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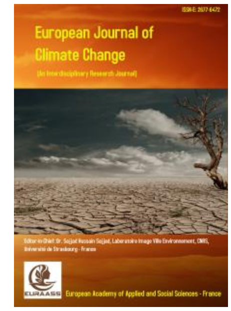

Research Article

Climate change impacts on hydrology in the Dak B'la watershed, Central Highland Vietnam based on SWAT model

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Abstract:

Climate is the main factor affecting hydrology in a watershed. For purely agricultural watershed, hydrological assessment and management play a very important role in the region's agricultural development. In this study, the hydrological was simulated by the Soil and Water Assessment Tool (SWAT) model. This paper aimed to calibrate and validate the SWAT model in Dak B'la watershed in Central Highland Vietnam and assess the climate change on water discharge. The coefficient of determination (R^2) and Nash-Sutcliffe index (NSI), and Percent BIAS (PBIAS) during the calibration process was 0.75, 0.72, and -1.15 respectively and validation process was 0.82, 0.83, 3.67 respectively. It proved the high reliability of the SWAT model after calibration. The two climate scenarios were selected in this investigation: scenario A is the existing climate using the data from 2001 to 2018 and scenario B is the A1B emission scenario for the future period from 2020 to 2069. Compared to the average water discharge from 2001-2018 and average water discharge from 2020 to 2069, the results indicated that climate change increases the average water discharge (0.55%), especially in 2050, the water discharge in the flood season (in November) is 584 m^3/s, which higher than the largest flood in 2009 of 450 m^3/s.

Keywords: climate change, SWAT, hydrological process, Dak B'la watershed, Central Highland Vietnam

1. Introduction

The Intergovernmental Panel on Climate Change report reaffirmed that 'global warming' is occurring (IPCC, 2007). Climate is the main factor, which affects the hydrological cycle, and thus changes the stream flow and modifies the transformation and transport characteristics of sediment as well as water pollutants (Tu, 2009). Therefore, climate change is an important factor in influencing hydrological conditions. Varieties of studies performed on the impact of climate change on hydrology (Githui et al., 2009; Kim and Kaluarachchi, 2009; Boyer et al., 2010; Bauwens et al., 2011). Most of those studies indicated that variations of streamflow are closely associated with changes in temperature and precipitation. In the studies of climate change, the outputs of general circulation models (GCMs) used to generate the future climate conditions for a study area and then using a hydrological model to estimate the climate change impact on runoff behavior. In addition to climate information, land use information is essential in watershed hydrology. The effects of land

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use directly linked to changes in hydrologic components in a watershed, such as evapotranspiration, surface runoff, groundwater, stream flow. Many previous studies around the world have demonstrated that land use significantly affects hydrological processes (Mueller et al., 2009; 2011; Nie et al., 2011). Generally, hydrological models commonly used to investigate the influences of land use change on runoff and the studies of land use change often conducted with the assumption that the climate would keep the same for the simulation period.

In the face of potential climate and land use changes, studies of the impact of climate and land use change on hydrology are essential. Many studies have addressed the change in hydrology with impacts of climate and land use changes (Wang et al., 2008; Li et al., 2009; Li et al., 2012; Ma et al., 2009; Mango et al., 2011), but few have investigated the impact on sediment yield at a basin scale. In general, regional impacts of climate change and land use change on hydrology vary from place to place and need to consider for a local scale (Wang et al., 2012).

Three-fourths of Vietnam is in the upland with a complex topography and steep slopes. Forests play an important role in environmental protection (Lung, 1995). However, under the pressure of economic development, the demand for agricultural land and other sectors has been expanding. Natural forests mostly are distributed in highland areas, which destroyed, leading to decreased land cover and rapidly declining soil quality. Therefore, this country is facing soil erosion, especially in the highland areas. Moreover, Vietnam has experienced such climate changes as rising air temperatures and variable precipitation. From 1958 to 2007, the annual average temperature increased by 0.5- 0.7^{o}C. Annual precipitation decreased in Northern Vietnam but increased in Southern Vietnam. For the entire country, rainfall decreased an average of 2% over the past 50 years (1958- 2007) (MONRE, 2009). These changes have affected significantly the availability of water resources in Vietnam.

Some studies performed to investigate the impact of land use change and climate change on hydrology in Vietnam. Hung et al. (2010) used SWAT (Soil and Water Assessment Tool) model to evaluate impacts of different re-forested area scenarios (25% and 50% of total 2005-year forested area in the river basin) on the hydrological regime of the upper part of Ma river basin, Northwest of Vietnam. On the other hand, most studies related to climate change primarily based on climate change scenarios for Vietnam (MONRE, 2009) or on outputs from individual GCMs. There are many examples; Kawasakia et al. (2010) used the output from the Japanese Meteorological Agency GCM for IPCC SRES A1B scenario and the hydrological model HEC-HMS (Hydrologic Modeling System) to consider the climate change impact on water resources in the central highland of Vietnam. That data were downscaled from GCMs by the MAGICC/SCENGEN model to evaluate the impact of climate change on the flow in the Hong-Thai Binh (located in North Delta) and Dong Nai river basins which located in the Central Highland and South Delta. The climate scenarios from MONRE (2009) were developed only for Vietnam's seven climate zones: Northwest, Northeast, North Delta (Red River Delta), North Central Coast, South Central Coast, Central Highlands and South Delta (Mekong River Delta). Therefore, it is unable to reflect accurately the specific local details of climate change in Vietnam (MONRE, 2010).

The methods of assessing the hydrologic effects of environmental change include paired catchment, statistical analysis, and hydrological modeling (Li et al., 2009; Li et al., 2012). Among these approaches, the hydrological modeling method is most suitable for use in scenario studies. Widely used hydrological models in studies on the impact on hydrology include the Hydrologic Simulation Program–Fortran, the Soil and Water Assessment Tool (SWAT), WaTEM/SEDEM, and the Water Erosion Prediction Project. The SWAT model selected for the present study because it is widely used to assess hydrology and water quality in agricultural catchments around the world. Another reason for this selection is its availability and user-friendliness in handling input data (Arnold et al., 1998).

Dak B'la watershed is selected as a study area. At present, there are many critical issues for soil and water resource management in the river basin (The Government of Vietnam, 2006). These problems range from hydrological variability (including floods and droughts) to environmental degradation (including pollution of waterways and deforestation of catchments), erosion and resultant sedimentation of reservoirs, over-exploitation of groundwater, conflicts over the use of water for different purposes, and trans-boundary conflicts (inter-district). So far, few studies have quantified the combined potential future impacts of climate and land use/land cover change on hydrology in Vietnam. (Ty et al., 2012, Quyen et al., 2014) but no study assesses the climate change impact on hydrology in Dak B'la watershed. SWAT is a physically based semi-distributed hydrological model with an ArcView GIS interface. It is developed by the Black land Research and Extension Center and the United States Department of Agriculture - Agricultural Research Service (USDA- ARS). It can be applied at the watershed scale to simulate the impact of land management practices on water, sediment and agrochemical yields in large watersheds with varying soils, land use, and agricultural conditions over extended periods of time (Arnold et al., 1998). This paper attempts to assess climate change impact on hydrology in the climate change context in Dak B'la watershed, Kontum province, Central Highland Vietnam.

2. Description of Study Area

2.1 Geographical Location

The Dak B'la watershed is located in the Central Highland of Vietnam. Dak B'la river is a left branch of Se San river with an area of 3.507 square kilometers, the length of the main river is 152 km. It is bordered by the Thu Bon river in the North, the Ba River in the East, and the Se San river in the South. Dak B'la river originates from the Ngoc Co Rinh Mountain with a high of 2.025 meters, flows in the northeast-southwest direction through Kon Tum and Gia Lai provinces to Ya Ly lake in the downstream as shown in Figure 1. The Dak Bla river basin has a quite expanded system of rivers and streams with a river network density of 0.49 km / sq.km and a meandering coefficient of 2.03, the average slope of the main river bed is 4% (Cuong, 2012).

2.2 Topography

The terrain characteristics of the Dak B'la watershed are quite complicated, the elevation of the terrain gradually decreases from north to south and gradually slopes from east to west with alternating hills, plateaus, and valleys. The meteorological and hydrological monitoring system in the basin has not been invested and developed adequately (the number of stations is still limit scattered in space, the equipment has not been upgraded). The economy in the study area depends heavily on cultivation activities with the main crops being rubber and coffee grown on basalt soil. Besides, agricultural production also plays an important role in the local economy. Therefore, the simulation and forecast of the flow in the basin are extremely important (Vu et al., 2012).

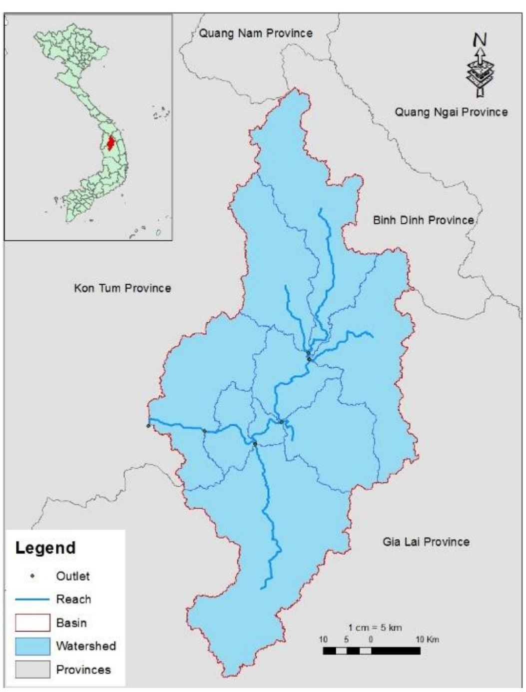

Figure 1: Location of Dak B'la watershed.

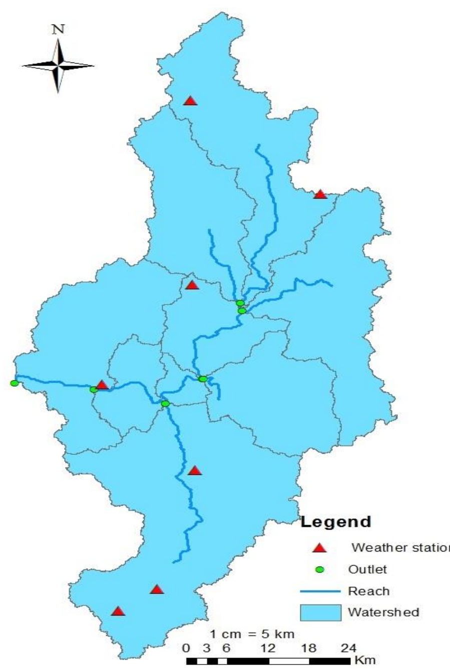

Figure 2: Meteorological stations of Dak B'la watershed.

2.3 Climate

The Dak B'la watershed belongs to the tropical monsoon region of the Central Highland of Vietnam, there are two distinct seasons every year: the rainy season is from May to October while the dry season is between November and April next year (Cuong, 2012). The average annual temperature is about 20-25oC, the total annual rainfall is 1,500-3,000mm, and the average annual evaporation is about

1,000-1,500m. Most of the river basin area is covered by tropical forests with major forest types such as evergreen forest, mixed forest, plantation forest, and shrub (Vu et al., 2012). In the Dak B'la watershed, there are two measuring points for rainfall at Dak Doa, and Mang Canh, two meteorological stations at Kon Tum city, Pleiku city, and 2 hydrological stations at Kon Tum and Kon Plong district in the basin as shown in Figure 2.

3. Data and Methods

3.1 Data collection

SWAT requires meteorological data such as daily precipitation, maximum and minimum air temperature relative humidity, wind speed and solar radiation. Furthermore, spatial datasets including digital elevation model (DEM), land use/land cover and soil maps. Calibration and validation of water discharge simulation use water discharge data. Table 1 shows the sources and types of data collected. The topography map, soil map and land use map in 2010, 2015 in Dak B'la watershed are shown in Figure 3 as input SWAT model.

Table 1: Sources and types of data collected for SWAT simulation.

Data type	Sources
Topography map	Department of Natural Resources and Environment KonTum and Gia Lai provinces
Land use map	Department of Natural Resources and Environment KonTum and Gia Lai provinces (2010, 2015)
Soil map	Department of Natural Resources and KonTum and Gia Lai province
Weather	The National Hydro-Meteorological Centre, Central Higland Vietnam
Water discharge	The National Hydro-Meteorological Centre, Central Higland Vietnam

3.2 Methods

3.2.1 Simulate stream flow using SWAT model

The SWAT model approach was applied to the case study area of Dak B'la watershed. The main steps of the procedure are: watershed delineation, HRU analysis, write input tables and run SWAT as shown in Figure 4. In this study, the 2 climate scenarios were selected: scenario A is the existing climate using the data from 2001 to 2018 and scenario B is the A1B emission scenario for two future periods from 2020 to 2069.

The simulation was run first for the calibration period of 2011 to 2014 using the first year as a warm-up period to stabilize the model. In the last step in the modeling process, the SWAT model was calibrated with 4 years of discharge data from 2018 to 2018. The SWAT model is considered through three statistic parameters includes Nash-Sutcliffe parameter (NSI), percent bias (PBIAS) and the coefficient of determination (R^2). Performance ratings for the three above parameters of this model are considered on different levels due to classification by Moriasi and Arnold, 2007. Using the climate scenario to simulate the water discharge up to 2069. The SWAT model approach in the DakBla river basin is described as shown in Figure 5.

3.2.2 Assessing the impacts of climate variability

Based on downscaled General Circulation Models, regional projections of climate change, SEA-START-AR4 (2009) developed climate change scenarios such as the A1B and A2 emission scenarios for the future period from 2020 to 2069. The A1B scenario is selected in this study because they are simulated by most GCMs in SEASTART-AR4 and our study focuses on midcentury change, in which period A1B exhibit similar greenhouse gases (GHG) emission forcing. The two climate scenarios were selected in this investigation: scenario A is an existing climate using the data from 2001 to 2018 and scenario B is the A1B emission scenario for the future period from 2020 to 2069.

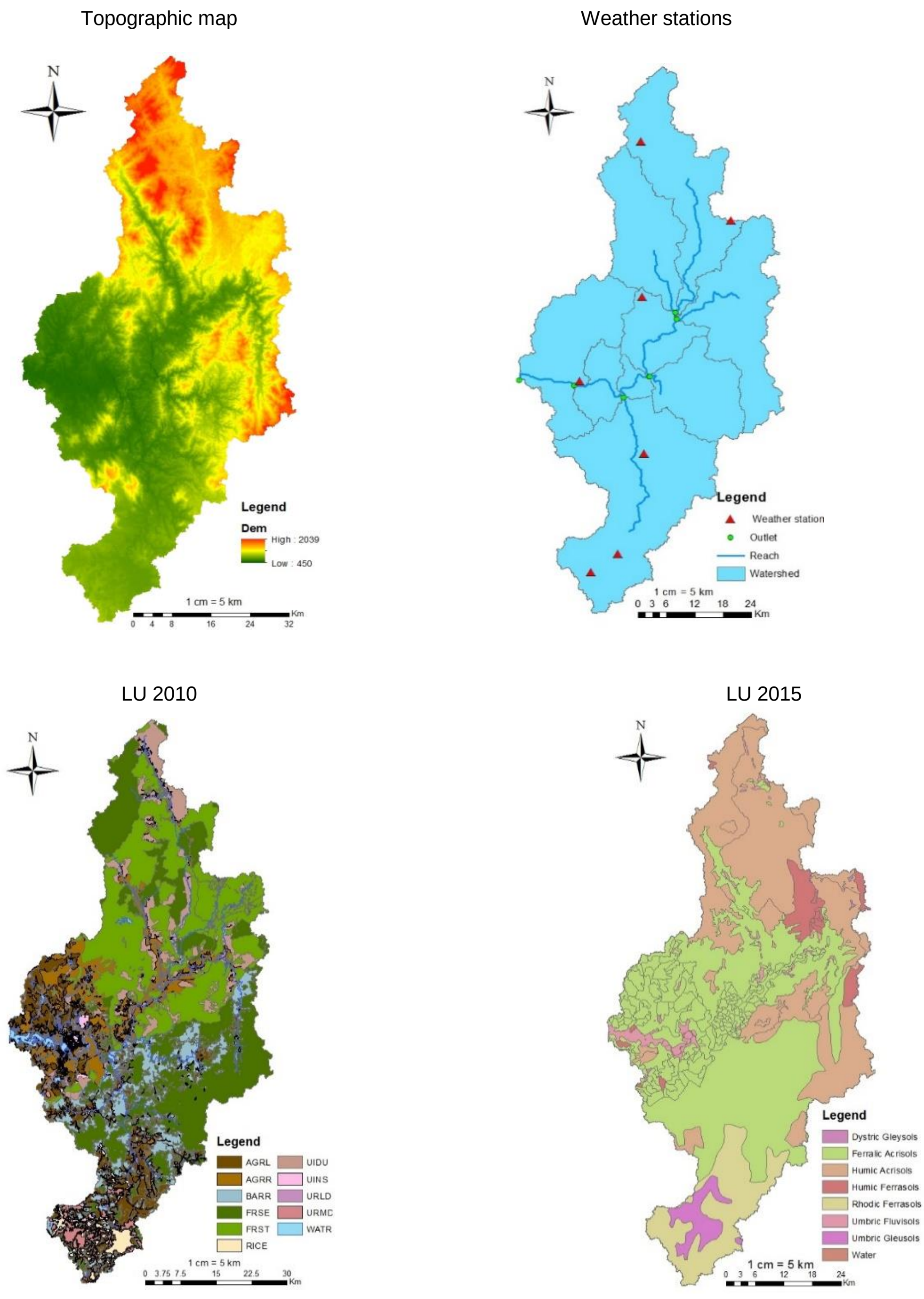

Figure 3: Input data of SWAT model.

GCMs accurately represent climate on a global scale. Using the delta change method (Diaz-Nieto and Wilby, 2005) is in order to apply GCMs on a regional scale and create future climate scenarios for local hydrological impact assessment. This method has been widely used in previous climate change studies. In essence, it modifies the observed historical time series by adding the difference between the future and the baseline periods as simulated by a GCM. The monthly differences between the future and reference periods calculated due to temperature (maximum and minimum) and precipitation over the region covering at least one grid point, depending on the resolution of each GCM. Regional differences obtained with more grid points give more physically representative results than a value calculated with just one grid point (Boyer et al., 2010). There are differences to add the observed daily maximum and minimum temperature during the baseline period while the ratio is applied to precipitation.

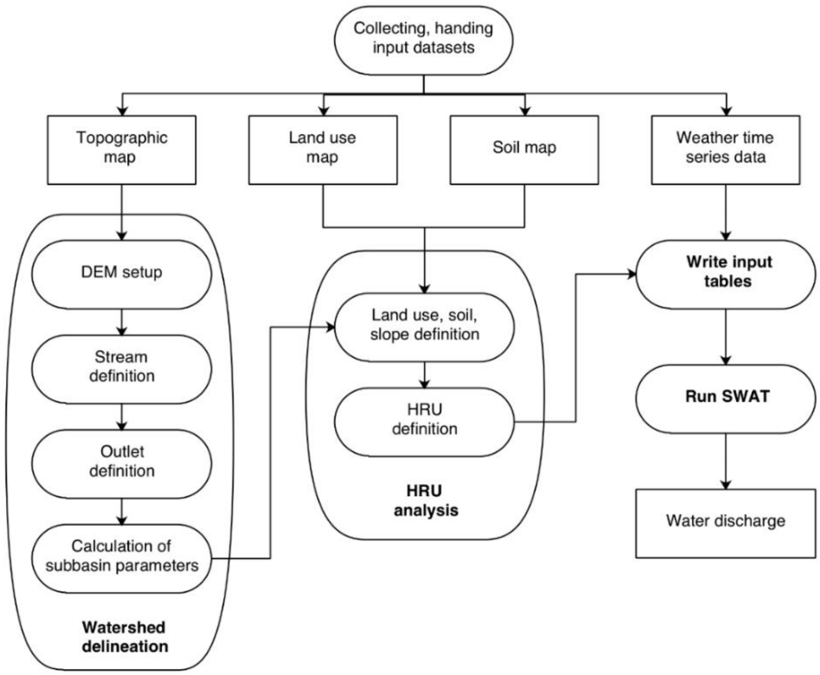

Figure 4: Flow chart of modeling stream flow in Dak B'la watershed.

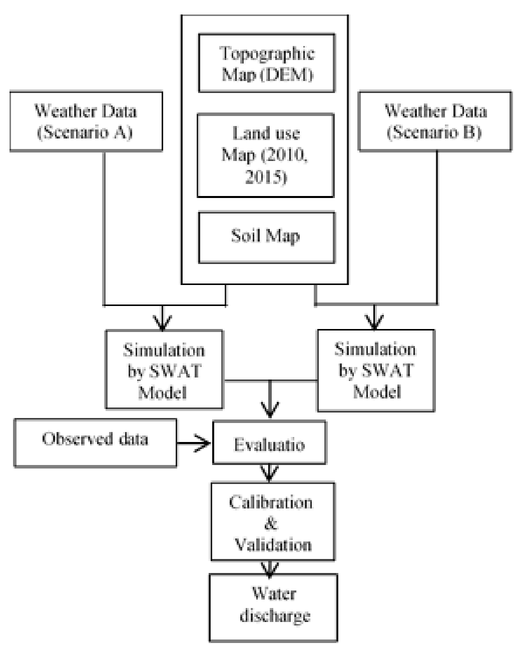

Figure 5: The SWAT model approach in the DakBla river basin.

4. Results and Discussion

4.1 SWAT Calibration and Validation in Dak B'la watershed using water discharge

Input data for the SWAT model in the base scenario include topographic map, land use map (2015), soil map, and climate scenario (scenario A) with weather data from 2011 to 2018. In order to improve the accuracy of the model for the Dak Bla watershed, conducting to calibrate the model is necessary. The calibration period was set during a period from 2011 to 2014 using the SUFI2 algorithm in the SWAT-CUP tool. Sensitivity parameters related to soil physical properties is adjusted such as CN2 (Moisture condition II curve number), ALPHA_BF (Baseflow recession constant), GW_DELAY (Delay time for aquifer recharge), GWQMN (Threshold water level in the shallow aquifer for base flow). The result after adjustment gives the optimal set of parameters with the set value as shown in Table 2. Using the optimal parameters taken from the model calibration, the simulation of water discharge in the watershed is conducted in the next period from 2015 to 2018 to validate the model. The SWAT calibration and validation are shown in Figure 6 and Table 3.

The coefficient of determination (R^2) and the Nash-Sutcliffe index (NSI), and Percent BIAS (PBIAS) during the calibration process was 0.75, 0.72, and -1.15 respectively as shown in Figure 6 and Table 3. The PBIAS was -1.15 which indicates a slight underestimation of the simulated values. The model performance was evaluated over the 4-year validation period (2015 – 2018) following the calibration. The statistical indices showed that the model performance was as good as for the validation period with R^2 = 0.82, NSI = 0.83, PBIAS = 3.67. It proved the high reliability of the SWAT model after calibration. The difference between the simulated and observed results during the flood season (especially in September) is shown in Figure 6, the simulation value is smaller than the monitoring value.

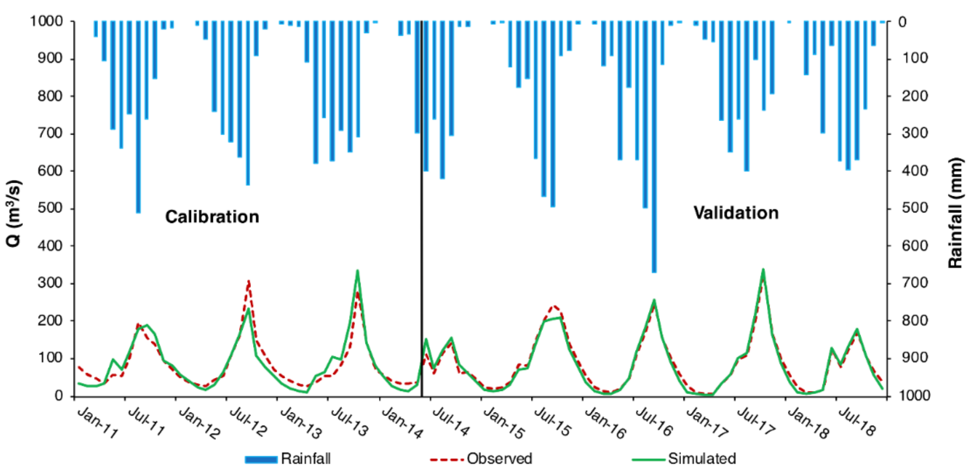

Figure 6: Water discharge in Dak Bla river basin in calibration and validation period.

4.2 Climate change scenario

Scenario A based on existing climate from 2001 to 2018 and scenario B is the A1B emission scenario for the future period from 2020 to 2069, both scenarios were utilized as SWAT input for the simulation results of the flow in the Dak Bla watershed in the period 2001 to 2019 and 2020 to 2069 are shown in Figure 7, Figure 8.

Based on simulated water discharge using the Scenario B found that the discharge in the dry season in the scenario B is higher than in Scenario A and vice versa the rainy season flows lower than Scenario A. This may be explained that water discharge is greatly affected by rainfall. In Scenario B (Climate change scenario), the rainfall tends to be evenly distributed throughout the year so flows increased in the dry season and decreased in the rainy season compared to Scenario A. There will be many years of low water discharge causing the most serious water shortage in the dry season as in the year 2028, 2030, 2037, 2038, 2039, 2040 with the monthly average discharge is about 150 m^3/s. Besides, there will occur the discharge such as 2024, 2046, 2050 with approximately higher 400 m^3/s. Especially in 2050, the water discharge in the flood season (in November) is 584 m^3/s, which higher than the largest flood in 2009 of 450 m^3/s. For surface water, the height of average monthly surface water changes but this change is not much as shown in Figure 9. In the period of 2001-2018, the largest amount of water was reached in September. In the period of 2020-2069, the surface water height tends to change towards the end of the year (in November). In the period of 2020-2069, this tendency is to be more stable, meaning that the amount of water will increase in the dry season and decrease in the flood season.

Table 2. Sensitive parameters and calibration values.

Parameters	Description	Calibration value		
		Appropriate value	Minimum value	Maximum value
CN2	Moisture condition II curve number	-0.16	-0.20	0.20
ALPHA_BF	Baseflow recession constant	0.10	0.00	1.00
GW_DELAY	Groundwater delay time	324.00	30.00	450.00
GWQMN	Threshold water level in shallow aquifer for base flow	0.20	0.00	2.00

Table 3: Statistical indices of SWAT model at Thanh My stream gauge in the VGTB river basin.

Period \ Index	R^2	NSI	PBIAS
Calibration (1995-2004)	0.75	0.72	-1.15
Validation (2005-2014)	0.82	0.83	3.67

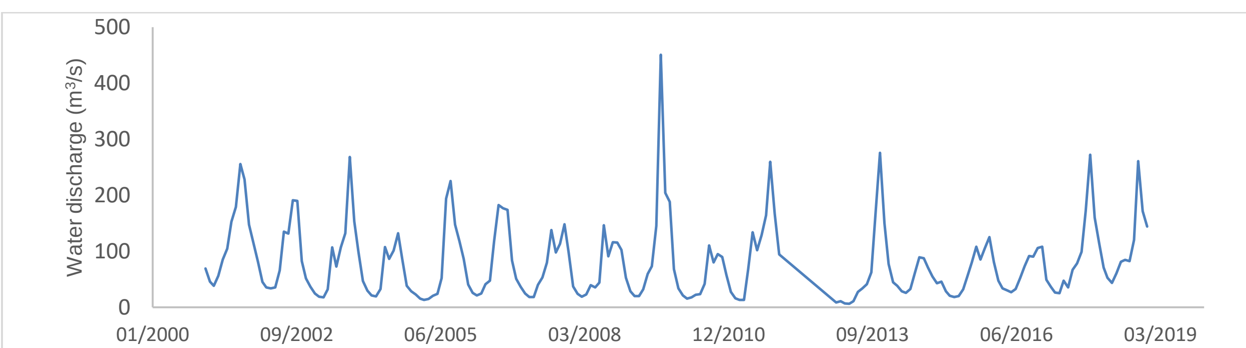

Figure 7: Water discharge in Dak Bla river basin in the period 2001 – 2018 with existing climate data (scenario A).

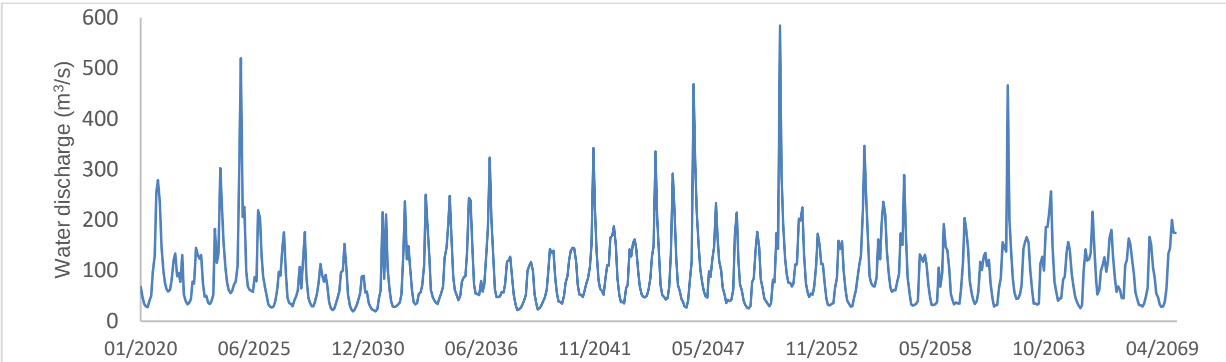

Figure 8: Water discharge in Dak Bla river basin in the period 2020 – 2069 with climate.

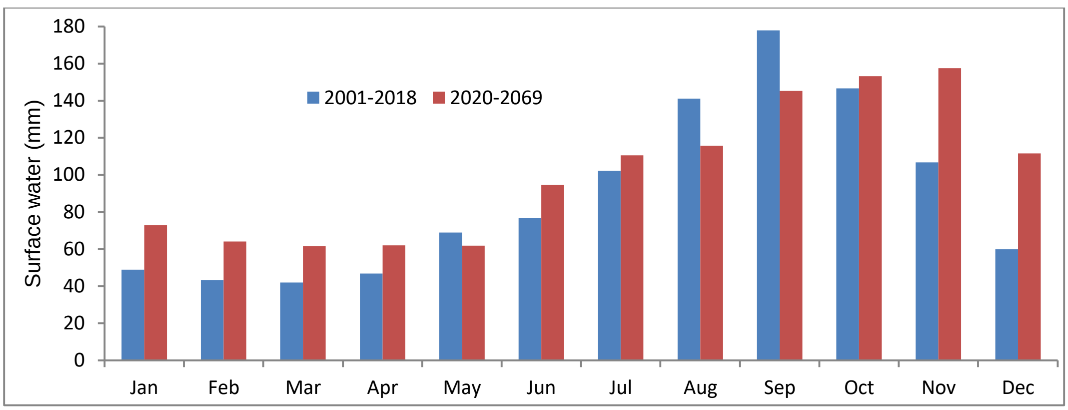

Figure 9. The height of monthly average surface water in Dak Bla river basin.

5. Conclusions

Through this study, using SUFI2 algorithm in the SWAT-CUP to determine an approriate sensitivity parameters CN2, ALPHA_BF, GW_DELAY, and GWQMN was -0.16, 0.10, 324.00, 0.20 respectively. The result after adjustment gives the optimal set of parameters with the set value. The results of the calibration and validation period of the model gave the optimal parameters to assess the impact of climate change on water discharge up to 2069. Moreover, besides some negative impacts on the water discharge such as erratic changes of flow, drought, or flood phenomena, there are also positive effects like more regulating flow among many months of the year.

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