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*Article*

# Evaluation of the Water Footprint of Sugarcane in Eastern Thailand

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**Abstract.** This paper aims to present the three kinds of water footprint of sugarcane in eastern Thailand. The water footprints of sugarcane were assessed as the volume of yield in water per product unit ($m^3$/ton). Because of, sugarcane is an important crop in Thailand. The residue left from sugarcane can develop into useful products include fuel to produce electricity, organic fertilizers, pulp and scientific material. In present, area for sugarcane is likely to add more acreage. The cultivated area would affect the use of water resources. Therefore, the study the water footprint of sugarcane is an important crop. The result water footprint of sugarcane from the period 2013-2014 is 178.32 $m^3$/ton (129.60 $m^3$/ton of green water footprint, 17.61 $m^3$/ton of blue water footprint and 31.11 $m^3$/ton of grey water footprint). The highest and lowest water footprints are Prachinburi and Chonburi respectively. The water footprint in the eastern Thailand for sugarcane is lower than the global average. Excepting, the grey water footprint is about 3 times higher than that. This is mainly because of high fertilizers application rate for sugarcane are 125-156.25 kg/ha. Another one, the water footprint can be using prediction implement of yield of sugarcane.

**Keywords:** Crop water requirement, sugarcane, water footprint, water management.

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## 1. Introduction

Sugarcane is an important crop in Thailand. It has many advantages as it can be both a food and an energy crops. In addition to the production of sugar, it can also be used to produce ethanol as alternative energy. Molasses from sugarcane can be developed into useful products including fuel to produce electricity, organic fertilizers, pulp and scientific material. Sugarcane has high potential to contributes to economic and social development. Renewable energy from sugarcane also reduces environmental impacts. In recent years, Thailand exports sugar second only to Brazil and there is a tendency to expand sugarcane growing areas. The acreage of sugarcane in Thailand in 2014 was estimated at 62.99 million hectares [1], 90 percent are non-irrigated.

Water resources in Thailand are likely to diminish and because of the increasing social and economic pressures, the drought situation will likely worsen. As the volume of water usage is likely to rise, it is important to improve the management and conservation of water. In order to control and manage water to produce goods and also service, the "water footprint" concept has been adopted.

The "water footprint" is a concept concerning the amount of water used in the production of goods, crops or products and was developed by combination of international organizations that recognize the importance of the water crisis such as UNESCO, IFC, WWF and WBCSD, etc. The Water Footprint Network jointly conducted footprint analyses of services and products that a given country produced and sold in the world. The water footprint measure of the water production is determined both directly and indirectly by calculating the sum of all the water used throughout the production process. The result is considered as water use per unit of output.

Thailand has recently implemented the concept of water footprint under standard ISO 14046. Life cycle assessment applies the criteria of all products out to analyze the life cycle of the product (the process from start to finish). There are several countries that have adopted this principle in policies relate to imported goods to be sold in the country. For example, France requires that such goods much have at least two types of such environmental labeling. The water footprint in Thailand does not cover a wide range of all the goods exported. This is especially true for products manufactured in factories. According to the Department of Industrial Production, sugar factories have the 6th highest water usage. Besides water footprint of sugarcane, that of maize [2] and oil palm [3] in Thailand was also studied.

The purpose of this study is to assess the water footprint of sugarcane in the eastern region of Thailand. The result can be used to prepare guidelines for water resource management.

## 2. Materials and Methods

Hoekstra [4] initiated the water footprint concept, and then Hoekstra and Chapagain [5] elaborated by providing a framework for analysis of the linkage of human consumption to the global freshwater allocation.

The green, blue and grey water footprints of sugarcane in eastern Thailand are determined following the methodology of Hoekstra et al. [6]. The crop evapotranspiration and yield, required for the estimation of green water footprint. This is following the method and assumptions by Allen et al. [7]. The potential crop evapotranspiration ($ET_p$, mm/day) depends on climate and crop characteristics (Crop coefficient, Kc) [7]:

$$ET_p = K_c ET_o \qquad (1)$$

$ET_p$ value used to assess the water requirements of sugarcane each month that separate green and blue water footprint with the water available by excess rainfall method.

where $K_c$ is the crop coefficient and $ET_o$ the reference evapotranspiration (mm/day). The crop coefficient varies in time, as a function of the plant growth stage. During the initial and mid-season stages of the crop development, $K_c$ is a constant and equals $K_{c,ini}$ and $K_{c,mid}$, respectively. During the crop development and late season stages, $K_c$ varies linearly and linear interpolation is applied for days within the development and late growing seasons. The value of $ET_o$ is calculated by FAO Penman-Monteith equation [8]:

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

where $ET_o$ is reference evapotranspiration (mm/day), $R_n$ net radiation at the crop surface (MJ/m$^2$/day), G soil heat flux density (MJ/m$^2$/day), T mean daily air temperature at 2 meter height (°C), $u_2$ wind speed at 2 meter height (m/s), $e_s$ saturation vapour presser (kPa), $e_a$ actual vapour presser (kPa), $e_s$-$e_a$ saturation vapour presser deficit (kPa), $\Delta$ slope vapour presser curve (kPa/°C), $\gamma$ psychrometric constant (kPa/°C). The case study use climate data from Thai Meteorological Department (period 1984 -2013).

A water footprint can be presented as a water volume per product unit or per time unit. However, the process water footprint is presented in terms of volume per unit of time.

Green water footprint is crop water use from the effective rainfall which is stored above or below soil surface to be used by crop as evapotranspiration. The green water footprint in a process step is equal to:

$$(WF_{green} = \frac{CWU_{green}}{Ya} \tag{3}$$

$$CWU_{green} = \sum_{d=1}^{lgp} ET_{green} \tag{4}$$

where $WF_{green}$ is green water footprint (m$^3$/ton), $CWU_{green}$ green component of crop water usage (mm/day), $l_{gp}$ the length of growing period in days and $Y_a$ is the sugarcane yield (ton/ha).

The blue water footprint is indicator of consumptive use of fresh surface or groundwater by use irrigation systems. The blue water footprint in a process step is equal to:

$$WF_{blue} = \frac{CWU_{blue}}{Ya} \tag{5}$$

where $WF_{blue}$ is the blue water footprint (m$^3$/ton), $CWU_{blue}$ the blue component of crop water usage (mm/day) for irrigation systems in a field, $Ya$ the actual sugarcane yield (ton/ ha).

The grey water footprint of sugarcane is the volume of water needed to dilute the fertilizers that reach surface or ground water. Leaching and runoff of nutrients from sugarcane fields are the major cause of non-point source of surface and subsurface water pollution. The grey water footprint was indicated by nitrogen only. The grey water footprint ($WF_{grey}$, m$^3$/ton) is equal to:

$$WF_{grey} = \frac{(\alpha \times AR)/(c_{max} - c_{nat})}{Ya} \tag{6}$$

where $\alpha$, is leaching-runoff fraction (%), AR is the application rate of nitrogen (kg/ha), $c_{max}$ is the maximum acceptable nitrogen concentration (kg/m$^3$), $c_{nat}$ is the natural nitrogen concentration in the water body (kg/m$^3$) and $Ya$ is the sugarcane yield (ton/ ha).

The total water footprint for growing sugarcane ($WF_{proc}$) is the sum of all three the components:

$$WF_{proc} = WF_{green} + WF_{blue} + WF_{grey} \tag{7}$$

These sugarcane area productions and yield during time 2013-2014 get data from Office of the Cane and Sugarcane Board [1] show in Figs. 1-2 and Table 1.

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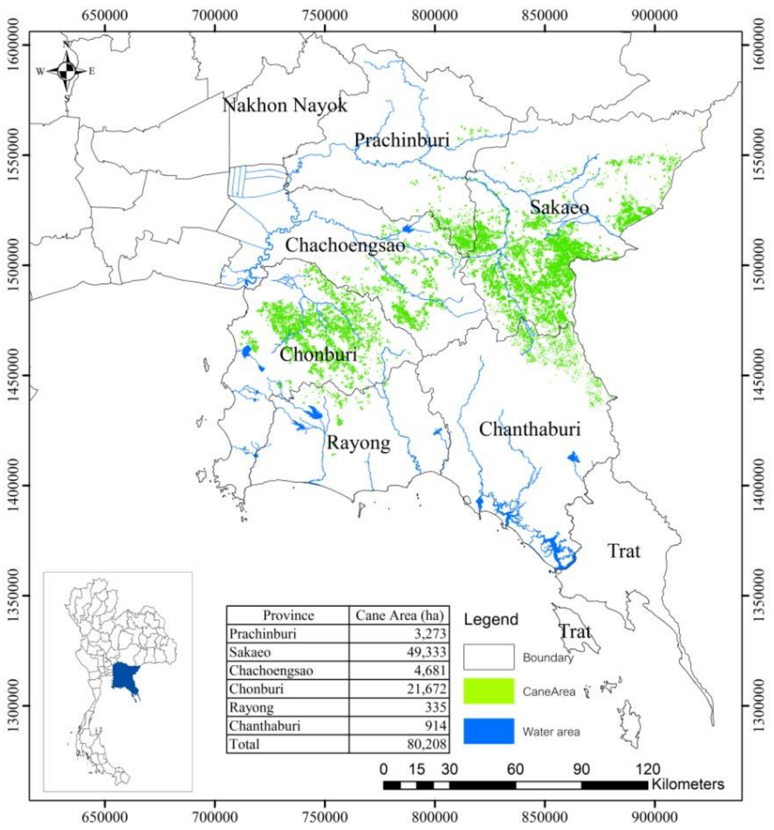


Fig. 1. Sugarcane area production.

Table 1. Sugarcane area production and yield during time 2013-2014.

| **Area description** | **Area (ha)** | **Yield (ton)** | **Area Harvested (ha)** | **Yield Harvested (ton)** | **Average Yield Harvested (ton/ha)** |
|---|---|---|---|---|---|
| Northern | 366,288 | 25,532,457 | 347,387 | 24,214,998 | 69.71 |
| Central | 475,268 | 34,151,374 | 419,437 | 30,139,087 | 71.86 |
| Northeastern | 690,720 | 48,238,953 | 643,017 | 44,909,547 | 69.84 |
| East | 80,208 | 5,339,380 | 67,639 | 4,502,832 | 66.57 |
| Prachinburi | 3,273 | 219,116 | 2,755 | 184,386 | 66.94 |
| Sakaeo | 49,333 | 3,345,391 | 41,657 | 2,824,848 | 67.81 |
| Chachoengsao | 4,681 | 296,979 | 3,942 | 250,086 | 63.44 |
| Chonburi | 21,672 | 1,397,823 | 18,235 | 1,176,129 | 64.50 |
| Rayong | 335 | 21,600 | 283 | 18,256 | 64.50 |
| Chanthaburi | 914 | 58,470 | 768 | 49,127 | 63.99 |

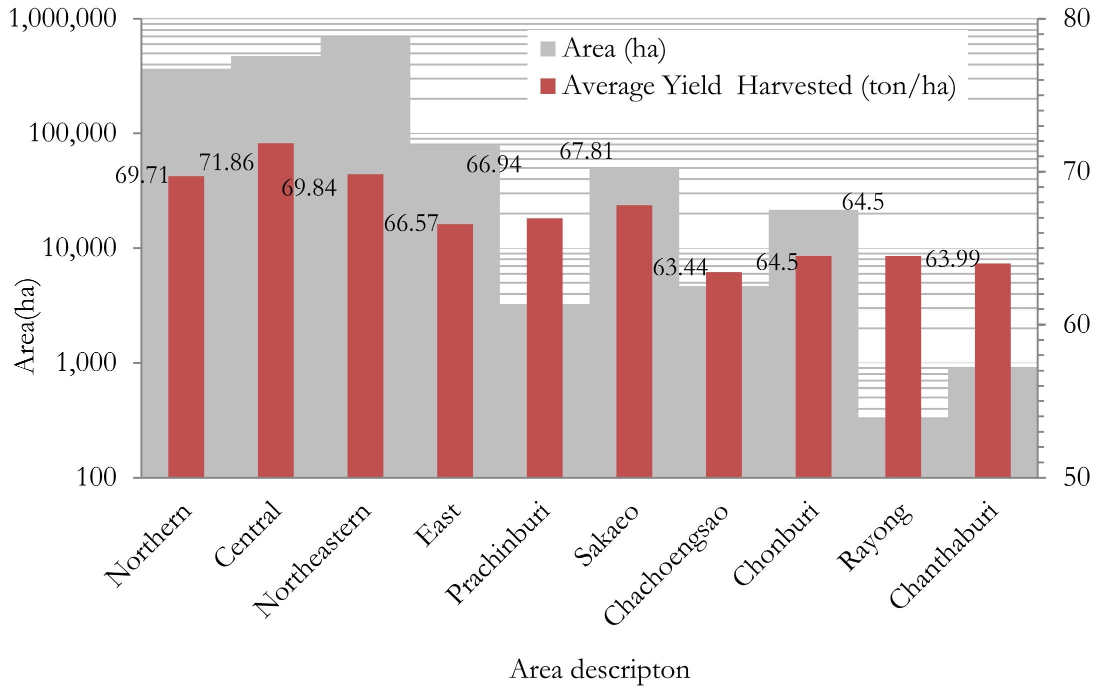


Fig. 2. Comparison sugarcane area production and yield during time 2013-2014.

Survey data from sugarcane managers must be to use planting time, irrigation systems and fertilizers application rates. The planting time varies from late November to April. Therefore, initial time for planting to be in December. The amount of water used in the irrigation of goods sugarcane are 312.5-1437.5 $m^3$/ha. And nitrogen fertilizer application rates for sugarcane are 125-156.25 kg/ha.

Crop coefficients ($K_c$) of sugarcane get data from the Royal Irrigation Department [9] and Allen et al. [7] (Table 2). Sugarcane planting dates and lengths of cropping seasons for most sugarcane producing regions were determined from field survey.

Table 2. Crop coefficients ($K_c$) of sugarcane.

| **Month** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $K_c$ | 0.4 | 0.59 | 0.96 | 1.12 | 1.12 | 1.12 | 1.12 | 1.12 | 1.12 | 1.02 | 0.85 | 0.69 |

Based on survey data, sugarcane average nitrogen fertilizer application rates which Prachinburi province is 156.25 kg/ha and Prachinburi, Sakaeo, Chachoengsao, Chonburi, Rayong and Chanthaburi province are 125 kg/ha. It was assumed that on average 10% of the nitrogen fertilizer is leached or runoff, as in Hoekstra et al. [10]. The recommendation for standard value of nitrate in surface and groundwater by the World Health Organization and the European Union is 50 mg nitrate ($NO_3$) per litre and the standard recommended by US-EPA is 10 mg/litre measured as nitrate-nitrogen ($NO_3$-N). In this study we used the standard of 10 mg/ litre of nitrate-nitrogen ($NO_3$-N), following Chapagain et al. [11] that the method is used for various.

## 3. Results and Discussion

### 3.1. Results

The average water footprint of sugarcane from duration time 2013-2014 in eastern Thailand is 178.32 $m^3$/ton (Table 3) and divide each sugarcane area production in Prachinburi, Sakaeo, Chachoengsao, Chonburi, Rayong and Chanthaburi province are 186.79, 174.73, 181.23, 158.90, 185.94 and 182.32 $m^3$/ton respectively. However, this volume each average water footprint less than global average. Not including, grey water footprint. Those are 31.11 and 13 m³/ton respectively.

Figure 3-4 show the volume each water footprint in sugarcane area production and total water footprint mapping. The total that highest and lowest are Prachinburi (186.79 m³/ton) and Chonburi (158.90 m³/ton) respectively.

Table 3. The water footprint of sugarcane in planting areas.

| **Province** | **$WF_{green}$ (m³/ton)** | **$WF_{blue}$ (m³/ton)** | **$WF_{grey}$ (m³/ton)** | **Total (m³/ton)** |
|---|---|---|---|---|
| Prachinburi | 126.78 | 33.33 | 26.68 | 186.79 |
| Sakaeo | 125.14 | 16.67 | 32.92 | 174.73 |
| Chachoengsao | 133.77 | 16.67 | 30.79 | 181.23 |
| Chonburi | 113.29 | 15.33 | 30.28 | 158.90 |
| Rayong | 135.73 | 15.33 | 34.88 | 185.94 |
| Chanthaburi | 142.88 | 8.33 | 31.11 | 182.32 |
| Average | 129.60 | 17.61 | 31.11 | 178.32 |
| Average northern Thailand | 90 | 87 | 25 | 202 |
| Global average | 139 | 57 | 13 | 210 |

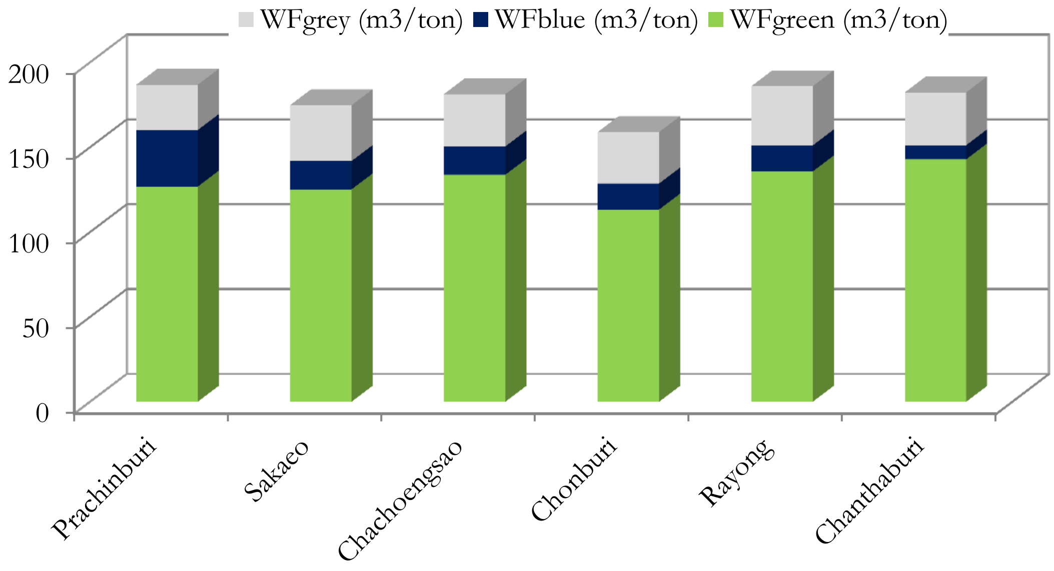


Fig. 3. The green water footprint, blue water footprint and grey water footprint of sugarcane yield period 2013-2014.

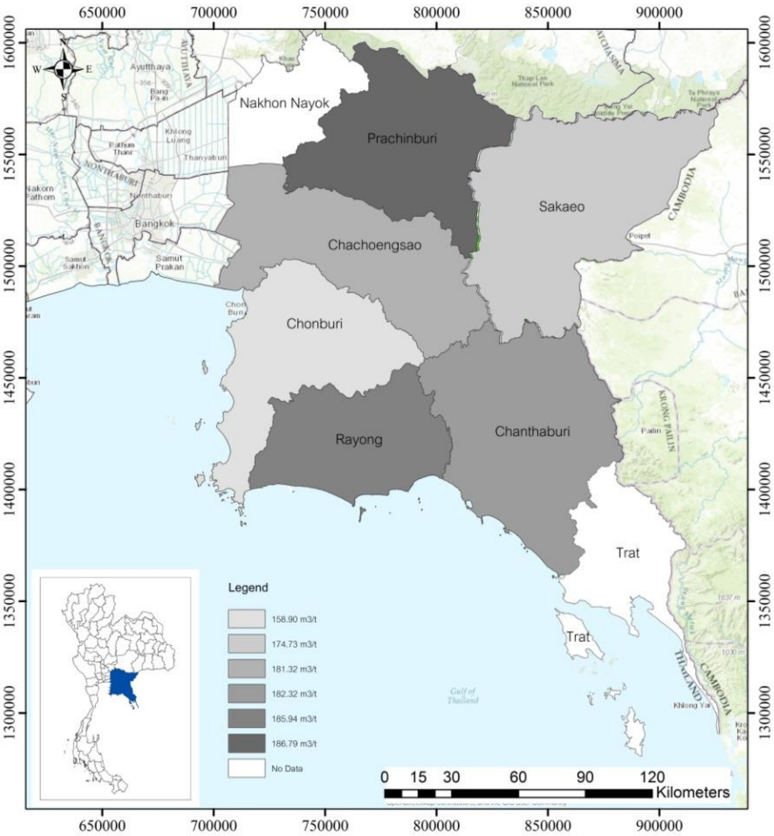


Fig. 4. Water footprint of sugarcane in eastern Thailand.

### 3.2. Discussion

The results of this study are comparing to water footprint of sugarcane as shown in Table 3. The average data that found in this study is 178.32 m$^3$/ton. Another average data that of global and Northern Thailand were 210 and 202 m$^3$/ton [7, 12] respectively.

Figures 5-6 show about the blue water footprint are generally scarcer and lower than green water footprint in eastern Thailand. And, the grey water footprint is about 3 times higher than global average. This is mainly because volume of water to dilute fertilizers reaches surface or ground water to high in this sugarcane area production.

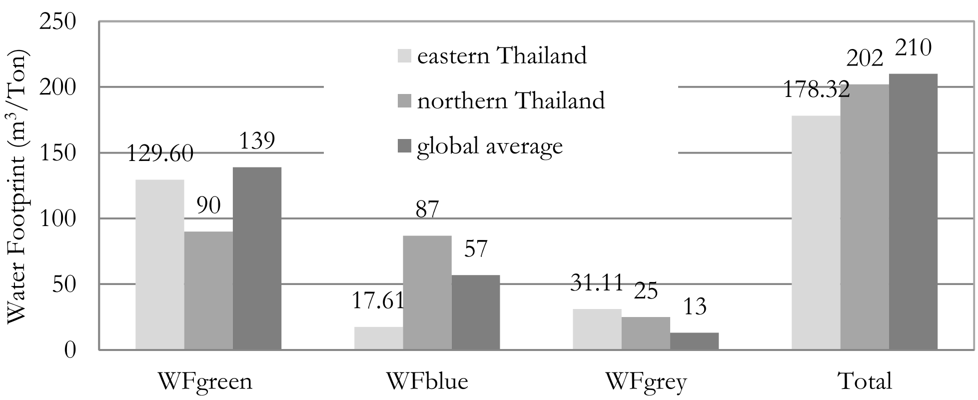


Fig. 5. The comparison water footprint of eastern Thailand, northern Thailand and global average.

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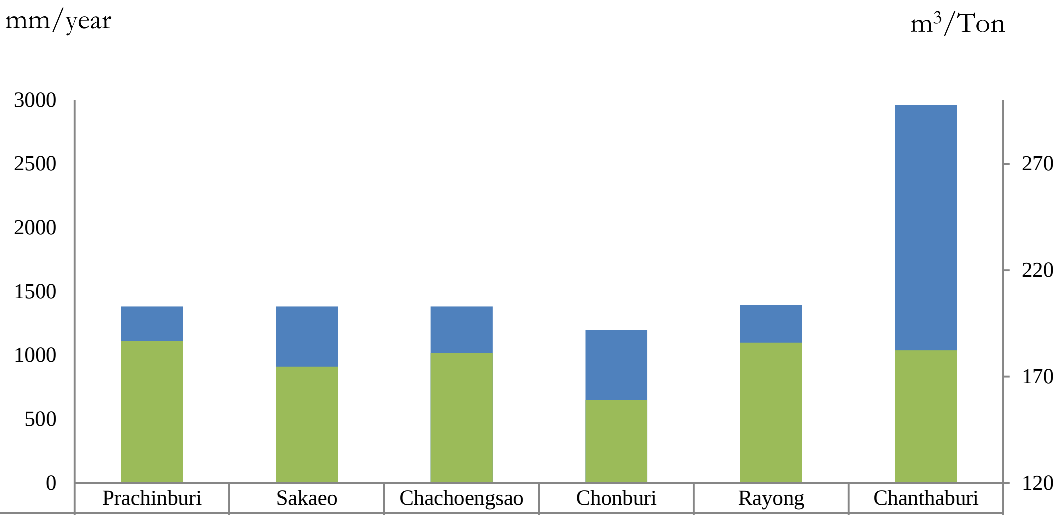
The green water footprint estimated is sensitive to various assumptions, such as (a) the daily precipitation pattern, (b) the modeling of runoff, (c) root zone, (d) the soil texture and its determines the soil water holding capacity, (e) the planting and harvesting times and thus the length of the growing period, (f) the soil moisture content at planting time and (g) the yield.

The blue water footprint can be estimated (Eq. (5)) from data resource actual irrigation in the study area, which is difficult in this stage to avoid the uncertainties. In this study use discussions of farmers and factory staff to estimate data, so it is difficult to calculate. Figure 6 shows a graph comparing the water footprint in the eastern region of Thailand and rainfall data.




| | Prachinburi | Sakaeo | Chachoengsao | Chonburi | Rayong | Chanthaburi |
|---|---|---|---|---|---|---|
| Rain | 1382.4 | 1382.4 | 1382.4 | 1198.7 | 1395.2 | 2960.5 |
| WFTotal | 186.79 | 174.73 | 181.23 | 158.9 | 185.94 | 182.32 |

Fig. 6. The comparison water footprint in the eastern region of Thailand and rain data (Thai Meteorological Department (1984 -2013) [13]).

The grey water footprint estimation in this study is relies on simplification by assuming a leaching fraction of runoff and a maximum concentration of nitrogen in the receiving water body. This approach is a rather rough estimate. More advanced technique may be applied to calculate the lost of nitrogen from leaching. These are recommend by Mekonnen and Hoekstra [14].

## 4. Conclusions

The water footprint of sugarcane from the period 2013-2014 in eastern Thailand is 178.32 $m^3$/ton (129.60 $m^3$/ton of green water footprint, 17.61 $m^3$/ton of blue water footprint and 31.11 $m^3$/ton of grey water footprint). The global average of water footprint of sugarcane [5] is 210 $m^3$/ton. And, water footprint of sugarcane for northern Thailand [12] is 202 $m^3$/ton. The water footprint eastern Thailand for sugarcane is lower than the global average. Not including, the grey water footprint is about 3 times higher than that. This is mainly due to high fertilizers rate in this area. The results shows that water use efficiency of eastern Thailand, is greater than the water used to grow sugarcane in northern Thailand and the global average water footprint.

The grey water footprint can be generally lowered substantially by appropriate fertilizers application rate, planting time and application technology (precision farming), so that less fertilizers leaches to groundwater or runoff to surface water [15, 16].

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