Using Green-Ampt Loss Method in Surface Runoff Simulationff Klang Watershed inWest Malaysia

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Abstract:-Usual methods of runoff and flooding estimation are expensive, time consuming and inaccurate because of various variables of the watershed. As such, using Geographic Information System (GIS) to develop hydrology model through the sub-watershed data in water resources management and planning is the only viable method to date. The main aim of this research is to estimate of the peak flow in the Klang watershed using the Green-Ampt method as a major component in runoff and flood modelling. The storm daily surface runoff and flow data were compared to observed values at the outlet of the watershed. The study is conducted in the 674 km² Kuala Lumpur watershed located in Klang basin of Malaysia. The catchment delineation is generated for the Klang watershed to obtain the sub-watershed parameters using HEC-GeoHMS extension in ARCGIS. All necessary parameters are assigned to the models applied in this study to run the runoff and flood model. The results show in a high accuracy and a good fit with the measured discharge and flow at the basin outlet. These results show that the method is capable to make accurate calculations and predictions for flooding events in the Kuala Lumpur watershed.

Keywords:Green-Ampt, Loss Method, GIS, HEC-Geo-HMS, Runoff, Flood modelling

1 Introduction

There are different methods for surface runoff simulation in HEC-HMS and these methods have different results. Green-Ampt is one of the best methods available to product estimation of the impacts of land use on runoff. As stated by Wilcox et al. (1990) infiltration parameters can be directly related to watershed characteristics.Some studies have been conducted on the performance of Green-Ampt (Zhang et al. 1995; Nearing et al. 1996).Arekhi et al. (2011) compared the different methods of precipitation loss in HEC-HMS. The results showed Green &Ampt method placed in second preferences compare the Initial and constant loss rate method. However, Wilcox et al. (1990) indicated that SCS-CN and Green-Ampt models leave the results close to where the scope of the study was on six small catchments in the USA.SinaAlaghmand et al, (2011), calibrated and validated the HEC-HMS model in KayuAra River Basin in Malaysia, They demonstrated that average and median parameter values of calibration sets is reliable for validation in comparison with mode of parameter values when using the Green-Ampt loss method in Hec-HMS.

In this study, Green-Ampt equations is applied to determine loss model as a major component in rainfall-runoff modelling. The main objective of this study is s to evaluate the performance of the HEC-HMS program in simulating the rainfall-runoff for the Klang watershed with Green-Ampt infiltration loss method with Mean Square Error (MSE) and Mean Absolute Percentage Error (MAPE) and coefficient of determination (R^2).

2 Material and method

2.1 Study area

Klang watershed is located in Selangor province in Malaysia, between 101°.30´ to 101°.55´ E Longitudes and 3° to 3°.30´ N latitude and covers about 674 Km².The altitude ranges from 10 to 1400 with a mean annualrainfall 2400. The Klang basin can be a suitable study river basin for this research

ISBN: 978-1-61804-147-0

because of a large part of the river basin area is well developed urban area (About 50%) with different land use and also high population density that shows the importance of this river basin.The land use, soil, rainfall data and hydrometric data were obtained from Department of Irrigation and Drainage of Malaysia (DID). Digital Elevation Model (DEM) obtained from the Shuttle Radar Topography Mission (SRTM) with the resolution of 90 m per pixel.

The program simulates a rainfall-runoff response of a river basin system to a precipitation input by representing the entire river basin as an interconnected system of hydrologic and hydraulic components, which include river basins, streams and reservoirs (U.S. ACEHEC, 2006). HEC-HMS software is used for runoff and flooding analysis.HEC-HMS has been applied as one of the most utilized hydrological models in the hydrological studies (e.g. Stehr et al., 2008; Ellouze et al., 2009). ArcGIS software with the HEC-GeoHMS extension was used to create hydrological maps. Catchment delineations have been created for the Klang watershed to make the sub-watershed parameters through HEC-GeoHMS extension in ARCGIS as an input into HEC-HMS. In this regard, there has been attempt to reproduce all the spatial maps such as initial content, saturated content, suction and conductivity maps have been reproduced.The transformation component, applied Snyder UH method for Klang area which includes the parameters of lag time and peaking coefficient. For base-flow component of HEC-HMS, the Threshold Discharge as recession method was used in HEC-HMS for Klang river watershed. The storage-outflow relationship for the existing reservoirs must be specified. It was provided several storage-outflow relationships for reservoir routing base on the storage-Discharge relationship. There are two major reservoirs in Klang watershed which are Batu dam and Klang gate dam.

The HEC-HMS program is used to simulate the runoff from the rainfall data for the study area as used for the period starting from 1st January 1974 until 31st December 2007.

used in Green-Ampt method to calculate the loss parameters. In order to estimate soil properties in the Klang watershed it is categorised into USDA soil texture classification. Therefore, the values suggested by Rawls and Brakensiek (1983) have been adapted in soil characterisations.

2.2 Loss model to determine excess precipitation (Direct Runoff)

Green and Ampt infiltration method in HECHMS is a conceptual model for calculation of precipitation loss in permissible surfaces in a specific time period in a watershed. Green-Ampt method is also used to calculate the infiltration and loss rate in runoff modelling. The Green-Ampt Method is an acceptable loss model and is a simplified representation of the infiltration process in the field (Chu 1978). It is a function of the soil suction head, porosity, hydraulic conductivity and time. The general formula of Green-Ampt method is given below (Mein and Larson 1973),

$$\int_{o}^{F(t)} \frac{1-\Psi\,\Delta\theta}{F+\Psi\Delta\theta}\,dF = \int_{o}^{t} K\,dt \quad Eq(1)$$

whereFis the total depth of infiltration. Ψ is wetting front soil suction head, θ is water content in terms of volume ratio and K is a saturated hydraulic conductivity.

The soil texture is important component due to it impacts soil physical properties which are

2.3 Flow calculation in reaches

The Muskingum method is a hydrologic river routing technique based on the continuity equation (Al-Humoud and Esen, 2006). Muskingum method for flow modeling X and K parameters must be evaluated. Theoretically, K is time of passing of a wave in reach length. The Muskingum X is the weighting between inflow and outflow influence; it ranges from 0.0 up to 0.5. In urban areas of Klang watershed, natural drainage system is rarely observed. Most of channels have uniform geometric cross section made by concrete. X was set to 0.4 (according to Raghunath(2006)) in all reach elements and K was estimated by travel time through the reach elements.

ISBN: 978-1-61804-147-0

Table 1: Texture class estimates (based on Rawls and Brakensiek, 1983)

Soil type	Porosity	Suction head (mm)	Hydraulic conductivity (mm/h)	Initial Moisture Deficit
Sand	0.437	49.5	117.8	0.346
loamy sand	0.437	61.3	29.9	0.312
sandy loam	0.453	110.1	10.9	0.246
loam	0.463	88.9	3.4	0.193
silt loam	0.501	166.8	6.5	0.171
sandyclay loam	0.398	218.5	1.5	0.143
clay loam	0.464	208.8	1	0.146
Siltyclay loam	0.471	273	1	0.105
sandy clay	0.43	239	0.6	0.091
silty clay	0.479	292.2	0.5	0.092
clay	0.475	316.3	0.3	0.079

Table 2: Land use/ cover classes present in the Klang watershed (from DID 2002

Land use	Area (Km^2)	Percent of total area
Agriculture	59.45	8.82
Forest	248.28	36.83
Mining	4.1	0.61
Newly cleared land	8.58	1.27
Pasture	6.23	0.92
Swamps	0.64	0.09
Urban	334.82	49.67
Water body	11.97	1.78
Total area	674	100

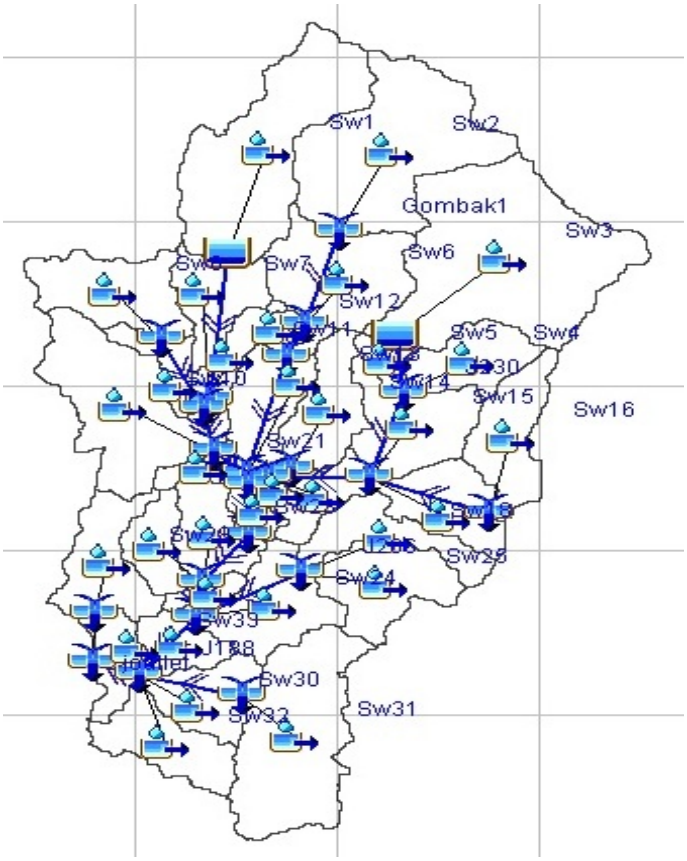

Figure 1: HEC-HMS model for Klang watershed

ISBN: 978-1-61804-147-0

3 Results

3.1 Generating Green-Ampt maps

To calculate Green-Ampt parameters all the relevant infiltration values adapted from Rawls and Brakensiek (1983) were assigned into soil texture map in GIS. An average value of the infiltration parameters according to sub-watershed boundary by HEC-Geo-HMS is estimated to calculate the loss model maps such as hydraulic conductivity, suction and initial maps and also the percentage of impervious map.

3.2 Calibration and verification of HEC-HMS

HECHMS was calibrated for the storm events of 1974 to 2000. This event had daily rainfall duration (24 h). Precipitation data were taken from 18 rain gages that are located within the study area. The basin mean areal rainfall depth for the calibration and validation rainfall events which were calculated with Thiessen method in GIS was applied in HEC-HMS.

A total of 101 rainfall events which were occurred between the year 1974 and 2000 were selected for calibration process and 34 rainfall events between the years 2001 and 2007 were used for validation. Figure 5 and 6 show the detail and characteristics of the rainfall events for calibration and validation processes, respectively. The maximum runoff peak discharge was observed on 22th March 1995 which is 211 m3/sec.

The HEC-HMS model is validated in order to evaluate the performance of the model. This event had daily rainfall duration (24 h). Figure 6 shows, the 34 selected rainfall events for validation of HEC-HMS were observed between the years 2001 and 2007. The minimum and maximum validation events were observed on the 20th February 2003 and 9th Nov 2001. The maximum observed runoff peak discharges are 39.94 and 114.81 m^3/sec, respectively. Figures 7 and 8 represent the values of observed runoff peak discharge, of selected rainfall event for calibration and validation of HEC-HMS respectively.

4. Discussion and Conclusion

The aim of this study is using of Green-Ampt precipitation loss estimation method. Results of simulation in a long time (1974-2007) and comparing with observation hydrographs showed that model is useable in Rainfall-Runoff simulation. The statistical performances include the computation of R^2 that measure the degree to which two variables are linearly related, the Mean Square Error that measured goodness-of-fit for the peak runoff and the Mean Absolute Percentage Error that measured goodness-of-fit for the moderate runoff for the output of the model compared with observed data (HEC, 2000).

The results show that the model gave the best simulation in the catchment using the Green-Ampt method with the Mean Square Error equal to 0.64 m^3/sec and Mean Absolute Percentage Error equal to 9.9% and also and coefficient of determination equal to 0.84.

According to the results of this research, it can be concluded that Green-Ampt loss method is able to be applied in rainfall-Runoff model in HEC-HMS for Klang Watershed to generate design hydrographs.

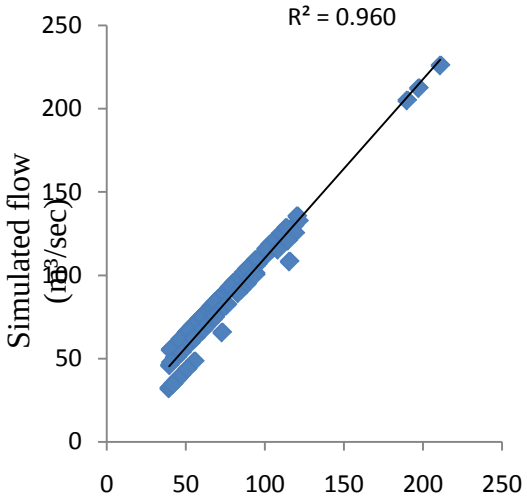

Figure 9: Scattering for HEC-HMS simulation in Klang basin

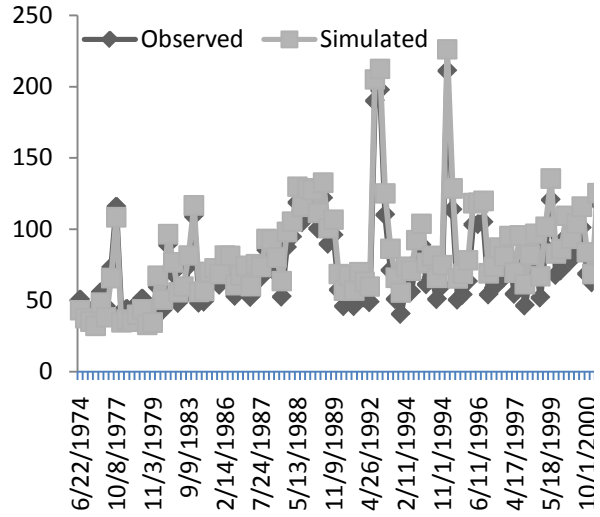

Figure 7: Calibrated result of measured and simulated discharges

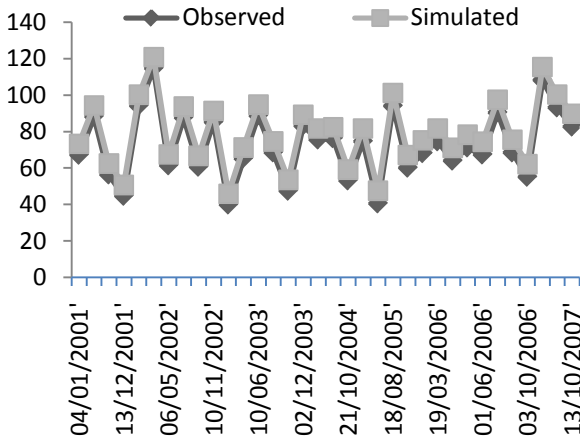

Figure 8: Validation result of measured and simulated discharges

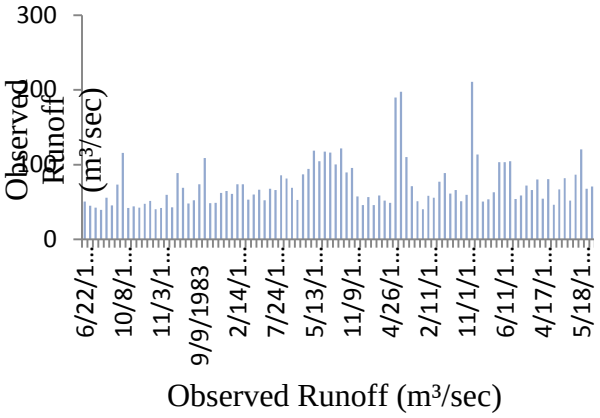

Figure 5: Observed rainfall events for hydrologic model calibration of Klang basin hydrological model

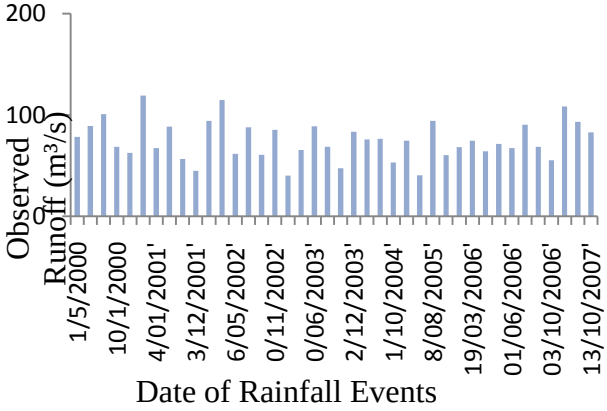

Figure 6: Observed rainfall events for hydrologic model validation of Klang Basin hydrological model

References:

[1] Alaghmand S., Abdullah R.B., and Abustan I. 2011. Selecting the Best Set Value in Calibration Process for Validation of Hydrological Modeling (A Case Study on KayuAra River Basin, Malaysia). Research Journal of Environmental Sciences, 5, 354-365.

[2] Al-humoud, j. m. and Esen, I. I. 2006. Approximate Methods for the Estimation of Muskingum Flood Routing Parameters. Water Resources Managementl. 20, 979–990.

[3] Arekhi, S., Rostamizad, G., and N. Rostami. 2011. Evaluation of HEC-HMS Methods in Surface Runoff Simulation. Advances in Environmental Biology, 5(6), 1316-1321.

[4] Chu, S. T. 1970. Infiltration during unsteady rain, Water Resour, Res, 14(3), 461-466.

[5] Ellouze, M., Abida, H., and Safi, R. 2009. A triangular model for the generation of synthetic hyetographs. Hydrol. Sci., 54, 287-299.

[6] Mein, R. G., and Larson, C. L. 1973. Modeling infiltration during a steady rain, Wat. Recour 9 (2), 384-394.

[7] Nearing, M. A., Liu, B. Y., Risse, L. M., and Zhang, X. 1996. Curve numbers and Green-Ampt effective

hydraulic conductivities. Water Resour. 32(1), 125-136.
[8] Raghunath, H. M. 2006. Hydrology: Principles, Analysis and Design, New Delhi, New Age International.
[9] Rawls, W.J., and Brakensiek, D.L. 1983. A proceedure to predict Green and Ampt infiltration parameters, Proc. of the Nat'l Conference on Advances in Infiltration Chicago, IL, 12-13.
[10] Stehr, A., Debels, P., Romero, F., and Alcayaga, H. 2008. Hydrological modelling with SWAT under conditions of limited data availability: Evaluation of results from a Chilean case study. Hydrol. Sci., 53, 588-601.
[11] U.S. ACEHEC. 2006. HEC-HMS Hydrologic Modeling System Users Manual. Davis Publisher, California.
[12] Wilcox, B. P., Rawls, W. J., Brakensiek, D. L., and Wight, J. R. 1990. Predicting runoff from rangeland catchments: A comparison of two models, Water Resour. Research, 26(10), 2401-2410.
[13] Zhang, X. C. and Liu, W. Z. 2005. Simulating potential response of hydrology, soil erosion, and crop productivity to climate change in Changwu tableland region on the Loess Plateau of China, Agr. Forest Meteorol., 131, 127-142.