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Water Footprint of Rice Production in Malaysia: A Review of Evapotranspiration and Factors of Climate Change for Rice and Food Security in Malaysia

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Abstract Rice is a special crop that requires a thin layer of water to produce, and is produced differently from other crops. The rice sectors in Malaysia continue to be developed in a proactive and progressive manner. Due to its growth process, rice has a different water footprint (WF) compared to other crops. This study improved the calculation of the blue and green WF of rice production and examined the variations of these footprints under the primary granary area of Malaysia. The effects of climate change will, however, make it more difficult to achieve food security and increase rice yields in the future. Therefore, this paper aims to discuss climate change impacts on rice production and food security in Malaysia. Many countries worldwide are becoming increasingly vulnerable to natural disasters due to climate change. Many climate models predict a decline in agricultural productivity due to excessive heat in tropical and subtropical regions, especially in Southeast Asia. Malaysia is no exception. Therefore, the present study examined the impact of climate change on rice yields in Muda Granary, Malaysia. Utilizing literature reviews, we assessed the value of evapotranspiration (ET) in order to calculate the green WF for the area. Climate variables (such as ET), yield, and variance of impact during the main season and off-season were the primary objectives of the study. Precipitation did not show a statistically significant difference between the main and off-seasons from 2011-2015. During the main crop season, the maximum ET was negatively associated with yield, but the minimum ET showed a positive association. In the off-season, green WF levels were higher than those in the main season. These findings indicate that climate change poses a serious threat to rice production, which will in turn affect food security as they are highly interconnected. Thus, it is high time for Malaysia to revamp its paddy and rice intervention strategies by giving due attention to enhancing the adaptive capacity of rice farmers to cope with climate change.

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Introduction

Water withdrawals for agriculture account for approximately 70% of total withdrawals. Along with population growth and economic growth, climate change may further reduce the amount of water available for food production. Therefore, it is imperative that crop producers evaluate and manage water resources efficiently. As a result of the introduction of the WF concept and its mathematical models, agricultural producers now have a new tool for assessing water resource use and management (Li *et al.*, 2018; Hoekstra, 2015; Yoo *et al.*, 2014; Gheewala *et al.*, 2018; Mungkung *et al.*, 2019; A. Chapagain and Hoekstra, 2010). WF measures not only irrigation water consumption, but also precipitation consumption and pollution dilution water consumption, which differs from the traditional method of agricultural water accounting. According to Li et al. (2017), green WF refers to the volume of precipitation consumed, which is usually expressed as effective precipitation; blue WF refers to the volume of surface and groundwater consumed, which is usually expressed as irrigation water; and grey WF is a measure of pollution, which is expressed as the volume of fresh water required to assimilate the load of pollutants. Rice is one of the most important crops in the world. The rice growth process differs from that of other crops since rice needs a thin layer of water coverage for a long period of time. Steeping of the field, irrigation, evapotranspiration, drainage, and infiltration are also to be considered. The management of rice fields involves considerably more water, and calculating water demand is more complicated than it is for other crops. Therefore, there are fewer evapotranspiration studies that calculate rice water needs.

The main water sources for rice production are rainfall and irrigation (Li *et al.*, 2018). Rice is a major crop and also a crucial part of the Malaysian people's diet. A report from (Omar *et al.*, 2019) stated that 1.66 million metric tons of rice had been produced in Malaysia, while statistics showed a worldwide production of 36.3 million metric tons. This shows that the country's production of rice is only about 0.4% of the total world rice production. Up until today, Malaysia only requires 80% of the produce, and exports the rest to neighboring countries such as Vietnam and Thailand. Due to declining trends in accessible fresh water for agriculture and a rising global population, rice water use needs to be examined under climate change settings (Djaman *et al.*, 2019). As various sectors are competing for land and water for both industry and rural development, increasing rice areas will become even more challenging in the future (Mekonnen and Hoekstra, 2012). Agriculture is likely to be affected by climate change through increased demands for water, a decrease in crop productivity, and reduced water availability. Water is essential for rice farming and its supply in adequate quantity is one of the most important factors in rice production. Most studies on the constraints of high rice yield showed that water is the main factor for yield gaps and yield variability from experiment stations to farm. As fresh water becomes increasingly scarce, the demand for available water from urban and industrial sectors is likely to receive priority over irrigation. In irrigation schemes where the hydrologic cycle is affected by human activities such as irrigation and drainage, it is vital to establish a reasonable framework for evaluating productivity and managing water resources. The major problem of improving irrigation efficiency in most irrigation schemes is poor and uneven water distribution. Rice is the only agronomic crop in Malaysia that is grown under flooded conditions and that is maintained at a constant depth of about 5–10 cm throughout the entire growing season (Abdullahi *et al.*, 2013). A rice plantation in Muda Granary area was based on the standard cultivation practice (SCP) system, in which the depth of the water is maintained continuously for 105 days. Maintaining a ponding environment, however, requires a higher amount of irrigation in rice compared to other crops (Rowshon *et al.*, 2014). Proper irrigation scheduling and water supply is therefore very important to improve rice yield and quality (Yan *et al.*, 2017).

Water scarcity is a critical issue in many communities throughout the world. It is inextricably tied to the food sector, since over 80% of withdrawn water worldwide is used to meet the demands of an ever-increasing population and unending development (Shrestha et al., 2013). To meet their food demands and compensate for water constraint, many countries import food from other countries. As a result, WF, which can measure the strain on water resources, is evaluated as a tool to manage global, regional, national, and local water scarcities. WF refers to the amount of fresh water consumed and used for diluting pollutants during crop production (Li *et al.*, 2018). Crop production generally involves fertilizers (nitrogen, phosphorus, etc.), pesticides, and insecticides. WF can be described as the stage of production or consumption of a product (goods/services) consumed by an individual or a community (Hoekstra and Hùng, 2005). The study of WF is defined as the volume of freshwater used to produce a particular product, measured at the point of production (Chapagain and Hoekstra, 2011; Hoekstra, 2011). WF analysis connects a diverse set of sectors and concerns, resulting in a multidisciplinary framework for better water resource management (Aldaya *et al.*, 2010). The combination of WF and VW flows might reveal a country's or river basin's actual water scarcity (Hoekstra and Chapagain, 2008). The WF idea was established by Hoekstra and Hung (2005) as a tool for measuring water usage in the product supply chain in terms of time and location. There have been a few WF studies in Malaysia to date, but on a nationwide scale. This study fills in the gap by looking at the WF of rice production in the Muda Area and analyzing the trend in WF which look into blue water stress.

For the past few years, several studies have been conducted on WF of rice cultivation in many regions (Mekonnen and Hoekstra, 2010; A.K. Chapagain and Hoekstra, 2010; Bulsink *et al.*, 2009; Yoo *et al.*, 2014; Gheewala *et al.*, 2014; Yusoff and Panchakaran, 2015; Lee *et al.*, 2018; Hanafiah *et al.*, 2019). The majority of earlier research concentrated on determining the blue and green WFs. The WF recorded during the wet season (main season) was higher than the WF recorded during the dry season (off-season). The WF for rice farming was also measured in this study for two separate seasons. Throughout the year, Malaysia is classified as equatorial, hot, and humid, with average daily temperatures ranging from 21 to 32 degrees Celsius (Tan *et al.*, 2021). Average annual rainfall in Malaysia is approximately

2500 mm (Mo'allim *et al.*, 2018). Rice is cultivated twice a year in major granary areas, during the off-season (March to July) and the main season (August to February). Due to the northeast monsoon's considerable rainfall, the main season has high air humidity, while the off-season has low air humidity and less rainfall (Firdaus *et al.*, 2020a). Due to location-specific factors such as weather conditions, cultivation areas, and agricultural practises, the average yield per hectare differs among different granary areas (Firdaus *et al.*, 2020b).

Rice WF accounting can clearly estimate overall water demand, water location, and the water consumption process during rice growing. It is vital to make optimal use of water resources in circumstances when the distribution of water resources is uneven among rice-growing areas. To reduce irrigation water use, it is preferable to use rainwater as much as possible. Precipitation, on the other hand, has not only a skewed regional distribution, but also yearly and inter-annual variability. Hence, irrigation should be adjusted based on the year's rainfall. Irrigation water may be saved during the rice growing season if there was more rain in a given year. Less rainfall, on the other hand, would necessitate more water for irrigation. Research into the differences in rice WF throughout different evapotranspiration could pave the way for more efficient irrigation and water use. The majority of previous studies used monthly meteorological data to calculate the WF of rice production at global, national, and regional levels (A. Chapagain and Hoekstra, 2010; Gheewala *et al.*, 2014; Shrestha *et al.*, 2013; A K Chapagain and Hoekstra, 2010; Lee *et al.*, 2018). However, evapotranspiration and effective precipitation were not calculated accurately. Most of the time, effective precipitation was greater than actual precipitation, and therefore, rice production's green WF was greater than actual rice production. In addition, the CROPWAT method does not account for irrigation water loss in its calculation of rice evapotranspiration. Consequently, it misrepresents the actual consumption of water resources by estimating the water demand and the blue WF lower than their actual values. A study conducted in China by Li et al. (2018) showed that the water demand of rice varied greatly in different rainfall years. The study was conducted to analyze the correlation between water demand and evapotranspiration (ET) of rice over several years. The type of rainfall in a year has a large influence on the water requirements of rice (Li *et al.*, 2018). The utilization of irrigation water and the amount of water required for rice cultivation are clearly incompatible. In several Asian countries and other parts of the world, rice water utilization under flooded irrigation is widely recorded. The WFs of rice production in various ET values might be used to check the precipitation and irrigation consumption ratios and improve irrigation use. The value of ET was evaluated using various approaches in different regions. Furthermore, rice WFs in dry, normal, and humid years were calculated using an improved approach that took evapotranspiration into account.

Consequently, the purpose of this paper is to review the interplay of climate change on rice production. It will do so by reviewing existing literature related to climate change impacts on rice productions and food security. In particular, it aims to understand the relationships between the above- mentioned themes and their pragmatic implications. To substantiate the review and discussion, we analyzed the effectiveness of precipitation and temperature in the main granary areas in Malaysia using the evapotranspiration method in green WF. To synthesize the current understanding and identify future research priorities in East Asia, particularly Malaysia, we also compared other methods used in the country. These methods interrelate with total rainfall in the area to maintain rice production and food security. This will help to understand the possible areas of integration in concepts and the effectiveness of crop yield. Hence, adaptation at the farm level remains crucial, specifically during the off-season, since climate change could widen the gaps in rice yields between cropping seasons in the Muda granary area. Rice cultivation in the Muda area will benefit from this information, particularly in the state of Alor Setar. For example, ET is useful in determining the period of water deficit, crop water requirements, and irrigation needs. Additionally, this study could inform water management decisions in this specific area for more efficient water use, which will help to understand the possible areas of integration in concepts, future researches, strategic interventions, and policy reforms.

Materials and Methods

Study Area Description

This study will focus on rice production in Kuala Muda, Malaysia (Figure 1). In this research, the Muda Irrigation Scheme is the largest rice granary in Malaysia. Covering some 100,685 ha of rice land, it is situated along the coastal plain in the northern states of Kedah and Perlis in Peninsular Malaysia. One of Malaysia's eight designated rice granary areas is the Muda Irrigation Scheme, which is under the management of Muda Agricultural Development Authority (MADA). As mentioned by officer in MADA, despite a lower national average of 3.74 tons/ha, the seasonal net yield in the region is 5.0 tons/ha. Muda represents 23% of the nation's rice production area, but accounts for almost 40% of the area's rice cultivation. Peninsular Malaysia is predominantly covered by tropical rainforests. However, only the Muda region and its periphery, where there is a pronounced dry season, are subject to tropical monsoon climates because they are protected by the rain-bearing northeast and southeast monsoons that blow from the Central Range and Sumatra, respectively (Ali and Shui, 2009).

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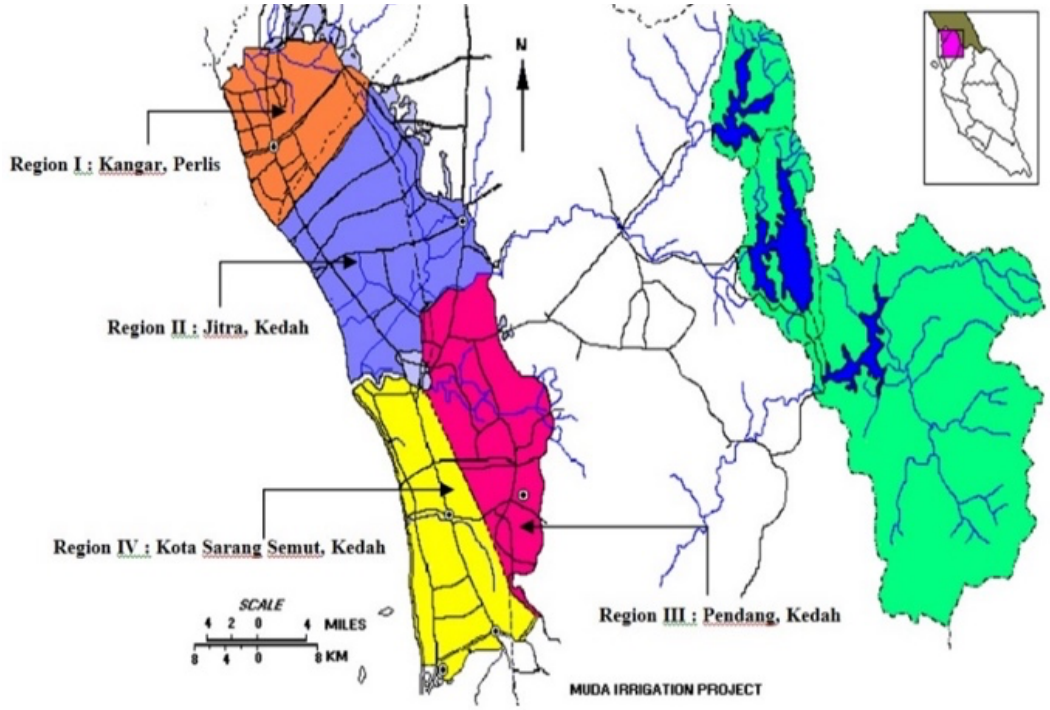


Figure 1. Layout Plan of Muda Area

Granary locations in Peninsular Malaysia are frequently hotter during the main season than during the off-season, (Boon Teck *et al.*, 2021). Furthermore, throughout the main season, temperatures (both minimum and maximum) were lower than during the off-season. In contrast, during the main season, the average rice output per hectare was higher than the off-season. These findings suggest that while temperature had a detrimental impact on rice output, precipitation had a favourable impact. The purpose of this study was to evaluate potential evaporation (ET) to increase crop production, particularly rice production. Higher temperatures cause more evapotranspiration, affecting the hydrological cycle and water resources (Shahid, 2011). Thus, quantifying the changes in ET due to climate change is very important for the management of long term water resources (Tukimat *et al.*, 2012). Rice yields, on the other hand, are harmed by excessive or insufficient water availability. Water should be delivered in sufficient quantities and at regular intervals to improve crop productivity. While the study area's water supplies are currently sufficient on an annual scale, there are seasonal issues. In fact, during the dry season, water resources are scarce and of diminishing quality. Estimating rice's water requirements is critical for agricultural planning and irrigation project design. The whole regional water demand is dominated by evaporation and evapotranspiration processes (ET). Accurate estimation of evapotranspiration is important in efficient water management for improving water use efficiency. Because of the significance of ET, hydrologists have devised a variety of ways to calculate it. Each method has its own point of view and concept as well as being tailored to a given climate. Some of these techniques are essentially tweaked versions of others. However, the method's dependability and accuracy are the primary concerns for estimating ET (Tukimat *et al.*, 2012).

Historical Weather Data

The climate of the region, like that of the rest of Malaysia, is divided into four seasons: south-west monsoon (May–September), north-east monsoon (November–March), and two inter-monsoon seasons. Warm seasons in the area are December–February and June–July, whereas humid seasons are April–May and September–November. The soil in the study area is heavy clayey. The average temperature ranges from 27 to 32 degrees Celsius. The relative humidity ranges from 54 to 94 percent. Due to year-round rainfall, Malaysia has significant water resources. Rice is the most important crop in the country, accounting for 85 percent of all farmland. It accounts for over 90% of the water used in the country's agricultural industry (Pour *et al.*, 2020). Rice is cultivated in two seasons: primary (June–December) and secondary (March–July). In years with average or above-average rainfall, it doesn't require irrigation. Only in years of below-average rainfall is supplemental irrigation necessary. In the second rice-growing season, additional irrigation is usually required.

In the Muda area, the water requirement for the first (off) season crop is 1,300 mm and 1,100 mm for the second (main) season crop (Mohamed Rusli *et al.*, 2018). Hence, the total water requirement for double cropping is 2,400 mm. the water requirement is met from four sources: rainfall (52%), the run of the river (10%), dam release (30%), and recycled pump water (8%). Increase in water productivity, therefore, has a great impact in ensuring the sustainability of sufficient water supply for all sectors. The Muda Irrigation Scheme is the largest rice field in Malaysia. An accurate estimation of ET and its possible variations due to climate change are therefore extremely crucial for water resources planning and management in the scheme. Therefore, this paper is primarily based on reviewing the literature, which is limited to articles published on ET in rice production. The literature search mainly focused on themes such as the method calculation of ET, climate change, rice, and sustainability of rice farming within the Malaysian context as well as other Asian perspectives to some extent. The literature review is accompanied by an analysis of the yield production during both seasons in the Muda Granary area to determine whether the ET values are correlated with yields of rice. In this research, data were compiled from various secondary data sources such as books, publications, reports, and government agencies including the Department of Irrigation and Drainage, the Malaysian Meteorological Department, the Department of Agriculture for Peninsular Malaysia, the Department of Statistics, MADA, and the National Water Services Commission.

Potential Evapotranspiration, *ET*

Evapotranspiration (ET) is the only link between the water and energy cycles, and is the main source of water vapor in the atmosphere. It plays a similar role to precipitation in determining the moisture balance in the atmosphere. It is crucial to manage irrigation, catchment water equilibrium, water resource planning, ecosystem health, and reservoir operation according to reference ET (ET_o). Moreover, it is considered to be one of the most crucial factors in any hydrological and climatic study (Pour *et al.*, 2020). Managing water resources and designing adaptation strategies to climate change require understanding change in evapotranspiration (Wang *et al.*, 2016). There are a few methods to calculate the value of ET (Tukimat *et al.*, 2012). Evaporative processes are highly complex, and they are affected by many factors that are dependent on local conditions. In addition to precipitation and meteorology, soil moisture, plant water requirements, and type of land cover all contribute to these conditions (Mo'allim *et al.*, 2018). To conserve water resources for sustainable food and fibre production, there are challenges in developing and evaluating optimal water management strategies. The availability of rice for rice production has recently become critical in the country, especially during the dry season (Mar- May) (Rowshon *et al.*, 2014). The rainfall is, however, distributed irregularly both temporally and spatially, and the distribution is not ideal for rice growing seasons. Research on rice water requirements for rice fields is crucial to utilizing the available water resources efficiently. Evapotranspiration, on the other hand, contributes significantly to the water balance in rice fields. It includes the loss of water from both soil and plant surfaces, playing an influential role in both rain-fed and irrigated fields. It depends upon the evaporative demand of the atmosphere.

Crop evapotranspiration (ET_c) is the main component of water consumption in rice fields; accurate estimation of ET_c is important in efficient water management and improving water use efficiency (Shui, 2003; Abdullahi *et al.*, 2013; Yan *et al.*, 2017; Ikawa *et al.*, 2017; Ahmad *et al.*, 2017; Djaman *et al.*, 2019; Pour *et al.*, 2020;). Because of its simplicity, practicability, and acceptable accuracy, the crop coefficient (K_c), which is the ratio of ET_c to reference evapotranspiration (ET_0), is frequently employed to determine ET_c. Several researches on evapotranspiration and the crop coefficient in rice fields have been presented in various parts of the world to date. In the present research, the performance of these simple ET methods was evaluated by comparing them as per Table 1.

Table 1. Comparison study and references for evapotranspiration (ET)

No.	Reference	Region	ET_c (stage)	Method
1.	Mungkung et al. (2019)	Thailand	4.5 mm/day (average)	Penman-Monteith
2.	Li et al. (2017)	China	5.3 mm/day (Re-greening) 4.3 mm/day (Tillering) 4.6 mm/day (Jointing and booting) 4.2 mm/day (Heading and flowering) 4.2 mm/day (Milking maturity) 2.3 mm/day (Yellow maturity)	CROPWAT
3.	Djaman et al. (2019)	West Africa	4.4 – 8.0 mm/day (transplanting to tillering stage – 44 DAT) 10.0 mm/day (43 – 74 DAT) *DAT = days after transplanting	Penman-Monteith
4	Yan et al. (2017)	Japan	5.3 mm/day (Initial Stage) 4.4 mm/day (development) 7.4 mm/day (middle-season) 6.3 mm/day (late season)	Penman-Monteith
5	Ngoc et al. (2021)	Vietnam	5.13 mm/day (dry season) 4.60 mm/day (wet season)	Hargreaves-Samani model
6	Ali et al. (2009)	Kedah, Malaysia	Best method using in MUDA area is Penman-Monteith (4.4 mm/day average)	Penman-Monteith, Penman Method, FAO-PM method, Blaney-Criddle Method and Christiansen Method
7	Rowshon et al. (2014)	Kelantan, Malaysia	4.0 – 9.0 mm/day (average)	Marriot tube lysimeter
8	Abdullahi et al. (2013)	Tanjung Karang, Malaysia	5.05 mm/day (wet season) 5.47 mm/day (mid-season) 5.24 mm/day (off season)	Micro-lysimeter
9	Ahmad et al. (2017)	Alor Setar, Malaysia	1823.76 mm/year (average)	Penman-Monteith
10	Ikawa et al. (2017)	Japan	3.5 (growing) 4.4 (energy balance forced) 420 mm/year (average)	Penman Method
11	Tukimat et al. (2012)	Kedah, Malaysia	4.0 – 5.0 (average) 1360 -1490 mm/year	Priestley-Taylor, Makkink, Turc, Hargreaves-Samani, Thornthwaite and the Blaney-Criddle.
12	Mo'allim et al. (2018)	Tanjung Karang, Malaysia	5.2 mm/day (off season) 5.6 mm/day (main season)	Penman-Monteith

The most important elements affecting agricultural productivity are weather and climate. The agriculture industry is extremely vulnerable to the effects of climate change because to its openness to the whims of nature. The term "weather" refers to the "atmosphere's state at a given time and location with respect to variables, such as temperature, moisture, wind speed, and barometric pressure". Based to Table 1, it can be concluded that crops are sensitive to climate change, including changes in temperature and precipitation. The main influence on grain yields is precipitation. An area's climate affects the types of plants that can grow there. Plant growth is dependent on precipitation and temperature. Since crop output is one of the major elements influencing food security. To assist decision-makers, a seasonal ETc evaluation was done to determine the best times of year to check on the vegetation in drought-prone and food-insecure areas. Due to Malaysia's high yearly rainfall, irrigation is only necessary during the dry season to supply the water needs of rice farming. Farmers should use an appropriate fertiliser application technique for rice plantations to ensure full crop recovery.

Water Footprint Calculation

The water footprint (WF) is a method used in agriculture to determine how much water is used in the production of a crop. Annual and perennial crops can also benefit from the WF approach of crop cultivation (Haruna and M. Hanafiah, 2017). The following general formula was used to calculate the overall WF of the crop growing process (WFcrop). The WF of rice was based on Hoekstra et al. (2003). The total WF of growing rice (WFrice) is the sum of the green, blue, and grey components as follows:

$$\mathrm{WF_{rice}} = \mathrm{WF}_{\mathrm{blue}} + \mathrm{WF}_{\mathrm{green}} + \mathrm{WF}_{\mathrm{grey}}\ (\mathrm{m^3/ton}) \quad (1)$$

For this study, the water for rice cultivated from precipitation is used for (WFgreen) calculation. Blue and green CWU is crop water used, expressed in unit of m^3/ha, and was calculated by summation of daily ET (mm/d) over the complete rice-growing period. The factor 10 was used to convert water depths in millimeters into volumes of water per land surface (m^3/ha). The total length (lgp) of growing period (days) was considered starting from the first day of planting to harvesting day.

$$WF_{green/blue} = \frac{CWU}{Y} = \frac{10 \times \sum_{\mathrm{d-1}}^{\mathrm{lgp}} \mathrm{ETc}}{Y} \quad (2)$$

$$ET_c = K_c * ET_o \quad (3)$$

Where

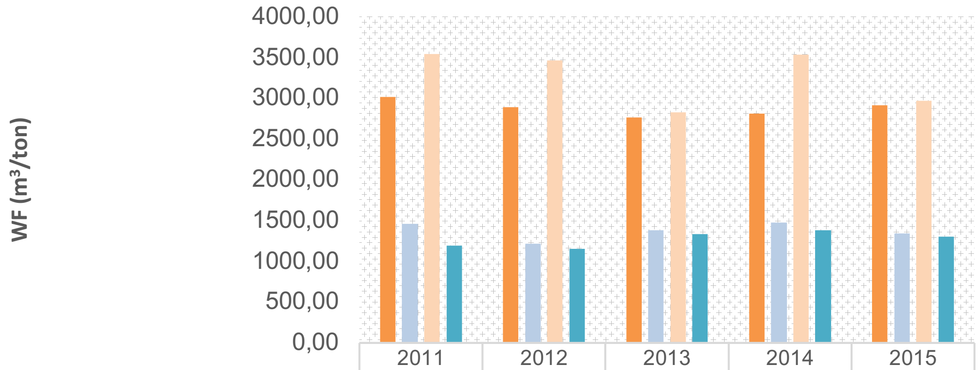
Crop coefficient (K_c), reference crop evapotranspiration (ET_o), and crop evapotranspiration (ET_c). In the WF study, water requirement is the amount of water needed to normally grow a crop, either by irrigation, by precipitation, or both. Because the water used for metabolic activities of plants only accounts for 1% of the total quantity of water used, this is considered directly as consumptive use in the calculation. Effective rainfall is defined as the fraction of rain which is effectively absorbed by the crop after surface runoff and deep percolation losses have been accounted for. Irrigation requirements and groundwater levels were also included. Typically, irrigation requirements refer to the amount of water that must be used to supplement the water supplied by rainfall. The CWU was also calculated using other parameters including crop, soil, and irrigation. In this study, value of ET_c was assumed to be equal 1823.76 mm/year (Ahmad *et al.*, 2017).

Results and Discussion

As a result of this assessment, we will now discuss the potential and limitations of evapotranspiration rate-based WF calculation. Using this method, we will be able to estimate crop WFs for possible water planning in water-scarce areas. Grey WFs were not taken into account when comparing green and blue WFs.

Water Footprint

Rice cultivation has different irrigation requirements, yields, cropping patterns, and environmental impacts, depending on the region. Figure 2 illustrates the estimated WF for cultivating rice during the main season and the off-season. Off season refers to the rice grown in March-July, considered as dry months in Malaysia, while the main season refers to the rice grown in August to February, known as the rainy or wet season. According to this study, the total WFs for cultivating rice for both main and off-seasons range between 4,100 and 4,500 m^3/t and 4,100 and 4,900 m^3/t, respectively. Fig. 4 shows that the green WF in the main season ranges between 2,700 and 3,000 m^3/t, whereas the blue WF ranges between 1,200 and 1,480 m^3/t. According to our analysis, the blue and green WFs in the off range are 2,800 to 3,550 m^3/t and 1,100 to 1,400 m^3/t respectively. Table 2 shows detailed results of the WF for the Muda Irrigation Scheme from 2011-2015. It is mostly the amount of precipitation received and the crop yield that determines the variation in WFs across different years.



	2011	2012	2013	2014	2015
Main Season Green WF (m3/ton)	3014,98	2889,35	2765,37	2815,31	2912,42
Main Season Blue WF (m3/ton)	1458,53	1216,27	1383,67	1474,68	1341,04
Off Season Green WF (m3/ton)	3543,35	3463,27	2826,66	3533,73	2969,81
Off Season Blue WF (m3/ton)	1193,32	1152,19	1333,82	1383,77	1302,86

Figure 2. Water footprint of rice production during main and off-seasons in MADA (2011-2015)

In the Muda region, the largest total WF for rice cultivation during the main season was 4,473 m^3/t in 2011, while the largest total WFs during the off-season was 4,917.50 m^3/t in 2014. The present study found that the green WF for the Muda area was 2.1 and 2.6 times greater than the blue WF of rice production in both the main and off-seasons. Rice is one of the most important crops in the Malaysian diet, hence a large amount of rice is produced each year. The ratio of green to blue water varies greatly, both over time and space. In countries like India, Indonesia, Vietnam, Thailand, Myanmar, and the Philippines, the green water fraction is substantially larger than the blue water fraction (Chapagain and Hoekstra, 2011). According to Hanafiah et al. (2019), Malaysia's annual rainfall rate is sufficient to provide the water requirements for rice agriculture, and irrigation is only required during the dry season. The topography and climate of Malaysia ensure that water is available in sufficient quantities to meet crop production needs, particularly rice farming (Hanafiah *et al.*, 2019).

However, in this study, the result was the opposite. Figure 2 shows that water is most needed for rice cultivation in the off-season compared to the main season. Effective rainfall and yield are the two main factors affecting irrigation water requirements. In this study, the amount of blue WF was essential because blue water withdrawal was used to determine water deprivation potential during rice cultivation in the Muda Scheme Irrigation. In our study, we found that rice cultivation had a significantly different WF throughout the years. The higher the yield, the smaller the WF per ton, which implies that the higher the yield, the smaller the WF. A study was conducted by Boon Teck et al. (2021) to assess the impact of climate change on rice yield in Malaysia, which compared eight granary areas in Peninsular Malaysia. The main objective of the study was to assess the impact of climate change on rice yield and the variance of the impact during the main and off-season. Regarding climate variables, the Integrated Agricultural Development Area (KETARA) had the highest total precipitation (2680.55 mm) compared to MADA, which had the lowest (2046.7 mm). The results strongly support that fact that granary areas in Peninsular Malaysia are usually hotter during the main season when compared to the off-season (Boon Teck *et al.*, 2021). Furthermore, the average rice yield per hectare during the main season was higher than that in the off-season. Precipitation had a positive impact on rice yield (Boon Teck *et al.*, 2021). According to Vaghefi et al. (2016), an increase in precipitation might not be enough to offset the negative impact of temperature increases on rice yield predicted for the year 2030 in Peninsular Malaysia. However, despite the results of this study showing that the average WF for rice cultivation in Muda Granary may be larger for regions with lower yield, the results may differ for other granaries due to climate variations. Additionally, another aspect of the WF assessment is interference by farming practices, such as poor drainage systems, conventional or organic farming approaches, etc. By the year 2030, MADA's yield is also predicted to decline by -3.81% and followed by -0.02% over the following decade (Boon Teck *et al.*, 2021). Another seven granary districts are also likely to experience a drop.

Comparison with Previous Study

In Thailand, rice has higher water requirement because the rice field cultivation is under flood conditions. A research reported that rice is one of the largest water consumers in the world and requires large areas to irrigate the rice fields (Chapagain and Hoekstra, 2011). India, China, Indonesia, Bangladesh, Thailand, Myanmar, Vietnam, the Philippines, and Brazil are the top water consumers of rice. For the group of nations responsible for more than 98 percent of the global WF, the composition of the WF due to rice consumption is shown (Chapagain and Hoekstra, 2011). Table 2 summaries previous research on the WF of several crops that have been published in Southeast Asian countries. In the Muda area, the WF of rice was determined to be 4,454 m^3/ton, which is the highest WF. In some cases, there is a difference between the ratios of the studies, which may be due to differences in effective rainfall calculations among the various component calculation methods. In the study, the rice WF was 2,135 m^3/ton more than the world average (2,319 m^3/ton) as well as the WF for major rice-producing countries. WFs differ between countries because of differences in crop yield, growing season, rainfall, and fertilizer consumption. In Korea, where WF is the lowest, average yields are high, and crop water needs are low. The green and blue water levels in Muda area were higher, even though Thailand is a major rice exporter. A difference in climate and agricultural practices led to slight regional differences in the WFs of crops (Bulsink *et al.*, 2009). Thus, agricultural practices determine yield, thereby affecting the WF of the product. Crop water requirements vary across countries depending on the availability of modelling parameters, assumptions, limitations, and input data required for assessing the WF of crops (Haruna and M. Hanafiah, 2017; Harun *et al.*, 2021; Harun and Hanafiah, 2018).

Table 2. Comparison of average rice WF between major rice-producing countries

Countries	WF (m^3/ton) of rice production			
	Green	Blue	Grey	**Total**
Muda Area [a]	3,073	1,324	57.32	4,454
Thailand [b]	942	559	116	1,617
Korea [c]	294.5	501.6	48.4	844.5
Indonesia [d]	2,535	729	208	3,473
Global average	1,465	751	103	2,319

[a] This study
[b] Chapagain and Hoekstra (2010)
[c] Yoo *et al.*, 2013
[d] Bulsink *et al.*, 2009

Trend Analysis

In rice fields, especially rainfed rice farms, there is great concern about measuring the amount of water consumed. Rainfall determines how much water is in a flooded system. Additionally, farmers do not always measure the level of water within the rice fields in order to prevent pathogens and grass from growing. When it comes to irrigated areas, the amount of water depends on the irrigation efficiency and the location of farms where irrigation is adequate or not (Mungkung *et al.*, 2019). The value of the WF varies according to the way water resources are managed in a particular area. Hence, when used to indicate actual water use impact, the total WF (blue and green) needs to be considered for better understanding of water scarcity impacts. The majority of crops in Malaysia are grown using rainwater. Malaysia receives an average rainfall of 2500 mm per year, which helps to grow crops. Generally, consumption of blue water, i.e. groundwater or surface water, has a larger impact on the environment than consumption of green water (Falkenmark, 2008). Consequently, increasing reliance on surface water will contribute to water scarcity, and some arid areas are particularly vulnerable to drought and deficiency of precipitation induced by climate variability.

Adaptation of the production layout based on rice WF

The analysis of WFs can clarify the source and structure of the water demand for crop production and allow for the rational use of water resources. Rainfall and irrigation are the two main sources of water for crop growth. Rainfall affects the amount of irrigation required and has both annual and interannual variations. More rainfall resulted in decreased irrigation when the rice water demand was calculated. As a result, if the rainfall could be fully utilised, irrigation should be reduced, saving water from rivers, lakes, and groundwater. Each year's rainfall and infiltration varied during the rice growing season. The rice WFs in the Muda region were greater, with high green WF and poor yields in the rice production area, according to the findings of this study. The high WF in the region, on the other hand, was caused by the lower yield. Because rice farming in certain areas will be maintained, crops that use less water should be cultivated. Because the Muda region is Peninsular Malaysia's largest granary area, water-saving irrigation techniques should be implemented in the region to improve the utilization rate of water resources and improve total production. It is advised that agricultural structures should be adjusted in accordance with the state of local water supplies and rainfall forecasts, particularly during the main season when crop yields can meet the water demand.

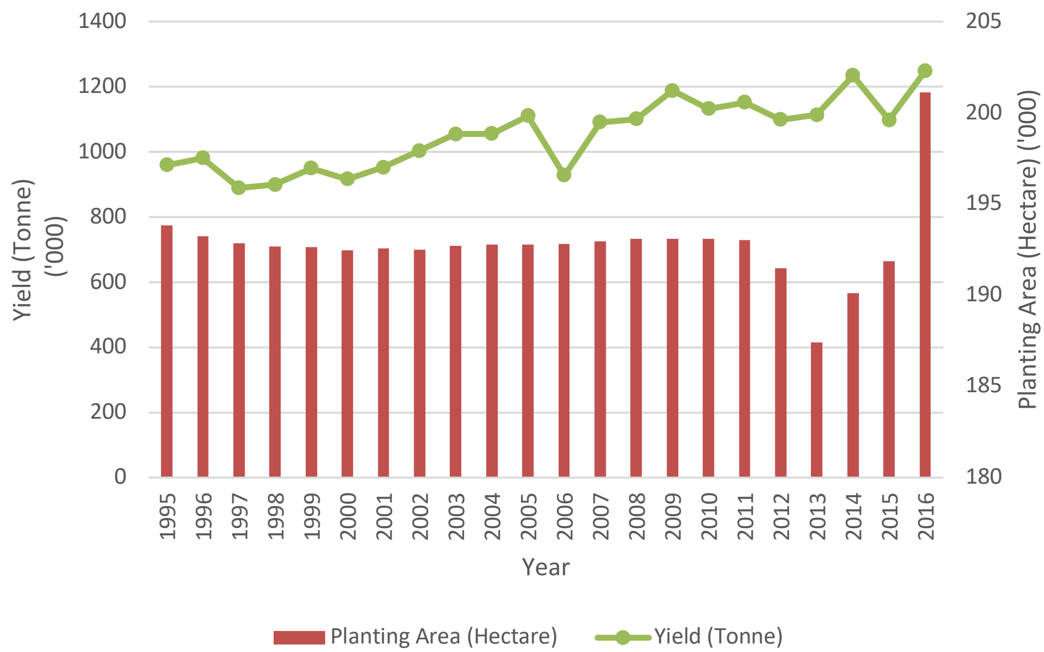


Figure 3. Rice yield from 1995 to 2016 in Muda Area

Flooding would be exacerbated by such an increase in precipitation. Floods have caused significant losses to rice farmers over the years, particularly in MADA Kedah, Malaysia's largest granary. There are many factors that influence rice land productivity. Some of the more significant factors are: soil types; seeds; agronomic practices; harvesting loss; good water management and cropping intensity. Crop production of rice in the Muda area for 1995-2016 is presented in Figure 3. The exceptionally low yield production in the Muda region was due to severe floods which occurred in December 2014. As shown in Figure 3, the rice yield in the subsequent year was impaired by several flood events in 2003 and 2006. Flooding in Kedah and its neighboring state of Pulau Pinang resulted in a considerable drop in rice production in the country in 2015 compared to the previous year. These have had a significant impact on not only farmers' output, livelihoods, and income, but also the country's food security. Floods in the MADA area affected 18,250 acres of rice fields and 10,580 farmers during the main cropping season of 2005/06. (MADA, 2010). As a result, rice imports increased by 45 percent in 2006 (Firdaus *et al.*, 2020b).

It is not necessary to irrigate rice during the dry season in Malaysia because the annual rainfall rate is sufficient. Malaysia's topography and climate make water readily available for rice cultivation. The amount of rainfall and yield determine the amount of irrigation water required. In the river basin, water withdrawal was used to assess potential water deprivation associated with rice cultivation, so WF was crucial to the study. In Malaysia, water is readily available due to its topography and climate, which is especially suitable for rice farming. Climate and agricultural practices have the greatest impact on irrigation water requirements. The amount of blue water withdrawal was critical for this study since blue water withdrawal was used to estimate water shortages during rice production in Muda Scheme Irrigation. Research has shown that rice farming's WF changes significantly over time as a result of our study. Rice production consumes an enormous amount of water. Rice plantation used a large amount of fresh water based on the assessment between rice plantation and rice milling. Therefore, it is ideal to increase the efficiency of water use in rice fields since water is less available to stressed river systems. Consumptive (evaporative) use is to be targeted for efficiency gains rather than total usage. Based on yield production levels, rice cultivation WF varies significantly. Higher yielding crops have a lower WF per kg than those with lower yields, which means higher yielding crops have a lower WF. In Malaysia, the average WF for rice cultivation was higher in states with lower yields, but results may vary by region due to climate change. It is also important to consider the impact of farming practices on the field, such as improper drainage systems, conventional farming methods, etc. (Hanafiah et al., 2019a).

Rainwater is necessary for rice growth to maintain soil moisture and to maintain the standing layer of water over the rice field. In major rice producing regions across the world, rice is grown during the wet (monsoon) season, which reduces the irrigation demand by effectively using rainwater. This study of rice production took into consideration rainfall for the two main seasons. For one, the WF was studied to evaluate rainfall water used in the green WF, to raise awareness in the use of resources and the environment that affects the ecosystems as well as management to achieve the most effective solution. In the Muda area, the WF for the first (off) season crop is higher than second (main) season because during the main season, the rice usually receives heavy rainfall, which is in August to February. Although green WF had a higher value than blue WF, rice production did not correlate significantly between 2011 and 2015 (Figure 2). Therefore, rice production was not correlated with the planted area. According to Boon Teck et al. (2021), the average WF of rice differs significantly for non-granary and granary areas across certain states. In general, the WF of rice in granary areas is better than WF in non-granary areas. For granary areas, the highest yield was recorded for KETARA, where the annual yield was the same as MADA, although the total planted area in MADA is larger than KETARA. Meanwhile, IADA Kemasin had the lowest yield for a small planted area compared to the eight other granaries.

Since, rice is a staple food crop that provides more calories to the global population than any other crop. Freshwater supplies are also extensively used in the rice producing process. Therefore, adjustments to rice evapotranspiration (ET_c) due to anticipated warming patterns are now required in any management of water resources and food security assessments

Conclusion

Understanding the statistical features of historical data of main climatic parameters such as rainfall and evapotranspiration will help to create an effective water management planning system. This study examined rice production's WF and how yield potential is affected by climate change. Methodologies, techniques, and indicators for analysing the implications of freshwater use are currently being developed. The concept of a WF, on the other hand, is an essential step in the right direction. WF study on rice fields will be critical not only for research but also for Malaysia's agricultural growth. As a result, it will serve as a benchmark for other agricultural activities in Malaysia. The WF reflects the interaction between water consumption and yield, and lowering the WF is a primary goal that would indicate the effective utilisation of water resources. The sensible arrangement of agricultural production regions was one of the strategies to achieve lower WFs and lower water use while maintaining good yields. As a result, regions with less WF and higher economic and environmental benefits should be identified.

Evapotranspiration is a key role in governing hydrological processes. Climate change will have a major impact on hydrological systems, particularly evapotranspiration. As a result, assessing ET, particularly in the context of climate change, is critical. The study is expected to benefit a variety of stakeholders, including water managers, hydrologists, agricultural organisations, water resources development/planning authorities, and environmental agencies, by improving their understanding of preferred methods for estimating ET in Malaysia's irrigated areas. There are many factors that influence rice land productivity. Some of the more significant factors are: soil types; seeds; agronomic practices; harvesting loss; good water management; and cropping intensity. Climate change would have a significant influence on Malaysia's rice crop. As a result, research into the influence of climate change on rice productivity is critical, as rice is a staple diet for Malaysians. Using evapotranspiration in Peninsular Malaysia, this study looked at the influence of climate change on rice output. Climate factors have a considerable impact on rice output, according to the primary findings. Precipitation has only a negative impact on rice output during the main season, which is also known as the wet season. Increased precipitation would result in floods, which is common around this time of year. The minimum temperatures in the main season and off-season, on the other hand, may have inverse consequences.

Since the Muda irrigation Scheme is the country’s leading rice granary area as far as rice production and efficient water management practices are concerned, its WF of rice should be adopted as the benchmark for other irrigation schemes to emulate. Besides, the water use efficiency (90%) in the scheme is among the highest in the regions. Therefore, the target for WF for the granary areas can be reasonably set after the analysis and result of this research. Besides the amount of WF, there are a few other factors that might affect the yield of rice plantation. From the results, we can conclude that for rice cultivation, which needs relatively high-water inputs, especially irrigation water in the dry season, several factors which affect productivity are:

I. Irrigation efficiency and agricultural production technologies;
II. Water management and land preparation;
III. Field conditions such as drainage, field road, water retaining boundaries and field dryness before harvesting (Yusop *et al.*, 2021);

IV. Climate factors such as temperature, sunshine duration and intensity, humidity and wind speed

Climate change makes it more difficult to meet the increasing demands for water, energy, and food, particularly in developing countries. Nevertheless, the water-energy-food nexus is a very relevant concept and strongly related to climate change. All levels of society and stakeholders must recognize the link between climate change and the nexus to achieve the Sustainable Development Goals. We must optimize the efficient use of water, land, energy, and other natural resources so that water, energy, and food-related challenges can be addressed harmoniously across the various stakeholder groups for sustainable development. For human health, it is vital that water resources are available and conserved, as well as wise use of this resource. Global approaches involving water withdrawals, supply, and consumption need knowledge, wisdom, and behaviors that work well. In addition, as a rice bowl, climatic conditions will enhance rice yield variability between granaries and cropping seasons in the future decade. Smaller Southeast Asian countries such as Malaysia are projected to acquire an increasing percentage of their future cereal consumption (for example, rice) from the international market. 30 percent of Malaysia's rice is imported at the moment. Even if Malaysia is not a net importer of rice, sustaining a long-term upward trend in output is critical for reducing reliance on imports. This effort is crucial not just for small-scale farmers' livelihoods, but also for food security.

According to the findings of the study, the government needs an adequate measurement to manage the sustainable use of water resources to avoid water shortages as a result of increased demand on agricultural activities, particularly rice cultivation. Agriculture-related authorities and departments must improve the efficiency of water usage by amending the agriculture production policy that has been created for farmers as a guidance in cultivating crops. There are many parties involved in the management of the water resources in the catchment, including Department of Irrigation Department (DID) Kedah, MADA, Syarikat Air Darul Aman (SADA), Perbadanan Bekalan Air (PBA) and others. To guarantee the equitable distribution of water to all users during times of surplus as well as water stress, it is crucial to take into account both the long-term sustainability of the basin's water resources and short-term operational factors. Despite the fact that the basin's crucial hydraulic infrastructure is overseen by various agencies, their activities must be coordinated. In future, it is recommended that a comprehensive study is conducted to assess the impacts of nutrient enrichment on freshwater resources by including grey water in the WF assessment. Since this study only applied to the Muda Irrigation Scheme, other granary areas could be included as well in future studies.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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