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i. Tittle: Impact of Land Use/Land Cover Change on Runoff using SWAT Modelling: A Case Study in Uper Prek Thnot Watershed in Cambodia

ii. Running title: Impact of LULCC on Runoff

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IMPACT OF LAND USE/LAND COVER CHANGE ON RUNOFF USING SWAT MODELLING: A CASE STUDY IN UPPER PREK THNOT WATERSHED IN CAMBODIA

ABSTRACT

Changes in land use/land cover (LULC) may result in water shortages, flood risk and soil erosion, contributing to the degradation of living conditions. Recognition of the impacts of LULC changes on water resources is a crucial aspect of watershed management. Thus, this paper aims to determine how LULC change affects runoff and other hydrological components including: groundwater, water yield, procolation and evaportranspiration in Upper Prek Thnot watershed from 2006 to 2018 by using SWAT modelling. The result indicates that LULC of Upper Prek Thnot watershed experienced such significant changes during these 13 years. Conversion of forest area into agricultural land was the main modification in the study area, which accounts for 39%. This followed by an increase of rubber plantation, built-up area, barren land and water bodies and a decrease of the wood shrub. These changes resulted in a corresponding increase in annual average surface runoff (36%) and water yield (2%), and a decrease of groundwater (24%), percolation (8%) and evapotranspiration (1%). In particular, if the forest area is converted to agricultural land, especially if the conversion takes place in large numbers, the hydrological elements will be significantly affected. Consequently, due to a noticeable alteration of LULC in the study area, a sound strategic management plan should be applied considerably to ensure the sustainability of ecosystem services.

KEYWORDS: Cambodia, hydrology, land use/land cover change, runoff, SWAT, Upper Prek Thnot watershed.

INTRODUCTION

Change in land use/land cover (LULC) is a complicated, dynamic process that connects natural and human processes, which directly affects soil, water, and atmosphere and is related to many of the world's environmental issues (Koomen and Stillwell, 2007). Such factors associating with the growth of population, economic development, and demands for land have been dominant causes of LULC change in most developing countries (Matlhodi et al., 2019; Msofe et al., 2019; Vadrevu et al., 2019). According to Metternicht (2018), inadequate governance is an important constraint for sustainable development planning; this encompasses land degradation and may intensify land-use conflicts. If land use planning and management are properly synchronized, valuable ecosystems will be protected sustainably from clearing as well. Also, analysis and explanations of past patterns, as well as a forecasting of future patterns, require an assessment of the major factors behind LULC change (Metternicht, 2018). Such decoupled knowledge is regularly provided by numerous LULC change applications, varying from ecological preservation and hydrological evaluations to land-use planning (Crews, 2008). Therefore, it is important to understand and define up-to-date and accurate information on LULC change and other ecological and hydrological components, especially for assisting in watershed management planning.

Watershed management is the integrated use of land, vegetation and water in a geographically discrete drainage area for the benefit of its residents in order to protect and preserve the hydrologic services provided by the watershed, as well as to reduce or avoid negative downstream and groundwater impacts (Darghouth et al., 2008). Moreover, an assessment of the impact of LULC change, especially on hydrology, is very important for developing sustainable water resource management strategies to maximize economic and social welfare without compromising vital ecosystem sustainability. Many studies over the world had been carried out to define the relationship between LULC change and hydrological components and its impact on runoff (Homdee et al., 2011; de Paulo Rodrigues da Silva et al., 2018; Mekuriaw, 2019; Hu et al., 2020). In assessing data simulation, several hydrological models have been advanced with different utility, applicability, and their unique features (Singh, 2018). These models are included TOPography based hydrological MODEL (TOPMODEL) (Devi et al., 2015; Singh, 2018), Variable Infiltration Capacity approach (VIC) (Das et al., 2018), the Hydrologic Modeling System (HEC-HMS) (Moraes et al., 2018), Soil and Water Assessment Tools (SWAT) (Gassman et al., 2007) etc.

However, not many studies have been conducted to determine the relationship between runoff and LULC change and its effects in Cambodia, especially in Prek Thnot watershed. Only a few types of research similarly related to hydrological components in Cambodia. For example, Sam (2007) carried out on distributed hydrological modelling of the Upper Prek Thnot watershed. The result showed the comparison of simulated and observed runoff from 2001 to 2003 with the model operation. Another instance, Ang and Oeurng (2018) studied on runoff simulation in Stung Pursat River Basin using SWAT model. The purpose of this study was to test the model applicability thru calibration and validation for predicting runoff on a daily and monthly basis. Also, the study of Try et al. (2020) focused on the comparison of gridded precipitation datasets for rainfall-runoff and inundation modelling in the Mekong River Basin. Nevertheless, none of these studies focuses on how LULC change affect runoff.

Moreover, Cambodia is one of Southeast Asia's climatically challenged countries and also has suffered from less precipitation, warmer weather, and delayed or shorter monsoon that affecting by El Niño events (Mishraet al., 2018). Also, two devastating events of abiotic stress – droughts and floods – occur every year in Cambodia (Chhinh & Millington, 2015). Chhinh and Millington (2015) highlighted that based on the means of long-term climate, Cambodia's annual precipitation regime consists of a 5-month dry season, which is from December to April, and a longer rainy season from the onset of the South East Asian Moonsoon, which usually from May to November. It also contains a short drought period in the rainy season which normally occurs in mid August. Over 80% of rainfall typically occurs in the rainy season (Chhinh & Millington, 2015). Additionally, according to Tsujimotoet al. (2018), the rainfall pattern can be significantly influenced by surface variability over time and space due to the unique hydrological characteristics of the land in Cambodia.

Furthermore, in terms of data, there are not many available hydrological and metrological stations in Cambodia as well as Prek Thnot watershed. Some stations are just recently built up and mostly located in the central of provinces or districts. Due to the limitation of data, effective and efficient management and monitoring in Prek Thnot watershed could be possibly affected. Though an advancement of technology and application is required, that could be applied to analyse and assess with a scarcity of the data. As the model development, SWAT model only needs a few specific calibrations for achieving such significant hydrological estimations (Devi et al., 2015). Also, SWAT was initially developed in order to assess water quality and quantity under various circumstances in small- and large catchments with adequate precision over time (past, present and future) (Moreira et al., 2018). With scarcity and limitation of the data, especially rainfall and weather data, SWAT model still provides potentials in data estimation with a satisfactory result (Ndomba et al., 2008; Nyeko, 2015; Leta et al., 2018; Mengistu et al., 2019).

Thus, in order to parameterize the spatial and temporal heterogeneity of LULC in Upper Prek Thnot watershed, the SWAT model, as a distributed hydrological model which is used widely in the world (Sertel et al., 2019; Shang et al., 2019), is proposed in this paper. The paper ~~also~~ aims to simulate and determine the impact of LULC change on runoff and other hydrological components such as groundwater, water yield, procolation and evaportranspiration in the study area.

MATERIALS AND METHODS

Study Area

Upper Prek Thnot watershed locates in Kompong Speu province and some parts of Koh Kong and Preah Sihanuk provinces, with a coverage of 3,450 km^2 (Khorn et al., 2020). It lies between latitudes of 11°00’ and 12°10’ N and longitudes of 103°40’ and 104°20’ E (Figure 1). Upper Prek Thnot watershed was characterized by conducting watershed delineation based on Prek Thnot watershed boundary (FA and APFNet, 2016), digital elevation map (DEM), and Peam Kley gauged station as an outlet. The Prek Thnot River flows from the Cardamom Mountains in the southwest of Cambodia towards Bassac River, a part of Mekong River. The elevation ranges from 38 m to 1,810 m above sea level. Upper Prek Thnot watershed is dominated by a tropical monsoon climate that having two specific seasons, such as the rainy season (May-October) and the dry season (November-April).

SWAT Model Description

SWAT is a basin−scale, continuous−time model that operates on a daily time step and is designed to forecast the impact of land management activities on the water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over a long period of time (Arnold et al., 2012). SWAT allows simulation of various physical processes in a watershed. For modelling purposes, a watershed can be divided into several subbasins and subsequently subdivided into hydrologic response units (HRUs) that comprised of homogeneous land use, management, and soil characteristics (Arnold et al., 2012). The HRUs describe proportions of the subbasins area and are not spatially identified in a SWAT simulation. On the other hand, a watershed can be subdivided into only subbasins that are categorized by dominant land use, soil type, and management (Gassman et al., 2007; Arnold et al., 2012). The hydrological cycle simulated by SWAT is based on the water balance equation:

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

where SW_t (mm) is the final soil water content; SW_0 (mm) is the initial soil water content on the day i (mm H_2O); t (days) is time, R_{day} (mm H_2O) is the precipitation amount on the day i; Qsurf is the amount of surface runoff on the day i (mm H_2O); E_a is the amount of evapotranspiration on the day i (mm H_2O); W_{seep} is the amount of water entering the vadose zone from the soil profile on the day i (mm H_2O), and Q_{qw} is the amount of return flow on the day i (mm H_2O).

Data Acquisition

SWAT input data includes topography, climate, land use/land cover, and soil map, as summarized in Table 1. The LULC maps in this study were reclassified based on the data which was provided from the Forest Administration (FA) under the Ministry of Agriculture, Forestry and Fisheries, and the Ministry of Environment (MOE) (Khorn et al., 2020). The soil map was taken from the FAO Soil Database and soil form descriptions (FAO, 2003). Hydrologic and climatic data such as rainfall, temperature, humidity, evaporation, flow data, were given from the Ministry of Water Resources and Meteorology (MOWRAM). However, the weather data from the station in Phnom Penh city is used to prepare for the weather database in ArcSWAT, since it is the nearest available station for this study. The station is about 40 km to Kampong Speu province (the centre of Prek Thnot watersed), and it is also part of Prek Thnot watershed as well (Figure 1).

SWAT Model Setup

The model operates readily available input data such as Digital Elevation Model (DEM), land use data, soil data and climatic data, as outlined in Table 1. In this analysis, the hydrological process was modelled using the extension of SWAT for ArcGIS software called ArcSWAT i.e. Khalid, (2018) and Kateb, et al. (2019). In the model setup, the first step was to delineate the watershed into multiple connected subbasins by using the DEM. The subbasins were further divided into HRUs, which were lumped land areas within the subbasins that were consist of land use, soil, slope, and management combinations. A total of 17 subbasins were generated, together with 144 HRUs (Figure 2). The HRUs were generated by defining the thresholds of land use over subbasin area at 10%, soil class over land-use area at 10%, and slope class over soil area at 10% using the multiple HRUs definitions. According to Her et al. (2015), if model results are desired at a finer resolution than the watershed outlet, such as the subwatershed outlet or HRU, relatively smaller thresholds should be employed.The model was run on a monthly time step for a period of 13 years from 2006 to 2018 with a warm-up period of 2 years (2006-2007).

Sensitivity Analysis

Sensitivity analysis was carried out to identify the most sensitive flow parameters that influence the watershed represented by SWAT for calibration (Arnold et al., 2012; Moreira et al., 2018). This was done by using the global sensitivity approach in semi-automated Sequential Uncertainty Fitting

(SUFI2) algorithm. The global sensitivity analysis method takes into account the sensitivity of one parameter relative to the other for statistical significance (Arnold et al., 2012). The t-statistics and p-values of the parameters were used to classify the individual parameters which influenced flow and the final selection done based on the significance of the ranked values (K. Khalid et al., 2016). The flow parameters tested for the sensitivity are shown in Table 2. These are useful for estimating the flow rate from a watershed.

Model calibration and validation

The model calibration was carried out through the comparison of model predictions (output) for a particular set of assumed conditions with the observed data under the same conditions by carefully selecting values in model input parameters within their respective uncertainty ranges (Arnold et al., 2012). After identifying the most sensitive model parameters, these were used again to calibrate the SWAT model using the SWAT-CUP in combination with the SUFI-2 method. Upon calibration by using the 2008–2015 runoff data, the model accuracy was analyzed during the validation process with the help of the data, which was not used during the calibration of the model. Hence, the simulated monthly runoff for 2016–2018 was compared to the observed monthly runoff data from the same period. The validation process also included all model evaluation parameters used for calibration.

Model performance evaluation

The model performance was evaluated by visual and statistical comparison of the observed and simulated data (ASEC, 1993; Ndulue et al., 2015). In watershed simulation model performance evaluation, Moriasi et al. (2007) recommended three quantitative statistics such as the Nash-Sutcliffe efficiency (NSE), the percent bias (PBIAS), and the ratio of the root mean square error to the standard deviation of measured data (RSR). General performance ratings of recommended statistics for runoff simulation were suggested by Moriasi et al. (2007), as shown in Table 3.

NSE describes the deviation from the unity of the ratio of the square of the difference between the observed and simulated values and the variance of the observations (Nash and Sutcliffe, 1970). NSE demonstrates how the observed data versus simulated data correlate well with 1:1. The ranges of NSE vary from $-\infty$ and 1. In general, values between 0 and 1 are considered an acceptable level of performance. In contrast, values < 0 illustrate that the mean observed value is a better predictor than the simulated value, which indicates unacceptable results (Moriasi et al., 2007). NSE is defined as:

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(Q_i^{obs} - Q_i^{¿} \right)^2}{\sum_{i=1}^{n} \left(Q_i^{obs} - Q_{mean}^{obs} \right)^2}$$

where Q_i^{obs} is ith observed runoff, $Q_i^{¿}$ is ith simulated runoff, and Q_{mean}^{obs} is the mean of observed data.

PBIAS describes a larger or smaller tendency of simulated data than the observed data. The optimal PBIAS value is 0, which means the model was simulated accurately. A model bias towards underestimation is indicated by positive values, while negatives show a bias towards overestimation (Gupta et al., 1999). PBIAS is calculated as:

$$PBIAS = \frac{\sum_{i=1}^{n} \left(Q_i^{obs} - Q_i^{¿} \right) \times 100}{\sum_{i=1}^{n} \left(Q_i^{obs} \right)}$$

RSR is an error-index that standardizing the root mean square error (RMSE) by using the standard deviation of observed data, which is calculated as shown as:

$$RSR = \frac{\sqrt{\sum_{i=1}^{n} \left(Q_i^{obs} - Q_i^{¿} \right)^2}}{\sqrt{\sum_{i=1}^{n} \left(Q_i^{obs} - Q_{mean}^{obs} \right)^2}}$$

The optimal RSR value varies from 0 to 1, which indicating zero RMSE or residual variation and thus, perfect model simulation at a great positive value (Moriasi et al., 2007).

RESULTS AND DISCUSSION

SWAT model performance evaluation results

Sensitivity analysis

Sensitivity analysis is essential in reducing the value of model parameters for the calibrated process and defining the most sensitive parameter that significantly affects surface runoff and base flow (Arnold et al., 2012). As presented in Table 4, parameters were defined to be the most sensitive parameters for the runoff predictions. The most sensitive parameters were ranked from the least to the most sensitivity due to their p-values. As a result, Curve Number (CN2), threshold water depth in the shallow aquifer for flow (GWQMN), effective hydraulic conductivity of main channel (CH_K2), base flow alpha-factor (ALPHA_BF), and available water capacity of the soil layer

(SOL_AWC) were relatively highly sensitive parameters that significantly affect surface runoff for scenario 1 (S1). However, CN2 and CH_K2 were the most sensitive parameters for scenario 2 (S2), as shown in Table 4.

Model calibration and validation

After the most sensitive parameters associated with runoff simulation were chosen in the sensitivity analysis procedure, the process of the calibration was also used to determine the fitted values, which recommended by Arnold et al. (2012). Table 5 shows the final fitted values of the parameters which generating by SWAT-CUP analysis.

Overall, the model performance was evaluated using the Nash-Sutcliffe efficiency (NSE), the ratio of the root mean square error to the standard deviation of measured data (RSR), and the percent bias (PBIAS). The coefficient of determination measures the proportional variation in the simulated variable explained by the measured variable and indicates the linear relationship between the estimated and measured variables (Moriasi et al. 2007). Moreover, it was addressed that monthly values came closer to the statistical criteria than daily values. It was also recommended that NSE and R^2 be used to analyze the monthly output for the evaluation of daily output by comparing SWAT results with observed runoff (Coffey et al., 2004). According to the study of Ang and Oeurng (2018), which conducted in Stung Pursat catchment in Cambodia, it showed that the performance of the model at monthly time scale is more satisfied than daily time scale due to data scarcity and uncertainty. Therefore, monthly runoff simulation was employed to determine the effect of LULC change on runoff in the study area.

The result of both scenarios indicates that NSE and RSR were defined as “good” for calibration, yet they were “unsatisfactory” for validation (due to divergence of observed and simulated values), based on the model performance rating of Moriasi et al. (2007). The differences between the observed and simulated values in the period of 2016 and 2018 may cuase by the effect of dam construction in the upstream of the watershed, which similar to the study of Li et al. (2016). Mailhot et al. (2018) addressed that the operation of the dam could affect the flow series recorded. When using the recorded flow of ungauged basin, impacts from dam operation are important and it is evaluated by unimodal distribution of the daily flow. Lee et al. (2019) also described that the upstream dam discharge greatly affected the downstream dam inflow. However, PBIAS was categorized as “very good” for calibration and validation in both scenarios. The statistical values of NSE, RSR and

PBIAS, are described in Table 6. Moreover, the result also shows that R^2 are 0.75 and 0.49, respectively (Figure 3 and 4). The hydrographs of monthly simulated and observed streamflow comparison with rainfall for scenario 1 and 2 are illustrated in Figure 5. The pattern of simulated streamflow for both scenarios indicates a similar trend. Hence, the R^2 and NSE values of the calibrated and validated simulations imply that the model calibration can sufficiently define streamflow variance within the basin and be further applied to determine the impacts of LULC change on hydrological responses.

Land use/land cover change

Upper Prek Thnot watershed was experienced such considerable changes in LULC between 2006 and 2018, as shown in Table 7 and Figure 6. Forest area decreased from 2,819.60 km^2 to 1,657.54 km^2, which accounts for 33.67% of a total change. There was no rubber plantation in Upper Prek Thnot watershed in 2006, however; it was estimated to be 10.55km^2 (0.31%) in 2018. Wood shrub declined from 239.29 km^2 to 77.51 km^2 with a net change of 4.69%. Agricultural land extensively increased from 380.93 km^2 to 1,639.91 km^2, which corresponds to 36.38% of a net change. Moreover, built-up area and barren land gradually increased from 10.64 km^2 to 44.28 km^2 (0.97% of a total change) and from 0.09 km^2 to 4.96 km^2 (0.14% of a total change), respectively. Water bodies enlarged from 0.23 km^2 to 16.12 km^2 with a rate change of 0.46% due to the construction of a water dam, which known as Tasal Dam. Such changes were driven by population growth and demand for land for rice production, cultivation (including sugarcane and other agro-industry crop plantations conversions by local people and economic land concession (ELC) companies and), residences and economic development matters (Khorn et al., 2020).

Impact of land use/land cover change on hydrological components

From 2006 to 2018, LULC in upper Prek Thnot watershed were changed significantly (Figure 6). 39% of total forested areas were converted into agricultural land. The 13-year LULC change in upper Prek Thnot watershed occurred to affect runoff at the diverse degree at the subbasin levels. It indicates that each type of land use could be relatively sensitive to runoff generation and other hydrologic components (Astuti et al., 2019). Consequently, the changes of LULC between 2006 and 2018 affected an increase of annual average surface runoff (36%) and water yield (2%), and a decline of groundwater (24%), percolation (8%) and evapotranspiration (1%), as shown in Figure7. These changes were relatively small, which are less than 20mm. By comparing to other components, surface runoff was greatly impacted by the changes in LULC between 2006 and 2018. At the subbasin levels, furthermore, a decline of forested areas and an expansion of agricultural land areas resulted in an increase of streamflow and surface runoff. However, streamflow was decreased in subbasin 3 and 6 due to the construction of a water dam in the subbasin 6 (Figure 8). It was concluded that runoff generation time in forest watersheds was greatly delayed, and peak flow was reduced significantly, which suggests that vegetation has played a significant role in rainfall accumulation and absorption (Zhang et al., 2007).

Discussion

The study revealed a significant change in LULC of the upper Prek Thnot watershed from 2006 to 2018. The expansion of agriculture from forested areas had undergone on a large scale in the study area. These alterations resulted in a modification of the hydrologic responses of the watershed. The results indicated that the 13-year change in LULC had affected a long-term increase of streamflow, surface runoff, and water yield, as well as a decrease of groundwater, percolation, and evapotranspiration. Wei et al. (2016) addressed that an increase or a decrease in annual streamflow, peak flow and baseflow is caused by deforestation or reforestation, respectively. It can be argued that the 13-years conversion of forest area to agricultural land with 39% net change may be sufficiently effective in creating significant changes in the annual long-term average of surface runoff and groundwater. Yet, the annual long-term average of water yield might not be significant enough. Moreover, Chang (2013) explained that forests could influence both water quantity and quality. The combination of canopies, root systems and litter floors could lower surface runoff and water yield and delay runoff generation in forest watershed than those in the non-forest watershed. Chang (2013) also added that forest clearing generally increases the yield of water. The growth is most substantial when the deforestation is occurred in watersheds with needle-leaf species, following by hardwoods and grasses.

In addition, numerous studies similarly found that hydrologic components are affected by the modification of forest lands into agricultural land (Wang et al., 2015; Truong et al., 2018; Munoth and Goyal, 2019). For instance, Babar and Ramesh (2015) stated that although a minor change in LULC could slightly influence the hydrologic parameters, yet it could affect runoff pathways which contribute to peak flows. Bathurst et al. (2011) described that forest cover impacts on peak discharge interactions and integration in response to smaller floods. The response in a small watershed is higher than in a large watershed in comparison to the flow rate pre and post deforestation (Truong et al., 2018). Deforestation also reduces actual evapotranspiration, and it raises water yields causing by conserved water from the tree's root systems (Chang, 2013). It was concluded that large water infiltration and evapotranspiration rates led to a decline in water yield coefficients in the forest area than in other types of LULC (Li et al., 2018).

Nevertheless, some studies showed that hydrology is more severely affected by climate variability than by LULC. The result of He et al. (2013), for example, revealed that changes in runoff ranged from 20 to 30% and 40% to 55%, which contributed by LULC and climate change, respectively. Another study by Shang et al. (2019) showed that the change in climate was much more sensitive to runoff than in LULC. The contribution rate was 87.15% for climate change, and 12.85% for LULC change. Moreover, it was also argued that climate change lowered seasonal streamflow about 20% and led to a significant change in flow seasonality. Conversely, LULC alteration partly counteracts the declining trend in streamflow driven by climate change (Farinosi et al., 2019). Similarly, according to Martin et al. (2017), future water balance was less impacted by changes in LULC than in climate. Although baseline behaviour could occur in hydrological processes, it was assumed that the responses largely depended on fine-scale LULC variations that were not addressed in past modelling research.

Furthermore, in an application of rainfall-runoff model, the event magnitude dependency was defined by a simple linear relation between the gamma distribution scale parameter and effective rainfall rate (Kokkonen et al., 2004). Kokkonen et al. (2004) explained that effective rainfall is most generally described as the rainfall portion which generates direct or surface runoff. The observed rainfall does not place a strong enough constraint on the effective rainfall when the storm event generates very little streamflow, which easily leads to several local optima within the parameter space. Beven (2012) argued that any inaccuracies due to a linear assumption that the runoff is to be routed are typically lower than the inaccurate determination of the rainfall to be taken, i.e. the problem of the effective rainfalls or runoff coefficient estimation for an event. A solved problem and a number of competing models remain in place to estimate effective rainfall on the basis of various assumption. Thus, rainfall-runoff models should be selected based on project objective, data availability, study size, required output and desired simplicity (Sitterson et al., 2017).

CONCLUSION

Upper Prek Thnot watershed signifies, a typical tropical watershed in a developing country was experiencing a change of LULC over time. Inadequate management practices in the Upper Prek Thnot watershed are still troubling. This means that any rapid modification in the LULC can inflict more severe risks to the watershed, particularly in regions where data are quite limited for monitoring frequently. The study highlights that 13-year changes in LULC led to alter runoff and other hydrologic components in Upper Prek Thnot watershed. A noticeable alteration of forested lands into agricultural lands between 2006 and 2018, the effects have increased annual average surface runoff (36%) and water yield (2%), and a decrease of groundwater (24%), percolation (8%) and evapotranspiration (1%). It can be concluded that the hydrologic components will be considerably affected if the forest areas are transformed into agricultural land, especially when the conversion is massive. Therefore, a wise strategic management plan should apply significantly to ensure the sustainability of the ecosystem services due to the significant changes of LULC in the study area. Also, SWAT modelling can be able to assist researchers and planning developers in estimating the effect of LULC change on hydrological components with scarcity and uncertainty of the data as in Upper Prek Thnot watershed case.

REFERENCES

American Society of Civil Engineers (ASEC). (1993). Criteria for evaluation of watershed models. *Journal of Irrigation and Drainage Engineering*, *119*(3), 429–442.

Ang, R., & Oeurng, C. (2018). Simulating streamflow in an ungauged catchment of Tonlesap Lake Basin in Cambodia using Soil and Water Assessment Tool (SWAT) model. *Water Science*, *32*(1), 89–101. https://doi.org/10.1016/j.wsj.2017.12.002

Arnold, J. ., Moraisi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., … Jha, M. K. (2012). SWAT: model use, calibration and validation. *American Society of Agricultural and Biological Engineers*, *55*(4), 1491–1508.

Astuti, I. S., Sahoo, K., Milewski, A., & Mishra, D. R. (2019). Impact of Land Use Land Cover (LULC) Change on Surface Runoff in an Increasingly Urbanized Tropical Watershed. *Water Resources Management*, *33*, 4087–4103. https://doi.org/10.1007/s11269-019-02320-w

Babar, S., & Ramesh, H. (2015). Streamflow response to land use-land cover change over the Nethravathi River Basin, India. *Journal of Hydrologic Engineering*, *20*(10). https://doi.org/10.1061/(ASCE)HE.1943-5584.0001177

Bathurst, J. C., Iroumé, A., Cisneros, F., Fallas, J., Iturraspe, R., Novillo, M. G., … Ramírez, M. (2011). Forest impact on floods due to extreme rainfall and snowmelt in four Latin American environments 1: Field data analysis. *Journal of Hydrology*, *400*(3–4), 281–291. https://doi.org/10.1016/j.jhydrol.2010.11.044

Beven, K. (2012). Evolution of Rainfall–Runoff Models: Survival of the Fittest? In K. Beven (Ed.), *Rainfall-Runoff Modelling: The Primier* (Second Edi, pp. 25–50).

Chang, M. (2013). Characteristic Forests. In M. Chang (Ed.), *Forest Hydrology: An Introduction to Water and Forests, Third Edition* (Third, pp. 123–156).

Chhinh, N., & Millington, A. (2015). Drought Monitoring for Rice Production in Cambodia. *Climate*, *3*, 792–811. https://doi.org/10.3390/cli3040792

Coffey, M. E., Workman, S. R., Taraba, J. L., & Fogle, A. W. (2004). Statistical procedures for evaluating daily and monthly hydrologic model predictions. *Transactions of the American Society of Agricultural Engineers*, *47*(1), 59–68. https://doi.org/10.13031/2013.15870

Crews, K. A. (2008). Landscape Dynamism Disentangling Thematic versus Structural Change in Northeast Thailand. In R. J. Aspinall & M. J. Hill (Eds.), *Land Use Change: Science, Policy and Management* (pp. 99–118).

Darghouth, S., Ward, C., Gambarelli, G., Styger, E., & Roux, J. (2008). *Watershed management approaches, policies, and operations: Lessons for scaling up* (No. 11). *Water Sector Board Discussion Papers*. Retrieved from http://documents.worldbank.org/curated/en/2008/05/9608907/watershed-management-approaches-policies-operations-lessons-scaling-up%5Cnhttp://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2008/06/26/000020439_20080626162646/Rendered/PDF/442

Das, P., Behera, M. D., Patidar, N., Sahoo, B., Tripathi, P., Behera, P. R., … Roy, P. S. (2018). Impact of LULC change on the runoff , base flow and evapotranspiration dynamics in eastern Indian river basins during 1985 – 2005 using variable infiltration capacity approach. *Journal of Earth System Science*, *127*(2), 19. https://doi.org/10.1007/s12040-018-0921-8

de Paulo Rodrigues da Silva, V., Silva, M. T., Singh, V. P., de Souza, E. P., Braga, C. C., de Holanda, R. M., … Braga, A. C. R. (2018). Simulation of stream flow and hydrological response to land-cover changes in a tropical river basin. *Catena*, *162*(2018), 166–176. https://doi.org/10.1016/j.catena.2017.11.024

Devi, G. K., Ganasri, B. P., & Dwarakish, G. S. (2015). A Review on Hydrological Models. *Aquatic Procedia*, *4*, 1001–1007. https://doi.org/10.1016/j.aqpro.2015.02.126

FA (Forestry Administration of Cambodia), & APFNet (Asian-Pacific Network for Sustainable Forest Management and Rehabilitation). (2016). *Watershed Characterization of Prek Thnot Watershed*.

Farinosi, F., Arias, M. E., Lee, E., Longo, M., Pereira, F. F., Livino, A., … Briscoe, J. (2019). Future Climate and Land Use Change Impacts on River Flows in the Tapajós Basin in the Brazilian Amazon. *Earth's Future*, *7*, 993–1017. https://doi.org/10.1029/2019EF001198

Food and Agriculture Organization of the United Nation (FAO). (2003). Digital soil map of the world (DSMW). Version 3.6. Land and Water Development Division, FAO, Rome.

Gassman, P. W., Reyes, M. R., Green, C. H., & Arnold, J. G. (2007). The Soil and Water Assessment Tool: historical development, applications, and future research directions. *American Society of Agricultural and Biological Engineers*, *50*(4), 1211–1250.

Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration. *Journal of Hydrologic Engineering*, *4*(2), 135–143.

He, Y., Lin, K., & Chen, X. (2013). Effect of land use and climate change on runoff in the Dongjiang basin of south China. *Mathematical Problems in Engineering*, *2013*. https://doi.org/10.1155/2013/471429

Her, Y., Frankenberger, J., Chaubey, I., & Srinivasan, R. (2015). Threshold Effects in HRU Definition of the Soil and Water Assessment Tool. *American Society of Agricultural and Biological Engineers*, *58*(2), 367–378. https://doi.org/10.13031/trans.58.10805

Homdee, T., Pongput, K., & Kanae, S. (2011). IMPACTS OF LAND COVER CHANGES ON HYDROLOGIC RESPONSES : A CASE STUDY OF CHI RIVER BASIN , THAILAND. *Journal of Japan Society of Cilvil Engineers*, *67*, 31–36.

Hu, S., Fan, Y., & Zhang, T. (2020). Assessing the effect of land use change on surface runoff in a rapidly Urbanized City: A case study of the central area of Beijing. *Land*, *9*(1). https://doi.org/10.3390/land9010017

Kateb, Z., Bouchelkia, H., Benmansour, A., & Belarbi, F. (2019). Hydrological modeling using the SWAT model based on two types of data from the watershed of Beni Haroun dam, Algeria. *Journal of Water and Land Development*, *43*, 76–89. https://doi.org/10.2478/jwld-2019-0065

Khalid, C. (2018). Hydrological modeling of the Mikkés watershed (Morocco) using ARCSWAT. *Sustainable Water Resources Management*, *4*, 105–115. https://doi.org/10.1007/s40899-017-0145-0

Khalid, K., Ali, M. F., Rahman, N. F. A., Mispan, M. R., Haron, S. H., & Zulhafizal Othman, M. F. B. (2016). Sensitivity analysis in watershed model using SUFI-2 algorithm. *Procedia Engineering*, *162*(2016), 441–447. https://doi.org/10.1016/j.proeng.2016.11.086

Khorn, N., Ismail, M. H., Kamarudin, N., & Nurhidayu, S. (2020). Land Use Change using Geospatial Techniques in Upper Prek Thnot Watershed in Cambodia. *Pertanika J. Sci & Technol*, *28*(3), 879–892.

Kokkonen, T., Koivusalo, H., Karvonen, T., Croke, B., & Jakeman, A. (2004). Exploring streamflow response to effective rainfall across event magnitude scale. *Hydrological Processes*, *18*, 1467–1486. https://doi.org/10.1002/hyp.1423

Koomen, E., & Stillwell, J. (2007). Modelling land-use change. In E. Koomen, J. Stillwell, A. Bakema, & H. J. Scholten (Eds.), *Modelling land-use change* (pp. 1–21).

Lee, G., Lee, H. W., Lee, Y. S., Choi, J. H., Yang, J. E., Lim, K. J., & Kim, J. (2019). The Effect of Reduced Flow on Downstream Water Systems Due to the Kumgangsan Dam under Dry Conditions. *Water*, *11*, 739. https://doi.org/10.3390/w11040739

Leta, O. T., El-kadi, A. I., & Dulai, H. (2018). Assessment of SWAT Model Performance in Simulating Daily Streamflow under Rainfall Data Scarcity in Pacific Island Watersheds.

Water, *10*, 1533. https://doi.org/10.3390/w10111533

Li, E., Mu, X., Zhao, G., Gao, P., & Sun, W. (2016). Effects of check dams on runoff and sediment load in a semi-arid river basin of the Yellow River. *Stochastic Environmental Research and Risk Assessment*, *31*, 1791–1803. https://doi.org/10.1007/s00477-016-1333-4

Li, S., Yang, H., Lacayo, M., Liu, J., & Lei, G. (2018). Impacts of land-use and land-cover changes on water yield: A case study in Jing-Jin-Ji, China. *Sustainability*, *10*, 960. https://doi.org/10.3390/su10040960

Mailhot, A., Talbot, G., Ricard, S., Turcotte, R., & Guinard, K. (2018). Journal of Hydrology : Regional Studies Assessing the potential impacts of dam operation on daily fl ow at ungauged river reaches. *Journal of Hydrology: Regional Studies*, *18*, 156–167. https://doi.org/10.1016/j.ejrh.2018.06.006

Martin, K. L., Hwang, T., Vose, J. M., Coulston, J. W., Wear, D. N., Miles, B., & Band, L. E. (2017). Watershed impacts of climate and land use changes depend on magnitude and land use context. *Ecohydrology*, *10*(7), e1870. https://doi.org/10.1002/eco.1870

Matlhodi, B., Kenabatho, P. K., Parida, B. P., & Maphanyane, J. G. (2019). Evaluating Land Use and Land Cover Change in the Gaborone Dam Catchment, Botswana, from 1984 – 2015 Using GIS and Remote Sensing. *Sustainability*, *11*, 5174.

Mekuriaw, T. (2019). Evaluating Impact of Land-Use/Land-Cover Change on Surface Runoff using Arc SWAT Model in Sore and Geba Watershed, Ethiopia. *Journal of Environment and Earth Science*, *9*(10), 7–17. https://doi.org/10.7176/jees/9-10-02

Mengistu, A. G., Rensburg, L. D. Van, & Woyessa, Y. E. (2019). Journal of Hydrology : Regional Studies Techniques for calibration and validation of SWAT model in data scarce arid and semi-arid catchments in South Africa. *Journal of Hydrology: Regional Studies*, *25*(2019), 100621. https://doi.org/10.1016/j.ejrh.2019.100621

Metternicht, G. (2018). *Land Use and Spatial Planning: Enabling Sustainbale Management of Land Resources*. https://doi.org/10.1787/9789264061330-8-en

Mishra, A. K., Bairagi, S., Lourdes, M., & Mohanty, S. (2018). Impact of access to capital and abiotic stress on production e ffi ciency: Evidence from rice farming in Cambodia. *Land Use Policy*, *79*, 215–222. https://doi.org/10.1016/j.landusepol.2018.08.016

Moraes, T. C. de, Santos, V. J. dos, Calijuri, M. L., & Torres, F. T. P. (2018). Effects on runoff caused by changes in land cover in a Brazilian southeast basin: evaluation by HEC-HMS and HEC-GEOHMS. *Environmental Earth Sciences*, *77*(6), 250. https://doi.org/10.1007/s12665-018-7430-6

Moreira, L. L., Schwamback, D., & Rigo, D. (2018). Sensitivity analysis of the Soil and Water Assessment Tools (SWAT) model in streamflow modeling in a rural river basin. *Ambiente &*

Água - An Interdisciplinary Journal of Applied Science, *13*(6), e2221. https://doi.org/10.4136/1980-993X

Moriasi, D. N., Arnold, J. G., Liew, M. W. Van, Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *American Society of Agricultural and Biological Engineers*, *50*(3), 885–900.

Msofe, N. K., Sheng, L., & Lyimo, J. (2019). Land Use Change Trends and Their Driving Forces in the Kilombero Valley Floodplain , Southeastern. *Sustainability*, *11*, 505. https://doi.org/10.3390/su11020505

Munoth, P., & Goyal, R. (2019). Impacts of land use land cover change on runoff and sediment yield of Upper Tapi River Sub-Basin, India. *Intl. J. River Basin Management*. https://doi.org/10.1080/15715124.2019.1613413

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part 1 - a discussion of principles. *Journal of Hydrology*, *10*(1970), 282–290.

Ndomba, P., Mtalo, F., & Killingtveit, A. (2008). SWAT model application in a data scarce tropical complex catchment in Tanzania. *Physics and Chemistry of the Earth*, *33*(2008), 626–632. https://doi.org/10.1016/j.pce.2008.06.013

Ndulue, E. L., Mbajiorgu, C. C., Ugwu, S. N., Ogwo, V., & Ogbu, K. N. (2015). Assessment of land use/cover impacts on runoff and sediment yield using hydrologic models: A review. *Journal of Ecology and The Natural Environment*, *7*(2), 46–55. https://doi.org/10.5897/JENE2014.0482

Nyeko, M. (2015). Hydrologic Modelling of Data Scarce Basin with SWAT Model: Capabilities and Limitations. *Water Resource Management*, *29*(1), 81–94. https://doi.org/10.1007/s11269-014-0828-3

Sam, C. S., Goto, A., & Mizutani, M. (2007). Distributed Hydrological Modeling of Upper Prek Thnot River Watershed. *Transactions of The Japanese Society of Irrigation, Drainage and Rural Engineering*, *252*, 633–642.

Sertel, E., Imamoglu, M. Z., Cuceloglu, G., & Erturk, A. (2019). Impacts of Land Cover / Use Changes on Hydrological Processes in a Rapidly Urbanizing Mid-latitude Water Supply Catchment. *Water*, *11*, 1075.

Shang, X., Jiang, X., & Jia, R. (2019). Land Use and Climate Change Effects on Surface Runoff Variations in the Upper Heihe River Basin. https://doi.org/10.3390/w11020344

Singh, A. (2018). A Concise Review on Introduction to Hydrological Models. *Global Research and Development Journal for Engineering*, *3*(10), 14–19.

Sitterson, J., Knightes, C., Parmar, R., Wolfe, K., Muche, M., & Avant, B. (2017). *An Overview of Rainfall-Runoff Model Types*. U.S. Environmental Protection Agency, Washington, DC, EPA/

600/R-17/482, 2017.

Truong, N. C. Q., Nguyen, H. Q., & Kondoh, A. (2018). Land use and land cover changes and their effect on the flow regime in the upstream Dong Nai River Basin, Vietnam. *Water*, *10*, 1206. https://doi.org/10.3390/w10091206

Try, S., Tanaka, S., Tanaka, K., Sayama, T., Oeurng, C., Uk, S., … Han, D. (2020). Comparison of gridded precipitation datasets for rainfall-runoff and inundation modeling in the Mekong River Basin. *PLoS ONE*, *15*(1), e0226814. https://doi.org/10.1371/journal.pone.0226814

Tsujimoto, K., Ohta, T., Aida, K., Tamakawa, K., & Im, M. S. (2018). Diurnal pattern of rainfall in Cambodia: its regional characteristics and local circulation. *Progress in Earth and Planetary Science*, *5*, 39.

Vadrevu, K., Heinimann, A., Gutman, G., & Justice, C. (2019). Remote sensing of land use / cover changes in South and Southeast Asian Countries. *International Journal of Digital Earth*, *12*(10), 1099–1192. https://doi.org/10.1080/17538947.2019.1654274

Wang, K., Zhang, Q., Chen, Y. D., Singh, V. P., Wang, K., Zhang, Q., … River, E. (2015). Effects of land-use / cover change on hydrological processes using a GIS / RS-based integrated hydrological model : case study of the East River , China Effects of land-use / cover change on hydrological processes using a GIS / RS-based integrated hydrolo. *Hydrological Sciences Journal*, *60*(10), 1724–1738. https://doi.org/10.1080/02626667.2014.949723

Wei, X., Li, Q., Zhang, M., Liu, W., & Fan, H. (2016). Forest Cover Changes and Hydrology in Large Watersheds. In D. M. Amatya, T. M. Williams, L. Bren, & C. de Jong (Eds.), *Forest Hydrology-processes, management and assessment* (pp. 180–191).

Zhang, X., Yu, X., Wu, S., & Liu, H. (2007). Effects of forest vegetation on runoff and sediment transport of watershed in Loess area , west China. *Frontiers of Forestry in China*, *2*, 163–168. https://doi.org/10.1007/s11461-007-0026-z

TABLES:

Table 1. The available input data for SWAT model setting

Data	Information	Period	Source
DEM	Raster 30m-resolution	-	OpenTopogrphy
LULC map	Raster 30m-resolution	2006 and 2018	Khorn et al. (2020)
Soil type map	Raster 30m-resolution	-	FAOSOIL
Rainfall data	Daily	2006-2018	MOWRAM
Climatic data	Monthly	2006-2018	MOWRAM
Flow data (observed data)	Daily	2007-2018	MOWRAM

Table 2. Sensitivity analysis parameters

Parameters	Definition	Range		Method
		Min	Max	
Alpha-BF.gw	Base-flow alpha factor	0	1	Replace(2)
Ch_K2,rte	Effective hydraulic conductivity of the main channel	0	500	Replace(2)
Ch_N2.rte	Manning's value of main channel	0	0.3	Replace(2)
CN2.mgt	Moisture condition II Curve Number	-25%	25%	Relative(1)
Esco.hru	Soil evaporation compensation factor	0	1	Replace(2)
Gw_delay.gw	Groundwater delay (days)	0	500	Replace(2)
Gwqmn.gw	The threshold water level in a shallow aquifer for baseflow	0	5000	Replace(2)
Revapmn.gw	Threshold water level in shallow aquifer for revap	0	500	Replace(2)
Sol_AWC.sol	Available water capacity of the soil layer	-25%	25%	Relative(1)
Sol_K.sol	Saturated hydraulic conductivity	0	2000	Replace(2)
Sol_Z.sol	Depth of soil	0	3500	Replace(2)
Surlag.bsn	Surface runoff lag coefficient	0	24	Replace(2)

Note: (1) Multiplying initial parameter by value in the percentage
(2) Replacing the initial parameter by value

Table 3. Model performance rating based on RSR, NSE and PBIAS

Performance rating	NSE	RSR	PBIAS
Very good	$0.75 < NSE \leq 1$	$0.5 < NSE \leq 0$	PBIAS < ±10
Good	$0.65 < NSE \leq 0.75$	$0.5 < NSE \leq 0.6$	±10 ≤ PBIAS < ±15
Satisfactory	$0.5 < NSE \leq 0.65$	$0.6 < RSR \leq 0.7$	±15 ≤ PBIAS < ±25
Unsatisfactory	$NSE \leq 0.5$	$RSR > 0.7$	PBIAS ≥ ±25

Source: (Moriasi et al., 2007)

Table 4. Most sensitive parameters for runoff simulation in Upper Prek Thnot watershed

No	Parameter Name	Rank		Ranged value		p-value	
		S1*	S2*	Min	Max	S1*	S2*
1	V__GWQMN.gw	10	9	0	5000	0.68603	0.85744
2	V__GW_DELAY.gw	9	10	0	500	0.67052	0.77111
3	V__CH_N2.rte	8	6	0	0.3	0.61428	0.24818
4	V__SOL_K.sol	7	5	0	2000	0.61138	0.21603
5	V__ESCO.hru	6	8	0	1	0.32338	0.53127
6	V__SURLAG.bsn	5	4	0	24	0.26142	0.19048
7	R__SOL_AWC.sol	4	3	-25%	25%	0.04587	0.05247
8	V__ALPHA_BF.gw	3	7	0	1	0.01080	0.51537
9	V__CH_K2.rte	2	2	0	500	0.00473	0.00933
10	R__CN2.mgt	1	1	-25%	25%	2.05E-08	1.37E-13

Note: * S1 = Scenario 1: using land use/land cover map in the year 2006

S2 = Scenario 2: using land use/land cover map in the year 2018

Table 5. Final auto-calibration results of fitted sensitive parameters

No	Parameter Name	Ranged Value		Fitted Value
		Min	Max	
1	r__SOL_AWC.sol	-25%	25%	-0.105
2	v__SOL_K.sol	0	2000	860.000
3	v__CH_K2.rte	0	500	375.000
4	v__CH_N2.rte	0	0.3	0.009
5	v__ESCO.hru	0	1	0.690
6	v__SURLAG.bsn	0	24	15.600
7	r__CN2.mgt	-25%	25%	-0.245
8	v__ALPHA_BF.gw	0	1	0.650
9	v__GW_DELAY.gw	0	500	175
10	v__GWQMN.gw	0	5000	2250

Table 6. Model performance rating for calibration and validation

	Scenario 1			Scenario 2		
	NSE	RSR	PBIAS	NSE	RSR	PBIAS
Calibration	0.75	0.51	-1.20	0.75	0.50	-4.50
Validation	0.48	0.72	4.00	0.48	0.72	7.0

Table 7. Land use/land cover status (2006-2018) in the study area

LULC Class	2006		2018		Net changes	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Forest	2819.60	81.71	1657.54	48.03	-1162.06	-33.67
Rubber plantation	0.00	0.00	10.55	0.31	10.55	0.31
Wood shrub	239.39	6.94	77.51	2.25	-161.88	-4.69
Agricultural land	380.93	11.04	1639.91	47.52	1258.99	36.48
Built-up area	10.64	0.31	44.28	1.28	33.64	0.97
Barren land	0.09	0.00	4.96	0.14	4.87	0.14
Water	0.23	0.01	16.12	0.47	15.89	0.46
Total	**3450.87**	**100**	**3450.87**	**100**		

Source: Khorn et al. (2020)

FIGURES

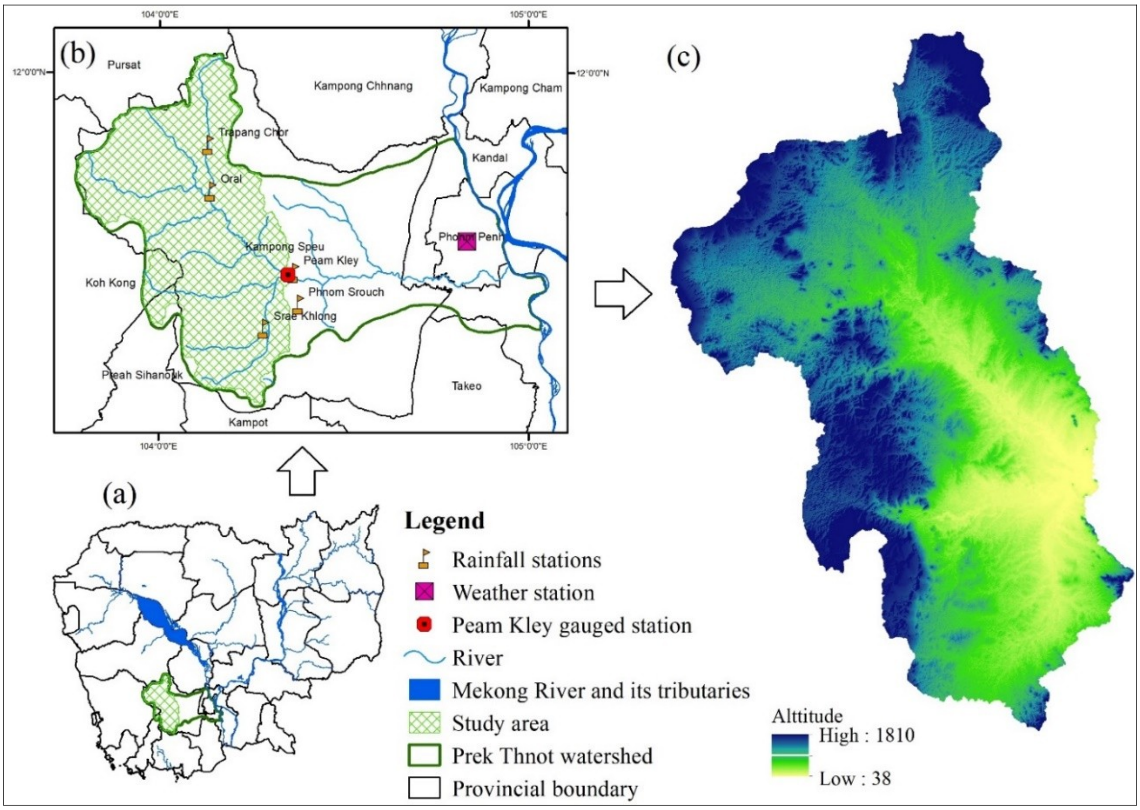

Figure 1. The location of Upper Prek Thnot watershed within (a) Cambodia and (b) Prek Thnot watershed with available hydrological and weather stations; and (c) Upper Prek Thnot's elevation (m)

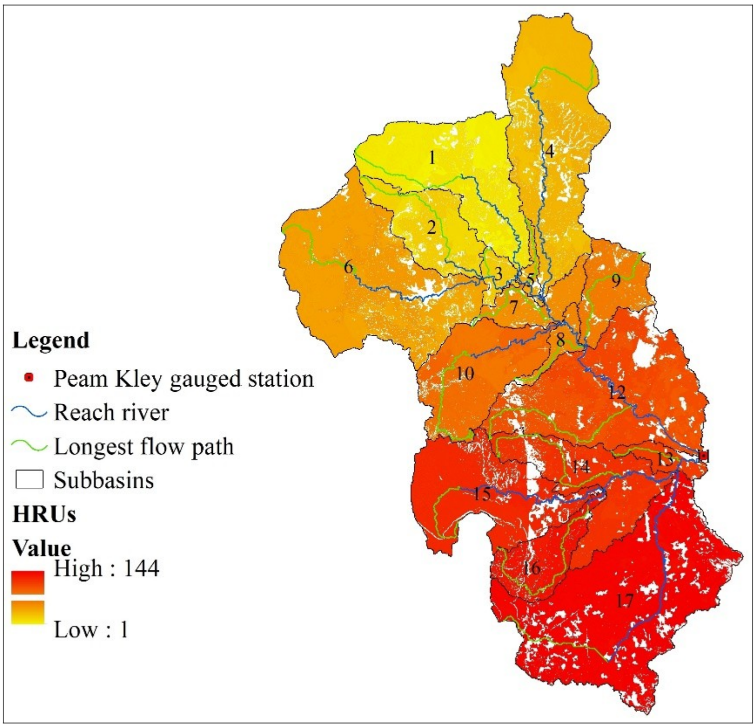

Figure 2: Subbasins and HRUs in the Upper Prek Thnot watershed that were generated by ArcSWAT applications

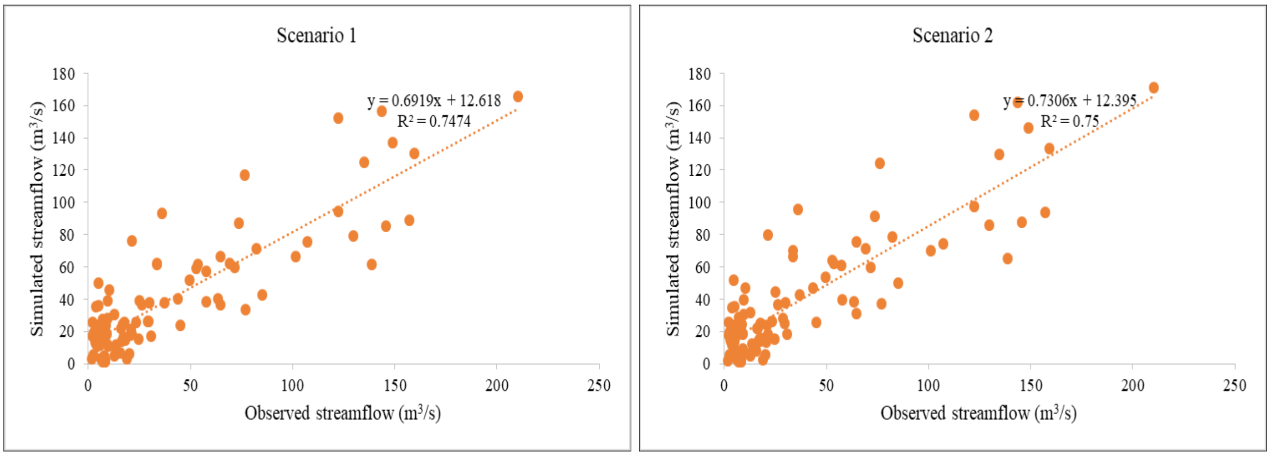

Figure 3. Observed and simulated streamflow for SWAT model calibration (a) scenario 1 and (b) scenario 2

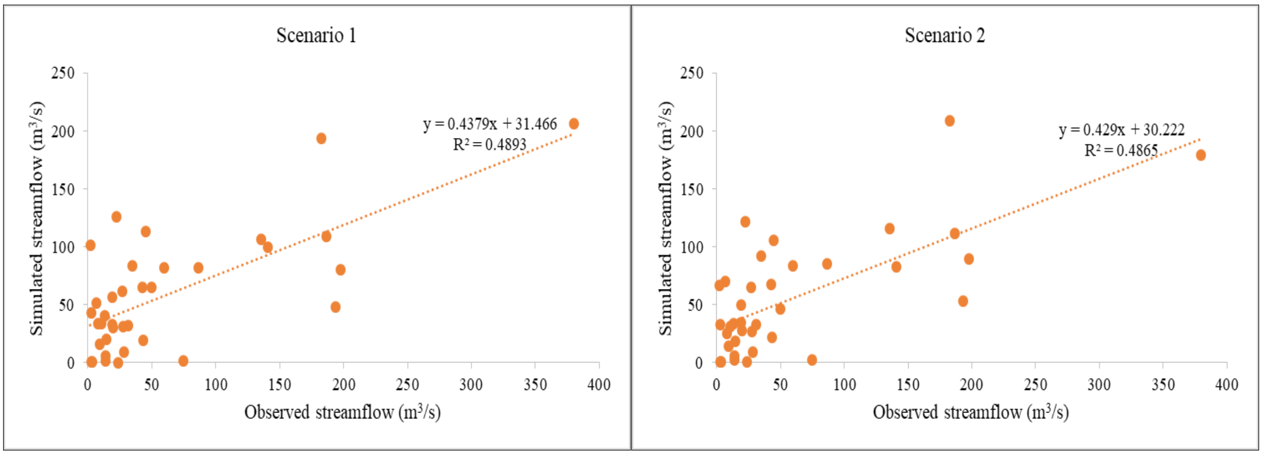

Figure 4. Observed and simulated streamflow SWAT model validation (a) scenario 1 and (b) scenario 2

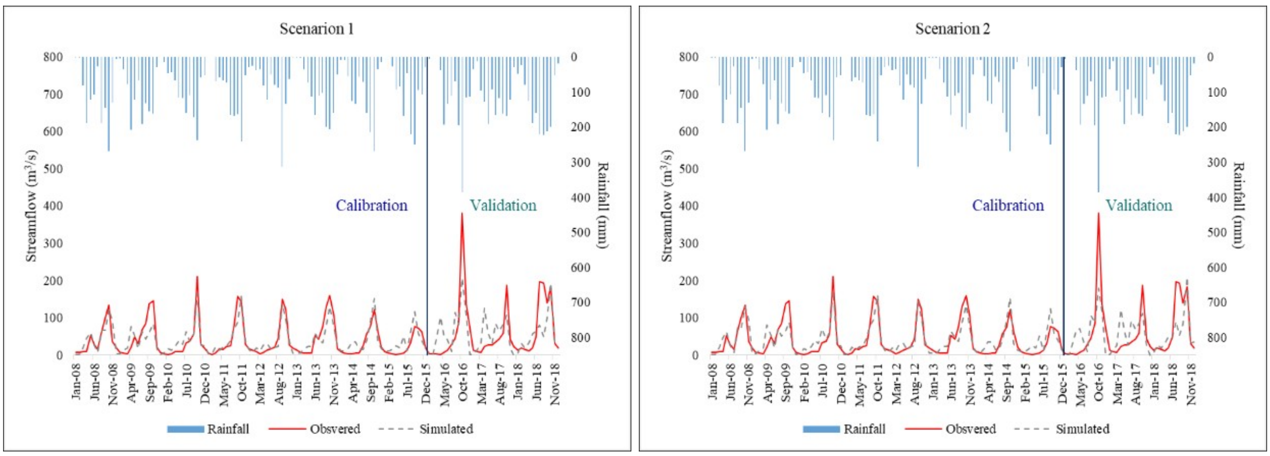

Figure5. The hydrographs of monthly simulated and observed streamflow (a) scenario 1 and (b) scenario 2

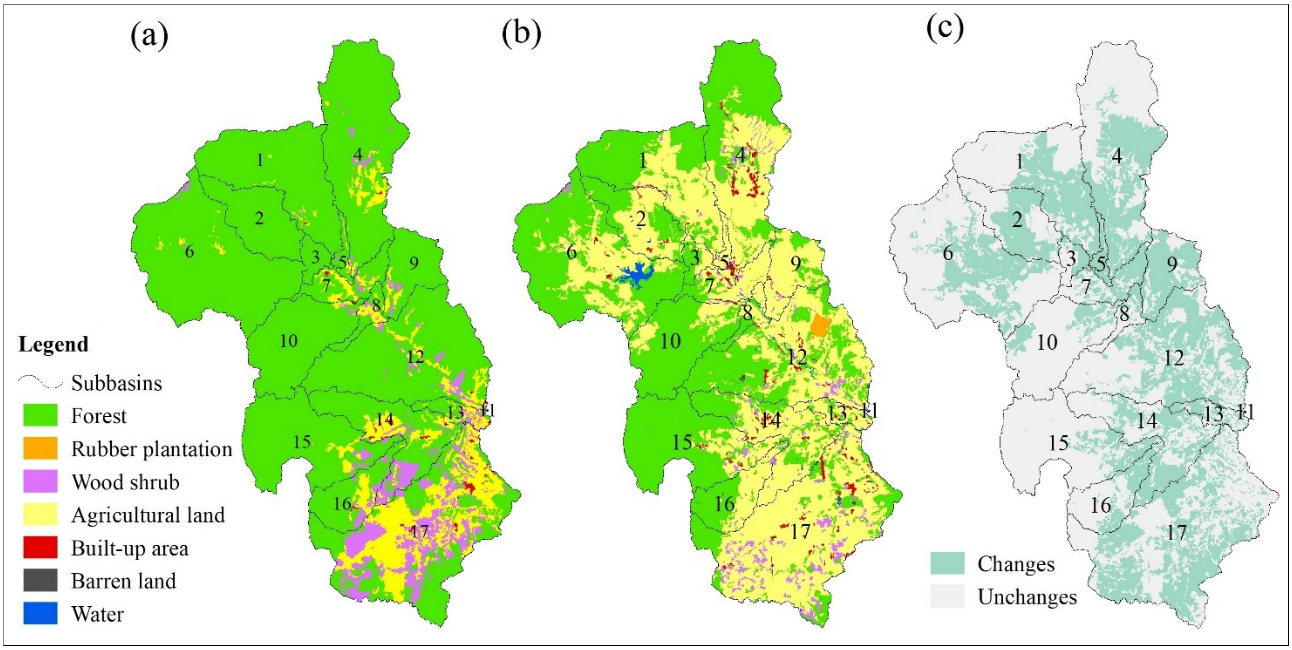

Figure 6. LULC (a) in 2006, (b) in 2018, and (c) changes between 2006 and 2018

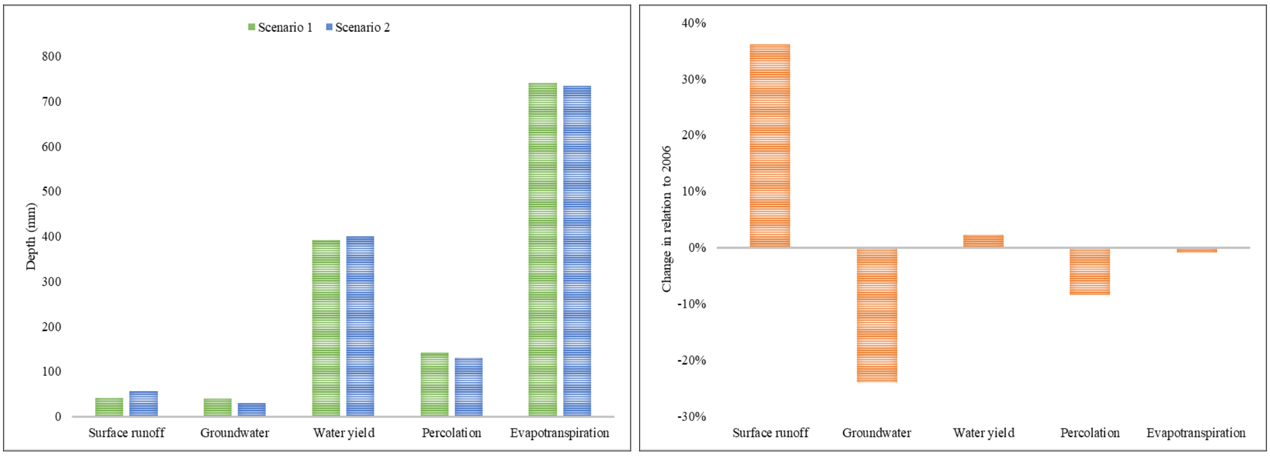

Figure 7. The alteration of hydrological components in (a) average annual values and (b) percentage that were affected by LULC change between 2006 and 2018

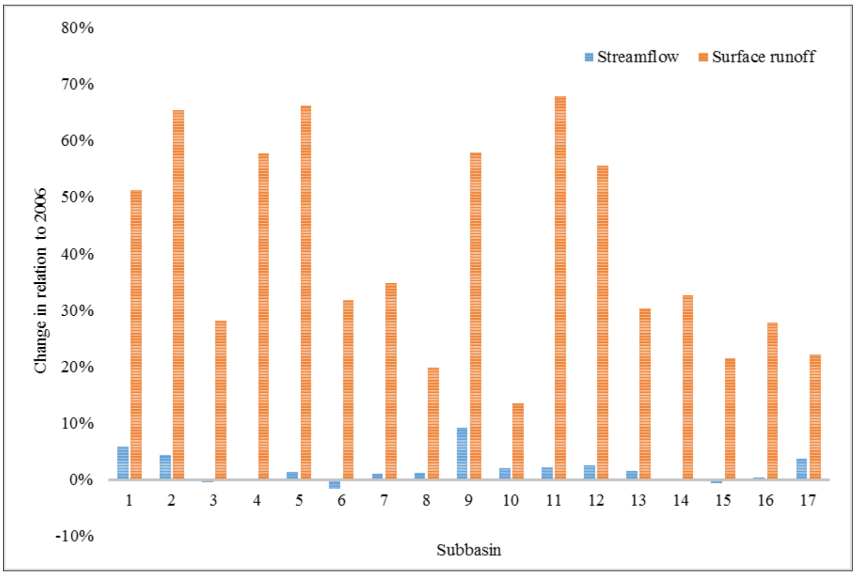

Figure 8. The alteration of surface runoff (mm) and streamflow (m^3/s) in each subbasin in Upper Prek Thnot watershed between 2006 and 2018