APPLICATION OF SWAT MODEL TO ASSESS THE IMPACT OF CLIMATE CHANGE ON SREPOK RIVER BASIN FLOW, DAK LAK PROVINCE, VIETNAM

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SUMMARY: Srepok River is the largest river in the river system in Dak Lak. It is not only an important tributary of the Mekong River but also a river-basin which plays an crucial role in the socio-economic development of Dak Lak province in terms of agriculture, hydropower, water supply for the living activities in the lower areas. The fast-delevoping pace in our country results in the higher demand in energy. Therefore, a series of hydroelectric power plants are built up in the Srepok river. The climate change has had clear impacts on the river basin in recent years. Hence, the application of modelling is a new approach to solve and predict potential problems occuring in the environmental field due to the climate change. Model SWAT (Soil and Water Accessment Tool) is applied to assess the impacts of land use and climate on the stream flow in the Srepok river basin, to provide information for the management strategies and for the Drang Phok's project planning, which will potentially contribute to the sustainable development strategy in the region. In our research, input data for the model SWAT (including DEM map, soil map, land use map and climatic condition of the river-basin) were taken from 2010 to 2012. fter calibrating and validating the model based on the real values of streamflow, the NSI indexes of three hydrological stations including Ban Don, Bridge 14 and Duc Xuyen at calibration step were 0.9424; 0.8953; 0.6458 and R^2 were 0.9548; 0,9569; 0.8267, respectively. At the validation step, the NSI indexes were 0.775; 0.7994; 0.6338 and R^2 were 0.8142; 0.8014; 0.7639 respectively. The results proved that SWAT model can be applied to assess the changes in stream flow in Srepok river-basin in the future, under the impact of climate change and land use changes.

1. INTRODUCTION

As Vietnam is emerging into the industrialization and modernization century, energy sector is required an intensive investment, as strong energy sector will underpin the development of other industrie. As a result, there are many hydroelelectric power plant were born including Drang Phok station, which is currently undergoing its the environmental evaluation. It is the 9th hydroelelectric power plants, and is built at the end of Srepok river (**Figure 1**).

LOCATION OF HYDROPOWER PLANTS ON SREPOK RIVER

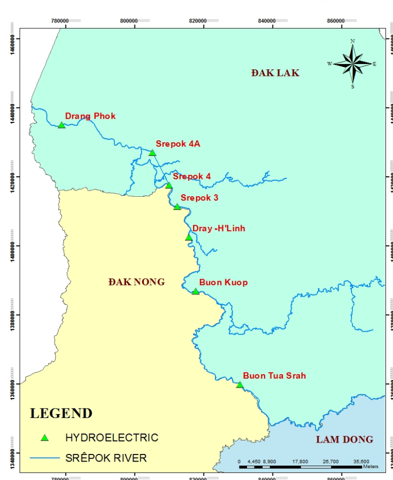

Figure 1. Location of hydropower plants on Srepok river

It is crucial to invest in Drang Phok hydroelectric power plant, as it not only to meet the current increasing demand on energy but also to contribute tax payment to the national budget. Looking at the social impacts, the project helps to raise literacy rate for local residents, creates beautiful environmental landscapes, which further develop tourism industry and other economic activities, as well as transform from the current agricultural and forestry economy to ango-industry. However, climate change poses many challenges to the hydroelectric industry in the future. Currently, drought in large scale has spreaded over the Central Highlands which seriously affected the flow of water in hydropower reservoirs, output capacities as well as the water level. Typically, hydropower production is directly influenced by three main factors including wind, temperature and rainfall. Temperature accelerates the water evaporation in the reservoir (wind speed also affects the process of evaporation) and the cooling turbine; whereas rain fall affects the flow of stream.

Normally, climate change will not cause serious impacts on power industry. However, if any significant incidents occur, the thermal power industry will encounter extremely dramatic damages. Therefore, it is crucial to apply SWAT model to assess the stream flow of the water supply for Drang Phok hydropower reservoir. It could help support the decision making process or the strategy development. For example, it can help propose water regulation within the local area to manage water level in the hydropower reservoirs, to ensure water sufficiency for agricultural production and living demand, as well as power production.

2. RESEARCH METHOD

SWAT Model (Soil and Water Assessment Tools) is a set of physical models developed by Dr. Jeff Arnold, the Center for Agricultural Research Service, United States Department of Agriculture since the 90s of 20th century. The model was developed to simulate the impact of water and land use management on the river basin over a certain periods of time. SWAT will directly model the physical processes associated with water movement, sedimentation, crop growth, nutrient cycling, ... by using the input data. In SWAT, a watershed will be divided into a number of sub-basins according to the topographical and hydrological networks, then each sub-basin is partitioned into hydrological response units (HRUs) - each HRU is specified by the particular characteristics of soil and land use (**Figure 2**). Among the hydrological models, SWAT is an appropriate choice for modelling the large river-basins, when the measured data are limited [1] .

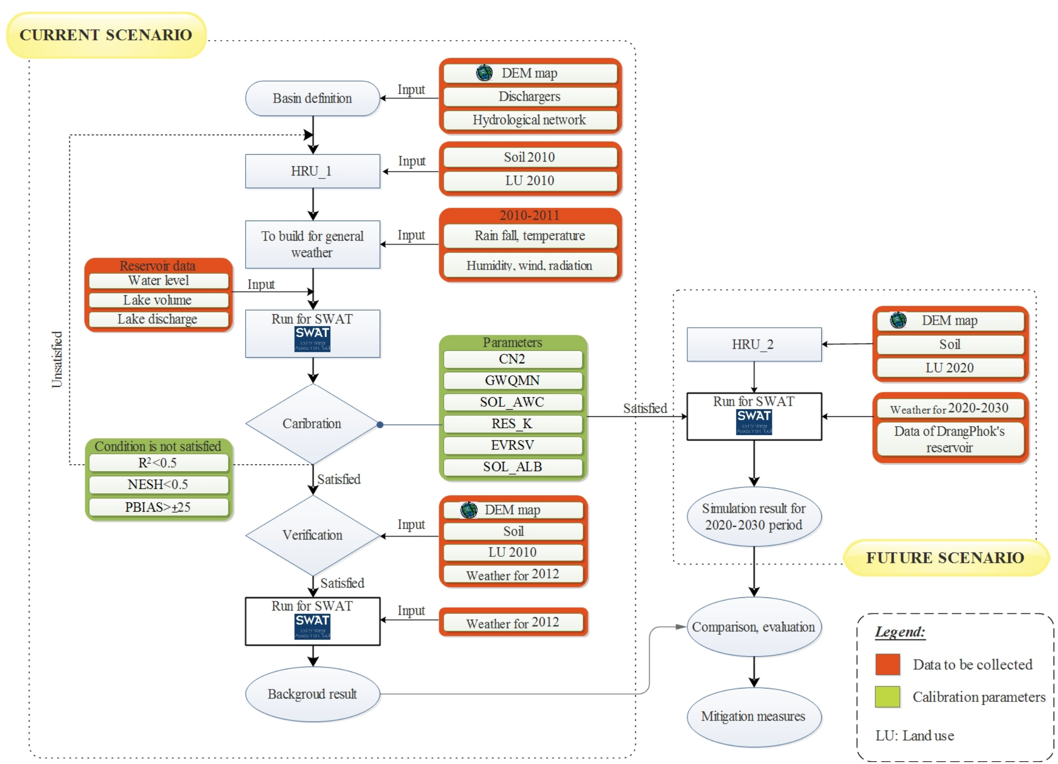

Figure 2. SWAT model operation steps

The hydrologic simulation of the watershed can be divided into 2 phases: Land phase of the hydrologic cycle: Control the inflow of water, sedimentation, nutrients and pesticides to the mainstream of each sub-basin; The routing phase of the hydrologic cycle: This phase is also called computing phase or computing model, it will calculate the components of the process according to water movement, sedimentation, ... that takes place from river-basin to the outlet of river system.

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

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right)$$

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

The efficiency of the hydrological model was assessed by Nash - Sutcliffe coefficient (1970), it is defined as [2]:

$$E_{NS} = 1 - \frac{\sum(Q_{td} - Q_{mp})^2}{\sum(Q_{td} - \overline{Q_{td}})^2}$$

ENS: Nash-Sutliffe efficiency, ENS ≤ 1,0; Q_{td}: Observed discharge at time step (month); Q_{mp}: modeled discharge; $\overline{Q_{td}}$: Observed discharge over the entire simulation period of length.

3 USED DATA

The input data used for SWAT 2012 model were collected from the Department of Environment and Natural Resources in Dak Lak Province, Radio Hydrometeorology of Highlands Region, and from Geographic Information System websites all over the world. Data includes digital elevation model (DEM) map, soil maps, land use maps, slope maps, meteorological and hydrological data and basin reservoirs' information of the chosen basin.

3.1 The input data for the baseline scenario: 2010 - 2012

Data map:

Digital elevation model (DEM) maps of the Srepok river-basin were taken from the website of the USGS http://www.gdex.cr.usgs.gov/NASA with spatial resolution of 30 m. Altitude study area is divided into 8 groups: 75-349 m, 349-510 m, 510-659 m, 659-838 m, 838-1068 m, 1068-1320 m, 1320-1619 m, 1619-2445 m (**Figure 3**). Slope map was derived from the DEM map of the basin. The slope of the Srepok river-basin is divided into 5 groups as follows: 0 to 16.75%; 16.75 to 39.65%; 39.65% above (**Figure 5**). Land use map (**Figure 4**) collected from site: http://www.globallandcover.com, which belongs to The National Geomatics center of China (NGCC). It is the landsat image which has a resolution of 30 m. After processing data, analyzing and encoding the types of land use according to the request of the SWAT model, we obtained a Srepok's land use map with 6 types of land use: AGRL - agricultural land, FRSE - Forest, HAY - hay, URMD - urban area, WETN - non-forested wetland, WATR - water surface. Soil map of the basin (**Figure 6**) was taken from Vietnam ATLAS soil map (2010) in the ArcGIS software format. After editting and encoding different types of soil according to SWAT code table, we got a soil map of the river-basin Srepok with 9 types of soil as (**Figure 6**), they are: Jc29-2-3a-110 – clay, Je31-2-3a-123 – clay, Lc13-1a-127: sandy humus, Lf18-2a-130 – sandy silt loam, Nd11-153 - sandy silt loam, Xh15-2a-305 - clay silt, Xh2-3a-313 - clay soil, Zo16-3a-3327 – silty clay, WATER - water surface.

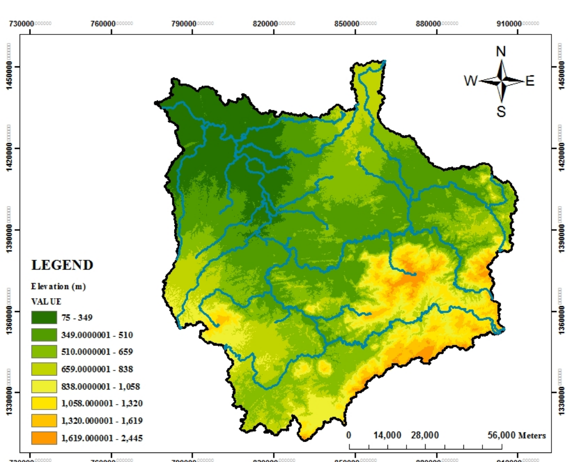

Figure 3. DEM map of Srepok river-basin

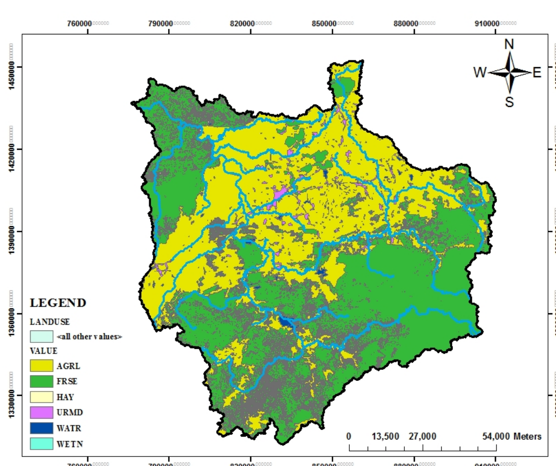

Figure 4. Land use map of Srepok river basin in 2010

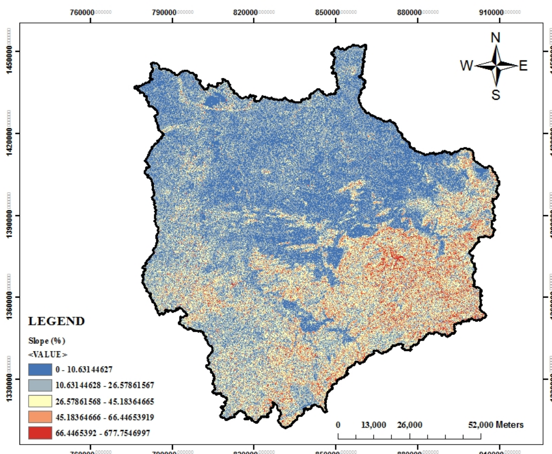

Figure 5. Slope map of Srepok river-basin

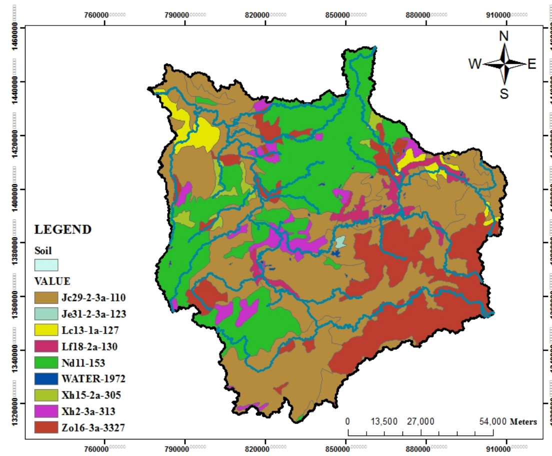

Figure 6. Soil map of Srepok river-basin in 2010

Attribute data:

Hydro-meteorological data at the stations of Srepok river were collected from Hydro-meteorology station in Highlands region. Therefore, collected documents are reliable. Monitoring data obtained from the stations were the original documents used for the hydro-meteorologicala analysis, which may support the Drang Phok hydroelectric power plant planning. Hydrological data collected from 2010 to 2012 at the station Ban Don, Bridge 14, Duc Xuyen by Hydrometeorology Station Highlands was the average monthly discharge value. It is used to calibrate and validate the model. The calibration stage was from 2010 to 2011 and the validation stage was from 2011 to 2012.

Table 1. Coordinates of Hydrological stations

Numerical order	Hydrological station name	Coordinates X	Coordinates Y
1	Ban Don	801941	1427269
2	Bridge 14	818156	1396617
3	Duc Xuyen	824530	1361539

Meteorological data from 2010 to 2012 at the stations including Buon Me Thuot, Buon Ho, Dakmin, Eakmat, Lak were collected from Highlands Hydrometeorology Station, which consists of Air temperature (Max, min); Wind speed; Radiation; Humidity; Rainfall.

Table 2. Coordinates of Meteorological stations

Numerical order	Meteorology station name	Coordinate X	Coordinate Y
1	Buon Me Thuot	12.67	108.05
2	Buon Ho	12.92	108.27
3	Đakmin	12.43	107.6
4	Eamat	12.67	108.12
5	Lak	12.4	108.18

3.2 Input data for climate change scenarios

Map data:

DEM maps, soil maps of the basic scenario are reused. Hydraulic system maps are digitized by ArcMap 10.1 (supplement a canal of water from the Srepok 4A) as shown in (**Figure 7**). Land use map is integrated with the hydroelectric power plants planning map at the surveyed river-basin.

Figure **8**) has shown the land use map of the river basin Srepok, with 7 types of land use: AGRL - Agricultural land, FRSE - forest, HAY - Hay, URMD -urban area, WETN - non-forested wetland, UIDU - industrial Area, WATR - water surface.

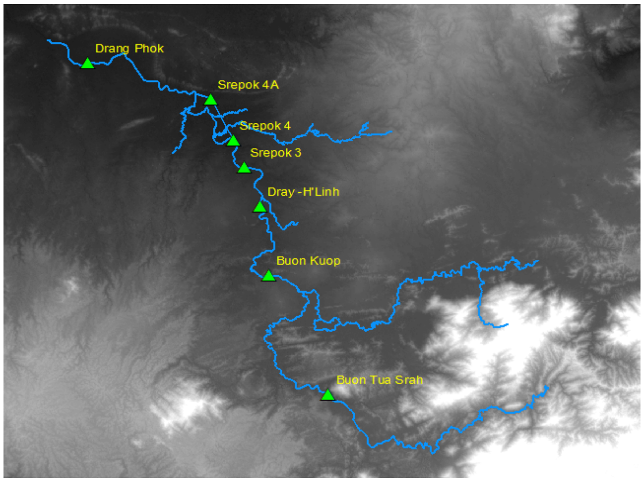

Figure 7. The map of the digitized main tributary river

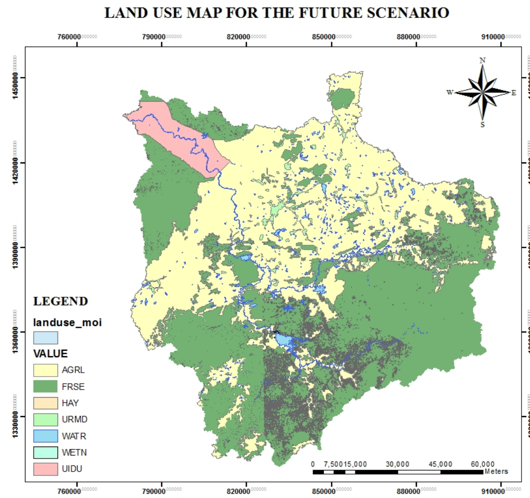

Figure 8. Land use map for the future scenario

Attribute data: Reservoirs data of hydroelectric plants were built between 2010 and 2012 within the Srepok river basin, including: Dray H'linh, Commercial Kuop, Srepok 3, Srepok 4, Buon Tua Srah. Additional data contains 2 hydropower plants named Srepok 4A and Drang Phok.

Meteorological data: Due to the lack of statistics on meteorology in the Srepok river basin, data used in this study have been collected from 17 meteorological stations in the years of 1980-1999 at the global weather data website: http://globalweather.tamu.edu/.

3.3 WebGIS Solution

Climate change scenario: This study has inherited climate change scenario B2 from "Scenario of climate change and sea level rise for Vietnam" in 2012 by the Ministry of Natural Resources and Environment as shown in **Figure 9**. Data on the changes of temperature and rainfall in B2 scenario are shown in **Table 3**.

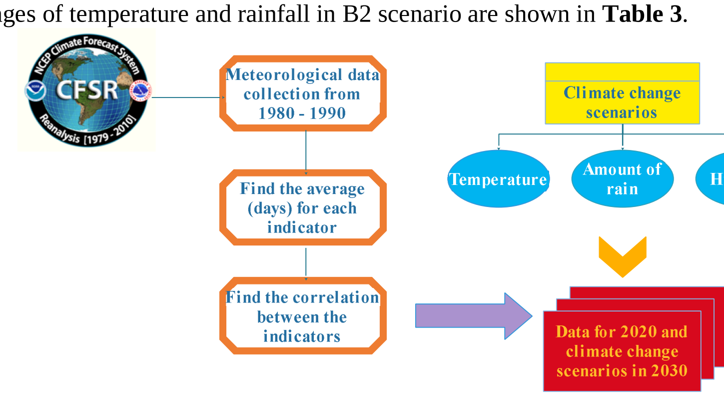

Figure 9. The process of building set of meteorological data for climate change scenario in 2020 and 2030

Table 3. The change in temperature (^oC), the annual rainfall(%) compared to the period 1980-1999 according to the average emissions scenario (B2)

Temperature (^oC)			
Numerical order	Provinces	The timeline of the 21st century	
		2020	**2030**
1	Đak Lak	0.5	0.7
Rainfall (%)			

1	Đak Lak	0.5	0.7

To calculate the average scenario, -1.5% is the average value that we used to calculate the humidity for two years 2020 and 2030.

3. 4. Develop scripts to run model

This paper will apply the SWAT model for 3 scenarios as follows:
Scenario 1: This is a current condition scenario associated with the input data for the model including **Figure 3**, **Figure 4**, **Figure 5**, **Figure 6**, the meteorological data in **Table 2** and the hydrological data in the years of 2010 - 2012. This scenario is to assess the appropriateness between simulated results and real values. From which, calibration and validation can be used to find the appropriate parameters for the flow simulation of Srepok river basin in the future.
Scenario 2: Inputs for this scenario includes spatial data and meteorological data. Spatial data consists of maps used in Scenario 1 and replace the hydraulic system with the reservoir data of Srepok 4A hydroelectric power plant. Meteorological data uses data in the medium climate change scenario (B2). Scenario 2 is to evaluate the impact of climate change on the stream flow in the Srepok river-basin in the future (2020 and 2030), in the absence of the hydropower plant, Drang Phok.
Scenario 3: Input data for this scenario is as following: Spatial data consists of maps used in Scenario 1, and replace the land use map (**Figure 8**), hydraulic system, the reservoir data of Srepok 4A and Drang Phok hydroelectric power plant. Meteorological data used data in medium climate change scenarios (B2). Scenario 3 is to assess the impact of climate change on streamflow of the Srepok river-basin in the future (2020 and 2030), in case of Drang Phok hydroelectric power plant is built.

4 RESULTS AND DISCUSSION

4.1 Demarcation of the river-basin boundary

SWAT 2012 model running on 10.1 ArcMap is used to divide the Srepok river-basin into 21 sub-basins and 21 hydrological response units (HRU), the entire catchment is 1166346,6 ha.

4.2 Evolution flow Srepok river basin in scenario 1

After analyzing the hydrological units, SWAT input files are intergrated with the meteorological data from 2010 to 2012 at the stations as shown in **Table 2**, especially, 2010 data was used to "warm-up" model (which means that it was just used to run the model, not for the results). The stream flow results at the hydrological stations simulated by SWAT in the years of 2010 - 2012 will be used to calibrate and validate the model. After running the model, we found that the simulation results are different from the real values. Therefore, to achieve the appropriate simulation model, we have calibrated parameters based on our experience and research literature from different source of reference. After calibrating and comparing the real values with the simulated values of the streamflow, the NSI index of the stations Don, Bridge 14 and Duc Xuyen from 2010 to 2011 is collected as 0.9424; 0.8953 and 0.6458, respectively, R2 is 0.9548; 0.9569; 0.8267. Thus, the results of calibration model were acceptable.

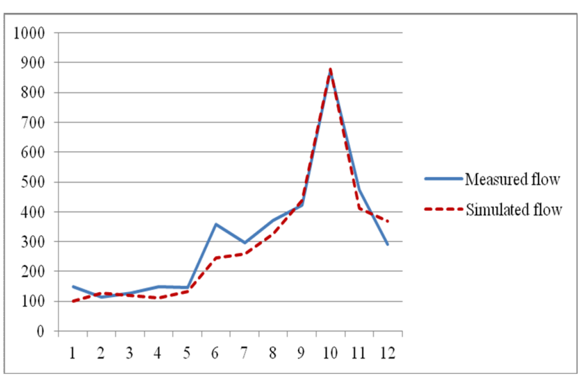

Figure 10. Graph comparing simulated results and measured results at Ban Don station in 2011 (Unit: m^3/s)

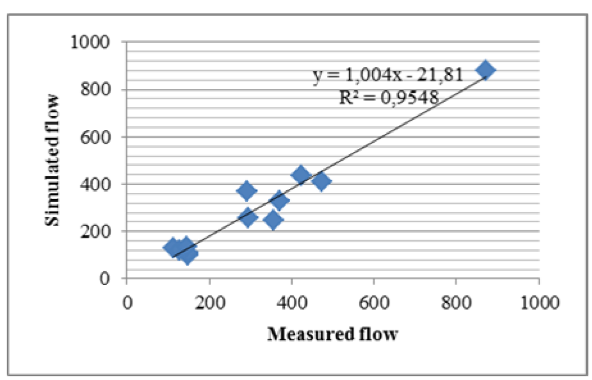

Figure 11. The correlation between the simulated results with measured results Ban Don station 14, 2011 (Unit: m^3/s)

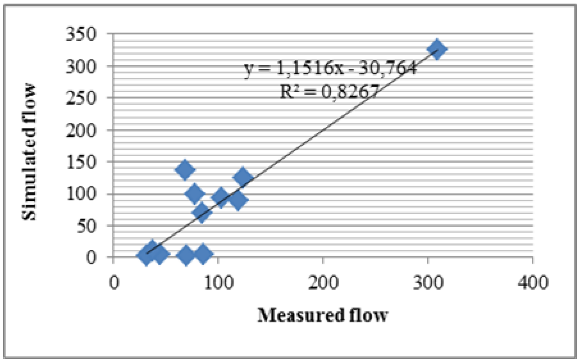

Figure 12. The correlation between simulated results and measured results at Duc Xuyen station in 2011 (Unit: m^3/s)

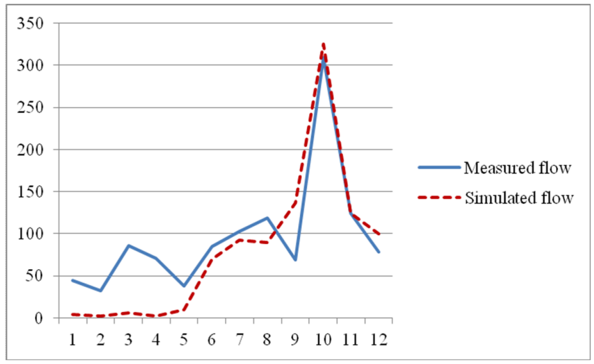

Figure 13. Graph comparing simulated results with measured results at Duc Xuyen station in 2011 (Unit: m^3/s)

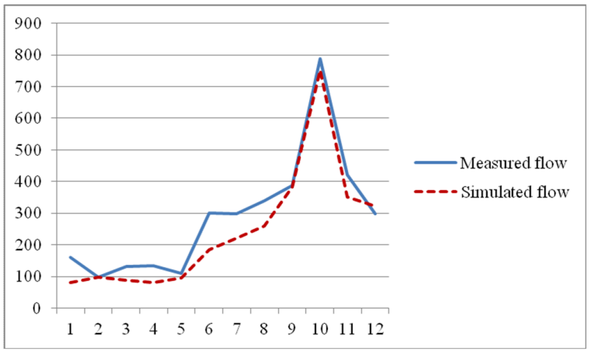

Figure 14. Graph comparing simulated results with measured results at Bridge 14 station, 2011 (Unit: m^3/s)

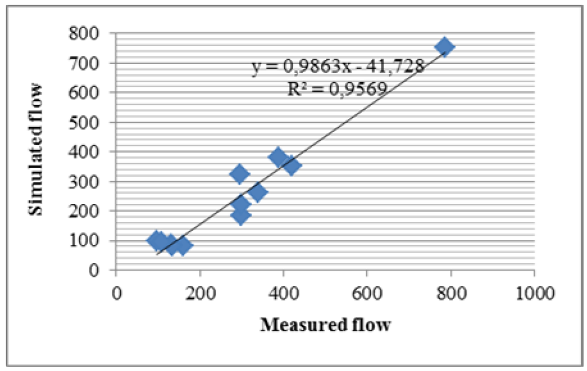

Figure 15. The correlation between the simulated results with measured results at Bridge 14 station in 2011 (Unit: m^3/s)

To evaluate the effectiveness of the calibration parameters, we conducted model validation by comparing the stream flow measured at 3 stations from 2011 to 2012 with the results simulated by SWAT after adjustment.

Nash indexes obtained were 0.775; 0.7994; 0.6338 and R2 were 0.8142; 0.8014; 0.7639 in model at the validation step. This result shows that the SWAT model can be applied to assess the stream flow trend of the Srepok river-basin in the future, under the impact of climate change and land use change.

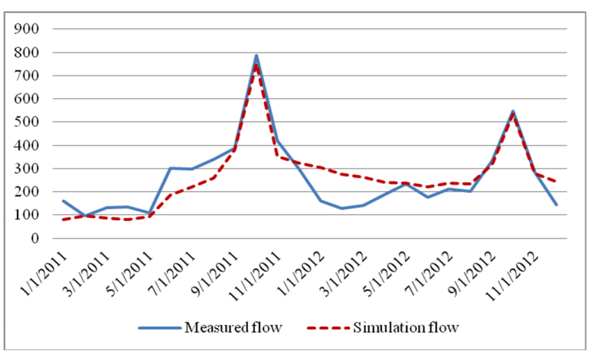

Figure 16. Graph to compare simulation results with the measured results at Bridge 14 Station from 2011 to 2012 (Unit: m^3/s)

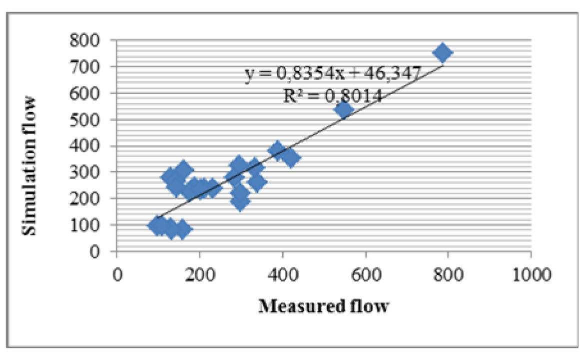

Figure 17. The correlation between the simulation results with the measured results from 2011 to 2012 at Bridge 14 Station (Unit: m^3/s)

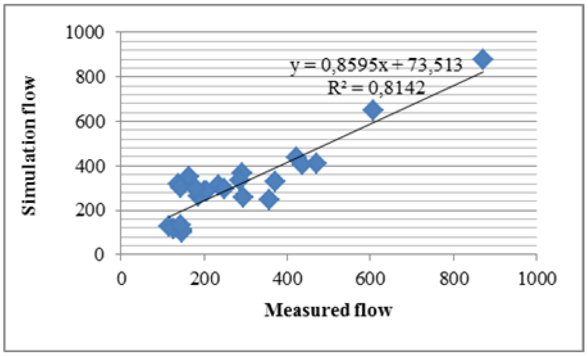

Figure 18. The correlation between the simulation results with the measured results Ban Don Station in the years of 2011- 2012 at (Unit: m^3/s)

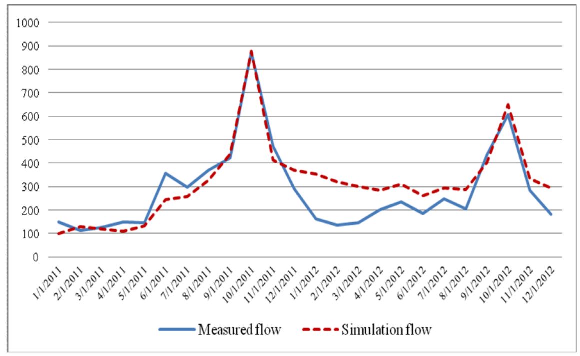

Figure 19. Graph of comparing simulation results with the measured results in 2011 and 2012 at Ban Don station (Unit: m^3/s)

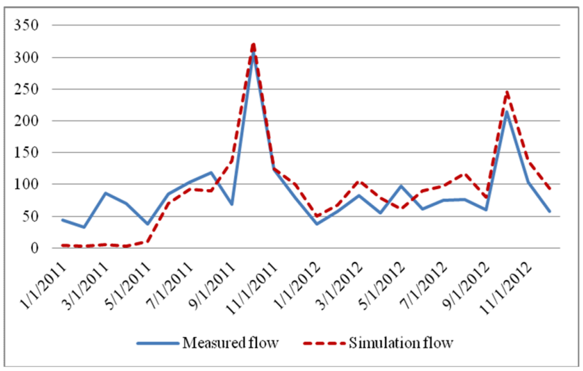

Figure 20. Graph to compare simulation results with the measured results at Duc Xuyen Station from 2011 to 2012 (Unit: m^3/s)

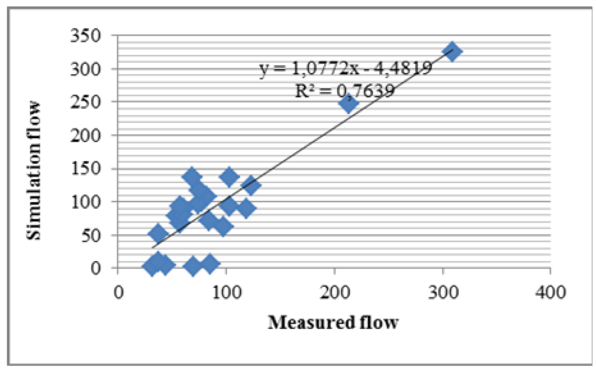

Figure 21. The correlation between the simulation results with the measured results in 2011 and 2012 at Duc Xuyen Station (Unit: m^3/s)

From the calibration and validation results, the simulation results were satisfied. Therefore, calibration parameters are applied to SWAT mode to simulate the flow in Srepok river-basin under the scenario 2 and 3.

4.3 Evolution of streamflow in Srepok river-basin according to scenario 2

In scenario 2, we will assess the impacts of climate change (changes in rainfall and temperature) on the stream flow in the river-basin, compared to the real status scenario (scenario 1).

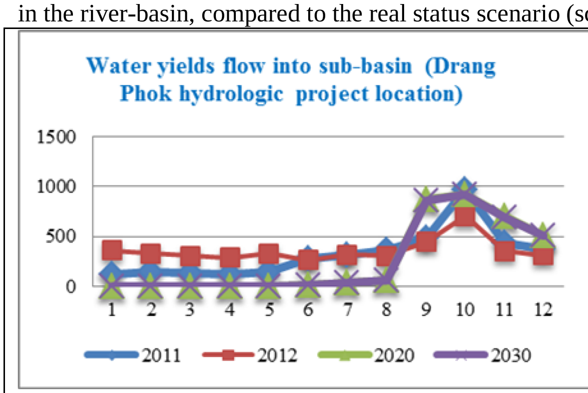

Figure 22. Water yields flow into the sub-basin during the years

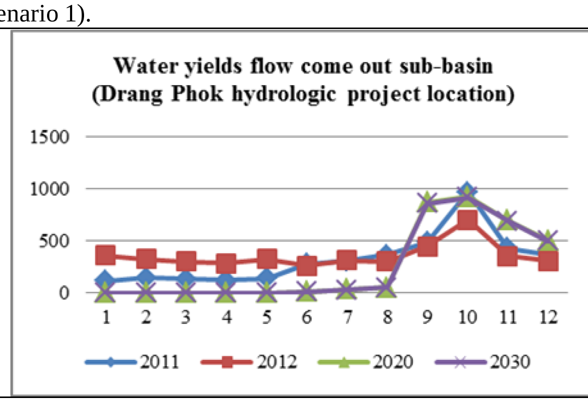

Figure 23. Flow sub-basin come out the years

Comparison of the results showed that:

During 2011 - 2012: streamflow entering into the spillway (which will be built in the future) tends to change accordingly to time periods: in dry season (from January to May), streamflow in the following year is higher than that of last year. However, in rainy season (from June to December), data in the following year is lower than that of the previous year.

From the result table, the surface flow in 2012 decreased comparing to that of the previous year. There are three main reasons:

- Rainfall in 2012 was lower than in 2011;
- The decrease in the amount of groundwater recharged for the rivers;
- The amount of surface water provided for the underground lines was higher.

From 2020 to 2030: the streamflow won't change very much. It is might be due to the climate change scenario, changes in temperature, rainfall, humidity and wind velocity in theses two years were almost stable. Hence, results were almost the same. If there was any difference, it is only a small difference in the flood peak of 2030, which seems to be a little bit higher.

Therefore, we will focus on analyzing the differences of the flow components in 2011 and 2020 to find the reasons of the changes in the flow, both in water level tendency and the principles.

- The simulation results showed that the streamflow at the surveyed river-basin in 2020 is clearly divided into two seasons: dry and flood season. The dry season lasts from January to August, with extremely dry conditions. Flood season comes and goes quickly within three months from Sep to Nov, and decreases rapidly in December. This poses a challenge to ensure the water supply for living and agricultural activities during the dry season.
- To unlock the reasons underlying the severe drought, we validated all components of the water balance in the river-basin and recorded the following results:
- The amount of precipitation of 2020 was higher than 2011. However, the amount of inflow water pouring into the two floors of groundwater has increased, in addition to the rise in evaporation due to increasing temperature, has caused the amount of surface water reduced significantly.

4.4 Streamflow evolution in Srepok river-basin in scenario 3

Scenario 3 will help to explore the impacts of climate change (changes in amount of precipitation and temperature) on the streamflow in the watershed, with and without Drang Phok hydropower plant (compared to scenario 2).

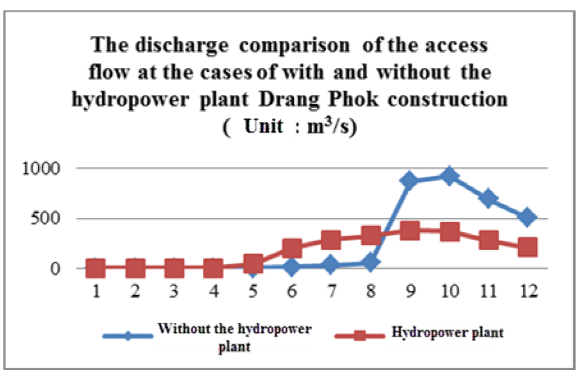

Figure 24. The discharge comparison result of the access flow at the cases of with and without the hydropower plant Drang Phok construction

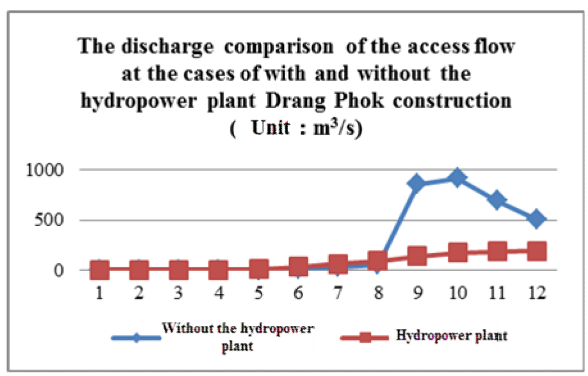

Figure 25. The discharge comparison result of the access flow at the cases of with and without the hydropower plant Drang Phok construction

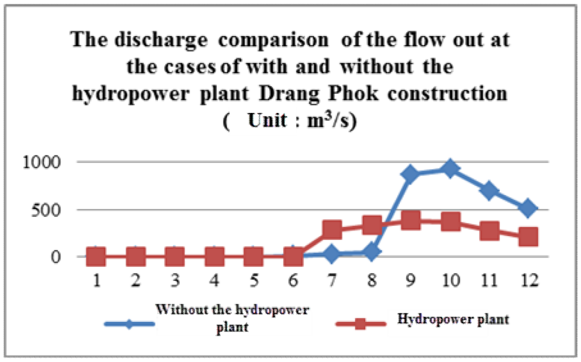

Figure 26. The discharge comparison chart of the flow out at the cases of with and without the hydropower plant Drang Phok construction

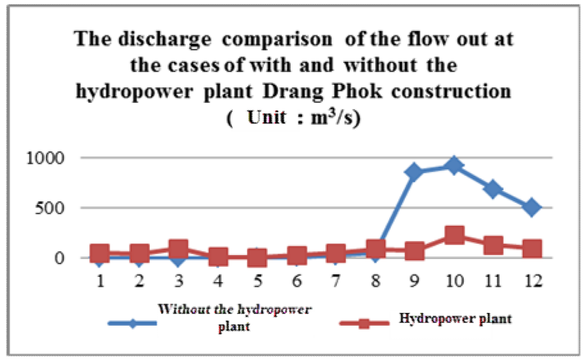

Figure 27. The discharge comparison chart of the flow out at the cases of with and without the hydropower plant Drang Phok construction

Based on the simulation results, in 2020 and 2030, the streamflow under investigation has had many negative changes due to the impacts of climate change. Without the hydropower plant, extreme scarcity of water supply along this river-basin will occur, lasting from May to August. After May, the streamflow will increase rapidly in September and October thanks to the increase in rainfall. However, rainfall will decrease in the following months, which will seriously affect negatively the daily lives and agricultural activities in local areas.
If the Drang Phock hydropower plant is built, it will help reduce the negative impacts of the water shortage in the dry season (May - August) and the flood in the rainy season. It also helps coordinate the amount of inflow water pouring into the river-basin regularly.

5 CONCLUSION

Srepok river-basin are strongly affected by the economic social development as well as the climate change. Therefore, local government needs to figure out efficient solutions and appropriate development plans for this river-basin, in order to adapt to the climate change and move forward to a sustainable development. The simulation results have shown that the stream flow of year 2020 in the chosen river-basin is sharply divided in two seasons: dry and flood season. While the dry season lasts for about 8 months beginning in January, the rainy season comes fast and goes rapidly within 3 months, from Sep-Nov and then, rainfall decreases rapidly in December. It poses a challenging problem which is how to manage water supply to meet the daily lives and agricultural demand during dry season.
To figure out the reasons behind the severe droughts, we analyzed the components of the water balance in the river-basin, the results received as following: The rainfall in 2020 was higher that of 2011. However, the amount of inflow water pouring into two floors of groundwater increased, in addition to the rapid evaporation due to the high temparature, caused the significant reduction in the amount of surface water. The results also revealed that there will be many changes in the principles and river flows in 2030. Dry season lasts longer and high flood season comes faster. We also found that the limitation on the real data could hurdle the accuracy of our study. Follow-up and on-going research should be continuing, to be able to calibrate and validate the streamflow simulation results at the hydrological stations in the river-basin. It will set a foundation for subsequent researchs regarding the assessment of erosion, sedimentation or the impacts of climate change on natural resources in the Srepok river-basin.

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