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Simulation of streamflow for Sungai Ketil catchment using SWAT model

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ABSTRACT

Climate change influences over years clearly can affect a catchment area in terms of quantity and quality of water. High annual rainfall in Malaysia does not solve water scarcity problems during the El Nino phenomenon and can cause severe flooding during La Nina. A simulation from year 1980 to 2006 has been done at Sg. Ketil streamflow station at Kuala Pegang, Kedah in the North region of Malaysia according to availability of data. The monthly streamflow later has been calibrated and validated using SWAT-CUP. Water level data was obtained from an inventory water level station recorded at the station. Land-use, soil type and slope are taken account to produce a number of hydrologic response units (HRU). This study used developed gridded daily hydrometeorological data set for Peninsular from 1980-2006using interpolation technique. The results shown that the calibrated model is able to simulate the flow for the river basin successfully with the R^2 = 0.65 and NSE=0.52 and validated value of R^2=0.5 and NSE=0.43. A recommendation is purposed to simulate the catchment using hydrometeorological data set in the stations located in the area to compare the results for further study.

Keywords:
Streamflow, SWAT, SWAT-CUP

1. Introduction

According to the Department of Environment of Malaysia, there are 473 rivers on 2012 [8]. Nevertheless, this figure has reduced due to land development, urbanization and industrialization [2,4]. Critical environmental problems have slowly occurred at many river basins in Malaysia with the related problems such as flooding, water pollution, and sedimentation [9]. Water associated activity that occurred in one part of a river basin may have significance in another [13]. Developing the knowledge and skills that are necessary to safeguard our catchments and river basins without changing the socioeconomic development is vividly essential in managing the water resources

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available in a sustainable way [17]. On 11 November 2015, Malaysian newspaper The New Straits Times have reported on the overflowing of Sungai Ketil. It is believed that strong river currents following heavy rain which lasted for a few hours had caused the river to overflow. The flood which hit several areas had caused Sungai Ketil to breach its bank causing widespread flooding.

Simulation programs applying models of watershed hydrology and river water quality are essential tools for watershed management for both operational and research purposes. In recent years many such simulation programs have been developed such as Simulators of Water Resources in Rural Basins (SWRRB), Environmental Policy Integrated Climate (EPIC), Groundwater Loading Effects of Agricultural Management System (gleams), TR20, HEC- 1, and HEC -2 [14]. Within each case, GIS is used for pre-processing and post-processing of data to assess water hydrology in a river basin, as shown in recent studies [4,18]. [12,14] performed an advanced study by developing an integrated distributed hydrological model with remote sensing and GIS.

The theory of watershed modeling is embedded in the interrelationships of geospatial and hydro-meteorological data and represented through mathematical abstractions. The major hydrologic processes include rainfall, interception, evapotranspiration, infiltration, surface runoff, percolation and subsurface flow have their own behavior. The behavior of each process is controlled by its own characteristics and by its interaction with other processes active in the catchment [16]. The study of hydrologic processes and their responses to anthropogenic and natural factors need watershed models. Unfortunately, models have their limitations in representations of complex natural processes and conditions therefore generally, they must be calibrated prior to application to closely match reality [18,19].

Soil and Water Assessment Tool (SWAT) is one of the hydrological model that is popular among researchers to predict the impact of land management practices on water, sediment and agricultural chemical products in water catchment areas in accordance with varying soil, land use and management conditions over time [5]. SWAT model has proven to successfully model the impacts of climatic change on hydrologic and biogeochemical cycles in various watersheds [5]. The model estimates predominant hydrologic components such as surface runoff, baseflow, evapotranspiration (ET), and soil moisture change for each HRU [20,21].

This model is able to predict and simulate the long-term effects of land use changes on water quantity and quality [1]. It is a continuous time model, which operates on a daily time step on the basin scale. Hydrologist mainly have been applying and testing SWAT since 1993 for related soft engineering issues [6]. [8] and [22] used SWAT model for the predication of the impact of land use changes. [11] used SWAT model to study the impact of land use changes in mixed land-use watershed. So far, however, most studies in SWAT have only been carried out in a small number of river basin in Malaysia and no hydrological research has been found in Sungai Ketil River Basin, Kedah, Malaysia. The author had tested the effectiveness of the SWAT model in Sungai Ketil at Kuala Pegang station by simulating its streamflow and then calibrating using SWAT-CUP. To confirm this assumption, the author compared the monthly observed and simulated stream flow to each other. To evaluate the model's performance in simulating streamflow changes the determination coefficient (R^2) was used as statistical tests. The R^2 value is an indicator of relationship strength between the observed and simulated values. This paper presents the result of streamflow simulation at Sungai Ketil's Kuala Pegang station using SWAT model.

2. Study area

Sungai Ketil Catchment is a semi-developed area of about 633 km^2in total area. It is located in the southern part of Kedah within the Muda River Basin, at latitude 05° 38°20°and 100° 48°45°longitude.

The area has two typical monsoons; namely, the east monsoon and southwest monsoon. The northeast monsoon usually occurs from November to February. The annual rainfall depth in the area is about 2000 to 3000mm.

The area comprises 57.17% eroded area and cleared land, as well as 30.25% forest. The remaining of the land comprise of idle grass, marshland, swamp, mixed horticulture, oil palm, rubber and urbanization. About 58.9% of the watershed area has sloping that higher than 20%.

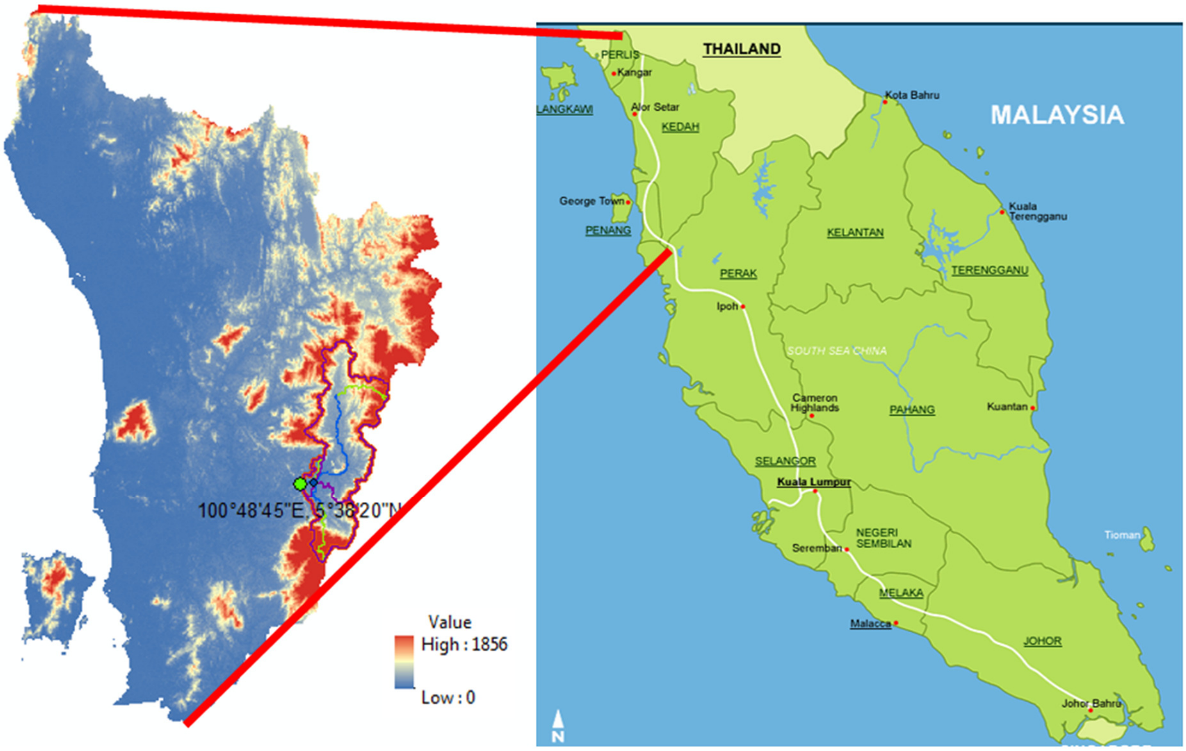

Fig. 1. Location of study area

3. Materials and methods / methodology

3.1. Input data

Digital Elevation Model (DEM)with 30m resolutionwasobtained from the Department of Irrigation and Drainage Malaysia (DID). Landuse map and soil map were retrieved from the Department of Agriculture (DOA), of year 2010 and 2002 respectively. Daily streamflow records from 1980 to 2006for Sungai Ketilrecorded at Kuala Pegang stationwere also obtained from DID. Daily records of rainfall and weather data such as maximum and minimum temperature, wind speed, solar radiation, and relative humidity from 1980-2006 were obtained from DID office. The data was developed for the whole Peninsular Malaysia using interpolation technique as described by [23].

Types of data	Period	Source	Remarks
DEM	-	[24]	-
Landuse map	2010	[25]	JPEG Format
Soil map	2002	[25]	JPEG Format
Streamflow	1980-2006	[24]	Sungai Ketil at Kuala Pegang station
Rainfall	1980-2006	[23]	Daily recorded
Weather	1980-2006	[23]	Daily recorded

3.2. Model setup

There are main procedures and various steps that must be followed in model application i.e. SWAT project setup, Watershed delineation, HRU Analysis, Write input table, Edit SWAT Input, SWAT Simulation. The project model was developed in GIS interface with input from Digital elevation model (DEM) map with 30 m resolution. The first process was watershed delineation which split the basin into 3 subbasins. The area of 633km^2 was delineated by the model. The areas of subbasins delineated after the process is shown in Fig. 2 and Table 1. Watershed land use categories and their coverage are shown in Fig. 3. The soilis classified based on their types and shown in Fig. 4. There are 3 classes of slope map reclassification shown in Figure 5: a) 0 - 10 %, b) 10– 20 %, and c) >20%. Reclassified slope map is shown in Fig. 5. Landuse map, soil map and slope were overlaid on top of each other and the 3 subbasins were further divided into a total of 12hydrologic response units (HRUs). Further division into multiple HRUs comprising of unique land use, soil, and land use management was based on user-defined threshold percentages [5]. The model requires daily data for precipitation and temperature that is provided by the user in the *.dbf* format and is stored in the project database. Remaining necessary climatic data can be generated as the user specified *.wgn* file. Characteristics of subbasins and HRUs were calculated and used in the SWAT simulation.

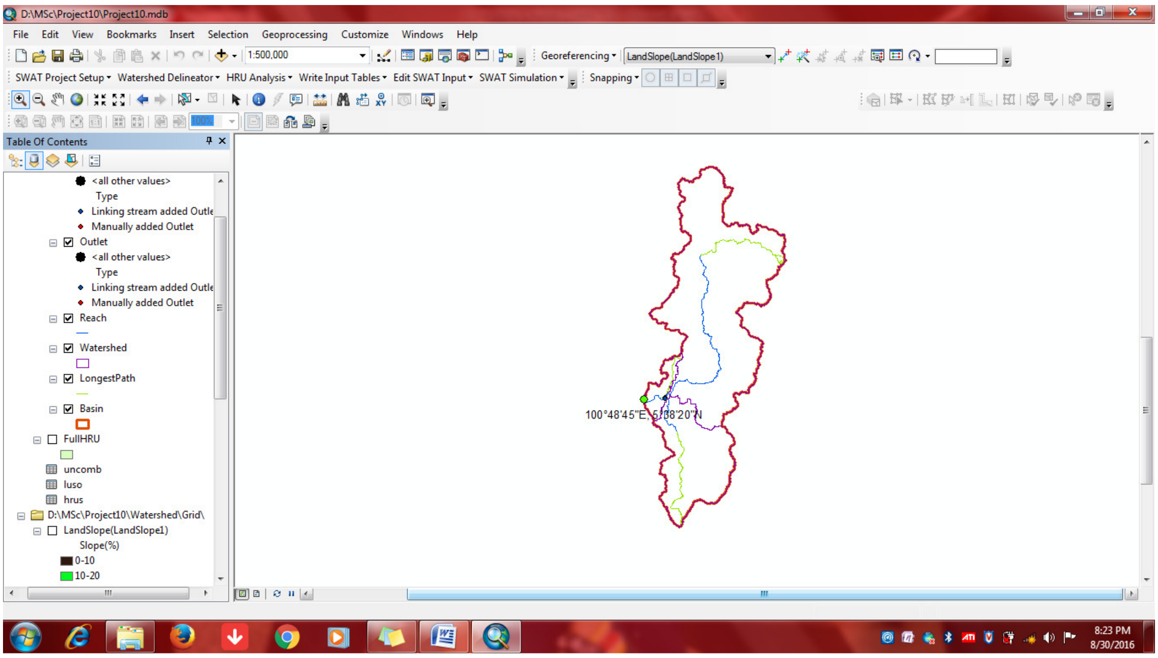

Fig. 2. Watershed Delineation of Sungai Ketil River Basin

Table 1
Percentage area of the subbasins

Subbasins	Area (km^2)
1	453.88
2	24.62
3	154.50
Total area	633

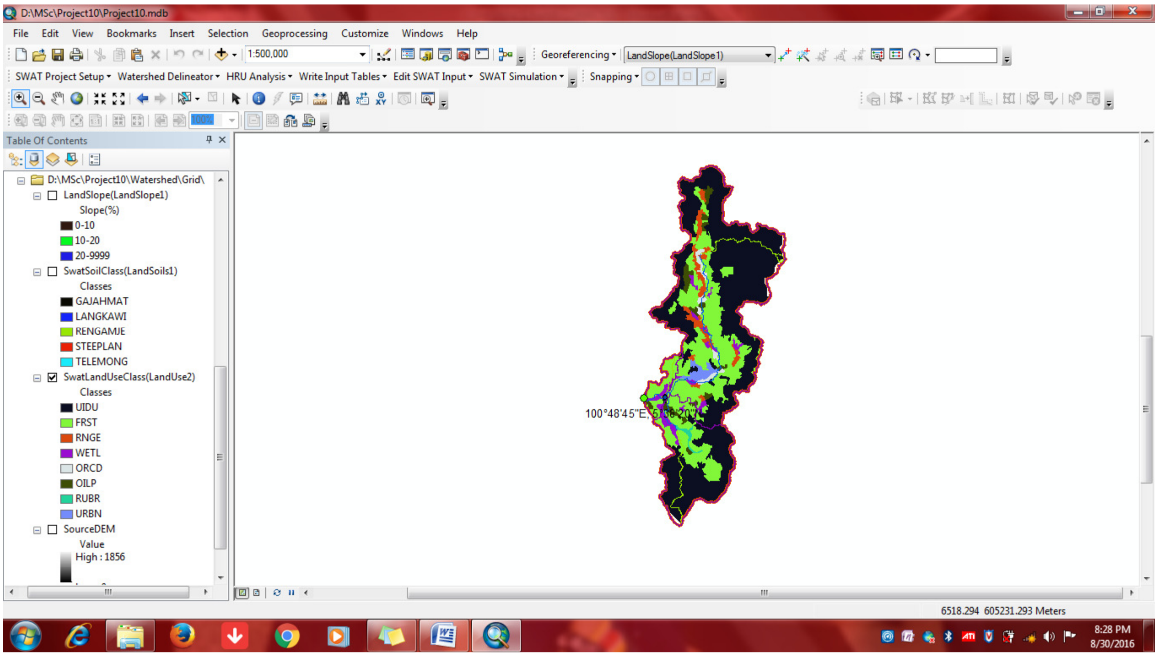

Fig. 3. Land use coverage in Sungai Ketil Basin

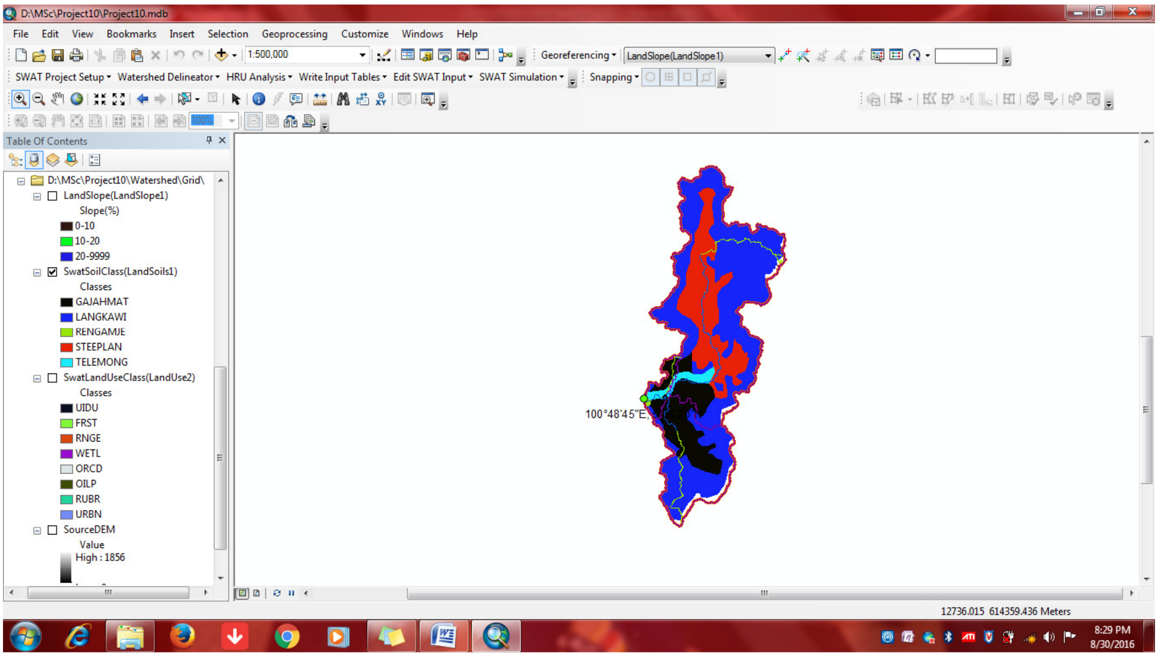

Fig. 4. Classification of soil type in Sungai Ketil Basin

3.3. Model calibration and validation

Model outputs were calibrated to fall within a percentage of average measured values by comparing the SWAT simulated data with the monthly observed discharge at Sungai Ketil at Kuala Pegangstation on monthly basis. Calibration parameters for various model outputs were constrained within the ranges described by [26]. Monthly stream flow was calibrated for the period from 1980 to 1993. Several SWAT parameters were selected and adjusted in every simulation. Table 2 shows the adjusted parameters in the calibration process and its values.

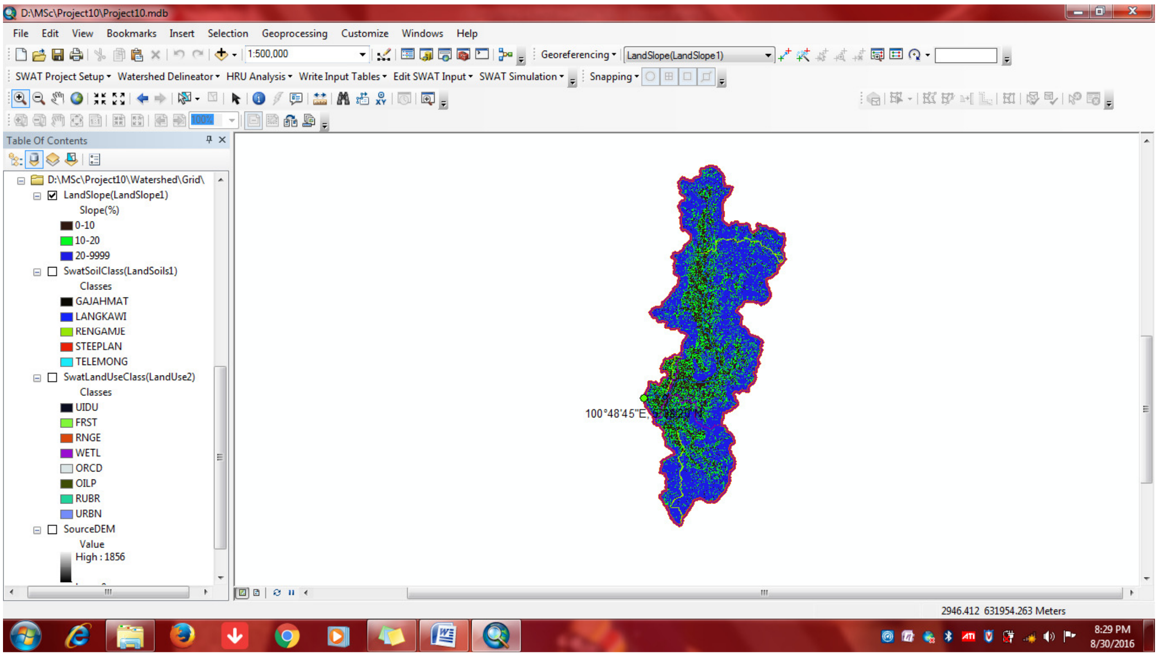

Fig. 5. Slope classification in Sungai Ketil Basin

In the validation process, the model is operated with the same input parameters set during the calibration process and the results are compared to the remaining observational data to evaluate the prediction model. Monthly measurements for the period from 2000to 2006 were used to validate the model. The performance of calibration model and validation process was determined by determination of coefficient (R^2) and Nash-Suttcliffe simulation efficiency (NS) [27]. R^2 show the correlation between two different variables, ranges from 0 to 1 (perfect). Although R^2=0.5 is acceptable for modeling, a higher value is considered to be better [15]. Nash-Suttcliffe simulation efficiency (NS) indicates how well the plot of observed versus simulated values fits the 1:1 line.

4. Results and discussion

Table 2
Adjusted parameters for calibration process

No	Parameter	Min Value	Max Value
1	CN2	-0.25	0.15
2	SOL_AWC	0	1
3	SOL_K	-0.2	300
4	ALPHA_BF	0	1
5	CH_K2	126.2995	199.6805
6	CANMX	0	100
7	SLSUBBSN	-0.1	0.1
8	OV_N	0.01	30
9	SURLAG	0.05	24
10	ESCO	0	1
11	ALPHA_BNK	0	1

The SWAT simulation has been conducted from January 1980 to December 2006. The SWAT model has been run for the current study and output was generated at monthly interval. Monthly observed streamflow volume data at Sungai Ketil at Kuala Pegang gauging site were also available for the same duration from January, 1980 to December, 2006. Statistical methods are used to evaluate the performance of the model in terms of simulated streamflow from year 1980 to 1999 for calibration, whereas from year 2000-2006 for validation. The results shown that the calibrated model is able to simulate the flow for the river basin successfully with the R^2 = 0.65 and NSE=0.52 and validated value of R^2=0.5 and NSE=0.43. Performance of calibrated model was in acceptable performance [15] and adjusted parameters for calibration process are shown in Table 2.

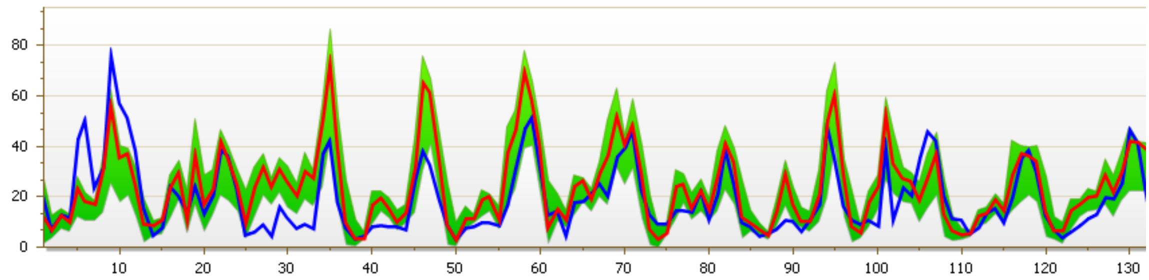

Fig. 6. Monthly streamflow calibration from 1983 to 1993

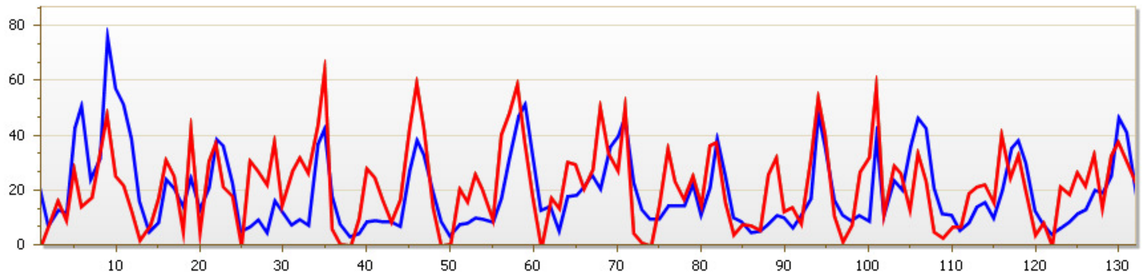

Fig. 7. Monthly streamflow validation during 1996-2006

5. Conclusion

Although SWAT has been applied to many watersheds throughout the world, it has only been carried out in a small number of river basins in Malaysia including Langat River Basin [1,4,9] and Upper Bernam River Basin [3,10]. A comprehensive documentation comprising detailed calibration, analyses, and recommendations for SWAT application is vital for subsequent applications of simulating all the river basins in Malaysia. This paper is intended to discuss a methodology, and the most sensitive parameters in river basin that have yet to be simulated by SWAT as well as increasing the number of Malaysia river basin analysis projects which the SWAT model has been applied.

This paper has proof that Soil and Water Assessment Tool (SWAT) has successfully modelled stream flow at Sungai Ketil Catchment. From this study, the result obtained were generally acceptable which R^2 value 0.59 for calibration and R^2=0.37 for validation. Although R^2=0.5 is acceptable for modeling, a higher value is considered better [20]. This shows satisfactory relationship between the simulated and observed monthly stream flow. Sungai Ketil Catchment was successfully modeled by SWAT2009 model. Curve number (CN2) was found to be the most sensitive parameter in this case as well as in most SWAT research studies. The capability of the model in predicting the stream flow was successfully proven. As a next step, it is suggested the SWAT model be calibrated and validated for sediment and nutrient transport.

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