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Consumptive Water Use of Sugarcane Affecting Lam Nam Pong River

Khanittha Chaibandit[1], Supasit Konyai[2]*, Khanita Kamwilaisak[3]

[1]PhD. Student, Department of Agricultural Engineering, Faculty of Engineering, KhonKaen University, Khon Kaen, 40002, Thailand.
[2]Assistant Professor, Department of Agricultural Engineering, Faculty of Engineering, KhonKaen University, Khon Kaen, 40002, Thailand
[3]Assistant Professor, Department of Chemical Engineering, Faculty of Engineering, KhonKaen University, Khon Kaen, 40002, Thailand.
*Corresponding author: Tel: +66-8-1661-9611, Fax: +66-43-362-149, E-mail: supako@kku.ac.th

Abstract

The Nam Pong River is one of important rivers in the Northeast, Thailand. It supplies water for two large hydroelectric power plants, the largest irrigation Project in the Northeast, and domestic water supply for many areas including the city of Khon Kaen. Sugarcane and paddy rice are the two main crops occupy the catchment of the river on the upland and lowland, respectively. The river demonstrates scarcity and pollution almost every year. In order to mitigate the scarcity and pollution problems we studied consumptive water use of sugarcane in the catchment using the water footprint concept on monthly basis. We applied two calculation approaches, one is the Water Footprint Network method and the other is our method. In our method, we calculate actual and crop reference evapotranspirations by Morton CRAE and Penman-Monteith-FAO respectively using Evapotransration Package in R Environment; and effective rainfall by the Natural Resources Conservation Service (US Department of Agriculture). We used the rainfall and climatic data from three crop years, 2013, 2014 and 2015 which are wet, moderate, and drought year respectively. The results from the two methods are in agreeable and very useful for the Nam Pong River management.

Keywords: Water Footprint Network, Evapotransration Package in R, Nam Pong River

1 Introduction

Northeast Thailand is well-known for being the drought stricken region of the country. Even though its average annual rainfall is quite high, 1,404 mm., second only to the South of Thailand (Kamontum and Mongkolswat, 2000). The Nam Pong River is one of important rivers in the Northeast. It supplies water for two large hydroelectric power plants, the largest irrigation Project in the Northeast, and domestic water supply for many areas including the city of Khon Kaen. Sugarcane and paddy rice are the two main crops occupy the catchment of the river on the upland and lowland, respectively. Temporal distribution of rainfall is not uniform over the year. About 90% occurs over the 6-month of rainy season between May and October. The remaining 6 months is dry season which most water comes from soil moisture, groundwater, natural lakes, and man-made reservoirs. Sandy soils with low water holding capacity together with irregular rainfall pattern are the causes of drought in Nam Pong basin. Mismanagement of water resource in the watershed exacerbates the water scarcity, however, water stress occurs only in the dry season especially near the end in April. From water utilizations classification in to 4 areas, i. e. domestic consumption, irrigation, industries, and ecological conservation, domestic consumption are the first priority. Irrigation and industries are the two largest shares. Ecological conservation, while very important, has a low priority in the basin.

To mitigate water stress, water resources in Nam Pong watershed should be properly managed to increase water use efficiency and water productivity. Water foot print is a concept of water stress indicator (Brown and Matlock, 2011). It was invented in 2002 in the Netherlands (Hoekstra and Hung, 2002).

In recent years, Thailand exports sugar second only to Brazil. The Northeast is the highest sugar production region of Thailand. Nam Pong basin is among the most important areas in the Northeast to plant sugarcane and to produce cane sugar. Sugarcane (*saccharum officinarum*) is a kind of upland crops that consume high amount of water (Shrivastrava et al., 2011). Water resource in Nam Pong watersheds is limited. It only depends on amount of precipitation in rainy season. This precipitation divides into 3 parts; first one becomes direct runoff to the river, second evaporates back to the atmosphere, and the last bit is stored in the watershed and slowly released to the river in the follow dry season (Chow et al., 1988). Every water user needs fair share of the limited water resource all year round especially during the dry season. In rainy season, the situation is not so difficult, river flow is plentiful, high level of groundwater, and high soil moisture content. Dry season is another story, all stakeholders fight for their shares. Since we concern with water consumptions of sugarcane planting, our objective of this paper is to present a study of monthly sugarcane water use in the Nam Pong Basin by using the water footprint (WF) concept. Only the green WF and blue WF involved not the grey WF which concerns with water quality and not relevant to sugarcane consumtive use.

2 Materials and Methods

2.1 Study area

Nam Pong River located in the middle of northeast, Thailand. It is the main tributary of the Chi River, with the catchment area of about 1,5051.38 km^2 The Nam Pong basin is divided into two sub-basins namely upper Nam Pong and the lower one seperated by the outlet of the Ubol Ratana resservoir. The upper part consists of several tributaries namely Lam Pong, Nam Phuai, Lam Phaniang, Nam Phrom, and Nam Choen. The lower sub-basin consists of the main Nam Pong River and Huai Sai Bat near the outlet to the Chi River as shown in Figure 1.

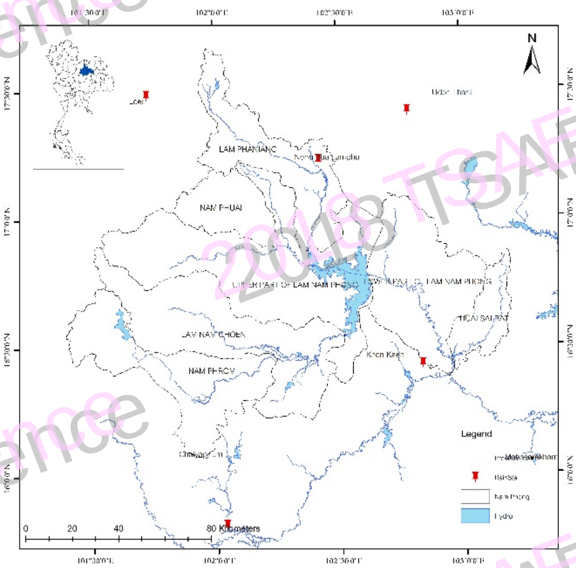

Figure 1 sub-basin in Nam Pong River

There are four sugar mills in the basin, 3 in the upper and one in the lower one, therefore sugarcane is the main upland crop of Nam Pong watershed (Figure 2). Sugarcane crop can be cultivated at any time of the year. Four stages of sugarcane growth are germination and emergence, tillering and canopy establishment, grand growth, and ripening (NaanDanJain, 2013). Average durations for each period are 30 days, 60, 180, and 95 days, respectively, make up 365 days which is closed to just one year. Normally in the Nam Pong watershed, sugarcane starts planting in November and harvesting in October upto February. Therefore, monthly water footprint of cane sugar production will be evaluated from November, says this year, up to about January next year.

We used daily rainfall and climatic data from 5 stations namely Loei, Nong Bualamphu, Udontani Chaiyaphom and Khon Kaen during the years 2013, 2014 and 2015 represented wet, moderate, and dry year, with the sugarcane harvested area of 1,183.51 km^2, 1,414.28 km^2 and 1,483.88 km^2, respectively as shown in Figure 2.

2.2 *Methods of water uses calculation*

We applied two calculation approaches, one is the Water Footprint Network (WFN) method and the other is hydrological method . The WFN method using CROPWAT model for calculating sugarcane crop water requirement (Chapagain, Orr, 2009). Crop water requirement can be expressed in crop water evapotranspiration (ET_c). ET_c value which is a function of time is estimatede from the multiplication of crop factor (K_c) and reference crop evapotranspiration (ET_o) (Allen et al., 1998) as,

$$ET_c = K_c \cdot ET_o \qquad (1)$$

The value of K_c is also a function of time, we used three values as 0.4, 1.2 and 1.0 for initial, mid season, and end period, respectively (Allen et al., 1998). ETo can be estimated from several formulae, however we selected the standardized method is FAO56 (Allen et al., 1998) in CROPWAT as

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \qquad (2)$$

where R_n is net radiation at the crop surface (MJ/m^2/day), G is soil heat flux density (MJ/m^2/day), T is mean daily air temperature at 2 meter height (°C), u_2 is wind speed at 2 meter height (m/s), e_s and e_a are saturated and actual vapour pressure (kPa), Δ is slope of saturated vapour pressure with respected to temperature (kPa/°C), γ is psychrometric constant (kPa/°C). The WFN method estimates the green consumptive water use (U_g) from selection of minimum values between effective rainfall (P_{eff}) and ET_c (Chapagain and Orr, 2009) as

$$U_g = \min(ET_c, P_{eff}) \qquad (3)$$

The blue water use (U_b) is the water required on top of the green water use to maximize sugarcane crop growth. It is the minimum value between irrigation requirement (I_r) and effective irrigation requirement (I_{eff}) as (Charchousi, et al., 2014)

$$U_b = \min(I_r, I_{eff}) \quad (4)$$

where Ieff is the water requirement on top of Ug which maximizes sugarcane yeild but not upto highest ETc (Inman-Bamber et al., 2012).

For hydrological method, we calculated ET_c, actual evapotranspiration (ET_a), and effective rainfall (P_{eff}) by ourselves. The values of ETc were calculated the same as Eqs. (1) and (2). However, ET_o was estimated using ET.PenmanMonteith function in the Evapotranpiration Package in R Environment (Gou, 2014) . We also calculated ET_a by using ET. MortonCREA function from the Evapotranspiration Package in R. The concept of Morton's Complementary Relationship Areal Evaporation (CRAE) model is that as a surface undergoes drying from initially moist conditions, the potential evapotranspiration (ET_p) increases while ET_a decreases. (Morton, 1983). For effective rainfall, we applied the SCS-CN method of the Natural Resources Conservation Service (US Department of Agriculture) (Chapagain, Orr, 2009). Then, water balance equation allows to estimate the dep percolation component (D) as

$$S_t = S_{t-1} + P - ET_a - R - D \quad (5)$$

where St and St-1 are water storage in the watershed at present and last time step respectively, P is rainfall, ETa is actual ET, R is runoff from SCS-CN method, and D is deep percolation to be determined.

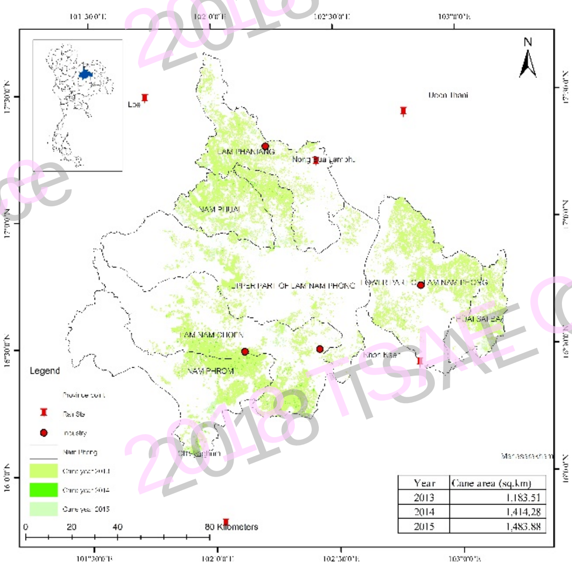

Figure 2 Sugarcane cultivation area in Nam Pong watershed.

3 Results and Discussion

3.1 Hydrological components

The values of hydrological components of the sugarcane planting area in Nam Pong Basin were calculoated by our hdrological method for the years 2013, 2014 and 2015. Firstly, the rainfall and runoff results from SCS-CN method were presented in Figure 3. The wet year of 2013 shows bimodal of 2 peaks clearly at July and September. The moderate year of 2014 show only one peak in August whereas the dry year of 2015 shows peak of equally depths at July, August, and September (Figure 3). The monthly runoff values are very small when compare to monthly rainfalls for all 3 years.

Figure 4 shows the hdrologicomponents of runoff (R), ETa, and deep percolation (D). We can see that ETa values are always highest of all and runoff values are the lowest with D is in the middle.

3.2 water consumption

From water footprint concept, there are two types of sugarcane consuptive water uses, green water and blue water use. The green water is free from precipitation while the blue water has to conway from surface water or groundwater. Since sugarcane cultivations in Nam Pong Basin are almost rainfed, therefore the green water is essential. Figures 5 and 6 compare the green with blue water uses by WFN and the hydrological method, respetively. Figure 5, using WFN method, shows that the green water is higher than the blue water use for 6, 6 and 4 months for the years 2013, 2014, and 2015. Figure 6 shows the results of hydrological method that the green water is higher than the blue water for 7, 7, and 6 months from May onward for the years 2013, 2014, and 2015, respectively. The hydrological method should be more accurate than the WFN method because the hydrological method based on daily calculation while WFN method based on monthly one. Considering the stage of sugarcane growth when the green water use is higher than the blue water in May is at the grand growth stage which crucial for biomass accumulation (Inman-Bamber et al., 2012). After November, when sugarcane is ripen, it does not need water. It needs only sunshine and cool weather to built up sugar content (Inman-Bamber et al., 2012). Figures 7 and 8 are sdimilar to Figures 5 and 6 the difference is only the units of depth and voume.

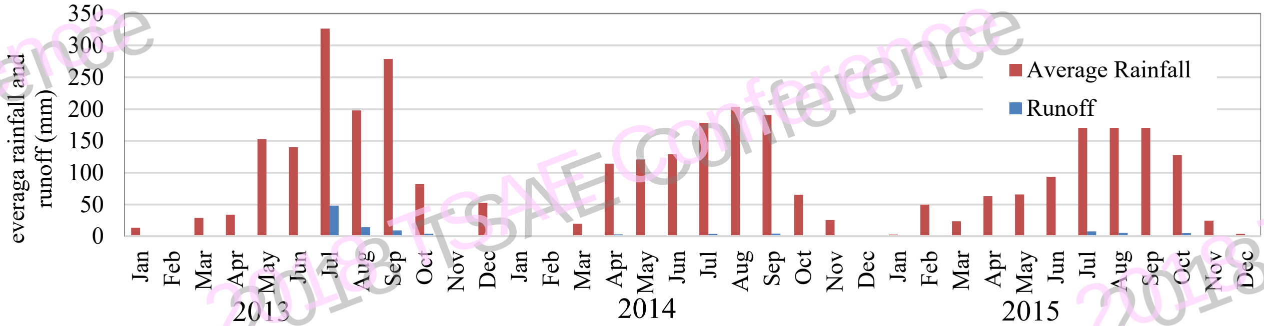

Figure 3 Average rainfall and runoff in preriod year 2013, 2014 and 2015

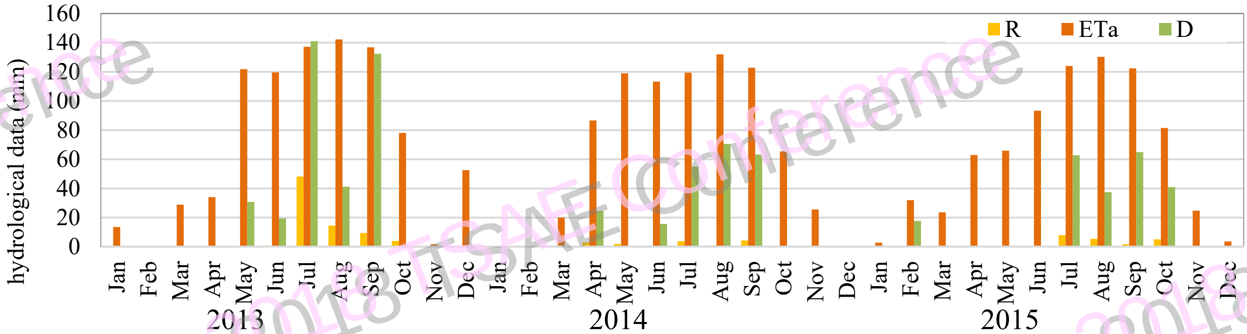

Figure 4 Runoff (R), actual areal evapotranspriration (ETa) and deep drainage (D) in Lam Pong Basin.

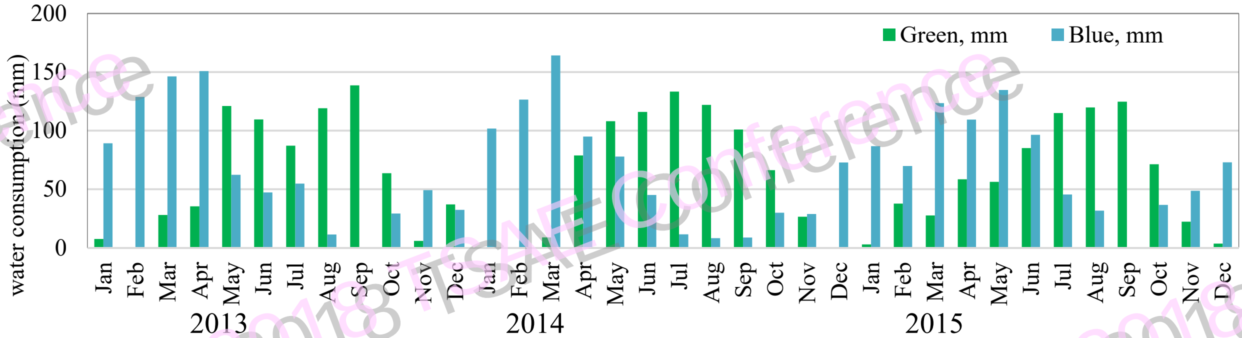

Figure 5 Water consumption of green and blue water by WFN method.

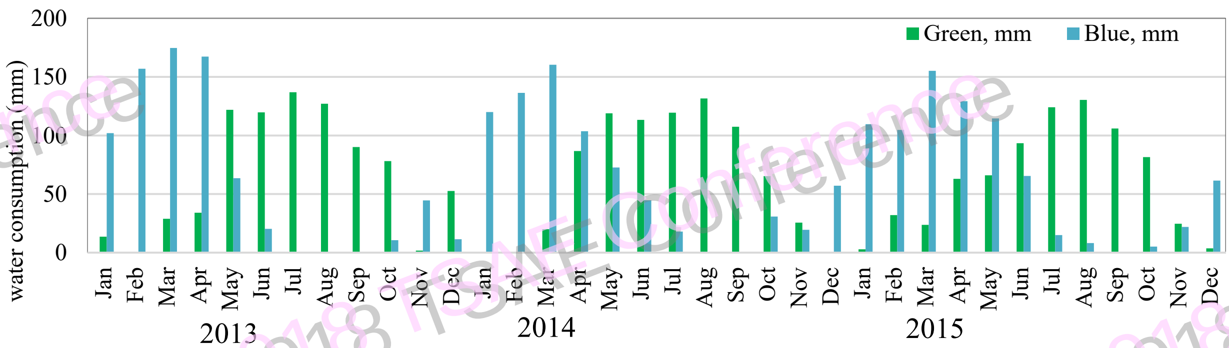

Figure 6 Water consumption of green and blue waters by hydrlogical method

Monthly water assumption explains distribution water use in 2013-2015 that input hydrologic soil group and climate data. As the result, we can be separate water use proportion on months in each year. Water usage in sugarcane stage with 2 methods is similarity in the claimate data inputs in the methods.

Analytical results of CROPWAT in Figure 5, the maximum water usage is 191.08 mm month^{-1} in May 2015 and minimum is 55.20 in November 2013 due to starting time for planting. As the result from Penman-Monteith with R evapotranspiration lower water use with CROPWAT which the maximum water usage is 203.66 mm month^{-1} in April 2013 and minimum is 45.18 in November 2014. We are show the annual result in the Table 2.

Table 2 water consumption of sugarcan in Nam Pong River with CROPWAT and Penman-Monteith

Consumption	water consumtion CROPWAT			water consumtion Penman-Monteith		
	Year			Year		
	2013	2014	2015	2013	2014	2015
Green, mm	754	762	725	846	789	751
Blue, mm	802	771	856	688	763	791
Sum, mm	1,556	1,533	1,582	1,533	1,552	1,542

3.3 Volume water consumstion in Nam Pong River

Nam Pong River has catchment area 1,5051.38 km^2 and average sugarcane area 1,360.56 km^2 (2013-2015) that it is 9 percent and tendency area increase in the future. Inceeasing area that it means increase water consumption in the area. Increaseing water stress will be influence to other priority. We show annual volume of water consumption for growthing sugarcane in the Nam Pong River in the Table 3 and monthly water consumption in Figure 7 and 8.

Table 3 water consumption of sugarcan in Nam Pong River with CROPWAT and Penman-Monteith

Consumption	water consumtion CROPWAT			water consumtion Penman-Monteith		
	Year			Year		
	2013	2014	2015	2013	2014	2015
Green, x10^6 m^3	892	1,077	1,076	1,001	1,115	1,115
Blue, x10^6 m^3	949	1,090	1,271	814	1,079	1,173
Sum, x10^6 m^3	1,841	2,168	2,347	1,815	2,195	2,288

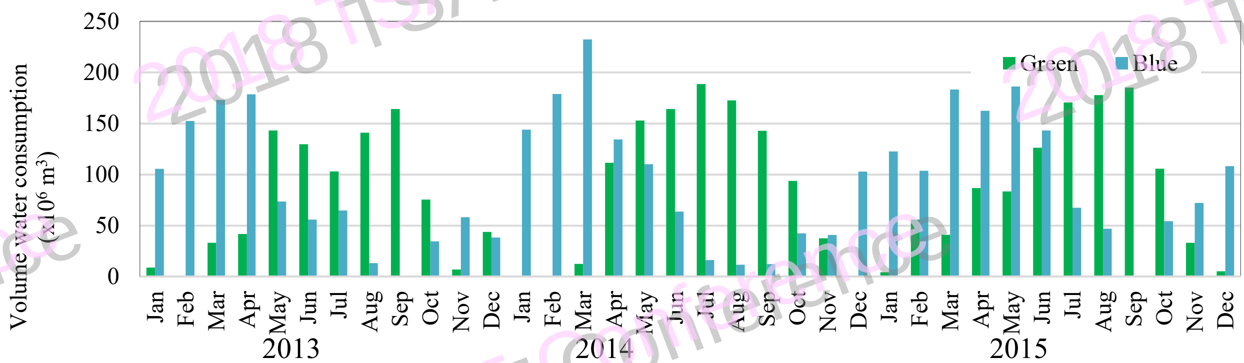

Figure 7 Volumetric water consumption for green and blue water by WFN method

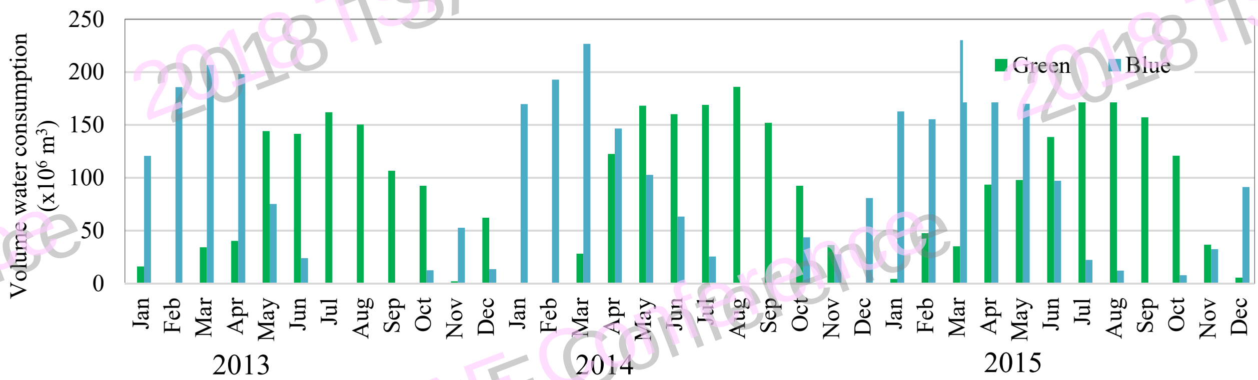

Figure 8 Volumetric water consumption for green and blue water by hydrological method

4 Conclusions

Sugarcane area in Nam Pong River is 10 percentage of catchment area that one of important sugarcane area in the Northeast, Thailand. There is large sugarcane area planting in the catchment and tendency to increase area. Large sugarcane area effect to direct and indirect water consumption.

For conciderate ratio of water consumption is important that can be planting water management. There are using Water Footprint Network method and hydrolical method by calculate actual and crop reference evapotranspirations by Morton CRAE and Penman-Monteith-FAO. We used the rainfall and climatic data from three crop years 2013, 2014 and 2015.

In case study we assume in unlimited water resource that sugarcane can be use all growth staps. The result classifieds in 2 typ of water assumption such as green and blue water footprint. The result of water footprint average of Nam Pong River is 1,550.09 mm include 781.67 mm of green and 768.43

mm of blue by Penman-Monteith and Morton method and 1,556.68 mm include 746.92 mm of green and 809.76 mm of blue by CROPWAT method. We can be seen that is a similar total water footprint but ratio between green and blue because of difference concept and condition. CROPWAT method considerate in effect rainfall but hydrological method considerate in water balance condition.

5 Acknowledgements

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