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SURFACE RUNOFF VARIATION ASSESSMENT USING PROCESS-BASED HYDROLOGIC MODEL

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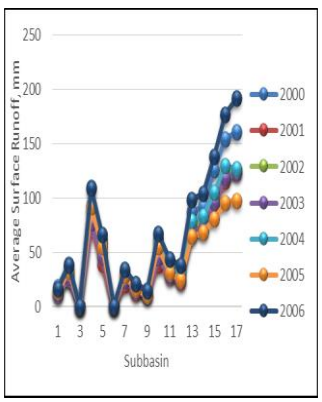
Graphical abstract



Abstract

Process-based hydrologic models are progressively being used to support decisions on many water resources management such as in the design and operation of the hydraulic structures, water supply, irrigation, flood control, and many other engineering practices. Many of these models share a common base in their endeavor to incorporate the diversity of the watershed and the spatial distribution of topography, vegetation, land use, soil characteristics and rainfall. Activities in the flood plain and catchment such as land clearing for other developments may increase the magnitude of the flood. Understanding on the reaction of the river basin on the floods scenario becomes a crucial part before any project of flood mitigation approach is implemented. The study attempts to highlight the simulation of the Soil Water Assessment Tool (SWAT) hydrologic model in determining the surface runoff distribution from a different sub-basin. For Langat River Basin, the sub-basin 17 was produced the highest amount of surface runoff in the basin. The assessment of the sub-basins response on the surface runoff can be used as guidance for modelers to understand the impact of a spatial heterogeneity of the river basin towards flood.

Keywords: Hydrologic model, SWAT model, surface runoff

1.0 INTRODUCTION

In Malaysia, floods are one of the most hazardous natural events often responsible for the loss of life and severe threat to infrastructure and environment. Activities in the flood plain and catchment such as land clearing for other developments may increase the magnitude of the flood. In the state of Selangor for the past ten years shows concerning 256 flood events were recorded since 2005 until June 2014 [1]. In the past, nature took care of itself as vast expanses of forests and wetlands soaked up rainfall excess and delayed the flow of water into the river basin. Absolute control over floods is rarely feasible either physically or economically. On the other hand, flood mitigation measures are undertaken to reduce flood damage to a minimum, consistent with the cost involved. Besides the construction of dams and reservoirs and the improvement of river systems, the process to increase infiltration and to store the excess water in small ponds and retention basins are being promoted [2].

Understanding on the reaction of the river basin on the floods scenario becomes a crucial part before any project of flood mitigation approach is implemented. The physiographic of the river basin and climatic factors play the most critical factors affecting the flood events of the river basin. These factors include basin characteristics, infiltration characteristics and channel characteristics. The assessment of the sub-basin response on the surface runoff will help the modelers to understand the impact of a spatial heterogeneity of the river basin towards flood.

Using the process-based model, the spatial heterogeneity is represented using visible physical characteristics of the basin. The models will able to simulate the complete runoff and the effect of catchment changes which is of particular importance in many cases of water resource management. The study attempts to highlight the whole simulation of a process-based hydrologic model, the Soil Water Assessment Tool (SWAT) model in determining the surface runoff distribution from a different sub-basin of the Langat River Basin, Selangor. The first section gives some basic explanation of the study area. The second section explained on the method and materials being utilized in the study area and followed by the SWAT model input and setup. Then, the third section discusses on the SWAT simulation output of the basin with the focusing on the calculated surface runoff from a different sub-basin in the watershed. Finally, the paper concludes by identifying key issues and gives some directions for future research.

2.0 METHODOLOGY

SWAT, which is a public domain model, has been successfully used by researchers around the world for distributed hydrologic modeling and management of water resources in watersheds with various climates and terrain characteristics [3], [4]. The model provides the continuous-time simulation to facilitate the real watershed responses in long simulation periods. The major geospatial input data includes Digital Elevation Model (DEM), soil data, land use and stream network layers. Data on weather and measured streamflow were also used for prediction of streamflow and calibration purposes.

DEM was derived mainly from a contour map of 20 m interval and a digital river network, which were provided by Department of Survey and Mapping Malaysia (JUPEM). The land used map of a study area was obtained from Department of Agriculture, Malaysia. The land use map needs to be reclassified according to the specific land cover types such as the type of crop, pasture, and forest. The dominant land used in the study area is a primary forest reserve (64.80%), followed by rubber (18.04%), urban area (7.58%), and orchard agriculture (3.69%). The majority of the study area is covered by a steepland (64.8%) and followed by a Renggam-Jerangau soil series (23.20%), Telemong-Akob-Local Alluvium (8.00%) and Munchong-Seremban (3.24%).

SWAT requires daily meteorological data that can either be read from a measured data set or be generated by a weather generator model. The weather variables used in this study are daily precipitation, minimum and maximum air temperature for the period 1976 to 2006. A weather generator developed by Schuol and Abbaspour [5] was used to fill the gaps due to missing data. Daily river discharge values for Kajang streamflow station were obtained from the Department of Irrigation and Drainage (DID) Malaysia. The model setup involved the following steps: data preparation; sub-basin discretization: hydrologic response unit (HRU) definition; parameter sensitivity analysis; calibration and uncertainty. The sub-basin discretization only focused on the 331 km^2 and the watershed was divided into 17 sub-basins and 142 numbers of HRUs after completing the first three processes in the model setup. The sub-basins numbers are based on the threshold areas of 1000ha of the HRU definition in the SWAT model. SWAT-CUP is a semi-automatic approach to a computer program for calibration of SWAT models, and the programs link SUFI-2 algorithms to SWAT was utilized in the study. It enables sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models [6] & [7]. After the process was completed, then the final simulation of the watershed was conducted using this calibrated input parameters for the whole 30 years period of study, 1976 to 2006 with the first four years data were utilized during warm-up periods.

The surface runoff component of SWAT simulation in the watershed from 1976 to 2006 processed into three separate periods; the first set from 1980 to 1989, secondly from 1990 to 1999 and the last set from 2000 to 2006. The analysis has covered the variation of the surface runoff spatially which was based on the 17 numbers of sub-basin and temporally for the three different periods of study. The analysis was only focused on the average value of monthly surface runoff, mm.

Langat River Basin occupies the south and south-eastern parts of Selangor and a small portion of Negeri Sembilan and Wilayah Persekutuan. The mainstream, Langat River stretches for 180 km and has a total catchment area of 2271km^2. The major tributaries are the Semenyih River and Labu River. The average yearly rainfall is about 2400mm, and the highest months (April and November) show rainfall amount above 250mm, while the lowest is in June, about the average of 100mm. The study only focused on the upper part of Langat River Basin with a catchment area of 331km^2 and the main streamflow station of the study area is located in Kajang town in the District of Hulu Langat as in Figure 1.

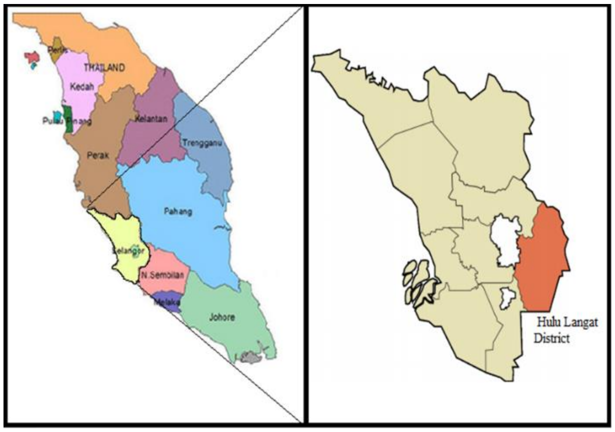


Figure 1 Langat River Basin in the Hulu Langat District of the Selangor Map

In Langat River Basin, a tropical river watershed in Malaysia is chosen for the study in assessing the surface runoff distribution studies for several reasons. The Upper Part of Langat River Basin (UPLRB) located at southern part of Klang Valley has compensated the virtue of 'spill-over' development from Klang Valley. It is undergoing rapid development that is influenced by some fast growing new centers, such as the Kuala Lumpur International Airport (KLIA), Cyberjaya, Putrajaya and other manufacturing zones. The study area is included in a Greater Kuala Lumpur projects which covering Kajang town areas as a southern boundary of the project. These changes of the undeveloped to developed area may contribute the changes of discharge and direct runoff volume into Langat River.

Due to flood tragedies in 2012, the Malaysian government was approved about RM7.5-million allocation for short-term flood mitigation measures in Hulu Langat where more than 3,000 families were badly affected by floods. The projects include a construction a new bridge on a major route and two culverts, and relocation of utilities was covered by the allocation. Department of Irrigation also proposed RM15-million project of six-hectare Sungai Serai retention pond in Hulu Langat be built in 2015. Several studies have been conducted on the watershed related to water resources and hydrological behavior of the basin [8]-[15]. All these studies and information show the important and the need for widespread sustainable water resources management study in the Langat River Basin. Therefore, it is important to predict correctly flow in rivers and direct surface runoff floodplains.

3.0 RESULTS AND DISCUSSION

3.1 Monthly Surface Runoff from 1980 to 1989

Figure 2 shows the average of the monthly surface runoff for a first set on the different sub-basin. The runoff values low at the upstream since most of the areas are occupied by the forestry areas. The value was evaluated increased from the upstream sub-basin towards the downstream sub-basin of the river basin with the exception on the sub-basin 4 and sub-basin 10. For sub-basin 4, even though with the watershed area of 1.09 km^2, the higher surface runoff was assessed due to higher slope at the sub-basin. The HRUs of terrain slope more than 20 degrees were represented about 59.61% of the sub-basin.

The surface runoff changes are minimal from sub-basin 1 to sub-basin 12. The values were obviously changed for sub-basin 13 onwards. The surface runoff at the sub-basin 13 onwards is higher with the value of the monthly surface runoff were calculated more than 40 mm. The higher surface runoff on these sub-basins was expected due to the nature of the land covers. The urbanization activities are dominants even though most of these sub-basins having terrain slope less than 10 degrees. Urbanization will reduce the infiltration processes and indirectly will increase the surface runoff.

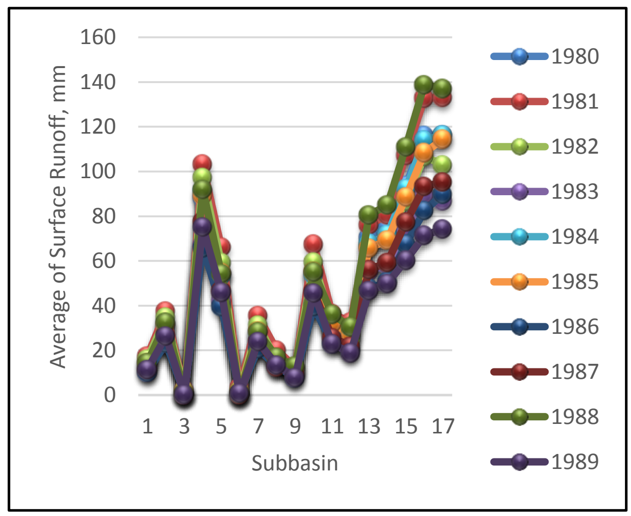


Figure 2 Mean monthly surface runoff, mm at different sub-basin from 1980 to 1989

The overall trend of the surface runoff changes at the sub-basin level is consistent at different years of assessment. The trends show that the higher runoff values were evaluated in 1988 and 1981. The values were lower in 1983 and 1989.

3.2 Monthly Surface Runoff from 1990 to 1999

Figure 3 shows the monthly average of the surface runoff in the second set on the different sub-basin. The average of the surface runoff output of this period ranges from 0.065mm and 0.149mm at sub-basin 3 and sub-basin 6, respectively to 136.263mm and 125.320mm sub-basin 17 and sub-basin 16, respectively.

The same trends are evaluated for the spatial segregation of the runoff values at the sub-basin level. The trends show that the higher runoff values were evaluated in 1993, 1995 and 1996. The trend of the runoff in 1995 slightly different from the other output. The results are relatively low at sub-basin 1 to sub-basin 12 but the higher value on the downstream sub-basin.

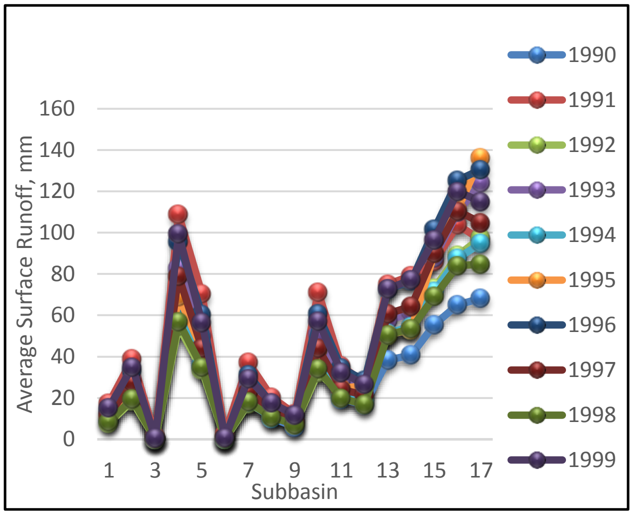


Figure 3 Mean monthly surface runoff, mm at different sub-basin from 1990 to 1999

3.3 Monthly Surface Runoff from 2000 to 2006

Figure 4 shows the monthly average of the surface runoff on the different sub-basin. The average of the surface runoff output of this period ranges from 0.165 mm and 0.271mm at sub-basin 3 and sub-basin 6, respectively to 192.101mm and 176.650mm sub-basin 17 and sub-basin 16, respectively. The value of 192.101 represented the highest monthly surface runoff value in the watershed. The same trends are evaluated for the spatial segregation of the runoff values at the sub-basin level. The trends show that the higher runoff values were evaluated in 2000 and 2006. The values were lower in 2003 and 2005.

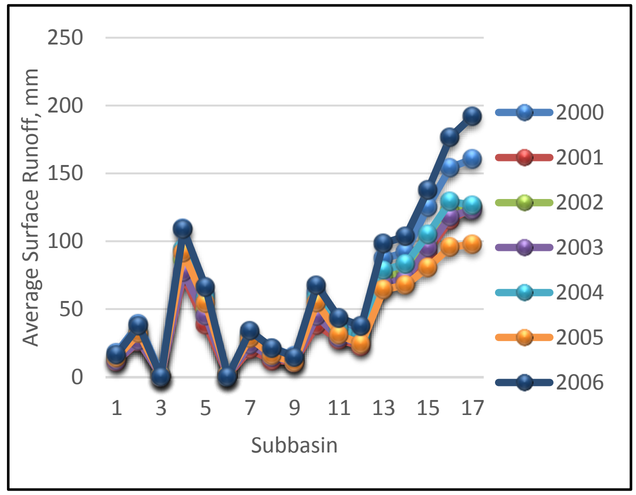


Figure 4 Mean monthly surface runoff, mm at different sub-basin from 2000 to 2006

3.4 Grand Average of Surface Runoff, 1980 to 2006

The grand average of the surface runoff output ranges from 1.027mm to 115.917mm as shown in Table 1 and the values basically increased from the upstream towards the downstream of the watershed. Except sub-basin 4, 5 and 10, there are no obvious changes of grand average of monthly surface runoff from the sub-basin 1 to sub-basin 12. The grand average of the surface runoff of these sub-basins was less than 50.00mm and the areas were occupied with agricultures and forests. The surface runoff at the sub-basin 13 onwards is higher with the value of the monthly surface runoff were calculated more than 60 mm. The urbanization activities are dominants in these areas even though most of these sub-basins having terrain slope less than 10 degrees.

Table 1 Grand average of monthly surface runoff, mm at different sub-basin

Subbasin No.	Years			Grand Average (mm)
	80-89 (mm)	90-99 (mm)	00-06 (mm)	
1	13.404	11.783	14.397	13.195
2	29.961	26.850	32.324	29.712
3	0.977	0.539	0.931	0.816
4	84.752	76.910	91.617	84.426
5	51.712	46.572	53.375	50.553
6	1.207	0.800	1.074	1.027
7	27.031	24.231	27.830	26.364
8	15.309	14.240	17.244	15.598
9	10.672	8.952	12.806	10.810

Subbasin No.	Years 80-89 (mm)	90-99 (mm)	00-06 (mm)	Grand Average (mm)
10	51.854	46.524	53.805	50.728
11	29.562	26.112	33.932	29.868
12	24.861	22.743	28.712	25.439
13	63.317	58.008	76.902	66.076
14	66.960	61.388	81.221	69.856
15	85.921	82.150	105.13	91.067
16	105.39	100.623	130.34	112.119
17	106.69	105.254	135.81	115.917
Grand Average, mm	45.269	41.981	52.791	46.681

Figure 5 shows the grand average of the monthly surface runoff on the different sub-basin of the UPLRB watershed. The overall trend of the surface runoff changes at the sub-basin level is consistent at different years of assessment. The higher runoff values were evaluated for the period of study from 2000 to 2006 once compared with the grand average surface runoff. It found that the surface runoff for sub-basin 13 onwards shown 14% increment comparing with the grand average values. The other two sets of the period were found fluctuated with the grand average values. The different of runoff are seen very minimal from sub-basin 1 to sub-basin 12, but lower runoff was calculated for the sub-basin 13 onwards.

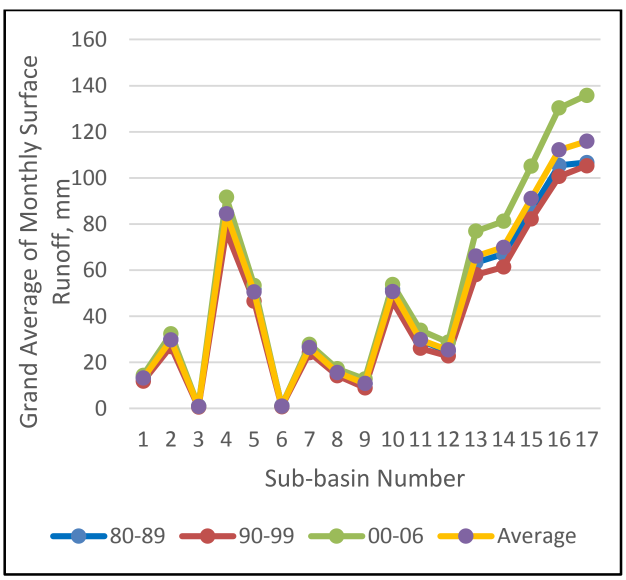


Figure 5 Grand average of monthly surface runoff, mm at different sub-basin

Figure 6 shows the overall distribution of mean monthly surface runoff map at different sub-basin for the whole period of study. The surface runoff lows at the upstream, and the value was increased towards the downstream sub-basin of the river basin. The sub-basin 17 with the total area of 46.29km^2 @ 13.95% of the UPLRB watershed produced the highest surface runoff in the basin.

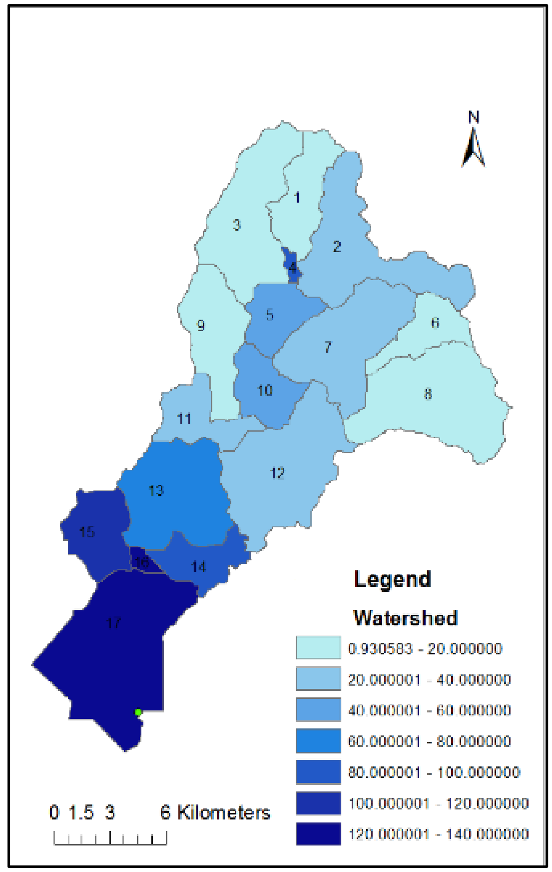


Figure 6 The mean surface runoff maps on the 17 sub-basins

4.0 CONCLUSION

A watershed of the upper part of the Langat River Basin was successful been modeled by SWAT2009 model and capable of predicting the streamflow and surface runoff at sub-basin level. The runoff values were analyzed low at the upstream, and the value was evaluated increased from the upstream sub-basin towards the downstream sub-basins of the river basin.

Enhancing infiltration and reducing run-off in managing water resources should be explored in terms of the most optimal method against flood in the watershed. The future works will investigate the details spatial study of the surface runoff production based on the hydrologic response units (HRU), the basic unit in the SWAT model.

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