

Study on Climate Change Impacts on Hydrological Response using a SWAT model in the Xe Bang Fai River Basin, Lao People's Democratic Republic

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기후변화에 따른 라오스인민공화국의 시방파이 유역의 수문현상 예측에 대한 연구: SWAT 모델을 이용하여

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Abstract : A calibrated hydrological model is a useful tool for quantifying the impacts of the climate variations and land use/land cover changes on sediment load, water quality and runoff. In the rainy season each year, the Xe Bang Fai river basin is provisionally flooded because of typhoons, the frequency and intensity of which are sensitive to ongoing climate change. Severe heavy rainfall has continuously occurred in this basin area, often causing severe floods at downstream of the Xe Bang Fai river basin. The main purpose of this study is to investigate the climate change impact on river discharge using a Soil and Water Assessment Tool (SWAT) model based on future climate change scenarios. In this study, the simulation of hydrological river discharge is used by SWAT model, covering a total area of 10,064 km² in the central part of country. The hydrological model (baseline) is calibrated and validated for two periods: 2001-2005 and 2006-2010, respectively. The monthly simulation outcomes during the calibration and validation model are good results with R² > 0.9 and ENS > 0.9. Because of ongoing climate change, three climate models (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) indicate that the rainfall in this area is likely to increase up to 10% during the summer monsoon season in the near future, year 2030. As a result of these precipitation increases, the SWAT model predicts rainy season (Jul-Aug-Sep) river discharge at the Xebangfai@bridge station will be about 800 m³/s larger than the present. This calibrated model is expected to contribute for preventing flood disaster risk and sustainable development of Laos

Key Words : climate change, hydrological model, SWAT model, Xe Bang Fai river basin

요약 : 보정된 수문모델은 기후변화와 지표피복변화가 하천의 유량과 수질, 그리고 하천퇴적물의 양에 미치는 영향을 정량적으로 파악할 수 있는 수단이 된다. 라오스 중부에 위치한 시방파이(Xe Bang Fai) 유역(10,064 km²)은 태풍의 영향권에 놓여 있으며, 여름철은 높은 강우강도로 인해 매년 주기적인 범람의 위험을 안고 있다. 특히 현재 진행되고 있는 기후변화로 인해 태풍의 빈도와 강도가 크게 변할 것으로 예상되기 때문에 홍수로 인한 피해의 위험성은 점차 높아지고 있다. 이 연구의 목적은 Soil and Water Assessment Tool(SWAT) 모

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델을 이용하여 예상되는 기후변화 시나리오에 따라 하천유량에 미치는 영향을 예측하는 것이다. 이 연구에서 SWAT 모델은 2001년과 2005년 사이 기후 및 유량자료를 통해 보정하였으며, 2006년과 2010년의 예측치와 실측치 비교를 통해 검증하였다. 모의한 월별 유량과 실제 측정된 유량간의 일치도는 R^2 값이 0.9(ENS>0.9)를 넘어 모델의 예측력이 높은 것으로 나타났다. 세 개의 기후모델(IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030)은 현재 진행되고 있는 기후변화로 인해 가까운 미래인 2030년에는 여름 몬순기간 동안 강우량이 약 10% 증가할 것으로 예측된다. 이 경우 우기인 7월과 9월 사이 시방파이 다리 부근에서 관측되는 하천의 유량은 현재보다 약 $800\text{m}^3/\text{s}$ 정도 증가할 것으로 예측되었다. 이 연구에서 보정된 SWAT 모델은 향후 홍수저감과 라오스의 지속가능한 발전정책의 수립에 효과적으로 사용될 것으로 기대된다.

주요어 : 기후변화, 수문모델, SWAT 모델, 시방파이 유역(Xe Bang Fai)

1. Introduction

Climate variation is one of the most significant driving factors for year-by-year variation in agricultural production and available water resources. Water is the most important natural resource that it is a major constituent of overall subsistence on the planet earth (Bazzaz and Sombroek, 1996), because water is the single most significant requirement for life. Over the decade's quick growth of population, industrialization and urbanization, transformations of social and economic activities raised requirement of available water. Thus, it is important to study the climate variation. One important approach is to simulate the surface runoff with suitable precision based on data driven and modeling methods.

According to the report of Mekong River Commission, Lao People's Democratic Republic (Lao PDR) has experienced frequent flooding along the Mekong River and its tributaries (MRC, 2011). The Xe Bang Fai river (one of Mekong's tributaries) basin is located in Khammouane Province, which is often influenced by tropical storms in rainy season. For instance, in the year 2011, the northern and central part of Laos confronted two tropical storms, namely HAIMA and NOCK-TEN. It resulted in heavy flooding in the five provinces of central and southern part of country, including Vientiane, Bolikhamxay, Khammuan, Savannakhet, and Cham-

passak provinces respectively (MRC, 2011). As the Laos government report in 2011, the Xe Bang Fai river basin was affected by two tropical storms as mentioned above. As a result of both storms, numerous districts in Khammouane province sited along the Xe Bang Fai river were highly affected by floods as shown in Figure 1. In this province, on the downstream of the Xe Bang Fai river basin, more than 400 villages or approximately 70 % of overall villages suffered from these storms. Approximately 37,000 ha of rice fields or 63% of rainy season rice crop and 17,000 ha of crops were destroyed by floods. In that time, however, many organizations offered relief supplies through the provincial authority, but more than hundreds of households remained to need assistance, especially food and other supplies to assist flood victims for recovering their regular lives (Lao Embassy, 2011). Major regions of irrigated rice fields and rain-fed are located in these floodplains, but the structure of flood domination, especially levees and embankments haven't been built *yet* along these agricultural regions. So when severe inundations occurred, the whole floodplain region in the Xe Bang Fai river basin was awash.

At the present time, the Xe Bang Fai river basin mostly provides water to irrigated regime of around 12,000 ha in dry season (LNMC, 2011a). In previous study of Lao's government, approximately up to 100,000 ha of irrigated regime are able to be extensible based on the topographic characteristic in this basin. The topography of this basin



Figure 1. Tropical Storm HAIMA and NOCK-TEN affected to Lao PDR in 2011: (a) Mekong River was flooding central part of Lao PDR and (b) the Xe Bang Fai river was flooding in area of the Phanang village, Boulapha district, Khammouane Province, source: Google.

area is commonly hilly in upstream part and flat land in the middle to downstream. The large middle part, with having sources of water, is appropriate for agricultural activities and the last of lower part is appropriate for rice cultivation because of irrigation water is available. Over 250,000 of local people living in this basin are not able to access to safe water yet, however most of them settle along both sides of the Xe Bang Fai river. According to the baseline data of health in 2000/2001 it has been reported that more than 1,600 households on the downstream area of the Xe Bang Fai river basin used unsafe drinking water. This means only a small part of households have accessed to some improved sanitation (Fewtrell & Kay, 2008). Thus water availability at the moment and future based on the climate change in the Xe Bang Fai river basin requires estimates to improve the framework on the sustainable water resources management (LNMC, 2011b).

If there are any models that accurately study the effect of climate change on the hydrological system in the sub-basin of the Lower Mekong River (LMR), it will become a powerful tool for decision-making, mitigation, measurement, planning for water resources management and controlling water quality. The outcome of

study will support local human well-being for those who live along the downstream. Soil and Water Assessment Tool (SWAT) (Arnold *et al.*, 1998) is assigned to use for studying climate change impact on hydrological response based on climate change scenarios in the future, because this hydrological model is the most broadly used model in the water sector (Shao and Chu, 2012). There are many previous hydrological research studies, for instance, Resenthal *et al.*, (1995) studied the stream flow volume in the Lower Colorado River basin of Texas by linking a geographic information system (GIS)-hydrological model to SWAT model, with no monthly simulation and calibration of river discharge amount. The research results found that the future upstream of urbanization will be main effects to river discharge change along downstream of Lower Colorado River basin. Borah & Bera (2004) simulated 11 basin-scale hydrological and nonpoint-source pollution models. These models were used for estimating long-term impacts of hydrological changes based on watershed management practices, particularly crop practices. The mathematical method of various model components was selected to use at the most accuracies for developing new approaches in the future. Gassman *et al.* (2007) reviewed using SWAT models, for instance

river discharge calibration and associated hydrological analysis, climate change effects on hydrological response, pollutant load evaluations, comparisons with other hydrological models, and sensitivity analyses and calibration techniques.

As mentioned above, advantages of the hydrological models were indicated by SWAT model. Therefore, SWAT model was assigned to use in this basin. In the past, there were hydrological research studies, especially a study on discharge of the Xe Bang Fai river basin tributaries to support information for water resources management policies in Lower Mekong Basin of Laos (NT2, 2003; MRC, 2010; LNMC, 2011b). These models are generalized hydrologic simulation package, which are capable for applying regulated and unregulated streams. The models are designed to be capable for addressing water quality and quantity and also environmental issues.

The objectives of this study are to evaluate the effect of climate variation on hydrology of the Xe Bang Fai River Basin in Lao PDR. The procedure of this study is based on the recent and future situations by applying data driven modeling methods. The specific purposes are described following: simulating the river discharge of the Xe Bang Fai river basin (baseline) using SWAT model to compare the future river discharge based on climate change model in 2030, which the expected result of this study is to provide a hydrological information on water resource administrators and policy-makers for taking into consideration in improvement of the project's plan on sustainable integrated water resources management in the future.

2. Study Area

The Xe Bang Fai river is an east-side tributary of the Mekong River. The total length of the Xe Bang Fai river has approximately 370 kilometer with its origin in the

mountainous area of the Boualapha District, access to this river is approximately 50km south of Thakhek district (Kottelat, 2015). The Xe Bang Fai river is a major tributary of the Mekong River which is fed by 4 tributaries, namely Se Noy river, Ou La river, Phanang river and Ngom river. The Xe Bang Fai river basin is a sub-basin of the Mekong River Basin which is located in the central part of Laos, with the total area of this basin approximately is 10,345 km² or (4.36% of national area of Lao DPR). The area of Basin covered 2 provinces of Laos including Khammoune and Savannakhet provinces. The majority area of this basin is on Khammoune Province (Sioudom, 2013). The study area is located between 16°40'00"-18°00'00" North Latitude and 104°20'00"-106°30'00" East Longitude, with covers a total area of 10,064 km² of 809,500 km² of the Mekong River Basin area as shown in Figure 2 (LNMC, 2011b).

In this basin area, the climate characteristics of the Xe Bang Fai river basin are described by two different seasons; a dry season (November to April) and a wet season (May to October). The annual mean temperature ranges from 21.24 to 31.75oC based on average overall of the temperature. In the mountainous areas, the annual mean temperature drops to as low as 15oC in January and February at night. This region receives approximately 1,422 to 2,500mm of annual rainfall, during the wet season, which contributes more than 80% of the annual rainfall due to monsoons, tropical storms, tropical cyclones and depressions (Champathangkham and Pandey, 2013). The average natural discharge in the Xe Bang Fai river basin is approximately 220m³/s (NT2, 2003). The Xe Bang Fai river basin is still rich in forest, water, land, biodiversity and other natural resources. The main land use/ land cover (Figure 3b) in the river basin area consists of forest area (51.79%), agricultural area (36.75%) and other land use/land covers are open barren and wood land in this river basin (Champathangkham and Pandey, 2013).

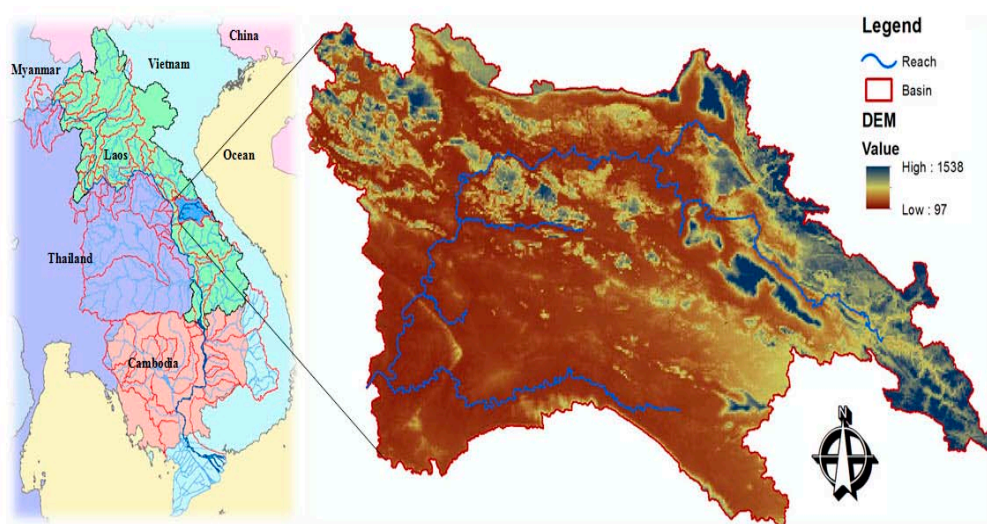


Figure 2. Location of the Xe Bang Fai river basin.

3. Methods and Data

To study the climate change impact on hydrological response in the Xe Bang Fai river basin, first data needs to be collected, especially hydro-meteorological data and geographical data. The materials and research methodological procedures were analyzed based on SWAT model (Arnold *et al.*, 1998). The main analysis procedure is carried out as following below.

1) SWAT Model

The Soil and Water Assessment Tool (SWAT) is developed by Dr. Jeff Arnold for the USDA-ARS (Arnold *et al.*, 1998). This tool is a distributed hydrological and physically-based model, which has been broadly used to simulate and predict hydrological response for water resources management (Arabi *et al.*, 2008; Neitsch *et al.*, 2011). This hydrological model is used to forecast amount of surface runoff and soil loss (Morgan, 2001; Grønsten and Lundekvam, 2006; Champathangkham and Pandey, 2013), climate change impacts on water

quality modeling (Andersson, 2006; Shrestha *et al.*, 2013), estimating impact of land use/land cover change (Sheng *et al.*, 2003; Wu *et al.*, 2007; Wang *et al.*, 2014) and modeling water quality (Debele *et al.*, 2008; Abbaspour *et al.*, 2007; Zhang *et al.*, 2013). Currently, SWAT model has been developed into various versions (Neitsch *et al.*, 2011), which is attached to ArcGIS interface called ArcSWAT. It is computationally powerful with user friendly tools that can simulate the long-term changes in regional hydrological cycle associate with the ongoing climate change.

The basic component of hydrological model in SWAT model includes groundwater flow, surface and peak runoff, sediment yield and evapotranspiration for each HRU-Hydrological Response Unit¹⁾ based on analysis of SUFI-2- Sequential Uncertainty Fitting²⁾ algorithm technique.

$$SW_i = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

Where, SW_i is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the amount of precipitation on day i (mm);

Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm) and Q_{gw} is the amount of return flow on day i (mm).

2) Model Setup

The model setup includes 4 steps: (1) data input; (2) watershed delineation; (3) SWAT model calibration and validation and (4) hydrological model evaluation.

(1) Data Input

Spatial Data: In the processing hydrological model, the spatially distributed GIS data was required for inputting into the ArcSWAT interface. The spatial GIS dataset consists of soil data, land use/land cover (LULC), Digital Elevation Model (DEM) and stream network layers.

In addition to weather and stream flow data are applied for forecasting the river discharge and calibration objective. The measured monthly rainfall data and discharge data are collected from the Department of Meteorology and Hydrology (DMH) under the Ministry of Natural Resource and Environment (MONRE). In this study, there are eight rainfall stations, namely Signo, Mahaxay, Ban Veun, Thakhek, Xeno, Savannakhet, Donghen and Xepon and also one station for gauging river discharge, namely the Xebangfai@brige station for using calibration model as shown in Figure 3(a).

The 30×30 m resolution DEM map as shown in Figure 3(b), and land use/land cover map year 2010 and soil type maps (1:250,000) 1998 as shown in Figure 3(b) and (d) are obtained from the Natural Resources Research Center, Natural Resources and Environment Institute (NREI) under MONRE. Moreover, the stream network is taken from the Lao National Mekong Committee un-

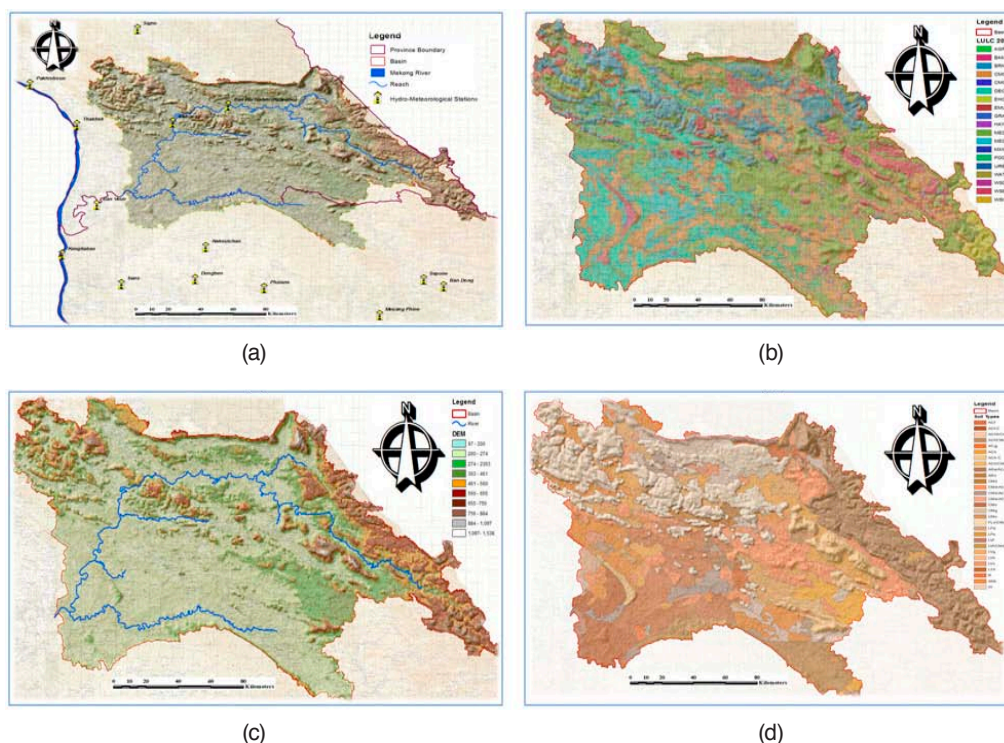


Figure 3. Weather Station (a), DEM (c), LULC (b) and Soil Types (d) in the Xe Bang Fai river basin.

der MONRE, and the observed monthly discharge data period 1998–2010 applied in this hydrological model is subdivided into two periods: calibration model (2001–2005) and validation model (2006–2010). For the data input, including the monthly precipitation, temperature and wind speed were used to input in SWAT model with the weather generator tool for simulating river discharge

(2) Watershed Delineation

The watershed delineation of the Xe Bang Fai river basin is based on its DEM characteristics. Watershed area is automatically delineated from DEM to analyze the drainage patterns of the land surface terrain in the Xe Bang Fai river basin by ArcSWAT tool. In the analysis, stream delineation of watershed is generated by the mask area function in ArcSWAT interface which the stream networks in SWAT model are digitized from DEM based on procedure of automatic delineation (Neitsch *et al.*, 2011).

The ArcSWAT offers the minimum, maximum and advised scale of the sub-watershed area in term of hectare to identify the minimum drainage region. Typically, the smaller the threshold region, the more detailed the drainage systems and the number of sub-watersheds and HRUs. In this study, the smaller area approximately 5,000 hectares is assigned to receive all sub-watershed of the Xe Bang Fai river basin for determining the minimum drainage region, and the outlet of this basin is identified where it is later taken as a calibration point of the simulated flows. As a final result of watershed delineation, there are 11 sub-watersheds are generated in the Xe Bang Fai river basin based on ArcSWAT analysis.

Hydrological Response Unit (HRU) is the smallest spatial values of the model, which the standard method of HRU definition combines overall of homologous slopes, landuses and soils in a sub-basin based on user-assigned thresholds (Kalcic *et al.*, 2015). Thus, the results of HRU analysis in SWAT model showed notable features of HRUs within each sub-basin area including soil, slope

and land use/land cover. The single HRU in each sub-basin cannot appropriately explain the characteristics of the sub-basins. In this study, the good assessment of river discharge simulation was defined by threshold combination of 10% land use, 10% soil and 10% slope respectively for giving a better evaluation of river discharge. The result of this combination in the whole area of the Xe Bang Fai river basin has received 716 HRUs. The characteristics of land use, soil and slope are distributed within each HRU have the largest effect on the predicted stream discharge. As the percentage of soil, land use/land cover and slope threshold rises, the exact evapotranspiration reduces due to eradicated land use classes. Consequently, the HRUs characteristics are the main factors influencing the river discharge.

(3) SWAT Model Calibration and Validation

In SWAT model, the calibration is the procedure of modification of model parameters in the recommend standard ranges in order to optimize the output of model so that it will match with measured dataset. In the modification, the many various parameters for adjustment are able to differ based on the actual condition of study area and user experience. These values are able to be modified manually or automatically until the model output will be get an optimal value and fit with the measured data. In this study, SWAT-CUP(3) is used for model calibration and validation as the outlet of river discharge of the Xe Bang Fai river basin, because of SWAT-CUP³ capacities to provide the result of values of the Nash-Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2). For the validation model in SWAT-CUP is the step of assigning the degree in which simulate a precise delegation of the measured dataset from the outlook if the designed uses of the SWAT model. The monthly flow data at Xebangfai@bridge station during the years 1998–2010 is used for calibration and validation and the monthly discharges of 1998–2000 years was skipped from model warm-up period, which model could significantly modi-

fy one's flow system.

(4) Hydrological Model Evaluation

To verify the outputs of hydrological model are good or not, the accuracy assessment in hydrological model is the most important step for getting optimized values (Moriassi *et al.*, 2007). Thus, the best fundamental method to evaluate hydrological model in terms of performance is based on visual investigation of the measured and simulated hydrographs. There are widely two proficiency criteria, for instance Nash-Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2), which are generally utilized in hydrological model researches and informed in the literature regarding SWAT model. The other factor is the goodness-of-fit which can be calculated by the Nash-Sutcliffe efficiency (E_{NS}) and coefficient of determination (R^2) (Setegn *et al.*, 2010). Based on this analysis, two quantitative statistics, E_{NS} and R^2 , are the recommended model evaluation statistics (Santhi *et al.*, 2001). R^2 is the mathematical statistic with line regression providing a gauge of how good observed outcomes are duplicated by the model. E_{NS} is the normalized statistics used to assign the related amplitude of the residual variance comparing the observed data variance (Nash and Sutcliffe, 1970; Setegn *et al.*, 2010). The E_{NS} range is between $(-\infty)$ to 1, with $E_{NS} = 1$ is the optional value. In case $E_{NS} < 0$, the measured average is a better forecaster than the model (Moriassi *et al.*, 2007).

In hydrological evaluation in the SWAT model, SWAT-CUP tool is used for accuracy assessment under calibration and validation model of the river discharge in the Xe Bang Fai river basin. In general procedure of accuracy assessment during 1998-2010, SWAT model is carried out in three parts: warm-up (1998-2000), calibration model (2001-2005) and validation model (2006-2010), respectively by comparing with observed data of river discharge at the Xebangfai@bridge station (river discharge gauge station). In the approach of running SWAT model, the part of warm-up period was skipped, because of the

model simulation will have to modify one's flow system efficiently. There are only two periods focused by assessing model accuracy as calibration and validation model under the coefficient of determination (R^2), Nash-Sutcliffe efficiency (E_{NS}) approaches (Van Liew *et al.*, 2003).

4. Model Calibration and Verification

The potential impact of climate change on water resources is a globally debated topic that has drawn increasing attention over the last decades. Recently, IPCC's scientists study found that climate change has affected the operation and function of existent water foundation and water management (Parry, 2007; Craig, 2010). In this research, the hydrological river discharge model in the Xe Bang Fai river basin was influenced from tropical monsoon climate. In hydrological model simulation, the main spatial dataset and whole parameters were input to SWAT model as shown in (Figure 3 including the land use/cover map, DEM, slope map and soil map) for forecasting the future river discharge of the Xe Bang Fai river basin in 2030, which there are still gaps in knowledge regarding the impacts of climate change on the hydrological system in the river basin and the application of knowledge and experience acquired from other regions to the Xe Bang river basin.

The comparison of monthly hydrograph between simulated and measured discharges at the Xebangfai@bridge station is shown in Figures 4 and 5. Table 1 summarizes the statistics of the monthly-mean simulated and observed discharge in the basin. We can see that the both of the monthly simulated and observed discharge are quite similar to each other; the monthly-mean river discharges are approximately $400 \text{ m}^3/\text{s}$. In the calibration and validation of hydrological model of the monthly river discharge in the Xe Bang Fai river basin, the calibration and validation of monthly simulated discharge model

were represented during the period (2001-2005) for discharge model calibration and the period (2006-2010) for the discharge model validation respectively, along with three year (1998-2000) for the warm-up model period. In this study, the monthly simulated discharge matches the monthly measured discharge values for the periods of calibration and validation of river discharge model with $R^2 = 0.970, 0.966$ and $E_{NS} = 0.967, 0.960$ for measuring locations (Xebangfai@bridge station), respectively. The Coefficient of Determination (R^2) and Nash-Sutcliffe Efficiency (E_{NS}) of the monthly calibrated period (2001-2005) and the validated period (2006-2010) are summarized in Table 2, verifying that there is a good agreement between monthly measured and simulated river discharges.

The calibrated hydrograph of the monthly measured and simulated river discharges at the Xebangfai@bridge station (river discharge gauge station) during the calibration period (2001-2005) as shown in Figure 4. We can see that the monthly simulated river discharges in SWAT model closely matches the monthly observed river discharges, especially at the peak of river discharge in August 2005. The performance of the SWAT model for the study area is very good for both of the calibration period

(2001-2005), with $R^2 > 0.970$ and $E_{NS} > 0.967$ and the validation period (2006-2010), with $R^2 > 0.966$ and $E_{NS} > 0.960$ in the gauging locations.

As the monthly hydrograph of the measured and simulated river discharges are higher than other periods, because this was the year of heavy rainfall in Lao PDR. The most areas along the main tributaries of Mekong River were impacted by flooding. According to MRC (2006), year 2005 is certainly the most serious flood for the central region of Lao PDR, especially Khammouane and Savannakhet provinces. After applying the model calibration, the SWAT model reasonably simulates the hydrological characteristics of the extreme flood event (year 2005). Considering the good results of E_{NS} and R^2 above, therefore, the hydrological model is able to be applied for the future studies of hydrological response in the basin.

Figure 5 shows that the SWAT model under-forecasts the peak values of monthly simulated discharge are lower than measured discharge. The poor prediction of the peak discharges of the SWAT model could be reported by previous researchers, because there is possibly uncertainty in the data (Rosenthal *et al.*, 1995; Borah & Bera, 2004; Gassman *et al.*, 2007). The SWAT model simula-

Table 1. Statistical analysis of the monthly simulated and observed discharge at the Xebangfai@bridge station (river discharge gauge station).

Time Period		Measured 2001-2010	Simulated 2001-2010
Average	m ³ /s	401.47	409
Standard deviation	m ³ /s	623.88	588.68
Maximum	m ³ /s	3691.52	3356
Minimum	m ³ /s	14.24	2.29

Table 2. Results of the monthly correlation between simulated and observed river discharge at the Xebangfai@bridge station (river discharge gauge station).

Time Period	Calibrated 2001-2005	Validated 2006-2010
Coefficient of Determination (R^2)	0.970	0.966
Nash-Sutcliffe Efficiency (E_{NS})	0.967	0.960

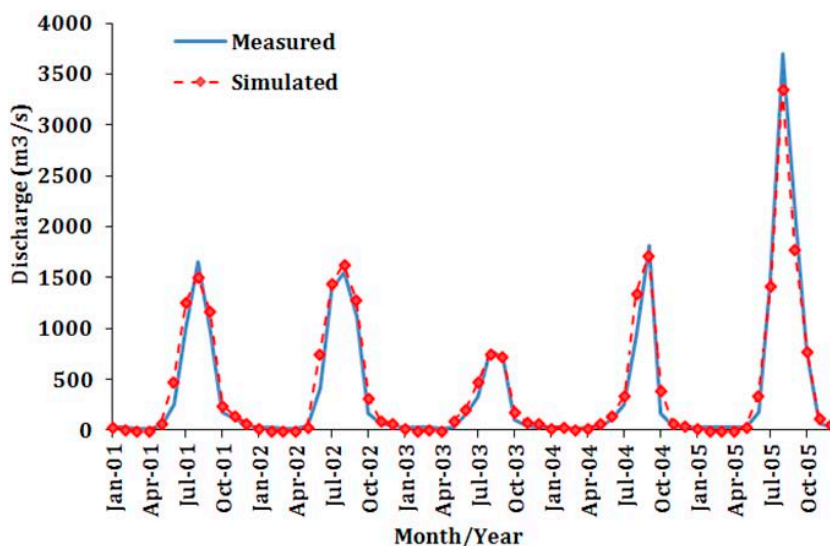


Figure 4. Monthly measured and simulated river discharge for calibration period (2001-2005).

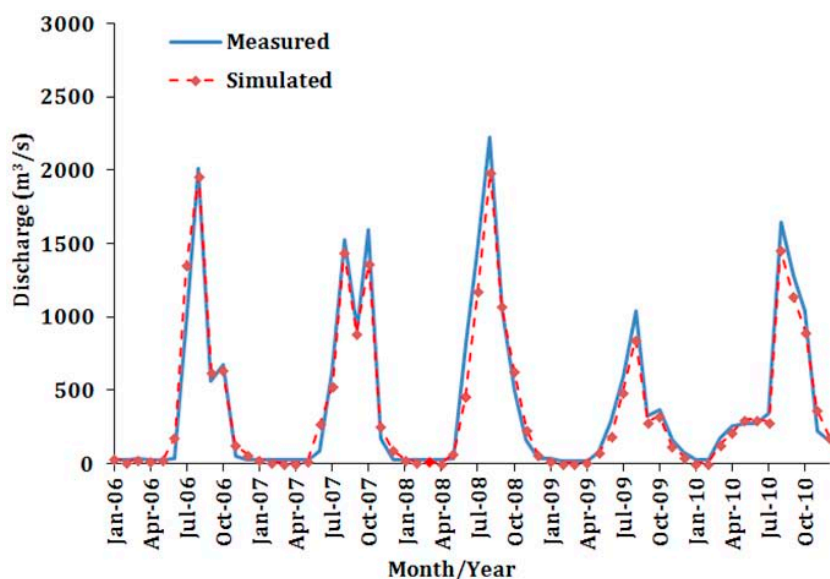


Figure 5. Monthly measured and simulated river discharge for validation period (2006-2010).

tions agree well with the measurements in this basin area during the validation periods with R^2 and E_{NS} are bigger than 0.9. Therefore, the SWAT model is likely to be a useful tool for the hydrological assessment of Mekong river basin, especially overall of the watershed in Laos. From this hydrograph of monthly measured and simulat-

ed discharges is illustrated at the peak of river discharge from Mekong River Commission (MRC) reports in October, 2007 (MRC, 2008); June, 2008 (MRC, 2009) and October, 2010 (MRC, 2011). During these years, Khammouane and Savannakhet Province experienced heavy rainfall from tropical storms and most areas were

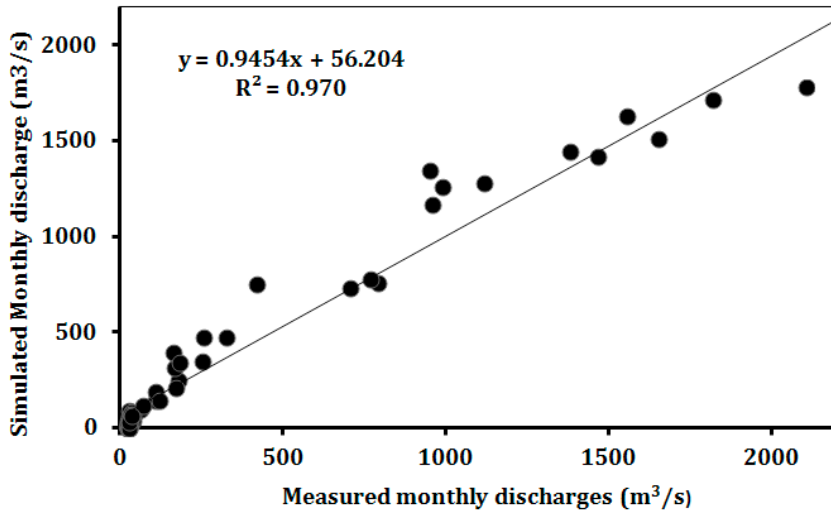


Figure 6. Scatter plot of the monthly discharges for the calibration period (2001-2005).

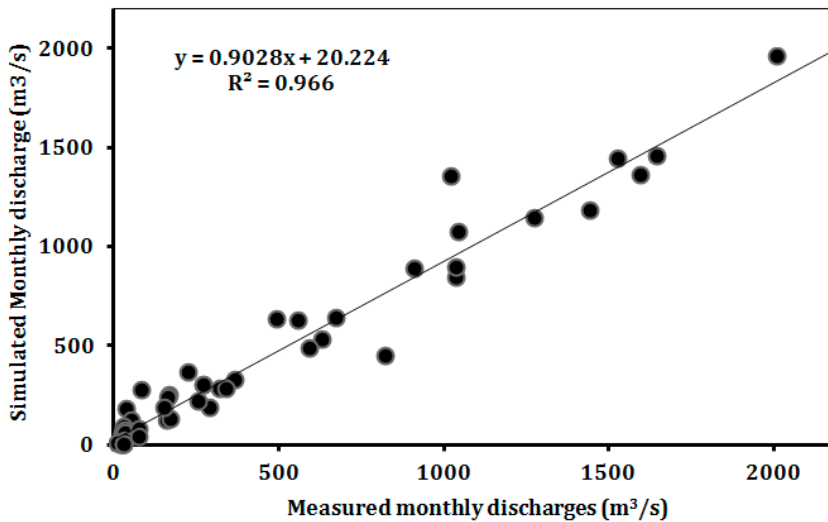


Figure 7. Scatter plot of the monthly discharges for the validation period (2006-2010).

flooded.

However, the similar thing is not reflected in the observed runoff data. It is assumed that there are probably uncertainties in the data. From the scatter plots of the monthly measured and simulated river discharges of the Xebangfai@bridge station during the periods of discharge model calibration (2001-2005) and discharge model validation (2006-2010) are shown in Figure 6 and

7 below respectively. Both of the scatter plots represent relatively good R^2 values: 0.970 and 0.966.

From Table 2, the value of Nash-Sutcliffe efficiency (E_{NS}) commonly ranges from 0-1. In the previous research, Saleh *et al.*, (2004), indicated that the better prediction of model should be greater than 0.65 ($E_{NS} > 0.65$), whereas lower (E_{NS}) values are generally regarded as a poor model prediction. In addition to Moriasi *et al.*

(2007) indicated that the simulations of SWAT model in term of monthly time are generally able to decide acceptable value when (E_{NS}) value is bigger than 0.5. According to these suggestions, the result of SWAT model in this study on river discharge simulation of the Xe Bang Fai river basin is very good in the calibration period of (E_{NS}).

5. Impact of Future Climate Change

The impact of future climate change has a potential threat on water resources, which has become a subject debated globally for decades (Arnell, 1999). The variability of climate will effect river runoff in the basin. Recently, IPCC's scientists study found that climate change has affected the operation and function of existent water foundation and water management (Parry, 2007). The previous researches of IPCC-Intergovernmental Panel on Climate Change on estimation of climate change impact on water resources (Bates *et al.*, 2008), with also a technical paper on climate change and water (Kundzewicz *et al.*, 2008). According to several researches provide a significant basis to understand the climate change impact on river watersheds. In addition, numerous researches have studied variations in climate change, which associates with main hydrological system in the Mekong River Basin (Delgado *et al.*, 2012; Räsänen *et al.*, 2012). In addition to the climate change impact on hydrological system of Mekong River (Västilä *et al.*, 2010; Piman *et al.*, 2013) under various suppositions about the future of the Mekong River Basin (MRB).

This research is the river discharge simulation based on the climate change scenarios in the Xe Bang Fai river basin by 2030, and estimates the uncertainty of future climate projections. The climate model was generated by RCP6.0 simulations from 4th intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014) assessment to test how the climate is likely to change in the Xe Bang

Fai river basin, and also the effect of change on water resources in basin. The model provides primary evaluation of the potential impact of these changes on water resources (Eastham *et al.*, 2008). In this research indicates that the amount of river discharge in the Xe Bang Fai river basin is increase under 2030 climate change scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030). However, since the basin area and volume of water in the basin is small, the impact on river discharge and water availability in the Xe Bang Fai river basin downstream is probably to be significant for both during the period of rainy and dry season. Based on the climate change scenarios in 2030, total annual runoff from the Xe Bang Fai river basin is likely to doubled increase more than 315 m³/s of river discharges (Baird *et al.*, 2015). According to the three climate change scenarios, runoff increase of the Xe Bang Fai river is estimated for overall catchments, generally resulting from increased runoff during the rainy season. Runoff in dry season is predicted to remain the same or doubled its previous dry season discharge that has trended dramatic impacts, changing the stream's ecology and basically altering its relationship to local communities (Baird *et al.*, 2015)

1) Climate Change Scenarios

For comparing the river discharge change based on climate change scenarios, the climate change model of three institutes, namely Institute Pierre-Simon Laplace (IPSL), NASA Goddard Institute for Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL) were used for estimating river discharge change in 2030 (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) (Sperber *et al.*, 2013). In this study, the three climate models (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) were generated by RCP6.0 scenario based on cooperating between Mekong River Commission (MRC) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

GmbH. The configuration of the Xe Bang Fai Sub-basin is identically from MRC SWAT sub-basin, which the climate change factors from the regional model were applied to the SWAT model of the Xe Bang Fai river basin. The data of change factors generated in the project were acquired in a feature that is agreeable with the clarification of change factors usable for SWAT models in MRC (MRC, 2014a). In these tables, overall of the factors were given by the Lao National Mekong Committees (LNMCs) working with Mekong River Commission.

Therefore, this study on climate change impacts on hydrological response can be used as important information for water resources management and natural disaster protection. In addition, the hydrological model can be used for quantifying sediment transportation and water quality analysis, those of which are valuable for the sustainable development of the Lao PDR in the future.

2) Hydrological Response with Climate Change Scenarios

As shown in Figure 9, the comparison of monthly hydrograph in the Xebangfai@bridge station between the

baseline and climate change scenarios indicates that river discharge generally increases in the middle of July and decreases in the middle of September in the future, while the highest of hydrograph is in the middle of August more than 1500 m³/s (monthly-mean) and after in the middle of September, the hydrograph is straight down. In hydrograph of three scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030), their scenarios are higher than baseline in rainy season. With the discharges result of the (IPSL CM5A-MR 2030) obtained is lower in the dry season (Feb-May), which is lower than the baseline and during the wet season is above the baseline as shown in Figure 10. As shown in Figure 8, 9 and 10, the results of the three climate change scenarios (IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030) are compared to baseline produced by SWAT model that included climate change factors applied to the original baseline data.

The scenarios of (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030) were represented in the discharge of both wet and dry seasons. While the result of three scenarios, the (IPSL-CM5A-MR 2030) has provided lower discharges in the dry season (Feb-

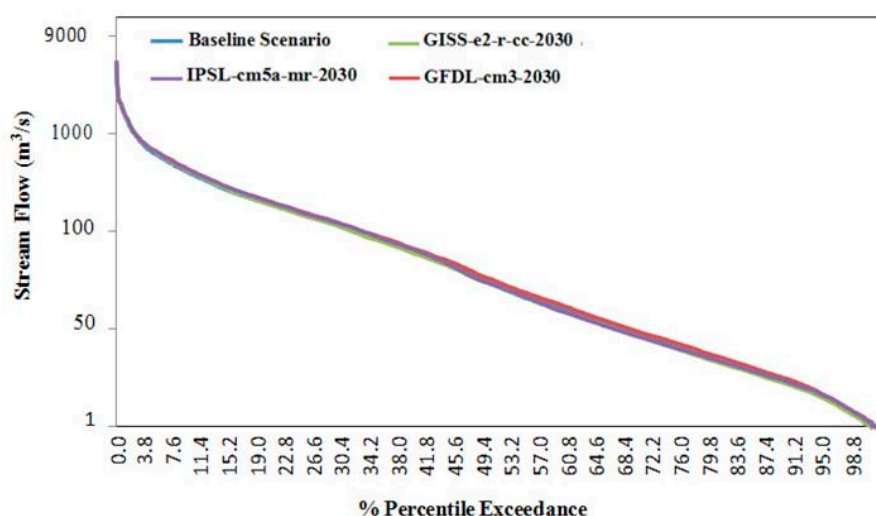


Figure 8. Comparing discharges of the climate change scenarios with baseline

Table 3. Climate change scenarios, which effected in surface runoff.

Months	Monthly Scenarios Flow				Percentage Differences Compared to Baseline		
	Baseline Flow (m ³ /s)	IPSL 2030 flow (m ³ /s)	GISS 2030 flow (m ³ /s)	GFDL 2030 flow (m ³ /s)	% Difference of IPSL 2030	% Difference of GISS 2030	% Difference of GFDL 2030
Jan	18.72	19.15	18.63	18.94	2.30	-0.48	1.18
Feb	19.43	19.03	19.28	19.79	-2.06	-0.77	1.85
Mar	21.75	20.29	23.32	25.57	-6.71	7.22	17.56
Apr	29.43	25.52	28.67	29.72	-13.29	-2.28	0.99
May	95.53	88.65	98.85	105.79	-7.20	3.84	10.74
Jun	270.64	277.91	282.24	278.87	2.69	4.29	3.04
Jul	742.35	835.52	825.34	822.58	12.55	11.18	10.81
Aug	1463.23	1582.87	1518.9	1585.78	8.18	3.80	8.38
Sep	1263.19	1398.89	1338.08	1320.78	10.74	5.93	4.56
Oct	452.39	493.82	444.89	459.39	9.16	-1.66	1.55
Nov	57.36	58.54	65.36	69.26	2.06	13.95	20.75
Dec	23.25	24.05	23.37	23.75	3.44	0.52	2.15
Annually	Annually Scenarios Flow				% Annually Change		
	371.43	403.68	390.57	396.68	1.82	3.74	6.96

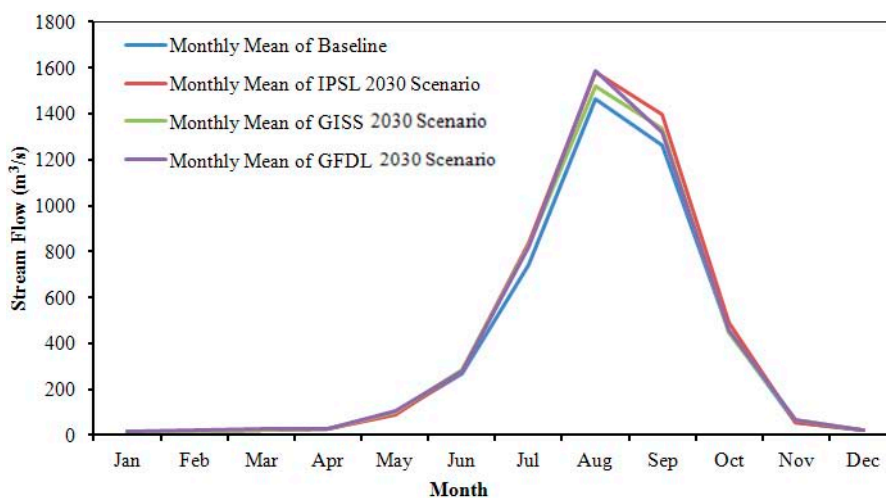


Figure 9. Comparing monthly changes in discharge of the Xebangfai@bridge station of the climate change scenarios with baseline scenario.

May) than the baseline scenario, as the end of the wet season is above the baseline scenario. The flow of climate change scenarios generated more than 800 m³/s of the monthly (July, August and September) with comparing the baseline scenario at the Xebangfai@bridge station as

shown in Table 3 and Figure 9. The peak discharge during these months of this area is commonly because of the southwest monsoon (wet season) in the middle of May to early October, which is a dominant phenomenon when air pressure is substantially low over Southeast Asia. In

Table 4. Monthly averages of scenarios 2030 in the dry season of the Xebangfai@bridge station (river discharge gauge station).

Dry Season	Monthly Mean of Baseline (m ³ /s)	Monthly Mean of IPSL 2030 (m ³ /s)	Monthly Mean of GISS (m ³ /s)	Monthly Mean of GFDL (m ³ /s)
Nov	57.36	58.54	65.36	69.26
Dec	23.25	24.05	23.37	23.75
Jan	18.72	19.15	18.63	18.94
Feb	19.43	19.03	19.28	19.79
Mar	21.75	20.29	23.32	25.57
Apr	29.43	25.52	28.67	29.72

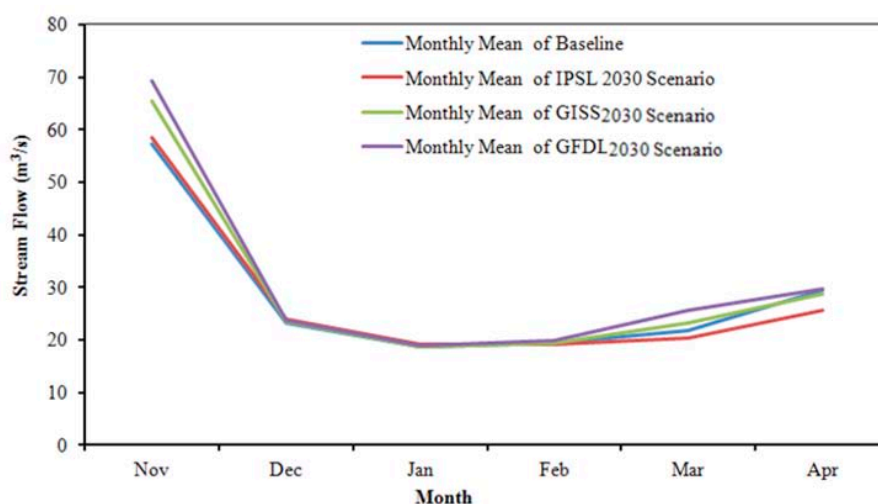


Figure 10. Monthly mean plots in the dry Season of overall scenarios and baseline.

addition to Lao PDR is influenced from heavy rainfall by citing some researches: Snidvongs *et al.*, (2003); Eastham *et al.*, (2008) and Västilä *et al.*, (2010); SONNASINH (2009); MRC (2015). The severe change scenario is overall of three scenarios as (IPSL CM5A-MR 2030), (GISS E2-R-CC 2030) and (GFDL CM3 2030), while the amount of monthly high surface runoff which the duration of the monthly high surface runoff also increases and expands until the first week of September. The stream flow comparison is given in Table 3 and Figure 9.

According to the results of Table 4 and Figure 10, they found that in the starting point they respond the information, and during the water resources availability in the

dry season is very little throughout the years, of which discharge is lower than 20 m³/s, which is able to result extreme drought in this southern part of region, but during the wet season in this region is under water. As the Table 3 shows the stream flow of the Xe Bang Fai river basin for the year 2030 based on the future climate change factor of three institutes recommended river discharge taking into account, the climate change is resulted in as well as in normal conditional distribution.

6. Conclusion

In this study, the hydrological response of Xe Bang Fai river basin to future climate change scenarios is evaluated by applying the dataset of exploratory climate change factors. The statistical data of climate change is applied to the SWAT model in the Xe Bang Fai river basin. The present-day monthly hydrographs are successfully calibrated and validated by using the SWAT model in the Xe Bang Fai river basin. The results are represented with the possible gauging the calibration and validation model for two periods as follows: 2001-2005 and 2006-2010. In this study, the results of the monthly simulation R^2 and E_{NS} are 0.970 and 0.967 during the calibration periods and are also 0.966 and 0.960 during the validation period.

In this study, the baseline results of calibrated hydrological model during the period 2001-2010 was used to compare the river charge change of the Xe Bang Fai river basin with the scenarios of climate change, namely IPSL CM5A-MR 2030, GISS E2-R-CC 2030 and GFDL CM3 2030 for forecasting surface runoff in the year 2030. The simulated runoffs based on the three models of different climate-simulated precipitations are widely different each other. For instance, the average monthly changes (specifically Percentage differenced rank) are (-13.29 to 12.55) for IPSL CM5A-MR, (-2.28 to 13.95) for GISS E2-R-CC and (1.18 to 20.75) for GFDL CM3 2030 scenario respectively. Notwithstanding the data uncertainty (Abbaspour *et al.*, 2004), the SWAT model can generate good simulation results of monthly time processes which are potentially valuable for water resources management in the Xe Bang Fai river basin as well as the whole sub-watershed in the Mekong river basin.

According to these results of climate change scenarios, the model can be used as valuable information for water resources management and natural disaster protection

in the future. The results of climate change model's scenarios can be also used for better information in future researches. Furthermore the SWAT model is able to be applied as the standard model for future study on sediment yield and water quality analysis. Additionally, this study is able to be conducted in the planning on hydropower dam construction irrigation system, levee and flood disaster risk management in the future which results of research are valuable for the sustainable country development under the 8th National Social-Economic Development Plan (2016-2020) of Lao PDR.

Notes

- 1) HRU is “the smallest spatial unit of the model and the standard HRU definition approach lumps all similar land uses, soils, and slopes within a sub-basin based upon user-defined thresholds” (Kalc *et al.*, 2015)
- 2) SUFI-2 is “the algorithm for using calibration and validation model in SWAT-CUP” (Abbaspour, 2015)
- 3) SWAT-CUP is “a calibration/uncertainty analysis or sensitivity program interface for SWAT model” (Abbaspour, 2015)

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