Estimating flow rate in gauged and ungauged stations in Kuantan river basin using Clark method in Hec-HMS

To cite this article: AAG Nadiatul Adilah and S Nuramirah 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **244** 012014

Estimating flow rate in gauged and ungauged stations in Kuantan river basin using Clark method in Hec-HMS

AAG Nadiatul Adilah[1,2] and S Nuramirah[2]

[1]Faculty of Civil Engineering, Universiti Teknologi Mara, 40450 Shah Alam, Selangor, Malaysia
[2]Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300, Gambang, Pahang, Malaysia

Email: nadiatul@ump.edu.my

Abstract. Hydrologic simulation that engages incomputer models is the cutting edge to boost the understanding and provide further reliable outcomes in estimating flow rate. US Army Corps of Engineers has taken an initiative to develop a stable and dependent model, HEC-HMS that can be used for many hydrological simulations. The value of parameter needed for the simulation basically depends on the method chosen for loss, transform and base flow. In this study, the model parameters are changed and the model calibration had been performed separately for the three selected methods, the Soil Conservation Service Curve Number (SCS CN) loss method, the Constant Monthly base flow and the Clark Unit Hydrograph for transform method, to determine the most suitable simulation and to obtain the highest peak discharge for every sub-basin of the Kuantan River. Every flow simulated undergoes the validation and calibration process, with the Nash-Sutcliffe index used as a criterion to compare the outcomes between observed and simulated hydrographs. At the end of the study, it can be concluded that SCS Curve Number, Constant Monthly and Clark Unit Hydrograph is the best method for loss, base flow and transform method consecutively in estimating the flow rate in Kuantan River Basin.

1.0 Introduction

The prolonged and heavy rainfall during North East Monsoon (NEM) is one of the responsible causes of flooding in the Kuantan River Basin (KRB). This comes about as a result of the surplus surface runoff that exceeds the basin compensation capacity, causing floods to low laying areas that hamper human social and economic life. The KRB has experienced seasonal floods in past period's incidences. It has been observed that the change in climatic conditions has resulted in abnormal rainfall pattern, perceiving anthropogenic activities. There have been changes in the flood nature and incidence, getting more frequent with variable concentrations. The years 2001, 2011 and 2013 are considered to be the worst flood disasters, after 1971 catastrophic event. According to the Kuantan Municipal Council, the city is predicted to experience more extreme weather conditions in future that with a change in rainfall pattern [1]. The need of a modeling system is stimulated, and sometimes even enforced, by many activities required by the river basin planning and management, ranging from timely flood alert to the demarcation of areas at risk of flooding, to the programming of water budget at the basin scale, according to the national and regional regulations in the field [2]. By creating a river model based on the actual data of rainfall and stream flow, along with the satellite image, the true phenomenon of what and how it is really happening can be understood.

1.1 HEC-HMS Model for flow simulation

HEC-HMS (Hydrologic Engineering Center- Hydrologic Modeling System) model had been developed by the US Army Corps of Engineers that could be used for many hydrological simulations. The HEC-HMS model can be applied to analyze urban flooding, flood frequency, flood warning system planning, reservoir spillway capacity, and stream restoration [3].This also includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff [4].According to Kalita [5], the proliferation of personal computers and the development of the HEC-1 model of the U.S. Army Corps of Engineers in 1998 to a GUI-based(Graphical User Interface) user-friendly HEC-HMS model is available in the public domain. This comes as another useful tool to the field hydrologists. Unfortunately, the HEC-HMSmodel or any of the many watershed models for that matter has not found many takers due to the uncertainty involved in the estimation of parameters of the models. But, parameter estimation on a regional scale at least may be possible to switch over to watershed models, such as, the HEC-HMS to take advantage of the high speed computer programs, in contrast to the spreadsheet exercises.

2.0 Methodology

The KRB of the major river of Pahang that starts from Sg. Lembing passing through Kuantan City and drained into the South China Sea, has been chosen as the study area. It covers an area of 1630 km^2. The elevation range is from 0 at the mouth of the watershed to 1511m in the remotest part of the North-West watershed. The KRB contains several main tributaries, which drain into the rural, agricultural, urban and industrial areas of Kuantan [6].

2.1 Data Pre-processing

ArcGIS 10.3 is used to pre-process the collected data for the study area, namely, the land use data from the Department of Survey and Mapping Malaysia, JUPEM. From the raw data, such as, the digital elevation model, several processes were carried out in the software to extract the model-specific information from it. On the basis of elevation geometric algorithms, there werea few hydrologic parameters that were computed, such as the river lengths, longest flow path, curve number [7] slope and the whole and even sub-basin areas.After the particular information on the basin areas had been obtained, the basin images are converted into the AutoCAD software, which was then converted into AutoCAD interchange file or dfx file type, to enable them to be imported into HEC-HMS. This file would then serve as the background map to ease the process of constructing the components, such as, the sub-basins, reaches, and even junctions. The configuration of HEC-HMS for the Kuantan River Basin is depicted in Figure 1.

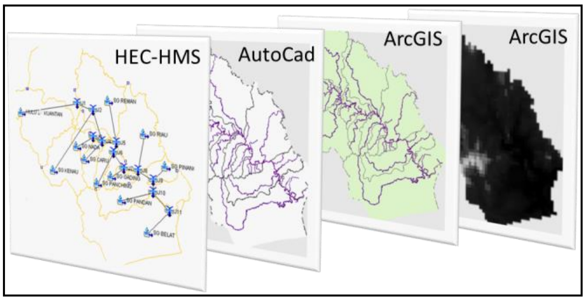

Figure 1. The process of obtaining the configuration for the Kuantan River Basin

2.2 Data Collection

Rainfall data was collected from five stations, namely, Sg Lembing PCLL (3930012), Ladang Nada (3931013), Ladang Reman (3931014), Pam Paya Pinang (3832015), and SK Gambang (3731018). Stream flow data was collected from station3930013 at Sg Kuantan @ Bukit Kenau. The rainstorm event for the calibration process was set on 04th September 2010 from 6.45 pm until 07th September 2010, 12.00 am, while the data used to validate the calibrated modelwasthe rainstorm event on 12th October 2013 at 7.30 pm up to 13th October 2013, 8.15 pm. The purpose of the date chosen for the validation is due to the similarity rainfall pattern with the date used in calibration process. The similarity rainfall pattern will produce the exact same graph and result. In order to achieve the definite estimation of the spatial distribution of rainfall, it is necessary to use an interpolation method. In this case, the Thiessen method was used to determine the rainfall station data for each sub-basin in the Kuantan River Basin. The polygon was as shown in Figure 2.

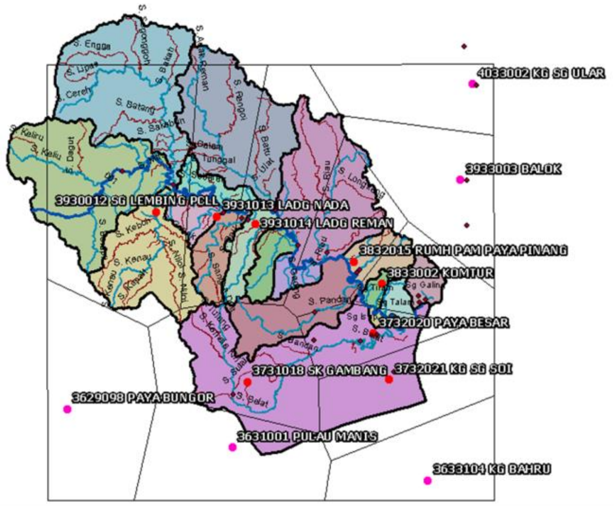

Figure 2. The Thiessen Polygon for Kuantan River Basin

2.3 Model Application

The data collected were computed using the HEC-HMS 4.0 model and the prepared map was used as the background map in the model. Both watershed and meteorology information were put together to fulfil the requirement to simulate the hydrologic response. Data required for the hydrological modelling of the catchments are, 1. area of the catchment and the sub-catchments, 2. land use patterns of the area involved, 3. daily rainfall and stream flow data, 4. base flow, 5. The imperviousness, 6.initial abstraction, 7. time of concentration, 8. storage coefficient and curve number [8]. However, these parameters may slightly differ according to the method of choice, for transform, loss and base flow methods. Some values of the parameters were obtained from the particular agencies, previous research and even through calculation by certain equations.

2.4 Model calibration

The calibration process follows after the first model application. It is done by varying each input parameter within the prescribed range,while keeping other constants and running the model. The output values were analysed to determine their variations with respect to the base output set and this is a measure of the sensitivity. The model was calibrated for the identified sensitive parameters to improve the agreement between the simulated and observed data [9].The value for the observed streamflow data at Junction 2 was compared. Hence, the sub-basins directly involved in the calibration process of wereSg Kuantan and Sg. Kenau. The preceding Figure 3 clearly shows the direct involvement of these two sub-basins towards the output values at Junction 2.

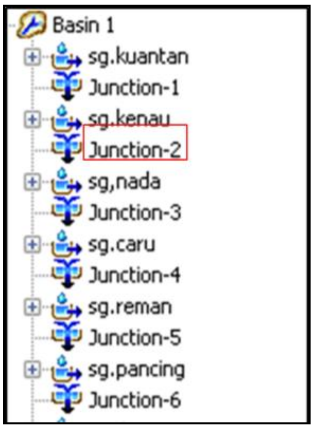

Figure 3. The sequence of the sub-basins in the Kuantan River Basin

The initial step in model calibration was manual adjustment of model parameters using the trial-and-error method, which enables the modeller to make a subjective adjustment of parameters to obtain an appropriate fit between the observed and simulated hydrographs [10]. The value of parameter for loss and transform method for both sub-basins, i.e. Sg. Hulu Kuantan and Sg Kenau were manually adjusted during simulation up until the hydrograph for observed and simulation had obtained the similarity of shape. The rest of the sub-basin was adjusted through the Weighted Area Method. Manual adjustment of Curve Number, Time of Concentration (T_c) and Storage Coefficient (R) weredone using the weighted area method, based on different land uses in the study area. The calibrated value at Kenau that employs calculation of weighted curve number (WCN) was shown in Equation1, as follows;

$$\text{WCN} = \frac{\Sigma_{i=1}^{i=n} CN_i . A_i}{\Sigma_{i=1}^{i=n} A_i} \quad (1)$$

Where, WCN is weighted curve number, A_i is area for*i*th land use type and CN_i is curve number for *i*th land use type. The values of area and *CN* at Kenau were constants, since this is the only gauged station with real streamflow data. The areas for the other sub-basins were manipulated values in the equation.

2.5 Model Validation

For the validation process, the generated hydrograph was compared with the observed discharge graph, to confirm the suitability of assumed values in the calibration process. The calibrated model parameters were validated using different runoff and streamflow data.

2.6 Statistical Evaluation

Numerous fit of statistical criteria was proposed in the literature for evaluating hydrological modelling results. In this study, the Nash-Sutcliffe index was used as the criterion to compare the results between observed and simulated hydrographs. When the Nash Sutcliffe model efficiency coefficient was between 0 and 1, the model does better than simply forecasting. The closer the Nash Sutcliffe model efficiency coefficient to one is, the better the performance of the model. Nash Sutcliffe model efficiency coefficient is defined in Equation 2 as follows;

$$\text{NSE}=1-\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{mean}\right)^2}\right] \quad (2)$$

Where $Y_i^{obs}$is*i*th data being evaluated, $Y_i^{sim}$is*i*th simulated data, Y^{mean} is the mean of observed data and *n* is the total number of observations.

3.0 Result and Discussion

During the calibration process, there werea few parameters that need to be assumed, such as, the initial abstraction and imperviousness. After comparing the observed and simulated hydrographs, and a high similarity between both has been obtained, then only the assumed value of the particular parameters were considered to be reasonable and further work can proceed.

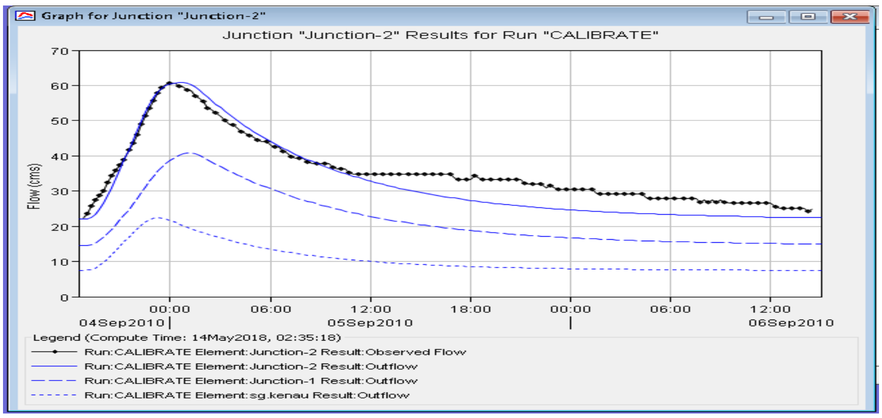

Figure 4. Simulated and observed hydrographs after a calibration process at Junction 2

IOP Conf. Series: Earth and Environmental Science **244** (2019) 012014 doi:10.1088/1755-1315/244/1/012014

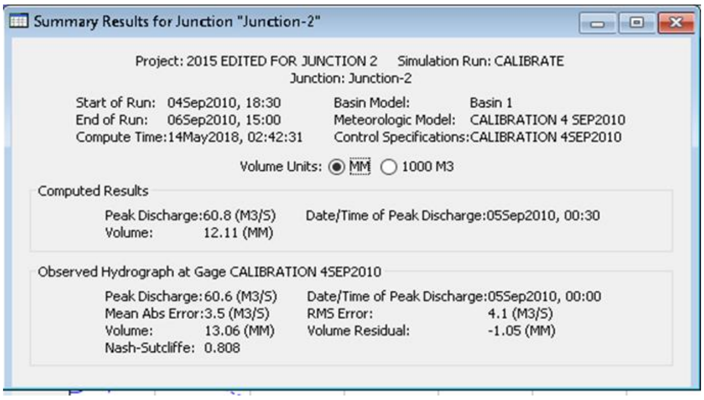

Figure 5. Summary results of calibration for Junction 2

$$\text{NSE} = 1-\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{mean}\right)^2}\right] \tag{3}$$

$$\text{NSE} = 1-\left[\frac{\sum_{i=1}^{n176}(2431.99)^2}{\sum_{i=1}^{176}(15460.750)^2}\right] \tag{4}$$

$$\text{NSE} = 0.8 \tag{5}$$

From the computed results, the shape of the observed hydrograph was represented by the black dotted line, while the simulated hydrograph by continuous blue line. There were not much differences between these two shapes of hydrographs and almost reach a perfect similarity. Both the maximum observed and simulated discharges at Junction 2 werefound to be 60.6m^3/s and 60.8m^3/s respectively. The model showed a good performance with a Nash-Sutcliffe value of 0.808, higher than the requirement value of 0.8 and almost unity. Since the model indicated a good performance based on the index of Nash-Sutcliffe, the validation process was preceded with a different set of rainstorm event.

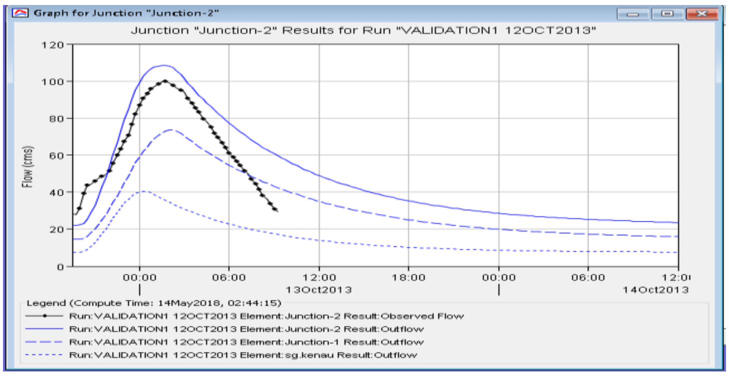

Figure 6. Generated hydrograph of simulated and observed data at Junction 2

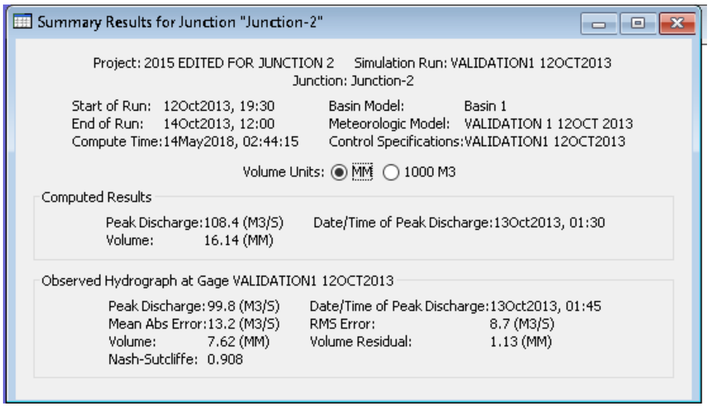

Figure 7. Summary results of validation for Junction 2

From the computed results, the shape of the observed hydrograph was represented by black dotted line, while the simulated hydrograph by continuous blue line. The shape of the hydrographs was almost similar and the simulated hydrograph showed a higher set of value than the observed. Both the maximum observed and simulated discharged at Junction 2 were 99.8m^3/s and 108.4m^3/s respectively. The model showed a good performance with a Nash-Sutcliffe value of 0.908, higher than the requirement value of 0.8 and almost unity.

4.0 Conclusion

The HEC-HMS 4.0 computer model can be reliable tool to assist in the simulation, calibration and validation of the Kuantan River Basin. As the transformation method in the model, the Clark Unit Hydrograph method simulates the flows successfully and the parameter value was easy and simple to be fulfilled. As for the loss method, SCS CN method did performed well and it was indeed one of theothergood options. Therefore, the Clark Unit Hydrograph method could be recommended as the best transformation method for the Kuantan River Basin with the SCS Curve Number for the loss method. As there were plenty of ungauged rivers located in the Kuantan River Basin, this approach can reliably be applied in order to simulate river flows in the other areas with the same characteristics. The same approach of calibration and validation can also be applied in other parts of the region.

References

[1] Zaidi SM, Akbari A, Ishak WM 2014 A Critical review of Floods History in Kuantan River Basin: Challenges and Potential Solutions

[2] Razi MA, Ariffin J, Tahir W, Arish NA 2010 Flood estimation studies using Hydrologic Modelling System (HEC-HMS) for Johor River, Malaysia *Journal of Applied Sciences* **10** (11):930-9

[3] Davis 2008 Engineers UA. Hydrologic modelling system (HEC-HMS) application guide: version 3.1. 0. Institute for Water Resources

[4] Scharffenberg WA, Fleming MJ 2013 Hydrologic modelling system HEC-HMS: User's manual US Army Corps of Engineers, Hydrologic Engineering Center

[5] Kalita DN 2008 A study of basin response using HEC-HMS and subzone reports of CWC In Proceedings of the 13th National Symposium on Hydrology National Institute of Hydrology, Roorkee

[6] Nasir MF, Zali MA, Juahir H, Hussain H, Zain SM, Ramli N. 2012 Application of receptor models on water quality data in source apportionment in Kuantan River Basin. *Iranian Journal of Environmental Health Science & Engineering* **9**(1):18
[7] Gyori MM, Haidu I 2011 Unit Hydrograph Generation for Ungauged Subwatersheds. Case Study: the Monoroştia River, Arad County, Romania. Geographia Technica
[8] Wijesekara RS, Kudahetty C 2010 Preliminary groundwater assessment and water quality study in the shallow aquifer system in the AttanagaluOya Basin. In *Proceedings of National Conference on Water, Food Security and Climate Change in Sri Lanka*. Water Quality, Environment and Climate Change **Vol. 2**, p. 77e87
[9] Roy D, Begam S, Ghosh S, Jana S 2013 Calibration and validation of HEC-HMS model for a river basin in Eastern India. *ARPN Journal of Engineering and Applied Sciences*
[10] Skhakhfa ID 2016 Ouerdachi L. Hydrological modelling of WadiRessoul watershed, Algeria, by HEC-HMS model *Journal of Water and Land development* **31**(1):139-47

Acknowledgement
The authors gratefully acknowledge the Universiti Malaysia Pahang for this research project (Grant No RDU170344). Many thanks to all research members from Universiti Malaysia Pahang, Universiti Teknologi Mara, Shah Alam and Felda Palm Industries Sdn Bhd., who have participated in this project.