Assessment of runoff generation using the Simple Biosphere Model including Urban Canopy for upper Chao Phraya River Basin, Thailand

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Abstract Upper Chao Phraya river basin is consisting of four river basins: Ping, Wong, Yom, and Nan which play an essential role essential water to the central part of Thailand. Each sub-basin has a variety of topography from mountainous area to flat plain. It is usually difficult for field measurement with complex terrain to directly measure the land and atmosphere interaction. The land surface model (LSM) is an alternative way to provide that information. In this study, the runoff simulated by a land surface model named Simple Biosphere Model including Urban Canopy (SiBUC) for the regional scale of the upper Chao Phraya River Basin. The forcing data are gathering from observation, reanalysis, and satellite estimation. A kinematic wave routing model was applied for the runoff product and analyzed at representative discharge observation stations for the upper Chao Phraya river basin. The validation is needed to test the performance of the model in the study area. The result could provide more understanding of the characteristic of runoff in the upper Chao Phraya river basin and should serve as the reference runoff generation data in the future research.

Keywords *Land surface model, Upper Chao Phraya River basin, Runoff generation*

Introduction

A Global Circulation Model (GCM) is one of the most reliable tools and widely used for research on climate change and related fields including its impact on the hydrologic cycle. Though GCM has a good agreement with observation data in many necessary parameters in large scale [1], there still have uncertainties in climate predictions for three sources: internal variability, model uncertainty and scenario uncertainty [2]. Bias correction techniques could be a way to reduce uncertainty in GCMs output. Several studies have developed bias correction methods to adjust GCM outputs. However, due to the north of Thailand sub-basin scale has a variety of topography from the mountainous area in the northern part to flat plain in the southern region. It is usually difficult for field measurement with complex terrain to directly measure the land and atmosphere interaction. To provide those data, land surface model is another way. Although, the land surface model need to evaluate their performance before entrusting the result from the simulation.

This paper presents the evaluation process of land surface model name SiBUC over the upper part of Chao Phraya River Basin, Thailand by feeding the runoff generation to the flow routing model and compare to the river discharge observation data at five representative point for each sub-basin and the joint position of Chao Phraya River.

Study Area

This study was performed on the fourtributaries of Chao Phraya River in Thailand, Ping River Basin, Wang River Basin, Yom River Basin, and Nan River Basin. The river flows through the northern part of Thailand to the southern part and meets at the middle of the country. The size of the basin are around 34,500 km^2, 10,800 km^2, 24,000 km^2, and 34,700 km^2 respectively. Figure 1 shows the river channel in upper Chao Phraya and points of evaluation for each tributary, and all the tributary joins together. The observation stations for each basin are select; Ping river: inflow to Bhumibol Dam, Wang river: W.3A stations, Yom river: Y.14, Nan river: inflow to Sirikit Dam, and C.2.

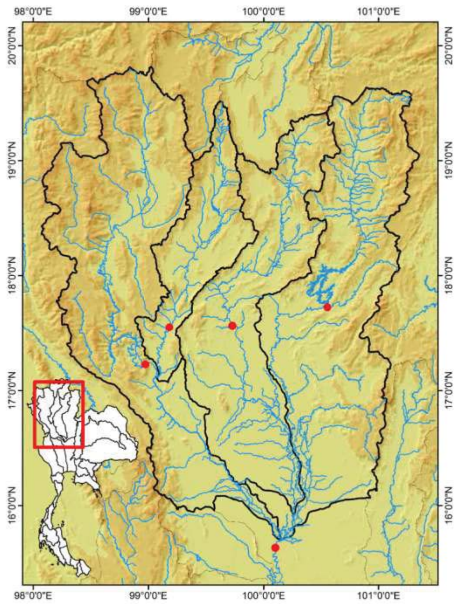


Fig. 1. upper Chao Phraya basin and river discharge observation stations (red dot) used in the study

Hydrologic Model

A. Land surface model

This study is utilized land surface process model to produce runoff generation. The land surface process model proposed by Tanaka [9] namely Simple Biosphere including Urban Canopy (SiBUC) developed from Simple Biosphere [10] with modify in [11] to more cooperate with cropping pattern in southeast region were used in the study. The SiBUC are using mosaic parameterization approach to include each land-use patch of the grid element to the atmosphere. The models are incorporated with three sub-models (green area, urban are and water body) to describe each grid cell. The average surface fluxes for each grid are from averaging the surface fluxes based on each land-use weighted by its sectional area. SiBUC is using Richards’ equation for soil moisture store in three sub-soil layer and Darcy’s law to expressed vertical exchanges between soil layers.

B. Flow routing model

The runoff generations are feed to a distributed flow routing model; 1K- FRM to simulate the river discharge. The models are based on one-dimensional kinematic wave develop in Hydrology and Water Resources Research Laboratory, at Kyoto University. The runoff generations are routed to the downstream according to the topography data. The model and program for preparing topography input can be obtained from 1K-FRM website (http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html).

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L \quad (1)$$

$$Q = \alpha A^m,\ \alpha = \frac{\sqrt{\sin\theta}}{n},\ m = \frac{5}{3} \quad (2)$$

The continuity equation is defined in (1). Where; t is time; x is space coordinate; A is flow cross-section area; Q is flow rate; q_L is lateral flow per unit length from the side of the main flow or can determine as rainfall intensity or runoff generation give vertically to the slope. Equation (2) are derived simplify momentum equation with Manning equation to rout the water. Where n is manning coefficient; θ is channel gradient.

C. Simulation setting

The cell size of SiBUC model are set into 10 km with aggregate all the input surface data include of land use, soil data, and vegetation data to the model resolution while the methodological data are utilized as same as an original resolution of JRA-55. The simulation periods start from 1 January 1991 to 31 December 2010 total of 20 years.

As the output runoff generate, they were used as input to flow routing model, 1K-FRM at 1 km spatial resolution. The simulation is set to the natural condition of the entire study area that means no dam structure includedand all replication in one, without dividing the watershed area.

Data

A. Forcing data

SiBUC needs seven components meteorological data to drive the model: precipitation, air temperature, specific humidity, surface pressure, wind speed, downward shortwave radiation, and downward longwave radiation. In this study, precipitation data were obtained from observation stations of Royal Irrigation Department, Thailand (RID) and Thailand Meteorological Department, Thailand (TMD) across the study area and using interpolation technique called inverse distance weighting to make a spatial precipitation dataset. Other data are gathering from the product of the Japanese 55-year reanalysis (JRA-55) [3] propose by Japan Meteorological Agency (JMA). The JRA-55 systems are configuration of data sources, quality control, data selection for observations, data assimilation system and forecast model. The spatial resolution of JRA-55 is TL319L60 or corresponding to a grid interval of 60 km.

B. Land use

The land use data are based on MODIS land use [4, 5]. These data sets are WGS 1984 coordinate system reprojected product of Global Mosaics of the standard MODIS land use data product (MCD12Q1) in the IGBP Land Use Type Classification at a spatial resolution of 10 km. Each cell class is modified to match on the land survey data from the Land Development Department, Thailand (LDD) on the category of an urban area, cropland and irrigation area.

C. Elevation and slope

The elevation data used in the study are obtained from Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales (HydroSHEDS) with also used to create the slope data. The HydroSHEDS is derived primarily from elevation data of the Shuttle Radar Topography Mission (SRTM) at 90 km spatial resolution.

D. Soil data and vegetation data

The soil texture data are calculated from soil physical properties from Digital Soil Map of the World (DSMW) [6] using criteria of twelve major soil texture classifications defined by the USDA [7]. DSMW is a digitized version of the FAO-UNESCO Soil Map of the World produced in the paper version. For other soil data such as soil depth and root depth are obtain from ECOCLIMAP [5]. ECOCLIMAP is included with an ecosystem classification and a coherent set of land surface parameters database at 1 km resolution developed by Centre National de RecherchesMétéorologiques, France (CNRM-GAME). The vegetation parameters used in this study are extracting from MCD15A3H V006 [8] which are combined fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI) datasets at a 4-day time interval and 500 m spatial resolution. The data were aggregated into 12-day interval to clear out the missing data.

Result

A. Runoff production

The SiBUC are given the result of runoff generation. It can compare to precipitation in term of runoff ratio to explain how much precipitation becomes runoff by calculating annual runoff divide by annual precipitation. On the other hand, they can also show how much the precipitation is lost through the evapotranspiration process. Figure 3 shows the annual average runoff ratio of the study area from 1991 - 2010. The ratios vary from 0.1 to 0.9 based on the land use tile. Most of the high value of the ratio is located in the urban area that considerate as impermeable pavement which does not allow the evaporation of soil moisture by the model. Still, the overall precipitation excludes the urban area are only around 20% to 30% are become runoff.

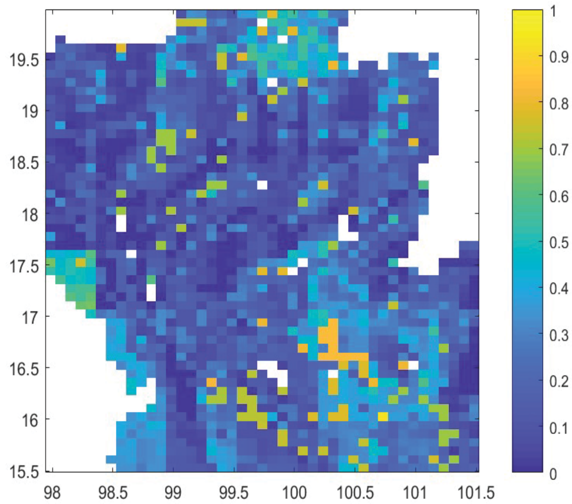
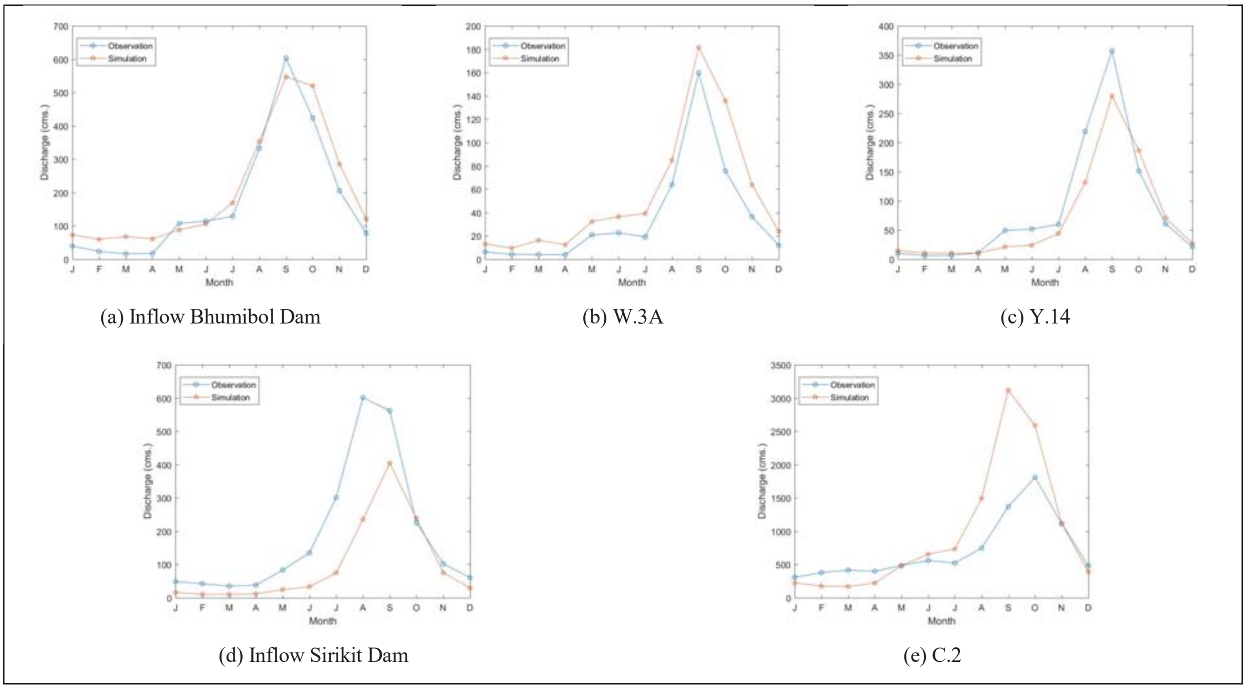


Fig. 2. runoff ratio

B. Monthly discharge

Monthly average discharge for 20 years is shown in Figure 4 for representative observation discharge point of 4 tributary and C.2 station. The simulation condition of the flow routing model for C.2 station did not include the dam in the upstream. So, the river discharge cannot directly compare and can assume that one of the reasons for causing the highly overestimates from the simulation. Hence, the explanations below will not be considerate with the C.2 station.

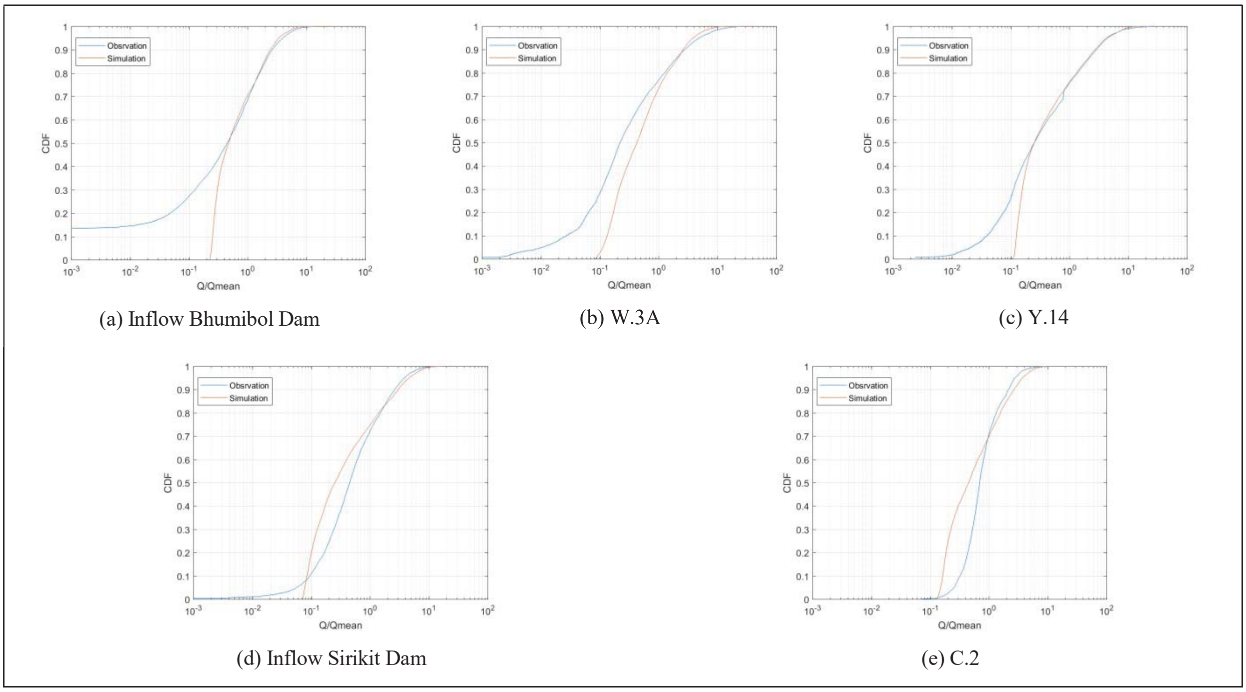
The result shows the hydrograph are followed the pattern of the observation data with some miss estimation on inflow to Bhumibol Dam, W.3A, and Y.14. For inflow to Sirikit Dam, they see a substantial underestimate between simulate result and observation for the entire period. The average observation flow in dry season for each river is 22%, 18%, 13% and 17% for inflow to Bhumibol Dam, W.3A, Y.14, and inflow to Sirikit Dam. When compared with the average flow in wet season while the simulation result of average flow in dry season to wet season is 21%, 13%, 17%, and 32% respectively. When comparing the average flow of simulation with observation in wet season, the difference is -12%, -24%, 33%, and 149% respectively. The negative percentage represents overestimate by simulate and positive are represent the underestimation. From this result also show a large underestimate value for inflow to Sirikit Dam that requires further analysis to understand the cause of huge amount of error.



(a) Inflow Bhumibol Dam (b) W.3A (c) Y.14

(d) Inflow Sirikit Dam (e) C.2

Fig. 3. Monthly average discharge from 1991-2010.



(a) Inflow Bhumibol Dam (b) W.3A (c) Y.14

(d) Inflow Sirikit Dam (e) C.2

Fig. 4. Cumulative distribution transformation for daily discharge from 1991-2010

C. Daily discharge

Figure 4 is present cumulative distribution function (CDF) of daily discharge for 20 years. The CDF has illustratedthe probability that discharge events are less or equal to a specified value based on the normalized of daily discharge for all representation observation stations. The value of normalizing daily discharge can describe the high discharge are more than 1 ($Q/Q_{mean}> 1$) and for low discharge are less than 1 ($Q/Q_{mean}< 1$).

With large difference in high and low flow rates in the upper Chao Phraya River basin. We expect a good estimation for extreme value to give the accurate data for study relate to high and low value of discharge in the future. The daily result show most of the stations have clear overestimate in the frequency of low discharge. On the other hand, the frequency of high discharge is somewhat overestimated when considering inflow BB and W.3A, slightly underestimate for inflow for SK and seem to good match at Y.14.

Concluding Summary

This paper present the performance of land surface model: SiBUC on upper Chao Phraya River Basin that includes 4 major tributaries: Ping, Wang, Yom, and Nan. Since the total runoff data are difficult to obtain by measurement in the real field; the river discharge is used to evaluate instead of runoff generated by the model. Discharge observation data of each river basin are used to representative comparison point for each sub-basin.

The result seems to perform well for monthly scale for inflow BB, W.3A, and Y.14 but still large underestimate for inflow SK. In the daily scale, the simulated performance for high and low discharge still found difficult to capture. From this result, the model is needed to focus on particular sub-basins to adjust the model parameter to improve the performance and can generate runoff more accurate. The runoff generation data from this study will provide as near reference runoff data and use for the future study.

Since this study does not include large dame in the simulation, we cannot directly compare the simulation result to the observation data. Hence, the significant difference can be assumed that it affects the dam structure which comes to two solutions for the future work. First, neutralize the river by removing the effect of Bhumibol dam and Sirikit dam as in [12] using the water balance equation and dam inflow data, dam outflow data. Second, include the dam operation function into the flow routing model.

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