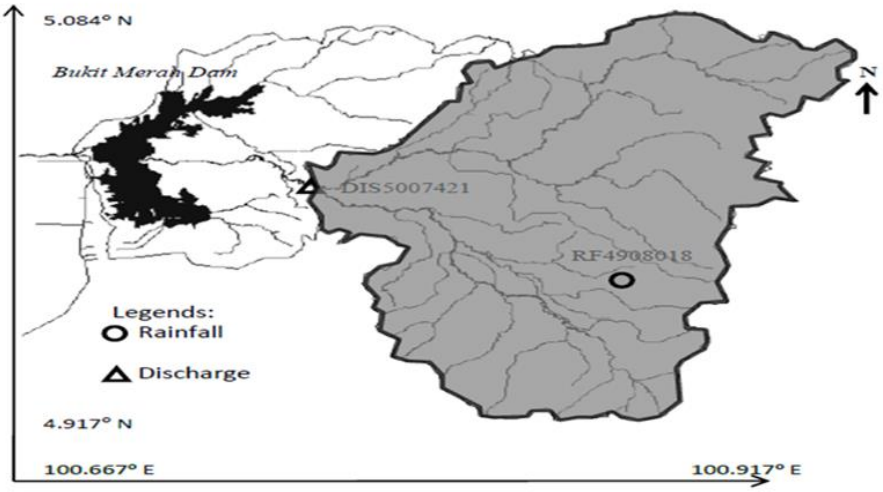

Figure 2: Location of rainfall and discharge station in Kurau River Catchment

A reservoir called Bukit Merah Reservoir was built at the downstream that received inflow from Kurau catchment (Figure 1). This reservoir was a multi-purpose reservoir with the primary function of supplying water for the Kerian irrigation system, as well as being the sole source of domestic water supply for the districts of Kerian and Larut Matang in Perak. This reservoir also functions as a structure for flood control. The catchment has an area of around 337 km^2 and was dominated by palm oil plantations, rubber fields, forestry and a small residential zone. The river originates partially from the Bintang Mountains, where the rugged and rocky upper terrain reached. At the headwaters of the river, the ground elevation was moderately high, with heights of 1200 and 900 m respectively in Batu Besar and Batu Ulu Trap [7]. Figure 2 illustrated the details of the Kurau River catchment rainfall and discharge station.

2. Materials and Methods

2.1 Hydrological modelling (HEC-HMS)

Hydrological modelling is a one-dimensional model that represents the conversion process of rainfall to river flows or runoff by using observational data as the model driver [8]. Those parameters denote catchment characteristics with meteorological time series as the input variable. The “best” hydrological modelling should be able to describe the natural process in the transformation of rainfall-runoff [9]. The Hydrological Modelling System (HEC-HMS) is designed to model dendritic watershed system precipitation-runoff processes. To solve the broadest range of problems possible, it is intended to be accessible in a wide variety of regional areas. This includes essential river basin water storage and flood hydrology, and minimal urban or natural runoff. Hydrographs created by the program are used to directly or in combination with other software to research water supply, urban runoff, flow forecasting, potential urbanization effects, reservoir spillway construction, flood risk management, floodplain control, and system activity. The software was a generalized modelling method that can represent many watersheds of different sizes. A watershed model was developed by splitting the hydrological cycle into manageable sections and by building boundaries across the watercourse of interests [10].

2.2 Data

Brief descriptions of the data used in the HEC-HMS modelling are as follows:-

i. Rainfall data

Rainfall data from year 2010 to 2019 were collected from Malaysian Department of Drainage and Irrigation (DID). Ldg. Pondoland, Pondok Tanjung was selected as rainfall station for this study since it was near to the inlet of Bukit Merah Reservoir.

ii. Predicted future rainfall data

The predicted future rainfall data for year 2020-2050 has been obtained from Malaysian National Hydraulic Research Institute (NAHRIM) that generated by PRECIS. These data became the input to simulate the streamflow for next thirty years in Kurau River Sub-basin by using HEC-HMS.

iii. Topography map

The topography map obtained from Department of Survey and Mappping Malaysia (JUPEM) was used to produce input for GIS database Kurau River Sub-basin.

iv. Main morphological and cross section data

Main morphological and hydrological descriptors for Kurau River were obtained from River Engineering and Urban Drainage Centre (REDAC), USM. Six sites were chosen for detailed analysis and as an input in channel parameter for HEC-HMS.

v. GIS database

GIS are combinations of hardware, software and geographically based data. These are very useful tools for river basin management due to their ability to generate, store and analyze spatially and temporally dispersed data. The GIS layers used in the database are the Land-use / land-cover, River system, 10 m x 10 m Digital Elevation Model (DEM), soil map and hydrologic stations.

2.3 HEC-HMS setup

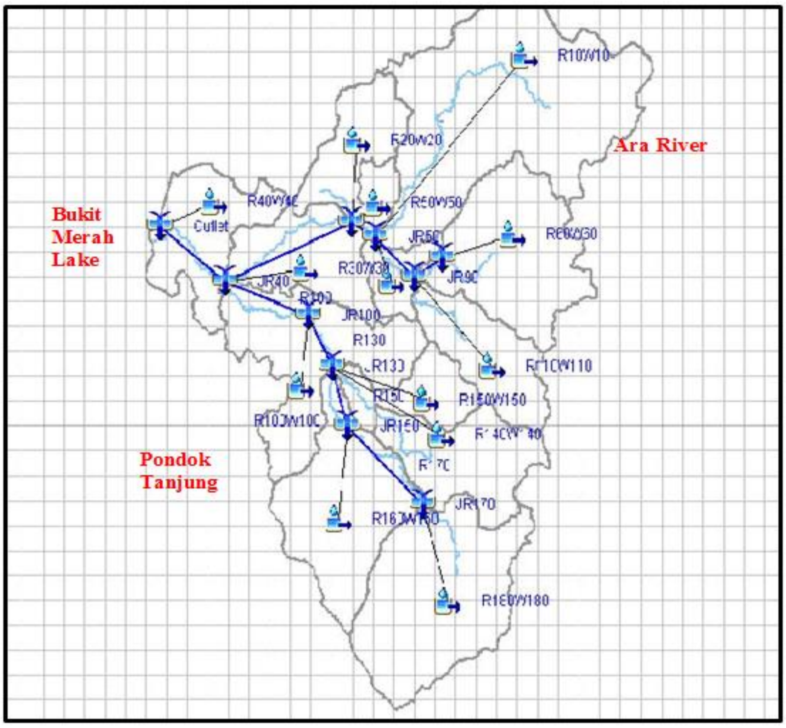

Figure 3: HEC-HMS layout model

The model HEC-HMS design for the Kurau River Sub-basin was shown in Figure 3. For the flows, there are nine (9) nodes from each sub-catchment and basin. Node R40 which is Pondok Tanjung station (id no. 5007421) recorded as the observed discharge data. There are 13 subcatchments used to describe the Kurau River hydrological model and can be split into two (2) rivers namely Kurau River and Ara River. Throughout the HEC-GeoHMS process, all of the sub-catchments were named and can be identified based on their location. The river will connect from Kurau River to Ara River and eventually meet at the junction named Pondok Tanjung and link via the Bukit Merah Lake outlet.

3. Results and Discussion

3.1 Calibration and validation results

Calibration is a method of deciding the properties or parameters defined by a function. Some parameters are determined by the calibration process such as initial abstraction, curve number, impermeability, lag time, initial discharge, recession constant and ratio, where the parameters are adjusted until the observed and simulated hydrograph was adjusted properly nearly. Several parameters are taken from the topographic map and the HEC-GeoHMS process such as slope, manning (n), bottom width, shape and length of the channel. Validation is the process whereby the model is tested for applicability using specific data sets. The software parameters which were added during the configuration process remain unchanged throughout the validation process. The comparisons of simulated and observed hydrographs will then demonstrate that there is a strong agreement between them. If the test outcome fails, otherwise the calibration process must be repeated.

The calibration and validation process is interrelated and involves some repetitive attempt and error. Model calibration and validation of discharge stations at Pondok Tanjung station (id no.5007421) were performed using two different data sets. The daily rainfall event starts from 5 January 2010 (00:00 a.m.) to 15 January 2010 (00:00 a.m.) was used for calibration and the daily rainfall event starts from 16 January 2010 (00:00 a.m.) to 26 January 2010 (00:00 a.m.) was used for validation. Month of January 2010 was selected because the El Nino phenomenon occurred and it caused temperature and pressure increased sharply and make the area become more drier and the sea level changed to more lower than normal. The accuracy of the hydrological model is determined on the basis of the value of the coefficient of determination (R^2). The nearer the R^2 value to 1, the better the accuracy of the model can be achieved, while the nearer the R^2 value to 0, the poorer the model. Figure 4 and Figure 5 shows the calibration and validation results. The summary of both results were showed in Table 1. Based on the results, the model has been shown to be validated and reliable as the simulated flow in HEC-HMS was closely in line with the observed flow and the specific percentage was less than 10%. Additionally, the R^2 value is similar to 1, so the model is known to be trustable and can be used for streamflow simulation.

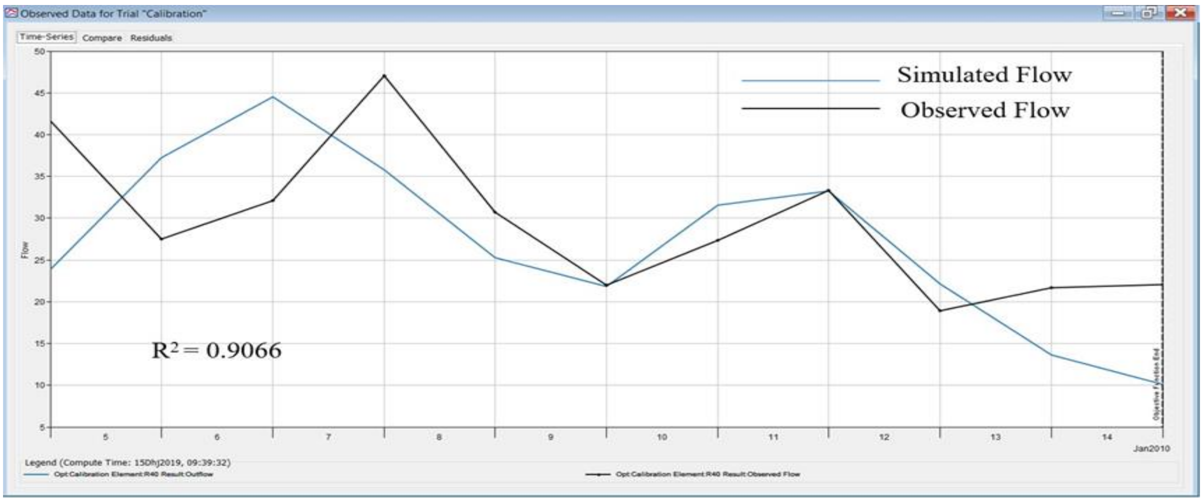

Figure 4: Calibration results

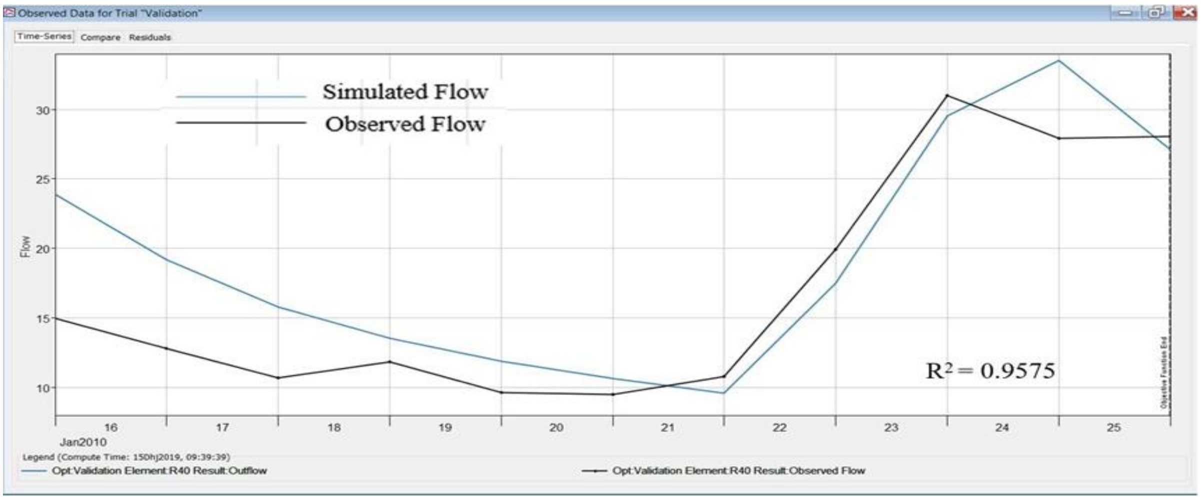

Figure 5: Validation results

Table 1: Summary of calibration and validation results

Process	Observed Peak Flow (m^3/s)	HEC- HMS Peak Flow (m^3/s)	Difference Peak Flow (m^3/s)	Percentage difference (%) Peak Flow	R^2 value
Calibration	47.00	44.50	2.50	5.30	0.9066
Validation	31.00	33.50	2.50	8.10	0.9575

3.2 Simulation of future streamflow

After the model has been verified, the predicted future rainfall data were used as the input of precipitation to simulate future streamflow for next thirty (30) years start from 2020 until 2050. The daily interval rainfall event starts from 01 Jan 2020 (00:00 time) until 31 Dec 2050 (00:00 time). The climate change issue, however, has made streamflow predictions a bit challenging. Therefore, the excess rainfall scenario and extremely lack of rainfall scenario are simulated in order to get the overall image of streamflow prediction even in extreme events. The amount of rainfall were increased by 5 times for the excess rainfall scenario and decreased by 5 times for the insufficient rainfall scenario.

The result of simulation of future streamflow in Kurau River Sub-basin under normal condition was shown in Figure 6. For the simulation of excess rainfall scenario and extremely lacking of rainfall scenario were shown in Figure 7 and Figure 8 respectively. The summary of the simulation results was shown in Table 2. Based on the simulation results, it shows that, using predicted rainfall data, the peak discharge for next thirty years would be 113.70 m^3/s. In the condition of excess rainfall, the peak discharge may rise to 544.70 m^3/s, which is 379.00 % higher than normal. It is quite terrifying and the devastating impact is unthinkable. Because of the extreme lack of rainfall, the peak discharge will drop to 23.50 m^3/s which is 79.33 % lower than normal and this will result in drought. Table 2 showed the summary of the simulation results.

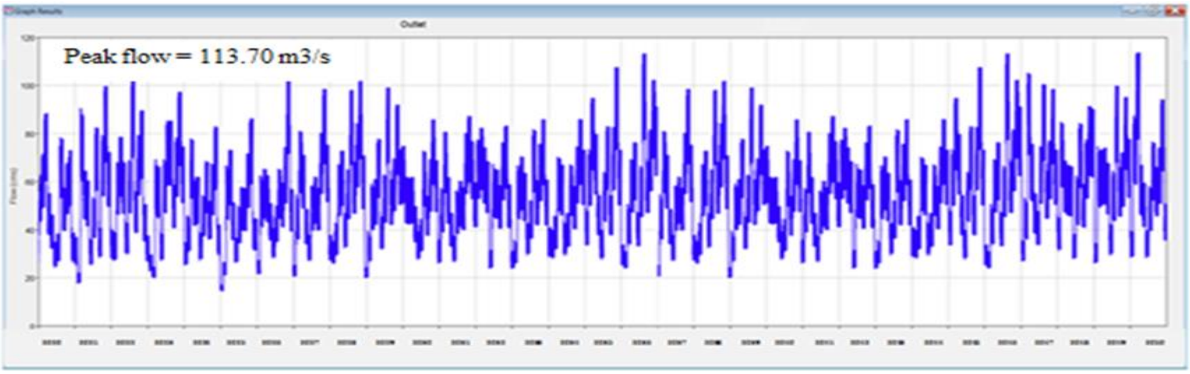

Figure 6: Simulation of future streamflow under normal condition

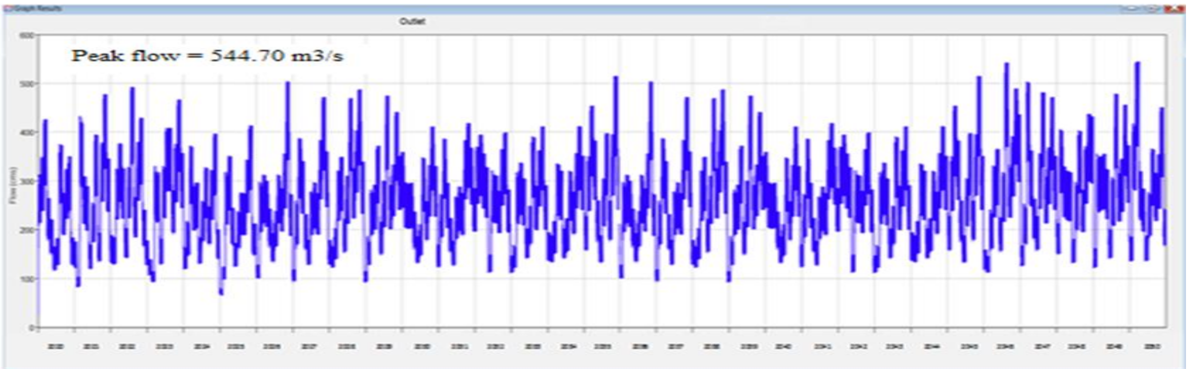

Figure 7: Simulation of excess rainfall scenario

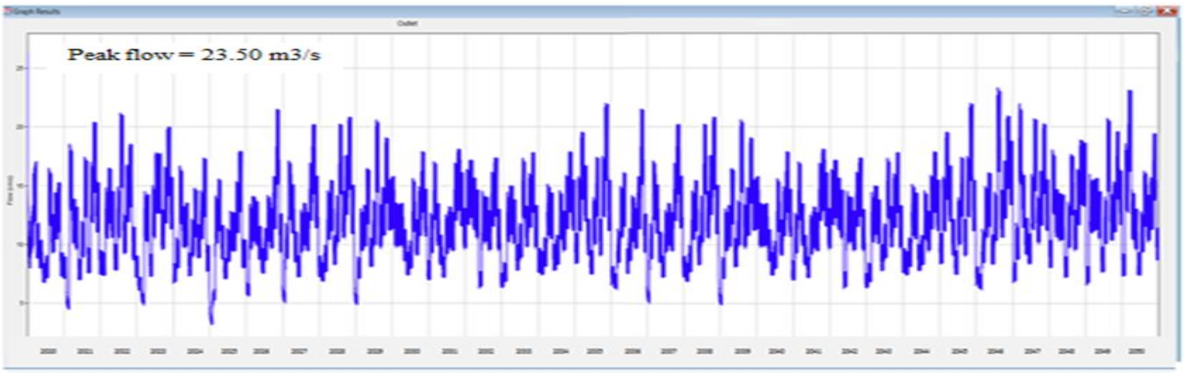

Figure 8: Simulation of insufficient rainfall scenario

Table 2: Summary of simulation results

Station	Peak Flow (m3/s)			Difference compared to normal condition (m^3/s)		Percentage difference compared to normal condition (%)	
	Normal condition	Excess rainfall	Insufficient rainfall	Excess rainfall	Insufficient rainfall	Excess rainfall	Insufficient rainfall
Outlet	113.70	544.70	23.50	431	90.2	+379	-79.33

4. Conclusion

Results of the study indicates from the simulation; it is clearly seen that Kurau River is a flood-risk area that can easily be flooded if there is excess rainfall in the region. Regardless of climate change, the flood would be higher than average as the results would result in excess rainfall and the drought would also be more severe as the results would result in extremely lack of rainfall. Hence, flood prediction using HEC-HMS can be used as a solution to tackle such events because it can predict such events earlier and provide the government and residents with lead time to take action. In HEC-HMS, it will reveal the expected date and time of the streamflow magnitude, so that it can take the preventive measures in time.

Acknowledgement

The authors would like to thank the Ministry of Higher Education Malaysia, Department of Irrigation and Drainage Malaysia, National Hydraulic Research Institute of Malaysia, Department of Survey and Mappping Malaysia, River Engineering and Urban Drainage Centre of USM and the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for the support of this research.

References

[1] H. A. Rahman and R. Suppian, Pemanasan global: impak terhadap masyarakat dan kesihatan. Universiti Utara Malaysia, 2015.

[2] MMD, "Climate change scenarios for Malaysia, 2001-2099 : Malaysian Meteorological Department Scientific Report." 2009.

[3] Y. Chai et al., "Influence of Climate Variability and Reservoir Operation on Streamflow in the Yangtze River," Sci. Rep., vol. 9, no. 1, p. 5060, 2019.

[4] J. Pengairan and D. A. N. Saliran, "Dan Alam Sekitar," Lap. Banjir Tah. Tahun 2016/2017, vol. 9, no. 2, pp. 1–81, 2017.

[5] N. Mat Awal, A. Jaludin, A. N. Che Abdul Rahman, and I. Ho-Abdullah, "'Is Selangor in Deep Water?': A Corpus-driven Account of Air/water in the Malaysian Hansard Corpus (MHC)," GEMA Online® J. Lang. Stud., vol. 19, no. 2, pp. 99–120, 2019.

[6] Z. A. Hasan, N. Hamidon, M. S. Yusof, and A. A. Ghani, "Flow and sediment yield simulations for Bukit Merah Reservoir catchment, Malaysia: A case study," Water Sci. Technol., 2012.

[7] W. R. Ismail and S. A. M. Najib, "Sediment and nutrient balance of Bukit Merah Reservoir, Perak (Malaysia)," Lakes Reserv. Res. Manag., 2011.

[8] T. Karvonen, H. Koivusalo, M. Jauhiainen, J. Palko, and K. Weppling, "A hydrological model for predicting runoff from different land use areas," J. Hydrol., vol. 217, no. 3, pp. 253–265, 1999.

[9] J. Wainwright and M. Mulligan, Environmental Modelling: Finding Simplicity in Complexity: Second Edition. 2013.

[10] W. Scharffenberg, "Hydrologic Modeling System HEC-HMS User's Manual," U.S. Army Corps Eng. - Hydrol. Eng. Cent., 2016.

[11] R. Ruggles, D. Brandes, and D. Kney, "Development of a geographical information system for watershed research, information and education," in Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges - Proceedings of the World Water and Environmental Resources Congress 2001, 2004.

[12] D. Josep, "D. Josep, "The effect of deforestation on catchment response in the tropical climate region: Case study for Sg Padas Catchment : Joseph Dinor. Thesis submitted in fulfilment of the requirements for the degree of Master of Science MARCH 2009," no. March, 2009.