12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Development of Integrated Water Balance Analysis System

Winai Chaowiwat, Kanoksri Sarinnapakorn, Surajate Boonya-aroonnet, Sutat Weesakul
Hydro Informatics Division, Hydro and Agro Informatics Institute
Bangkok, Thailand

ABSTRACT

The variability of weather causes some difficulties in water management in local or river basin resulting in damages from flood and drought. When the related government agencies do not have accurate future seasonal weather information, it could lead to management failure. Water management planning needs a seasonal weather forecast system in order to prepare an action plan in response to uncertain weather. Water balance analysis is a tool that uses water supply and water demand as input data to conduct an understanding of the water situation in sub-river basin level. Water analysis system is developed by composing bias correction of a seasonal weather forecast system, rainfall-runoff model, and water demand model. The bias correction system will correct biases of seasonal global circulation model data, and provide input variables for the two models, while the rainfall-runoff (SWAT) model is applied to simulate the direct runoff in river basin and the water demand model is used to estimate the crop water requirement. The water balance analysis system will integrate output of both models to calculate the water balance in each sub-river basin based on spatial analytic approach and generate a water balancing map for identifying drought risk areas. This paper proposes an integrated water balance system for indicating water deficit and surplus situation, especially in rain fed-agriculture areas. The results reveal that this system can produce a water situation map corresponding to the real situation.

KEY WORDS: bias correction; seasonal weather forecast; water demand; rainfall-runoff model; general circulation model.

INTRODUCTION

In 2015, Thailand experienced the severe drought condition that caused agriculture crop disaster and income loss. The government had advised farmers to adapt themselves to cope with water shortage in dry season by changing the crop types to low water consuming plants and stopping cultivation in agricultural areas. Water is an important factor for cultivating paddy rice and upland crops, which is the farming practice in rain fed areas. Since rain fed agriculture does not rely on irrigation system for water supply, but utilizes water from rainfall or natural water resources, the rain fed area is prone to risk of water shortage or surplus. Therefore efficient water management should be able to identify water deficit and surplus areas in advance for planning some measures to respond to water situation. The water balance analysis is a tool helps us understand the water status in the river basin.

There are many researches that used rainfall-runoff model or SWAT model as a tool for water balance analysis. Adeogun et al. (2014) suggested SWAT model as a promising tool to predict water balance and water yield in sustainable management of water resources. Furthermore some researchers developed SWAT model to predict the impacts of land use change on water balance. (Watson, 2003) Bansode and Patil (2016) applied SWAT model to determine the availability of resources in small watershed. Shawul et al. (2013) analyzed the influence of hydrologic parameters on the stream flow variability and estimated monthly and seasonal water yield.

Even though SWAT model (rainfall-runoff model) can be used to analyze water balance, it cannot deal with the changing water demand at a specific cultivating area. For water operation in practice, the water manager needs to know water status in real situation. Furthermore, the cultivation system varies dynamically and depends on farmers' crop in each sub river basin. That SWAT model cannot be adjusted according to the changing crop growth is the weakness of SWAT model. Thus this study tries to handle this problem and adds more ability for water balance analysis by integrating the weather forecast system, water demand model, and rainfall-runoff model conjunctively. Due to the multi-proposes of water balance results and clear information, the authors attempt to simplify the water balance map corresponding to water status for both flood and drought.

The objectives of this study are to integrate the forecasting results to analyze water balance in main river basin in Thailand and to implement the spatial water balance display system. The outcome of water balance analysis is water balance map in sub river basin. The advantage of this water balance analyzed results is that they provide spatial information to water managers indicating possible water deficit areas so that farmers can use to decide cropping in sub river basin.

STUDY AREA

Thailand is located in the tropical zone of South-East area of the continent between latitude 5º37' N - 20º27' and longitude 97º22' – 105º37' covering 513,115 square kilometers. The climate of Thailand is under the influence of monsoon winds of seasonal character, i.e., southwest monsoon and northeast monsoon. The southwest monsoon, which starts in May, brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially on the windward side of the mountains. Rainfall during this period is caused not only by the southwest monsoon, but also by the Inter Tropical Convergence Zone (ITCZ) and tropical cyclones, which produce a large amount of rainfall. The onset of monsoons varies to some extent. Southwest monsoon usually starts in mid-May and ends in mid-October, while northeast monsoon normally starts in mid-October and ends in mid-February.

DATA USED

The input data in this study is separated corresponding to the model in Table 1. The observed weather data of 106 rain gauge stations were collected from Thai Meteorological Department (TMD) such as rainfall, temperature, relative humidity, wind speed, solar radiation, and sunshine hours which based on daily and monthly basis from January 2015 to March 2016. The distribution of observed weather stations is shown in Figure 1. The seasonal forecast general circulation model (GCM) precipitation and temperature data is CCM3.6.6 with persistence SST anomalies (psst) which is the latest version of the NCAR Community Climate Model (Acker et. al., 1996) within forecasting period Aril 2016 to September 2016.

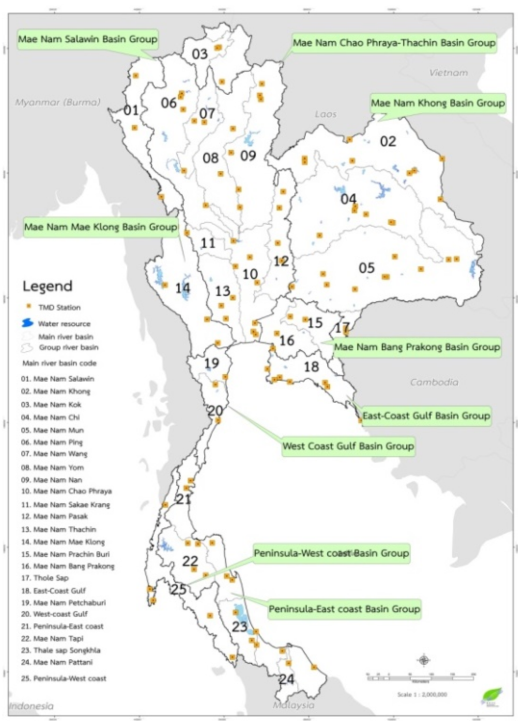

Fig. 1 Distribution of weather stations

METHODOLOGY

The methodology of this study includes four main procedures as follow. 1) forecast seasonal weather, 2) simulate seasonal runoff model, 3) estimate water demand, and 4) analyze the water balance based on monthly basis. The schematic diagram of integrated water balance system is illustrated in Fig. 2. For the detail of each procedure can be described as follows. The seasonal weather forecast is adopted the ratio of gamma CDF parameter bias correction method (Chaowiwat, 2016). The weather forecasts system is adopted from Chaowiwat (2016) by using bias correction method which performed a good agreement with the observed data. This bias correction method can reduce the root mean square error (RMSE) between 8.28% to 31.35% and reduce the mean absolute error (MAE) between 5.10% to 31.86% when compared with the original GCM rainfall.

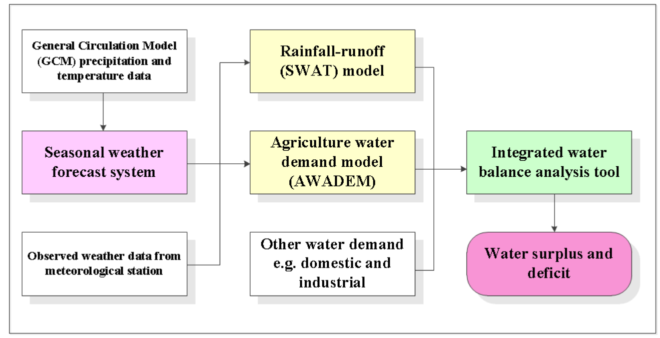

Fig. 2 Schematic diagram of integrated water balance system

The rainfall-runoff (SWAT) model is adopted from the development of database system and flood and drought model for 25 river basins of Thailand (HAII, 2012). For the hydrological of sub river basins can be distinguished to 860 sub river basins and formulated 137 models cover the 23 main basin of Thailand. The consistency of this model is performed a good agreement with the observed data that Nash-Sutcliffe model coefficient is in range 0.56 to 0.91. It is implied that the results of this model can be used for water balance analysis. The water yield of sub river basin will be applied as the water supply input data.

The water demand can be estimated by using the agricultural water demand estimation model (AWADEM 1.0) which developed by Chaowiwat (2015). AWADEM 1.0 was developed by MATLAB programing based on Penman-Monteith evapotranspiration equation (1948) and USDA SCS (1993) effective rainfall equation (Chapagain, 2009). The relevant monthly weather input data is employed the 30 year-average weather as the constant variables such as wind speed, relative humidity, and sunshine hour. Furthermore, the observed and bias corrected climate data include rainfall, maximum and minimum temperature, and relative humidity, and annual cultivated area include the main economical plants from Office of Agricultural Economic (OAE) and Royal Irrigation Department (RID) such major rice, second rice, maize, sugarcane and cassava. It is considered the parameter based on Thai agricultural pattern and calculated water demand in the sub river basin scale. The start date of cropping in wet and dry season is May 1st and November 1st, respectively. The percolation is assumed about 7 mm/week.

In additional, the other water demand includes domestic water demand and industrial water demand is integrated as the input data to the water balance analysis tool. The domestic water demand is estimated from the population multiply with water consumption rate and the industrial water demand is estimated from the horse power in each factory type multiply with the water consumption rate.

The water balance analysis tool is written by Python 2.7 program. The procedures are conducted as follow: 1) Import the related data to water balance analysis tool includes forecasting weather, water demand and water yield data. 2) Analyze the water balance in each sub river basin. 3) Generate the water balance map in each sub river basin. The water situation can be indicated by setting up the criteria of water balance results. 4) Summarize the water balance in each sub river basin.

According to the magnitude of water balance results varied very wide range, it lead to difficultly illustrate on the map in both flood and drought terms. Therefore the authors attempted to definite the criteria as the scale or legend of map. Normally the water deficit will be defined when the water balance result provided the minus value around 20% of water demand. In the other hand the flood also can be defined as the exact values based on general condition of Thai watershed yield capacity or carryover (about 40 million cubic meter/month).

The criteria of water balance results can be classified as 1) high water surplus is more than 200 million cubic meter/month, 2) low water surplus is in range 40 to 200 million cubic meter/month, 3) sufficient is in range 0 to 40 million cubic meter/month, 4) low water deficit (minus value) is in range 30% to 50% of water demand, and 5) high water deficit (minus value) is more than 50% of water demand. The water balance map will be generated seasonal water balance 6 months.

In order to the weather and water demand data is need to be continue calculating, so it would be combined the dataset of previous period and forecasting periods together.

RESULTS

The example of water balance results are illustrated the water balance results of Thailand in April and September in Fig.3 and 4. Nan river basin which locates in Northern of Thailand is used to represent the water balance results as shown in Table 1. It shows that highest surplus and deficit will occur in May and September with 1,332.9 million cubic meter /month and 575.3 million cubic meter/month. Furthermore, it shows that August and September will be shortage about 59% of river basin area. (see Table 1 (b))

Table 1 Summary of water balance in Nan River Basin
(a) Water balance analysis results

Month	Water supply (MCM/ month)	Water demand (MCM/ month)	Surplus (MCM/ month)	Deficit (MCM/ month)	Water balance (MCM/mo nth)
Apr	1019.8	323.6	799.9	-103.7	696.2
May	1576.0	251.9	1332.9	-8.8	1324.1
Jun	1483.5	415.1	1069.5	-1.1	1068.4
Jul	930.5	617.0	434.1	-120.5	313.5
Aug	706.0	941.5	310.1	-545.5	-235.4
Sep	288.6	751.3	112.6	-575.3	-462.7

(b) Number and area of surplus and deficit basins

Month	Number of surplus	Number of deficit	Surplus area (km^2)	Deficit area (km^2)	% Deficit
Apr	22	25	19455	14686	43
May	34	13	28712	5429	16
Jun	42	5	33609	532	2
Jul	27	20	24287	9854	29
Aug	13	34	14079	20062	59
Sep	13	34	14079	20062	59

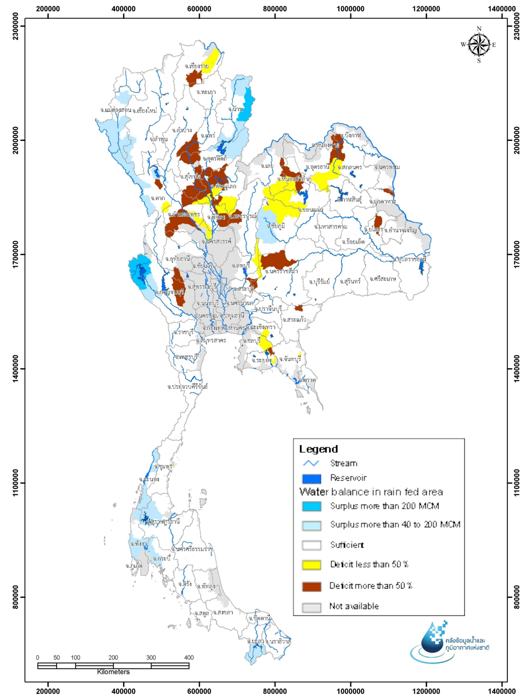

Fig. 3 Forecasting water balance map of rain fed agricultural area in main river basins in April

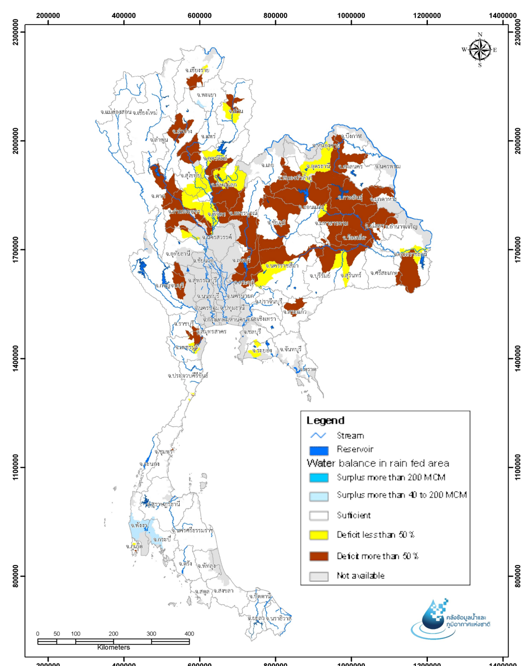

Fig. 4 Forecasting water balance map of rain fed agricultural area in main river basins in September

CONCLUSIONS

The weather forecast output can be applied to monitor the consequence on the runoff, water demand, and water balance results. The integrated water balance results can be used to identify the flood and drought risk area in the term of spatial and magnitude. Furthermore the water manager is able to apply the water balance map to plan the water management and adaptation measures in the specific sub river basin. However the overall results depend on the weather forecast output, so this system can be improved the accuracy by enhancing reliable weather forecasts capacity.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of Thai Meteorology Department for observed rainfall data distribution National Center for Atmospheric Research for GCM precipitation data. In additional, many thanks to Hydro and Agro Informatic Institute for providing the rainfall-runoff model in this manuscript.

REFERENCES

Acker T.L., Buja L.E., Rosinski J.M., Truesdale J.E., (1996). "User's Guide to NCAR CCM3," NCAR Technical Note/TN-421+IA, Boulder, Colorado.May.

Bansode S. and Patil K, (2016). Water Balance Assessment using Q-SWAT, International Journal of Engineering Research, Volume No.5, Issue No.6, pp: 515-518.

Chapagain, A.K.; Orr, S. (2009). An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. J. Environ. Manage., 90, 1219-1228.

Chaowiwat W., Sarinnapakorn K., Boonya-aroonnet S., (2016). Bias Correction of Seasonal Rainfall Forecasts of Thailand from General Circulation Model by Using the Ratio of Gamma CDF Parameter Method, Naresuan University Engineering Journal, Vol.11, Supplement, 1, May, pp 7-13.

Chaowiwat W., (2015). Agriculture Water Demand Estimation Model Manual (AWADEM Version1.0Beta) Hydro Informatic Department, Hydro and Agro Informatics Institute, Thailand, Sep.

HAII, 2012, The Development of Database System, Flood and Drought Model for 25 River Basins of Thailand, Hydro and Agro Informatic Institute.

Penman H. L., (1948). Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London A(194), S. : 120-145.

Shawul A. A., Alamirew T., and Dinka M. O., (2013) Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Ethiopia, Hydrol. Earth Syst. Sci. Discuss., 10, 13955–13978.

Watson B.M., Selvalingam S. and Ghafouria M., (2003). Evaluation of SWAT for modelling the water balance of the Woady Yaloak River catchment, Victoria, School of Engineering & Technology, Deakin University, Geelong, Australia.