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Identification, measurement, and assessment of water cycle of unhusked rice agricultural phases: Case study at Tangerang paddy field, Indonesia

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Abstract. According to one of UN reports, water scarcity has happened all around the world, including Indonesia. Irrigation sector takes up 70% of world water consumption and potentially increases 20% due to the population explosion. Rice is accounted for 69% of agricultural products contributions in Indonesia's water footprint. Therefore, evaluation of water cycle was essential to raise awareness among practitioners. Data collections were conducted in the functional unit of one-hectare rice field located in Tangerang. This study used CropWat 8.0 and SimaPro software. Identification involved data such as climate, crop, and soil. Nursery became the highest water consumed phase, requiring 419 mm in height. Measurement through water footprint resulted in consumption of green water footprint for 8,183,618.5 liters (62.9%), followed by grey for 4,805,733.2 liters (36.9%) and blue for 23,902.36 liters (0.2%). The grey consumption was exceeding the average, which indicated high doses of pesticides. Life Cycle Assessment showed negative impacts of fertilizers that caused damages like fossil depletion, respiratory health, and eutrophication.

Keywords: Agricultural phases; Life Cycle Assessment; paddy field; water; water footprint

1. Introduction

Due to its significant role in every aspect of life, freshwater has been scarce for several years in many regions. Water scarcity is one of the most crucial environmental problems [1]. This is in part due to changing climates and poor water management strategies, and parts of the scarcity problem find an explanation in natural factors [2]. Freshwater scarcity also happens in Indonesia.

High water consumption is contributed by several sectors, but the highest consumption comes from the agricultural sector in relation to irrigation practices. It takes up 70% of world water consumption and potentially increases 20% without any further improvement in management [3]. Another research said that agriculture was responsible for 85% of the overall global freshwater consumption [4] and caused significant environmental damages [5]. This negative potential is also caused by population explosion as predicted by UN. In 2050, world population will be 9.8 billion people, which from 2017 to 2050, it is expected that half of the world's population growth will be concentrated in just nine countries, including Indonesia [6]. Indonesia considered will be the 9th country that contributed to the total growth of the world's population according to UN reports. This explosion will lead to higher number of water consumption. As an agricultural country, Indonesia produces several crop products, such as rice, maize, cassava, soybeans, groundnut, and many more. Among these products, rice contributes the highest water consumption with 69% [7]. Based on previous facts, it is essential to evaluate the current water flow in rice agricultural phases especially in a paddy field.

Previous researches in Indonesia were mainly about how much water needed for irrigation of paddy field such as Fuadi et al [8] and Indonesian Center for Rice Research, Ministry of Agriculture [9]. There is a need to research to address water scarcity. A research about water footprint was introduced by Hoekstra in 2003. The water footprint of a product is defined as the total volume of freshwater that is used to produce the product [10]. Bulsink in 2009 studied water footprint of Indonesia provinces. He reported that Java is the most water-scarce island [7]. This study tried to identify, measure and assessment on a smaller scale to raise awareness among local farmers. Therefore, this study evaluates water footprint and LCA with identification, measurement, and assessment of agriculture phase at paddy field, a case study at Bojong Indah, Kemuning Village, Tangerang, West Java from September until December 2016 using CropWat 8.0 and SimaPro.

2. Methodology

This research focuses only on agricultural phases of unhusked rice as the main object. Unhusked rice is obtained directly from harvesting without any further process,it is still covered with husks. Data about this object was based on latest process happened in rice field located at Bojong Indah, Kemuning Village, Tangerang. The latest productivity of the rice field was 5.6 tons per hectare. An overallpaddy field is about 25 hectares and led by Mr. Diding, a local farmer.

To achieve the goal of this research, several steps were arranged, starting from preliminary research, problem identification, theoretical background, direct observation, data collecting and processing, data analysis and discussion, and conclusion. Steps in data collection and processing are shown in Fig 1. Data analysis measured impact assessment and evaluation of water cycle.

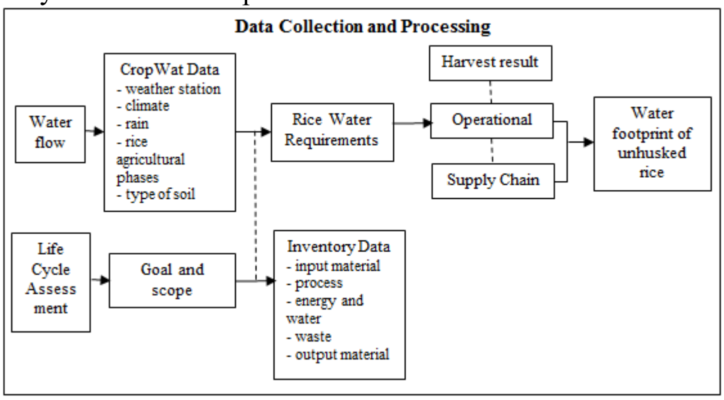

Figure 1. Steps in data collection and processing

This research had three major activities: identification, measurement, and assessment. Identification was used CropWat 8.0 to calculate water requirements in every agricultural phase. This data used a functional unit of one-hectare rice field. Measurement and assessment of the water cycle were examined through LCA using SimaPro. Life Cycle Assessment (LCA) is a tool developed to assist sustainable decision-making processes [2], which in this research, to evaluate the water cycle.

2.1. CropWat data

CropWat is a decision support tool developed by the Land and Water Development Division of FAO, a computer program for the calculation of crop water requirements and irrigation requirements based on soil,climate and crop data [11]. CropWat was used to calculate water requirement. Input data for this software were information about weather station, climate, rain, soil, and crop. Data was taken for 1 year from 1 October 2015 to 30 September 2016. Data about weather station was gathered through

BMKG [12]. The weather station mentioned here is the nearest station that measures some climate statistics in the concerned rice field. Based on search results, the weather station is located in Curug, Tangerang, geographically 6.29 S (latitude) and 106.6 E (longitude) with altitude 42 meters above sea level. Climate statistics needed for CropWat software are temperature, relative humidity, wind speed, the sun, and rain, with different units. Data was converted monthly from October 2015 until September 2016. A complete data about temperature was collected from AccuWeather. Meanwhile, the wind speed was taken from Weather Online. The rests were taken from BMKG (Curug Station) although not all daily data was available [13]. All statistics were then inputted in menu Climate/E To CropWat. For menu Crop, some statistics came from agricultural phases based on an interview with local farmers, especially for the duration of each phase. The rests were taken from CropWat database. Last, menu Soil was fully taken from CropWat database. The type of soil that was chosen was black clay soil according to direct observation and interview.

After all statistics data were inputted, crop water requirements were calculated automatically. The result was total water requirements are 820.1 mm (in height). The first phase (nursery phase) was the highest water required phase.

2.2. Water footprint

The component used in water footprint method was indirect consumption, which includes only processes to produce unhusked rice without further processes or consumption. Calculations were both for operational water requirements and supply chain water requirements, classified as green, blue, and grey water footprints. The blue water footprint refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of a good, the green water footprint refers to the rainwater consumed, the greywater footprint of a product refers to the volume of freshwater that was required to assimilate the load of pollutants based on existing ambient water quality standards [14].

In operational, all green consumptions were calculated from CropWat results of water requirements in the previous section. The water quantity was converted into a unit of volume (liter) by multiplying it with the functional unit (one hectare). The blue consumption was calculated from water consumption through the water supply, mostly charged with overhead consumption of local farmers. Meanwhile, the grey consumption is the volume of water to assimilate dangerous substances mostly for pesticides. It was calculated using (1). The value of α is a leaching-runoff fraction which was 0.01 (for pesticides) and 0.03 (for phosphorous) [10]. Appl is the amount of chemical substances released to the environment. Meanwhile, cmax is maximum allowable concentration of chemical substances, which was 0.1 µg/liter (for pesticides) and 200 µg/liter (for phosphorous) [15] [16]. Other values of cmax can also refer to CCME and EPA standards. Value 0 of cnat is given if pesticides are not naturally formed.

$$\text{Grey water footprint} = \frac{\alpha \times \text{Appl}}{c_{max} - c_{nat}} \quad (1)$$

The results of operational water requirements were presented in Table 1. The first six phases were direct consumption through agricultural phases of unhusked rice and the last two aspects were overhead consumption.

Table 1. Operational water requirements.

Phases/ aspects	**Operational water footprint (liters)**			
	Green	**Blue**	**Grey**	**Total**
Nursery	4,189,000	1,000	0	4,190,000
Land preparation	0	0	0	0
Plantation	382,000	0	0	382,000
Quick growth	1,062,000	0	0	1,062,000
Further growth	1,607,000	0	0	1,607,000
Maturation	941,000	98.38	4,707,222.2	5,648,320.58
Farmers consumption	0	22.500	93.750	116.250
Cleaning	0	0	0	0
Total	8,181,000	23,598.38	4,800,972.2	13,005,570.58

Using the same way, water consumption in the supply chain was also calculated. It includes fabric used in nursery phase, tractors for tilling, fertilizers, pesticides, and fuel to operate tractors (overhead). Several assumptions were stated to adjust calculations so that it can reflect real conditions. The result of supply chain water requirements can be viewed in Table 2. These two water requirements calculations were combined to get the total value of water footprint as presented in Table 3.

Table 2. Supply chain water requirements.

Materials	Supply chain water footprint (liters)			
	Green	**Blue**	**Grey**	**Total**
Fabric	2,618.5	0	357	2,975.5
Tractors	0	302.4	4,392	4,694.4
Fertilizers	0	0	0	0
Pesticides	0	1.58	0	1.58
Fuel	0	0	12	12
Total	2,618.5	303.98	4,761	7,683.48

Table 3. Total water footprint.

Type	Water footprint (liters)			
	Green	**Blue**	**Grey**	**Total**
Operational	8,181,000	23,598.38	4,800,972.2	13,005,570.58
Supply chain	2,618.5	303,98	4,761	7,683.48
Total	8,183,618.5	23,902.36	4,805,733.2	13,013,254.06

From the total water footprint calculation results, it was clear that the highest water requirement was green water footprint (62.9%), followed by grey (36.9%) and blue water footprint (0.2%). The total water footprint is 13,013,254.06 liters.

2.3. Life Cycle Assessment (LCA)

Standard steps in LCA are goal and scope definition, inventory data, impact assessment, and interpretation. This assessment was cradle-to-gate because only includes transformation from raw materials (which are rice seeds) into unhusked rice. This assessment was directed to identify potential damages of unhusked rice agricultural phases. Not only high water consumption that will correlate with water scarcity, damages of the phases have to be evaluated. Functional unit used was one hectare of rice field that produces 5.6 tons of unhusked rice.

To create inventory data, the generic unit process should be drawn based on every agricultural phase, involving energy and water used, also wastes. Several assumptions should be defined following insufficient information.

Impact assessment as the next step was done with two methods, one method from European methods, and another one from water footprint-based methods with the help software SimaPro. Because the focus in this assessment was various damages caused by phases, the European method used was ReCiPe endpoint, which covers damage to human, ecosystem, and resources. Because its correlation with ReCiPe three types of damages, Pfister et al. method [5] was used as water footprint-based impact assessment.

3. Results

Results from CropWat 8.0 showed that nursery phase was the highest water required which happens in parallel time with land preparation. The total height of water needed in the nursery phase is 419 mm (for 2 decades, each decade contains 10 days). It was far different compared to next decades which are around interval 34.6 mm until 44 mm, except the last decade which was only 7.3 mm because contains only 2 days.

This result showed that nursery phase was important to ensure the success of entire processes. The high water requirements for this phase are normal due to the significance of this phase to ensure the good harvest results. Besides its vital role, the effective rain in this phase was also minimum, 0.4 mm (for the first decade) and 0.5 (for the second decade). This value drives to the higher water supply.

The specific contribution of high water requirements can be assessed through water footprint calculation results. Based on total water requirements, operational water requirements take up 13,005,570.58 liters (99.94%), compared to the supply chain which is only 7,683.48 liters (0.06%). It indicates that the agricultural phases mostly consume water in operations, not from material or other inputs. The green consumptions happened in every single operational process. It comes from irrigation process that fully uses rainwater. A relative high operational consumption happened in maturation phase due to pesticides. It consumes 4,707,222.2 liters of water to assimilate dangerous substances. The highest consumption was still the green (62.9%), but the abnormal value of the grey (36.9%) should be anticipated. An indication of high doses of pesticide was highly concerned. To prove this indication, the overall value of water requirements is compared to average. The average value is taken from average water footprint of rice in Banten Province. The difference was converted into meter cubic per ton as presented in Table 4. Both green and blue water footprint were below average, but the grey was exceeding. Although the total water footprint was below average, the value of grey water footprintindicates there werehigh-levelpesticides used.

Table 4. Actual water footprint compared to average.

Value	Water footprint (m^3/ton)			
	Green	Blue	Grey	Total
Average	1,994	1,332	205	3,530
Actual	1,464.57	4.27	858.17	2,327.01

Pesticides can be exposed to human through different mediums. Without protective devices, pesticides can enter the body through direct exposure to skin, as well as a respiratory and digestive tract. Pesticides that touch skin can absorb into the body and cause toxicity. Pesticides can also enter respiratory tract. Gas and spray particles which are less than 10 microns get into lungs, whereas larger particles stuck in mucous membrane or throat. Finally, exposure canalso go through digestive tract while eating foods that contain pesticides or when pesticides carried by the wind into the mouth. Moreover, pesticides used in this agricultural phases are dangerous. It contained carbamate and pyrethroid types. A carbamate type called carbofuran (forbidden pesticide based on US EPA since 2008) was used. Also, the application of lambda-cyhalothrin (pyrethroid type which was classified as carcinogenic group D) should be concerned.

To explore other impacts of agricultural phases, the next step of Life Cycle Assessment is impact assessment. Further-growth seeds play a significant role because this was the major input in the last phase (maturation). Further-growth seeds are an accumulation of previous processes. According to ReCiPe normalization of damages, damage to resources becomes the highest, followed by human health and ecosystem.

Damage to resources was mainly caused by fossil depletion due to natural gas used in processing fertilizers and diesel used to generate energy for doing land preparation. Damage to human health is due to CO2 emission on fertilizers production processes, which is around 304.5 kg per ton of production. Diesel burning process was also producing dangerous substances such as particulates, CO2, CO, NO, methane, and much more. Meanwhile, damage to theecosystem was caused by the use of fertilizers that generates ammonia and nitric acid. The exceeding concentration of nitrogen and phosphor of fertilizers will lead to water eutrophication and soil acidification.

According to Pfister et al. [5] method, every damage was calculated with different units. Damage to resources was measuring the water consumption related to scarcity level. Damages of human health and ecosystem show that the higher water consumed, the higher its contribution to damages. In this case, the highest water consumption happened in ready-to-plant seeds, which is the main output of the nursery phase, followed by further growth seeds, unhusked rice, and quick-growth seeds.

Overall, farmers around the rice field should give attention and did an evaluation of their agricultural practices. An indication of dangerous use of pesticides should be concerned since the harvest results will be consumed. Standard setting, law enforcement, and direct socialization will be needed to educate farmers. In other sides, fertilizers mainly contribute to several damages. The amount of fertilizer used should be considered because of potential damages like fossil depletion, human respiratory health, water eutrophication, and much more.

4. Conclusion

Identification of water cycle showed the significance of nursery phase that consumed up to 419 mm (in height) water in a20-day period. The water requirements were contributed mostly from operational needs. The green consumption was 8,183,618.5 liters (62.9%), followed by the grey for 4,805,733.2 liters (36.9%) and the blue for 23,902.36 liters (0.2%). The grey consumption exceeded Banten Province average, which indicated the high doses of pesticides used, including carbamate and pyrethroid types that are highly toxic. Meanwhile, the assessment summed that fertilizers played important role in causing damages such as resource depletion from natural gas used, human health problem from emission in the production process, also water eutrophication from fertilizers substances like nitrogen and phosphor.

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