WATER BALANCE IN CHAO PHRAYA BASIN USING A DISTRIBUTED HYDROLOGICAL MODEL AND SATELLITE PRODUCTS

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ABSTRACT

In this study, water balance estimation was demonstrated by conducting hydrological simulation using two satellite dataset; GSMAP Gauge precipitation product and MODIS_MOD16 evaporation product.At first, observed data and satellite data were collected in Chao Phraya Basin, Thailand. Secondly, a distributed hydrological model has been set up in this basin which covers over 100,000 km2. River discharge was simulated combining with dam operation in 2001-2010 after calibration. Thirdly, the relationship between two commonly used satellite products defining water balance was investigated at study area based on model outputs'. The results showedspatial distribution and seasonal, inter-annual change of water balance though it is remaining uncertainty of satellite dataset.In the future, the improvement of precision of satellite observation would enable us to calculate water balance more precisely.

Keywords:remote sensing, water balance,hydrological modeling, satelliteevapotranspiration,Chao Phraya river Basin

1 INTRODUCTION

Quantification of water balance components over large regions is a key to understand the availability of water resources, the prediction of extreme hydrologic events such as floods and drought, and the interactions of the land surface with the atmosphere and climate(Sheffield et al. 2009). The terrestrial water balance is composed of the fluxes of precipitation (rain and snowfall), evapotranspiration (soil and canopy water evaporation, plant transpiration and snow sublimation), and runoff (surface and subsurface flow), together with storage on the land surface (snow pack, vegetation canopy, lakes, wetlands, rivers, etc). These components are related through equation (1) which states that the fluxes of precipitation (P), evapotranspiration (ET), and runoff (Q) are balanced by the change in water storage (S) at the Earth's surface:

(1)

The conventional way to obtain the water balance elements is to establish ground-based measurement networks. However, ground truth data are still scarce due to the difficulty of measurement over a large spatial range (Swenson, 2009) and maintenance cost. Furthermore, calculating water balance at regional and larger scales from ground-based measurements remains challenging due to the aggregation of error and inaccuracies, arising from their usually limited spatial representativeness.

Retrieval of water balance components from satellite observations can overcome the limited spatial coverage and representativeness. Therefore, many studies have discussed the application of remote sensing data in large-scale hydrological studies(Oliveira, 2013).

However, these studies combined ground-based observation with satellite products to improve the water fluxes estimation, andfew papers examine the water balance with the emphasis on satellite products alone. In Chao Phraya River Basin in Thailand, there is no research discussing long-term water balance using satellite products alone. However, it is important to understand the characteristics of water balance in such a strongly affected by monsoon river.Therefore, in this study,Chao Phraya River Basin was selected as a target basin.

The aim of this study is to examine the large-scale water balance over the Chao Phraya River Basin using readily available satellite products.

2 STUDY AREA

The Chao Phraya River Basin covers roughly 31% of the country's land surface and is the largest river basin in the country. The total drainage area is approximately 160,000 km^2 from upstream to downstream. In this study, the simulated areawas selected down to Chao Phraya Dam, which has 117,375 km^2(**Fig. 1**).

Chao Phraya River is composed of four major tributaries, namely Ping River (26239km^2), Wang River (10377km^2), Yom River (23982km^2), and Nan River (38030km^2), which is confluent at NakhonSawan. In the northern mountainous region, there are valleys covered with forest or bare soil. These valleys, stretching south to north, lead to headwaters.

Climate in Thailand is strongly affected by South East Asian monsoon which has rainy and dry season. Due to the monsoon, rainfall distribution over the Chao Phraya River Basin varies distinctly between the rainy (May-October) and dry (November-April) seasons. Mean rainfall during the rainy season accounts for about 90% of mean annual rainfall in the Chao Phraya River Basin. Total precipitation in Thailand is 1,000-4,000 mm. Chao Phraya River Basin has 1,000-1,500 mm. In addition, the evaporation rate is quite high; thus annual average height of run-off is as small as 200-300 mm.

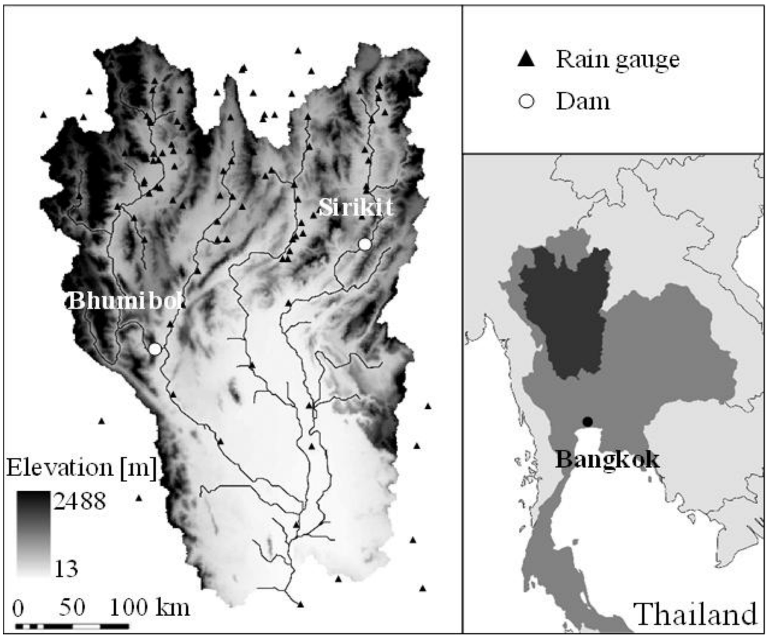

Figure 1.Location of Chao Phraya River Basin

3 METHODS

3.1 Dataset description

To evaluate the water balance in space and time, time-series precipitation data were used, obtained from Gauge Adjusted Global Mapping of Precipitation (GSMaP_Gauge) (Mega et al. 2014), potential evapotranspiration (PET) from Moderate Resolution Imaging Spectroradiometer (MODIS) evapotranspiration product MOD16 for 2001 to 2009(Mu et al. 2007).See Table 1.

Daily precipitation data were collected from twokinds of rain gauge network systems for calibration of hydrological model (see section **3.2**). One is an open-source rain gauge network data provided by the Royal Irrigation Department (RID) in Thailand. The other one is managed by the Thai Meteorological Department. The temporal resolution is daily for both data. Besides, daily observed discharge, which was also for calibration, was also provided by RID.

Digital Elevation Model (DEM) was obtained from the Shuttle Radar Topography Mission (SRTM) with a 90 m spatial resolution. As for soil type classification, Digital Soil Map of the World version 3.6 from Food and Agriculture Organization of the United Nations (FAO/UN) were used (**Fig. 2**). The most dominant soil classes were clay sandy, and sandy silt in the upper region, and lower region, respectively. See Table 2. The data set of land use types were obtained from Land Development Department, Thailand. Land use categories are paddy field, farm land, forest, grass land, bare land, urban area and water body (**Fig. 2**). In the northern area, the forest is dominant. In case for southern region, the major land use type is paddy field.

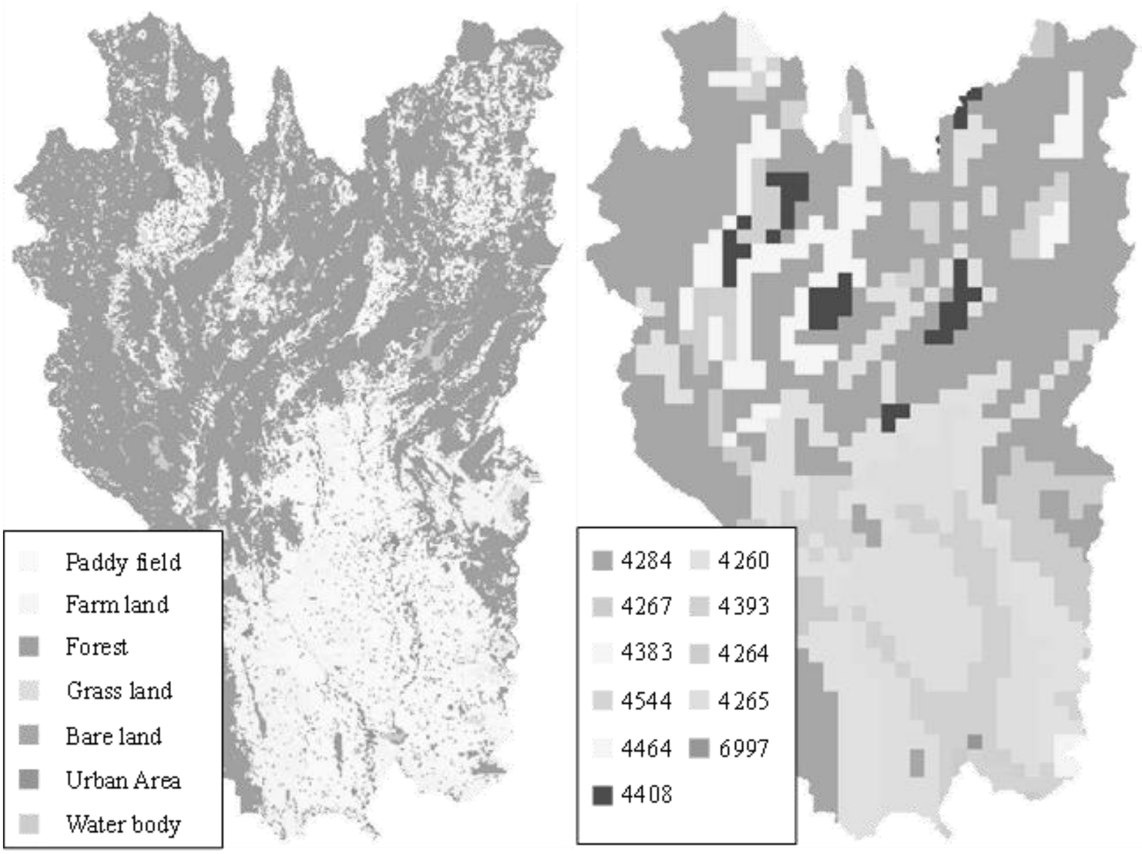

Figure 2.Map of land use and soil type in Chao Phraya River Basin

Table 1.Satellite products used in this study 2001-2009 and spatiotemporal resolution of hydrological simulation

Component	Product	Resolution	Data source
P	GSMaP Gauge	0.1°, hourly	JAXA. http://sharaku.eorc.jaxa.jp/GSMaP/index_j.htm
ET	MODIS_MOD16	1 km, 8-daily	University of Montana. http://www.ntsg.umt.edu/project/mod16
Q	GBHM simulated	1 km, hourly	
ΔS	GBHM simulated	1 km, monthly	

Table 2.Soil types in Chao Phraya River Basin

Soil No.	Dominant soil type	Sand (%)	Silt (%)	Clay (%)
4284	Orthic Acrisols	0	65	35
4267	Orthic Acrisols	0	100	0
4383	LITHOSOLS	0	100	0
4544	Dynamic Nitosols	0	50	50
4464	Orthic Acrisols	0	90	10
4408	Gleyic Luvisols	0	60	40
4260	Ferric Acrisols	30	70	0
4393	Eutric Fluvisols	0	100	0
4264	Gleyic Acrisols	0	100	0
4265	Gleyic Acrisols	15	85	0
6997	Water	0	0	0

3.2 Hydrological modeling

A physically-based semi-distributed hydrological model was applied to simulate water balance in theChao Phraya River basin. In this study, the Geomorphplogy-Based Hydrological Model (GBHM) was employed (Yang et al 2002).This model is mainly composed of two modules; hillslope module and river routing module.

In the calculation process, the target watershed is divided into grids to make river network. It is distributed into the sub-basins, and then flow intervals are defined depending on the distance from its outlet. Furthermore, lateral flow to mainstream is estimated by accumulating the runoff at each grid in one hillslope unit. This module calculates hydrological processes such as canopy interception, evapotranspiration, infiltration, surface flow and exchanges between groundwater and surface water.

In the river routing system, Pfafstetter numbering scheme(Verdin and Verdin, 1999) is applied to track water flow efficiently from upper to downstream. The water routing of the river network is determined along the river stream using one-dimensional kinematic wave equations.

4 RESULTS

4.1 Spatial change of water balance

As a results of simulation, spatial maps of water components; simulated evapotranspiration, groundwater depth are created (**Fig. 2**).

PET from MODIS satellite product showed that there is high potency of evapotranspiration in lowland paddy area and low potential in the north mountainous area. However, even though PET was high, simulated actual ET was low near the Bangkok, and in forest area, actual ET was higher than other land use area. According to these results it can be said that evapotranspiration is affected by land use. Regarding precipitation, there was high rainfall at southeast part of the Chao Phraya River Basin, and low at upper part of Nan and Ping river basin. In terms of groundwater depth, comparing the map withsoil type map and bed slope map, it might be said that groundwater level was affected by soil type and bed slope. The area covered soil no.4267, which is mainly composed on silt, had high groundwater depth from the groundwater depth map. The area where is mild slope or flat plain has deep groundwater layer. From this information, groundwater depth should be affected by geomorphological factors.

4.2 Inter-annual change of water balance

After calibration with observed data, the water balance was simulated with satellite data in 2001-2009 (**Fig. 3**).The overall average for rainfall, evapotranspiration, runoff and groundwater storage change werefound 1,564, 1,132, 449 and -5 mm; the median values were 1,588, 1,104, 439 and 4 mm respectively. In the Chao Phraya River Basin, approximately 70% of the rainfall turned to evapotranspiration, and the residuals mainly runoff.As the trend for long term, the rainfall pattern had a little variation, but runoff seemed to decrease as the year go by especially from 2006 to 2009. It probably caused due to the increase of evapotranspiration.

Runoff decreased from 600 mm in 2006 to 300 mm in 2009. In contrast, evapotranspiration increased from 1,100 mm to 1,300 mm. The reason to increase evapotranspiration might be the raising the potential evapotranspiration.

Seasonal water change in the Chao Phraya River Basin was simulated by taking the average in each month from 2001 to 2009 (**Fig. 4 and 5**). It shows that September had the highest precipitation in one

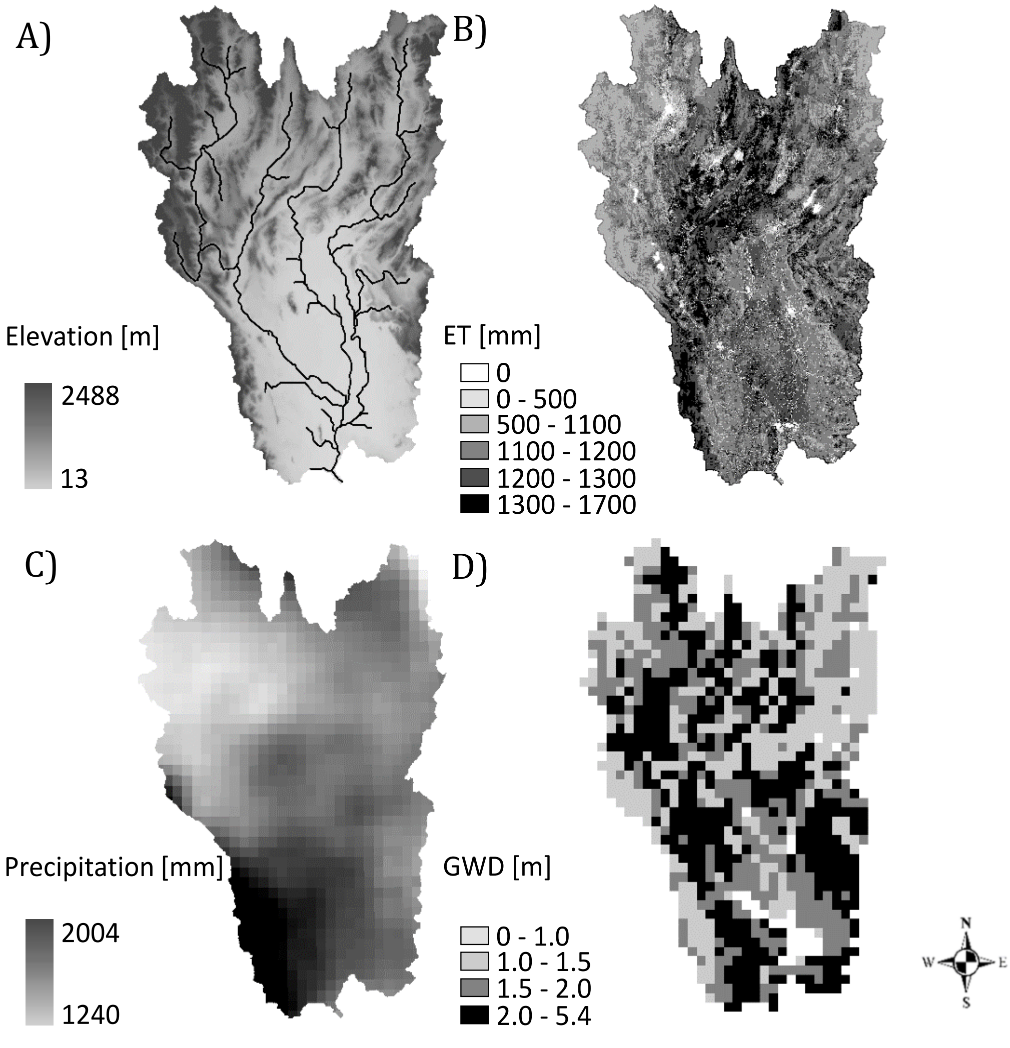

Figure 3. Spatial change of the water balance in the Chao Phraya River Basin,A) elevation ,B) simulated evapotranspiration by GBHM,C) precipitation,D) groundwater level.

year, and the runoff had the maximum value correspondingly to the precipitation. Regarding to the storage change, it took positive value in the rainy season. It indicated that the terrestrial water storage continue increasing in this season. Therefore, in September, the last month of rainy season had the largest water storage in the basin. It should describe that in this month there might be possibility to have a large flood due to the high soil moisture.

5 CONCLUSIONS

In this study, we demonstrated three steps to assess the water balance in Chao Phraya Basin, The results showed uncertainty of satellite products, however, from the view of a spatial distribution, seasonal analysis and long-term trend analysis, only using satellite products has the potential to close the water balance taking care to a bias of a satellite's estimation.

Anticipated improvement in the satellite observation technology is expected to increase the accuracy of their products. For example, the Global Precipitation Measurement (GPM) project has been carried out since February 2014. This advance is expected to improve the feasibility accuracy of large-scale water balance analysis using satellite data alone in the near future.

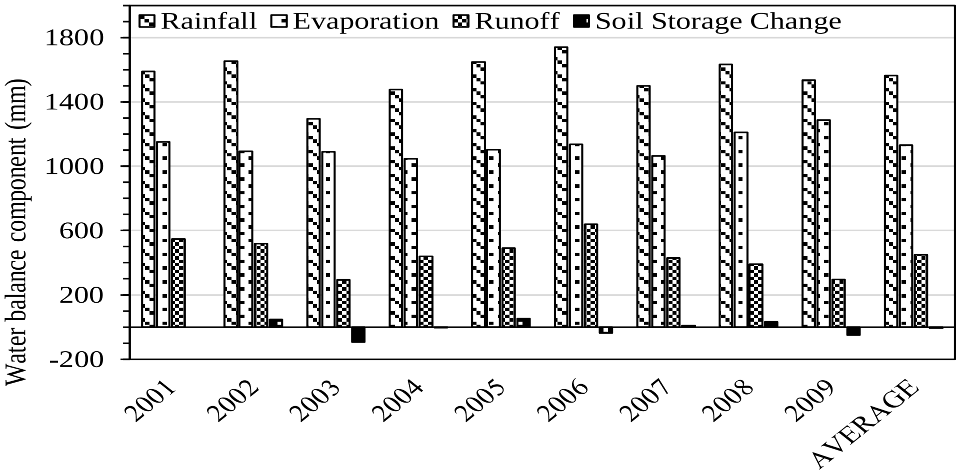

Figure 4. Inter-annual change of the water balance in the Chao Phraya River Basin

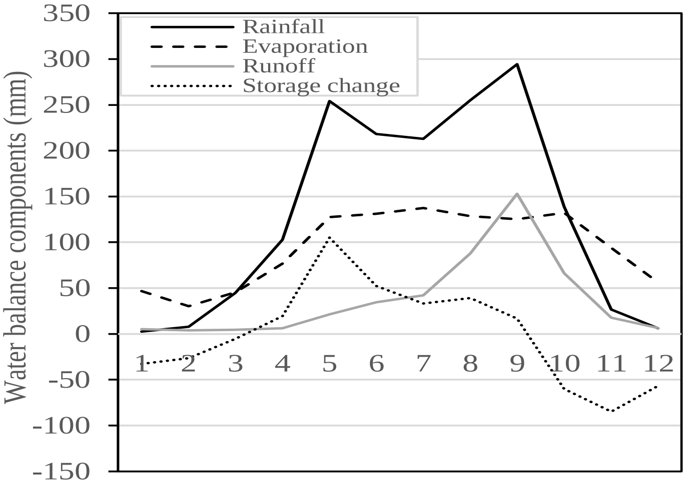

Figure 5. Seasonal change of the water balance in the Chao Phraya River Basin, the value in each month is average value from 2001 to 2009, precipitation is stored as a soil storage in rainy season

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