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Full Paper

Simulating changes in discharge and suspended sediment loads of the Bangpakong River, Thailand, driven by future climate change

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Abstract: Predictions about changes to the discharge and suspended sediment loads of the Bangpakong River that may occur in response to anticipated future climate change are made in this study. Rainfalls impacted by climate change for the period 2040-2069, estimated from six general circulation models (CCCMA_CGCM31, CSIRO_MK30, IPSL_CM4, NCAR_CCSM30, UKMO_HadCM3 and MPI_ECHAM5 projections under the SRES A1B emission scenario) were used as inputs to the calibrated soil water assessment tool (SWAT) model to simulate surface discharge at the outlet of Bangpakong River basin. Streamflow at gauging station was predicted well with Nash-Sutcliffe coefficient of efficiencies of 0.83 and 0.80 during monthly calibration (1995-1999) and validation (2000-2004) periods. The suspended sediment loads were then estimated using suspended sediment rating curve which had been established from the measured data. The modelling results show that, for the period 2040-2069, both the monthly average discharge and suspended sediment load at the outlet of the Bangpakong River basin are expected to increase by 1% in the rainy season and to decrease by 3% and 23% respectively in the dry season when compared to the baseline period. This study represents the first attempt to apply multi-model ensemble techniques to the Bangpakong River basin using the IPCC SRES A1B emission scenario.

Keywords: Bangpakong River, climate scenario, climate change, SWAT, suspended sediment

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INTRODUCTION

For the past three or so decades, concern has increased over the climate change caused by increasing concentrations of carbon dioxide and other trace gases in the atmosphere. The main effects are believed to be changes in the temperature, rainfall and discharge, sea level, tidal fluctuations and extreme events such as storms, floods and drought. Climate change has been observed and is predicted to result in significant and increasing changes in the timing and distribution of temperature and precipitation across different regions in the future [1]. Research indicates that climate change could significantly affect hydrological cycles [1-3], sediment generation and transportation processes [4, 5], and the consequent sediment flux in a river [6, 7]. The impact of climate change is expected to occur in Thailand including the Bangpakong River basin, where the local population primarily depend on the available water resources to support their dominant agro-based economic and social developments.

As the true future climate is unpredictable, models of the likely climate scenario become an alternative plausible means of investigating the potential impact of anthropogenic climate changes. Climate change scenarios based on global circulation models (GCMs) are normally used to simulate how the climate may change in the future in response to the changing levels of greenhouse gases in the atmosphere, which are largely based on assumptions about human factors such as global population, economic growth and energy use [8]. These factors are integrated into different special reports of emission scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) for the 21st century, i.e. A1, A2, B1 and B2, which are then used to drive the GCMs to determine the climate response [8]. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1 and B2, and three groups within the A1 family, characterising alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced) and A1T (predominantly non-fossil fuel) [8]. However, impact analysts may use non-IPCC SRES scenarios for specific interests [9]. Since global warming is a slow process, in order to clearly detect the change in future climate patterns, long-term climate projections over decadal to multi-decadal time periods are commonly needed. Projections this long certainly carry uncertainties from other sources such as those generated from the assumptions that were made as well as those due to the simulation technologies. Therefore, it is preferable to use several models and emission scenarios in order to better reflect the uncertainty in the range of possible future climate change [8-11].

The main objective of this study is to assess the potential future change in the monthly freshwater discharge and suspended sediment load of the Bangpakong River. In this work, six GCMs under moderate projection of greenhouse gas (IPCC SRES A1B) are used to simulate future monthly rainfall levels. These are then used as inputs to the calibrated hydrologic model in order to assess potential discharges and suspended sediment loads at the outlet of the Bangpakong River basin.

MATERIALS AND METHODS

Description of Study Site

The Bangpakong River basin is one of the most important river basins in Thailand. It is located between 13°05'-14°30'N and 100°57'-102°00'E in eastern Thailand with an area of approximately 8,573 km^2 (Figure 1) and the main river reach length is approximately 240 km. The basin can be divided into the upper Prachinburi River basin and lower Bangpakong River basin. The catchments of the upper parts of the Prachinburi River are located in hilly ranges. Below the ranges, the basin exhibits a flat topography in low-lying alluvial plains, ideal for rice and other farming activities. The catchments provide plentiful discharge in the wet season but are also prone to drought during the dry season. The lower part of the Bangpakong is a tidal river estuary, with a brackish water ecosystem that reaches about 120 km upstream during the dry season when the freshwater discharge is minimal [12].

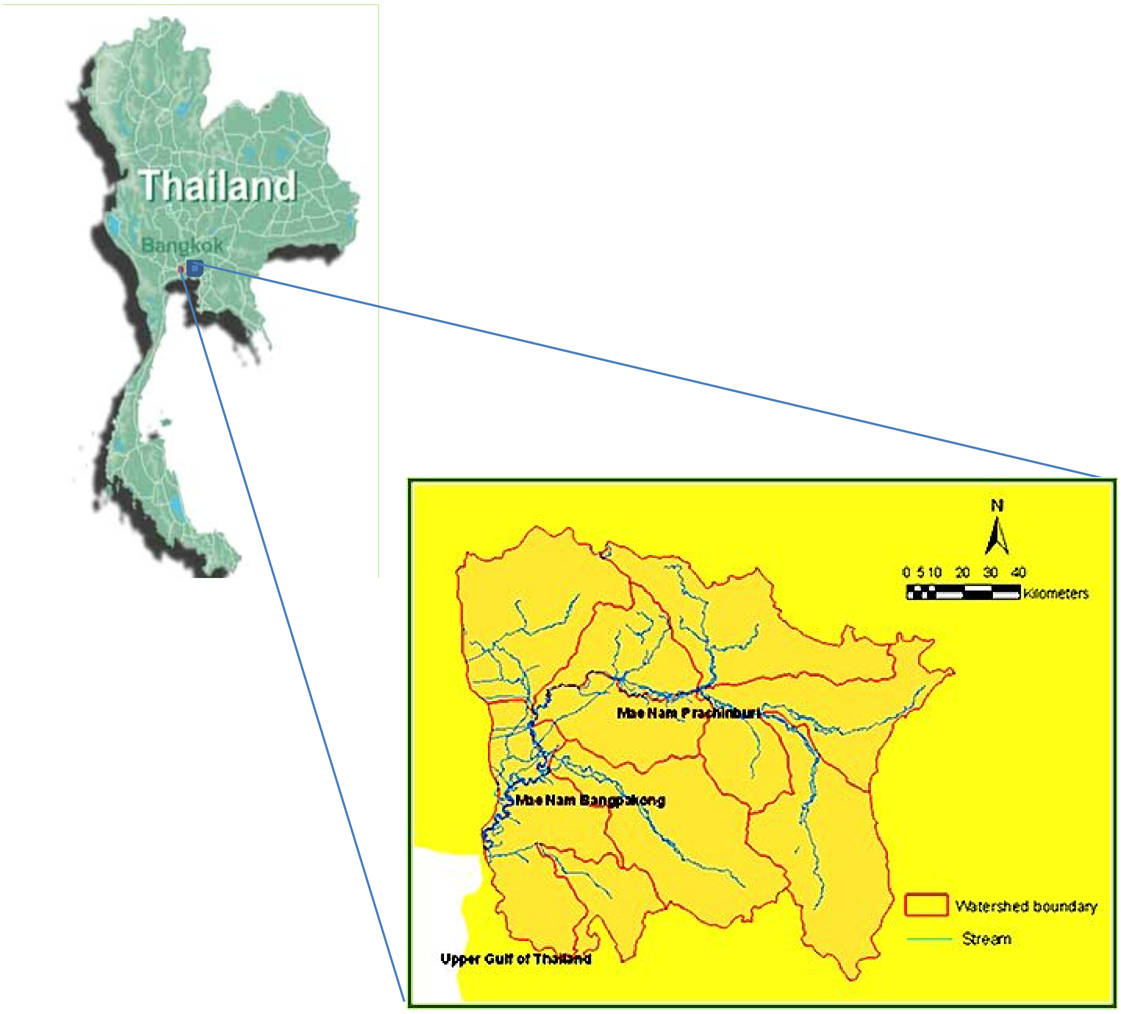


Figure 1. The Bangpakong River basin and its main sub-basins and reservoirs

The climate of the Bangpakong basin is of a tropical monsoon type with a north-easterly monsoon in the dry season (November-April) and a south-westerly monsoon in the wet season (May-October). Most of the catchments receive an average annual rainfall of 1,000-2,000 mm, most of which falls on a distinctly seasonal basis with only 10% of the discharge occurring in the dry season. The basin covers a mixture of land uses that range from wet- and dry-season rice, annual and perennial crops and rubber plantations to tropical and mangrove forests. The Bangpakong basin supports the livelihood of a wide range of communities involved in agro-forestry, agriculture and fisheries. Because of its proximity to Bangkok, the basin has also experienced a rapid development of private enterprises such as pig farms, shrimp and fish farms, and small- to medium-sized industries.

Global Circulation Models (GCMs)

GCMs are mathematical formulations of atmospheric, ocean and land surface processes that are based on classical physical principles and are used to simulate climatic patterns under a changing climate. GCMs have been developed by a number of research centres and are used to simulate long-term future climate conditions in order to assess their impact on a given sector in a specific area [9]. From the fourth assessment report (AR4) of the IPCC [9], twenty-three different GCM simulations, of which sixteen were selected as the most accurate models [13], were undertaken to generate climate change projections for the Asia/Pacific region. Table 1 summarises six GCMs of choice, all simulated using the moderate projection of greenhouse gas (IPCC SRES A1B scenario).

Table 1. List of GCMs [13] used in this study

	GCM	Research centre, Country
1	CCCMA_CGCM3.1	The Canadian Centre for Climate Modelling and Analysis, Canada
2	CSIRO_MK3.0	The Commonwealth Scientific and Industrial Research Organisation, Australia
3	IPSL_CM4	Institut Pierre Simon Laplace, France
4	NCAR_CCSM3	The National Centre for Atmospheric Research, USA
5	UKMO_HadCM3	Hadley Centre for Climate Prediction and Research/Met Office, UK
6	MPI_ECHAM5	Max Planck Institute for Meteorology, Germany

Downscaling from the Earth System Grid (ESG) data portal [14] was applied to the projections of these GCMs, based on the spatial interpolation of anomalies (deltas) of original GCM outputs, and was then applied to a baseline climate given by a high resolution surface [15]. Raw GCM outputs could not be directly used in our analysis due to their coarse resolutions (2 degrees). Hence finer resolution (30 seconds) data were consequently obtained from the International Centre for Tropical Agriculture (CIAT) and the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS) [13], with precipitation scenarios during 1961–2099 to be used in our project. The discrepancies between predicted precipitation scenarios and observed precipitation data, collected by Thailand Meteorological Department at five stations during 1967–2007, are shown in Figure 2.

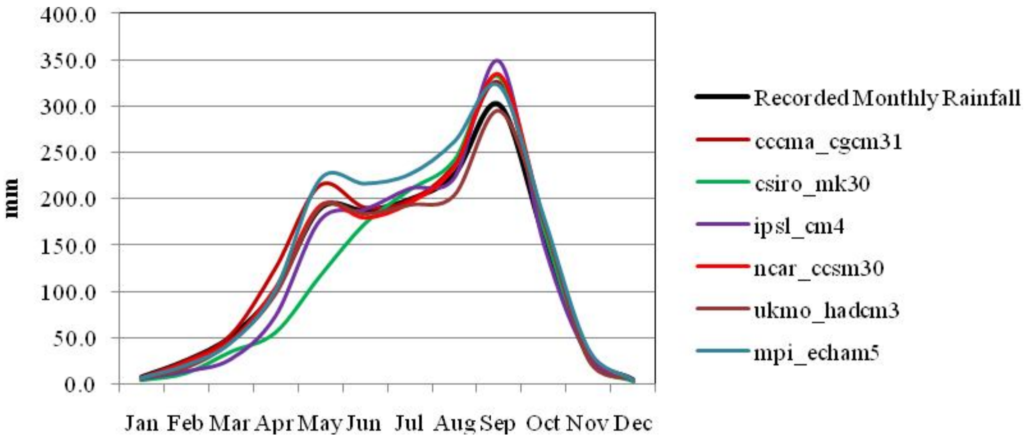


Figure 2. Comparison between observed mean monthly precipitation data (calculated over the 1967–2007 period) and predicted climate scenarios for each of the six GCMs (see Table 1) under A1B emission scenario, calculated over the model period of 1961–2099

Hydrological Model

Numerous models have been developed to simulate watershed-scale hydrologic processes. Among many others, the Soil Water Assessment Tool (SWAT) model [16] has been widely tested in different physiographic regions and in various parts of the world to simulate discharge and water quality response in a mixed land-use watershed [17-22]. In Thailand, SWAT has been used in the north-eastern part of the country, especially the Kong-Chi-Mun catchment area as well as in other parts of the country [23-25]. In this study, the continuous-time, spatially semi-distributed, physically-based SWAT model with ArcView interface (AVSWAT2000) [26] was used to investigate the impact of land cover and climatic change on the streamflow of the Bangpakong catchment. AVSWAT requires both the geographic information and weather data as the initial input data. The geographic information required is topographical feature, land use and soil classification maps, which are indispensable for the model to generate sub-basins as well as hydrological response units for calculation. Moreover, at least one out of five parameters of the weather data, i.e. precipitation, maximum temperature, minimum temperature, solar radiation and wind speed, is required for the model. Figure 3 depicts the composition and diagram for processing the AVSWAT model.

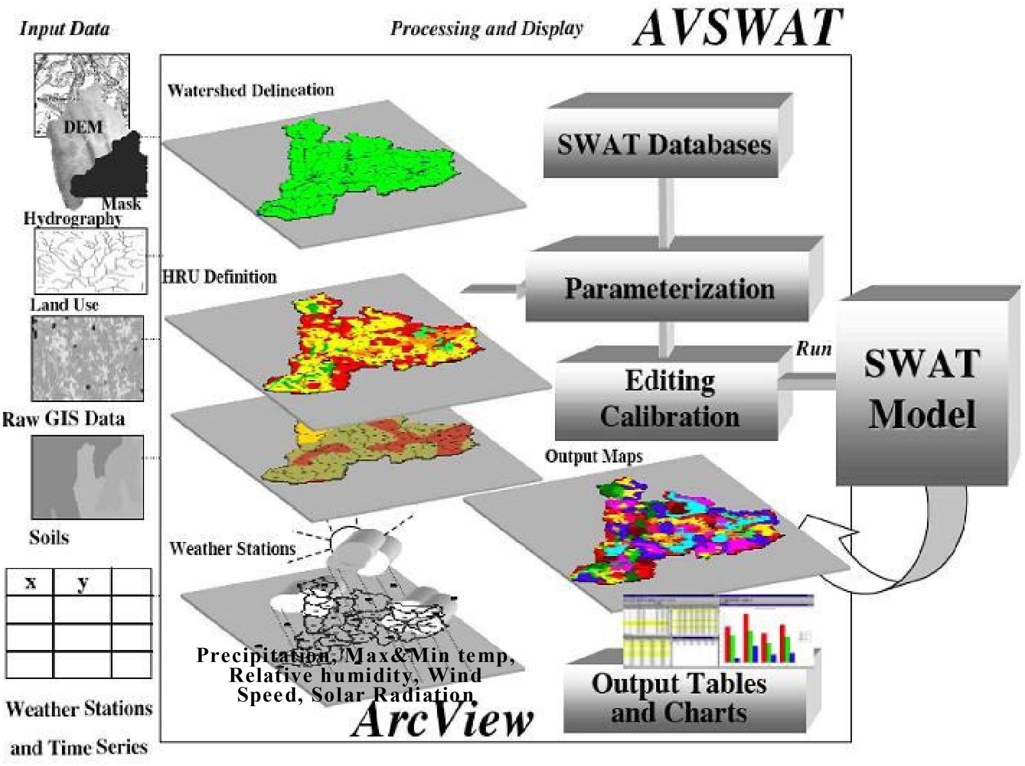


Figure 3. Flow chart of steps for processing the AVSWAT model (after [26])

The model was set up using readily available spatial and temporal data, and calibrated against the measured daily discharge. The topographical map was obtained from the Shuttle Radar Topography Mission (SRTM) [27] whilst the soil characteristics and land-use-type classification were obtained from the Land Development Department (Thailand). The twelve sub-basins were then delineated by the model based on this SWAT-derived topographical map (Figure 4) in order to calculate the discharge at each sub-basin outlet. Moreover, the daily precipitation data at five locations over a 30-year (1967–2007) period, which had been generated earlier from the six GCMs (see Figure 2), were imported into the model as input files.

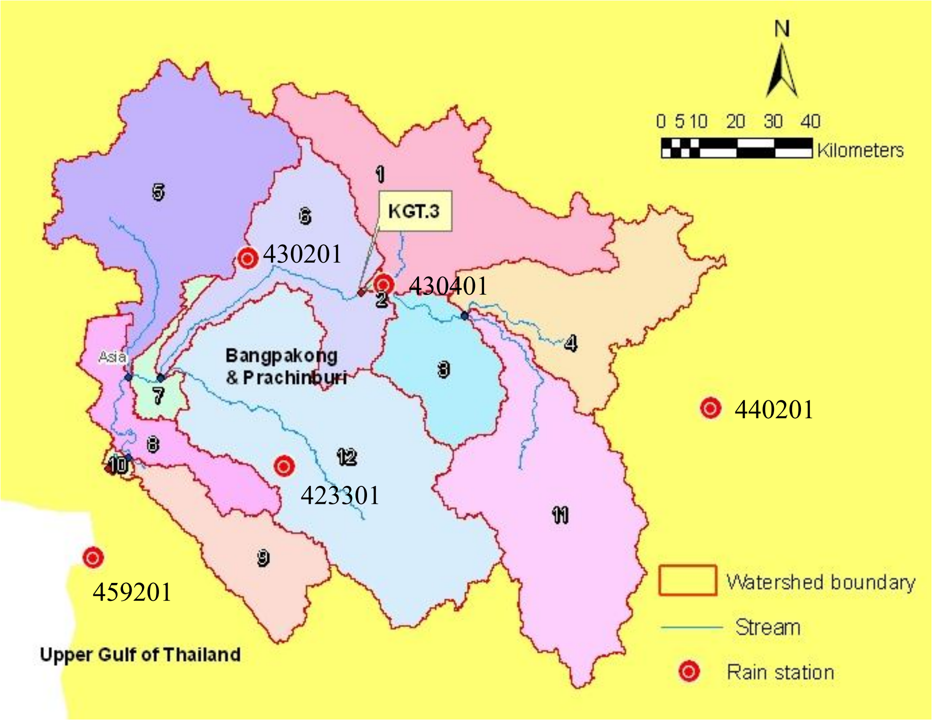


Figure 4. Sub-basins delineated by SWAT model

SWAT Model Calibration and Validation

A calibration and validation analysis was conducted on the AVSWAT2000 model. The hydrological component used for the calibration and validation in this study was the discharge. To evaluate the performance of the hydrological model in terms of the accuracy and consistency of the predicted flow compared to that of the measured flow, the coefficient of determination (R^2) and Nash-Sutcliffe coefficient (N_{SE}) were used as indicators [15-17]. The Royal Irrigation Department provided flow data at stream gauging stations, four of which were available in the watershed. Among these gauging stations, station KGT.3 is located closest to the watershed inlet (see Figure 4). Hence, observed stream discharge data from the KGT.3 gauging station were compiled to facilitate model calibration and validation of the SWAT model during the time period of interest. Data collected during 1995-1999 were used for model calibration and those collected between 2000-2004 were used for model validation, at both daily and monthly time-steps (Figures 5 and 6). The calibration and validation results at this location are shown in Table 2.

Suspended Sediment Prediction

The calculation of the suspended sediment load is usually made by linear regression of the log-transformed data. A sediment rating curve was built up by pairs of measurements of suspended sediment concentration and discharge (water flow) at each sampling occasion [28, 29]. Although SWAT can also be used to simulate sediment yield, we chose to adopt the sediment rating curve approach, using the actual measured data collected by the Marine Department in the year 2000, to estimate the suspended sediment flux at the Bangpakong River mouth. The regression equation was established from these data, as shown in Figure 6. The equation of the best fit regression line shown in Figure 7 is $Q_s = 0.155Q - 14.457$, where Q_s is the suspended sediment discharge and Q is the water discharge.

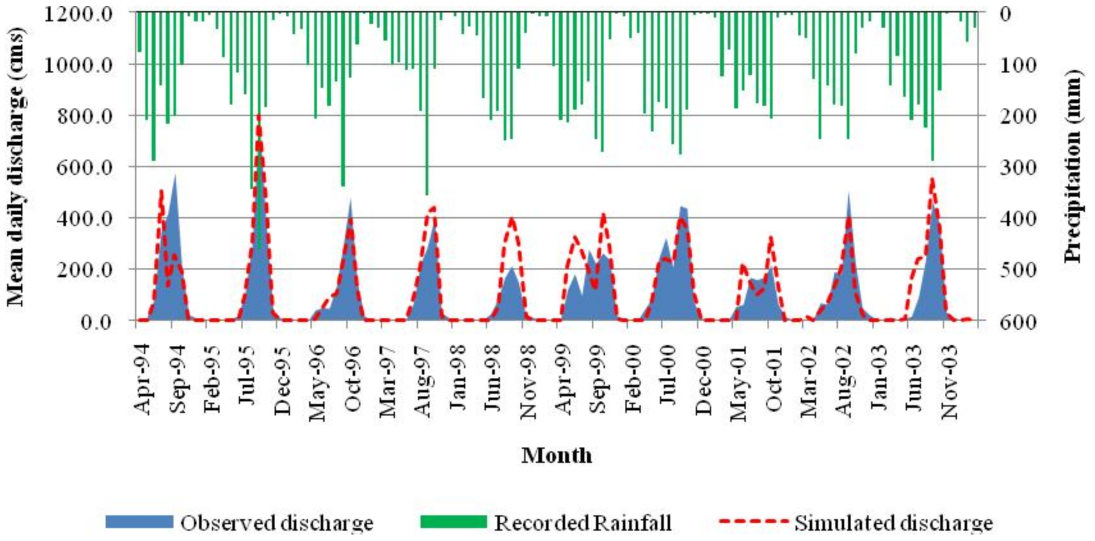
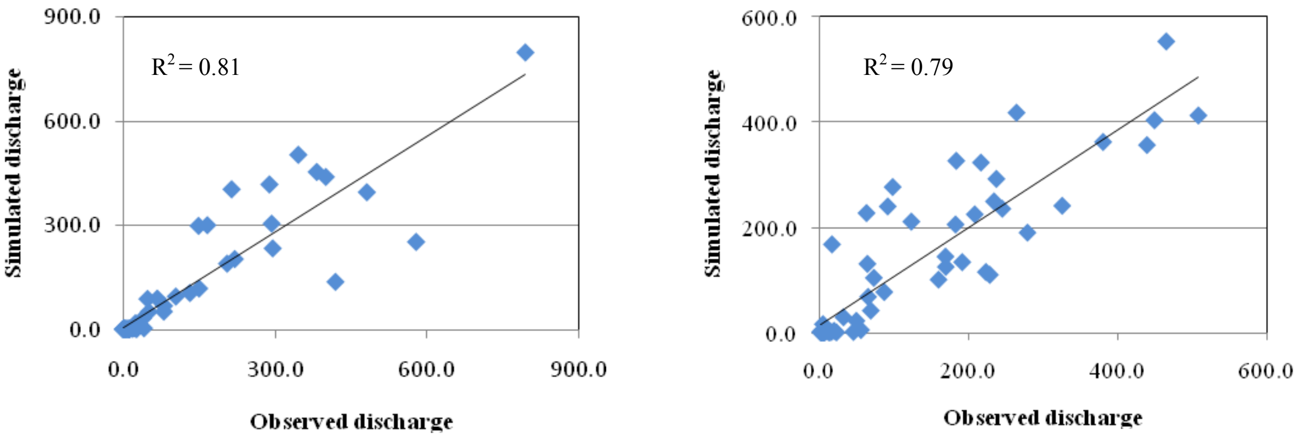


Figure 5. Calibration results for measured and simulated monthly mean daily flow at gauging station KGT.3



Calibration

Validation

Figure 6. Flow correlation, comparing between observed discharge and simulated discharge using rain fall adjusted by changes in future rainfall in GCMs, for calibration (1995-1999) and validation (2000-2004) periods at the KGT.3 gauging station

Table 2. SWAT calibration and validation results

	Calibration		Validation	
	Monthly	Daily	Monthly	Daily
R^2	0.81	0.73	0.79	0.65
E_{NS}	0.83	0.67	0.84	0.80

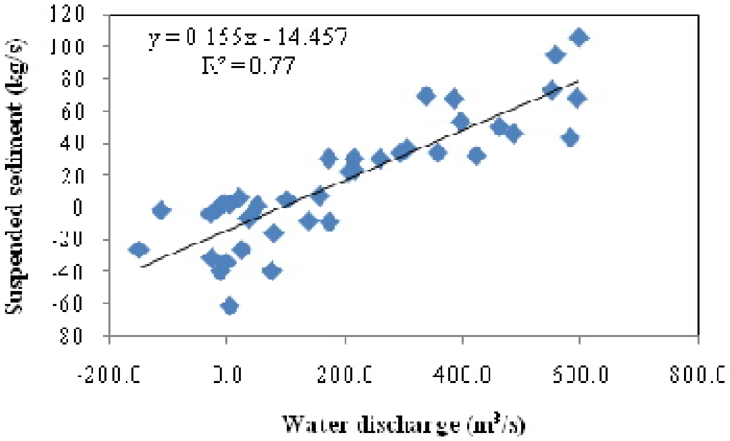


Figure 7. Suspended sediment rating curve established at the Bangpakong River mouth. Negative values indicate the inflow of water; positive values indicate the outflow from the river mouth.

RESULTS AND DISCUSSION

Variation in Predicted Future Precipitation in Bangpakong River Watershed

The downscaled mean monthly precipitation data for the period 1961-2099 from all six simulations can reproduce the observed characteristics of the historical mean monthly precipitation (1967–2007) reasonably well, particularly during the NE and pre-SW monsoon (Figure 2). Projection of these six GCMs yields the future mean monthly precipitation (average of six GCMs during 2040-2069), which reveals a slightly increasing trend in the mean monthly precipitation (5%) during the SW monsoon months of July-October when compared to the measured monthly precipitation in the study area during 1967–2007 (Figure 8). The precipitation projections during the pre-monsoon months of April-May, however, are more uncertain with some simulations clearly overestimating and others underestimating the mean monthly precipitation during the pre-SW monsoon months (Figure 2).

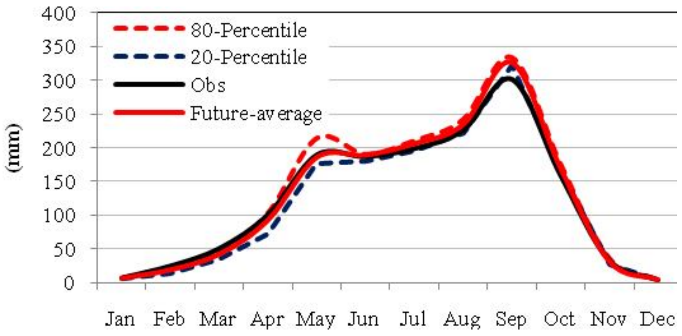


Figure 8. Observed precipitation averaged over 1976-2007 and predicted future precipitation of six GCM averaged over 2040-2069 period with 20- and 80-percentiles

Future Discharge and Suspended Sediment Load

The SWAT calibration results (Table 2) show a reasonably good agreement (R2 = 0.81, ENS = 0.83) between the simulated and observed monthly flow, as do the validation results (R2 = 0.79, E_{NS} = 0.84). Therefore, it is probable that SWAT is capable of satisfactorily and accurately simulating the hydrologic characteristics of the Bangpakong watershed. The time series of measured and simulated monthly flow results at KGT.3 station show that the simulated monthly flow mostly follows the observed flow, except in some situations where the flow is either overestimated or underestimated (Figure 5). Many factors may be responsible for the model errors when comparing the measured flow data with the simulated output, such as errors in the input parameters (i.e. rainfall and temperature), upstream dam operation, diversion of water for irrigation, and other unknown activities in the sub-basins.

Comparison of observed (year 2000) and simulated 30-year future discharges and suspended sediment loads (averaged over 2040-2069) are shown in Figure 9. Climate change is predicted to cause about 11% more fresh water discharge and 13% more suspended sediment load during September-October in the future, but both the predicted discharge and suspended sediment load in the future are lower than the present situation during June-July (Tables 3 and 4). Overall, during the period of 2040–2069, both the monthly average discharge and suspended sediment load are predicted to be higher than the current situation by 1% in the wet season (May-October) but lower by 3% and 23% respectively during the dry season (November-April).

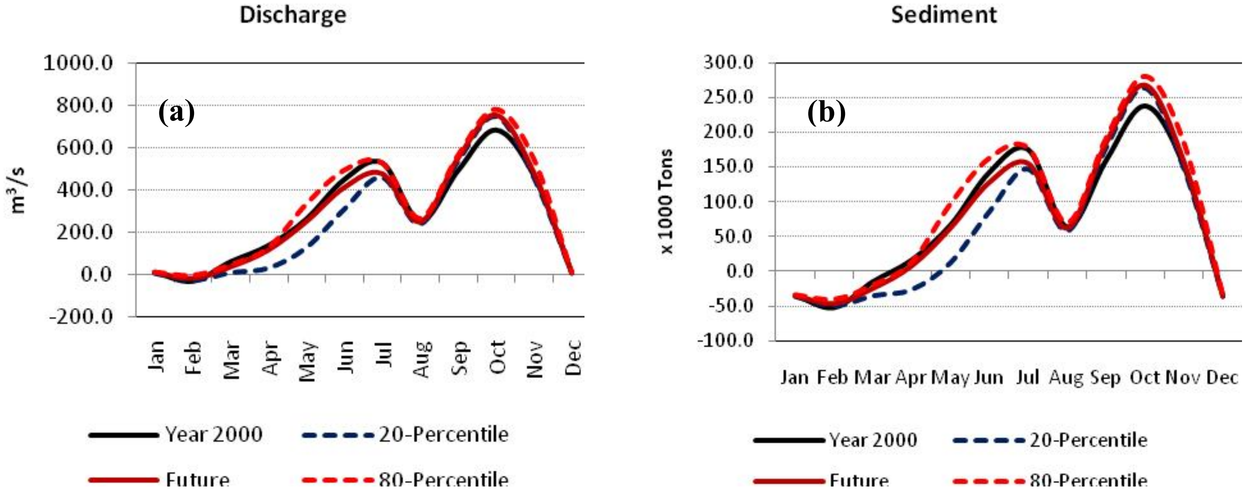


Figure 9. Average predicted (a) water discharge and (b) suspended sediment load, with the 20- and 80-percentiles, derived from the six GCM models over the period 2040-2069, and compared to year 2000 (as high flow year)

Table 3. Average predicted monthly discharge and per cent change of water yield drained by Bangpakong watershed for the period 2040-2069

	Monthly discharge (m^3/s)				% Change		
	Baseline	20-Percentile	Future-average	80-Percentile	20-Percentile	Future-average	80-Percentile
Jan	9.2	6.4	8.7	11.0	-30.7	-5.8	19.1
Feb	-33.9	-27.0	-19.3	-5.1	20.5	43.3	84.9
Mar	58.1	8.8	34.5	45.7	-84.8	-40.5	-21.3
Apr	134.9	30.8	114.3	126.5	-77.2	-15.2	-6.2
May	259.6	126.3	248.5	333.4	-51.4	-4.3	28.4
Jun	446.6	307.1	409.5	493.8	-31.2	-8.3	10.6
Jul	525.4	456.1	474.6	527.7	-13.2	-9.7	0.5
Aug	251.6	237.5	247.0	265.2	-5.6	-1.8	5.4
Sep	488.8	533.2	548.9	564.9	9.1	12.3	15.6
Oct	680.7	742.9	752.1	781.7	9.1	10.5	14.8
Nov	466.4	456.8	479.9	545.9	-2.1	2.9	17.1
Dec	6.6	6.3	6.7	8.3	-4.4	2.0	25.3

Table 4. Predicted change in the percentage of monthly average suspended sediment load drained by Bangpakong River in the period 2040-2069

	Monthly suspended sediment (x 1000 Tons)				% Change		
	Baseline	20-Percentile	Future-average	80-Percentile	20-Percentile	Future-average	80-Percentile
Jan	-35.0	-36.1	-35.2	-34.2	3.3	0.6	-2.1
Feb	-52.6	-49.7	-46.6	-40.8	-5.4	-11.4	-22.3
Mar	-15.1	-35.1	-24.6	-20.1	133.4	63.6	33.5
Apr	16.3	-26.2	7.9	12.8	-261.0	-51.5	-21.0
May	67.1	12.8	62.6	97.2	-81.0	-6.8	44.8
Jun	143.3	86.5	128.2	162.6	-39.7	-10.6	13.4
Jul	175.4	147.2	154.7	176.4	-16.1	-11.8	0.6
Aug	63.8	58.1	62.0	69.4	-9.0	-2.9	8.7
Sep	160.6	178.6	185.0	191.6	11.3	15.3	19.3
Oct	238.8	264.1	267.9	280.0	10.6	12.2	17.2
Nov	151.4	147.5	156.9	183.8	-2.6	3.6	21.4
Dec	-36.0	-36.2	-36.0	-35.4	0.3	-0.1	-1.9

CONCLUSIONS

This study represents the first attempt to apply multi-model ensemble techniques to the Bangpakong River basin using the IPCC SRES A1B emission scenario. Results indicate that the SWAT model performance of monthly discharge predictions is considered 'very good' during calibration and validation, with the E_{NS} values of 0.83 and 0.84 respectively, indicating that the model can reproduce accurately the observed streamflow. Overall, this study shows that the SWAT model can be an effective tool for describing monthly discharge from small watersheds in Thailand. We made predictions about changes in the monthly discharge and sediment transport regime of the Bangpakong River that may occur over human timescale in response to anticipated variations in climate. The results of this research may give an insight into how potential change in future precipitation might affect the coastal areas and natural ecosystem such as wetlands, as well as the economy of the agricultural, fishery and other sectors dependent on water availability, and hence the livelihood of the people.

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