ASSESSMENT OF PADDY CULTIVATION WATER FOOTPRINT COMPONENTS AND THE IMPACTS ON ENVIRONMENT

PANG CHIEN HAN

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Universiti Teknologi Malaysia

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DEDICATION

I would like to dedicate this thesis to my parents and my mentor who have given your precious ideas and guidance along the way; I could not have done this without your support.

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ABSTRACT

Water footprint quantification and environmental impact assessment across product's life cycle is becoming increasingly prominent. This study focused on developing a Life Cycle Assessment (LCA) based water footprint (WF) assessment approach of paddy cultivation. A case study applying the proposed methodological framework was carried out at Muda Rice Granary, Malaysia. As the study started in year 2016, the research analysis presented in this thesis area based on the data provided by MADA from year 2012 to 2015 and ISO 14046 was used as a guideline. The total water footprint of rice cultivation on Muda Rice Granary ranged from 1800-2600 litres/kg gross paddy. ReCiPe 1.08 methodology with Gabi 7 was used for the life cycle impact assessment in this study. The LCA results showed that paddy cultivation contributed 0.303kg Peq in freshwater eutrophication impact, 5.33 kg N eq in marine eutrophication impact, 20.6 kg 1,4 DB eq. in freshwater ecotoxicity impact and 1.24 kg 1,4 DB eq. in marine ecotoxicity impact. Water depletion risk ranging from 6000-11000m^3 was detected from year 2012 to 2015. This research recommends the use of the holistic WF assessment instead of single assessment as this method can evaluate all possible water-related environmental impacts associated with the process. The research outcome is capable to provide guidelines for the agricultural development authorities, rice farm owners, government as well as farmers in developing a sustainable paddy cultivation at all levels of rice farm.

ABSTRAK

Pengkuantitian jejak air dan penilaian kesan alam sekitar dalam kitaran hayat produk menjadi semakin penting. Kajian ini memberi tumpuan kepada pembangunan pendekatan penilaian jejak air (WF) berasaskan Life Cycle Assessment (LCA) untuk penanaman padi. Satu kajian kes menggunakan rangka kerja metodologi telah dijalankan di Muda Rice Granary, Malaysia. Kajian ini bermula pada tahun 2016, oleh itu analisis data berdasarkan data daripada MADA dari tahun 2012 hingga 2015 dibentangkan dalam tesis ini dan ISO 14046 digunakan sebagai panduan kajian. Jumlah jejak air beras dalam penanaman padi di Muda Beras Granary berjulat antara 1800-2600 liter/kg padi kasar. Kaedah ReCiPe 1.08 dengan Gabi 7 digunakan bagi penilaian impak kitaran hayat dalam kajian ini. Hasil LCA menunjukkan bahawa penanaman padi menyumbang 0.303 kg Peq dalam kesan eutrifikasi air tawar, 5.33 kg Neq dalam impak eutrifikasi laut, 20.6 kg 1,4 DB eq. dalam kesan ekotoksifikasi air tawar dan 1.24 kg 1,4 DB eq. dalam kesan ekotoksifikasi laut. Risiko kekurangan air pada julat 6000-11000 m^3 dikesan dari tahun 2012 hingga 2015. Penyelidikan ini mengesyorkan penggunaan penilaian WF holistik dan bukan penilaian tunggal kerana kaedah ini dapat menilai semua kemungkinan kesan alam sekitar yang berkait dengan air yang digunakan di dalam proses ini. Hasil penyelidikan ini mampu memberi panduan kepada pihak berkuasa pembangunan pertanian, pemilik ladang padi, kerajaan serta petani untuk membangunkan penanaman padi yang mapan di semua peringkat ladang padi.

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LIST OF ABBREVIATIONS

AI	-	Active Ingredient
CRIS	-	Crayfish And Rice Integrated System
GDP	-	Gross Domestic Product
GTP	-	Government Transformation Plan
I	-	Irrigation
IADA BLS	-	Barat Laut Manik Intergrated Agricultural Development Authority
IADA KEMASINSARAWAK	-	Kemasin Semarak Intergrated Agricultural Development Authority
IADA KETARA	-	Northen Terrenganu Intergrated Agricultural Development Authority
IADA KSM	-	Kerian Sungai Manik Intergrated Agricultural Development Authority
IADA P. PINANG	-	Pular Pinang Intergrated Agricultural Development Authority
IADA SEB. PERAK	-	Seberang Perak Intergrated Agricultural Development Authority
JPS	-	Department of Irrigation and Drainage
K	-	Potassium
KADA	-	Kemubu Agricultural Development Authority
LCA	-	Life Cycle Assessment
MADA	-	Muda Agricultural Development Authority
MADA	-	Muda Agricultural Development Authority
MSDS	-	Material Safety Data Sheets
N	-	Nitrogen
NRW	-	Non-Revenue Water

P	-	Phosphate
PSO	-	Particle Swarm Optimization
SSL	-	Self-sufficiency Level
vs	-	Versus
WEFN	-	Water-Energy-Food Nexus
WF	-	Water Footprint
WFLDB	-	World Food Life Cycle Assessment Database
WHO	-	World Health Organization

LIST OF SYMBOLS

%	-	Percentage
ha	-	Hectare
kg	-	Kilogram
g	-	Gram
yr	-	Year
DALY	-	Disability Adjusted Life Year
kg P eq.	-	Kilogram of Phosphate Equivalent
kg N eq.	-	Kilogram of Nitrogen Equivalent
kg 1,4 DB eq.	-	Kilogram of 1,4 dichlorobenzene Equivalent
m^3	-	Metre Cubed

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CHAPTER 1

INTRODUCTION

1.1 Background

Food and water are two fundamental necessities of life with water being the crucial key in the production of food (Seckler and Amarasinghe, 2001). Rice is the major crops supplied to the world population especially to the country in South Asia and Africa (Chapagain and Hoekstra, 2011). To meet the huge water demand in paddy cultivation and production of rice, large irrigation projects always become the key. Hence, it is not wrong to say that one of the largest water consumers in the world is rice (Chapagain and Hoekstra, 2011).

Water related problems could become more threatening to humanity in the upcoming 50 years (Dong *et al.*, 2013). Water issues such as water scarcity, water pollution and water sanitation are only expected to become worse. Severe scarcity of potable clean water is happening in some of the poor Asian countries. A report has indicated that there are 2.2 billion people who are unable to gain access to clean water globally (WHO & UNICEF, 2019).

The water footprint is an indicator of water use that looks at direct and indirect water use. The water footprint of a product (good or service) is the volume of fresh water used to produce the product, summed over various steps of the production chain (Aldaya *et al.*, 2010). Any process or production for any groups such as individual or family, city or village or nation levels can be used to calculate the water footprints from their activities (Petrovic and Cirovic, 2013). A water footprint is not only a digit that can show the total amount of water used, it is also referring to which type, when and where the water is used.

This thesis is useful to quantify the total amount of fresh water used to cultivate paddy in Malaysia, which comes from two sources: irrigation water, which is referred to surface water (blue water), and rainwater (green water). It is also able to assess the environmental impact to quantify the total amount of polluted water related to the use of pesticide, fertiliser and weed killer in paddy cultivation (grey water). As the study was started in year 2016, the research analysis based on the data provided by MADA from year 2012 to 2015 is presented in this paper. In future, the research framework will be useful for paddy cultivation activities and the data can be substituted with latest data.

1.2 Problem Statement

The Food Price Crisis in 2008 has brought serious impact to food security, especially among rice importing countries. Clearly, the country will need to import rice for the following years (Mittal, 2009). As a net importer of rice, national food security is partially determined by rice imports. In addition, climate change could bring certain impact to agriculture such as the increase in water demand, limited crop productivity and reduced water availability in irrigation area. Rice is the major crop supplied to the world population especially to the countries in the South Asia and Africa (Chapagain and Hoekstra, 2011).

Studies shown that the demand of rice in year 2030 will rise to around 533 million tonnes to satisfy the public globally. To accommodate with such challenge, adequate amount of water is the key for the production of rice, followed by research on how to increase rice production while reducing the water irrigation for the coming years (Ragab, 2006). As various sectors are competing for land and water for industry and rural development, increasing paddy areas will become even challenging in the future (Hoekstra *et al.*, 2011).

Today, Malaysia has taken an initiative to overcome food security problems in the future. Food security for a country is important to make sure that the country is in a stable condition for the economy and their citizen. To do this, a good plan to secure the condition is required. Malaysia is still insufficient in many major food items. Securing the food security is not only an action of responsibility by only one party, but also should not be neglected especially by all parties in the agriculture sector (Razak *et al.*, 2014)

As for Malaysia, in order to maintain its food security, the combination of domestic production and imports are made on products such as coconut and rice from Thailand as well as other agriculture products. Unlike Brunei and Singapore, they rely on imported food as they have no ability in producing them domestically but they have enough and large sufficient of foreign exchange to pay for the import (Razak *et al.*, 2014). On average, one Malaysian consumes about 280 litres of water daily, which is a very alarming rate by international standards. This compares with Singapore's 155 litres, the Philippines' 175 litres and Indonesia's 130 litres per person per day (Hamid, 2014). Hence, this shows how important it is to use the water wisely even though Malaysia is surrounded by water. Researches and sustainable cultivation practices have been on going to curb with these issue, but the total effects of practicing these practices into farm management are still unclear (Rose *et al.*, 2019).

Life cycle assessment (LCA) plays an important role as a tool that can be used to assess the environmental impacts of one system or process from cradle-to-grave perspective. LCA has been widely used by European country and applied to agricultural sector; however, limited studies have been carried out on rice production as rice is the staple food in Asia (Hokazono *et al.*, 2009). Malaysia is a developing country with a total rice production of 1.86 million tonnes (Firdaus *et al.*, 2020). However, research is yet to be conducted to assess the volumetric and environmental impact of the paddy cultivation in terms of WF. Very little attention has been paid to the life cycle assessment of paddy cultivation process, not to mention using LCA to assess water footprint. Also, previous studies on crop production have not deal with the assessment of environmental impacts from water consumption. Hence, research to assess the volumetric and impact of paddy cultivation WF is necessary to further understand the current condition in Malaysia and from there, the research will be able to improve the farm management especially in optimising the irrigation efficiency and minimising the environmental impact as much as possible.

By including both WF and LCA in this research, the significant environmental impacts on water quality from water usage can be assessed. Besides, hotspot can be identified by determining the process that used up a large amount of water. Instead of using stand-alone assessment, the proposed method recommends the use of the holistic WF assessment as this approach enables the assessment of all the possible impacts on the environment related to water during paddy farming (Mohammad Sabli *et al.*, 2017). International Standard Organisation (ISO) has released a guideline for presenting WF in 2013 to perceive the environmental impacts of WF (ISO 14046, 2013). Also known as ISO 14046, this design comprises four stages in the framework: goal and scope interpretation, inventory analysis of water footprint as well as water impact assessment. The environmental impacts of water can be reflected better by LCA-based water footprint than virtual WF as it can be systematically incorporated into LCA associated with three water footprints (Zhai *et al.*, 2019).

While extensive research on WF of crop yield have been conducted, limited study has suitably covered the LCA based water footprint for paddy cultivation especially in Malaysia. The aim of this study is to develop a framework to quantify WF in paddy cultivation and assess the environmental impact of water use (direct and indirect) on agricultural conditions. The research started by designing a methodology as a project guideline. As a worldwide requirement in assessing and reporting WF with the LCA method, the ISO 14046 was selected as a guideline in this research. Instead of calculating virtual water data (proposed by Hoekstra), this study developed a framework that can be used on the actual rice farming process using actual irrigation data.

1.3 Objectives of Research

This research aims to assess the water use of rice production from Muda area specifically as well as incorporate water stress characterisation factors into a revised water footprint concept using a life cycle basis. Besides, the studies on this sustainable assessment of agricultural industry that included potential environmental impacts from the water consumption are still scarce. Thus, this can benefit both the industry and researchers to work on this study. The objectives of this research are as follow:

1) To establish an inventory of direct and indirect water footprint of paddy cultivation based on data collection and analysis.
2) To assess the potential environmental impacts of paddy cultivation based on established inventory of water footprint using life cycle assessment (LCA) approach.
3) To propose countermeasures in minimising the environmental impacts of water footprint of paddy cultivation based on the hotspots identified by the LCA.

1.4 Scope of Study

In order to achieve the objectives listed, the scopes of study are stated below:

1) This study was focused on paddy cultivation in Muda area (Kedah and Perlis), Malaysia.
2) Data were collected from Muda Agricultural Development Authority (MADA).
3) Life cycle assessment method was used as a tool to identify the environmental impact of this industry, which included indirect and direct water usage throughout the whole process of paddy cultivation.

4) GABI Thinkstep, an LCA software, was used to assess "cradle-to-gate" approach for considering environmental impacts. Ecoinvent 3.3 database were used in the software.
5) ReCiPe was used in this study as impact assessment method. It is a method for the life cycle impact assessment (LCIA). The primary objective of the ReCiPe method is to transform the long list of life cycle inventory results into a limited number of indicator scores (Huijbregts *et al.*, 2017). These indicator scores express the relative severity on an environmental impact category. It comprised indicators at midpoint and endpoint levels. In this study, midpoint impacts were discussed as significant result was only found in midpoint level.
6) Data collection for the rainfall rate and climatic change in the studies hotspot was carried out with the cooperation from Lembaga Kemajuan Pertanian Muda (MADA).
7) Data from year 2012 to 2015 were collated for this study on the water consumption out when there is a different scenario based on four different years.

1.5 Significance of Research

Nowadays, researchers are taking environmental factors into consideration to preserve and conserve the environment. This research aims to obtain a revised methodological approach to assess the impact of water use incorporating water stress characterisation factors utilising life cycle basis. In this study, places of research were determined and identified, which allowed for the study on impacts to environment by the usage of water. Consequently, this research proposed a mitigation method in optimising and reducing the usage of water.

Since water footprint assessment is new in Malaysia, it would be a good opportunity to implement the approach in agricultural industry in Malaysia to curb with current issues especially from environmental aspect and impacts brought to environment.

Water footprints have attracted attention from the public and private sectors across various industries as water footprint is an intuitive concept that enables people from water management and non-water resources management sectors to use it as a communication tool. Hence, water footprints may inform or aid with business or policy decision that can be conveyed to decision makers such as government ministers or CEOs of companies in a better way besides gaining their attention on these matters.

As in Malaysia, agriculture sector plays an important role in national economic development. It helps secure the national food security and also arouses public incomes especially for people living in rural areas. Given its natural advantages, agriculture and livestock sub-sectors play an important role in ensuring Malaysian food security. Cassava, maize, rice, sugarcane and sweet potato are considered as cash crops in Malaysia. For the past 50 years, the government has allocated billions of Ringgits to maximise Malaysian agriculture production (Haruna & Hanafiah, 2017). Due to this scenario, farmers across the world including Malaysia have taken a step further in strengthening its food security.

The water footprint analysis can be used to determine the actual amount of water used for the entire process of producing agricultural product. The amount of blue water use from agriculture production can help us to determine the total amount of surface water consumed for producing crops. The results from this study are expected to convey the overall amount of consumptive water used by the selected cash crops in Malaysia.

This study will be a starting point to assess the amount of water consumed from crops farming using a comprehensive and holistic water footprint approach.

This study is also expected to provide benefits to agencies, policy makers and industries pertaining to the crops sector. This baseline information can be used to identify which area that needs to be conserved and what type of recommendation that should be drawn. Furthermore, it offers a number of benefits such as to identify the 'hotspots' in the value chain of activities and enhance initiatives towards sustainable agricultural practice and wise water management in Malaysia.

1.6 Thesis Outline

This thesis consists of 5 chapters. Chapter 1 introduces the background and motivation of this research. Chapter 2 provides an overview of the literature relevant to the research. Detailed novelty of the study is presented. This includes the overview of the water footprint, water footprint with LCA method and some comparisons of previous related studies. A development of water footprint method is also summarised.

Chapter 3 discusses the methodology of the research. ISO 14046 was used as a guide to account the water footprint of paddy cultivation. The framework of the study started from setting goal and scope. This was then followed by inventory analysis, water footprint sustainability assessment and finally interpretation or response formulation. Goal and scope definition was aimed at establishing the study objectives, functional unit (FU) as well as system boundaries and data sources. Life cycle impact assessment quantifies the relative importance of all environmental burdens identifies in the LCI by analysing their influence on selected environmental categories. Life cycle impact assessment is composed of classification and characterisation that convert LCI result into an indicator representative of each impact category.

In Chapter 4, the quantity of water usage of paddy cultivation and the potential environmental impacts of water usage for paddy cultivation of four consequence years are presented. The results presented in this chapter were based on a functional unit defined as 1 hectare of paddy field.

In Chapter 5, conclusions are drawn from the research and suggestions for future work are given. Appendix A is the conversation records between the farmers and the researcher. Meanwhile, Appendix B shows the rice check provided by MADA.

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LIST OF PUBLICATIONS

Indexed Journal

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