The 11th TSAE International Conference
26-27 April 2018
Available online at www.tsae.asia

Water Footprint Assessment of Rice in LAO PDR

Saranya Bhaktiwut[1], Nathsuda Pumijumnong[1]*, Kritsadapan Palakit[1], Worachat Wisawapipat[2]

[1]Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom, 73170, Thailand
[2]Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand
*Corresponding author: Tel: +66-8-9077-8837, Fax: +66-24-419-509-10, E-mail: nathsuda.pum@mahidol.ac.th

Abstract

Effective water use planning constitutes an indispensable prerequisite for Laos, where its economy is primarily driven by hydropower and agriculture. Nonetheless, hydroelectricity development could deteriorate the production of rice—the most vital economic crop of the country. Herein the water footprint (WF) of rice in rainfed and irrigated areas from ten representative rice-growing provinces of Laos was assessed. The climatic, crop and soil data were used for the WF calculation using CROPWAT model. Results of the model prediction revealed that average value of water footprint of rice (both rainfed rice and irrigated rice) in Laos was 1,295 m^3 ton^{-1} with the green, blue, and grey WFs of 68, 30 and 2%, respectively. The estimated WF value in the current was study slightly lower than for the global average WF of rice of 1,325 m^3 ton^{-1}. The average WF of the rainfed rice was 1,451 m^3 ton^{-1} (WFgreen, 99%; WFblue, 0%; and WF gray, 1 %), which was higher than for the irrigated rice of 1,139 m^3 ton^{-1} (WFgreen, 28%; WFblue, 69%; and WFgray, 3%). Interestingly, the average yield of irrigated rice yield with less water consumption was 4.01 ton ha^{-1}, which was higher than for rainfed rice yield (3.24 ton ha^{-1}), suggesting that local farmers could obtain satisfactory rice yield through appropriate agricultural practices with less water supply. Moreover, the green WF in rainfed areas could be ample for hydropower production.

Keywords: Water footprint, Rice, Rainfed, Irrigated

1 Introduction

Water is an extraordinary resources that it is essential for the humans. Water is a key driver of economic development while it has a basic function in maintaining the integrity of the natural environment and limited vital natural resource for humanity.In Laos, plenty of water is needed for an agriculture sector to respond to the demand of both domestic consumption and export market. Whether the government or the private sector, both have to make the difficult decisions on water allocation. More and more they have to apportion diminishing supplies between ever-increasing demands.

In order to response the increased consumption level, the economic and industrial sectors need to be expanded which leads to a continuously increasing of energy demand. The dam is constructed to generate a hydroelectric power which is an alternative energy production. The advantages of this energy are no air or water pollutants are produced, called “a clean technology”, and the cost is not too high. Laos has been benefited largely from the hydroelectric energy selling which is an important income for driving the country. The Government of Laos still rely on income from sales of electricity. Which is important factor in the future in driving the economic development in Laos.

Rice is an important crop in Laos - recognized as one of the leading countries in rice commodities exports. It is the most important cereal crops for human consumption. Furthermore, the farmers have been benefitted from rice farming which is 70% of total income of a family (Niranam, 2002). The staple food grain produced in Laos, with greater than 60 % of all agricultural lands are devoted to be a rice cultivation (USDA, 2011). Rice can be grown in almost any kind of soil if the climate is suitable and the water is sufficient for processing. The rice paddy cultivation in Laos uses the rainfall as a main water source. Significantly, rice is the major staple food crops of people in this country which presents in the agricultural land are mostly related with paddy. The total area of rice cultivation in Laos is about 630,880 hectares, divided into 2 parts including the rainfed rice area and irrigated lowland rice area which cover area 541,920 hectares and 88,960 hectares, respectively., In 2009, the total production of rice in Laos was 2.3 million metric tons (Kamphunwong, 2009).However, the production is not enough for human consumption. The socio-economic development plans regarding to the Laos Government indicated that in 2015, the rice production capability in Laos was expected to be about 4 million tons. (Ministry of Planning and Investment of Lao PDR, 2011) This expectation was set up in order to deal with a continuously increasing in domestic consumption and to ensure food security for the future. However, a human demand on water has increased dramatically which it also happened in Laos. This situation has an impact on water scarcity in the country. There are many sectors, namely agricultural, industrial and domestic use of water, have been affected from this problems because lots of water was stored in the dam to generate an electricity. In order to avoid the conflict between the sectors that use water for food processing and the sectors that need water for electricity generation to develop the country, the effects of water consumption rate are necessary to be studied.

The water footprint is an index to measure the amount of water used to produce each of the goods and services we use. It can be measured for a single process, such as growing rice. The water footprint studies both direct and indirect water use of a process, product, company or sector and includes water consumption and pollution throughout the full production cycle from the supply chain to the end-user (The Water Footprint Network, 2008). It can display the quantity of usage rainfall, irrigation water consumption and the volume of fresh water required for assimilation of pollutants as the standard of water source used for agriculture. Therefore, the water footprint analysis is a water balance recording for developing the water resources management that will be used for rice cultivation in Laos. The purpose of this research is to assess the water footprint of rice in Laos. The result can be used to prepare guidelines for water resource management. The purpose of this research is to assess the water footprint of rice in Laos. To comparison water footprint of rainfed rice and irrigated rice in Laos.

2 Materials and Methods

How to conduct research, the next step is data collection for rice cultivation, summarize and synthesize information obtained from a questionnaire cultivation. To calculate the evaporation plant with CROPWAT 8.0 by importing data on climate, soil and plant data.

The final step is to calculate the water footprint of rice. In this research, follow the guide "The Water Footprint Assessment Manual" recommended by (Hoekstra et al., 2011)

2.1 Research Area

The study areas cover 10 provinces of Laos. The provinces are grouped into 3 regions based on geographical, North (Xayaburi Province, Oudomxay Province and Luang Namtha Province), Central (Vientiane Province and Bolikhamxai) and South (Khammouane Province, Salavan Province, Attapu Province, Savannakhet Province and Champasak Province).The research water footprint of one crop earning cultivation in the years 2014-2015.

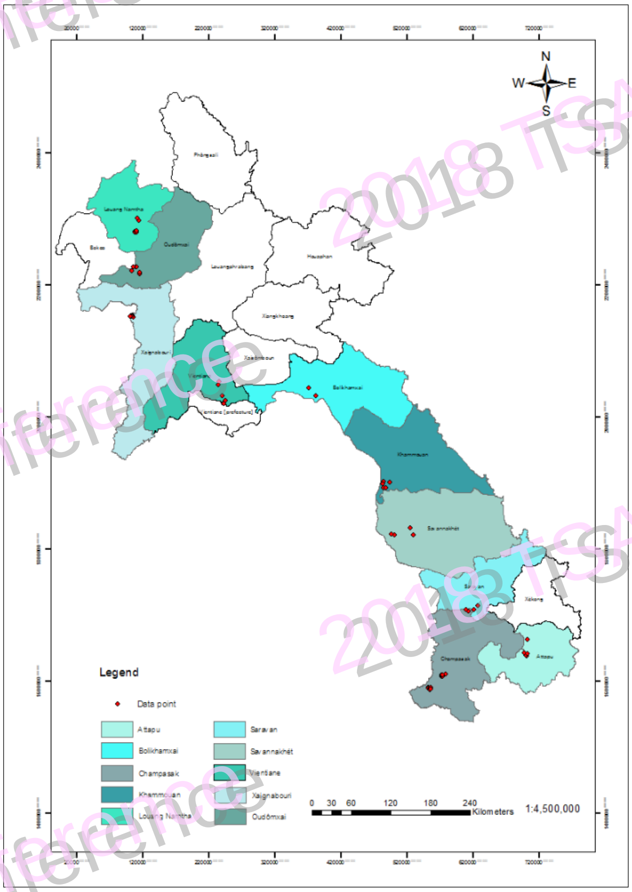

Figure 1 The study area of 10 provinces in Laos.

2.2 Input data for CROPWAT Model

The calculation of water footprint of the crop has been done using the climate data from the nearest and the most representative meteorological station located in the research areas (Laos Meteorological Department, 2013). The crop parameters and planting date, source of water use, quantity of fertilizer (kg/ha) that data and yield of rice and crop area of rice are obtained from the information from the questionnaires into the field by (Pumijumnong, 2015) and Food and Agriculture Organization of the United Nations: (FAO, 2011) and soil texture takes from the geographic information system (GIS) data of Food and Agriculture Organization of the United Nations (FAO, 2011).

2.3 Calculation water footprint of crop (WF_{proc})

The idea of considering water use along supply chains has gained interest after the introduction of the 'water footprint' concept by Hoekstra in 2002 (Hoekstra, 2003). Water Footprint is a measure volume of water use for the production of both direct and indirect of all sources. Water footprint includes of green blue and grey water.

Green water footprint refers to consumption of green water resources (rainwater insofar as it does not become run-off). Green water footprint is an indicator of the human use of so-called green water. Green water refers to the precipitation on land that does not run off or recharges the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. (Hoekstra & Chapagain, 2008)

Blue water footprint refers to consumption of blue water resources (surface and groundwater) along the supply chain of a product. 'Consumption' refers to loss of water from the available ground-surface water body in a catchment area. Losses occur when water evaporates, returns to another catchment area or the sea or is incorporated into a product.

Grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards (Chapagain & Hoekstra, 2011). Water footprint of crop is the sum of green, blue and grey water footprint as follow equation 1.

$$WF_{proc} = WF_{green} + WF_{blue} + WF_{grey} \qquad (1)$$

Where

WF_{proc} refers to water footprint of crop (volume/mass)

WF_{green} refers to green water footprint of crop (volume/mass)

WF_{blue} refers to blue water footprint of crop (volume/mass)

WF_{grey} refers to grey water footprint of crop (volume/mass)

Green and blue water footprint of crop are calculated as crop water use (CWU) (volume) divide by yield (Y) (mass/area) as follow in equation 2.2. Evapotranspiration was measured or estimated by means of model based on empirical formulas. Generally, one estimates evapotranspiration indirectly by means of a model that uses data on climate, soil properties and crop characteristics as input. There are many alternative ways to model Evapotranspiration (ET) (mm/day) and crop growth as follow equation 2.

$$WF_{green,blue} = \frac{CWU_{green,blue}}{Y} = \frac{10 \times \sum_{d=1}^{lgp} ET_{green,blue}}{Y} \qquad (2)$$

Where

$WF_{green,\ blue}$ refers to green or blue water footprint of crop (volume/mass)

CWU refers to crop water use (volume)

$ET_{green,\ blue}$ refers to green/blue evapotranspiration (mm/day)

Y refer yield of crop (mass/area)

Crop water use calculated by accumulation of daily evapotranspiration (ET) (mm/day) over the complete growing period (l_{gp}). Evapotranspiration estimated by CROPWAT Model version 8.0.This research assess the water footprint of rice into two schedule options of water use.

Grey water footprint of crop (WF_{grey}, m^3/ton) was calculated as follow equation 3.

$$WF_{grey} = \frac{(\propto \times AR)/(C_{max} - C_{nat})}{Y} \qquad (3)$$

Where

AR refers to the chemical rate to the crop (kg/ha)

α refers to fraction of chemical that leaches or runs off

C_{max} refers to the maximum acceptable concentration of chemical (kg/m^3)

C_{nat} refers to the natural concentration of chemical in the receiving water body (kg/m^3)

Y refers to crop yield (ton/ha)

This research considered chemical rate is nitrogen use only from chemical fertilizer application to the paddy field.

2.4 Method to calculate reference crop evapotranspiration (ET_0)

Estimation of actual evapotranspiration (ET_a) is of vital importance in water resources management and plan. Crop water requirements vary during the growing season, mainly due to variation in crop canopy and climatic conditions, and are governed by crop evapotranspiration (ET_c) (Benli et al., 2006).

The Penman-Monteith medthod equation was used to calculate reference evapotranspiration (ET_0), the variables of this equation were described in FAO Irrigation and Drainage Paper No.56 (Allenet et al., 1998) divided into three types

- The reference crop evapotranspiration (ET_0) can be computed from meteorological data. Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data.
- The crop evapotranspiration (ET_c) under standard conditions This is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions.
- The adjusted crop evapotranspiration ($ET_{c,adj}$) under non-standard conditions discusses the effect on ET of management and environmental conditions that deviate from the standard conditions. The environmental effects are described by introducing stress coefficients and by adjusting K_c to the field conditions.

Calculate evapotranspiration of plants by the irrigation schedule method (Irrigation schedule option). According to the water balance in the soil (Soil water balance) is a method that is accurate and is not complicated (Hoekstra et al., 2011). The irrigation schedule method determines the time and volume of water. The condition is irrigation when soil moisture drops to a critical point (Irrigation at critical depletion) and waters to soil moisture content moisture level irrigation (Refill soil to field.Capacity). This method calculates the evapotranspiration of the plant. (The adjusted crop evapotranspiration, ETc, adj or ETa) as follow equations 4.

$$ET_a = K_s\, ET_c = K_s\, K_c\, ET_0 \qquad (4)$$

Where

- ETa refers to actual water use by crop
- ET_0 refers to reference crop evapotranspiration (mm/day)
- Kc refers to the crop coefficient
- Ks refers to the effect of water stress on crop transpiration. Where the single crop coefficient is used, the effect of water stress is incorporated into Kc. For soil water limiting conditions, Ks< 1. Where there is no soil water stress, Ks = 1

The results of the program to compare values to calculate evapotranspiration and ET_{green} ET_{blue} following.

1) The simulation method requiring irrigation.Under the conditions of irrigated. (Irrigated condition) as follow equation 5.

$$ET_{green} = Et_a - ET_{blue} \qquad (5)$$

Where

- ET_{green}= green water evapotranspiration
- ET_a refers to actual water use by crop
- ET_{blue}= minimum (Total net irrigation, actual irrigation requirement)

2) The simulation method requiring irrigation. Under the conditions of rainfed (Rain-fed condition) as follow equation 6.

$$ET_{green} = ET_a \text{ and } ET_{blue} = 0 \qquad (6)$$

Where

- ET_{green}= green water evapotranspiration
- ET_a refers to actual water use by crop
- ET_{blue}= 0

3 Results and Discussion

The crop water use (CWU) of green and blue was determined by multiplying the calculated ET. The green, blue and grey water footprints of crop production were estimated following the calculated framework of (Hoekstra et al., 2009). The computations of rice evapotranspiration and yield, required for the estimation of the green and blue water footprint in crop production, have been done following the method and assumptions provided by (Allen et al., 1998). Calculated for green and blue water footprint of rainfed and irrigated areas are shown in Table 1-2

Table 1 Calculation for green and blue water footprint of rainfed rice.

Regions	Provinces	Yield (ton ha^{-1})	CWU (m^3 ha^{-1})			Water footprint of rice (m^3 ton^{-1})		
			Green	Blue	Total	Green	Blue	Total
Central	Vientiane	2.75	4,542	0	4,542	1,651	0	1,651
	Bolikhamxai	2.47	4,245	0	4,245	1,716	0	1,716
South	Khammouane	2.18	4,261	0	4,261	1,956	0	1,956
	Savannakhet	2.16	4,289	0	4,289	1,983	0	1,983
	Salavan	2.85	4,275	0	4,275	1,498	0	1,498
	Champasak	2.70	4,259	0	4,259	1,577	0	1,577
	Attapu	3.74	4,353	0	4,353	1,164	0	1,164
North	Luang Namtha	3.94	4,015	0	4,015	1,020	0	1,020
	Oudomxay	3.68	4,000	0	4,000	1,087	0	1,087
	Xayaburi	5.89	3,864	0	3,864	656	0	656

Table 2 Calculation for green and blue water footprint of irrigated rice.

Regions	Provinces	Yield (ton ha^{-1})	CWU (m^3 ha^{-1})			Water footprint of rice (m^3 ton^{-1})		
			Green	Blue	Total	Green	Blue	Total
Central	Vientiane	2.75	1,145	2,656	3,801	394	914	1,308
	Bolikhamxai	2.47	1,341	2,516	3,857	266	498	764
South	Khammouane	2.18	1,480	2,515	3,995	382	650	1,032
	Savannakhet	2.16	1,142	3,278	4,420	323	926	1,249
	Salavan	2.85	1,029	3,536	4,565	247	850	1,097
	Champasak	2.70	885	3,743	4,628	229	970	1,199
	Attapu	3.74	2,097	2,785	4,882	451	599	1,050

Grey water footprint estimation in this research 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 and more advanced technique may be applied to calculate the lost of nitrogen from leaching. These are recommend by (Mekonnen & Hoekstra, 2012) the grey water footprint of 10 provinces lower than that. This is mainly due to low fertilizers rate in this area.

The calculation of grey water footprint was considered especially nitrogen put in the crop areas and could be used for calculating leaching runoff to streams. The constant leaching run-off fraction (α) approach 10% of the applied nitrogen fertilizer is assumed polluted freshwater. In this research used the standard of 10 mg/ litre of nitrate-nitrogen (NO_3-N), that the method is used for various following (Chapagain et al, 2006). The maximum agreeable concentration load of pollutant according to the surface water quality standards, NO_3 in nitrogen should not exceed 5 mg/L. as follow the water quality the surface water (Pollution Control Department, 2012). The main constraints are poor facilities in Laos without information on the surface water quality standards. The natural concentration in the water body (C_{nat} in mass per m^3). Defined as zero due to lack of appropriate data based on the concept of (Hoekstra et al., 2011). The grey water footprint of rice in rainfed and irrigated areas was shown in Table 3

Table 3 Calculation for grey water footprint of rice.

Regions	Provinces	α	C_{max} (kg m^{-3})	Rainfed rice (m^3 ton^{-1})			Irrigated rice (m^3 ton^{-1})		
				Yield (ton ha^{-1})	N (kg ha^{-1})	WF_{grey}	Yield (ton ha^{-1})	N (kg ha^{-1})	WF_{grey}
Central	Vientiane	10	5	2.75	31.5	23	2.75	31.8	22
	Bolikhamxai	10	5	2.47	16.6	13	2.47	56.4	22
South	Khammouane	10	5	2.18	40.1	37	2.18	50.8	26
	Savannakhet	10	5	2.16	72.0	67	2.16	48.6	27
	Salavan	10	5	2.85	25.6	18	2.85	102.3	49
	Champasak	10	5	2.70	35.8	27	2.70	56.0	29
	Attapu	10	5	3.74	12.0	6	3.74	74.3	32
North	Luang Namtha	10	5	3.94	16.5	8	(Uncultivated)		
	Oudomxay	10	5	3.68	2.4	1	(Uncultivated)		
	Xayaburi	10	5	5.89	15.6	5	(Uncultivated)		

4 Conclusions

Most rice cultivation in each provinces of Laos are rainfed, of which some are also irrigated. The analytical results of the water footprint of the rainfed rice cultivation in each provinces are shown in Table 4 and Figure 2. As can be seen, Savannakhet province had the largest water footprint that accounted for 2,050 m^3/ton, following by Khammouane province (1,992 m^3/ton), Bolikhamxai province (1,729 m^3/ton), Vientiane province (1,674 m^3/ton), Champasak province (1,604 m^3/ton), Salavan province (1,516 m^3/ton), Attapu province (1,170 m^3/ton), Oudomxay province (1,089 m^3/ton), and Luang Namtha province (1,028 m^3/ton). Xayaburi province produced the smallest water footprint at 662 m^3/ton. The average water footprint in Laos among the rainfed study areas was 1,451 m^3/ton.

The analytical results of the water footprint of the irrigated rice cultivation in each provinces are shown in Table 4 and Figure 3. The largest water footprint of 1,329 m^3/ton was found in Vientiane province, following by Savannakhet province (1,276 m^3/ton), Champasak province (1,228 m^3/ton), Salavan province (1,147 m^3/ton), Attapu province (1,082 m^3/ton), and Khammouane province (1,059 m^3/ton). Bolikhamxai province produced the smallest water footprint at 786 m^3/ton, respectively. The average water footprint among the irrigated study areas was 1,139 m^3/ton.

In comparing with these results, the total amount of the green blue and grey water footprint of rice in Laos. Calculating the water footprint in the irrigated scenario with the average rice yield, the water footprint of rice cultivation in Laos relatively decreased. When comparing the water footprint of rice cultivation within 7 provinces, the results revealed that had Vientiane province, Bolikhamxai province, Khammouane province, Savannakhet province, Salavan province, Champasak province, Attapeu province, Luangnamtha province, Oudomxay province and Xayabouli province had the smaller values water footprints than the irrigated rice. Which indicates that the decreased in irrigation water did affect the rice yields. Considering the effect of the rice planting season on water resources related to cultivation, rainfed rice using water resources more than irrigated rice. According to comparing size of water footprint in this research, the green water footprint in every option of both provinces had the biggest size due to a lot of effective rainfall, followed by blue water footprint and grey water footprint, respectively as show in Figure 4

The average water footprint of paddy rice in Thailand computed by (Chapagain & Hoekstra, 2011) was 1,617 m^3/ton (WFgreen, 58%; WFblue, 35%; and WF gray, 7 %). and the global average water footprint 1,325 m^3/ton (WFgreen, 48%; WFblue, 44%; and WF gray, 8 %). Similarly, the study of (Thamniyom et al., 2012) showed that the average water footprint of either seasonal of off-seasonal rice cultivation was 1,653 m^3/ton as shown in Figure 5.

Based on the results of this study, the results shows that average water footprints of rainfed rice cultivation was 1,451 m^3/ton (WFgreen, 99%; WFblue, 0%; and WF gray, 1 %), which was higher than for the irrigated rice of 1,139 m^3 ton^{-1} (WFgreen, 28%; WFblue, 69%; and WFgray, 3%), the average water footprint of either seasonal of off-seasonal rice cultivation in Laos was 1,295 m^3/ton with the green, blue, and grey WFs of 68, 30 and 2%, respectively. which is smaller than the average water footprints of rice cultivation in Thailand and the global average water footprint. According to the interview with questionnaires, the average rice yield in Laos was 2.96 ton/hectare whereas the rice yield in Thailand was approximately 2.89 ton/hectare (Chimpalee, 2014). Therefore, the water footprints of rice yields in Thailand were larger than those in Laos.

In term of rice cultivation, we found that the overall rice yields in Laos tend to increase every year. In 2011, Laos could produce 3.61% more rice mainly due to the higher rice yields per hectare whereas the extension of rice fields was not significantly larger. In term of rice consumption, the demand of rice in 2011 was 1.46 million ton, increasing for 1.67% per year according to the population growth rather than the rate of rice consumption per person, which were only 1.67% higher per year (Eric et al., 2012).

Recently, Laos planned to increase its rice production and expect to be one of the rice exporters in the future according to The seventh five-year national socio-economic development plan (Ministry of planning and investment of Lao PDR, 2011) between the years 2011-2015 of the country. To ensure that the mentioned goals will be achieved, the Laos Government will encourage farmers to cultivate more rice. Hence, the demand of water usage for rice cultivation is also likely to increase. To meet such water demand, the government, as the country leader, should have an important role in agricultural water management for off-season rice cultivation throughout the growing season. If so, they will be able to increase the potential for economic development of the country.

5 Acknowledgements

This paper would not have been successful without the lenience of Associate Professor Nathsuda Pumijumnong. The authors would also like to express our sincere thanks Department of agricultural land and management ministry of agricultural forestry in Laos, Faculty of environment and resource studies and Faculty of graduate studies, Mahidol University.

Figure 2 Green, blue and grey water footprint of rice in rainfed areas

Figure 3 Green, blue and grey water footprint of rice in irrigated areas

Table 4 Water footprint of rice in Laos.

Regions	Provinces	Rainfed rice (m^3 ton^{-1})				Irrigated rice (m^3 ton^{-1})			
		WF_{grenn}	WF_{blue}	WF_{grey}	WF_{total}	WF_{grenn}	WF_{blue}	WF_{grey}	WF_{total}
Central	Vientiane	1,651	0	23	1,674	394	914	22	1,330
	Bolikhamxai	1,716	0	13	1,729	266	498	22	786
South	Khammouane	1,956	0	37	1,993	382	650	26	1,058
	Savannakhet	1,983	0	67	2,050	323	926	27	1,276
	Salavan	1,498	0	18	1,516	247	850	49	1,146
	Champasak	1,577	0	27	1,604	229	970	29	1,228
	Attapu	1,164	0	6	1,170	451	599	32	1,082
North	Luang Namtha	1,020	0	8	1,028	382	650	26	1,058
	Oudomxay	1,087	0	1	1,088	323	926	27	1,276
	Xayaburi	656	0	5	661	247	850	49	1,146
Average		1,431	0	21	1,451	324	783	31	1,139

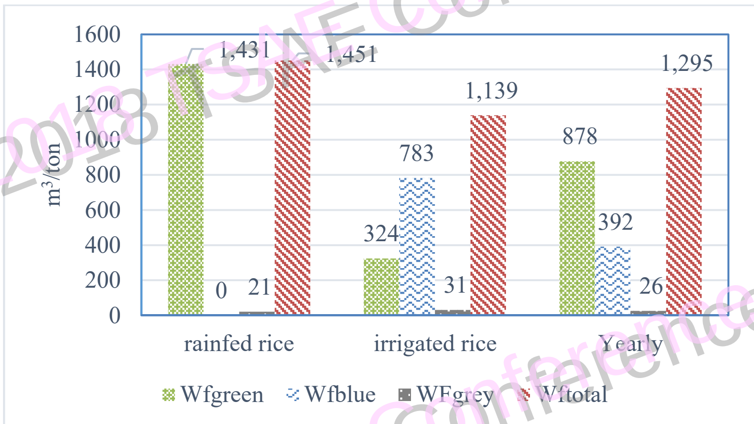

Figure 4 The comparison water footprint of rice in Laos

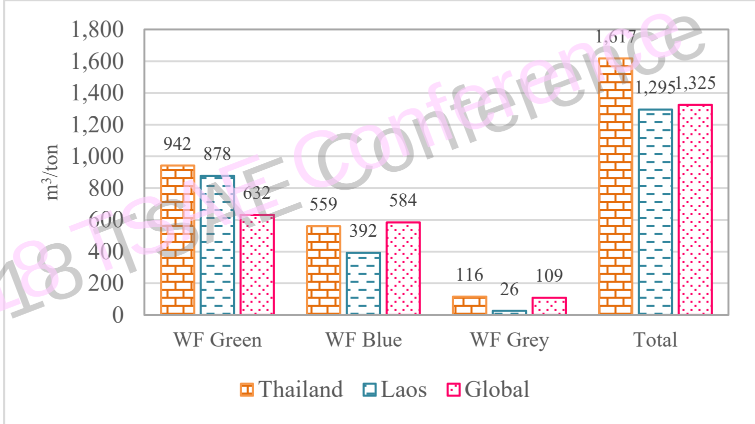

Figure 5 The comparison water footprint of Laos, Thailand and global average.

6 References

Allen RG, Pereira LS, Raes D, and Smith M. (1998). 'Crop evapotranspiration: Guidelines for computing crop water requirements', FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization, Rome.

Benli, B., Kodal, S., Ilbeyi, A., & Ustun, H. (2006). Determination of evapotranspiration and basal crop coefficient of alfalfa with a weighing lysimeter. Agricultural Water Management, 81(3), 358-370. http://dx.doi.org/10.1016/j.agwat.2005.05.003

Chapagain A.K. and Hoekstra A.Y. (2011). The blue, green and grey water footprint of rice from production and consumption perspectives. *Ecological Economics*. (2011) 70, 749–758.

Chapagain A.K., Hoekstra A.Y., Savenije H, and Gautam R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics. 2006; 60(1):186-203.

Chimpalee Ch. (2014). Statistics and Trends of Rice Plantation Area in Thailand (in Thai language). Retrieved from http://www.thairice.org/ doc_dl/seminar-29Oct13/3powerpoint (K.Chanpitaya).pdf. [Accessed 13 September 2015.]

Eric J. Wailes and Eddie C. Chavez "ASEAN and Global Rice Situation and Outlook" ADB Sustainable Development Working Paper Series No.22 2012

Food and Agriculture Organization. (2011). CROPWAT 8.0. Retrieved from http://www.fao.org/nr/water/infores_databases _cropwat.html [Accessed 15 August 2016].

Hoekstra A.Y. (2003). Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade', 12–13 December 2002, Value of Water Research Report Series No 12, UNESCO-IHE, Delft, Netherlands. Retrieved from www.waterfootprint.org/Reports/Report12. pdf. [Accessed 13 May 2016].

Hoekstra, A. Y., and Chapagain, A. K. (2008). Globalization of water: Sharing the planet's freshwater resources. Oxford, UK: Blackwell Publishing.

Hoekstra A. Y., Chapagain A. K., Aldaya M. M, and Mekonnen M. M. (2011). The Water Footprint Assessment Manual: Setting the Global Standard. Retrieved from www.waterfootprint.org [Accessed 20 December 2016].

Kamphunwong P. (2009). The 2009 Annual Economic Report on the (in Laos language). n.d.

Laos Meteorological Department. (2013). Statistics climate of the period of 10 years (2004 – 2013). (in Laos language). (n.d.)

Mekonnen, M. M. and Hoekstra, A. Y. (2012). The Green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences,Vol. 15, pp. 1577-1600.

Ministry of planning and investment of Lao PDR. (2011). The Seventh Five-year National Socio-Economic Development Plan (2011-2015). Retrieved 20 October 2017, from http://www.wpro.who.int/countries/lao/LAO20 112015.pdf

Niranam K. (2002). The techniques include agricultural Training. Courses Basic knowledge about rice cultivation techniques. (in Laos language).n.d.

Pollution Control Department. (2012). The quality of surface water standard (in Thai language). Retrieved from http://www.pcd.go.th/info_serv/ reg_std_water.html [Accessed 11 August 2017].

Pumijumnong N. (2015). Application and Dissemination of EPIC Model in Rice Farming System under Climate Change for Food Security of Lao PDR (in Thai language). Bangkok.

Thamniyom T. et al. (2012). Water footprint of rice in Kho katiam Operation and Maintenance Project Area (in Thai language). Bangkok. Kasetsart University.

The Water Footprint Network. (2008). what is a water footprint?.Retrieved from http://waterfootprint.org/en/water-footprint/what-is-water-footprint/ [Accessed 13 May 2016].

USDA (2011). LAOS: Sustainability of Future Rice Production Growth and Food Security Uncertain.
Retrieved from https://ipad.fas.usda.gov [Accessed 13 May 2016