

Calibration of Hydrological Streamflow Modeling Using MODIS

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Abstract: LULC (land use and land cover) plays an important role in mathematical hydrological modeling. As many countries, available LULC are not always updated to reflect the most current situation. In this regard, the objective of this study was to investigate the potential capability of moderate resolution satellite imagery such as MODIS (Moderate Resolution Imaging Spectroradiometer), acquired in 2010 for updated LULC. This issue was illustrated through the application of the most current LULC as one of the data inputs of the SWAT (Soil and Water Assessment Tool) model in the Tonle Sap Lake Basin, a sub-basin of the Mekong River. The streamflow was tested using moderate resolution LULC of 500 meters. The statistical evaluation results at a monitoring station for model calibration and validation showed that the R^2 for daily and monthly values range from 0.76 to 0.88 and 0.86 to 0.89 respectively, whereas the Nash-Sutcliffe efficiency daily and monthly values range between 0.75 to 0.85 and 0.76 to 0.87 respectively. The simulation result based on MODIS imagery demonstrates LULC at moderate resolution holds considerable potential as an effective hydrological modeling tool. An additional level of confidence is provided by the notion that the methods described here could be applied in similar watershed conditions.

Key words: LULC (land use and land cover), MODIS, SWAT (Soil and Water Assessment Tool), modeling, streamflow.

1. Introduction

LULC (land use and land cover) dataset, which is important in a watershed for hydrological and environmental modeling, require accurate LULC datasets to parameterize the physical system being simulated [1]. It is important that land-cover data be based on the most current data available, since the land-cover changes over time [2]. In watersheds, where LULC change takes place over the modeling period, using a single land-use geospatial data is not a true representation of the watershed condition [3]. The LULC data are one of the essential inputs for SWAT (Soil and Water Assessment Tool) model to which this research was applied.

SWAT is considered one of the most suitable physically-based models for simulating hydrological condition and is one of the most widely used watershed-scale water-quality models in the world. Nearly 600 peer-reviewed SWAT-related journal articles have been published and hundreds more have been published in conference proceedings and other formats [4]. Rossi et al. [5] pointed out that SWAT can potentially be used as an effective water quantity tool within Mekong basin. In which, SWAT model has been setup to simulate streamflow in each Mekong sub-basin [6]. In the Mekong Sub-basin the SWAT model has been calibrated using the most up-to-date available land use data of 2003 generated from Landsat image against available streamflow data for the period 1985-2000 [7]. The SWAT simulation result provided daily estimates of flow for 138 sub-basins covering

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entire the Lower Mekong basin except the delta south of Phnom Penh [6]. However, whether using simple or complex models, an accurate LULC dataset with an appropriate spatial or temporal resolution and level of detail is paramount for reliable predictions [8].

Landsat imagery is widely used to produce high resolution LULC data covering large river watershed. Although high resolution satellite imagery data can be extremely useful for LULC change detection and monitoring efforts, it can be difficult to obtain an image over the entire study area during a particular timeframe. In other words, only it is rarely possible to generate more than one scene of high resolution satellite imagery in a day. The revisit characteristics of the satellites, as well as the presence of cloud cover, can limit the availability of data [9]. In addition, spatial data, including land use, are usually expensive to obtain. This paper explores alternatives aimed at overcoming the limitations of LULC for hydrological modeling. To achieve the overall goal of the research, the status of LULC in 2010 was mapped out using both GIS (Geographic Information System) analysis and remote sensing data such as MODIS (Moderate Resolution Imaging Spectroradiometer) with 500 m resolution. The principle objective of this study is to assess whether free-data-MODIS can be effectively applied as an input for hydrological modeling. It is expected that the results of this study will contribute useful hydrologic information regarding the possibility of moderate-resolution of LULC data for large river watershed assessments.

2. Study Area

Tonle Sap Lake Basin is located in the northwest of Cambodia, between approximately latitudes $102^{\circ} 15'$ to $105^{\circ} 50'E$ and longitudes $11^{\circ} 40'$ to $14^{\circ} 28'N$. The Tonle Sap Lake Basin is a sub-catchment of the Mekong basin. The total drainage area of Tonle Sap Lake Basin is approximately $85,786 \text{ km}^2$, including a permanent lake area of around $2,350 \text{ km}^2$. That is approximately 10.8% of the total area of the Mekong

basin [10]. The majority of the catchment is located in Cambodia and only 5% is in Thailand (Fig. 1). Ground altitudes range from 1 m to 1,500 m above sea level. About one third of the area is covered by forests that consist of a mixture of deciduous trees. There are agricultural areas and numerous small settlements as well.

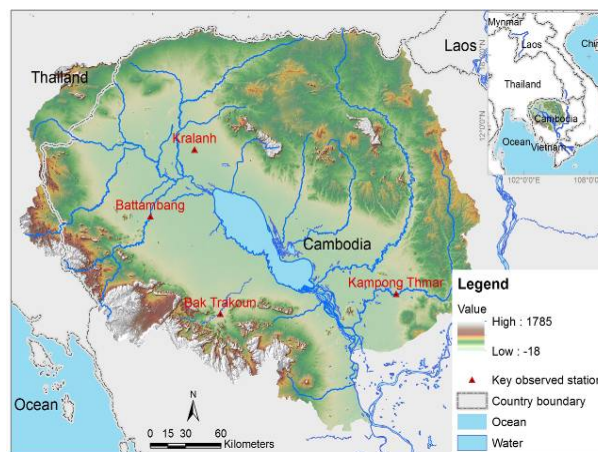


Fig. 1 Tonle Sap watershed.

3. Materials and Methods

3.1 Materials

Time series of 16-day composite MODIS imagery of MOD09A1 with 500 m resolution was acquired for LULC classification and mapping of spatial LULC of 2010. The other spatial data used are soil map of 50 m resolution based on FAO\UNESCO [11] classification system up to level three category and DEM (Digital Elevation Model) data of 50 m resolution. The other hydro-climatological quantities have been used from available gauges over the study area. Fig. 2 shows sets of required spatial data for SWAT hydrological modeling.

Most of the data preparation and analysis in this research was carried out using ArcGIS 10.1. Some specific image processing operations were executed using the ERDAS (Earth Resource Data Analysis System) Imagine software Version 8.0 (ERDAS Imagine is a remote sensing application designed for geospatial applications).

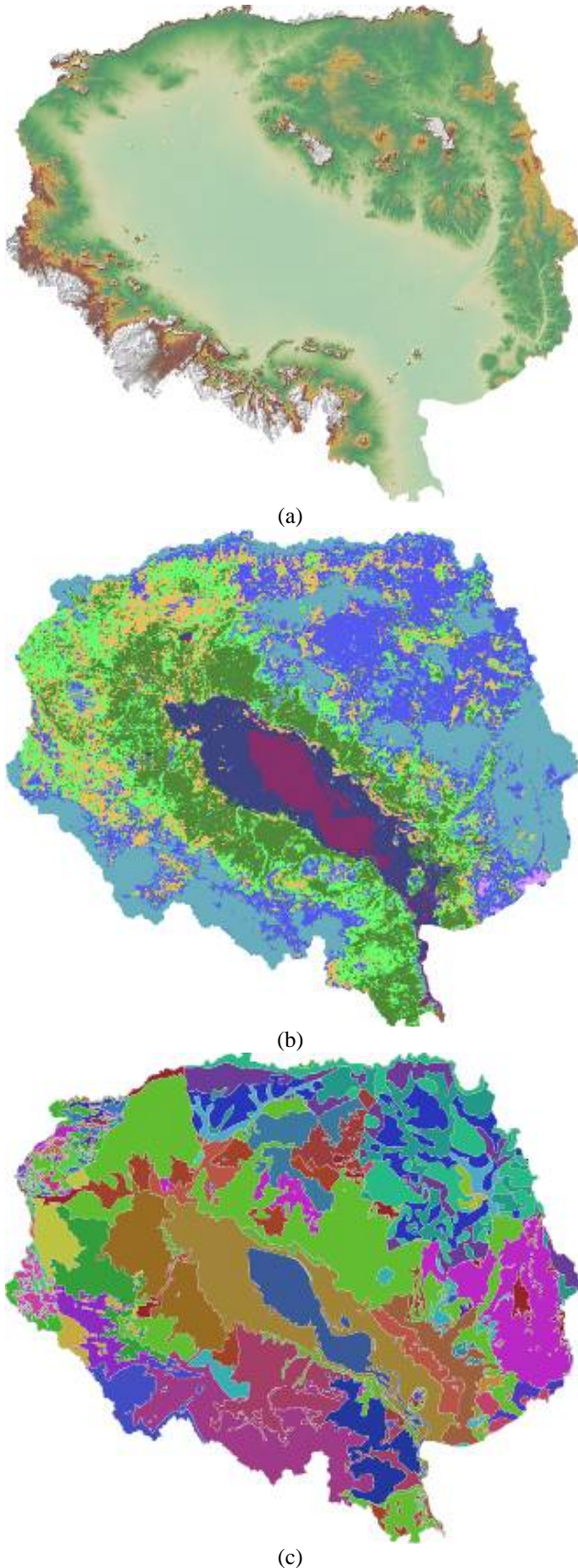


Fig. 2 Spatial data for SWAT model input: (a) DEM; (b) Land use; (c) Soil.

Other types of software employed are ArcSWAT Version 2012.10_1.7 for streamflow modeling and MRT (MODIS Reprojection Tool) for MODIS reprojection and transformation.

3.2 Methods

SWAT is a model developed by the USDA-ARS (United States Department for Agriculture, Agricultural Research Service). The main components of SWAT include hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management. The model can be used to predict impacts of land management practices on water, sediment and agricultural chemicals in catchments [12, 13]. The SWAT model simulates hydrology as a two-component system, composed of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. Soil water balance is the primary consideration by the model in each HRU (hydrological response unit), which Arnold et al. [14] represent as follow:

$$SW_t = SW + \sum_{i=1}^t (R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

where, SW is the soil water content; i is time in days for the simulation period t ; and R , Q , ET , P and QR respectively are the daily precipitation, runoff, evapotranspiration, percolation and return flow.

LULC data used for this hydrological modeling were derived from satellite MODIS imagery. The LULC classification of 2010 LULC was carried out using supervised classification and every training site was carefully selected. Post-classification was performed based on existing land use map of 2003 generated from Landsat, DEM and ground survey. Accuracy assessment was also executed based on those field surveys and existing land use data. Overall classification accuracy was greater than 80% [15]. To make LULC data useable for SWAT, ArcSWAT interface requires a table linking the values represented to LULC types already defined in the model. Hence, the look-up table that converts the

$$E_{NS} = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (2)$$

where, O_i and P_i are the observed and simulated data, respectively; \bar{O} is the average of the observed data and n is the total number of data records.

$$R^2 = 1 - \frac{\sum (Y_i - \hat{Y}_i)^2}{\sum (Y_i - \bar{Y})^2} \quad (3)$$

where, Y_i denotes the value of the i th dependent variable, \bar{Y} is the mean of the dependent variable and \hat{Y}_i is the i th fitted value.

4. Results and Discussion

4.1 Sensitivity Analysis

Sensitivity analysis has been carried out for each available observed streamflow data of each LULC SWAT project. SUFI2 (Sequential Uncertainty Fitting)

for the calibration of uncertainty in procedure was used for this analysis. Five parameters were found to be sensitive, with relative sensitive values in the range of 0.031 to 0.034. The most sensitive parameters are threshold depths of water in the shallow aquifer for “revap” to occur (REVAPMN.gw), Alpha_Bf factor (base flow alpha), Gw_Revap coefficient (groundwater “revap”), ESCO factor (soil evaporation compensation), initial SCS CN2 value (Curve Number II) respectively. These sensitive parameters were considered for model calibration. The remaining parameters had no significant effect on streamflow simulations. Changes in their values do not cause significant changes in the model output.

4.2 Calibration and Validation for Streamflow Estimation

Hydrological streamflow results for the observation station at Kampong Thmar gauge is being discussed (Fig. 4).

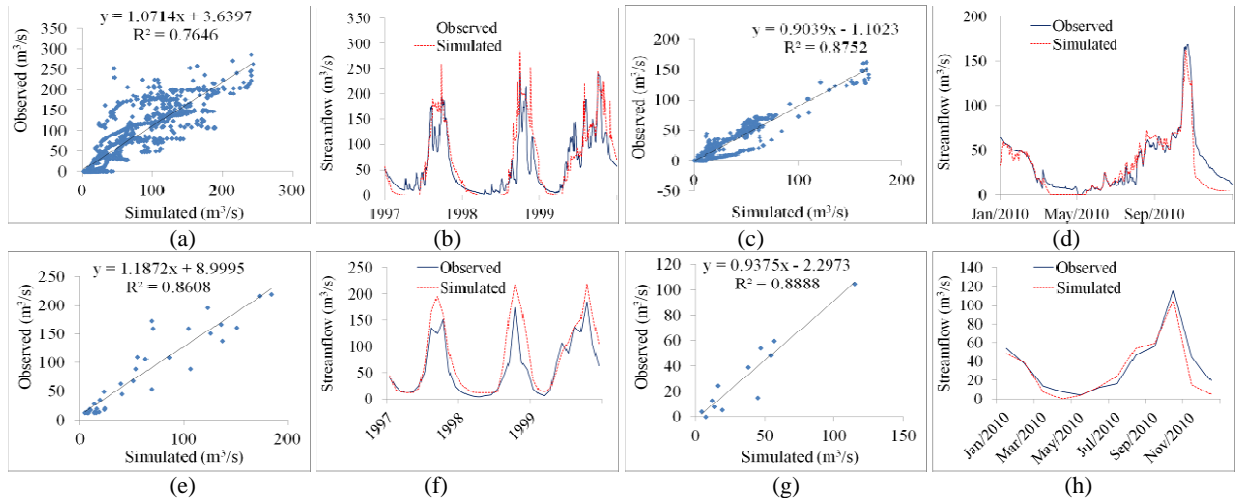


Fig. 4 Simulation results: (a) and (b)—Daily calibration result; (c) and (d)—Monthly calibration result; (e) and (f)—Daily validation result; (g) and (h)—Monthly validation result.

The monthly calibration results have shown better agreement between monthly observed and simulated flows in both calibration and validation processes. The result of the E_{NS} and R^2 are as high as 0.88 and 0.89 respectively (Table 2). Based on the statistical analysis of model evaluation results, conclusion of whether MODIS can be effectively applied as an input to

SWAT interface for hydrological streamflow modeling is noticeable.

Table 2 Calibration and validation results.

| | Calibration | | Validation | |
|---------|-------------|-------|------------|-------|
| | E_{NS} | R^2 | E_{NS} | R^2 |
| Daily | 0.75 | 0.76 | 0.85 | 0.88 |
| Monthly | 0.76 | 0.86 | 0.87 | 0.89 |

However, according to Benaman et al. [18], model simulation can be judged as satisfactory if R^2 is greater than 0.6 and E_{NS} is greater than 0.5. Hence study results agree reasonably well with these accuracy simulations of LULC parameters. Some of the model inaccuracy are caused due to data gaps and lack of accurate and efficient input data where is available such as rainfall, temperature and evapotranspiration. Hence, to increase model efficiency it is obviously depending on such data inputs, as well suitable distribution of the measuring stations over the watershed is required.

5. Conclusions

Model produced good simulation results for daily time steps which have demonstrated that moderate resolution of non-commercial and freely-available satellite imagery like MODIS holds considerable potential for application in hydrological modeling. However, the use of other hydrological models would be more beneficial for the hydrological modeler in order to enhance our understanding of alternative MODIS-based LULC as an input parameter for hydrological modeling. In addition to the modeling tool, the assessment of LULC data input capability would be more beneficial if simulation is tested by a number of hydrological parameters other than streamflow, such as surface run-off, water quality, etc.

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