Application of SWAT Model to Simulate Catchment Flows for Assessing Climate Change Impacts on Hydropower in Dak Nong Province, Vietnam

Ho Quoc Bang[1,*], Nguyen Hong Quan[1], Vo Le Phu[2]

[1] Institute for Environment and Resources (IER), VNU-HCM, Vietnam
[2] Ho Chi Minh City University of Technology, VNU-HCMC, Vietnam
(*) Corresponding author: bangquoc@yahoo.com

ABSTRACT

According to the Fourth Assessment Report – AR4 in 2007 of the Intergovernmental Panel on Climate Change (IPCC), climate change is a complex problem and becoming the leading challenge for humankind in the 21st century. Therefore, assessing climate change impacts on the social, economic activities and proposed solutions to respond to climate change is urgent and necessary. This study applied the SWAT model (Soil and Water Assessment Tool) to simulate catchment flows due to the impact of climate change. The models were applied for several catchments in and around Dak Nong province. The results of catchment flows can be useful information for many purposes, such as: flood forecasting, predicting sediment loads and impact assessment of climate change on water resource and hydropower. In this study, the issues of hydropower safety and electricity generation capacity in Dak Nong up the year of 2020 are focused. The results of SWAT model show some certain changes in catchment flows due to climate change, for example, the maximum streamflow in the upper part of Serepok River in 2020 is higher than in 2005-2010 period about 16.8%. The results also showed that the hydropower dams' safety in Dak Nong province is secured given the climate change scenarios. In addition, given the changes in catchment flows due to climate change the hydroelectric ouput of Dak Nong in 2020 are only 7,063 million kWh/year, which is less than about 12% in comparison to the expected production)

Keywords: Climate Change, SWAT model, hydropower safety, production, Dak Nong

1. INTRODUCTION

According to the IPCC's Fourth Assessment Report (AR4) , climate change is a complex problem and becoming the leading challenge for humankind in the 21st century (IPCC, 2007). Many studies showed that climate change is mainly caused by the emission of greenhouse gases (mainly CO_2 and CH_4). Especially since 1950, the rapid growth of urbanization and industrialization had led to an acceleration of human consumption and an increase in emissions. One of the biggest industries greenhouse gas emissions is electricity production, which occupies about 50% of global CO_2 emissions (Lansiti., 1989). Because electrical industry emits a large amount of greenhouse gases, therefore the energy sector has to cut greenhouse gas emissions for mitigation of climate change. Many solutions have been given to the energy sector, such as: using other fuels to produces less CO_2, using modern energy efficient alternatives or increasing use of renewable energy sources. Among the alternative power production in thermal power, hydropower is an attractive option because hydropower is a form of renewable energy, less greenhouse gas emissions and hydropower infrastructures have a long lifetime. Therefore, in recently years, although the construction of large-scale hydropower dams have displaced people and caused ecological impacts on the basin, governments in most countries have still continued to construct more hydropower plants beause of playing an important role in development of economy, especially in developing countries and less developing countries.

It is estimated that there will have 69 hydropower projects in Dak Nong province, Viet Nam by 2015. According to the Dak Nong industry and trade department, there were 37 hydroelectric projects (including 25 small-scale and 12 large-scale hydropower facilities) have been investing and operating in 2010 with a total capacity of 1905.96 MW. However, the massive hydroelectric development in recent years can be affected by climate change in the future. The change of water flow is likely one of the potential impacts in the age of human-induced climate change. Hence, for mitigating the impact of climate change on hydropower systems in Dak Nong, this paper presents an application of SWAT (**S**oil and **W**ater **A**ssessment **T**ool) model to simulate catchment flows, then results of the model are used for assessing climate change impacts on hydropower in Dak Nong province.

2. STUDY LOCATION, DATA AND METHODS

2.1 Study Location

Dak Nong is located in the southern part of Vietnam's Central Highland region (Fig.1). Dak Nong borders with Dak Lak in the north, Lam Dong in the south-east, Binh Phuoc and Cambodia in the west. Its elevation is about 500m above sea level. The terrain is lower in the west. Dak Nong coordinates at 11^{o}45' - 12^{o}50' northern latitude and 107^{o}13' - 108^{o}10' eastern longitude.

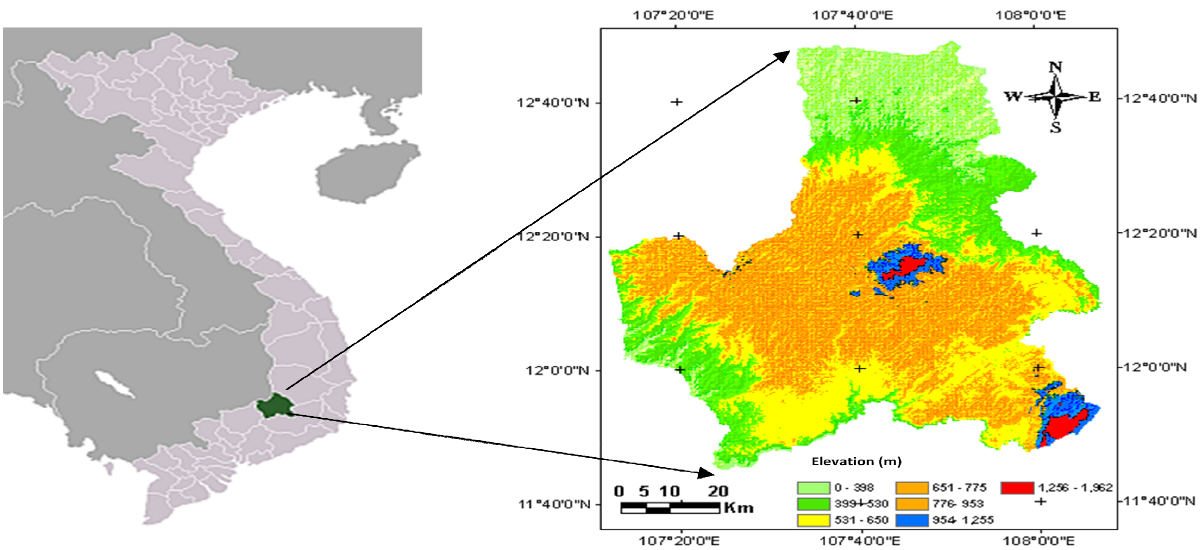

Figure 1. Location of Dak Nong province in Vietnam (left) and Its topography (right)

The province's climate condition is influenced by the climate of eastern and western of Truong Son moutain range. It is characterized by less directly affected by storm, high temperatures and solar radiations. The average annual temperature is about 21÷ 24^{o}C. Total yearly hours reaches 2,200 ÷ 2,400 hours/year. Total amount of radiation is 233 ÷ 240

Kcalo/cm^2. Annual evaporation, relative humidity and rainfall are abour 1,000 ÷ 1,400 mm, 81 ÷ 85% and 1,600 ÷ 2,500 mm respectively (Phuoc and Bang., 2011).

Dak Nong has two main river basins, including: Serepok and DongNai rivers. Almost area of the province is in the Serepok river basin and the remaining part is the DongNai river basin. The Serepok river has two major tributarties which are KrongNo and KrongAna rivers. The total area of KrongNo river basin is 4,620 km^2 and the main stream is 56 km in length. KrongAna river has a total river basin is 3,200 km^2, and the legnth of the main river section is 215 km. The DongNai river basin covers an area of approximately 2,526 km^2 (Phuoc and Bang., 2011). The stream nerwork in the province is quite complex, thick and many small tributaries. These are favorable conditions to exploit of water resources for agricultural practices, hydropower production and domestic uses.

2.2 Data Collection

Collected data in the catchments are meteorological and hydrological data in many stations in and around Dak Nong (including Cau14 station, GiangSon station, DakMil station, DucXuyen station and Dak Nong station). The collected data are (1) daily evaporation; (2) hourly rainfall; (3) wind direction and speed; (4) hourly temperature; (5) hourly humidity and (6) hourly streamflow.

Land use map is provided by the Dak Nong Department of Natural Resources and Environment, while the topographic map is collected at the Vietnam National Information and Communication Technology Department at 1:25.0000 Scale, which can be used later for generating a Digital Elevation Model (DEM). Climate change variations are up the year of 2030, including: temperature, rainfall, and evaporation from the Vietnam Institute for Meteorology, Hydrology and Environment (IMHEN, 2007).

2.3 Methods

2.3.1 SWAT model

The SWAT model was developed in the early 1990's by the U.S. Department of Agriculture, Agricultural Research Service (USDA–ARS) (Arnold et al., 1998). The model was developed to assess and predict the impact of land management affect on water, sludge, and the amount of chemicals using in agricultural practices on a large and complex basin with unstable factors of soil, landuse and management conditions in a long time. The model includes a set of regression calculations to describe the relationship between the input and output parameters. The SWAT model integrates many different models of ARS, which are developed from model for Simulator for Water Resources in Rural basins (SWRRB) (Williams et al., 1985; Arnold et al., 1990). Specific models that contributed significantly to the development of SWAT model were: (i) Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980); (ii) Groundwater Loading Effects on Agricultural Management Systems (GLEAMS) (Leonard et al., 1987); (iii) and Erosion-Productivity Impact Calculator (EPIC) (Williams et al., 1984). Many applications of SWAT model for assessing water resources have documented, they are: Van Liew and Garbrecht (2003) used the SWAT model to predict streamflow under varying climatic conditions for three nested watersheds in Little Washita River Experimental Watershed in Oklahoma. Chu and Shirmohammadi (2004) applied SWAT model for the calculation of surface flow for a small watershed in Maryland. Spruill and others (2000) used SWAT model to determine daily streamflow for a small karst-influenced watershed in central Kentucky during the period of 2-years, etc.

2.3.2 SWAT's application in Dak Nong province

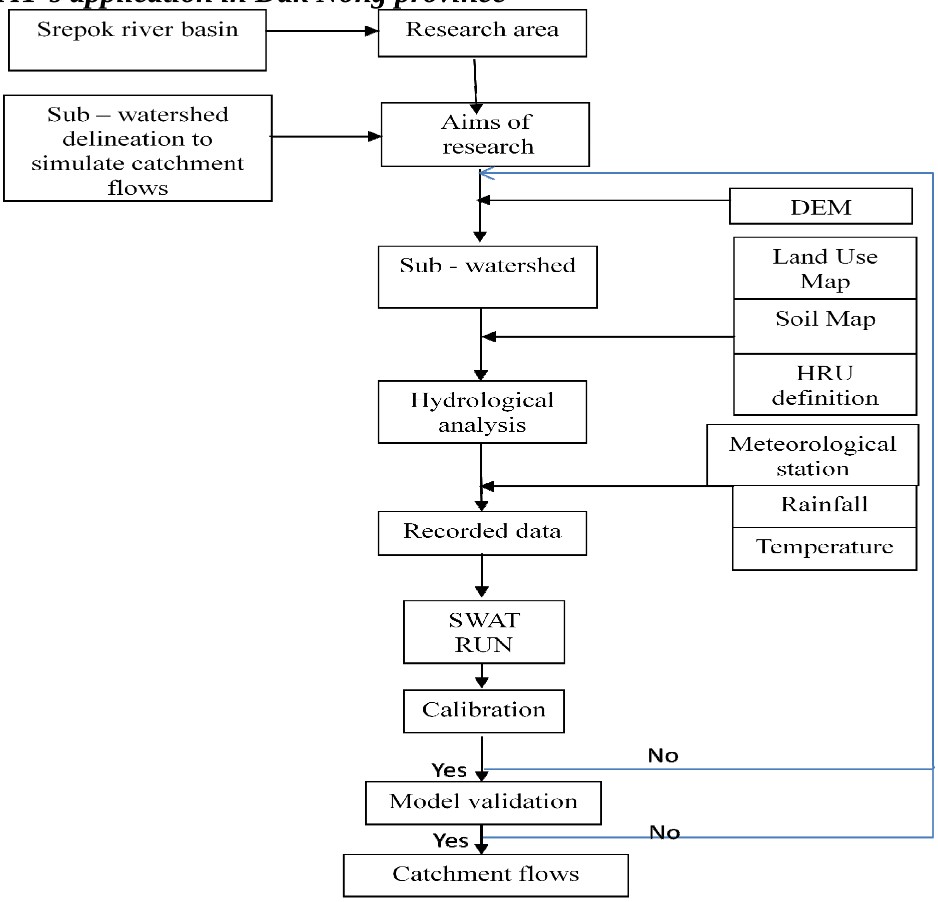

Figure 2. Application of SWAT in Dak Nong province (HRU is Hydrologic Response Unit)

2.3.3 *Model calibration and validation*

The SWAT model was calibrated by using SWAT-CUP software. Several statistical approaches can be used to check SWAT model performance such as: coefficient of determination (R2), Nash-Suttcliffe Simulation Efficiency (NSE) (Nash and Suttcliffe, 1970), mean absolute error (MAE), Root Mean Square Error (RMSE), and Theil's inequality coefficient (U). In this paper, the Nash-Suttcliffe simulation efficiency was used. The statistic results of the average NSE between simulations and measurements for model calibration and validation are 0.86, 0.89, 0.84 for Dak Nong station, DucXuyen station and Cau14 station, respectively. These NSE values are almost higher than 0.7, therefore the model and the parameters can be used to simulate catchment flows in the province under climate change scenarios.

3. RESULTS AND DISCUSSIONS

3.1 Results of streamflow

The continous of monthly stramflow up 2030 at the Cau 14 station and some statistical numbers of streamflow of four catchments in Dak Nong province are shown in Fig. 3 and Table 1.

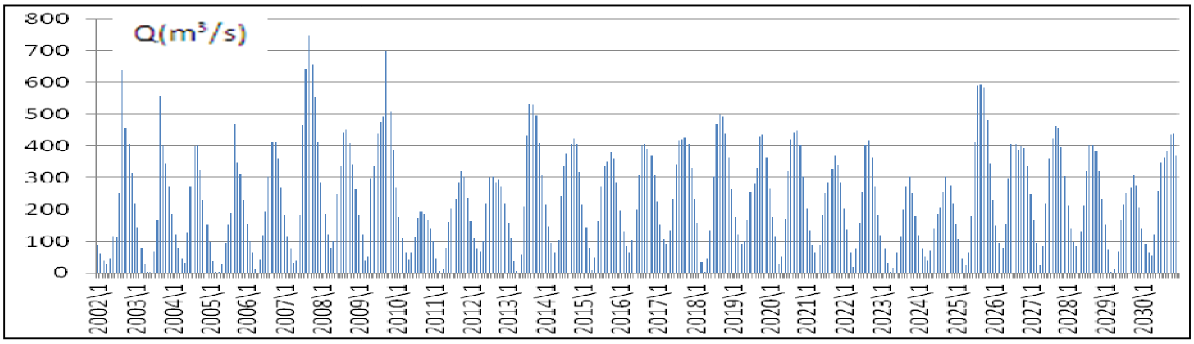

Figure 3. Predicted monthly streamflow in 2030 at the Cau14 station, Dak Nong

Table 1: Streamflow in 2005-2010, 2015 and 2020 at 4 catchments (m^3/s)

Streamflow	Serepok	KrongNo	DongNai's main stream	Dak Nong station
2005-2010				
Maximum	2210	1290	2600	147
Average	272	87.4	1110	18.2
Minimum	16.4	0.9	215	1.3
2015				
Maximum	1789.7	1263.5	1647.7	93.2
Average	220.3	85.6	703.4	11.5
Minimum	13.3	0.9	136.3	0.8
2020				
Maximum	2120.8	1507.2	2050.7	115.9
Average	261	102.2	875.5	14.4
Minimum	15.7	1.1	169.6	1

3.3 Assessing Climate Change Impacts on Hydropower

3.3.1 *Climate change impacts on hydropower safety*

Climate change likely leads to increased intensity of floods and the flood peak. In some extreme cases, the hydropower plant has to discharge to ensure the safety of hydropower dams in the flood season. Streamflows and flash flood levels are the parameters used to assess the impact of climate change on the safety of hydropowers (Thang et al., 2010). Thus, the changes of streamflows due to climate change from SWAT model simulations and the design flash flood flows of each hydropower are used to assess the impact climate change on the hydropower safety. The results show that the design flash flood flows of 37 hydropowers in Dak Nong are higher than the maximum level of streamflows in Dak Nong's catchments, although the maximum level of streamflows in some river of Dak Nong's catchements in 2020 are higher than 2005-2010 period. Such as: the maximum level of streamflows in Krong No river is 1507.2 m^3/s in 2020, while the maximum level of streamflows in 2005-2010 period is only 1290.0 m^3/s (Table 1). Therefore, the hydropower dams' safety in the province is secured given the climate change scenarios.

3.3.2 *Climate change assessment impacts on electricity generation capacity*

Climate change refers to any significant change in climate factors, including precipiration, temperature, storm patterns and intensity, etc.. The decrease of precipitation or increase of temperature will likely result in drought events. Drought and reducing streamflow lead to the reduction of hydropower supply (Cherry et al., 2010). Therefore, the change of streamflows from SWAT model simulations due to climate change and the expected streamflows for generating maximum electicity are used to assess the impact of climate change on electricity generation capacity in Dak Nong province. The results showed that the hydroelectric output in 2010 is about 5,450 million kWh/year. It is expected that the hydropowers are not affected by reduced streamflow due to climate change, in 2020 the hydroelectric output will reach to 8,072 million kWh/year. However, the hydroelectric ouput of Dak Nong in 2020 is only 7,063 million kWh/year. However, production tends to decrease as it is less than about 12% in comparison with the proposed production) due to the impact of human-induced climate change.

4. CONCLUSION

The results of SWAT model show some certain changes of catchment flows due to climate change, for example, the maximum streamflow in the upper part of the Serepok river in 2020 is higher than in 2005-2010 period about 16.8%. It also shows that the hydropower dams' safety in Dak Nong province is secured given the climate change scenarios. In addition, given the changes of catchment flows, in 2020 the hydroelectric output will reach 7,063 million kWh/year (less than about 12% in comparison with the expected production).

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