Applying SWAT model to simulate streamflow in Ben Hai River Basin in response to climate change scenarios

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Abstract. SWAT model was used to assess the impacts of climate change on the streamflow of Ben Hai River Basin. The daily streamflow for 1979 - 1996 and 1997 - 2006 was used to calibrate and validate the SWAT model, respectively. Nash efficiency values for the daily comparison were 0.72 for the calibration period and 0.74 for the validation period. Three scenarios were analyzed relative to the baseline with 28-year time series. A doubling of the atmospheric CO_2 content to 660 ppm (while holding other climatic variables) resulted in a 7.2% increase in average annual streamflow while the average annual streamflow changes of 59.75%; 81.9%; 75% and 190% were predicted for two periods of B2 and A1FI scenarios respectively. The seasonal variability was predicted to be high for the individual climate change scenarios and in specific months the streamflow variability was also large between scenarios. The results also show that the hydrology of Ben Hai River Basin is sensitive to climate changes.

Keywords: SWAT, Climate Change, Soil and Water Assessment Tool, hydrologic model, water resources

1. Introduction

The changes in hydrologic cycle due to the global climate change conditions are very diverse and complex. It has an effect on the water resources and the efficiency of water resources management, etc. Understanding these impacts for all aspects of water resources is very important for future water resources management.

In the past, a great amount of work on climate change has been done from different viewpoints. Quite a lot of investigators studied the impact of climate change on water resources and hydrological cycle, on groundwater, soil moisture in unsaturated zone, return flow, evaporation etc. Some studies compared output among different downscaling methods. Some gave an overview of the impact of climate change on runoff generation, discussed models dealing with the hydrological response to climate.

Labat et al. proved that streamflow increase by 4% for every degree Celsius increase in global temperature [1]. Changes in climate are expected to have stronger effects on the temperate area in both magnitude and frequency than others [2]. Legess et al. predicted a decrease of streamflow by 30% in response to a 10% decrease in rainfall amount whereas the considerable increase of 1.5% in air temperature result in a smaller decrease of only 15% [3].

Although studies about the impact of climate change on hydrology have been widely done over the world, evaluation of the impact of climate change and atmospheric CO_2

concentrations at watershed level is still necessary.

The main objects of this paper is to examine the effects of climate change and increasing CO_2 concentration on streamflow in Ben Hai River Basin, a small watershed with diverse topography and high frequency of extreme phenomenon.

2. SWAT model

SWAT is a distributed hydrological model that was developed in the early 1990s to assess the impact of landuse and chemicals in agriculture of river basin system.

Lumped hydrological model simulate a spatially averaged hydrological system, while distributed hydrological models involve a more detail representation of the hydrological system by considering the spatial variability of model parameters and inputs. Distributed hydrological models such as the SWAT generally divide the watershed into smaller sub-basin and require inputs that include weather, soil properties, topography and land use for each of sub-basins.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw} \right)$$

in which: SW_t is the final soil water content (mmH_2O); SW_o is the initial soil water content on day i (mmH_2O); t is the time (days); R_{day} is the amount of precipitation on day i (mm H_2O); Q_{surf} is the amount of surface runoff on day i (mm H_2O); E_a is the amount of evapotranspiration on day i (mm H_2O); w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O); Q_{gw} is the amount of return flow on day i (mm H_2O).

Climate change impacts are simulated directly in SWAT by accounting for the effects of increased CO_2 on plant development and evapotranspiration. SWAT simulates the plant growth component based on plant specific input parameters such as energy and biomass conversion, precipitation and temperature, canopy heigh, root depth and shape of the growth curve.

Penman – Monteith method is used in the model that accounts for the impact of changing atmospheric CO_2 concentrations in the transpiration computations. The impact of change in CO_2 concentration on leaf conductance was simulated by using modification of Easterling et al., a 40% reduction in leaf conductance is a result of doubling in CO_2 concentration, to 660 ppm, was found by Morison and Gifford (1983). In a give interval, from 330 to 660 ppm, a reduction in leaf conductance and CO_2 concentration is linear. [4]

3. Scenario

3.1. Simulation Method

The simulated process consists of two phases: an initial calibration and validation phase and a second phase in which the impact of variation in climatic inputs were assessed for the Ben Hai River Basin hydrology.

The following model options were used for all of the simulations in this study: CN method for surface runoff simulating, the variable storage for channel water routing method, Penman - Monteith method for potential ET method.

3.2. Baseline scenario

A baseline scenario was assumed to reflect current conditions, and was executed before simulating the climate change scenario and other scenarios to provide a component basis for comparison of the scenario impacts.

The predicted output can be affected by the choice of time period for the baseline scenario, because of climatic variations which have occured between different time periods. Arnell summarized simulation periods which was used in several hydrologic climate change impact studies and found out that a 30-year period from 1951 to 1980 or shorter was assumed to define baseline conditions for many studies [5]. 28-year period from 1979 to 2006 was used for calibration and validation, was selected to represent baseline conditions for this study. An atmospheric CO_2 concentrations of 330 ppmv was assumed for the baseline scenario.

3.3. Sensitive Runs

A depiction of climate change consists of two components: emission of CO_2 and a corresponding climate response. The emission component reflects the concentration of greenhouse gases in the atmosphere at any given time while the climate response defines the changes in climate caused by changes in CO_2 concentrations.

The impacts of these two climate change components on watershed can be simulated simultaneously in SWAT or simulated seperately by simulating only the effect of an increase in atmospheric CO_2 concentrations or simulating temperature, precipitation and other climate changes. Only CO_2 sensitive runs was analysed independently here.

Table 1. Annual and seasonal changes of temperature at Hue in the period 2010-2100 in comparison to 1990 for two emisson scenarios respectively (A1FI và B2)

Scenario	Period	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1FI	Year	0.2	0.3	0.6	0.9	1.4	2	2.6	3.1	3.5	3.9
	Dec – Feb	0.2	0.3	0.6	0.9	1.5	2.1	2.7	3.2	3.7	4
	Mar - May	0.2	0.4	0.7	1.1	1.7	2.4	3.1	3.7	4.3	4.7
	Jun - Aug	0.2	0.3	0.6	0.9	1.5	2.1	2.7	3.2	3.7	4.1
	Sep – Nov	0.2	0.3	0.6	0.9	1.4	2	2.6	3.2	3.6	4
B2	Year	0.3	0.5	0.8	1.1	1.4	1.7	2	2.2	2.4	2.6
	Dec – Feb	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.1	2.3	2.5
	Mar - May	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.6	2.8
	Jun – Aug	0.3	0.5	0.8	1.1	1.4	1.7	1.9	2.1	2.3	2.5
	Sep – Nov	0.3	0.5	0.7	1.1	1.4	1.6	1.9	2.1	2.3	2.5

Source:[6] Tran Thuc, Research the impacts of streamflow varitation of Huong River Basin

Table 2. Annual and seasonal changes of precipitation at Hue in the period 2010-2100 in comparison to 1990 for two emisson scenarios respectively (A1FI và B2)

Scenari	Period	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
A1FI	Year	0.5	0.9	1.5	2.5	4	5.7	7.3	8.7	10	11
	Dec – Feb	-1	-2	-3.3	-5.4	-8.5	-12	-15.4	-18.5	-21.2	-23.4
	Mar - May	0.4	0.8	1.3	3.1	3.4	4.8	6.1	7.4	8.4	9.3
	Jun - Aug	0.7	1.1	2.2	3.6	5.6	8	10.3	12.3	14.2	15.6
	Sep – Nov	1.1	2.1	3.5	5.7	8.9	12.7	16.3	19.6	22.4	24.7
B2	Năm	0.8	1.4	2.1	2.9	3.7	4.5	5.2	5.8	6.3	6.8
	Dec – Feb	-1.4	-1.5	-2.3	-3.3	-4.2	-5	-5.9	-6.6	-7.6	-7.8
	Mar - May	-0.9	-1.5	-1.8	-3.3	-4.2	-5	-5.9	-6.6	-7.7	-7.8
	Jun - Aug	1	1.8	2.7	3.8	4.7	5.9	6.9	7.7	8.4	9.1
	Sep – Nov	1.8	2.4	3.7	5.2	6.7	8.1	9.8	10.5	11.4	12.3

Source: [6] Tran Thuc, Research the impacts of streamflow varitation of Huong River Basin

3.4. Climate Change Scenario

Based on economic growth, population, environmental conditions. In this paper, two scenarios were selected to assess the impact of climate change on the water resources of the Ben Hai River Basin: the high emissions scenario (A1FI) and low emissions scenario (B2) from the Special Report on Emissions Scenario of IPCC (IPCC, 2001).

The resolution of GCMs is too coarse to resolve many important hydrological processes, and be inadequate for assessing the impact of climate change on the hydrology of river basins. Moreover GCMs were not developed for investigating climate change impact on hydrology and do not provide a direct estimation of hydrological response to climate change. Therefore, in climate change impact studies, hydrological models are used to simulate sub-grid scale phenomenon. Scenarios that was downscaled for Huong River Basin from the report "*Research the impacts of streamflow variation of Huong River Basin*" (Tran Thuc et al.) used as climate change scenario in simulation for Ben Hai river basin. Because of Huong and Ben Hai river basin were classed into the same climatic region, furthermore climate change is variation which occurs on a large scale, using results from the report could be acceptable. Precipitation and temperature in B2 and A1FI were showed in table 1 and 2. [6]

4. Results and discussion

Figure 1 shows the time-series comparison of predicted and measured daily streamflow for Ben Hai River Basin over the 17-year (from 1979 to 1996) calibration period. In general, SWAT tracked quite accurately the daily measured streamflow for this period, although some peaks were unreasonable.

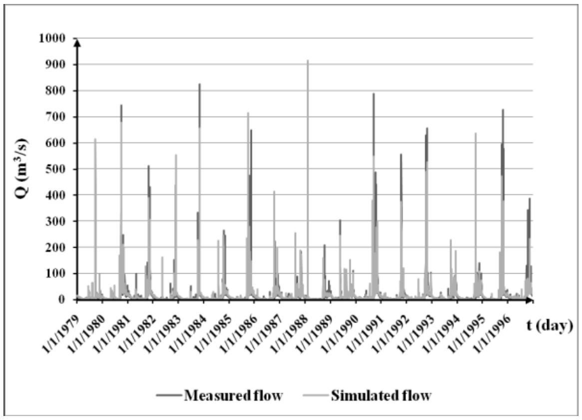

Figure 1. The time-series comparison of predicted and measured daily streamflow for calibration period at Gia Vong station

Figure 2 shows the time-series comparison of predicted and measured daily streamflow over the 10-year (from 1997 to 2006) validation period. The predicted flows closely followed the measured flows and simulated peaks have a better agreement as compared to the calibration period.

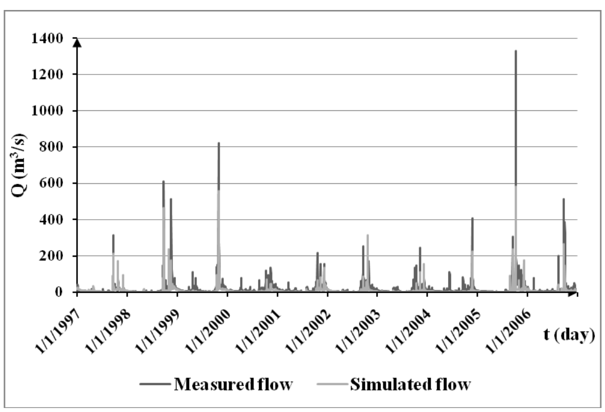

Figure 2. The time-series comparison of predicted and measured daily streamflow for validation period at Gia Vong station

These results confirm that SWAT was able to reflect hydrologic conditions in Ben Hai River Basin.

4.1. Sensitive Runs

The average monthly and average annual streamflows predicted at outlet of Ben Hai River Basin for the baseline scenario are significantly different from the CO_2 variation scenario. The average annual streamflow increase by 7.3% as doubling CO_2 concentration in 28-year period.

Water yield increases 2% to 22.6%. Because water yield and streamflow in BH river basin were low in comparision to the time series 28-year, the increasing trend occurred strongly in recent years. The streamflow increases from 3 to 18.2%, with the greatest increases occurring between April and August because in these months, the streamflow is low, in turn, a large increase in percent doesn't change the fact values much.

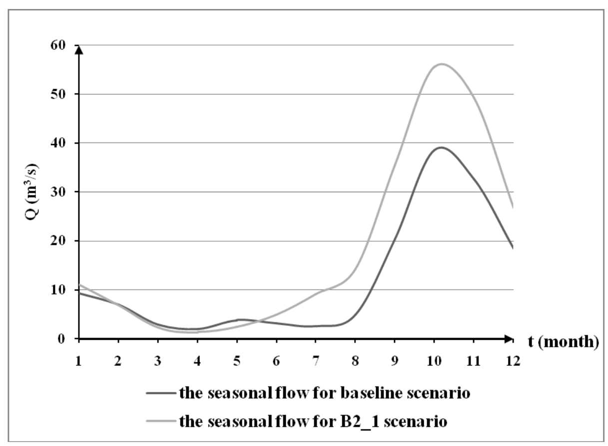

Figure 3. Variation of the seasonal streamflow between 2 scenarios

The trends shown in figure 3 also indicate that the flow increase magnitude were strongest in May and October, which are 2 flood times in year.

These results suggest that the hydrology of Ben Hai River Basin is quite sensitive to varied atmospheric CO_2 concentration and consistent with predictions: transpiration will decreases in response to increased CO_2 level, resulting in greater soil moisture levels and in turn higher flow.

4.2. Climate Change Scenario

The average annual streamflow varied greatly relative to the baseline, it was predicted to increase by 59.75% and 81.9% in two periods , the first half and the second half of the 21st century for B2 scenario; and the percentage of increase for two periods are 75% and 190% respectively for A1FI scenario.

In general, the seasonal and annual streamflow impacts varied greatly among scenarios, periods which reflect the wide range of temperature and precipitation. The fluctuation of predicted streamflow for A1FI scenario are greater, with a noticeable difference in season. Streamflow also varied greatly between scenarios each months. The greatest diffrence were predicted for the month of October, for which the streamflow ranges from about $40m^3/s$ to over $90m^3/s$, increases by 43% in the first half of the century for the B2 to 156% in the end period of the A1FI.

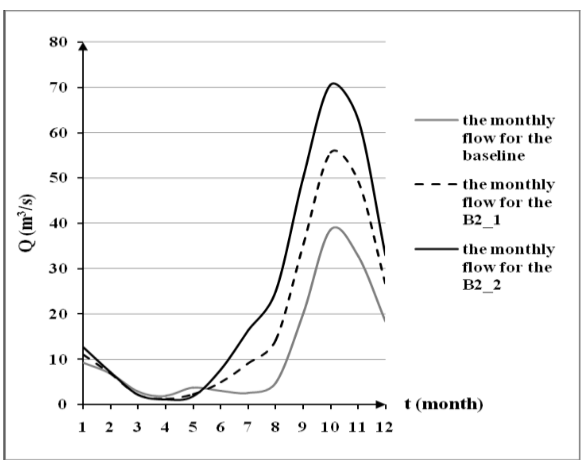

Figure 4. The variations of streamflow between scenarios and periods

For the fist half period of the 21st century, streamflow predicted for B2 scenario rises significantly in most months, except the period from March to May because of the forecasted decrease in precipitation during these three months, although a decrease in precipitation relative to the baseline scenario between December and February, streamflow still had a large relative increase because of extra groundwater from the previous months. In the second half period, only the decrease in streamflow occurred in the period from March to May.

In the first period, only February streamflow simulated for A1FI scenario decrease, on the other hand, in the second period streamflow increase in all of months. In this scenario, precipitation decrease within December to February, and increase from March to November cause the increase in streamflow in this period, and this trend continue in the next two months point to the extra groundwater. These results indicate that climate change impacts deal with increasing in dry flows, in turn could be less drought frequency. Thus, the effect of groundwater are relatively pronounced in streamflow of Ben Hai River Basin.

The scenarios resulted in large relative streamflow increase in most months and the largest increase of the average annual streamflow was estimated to be 190%. The increasing tendency in predicted flow was the largest during flood months, from August to December. The degree of this trend in other months is smaller.

5. Conclusion: The large relative

streamflow variations under climatic changes indicate that hydrologic system of Ben Hai River Basin is quite sensitive to climatic variations, both on seasonal and yearly periods. The sensitive runs showed that the atmospheric CO_2 concentration have a great relative effect on streamflow of Ben Hai River Basin. Changes in annual average streamflow for 2010 to the end of the 21st century were predicted to range from 59.75% to 81.9% for B2 scenario. In A1FI scenario, the variation of the annual streamflow is the same but has a tronger magnitude. The variable tendency of the seasonal streamflow is quite different between two scenarios, the dry flow decrease significantly for B2 scenario while the values of streamflow for A1FI scenario increase in most all of months.

References

1. Labat, D., Godderis, Y., Probst, J.L., Guyot, J.L., Evidence for global runoff increase related to climate warming. *Advances in Water Resources* 27 (2004) 631.

2. Prudhomme, C., Jakob, D., Svensson, C., Uncertainty and climate change impact on the flood regime of small UK catchments. *Journal of Hydrology* 277 (2003) 1.

3. Legesse, D., Vallet-Coulomb, C., Gasse, F., Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. *Journal of Hydrology* 275 (2003) 67.

4. S.L.Neitsch, J.G. Arnold, J.R.Kiniry, J.R.Williams, *Soil and water assessment tool theoretical documentation,* USDA_ARS Publications, 2001.

5. Arnell, N.W., *Global Warming, River Flows and Water Resources*, Water Science Series, Institute of Hydrology, John Wiley and Sons, New York, 1996.

6. Tran Thuc, Research the impacts of streamflow variation of Huong River Basin, *11st Science Report,* Institute of Meteorology, Hydrology and Environment, 2007 (in Vietnamese).