IMPACT OF CLIMATE CHANGE ON WATER FLOW OF ĐĂK B'LA RIVER BASIN, VIETNAM

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ABSTRACT

Climate change is one of the greatest challenges to human life in the 21st (twenty first) century. Effects of climate change impacts on all areas of human life and natural, especially the water flow of river basin. In recent many studies, the SWAT model has been widely used to assess soil and water resource and is considered to be a significant model in this field of research. The SWAT model was applied in this study to quantify the future impact of climate change on water flow of the Đăk B'la river catchment in Central Highland Vietnam. The results of the calibration and validation procedures with monthly stream-flow records showed that SWAT can be used to simulate the stream-flow in Dak Bla catchment with a Nash – Sutcliffe efficiency above 0.7 at the Kon Tum station. The climate change scenarios in this study were obtained from the Climate Change Scenarios which were established by SEA-START và RCCC-NLU. The scenario results revealed that climate change will significantly impact the basin and thus the establishment of timely adaptions is necessary.

1. INTRODUCTION

Nowadays, climate change has become a global issue which causes impact on all aspects of human life. According to recent studies (UNDP, 2007, World Bank, 2007, IPCC, 2007), Vietnam is one of the most vulnerable countries under the effect of climate change, in which water resources is the most effected resources. In Dak B'la River basin, which located at the Central Highland of Vietnam, floods and droughts occur frequently in recent years. These problems and the demand of water for daily need of residence as well as agricultural production have made the serious impacts to water resources of the area. [1]

This study was carried out based on the integration of GIS technology and SWAT (Soil and Water Assessment Tool) model to assess the impacts of climate change on the stream flow in the river basin. In contrast, GIS technology was applied to support the hydrological model regarding its accurately spatial distribution capability for the simulated hydrological processes taking place in the basin and reflects the actual function of the systems [2]. SWAT (Soil and Water Assessment Tool) was chosen because of its useful functions in simulating the water balance and hydrological processes such as water quality, climate change, crop growth and growth of land management practices [2] with a friendly user interface [3]. In addition, the effectiveness and reliability of the SWAT model has been confirmed in many different studies around the world, so this is an opportunity to test the suitability of the model for Dak B'la river basin. The main objective of the study was assess the stream flow of Dak Bla River basin in the context of climate change.

2. LITERATURE REVIEW

2.1 Study area

Dak Bla River basin located in the Central Highlands of Vietnam. Dak Bla river is the left branch of the Se San river with the area about 3,507km^2 (the area from the source of the river to Kon Tum stations is about 2,9715.2 km^2), the length of the main river is about 152 km. The Dak Bla river's boundaries are Thu Bon river system, Ba river systems, Se San River Basin in the north, the east and the south respectively. Dak B'la river originates from Ngoc Krinh Mountains with the height of about 2.025m, the direction of the flow is northeast-southwest through two neighboring provinces of Kon Tum and Gia Lai (Figure 1) before joining with the Sesan river at the confluence which located at 16 km downstream from Ya Ly dam. Dak Bla river basin has a very developed hydrological system with the density of 0.49 km/km^2, meandering coefficient of 2.03, the average slope of the river bed is 4% [4].

The variation in topography of Dak Bla River basin is pretty complex: lower elevation terrain from north to south; gradually incline from east to west with many hills, plateaus and valleys alternating. Meteorological and hydrological observation systems within the basins have not been well investment (limitation in the number of stations, scattered over space and equipment has not been upgraded). According to statistics, there are two people's rain gauges – the gauge station is set up at the house of residence - (Dak Doa, Mang Canh), two level 1 meteorological stations (Kon Tum, Pleiku), two hydrological stations (Kon Tum, Kon Plong) located in the basin (Figure 1).

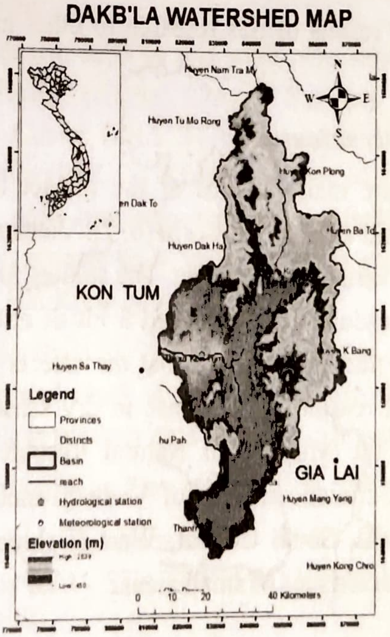

Figure 1. DakB'la basin and Hydrological-Meteorological station

Regarding climatic characteristic, Dak Bla River basin has the tropical monsoon of Highland, there are two distinct seasons annually: the rainy season from May to October, the dry season from November to April next year [4]. The area also has high temperatures with the annual average of about 20 - 25°C; annual rainfall on the average, from 1,500 to 3,000 mm and mean annual evaporation is about 1,000 to 1,500 meters [5]. Most of the catchment area covered by tropical forests with the main forest types included tropical evergreen forest, young forest, mixed forest, plantations and bush [5].

The economy in the study area significantly depends on farming activities with the main crops are rubber and coffee planting on a typical basaltic soils. In addition, agricultural production also plays an important role for the local economy. Therefore, simulation and forecasting the stream flow of the basin are very important [5].

2.2 Literature review

2.2.1 GIS (Geographic Information System)

GIS was first built in the '60s in the United States, Canada and growing rapidly during the past two decades due to the development of computer technology. GIS can store and display information completely separation, the information can be displayed in different proportions, a kind of information can be displayed in many different types of maps. The main purposes of GIS are data collection, data management, data analysis and data display.

2.2.2 SWAT (Soil & Water Assessment Tool)

SWAT model was developed from the 90s of last century to support the effectiveness of the management of soil and water resources. SWAT model was developed by Dr. Jeff Arnold of Agricultural Research Service (ARS) – United States Department of Agriculture (USDA). SWAT allows modeling of physical processes on the same basin. The strength of the SWAT model is a large basin can be divided into several sub-basins, the modeling by sub-basin beneficial when the regions have the same characteristics of land use and soil. This division helps the users can apply the results of this research to other areas when they have certain similarities.

2.2.3 Climate change and water resources

In recent years, there are many studies of the impact of climate change on water resources and hydrological basin all over the world [6, 7]. Vietnam is one of the five countries in the world most affected by variables in climate. The studies focus on evaluating the impact of climate change on water resources has attracted a lot of attention from scientists in the country. The results of these studies suggested that the effects of climate change make the stream flow increase in flood reason and decrease in dry season [8, 9]. These studies use climate change scenarios of the Ministry of Natural Resources and Environment (these scenarios was built for seven climatic regions of Vietnam included: Northwest, Northeast, Red River Delta, North Central, South Central, West Highlands and Mekong Delta) and didn't reflect the climatic characteristics of small areas.

3. DATA AND METHODOLOGY

3.1 Research data

Input data of the study include: land use map, soil maps, topographic maps, weather data, climate change scenarios. The collected data will be edited in accordance with the SWAT model.

- Digital Elevator Model (DEM): Performing for continuous variation of terrain elevation on a region of space. DEM data is taken from SRMT (Shuttle Radar Topographic Mission) of USGS / NASA, with a resolution of 30 m.

- Soil map: the 2010 soil map received from the Department of Natural Resources and Environment of Kon Tum and Gia Lai provinces were used to conduct soils identified in the study basin.

- Land use map: This is a very important component of the input data of SWAT. Forms of land use activity expressed through human cultivation in the study area. Cover of vegetation will directly affect stream flow and water quality of the study area. The 2010 land use map from the Department of Natural Resources and Environment of Kon Tum and Gia Lai provinces were used in this study.

- Weather data: input weather data was divided into two parts: part one is from 2000 to 2012, and part two is from 2013 to 2069. In contrast, weather data included: information of gauge stations (station name, station location), rainfall, rainfall of half an hour, the minimum and maximum in air temperature, wind speed, radiation, humidity and dew point.

- Hydrological data: in Dak Bla River basin, there are two stream flow observed stations, Kon Plong and Kon Tum. In which Kon Tum station is a level-1 gauge station with longer period of observation and better quality of observed data. In additional, Kon Tum station is located at the downstream of the Dak Bla river therefore its observed data could consider as the represent for the entire basin. Regarding these reasons, the study used the observed stream flow of the 2000 - 2012 period of Kon Tum stations as the input data for the calibration and validation process of SWAT model.

3.2 Climate change scenarios

The climate change scenario A1B in this study was inherited from the joint research between Southeast Asia START (Global Change **S**ys**T**em for **A**nalysis, **R**esearch and **T**raining network) Regional Center (SEA START) and the Research Center for Climate Change – Nong Lam University (RCCC - NLU). The data of 2013 – 2069 period (including daily maximum temperature, daily minimum temperature, daily rainfall, average daily wind speed, average daily humidity, average daily solar radiation) was used as the input to simulate the future stream flow at Dak Bla River basin.

The main utility in this study is SWAT model which was applied to simulate the stream flow of Dak Bla River basin and most of the input data in this study were considered as constant. The only one variable is weather data with two different time period:

Scenario A: observed data of Kon Tum hydrological station in the 2001 – 2012 period.

Scenario B: climate change scenarios of the 2012 – 2069 period based on the A1B emissions scenario provided by SEA - START and RCCC - NLU.

3.3 Methodology

The research methodology such as figure 2.

After the data has been edited in accordance with SWAT model requirement, SWAT was run with two climate scenarios of 2000 - 2012 and 2013 – 2069 period respectively, other factors such as DEM, soil map and land use were fixed.

The calibration process was established to determine optimal values for the parameters set. The automatically calibration program SWAT-CUP was employed with the Sequential Uncertainty Fitting method (SUFI-2) [11]. The simulation of stream flow of Dak Bla River basin was accomplised via ArcSWAT2012), an extension of ArcGIS version 10.1.

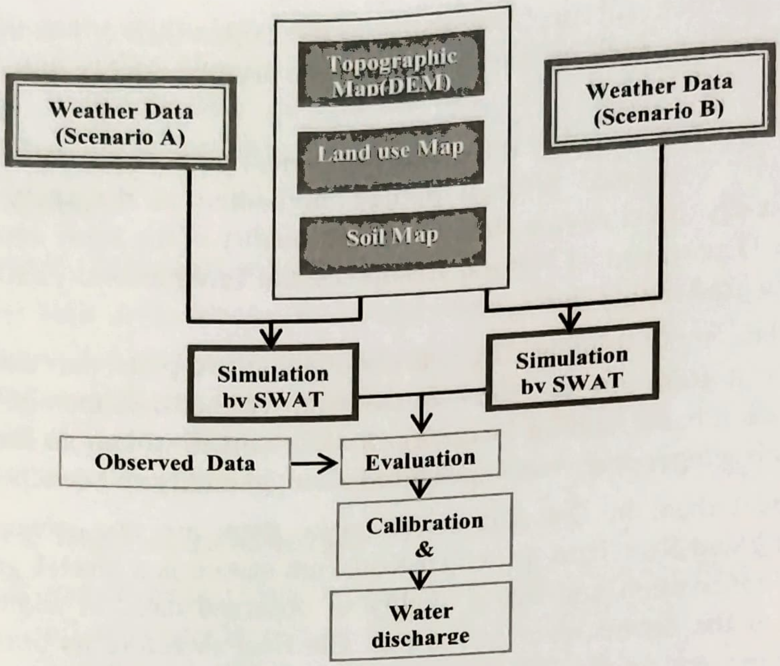

Figure 2. Research Methodology

After calibration, the validation process was conducted to evaluate the performance of the model with the calibrated parameters. The observed stream flow used for the validation process was separated and independent with the data which was used for calibration.

Calibration and validation process were focus on the coefficient of determination R^2 [12] and performance indicators Nash - Sutcliffe (NSI) [13]. The calculation of these indicators were expressed in the following equation.

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right)^2 \quad (1)$$

$$NSI = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (2)$$

The NSI > 0.5 and the $R^2 > 0.5$ indicate that the performance of the SWAT model is acceptable [14, 15].

4. RESULTS AND DISCUSSIONS

4.1 Scenario A stream flow

The watershed delineation divided the basin into 11 sub-basins in which the Kon Tum hydrological station located in the sub-basin number 9. The simulation results of flow in the Dak Bla River basin were shown in Figure 3. In rainy season, the simulated stream flow is higher than observed stream flow and the dry season is the opposite. The correlation coefficient R^2 and NSI index (Nash-Sutcliffe) between simulated data and observed data are 0.73 and 0.58 respectively. Initial results demonstrate the SWAT model is suitable for simulating stream flow in Dak Bla River basin. To improve the performance of the model, we conduct the calibration with observed data from 2001 to 2005.

The calibration was accomplished with SWAT-CUP software and SUFI2 method. This study focus on parameters related to soil physical properties such as: Moisture condition II curve number (Cn2.mgt), Base flow Recession constant (Alpha_Bf.gw), Delay time for aquifer recharge (Gw_Delay.gw), Threshold water level in shallow aquifer for base flow (mm) (Gwqmn.gw). The value of adjustment parameters was described in Table 1.

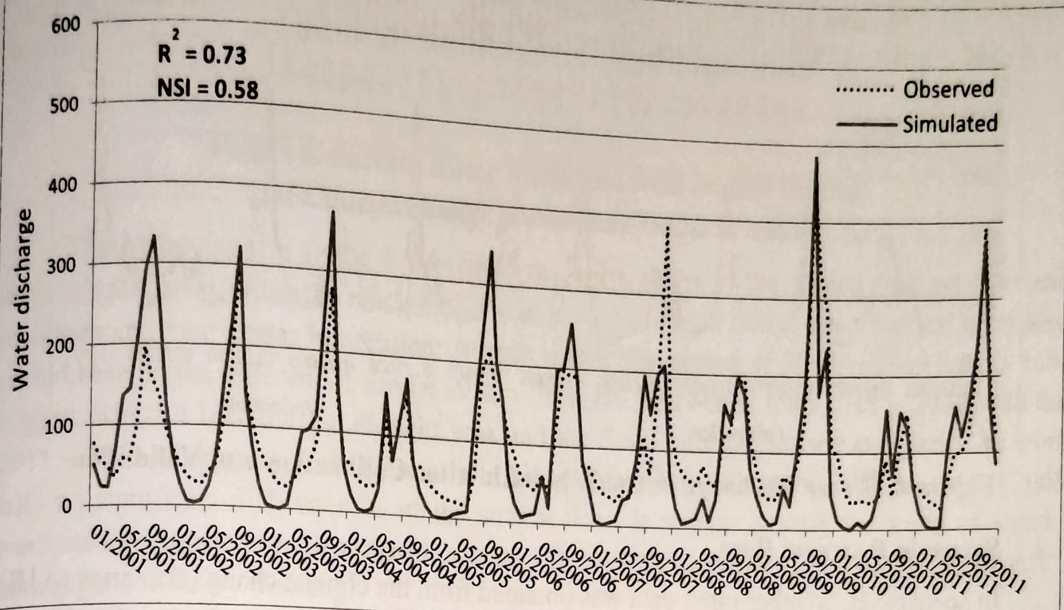

Figure 3. Observed and simulated water discharge before calibration

Table 1. The sensitive parameters and calibrated values.

Parameter	Description	Calibrated values		
		Optimal value	Minimum value	Maximum value
CN2.	Moisture condition II curve number	*-0.160000*	-0.200000	0.200000
ALPHA_BF	Base flow Recession constant	*0.100000*	0.000000	1.000000
GW_DELAY	Delay time for aquifer recharge	*324.000000*	30.000000	450.000000
GWQMN	Threshold water level in shallow aquifer for base flow (mm)	*0.200000*	0.000000	2.000000

The obtained parameters continued to be used in the validation process. In this period, the simulated stream flow was compared with observed data of the Kon Tum station from 2006 to 2011. The comparison between the hydrograph of the simulated and observed water discharge of the Kon Tum station were shown in Figure 4. In contrast, the performance of SWAT model of water discharge with the calibrated parameters was pretty good with the correlation coefficient R^2 and NSI (Nash - Sutcliffe) index are 0.75 and 0.72 respectively. This result proved SWAT model is reliable in simulating the stream flow of the Dak Bla River basin. There were also some errors in the simulated stream flow during flood season (especially in September), when simulated values smaller than observed values; and during dry season, when simulated values greater than observed values. These problems were credited for lack of detailed land use data, especially the type of forest cover in the basin.

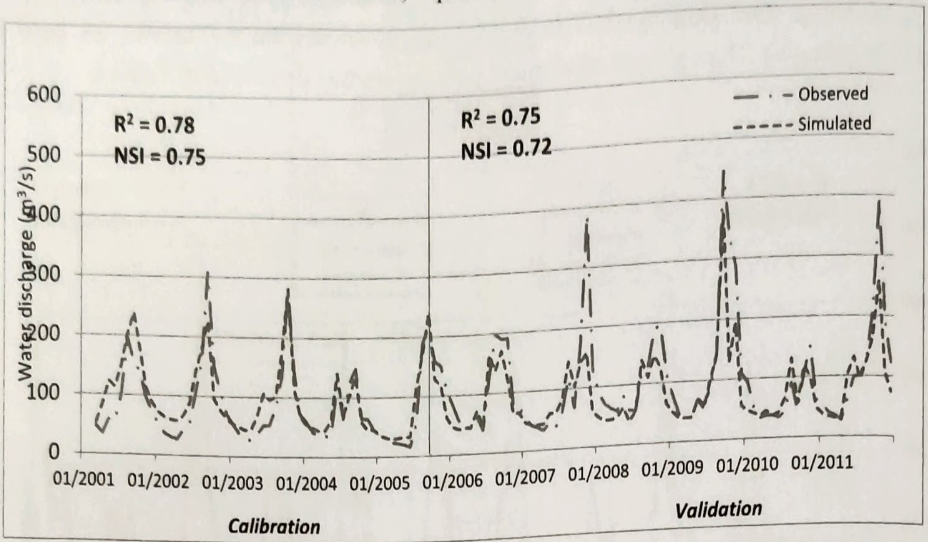

Figure 4. Water discharge in DakB'la basin after Calibration and Validation

4.2 Scenario B stream flow

In scenario B, weather input data was obtained from the climate change scenarios (A1B) from the year of 2013 to 2069, meanwhile the parameters of the model and other data had no different in comparing with scenario A. The simulated stream flow of Dak Bla River basin of scenario B is described in Figure 5.

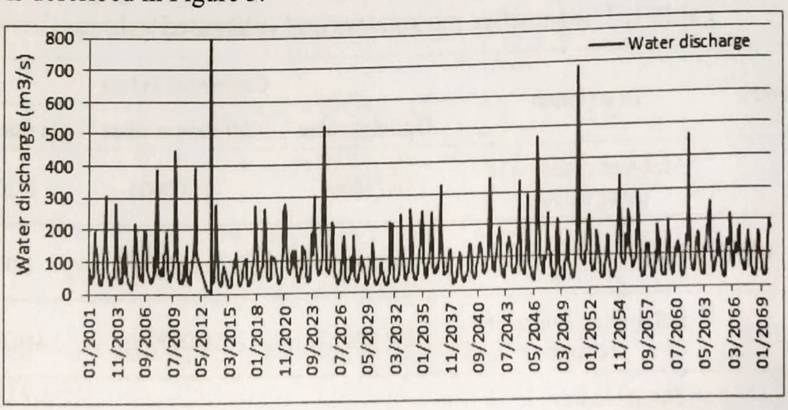

Figure 5. Water discharge in DakB'la basin in period 2013-2069

In contrast, the stream flow in dry season of scenario B is higher in comparing with scenario A and the stream flow of scenario B is lower than scenario A in rainy season. This result illustrated the significant role of precipitation in the stream flow when the annual precipitation in scenario B is redistributed with the increase in dry season and decrease in rainy season. In additional, the simulated stream flow of scenario B has a lot year with monthly value under 150 m^3/s such as: 2014, 2019, 2028, 2030, 2037, 2038, 2039, 2040 with the potential of shortage in water supply. On the contrary, the years of 2024, 2046 and 2050 have the monthly stream flow above 400m^3/s, especially in November, 2050 with 712m^3/s far higher than the historical flood in 2009 with the stream flow level of 445m^3/s.

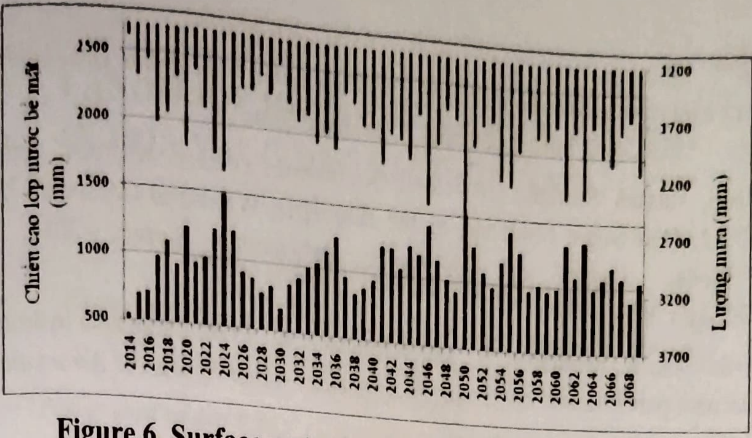

Figure 6. Surface water levels and total annual rainfall of Climate change Scenario in DakB'la basin

The hydrograph in figure 6 described the relationship of the annual precipitation and surface water level: when the precipitation increases, the height of the water surface layer also increases and vice versa. In addition, we can divide the period of 2013 – 2069 into 3 sub-period base on the different of annual stream flow: the first one is from 2013 – 2030 with the biggest different between the drought year and the flood one; the second sub-period is from 2031 – 2040 when the gap decrease a little bit, and the final sub-period is from 2041 – 2069 with no significant difference in annual stream flow. It reflects exactly the trend of annual precipitation climate change scenario (scenario B) with the downward in the number of years of drought and heavy flooding.

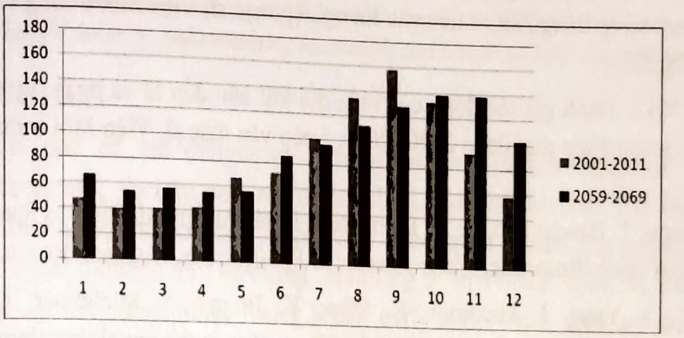

Figure 7. Average month water levels over the periods in DakB'la basin (mm)

In monthly simulated stream flow, the figure 7 illustrated the changing between the base period (2001 – 2011) and the future period (2059 – 2069). The highlight of this transform is moving of the peak from September (base period) to October (future period). Additionally, the surface water level in future period tends to be more stable, which means increasing the amount of water in the dry season and reduce the amount of water in the flood season.

5. CONCLUSIONS

Through this study we found:

(1) The use of SWAT model to assess the flow is entirely appropriate. Results of calibration and validation of the model provided optimal parameters of SWAT model to calculate the impact of climate change on stream flow.

(2) Beside the negative impacts on stream flow such as the fluctuation of stream flow, appeared the year of drought or floods, climate change also create positive effect in making the monthly stream flow more steadily.

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