Water Footprint of Rice in Iraq

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Abstract
There is a shortage of water and increasing demand for food in Iraq and other areas of the world will be difficult to meet in the future. Because agriculture is the primary consumer of water, without savings in consumption and precise knowledge of the actual need for water to irrigate important crops, food security cannot be guaranteed. Water footprint (WF) is an inclusive measure for freshwater use that can be used to evaluate the impact on both water volume and distribution of human water consumption. In this study, following the WF approach, the CROPWAT software with the crop water requirement option, the WF of paddy rice cultivation in 7 Iraqi provinces during the year 2017 were estimated. The results showed that the Iraqi paddy rice WF is 3072 m³/ton, which is higher than the global average (1325 m³/ton), the highest water of WF belongs to Muthanna Province with 6688.5 m³/ton and the lowest belongs to Al-Qadisiya Province with 2405.5 m³/ton. About 816,704,748 m³/yr of water were used to irrigate paddy rice-growing areas throughout the country to produce 265,852 tons, the blue WF is dominant and green WF is almost non-existent because rice in Iraq grows during the hot and dry summer. Some provinces like Muthanna and Misan produce little and have a high WF so, rice can be replaced with crops like vegetables that provide more economic benefit and need less water, and the production should be concentrated in low WF provinces such as Qadisiya and Najaf.

Keywords: Paddy Rice; Water Footprint; Iraq; CROPWAT

1. Introduction
Agriculture is the world’s leading freshwater consumer, accounting for nearly 70% of water. The water crisis has turned into a worldwide issue with the impacts of both socio-economic growth and climate change (Ewaid et al., 2019a). In Iraq, it is estimated that 85% of water resources are used in agriculture and about 8% is used for other reasons, while the remainder is lost, mainly by evaporation because of the hot desert climate (Ewaid et al., 2019b).

Iraq has a semi-dry climate and low rainfall, which, in addition to inefficient management, has caused a lack of water resources in recent decades, the impacts of climate change and
water policies in neighboring countries shared by Iraq in the Tigris and Euphrates basin have also contributed to this problem. The water level of the rivers has fallen by more than 60 percent in the last 20 years, partly as a result of the use and damming of upstream water (Al-Ansari et al., 2014).

Iraqi land irrigated by flooding was estimated at over 5.5 million ha of the 8 million ha suitable for agriculture of which 63% in the Tigris basin, 35% in the Euphrates basin, and 2% in the Shatt Al-Arab basin (Khash, 2016).

Irrigation is used in the summer for rice, corn, dates, cotton, vegetables, and fruits grown primarily in central and southern Iraq, wheat and barley are the main irrigated winter crops and there is no reuse of water in agriculture (Schnepf, 2003).

In addition to the large water loss due to evaporation, percolation, water losses in irrigation systems are substantial throughout Iraq. In general, water is transmitted to farmers' fields utilizing poorly maintained distribution systems made of canals and ditches that suffer significant water losses due to infiltration, leakage, or seepage. On-farm field application efficiency using the traditional surface gravity systems is probably near 20 percent or less (Lucani and Saade, 2012).

For the above reasons, prospects for increasing irrigated areas should mainly be based on increases in efficiency and reduction of waste by best management (AOAD, 2015).

Rice (*Oryzae sativa*) is the principal food for over half the world’s humans. About 480 million metric tons of milled rice is produced every year. China and India alone have 50% of the rice grown and consumed. Rice is critical for food security and gives up to 50% of the nutritional caloric supply for millions in Asia, Latin America, and Africa (Muthayya et al., 2014; Mungkung et al., 2019).

Rice is harvested in more than 100 countries from more than 163 million ha. It is cultivated in a variety of crop systems and environments, from single-crop systems in temperate and tropical regions under both rain-fed and irrigated conditions to intensive monoculture in irrigated areas in the tropics where rice is grown two or three times a year (LaPorte et al., 2017).

Large, irrigated fields are cultivated to meet rice production water requirements; therefore, rice is one of the largest consumers of water in the world (Chapagain and Hoekstra, 2011). In Iraq, rice is the most important summer crop and comes in third place after wheat and barley in terms of area planted and production, but Iraq is a country that imports cereals and its rice production is not enough to meet the needs of its population (1.1 million tons was imported in 2017) (SCO, 2019; Ewaid et al., 2020).

There is yearly fluctuation in the production and the harvested area of rice, over the past 20 years, the average area cultivated with rice was 59,046 ha, the production rate was 209,612 tons, the yield rate was 3.55 ton/ha, the highest production was in the year 2013 about 125,000 tons and the lowest production was in the year 2018 about 18,200 tons only (SCO, 2019). Each year, before the beginning of the planting season in summer, and depending on the amount of rain that fell in the previous winter, the Iraqi Ministry of Agriculture determines the provinces and land areas to be planted (SCO, 2019).

The 3.55 ton/ha of rice yield rate in Iraq is very low compared with the other countries, this low yield is mainly due to several reasons like soil salinity, mismanagement of farmers to their farms, and lack of water (Jaradat, 2003).
The production of rice in Iraq is mainly in central and southern Iraq with a large concentration in the Middle Euphrates especially Najaf and Qadisiya provinces and at a lower level in Muthanna, Misan, Dhi-Qar, Wasit, and Diyala provinces (Hameed et al., 2011).

The crop of Indian type is grown along the banks of the Tigris and Euphrates rivers, the best class is called locally as (Anbar) with aromatic long-grain types, considered in high demand in Iraq, also rice of Japanese type is cultivated in the north of Iraq in small quantities where irrigation is possible and locally known as (Bazian), (SCO,2019).

The growing season of rice starts in June-July and ends in October-November, the cultivation is still mainly depending on manual labor, the rate of seed used in planting is 120 Kg/ha (Hameed and Jaber, 2007).

Although the present average yield is only 3.55 ton/ha, some parts have recorded yield of 6-8 ton/ha for improved varieties, the yield may be increased all over Iraq to 6 ton/ha by using high productive rice variety with high improved technology (Hameed et al., 2008).

There are attempts to apply the System of Rice Intensification (SRI) which is a new concept requires changes in rice-growing practices that the Iraqi rice farmers inherited from their ancestors, the SRI is more production, low-water, a labor-intensive method using single-spaced younger seedlings, animal manure as a fertilizer and typically hand-weeded with special tools (Hameed et al., 2011).

Global rice agriculture will be increasingly challenged by water scarcity, while at the same time changes in demand will feedback on agricultural practices. These factors are changing traditional cropping patterns from double-rice cropping to the introduction of upland crops in the dry season, for example, aerobic rice or maize are cultivated in the dry season instead of paddy rice (Weller, et al., 2016; Janz et al., 2019).

The concept of water footprint (WF) has recently emerged among other environmental concepts like, ecological footprint, the carbon footprint, and the life cycle assessment which emerged to explain and address pollution, drought, and resource shortages (Weller, et al., 2016; Borsato et al., 2018; Janz et al., 2019; Mungkung et al., 2019).

The water footprint concept introduced by Hoekstra and Hung (2002) as an indicator of how, when, and where water is consumed and defines the complete volume of water utilized by a consumer or producer to produce a good or a service, measured at the production point based on the concept of the virtual water (VW) and includes volumes of consumption by source and polluted volumes by type of pollution (Hoekstra and Mekonnen, 2012). The WF includes three parts: the green WF is the evapotranspiration (ET) of water provided by rain; the blue WF is the ET of the irrigation water (IR) provided by groundwater and rivers, and the gray WF is the water needed to eliminate the pollution that occurs during the production process (Hoekstra et al., 2011).

Many global studies have been conducted to calculate the WF of the rice crop in the past two decades, but there are no Iraqi studies despite the importance of the rice crop and the scarcity of irrigation water, an evaluation has been carried out by Chapagain and Hoekstra (2011) using data from international trade and domestic production to study the consumption of freshwater in the 13 most important countries producing rice (over 90 percent of global production, average yield 4.49 ton/ha), on average, the global WF of rice production is 784 km³/year with an average of 1325 m³/ton (48% green, 44% blue and 8% grey). Yoo et al. (2014) researched to calculate the rice WF in Korea and found that it is equal to 844.5 m³/ton. Also, Marano and Filippi (2015) calculated rice WF with a similar result in Argentina: (845
m³/ton (43.5% green and 56.3% blue) in northern areas and 987 m³/ton (36.5% green and 63.5% blue) in southern, because of the climate differences, blue water use showed the greatest variability.

Fadillah and Marlia (2016) studied the green and blue WF of rice and the impact of water consumption in Malaysia, their results showed that the green WF is higher than the blue WF for both seasons and the potential water deprivation can be determined by integrating the WF and water stress index in Malaysia.

Karandish and Hoekstra (2017) carried out the first comprehensive WF assessment for Iran and estimated the blue and green WF related to the production and consumption of 26 crops, they find that in the period 1980–2010, crop production increased by 175%, the total WF of crop production by 122%, and the blue WF by 20%. Rice has a much larger WF (m³/ton) compared with cereals or roots and tubers. Rice is produced in the irrigated humid region and aggravates the demand for blue water, while cereals, roots, and tubers can be produced under rainfed conditions in the same region.

Wu (2018) found that the average annual WF of paddy rice in Taiwan for the years 2005-2014 was about 7,580 m³/ton, of which 80% was blue, 17% was green, and 3% was grey. This average annual WF was 5.7 times greater than the annual average WF of rice for countries around the world, 1325 m³/ton, of which 48% was green, 44% was blue and 8% was grey. The blue WF is Taiwan's most important source of rice water.

Li and He (2018) studied the green WF and blue WF of rice production during three different rainfall years in Jilin Province, China.

WF research has been rapidly established recently and the WF technique has been implemented in studies in several different areas related to water uses. Applications of agricultural product exploration methodology were common; with different studies that took into account various products and different countries. For example, the WF assessed coffee and tea consumption in the Netherlands by Hoekstra et al. (2011).

The WF technique was also used for other items used by individuals, for example, cotton, for the production of clothes (Gerbens-Leenes, 2012), and tomato (Aldaya et al., 2010). The WF approach was also extended to take WFs of various diets into account (Chakrabarti et al., 2014; Gheewala et al., 2014). Similarly, WFs were evaluated from various regions and countries (Marano and Filippi 2014; Mekonnen and Hoekstra, 2011). WFs have been used also to test, among other uses, the output of hydroelectricity and biofuels (Shrestha et al., 2013; Graphics, 2008; Yoo et al., 2013).

To analyze the national WF in Iraq, it is necessary to estimate the WF of rice when considering low food self-sufficiency and high-water use in agriculture. Finding the rice WF is very important in the development of a national water resource strategy since rice consumes a large part of Iraq's water. The information about water availability and crop water requirements (CWR) across the country is important for water resource planning to satisfy the increased demand for food production. The purpose of this study is to assess the blue and green WFs of rice production in Iraq during 2017 in the seven rice producers’ provinces of Iraq. Although Iraq is facing a shortage of water, especially for agriculture, studies to calculate the exact quantities of water needed are not available, and this is the first study to use the method of water footprint for rice.
2. Methods and Data

2.1 The study area:

The seven provinces included in this study (Diyala, Babylon, Najaf, Al-Qadysia, Muthanna, Dhi-Qar, and Misan) are located in the middle and southern region of Iraq (between 34°30′42″N - 31°00′23″N and 47°30′00″E - 44°30′00″E (Figure 1).

![Figure 1. Map of the Iraqi provinces (the study area).](image_url)

The region climate is characterized by dryness, extremely hot temperatures, rare rainfall, and the water regime is mainly determined by the Tigris and Euphrates rivers (Zakaria et al., 2013; Ewaid et al., 2019c).

The area of rice cultivated in Iraq varies from year to year as the Ministry of Agriculture determines the areas according to the abundance of rain and water in the season (SCO, 2019).

In the year of this study, rice cultivated areas and production in the 7 provinces were as in Table 1.

Table 1: Rice cultivated areas and production in 2017 (SCO, 2019).

| Province   | Cultivated Area (ha) | Production (ton) | ton/ha |
|------------|----------------------|------------------|--------|
| Diyala     | 1,938                | 5,537            | 2.9    |
| Babylon    | 1,031                | 5,132            | 5.0    |
| Najaf      | 33,129               | 143,965          | 4.3    |
| Qadisiya   | 17,610               | 106,562          | 6.0    |
| Muthanna   | 854                  | 1,825            | 2.1    |
| Dhi-Qar    | 675                  | 2,102            | 3.1    |
| Misan      | 289                  | 729              | 2.5    |
| **Total**  | **55,525**           | **265,852**      | **4.8**|
The methodology of green and blue WF assessment for rice crop is followed as set out in (Aldaya et al., 2011). The methodology of the CROPWAT model is based on (Allen et al., 1998).

2.2 CROPWAT 8.0 model

CROPWAT 8.0 model is a decision support software developed by the Land and Water Development Division of FAO to calculate the crop water requirements (CWR) and irrigation requirements (IR) based on soil, climate, and crop data (FAO, 2019). The model approach is based on the FAO publication by (Allen et al., 1998).

In this research, the CWR method is used to get the evapotranspiration of the crop (ET) by the CROPWAT model in ideal growth situations, which means that appropriate soil water is preserved by rainfall and/or irrigation, the CWR option was used because there were no local detailed soil data available for the study area (Hoekstra and Mekonnen, 2012).

Four types of data are essential for using the CWR method in the CROPWAT model: The climate/ reference crop evapotranspiration (ET0, mm), rainfall, crop, and soil data, the climate/ET0 data is used to determine the average ET0 per month based on the FAO Penman-Monteith Method (Allen et al., 1998).

The rainfall part in CROPWAT is used for the implementation of precipitation data and to calculate the effective rainfall (Eff. rain) using the USDA S.C. Method (Allen et al., 1998).

The rice option of the crop part in CROPWAT includes planting date, crop coefficient (Kc), length of the stages, puddling depth, rooting depth, and crop height. The parameters of soil for rice include maximum infiltration rate, total available water (TAW), maximum rooting depth, drainable porosity, initial soil moisture depletion, water availability at planting maximum water depth, and critical depletion for puddle cracking (Chapagain and Hoekstra, 2011).

2.3 Crop water requirement

It is the volume of water needed for a crop to grow. The reference crop evapotranspiration (ET0, mm) and the crop coefficient (Kc) influence the value of the CWR of the crop both are influenced by climate variations and calculated as follows:

\[ \text{CWR} = Kc \times ET0 \]  
\[ \text{CWR} = ETc \]

ET0 is the evapotranspiration rate from a hypothetical grass reference crop which affected only by climatic parameters. Kc is the value that discriminates field crops from the reference crop and its variations are identified by climate, crop variety, and crop growth stages.

The growing period of a crop is divided into 4 stages: the initial, the development, the mid-season, and the late-season stage. There are three Kc values implemented: the first at the initial stage, the second at the mid-season stage, and the third at the late-season stage (Allen et al., 1998).
2.4 Green crop water use

The green module of the crop water use (CWUgreen, m$^3$/ha) is the amount of green water (rainwater) used for evapotranspiration by the crop (Allen et al., 1998).

$$CWU_{green} = 10 \times \sum_{d=1}^{Igp} ET_{green}$$

(3)

The $ET_{green}$ is either the Eff. rain or the $ET_c$

Where Igp is the duration of the period of growth, factor 10 is used to convert water depth (mm) into water volume (m$^3$/ha).

$$ET_{green} = \min \ (ET_c, Eff.\ rain)$$

(4)

2.5 Blue crop water use

The blue module of crop water use (CWUblue, m$^3$/ha) is the size of irrigation water including surface and groundwater and calculated as:

$$CWU_{blue} = 10 \times \sum_{d=1}^{Igp} ET_{blue}$$

(5)

The $ET_{blue}$ is the difference between the $ET_c$ and the Eff. rain and also known as the irrigation requirement ($IR$). If the Eff. rain is above the $ET_c$, the $ET_{blue}$ is equal to zero and no irrigation is required. If the CWR doesn't fully meet by Eff. rain the $ET_{blue}$ is the difference.

$$ET_{blue} = \max \ (0, ET_c - Eff.\ rain)$$

(6)

2.6 The water footprint (WF) of rice

The total WF of rice per ton is the summary of the blue WF ($WF_{blue}$, m$^3$/ton) and the green WF ($WF_{green}$, m$^3$/ton) (Aldaya and Hoekstra, 2010).

$$WF = WF_{green} + WF_{blue}$$

(7)

The WF green and WF blue are calculated by dividing the $CWU$ (m$^3$/ha) by the crop yield ($Y$, ton/ha).

$$WF_{green} = \frac{CWU_{green}}{Y}$$

(8)

$$WF_{blue} = \frac{CWU_{blue}}{Y}$$

(9)

The production total WF of rice (m$^3$/yr) is the summary of the components green and blue by m$^3$/yr. The computations of the two parts are done by multiplying the yearly production (ton/yr) times the WF per ton of rice (m$^3$/ton) and the production total WF will be shown as (m$^3$/yr).
The grey water footprint was not calculated in this study due to the unavailability of data and it is very little that can be neglected.

\[
WF_{\text{green}} = WF_{\text{green}} \times \text{production} \tag{10}
\]

\[
WF_{\text{blue}} = WF_{\text{blue}} \times \text{production} \tag{11}
\]

2.7 Data Collection
To calculate the CWR, the monthly values of the climatic and rainfall data for the year 2017 obtained from the Iraqi Meteorological Organization and Seismology (IMOS) were used. The data entered in the CROPWAT program per every meteorological station in the seven producing rice provinces (FAO, 2019) (Table 1).

The meteorological station's data contains country, station name, longitude, latitude, altitude, and represent the state of the climate in the province. The meteorological data includes monthly rainfall data (mm/month), effective rainfall (mm), monthly averages for the climatic parameters; maximum and minimum temperature (°C), wind speed (km/h), relative humidity (%), and sunshine hours (Hrs) (IMOS, 2019).

The data of the rice crop Kc value per province was got from the CROPWAT database according to (Allen et al., 1998; FAO, 2019) containing critical depletion, yield response factor, rooting depth, crop coefficient, and length of rice growth stages.

The local data on rice yield (ton/ha), production (ton/yr), planting, and harvesting dates were gained from the Ministry of Agriculture (DEAT, 2018). In 2017 the amount of rainfall was moderate and close to average, which is why it was chosen to study here (IMOS, 2019).

The soil parameters gained from the CROPWAT program, containing details about the soil like initial moisture depletion, total available moisture content, maximum rooting depth, and maximum rain infiltration rate. USDA soil conservation method was used. The status of soil suitable for growing rice was considered as black clay soil (FAO, 2019).

3. Results and Discussion

3.1. General features of the climate in the study area
Diyala, Babylon, Najaf, Qadisiya, Muthanna, Dhi-Qar, and Misan are the main rice-producing provinces in the country. The climate in the region of the study is of a semi-arid, continental subtropical type; rainfall occurs during winter and spring from November to April, the annual average rainfall is around 152 mm, winter is cold, daytime temperatures are around 16°C, and at night is 2°C. Summer is hot and dry, with a shade temperature of more than 43 °C in July and August declines at night to 26 °C (Bishay, 2003; Al-Ansari and Knutsson, 2011).

Tables 1 and 2 which are the result of the application of the CROPWAT software describe the 7 meteorological stations and related 7 provinces included in this study, the spatial-temporal difference of station climate data, their position, and altitude. For the distribution of rain, it was relatively low and there are slight differences between provinces.

The average annual rain in the seven stations ranged from 96 mm in Najaf, receiving the lowest amount of rain to 317 mm in Diyala, receiving the highest amount of rain. January is the highest rainy month in the whole region, followed by December.
Table 2. The data of ETc, Eff. rain, IR, and related variables in the study area obtained from CROPWAT software. (dec = 10 days).

| Station | $ET_0$ (mm/d) | ETc (mm/dec) | Eff. Rain (mm/dec) | IR (mm/dec) | Humidity (%) | Wind (km/d) | Sun (hours) | Temp. °C |
|---------|---------------|--------------|-------------------|-------------|--------------|-------------|-------------|----------|
| Amarah  | 5.57          | 208.5        | 121.40            | 97.40       | 46           | 197         | 8.20        | 16.40    |
| Nasiriya| 6.23          | 284.40       | 67.80             | 216.20      | 44           | 259         | 8.10        | 16.60    |
| Semawa  | 5.73          | 246.40       | 77.70             | 171.60      | 38           | 204         | 8.10        | 16.40    |
| Najaf   | 6.11          | 274.30       | 56.00             | 219.00      | 39           | 241         | 8.30        | 16.80    |
| Diwaniya| 5.68          | 278.00       | 75.60             | 202.00      | 44           | 241         | 8.50        | 14.70    |
| Baghdad | 5.59          | 226.70       | 98.70             | 128.40      | 45           | 220         | 8.20        | 14.70    |
| Kanaqin | 4.80          | 212.00       | 210.00            | 42.40       | 36           | 158         | 7.60        | 14.70    |
| Average | 5.38          | 227.10       | 126.70            | 123.51      | 45           | 208         | 8.08        | 15.35    |

The average minimum and maximum air temperature values were 14.7 °C and 31.6 °C and the wind speed averaged 208 km/day. The daily average $ET_0$ was 5.38 mm/day. The total average Eff. rain was 126.7 mm/dec (Table 1). The $ET_0$ variable had little variation in the study region for the studied period but there are some differences in ETc, $ET_{green}$, and $ET_{blue}$ values among stations (Table 2). The humidity average was 45.25 % for the 7 stations.

The average irrigation requirement was 123.51 mm/dec (Table 1).

3.2. Crop Water Requirements (CWR, mm)

For the accurate calculation of the crop WF, data on variation in CWR is important. CROPWAT FAO model (Allen et al., 1998; FAO, 2019) used to assess the green (effective rainfall) and blue (irrigation) rice crop consumption of water. CROPWAT estimated both the Eff. rain and the ETc concerning climate, crop, soil parameters, and the moisture status of the daily soil profile. Tables 1 and 2 represent the 2017 climate data used for CWR calculation.

The average of ETc was 227.1 mm, the IWR was 123.51 mm, and the Eff. rain was 126.7 mm/dec. The Eff. rain values and ETc of rice grown in the 7 provinces have shown some local variation (Table 1). This may be due to spatial variations in the pattern of rainfall and temperature.

The ETc values for rice ranged from 208.5 mm to 284.4 mm and this difference should be measured in the rice WF calculation, the ETc is high because there is accessible water to meet CWR and because of the hot and sunny climate, as crops require more water than in a cool and cloudy climate.

3.3. Paddy Rice Water Footprint

The irrigation requirements, yields, and the environmental impact from water use for rice cultivation can vary greatly from provinces to provinces. The WF for cultivating rice was estimated for the 7 Iraqi provinces (Table 3) and the results show that the crop water use was 14,596 (m$^3$/ha), the total WF of rice production was 816,704,748 (m$^3$/yr) for the 56,014 (ha) cultivated area and 265,852 (ton/yr) production. The variation in the CWRs and WFs across different provinces depends mostly on the amount of the crop yield.
The results of the present study showed that the blue WFs for the 7 Iraqi provinces are much higher than the green WFs of rice cultivation. This means that the annual rainfall rate in Iraq cannot satisfy the water requirement for rice cultivation and that the irrigation requirement is needed. Iraq's topography and climate conditions mean that water supplies, especially for rice, are not adequate and the need to cultivate the crop is not met. The spatial variation of water use for rice production was shown in Table (3), total water used was varied from 12102 m$^3$/ha in Diyala to 16000 m$^3$/ha in Babylon Province.

Table 3. The climate characteristics of the 7 stations in the producing provinces, 2017.

| Province | Climate Station | Altitude (m) | Latitude North | Longitude East | Rice Planting & Harvesting date | $ET_{blue}$ Mm | $ET_{green}$ mm | Annual Rain mm |
|----------|----------------|--------------|----------------|----------------|---------------------------------|---------------|---------------|----------------|
| Diyala   | Kanaqin        | 202          | 34.3           | 45.43          | 15 May - 30 Oct.                | 1174.5        | 35.7          | 317            |
| Babylon  | Baghdad        | 34           | 33.23          | 44.23          | 20 May - 10 Nov.                | 1593.3        | 6.7           | 149            |
| Najaf    | Najaf          | 32           | 31.98          | 44.31          | 15 June - 1 Nov.                | 1515.5        | 2.2           | 96             |
| Qadisiya | Diwaniyah      | 20           | 31.98          | 44.98          | 15 June - 1 Nov.                | 1439.1        | 4.2           | 116            |
| Muthanna | Samawa         | 6            | 31.3           | 45.26          | 1 June - 15 Nov.               | 1403.2        | 1.4           | 109            |
| Dhi-Qar  | Nasiriya       | 3            | 31.8           | 46.23          | 15 May - 10 Nov.                | 1548.6        | 12.1          | 107            |
| Misan    | Amara          | 9            | 31.85          | 47.16          | 15 June - 15 Nov               | 1479.3        | 1.2           | 168            |
| Average  |                |              |                |                |                                 | 1450.5        | 9.07          | 152            |

The green, blue and total rice WF over the 2017 agricultural season in the seven provinces were calculated by the method of (Hoekstra and Mekonnen, 2012; Allen et al., 1998). For each province, the green WF (m$^3$/ton) was assessed as the proportion of the green water used (m$^3$/ha) to the crop yield (ton/ha), where the total use of green water is obtained by summing up the evapotranspiration of green water during the growing period. The blue WF was taken by rice yield equivalent to the ratio of irrigation water consumed; total WF is a green and blue WF summation.

The rice WF parts were evaluated for the 7 provinces (Table 3). The green WFs are low and varied from only 7 m$^3$/ton in Qadisiya to 123.1 m$^3$/ton in Diyala, but there are high blue WFs between 2398.5 in Al-Qadisiya to 6682 m$^3$/ton in Muthanna. The provinces of Al-Qadisiya and Babylon followed by Najaf and Diyala have a relatively low rice WF but Dhi-Qar, Muthanna, and Missan have the highest WF and use more water per ton of rice than the national average.
The average WF of rice production differs considerably across areas of production. Crops with high yields have a smaller WF per ton in contrast to crops with low yields, which means that the higher the yield, the lower the value of the WF. Although the average WF for Iraqi rice cultivation may have been greater for lower-yielding provinces, WF results in some areas may have been different due to the variations of climate. The interferences of the farming activity on the field such as bad irrigation systems, traditional agricultural policies, etc., are another factor crucial in the WF assessment.

These results indicate that the average annual rice WF in 2017 was about 3072 m$^3$/ton (Table 3), of which 99.7% was blue and 0.3% was green. This average annual WF was about 2.3 times larger than the average annual WF of rice for countries around the globe of 1325 m$^3$/ton, of which 48% was green, 44% was blue, and 8% was grey (Graphics, 2008). Several studies on the water footprint of rice cultivation have been conducted in several regions over the last few years (Table 4).

Hoekstra and Hung (2002) initially carried out a global calculation of the use of water for many crops. Many studies on a worldwide scale were performed from there. The overall amount of water used by crops according to Chapagain and Hoekstra (2011) is 6,390 gm$^3$/yr and rice accounts for approximately 21% of the overall freshwater withdrawal volumes, which is the biggest share of water used in world cultivation.

Yoo et al. (2013) estimated the WF of Korean rice, and the total WF was found at 844.5 m$^3$/ton.

The WF for rice farming in Nepal and India was performed by Shrestha et al. (2013) with a total WF of 3,483 m$^3$/ton.

Based on the above results, a good rice production zone could be expected in the seven Iraqi provinces if it has low WF. The Iraqi WF per ton of rice obtained in this study (3072 m$^3$/ton) is higher than the world average (1325 m$^3$/ton), and more than in the 13 major rice-producing countries, Table 4 (Chapagain and Hoekstra, 2011).

Table 4. The calculated total WF of rice production (m$^3$/ha) and the national paddy rice WF (m$^3$/ton) for the year 2017.

| Province   | Crop Water Use (m$^3$/ha) | Total WF of Rice Production (m$^3$/yr) | Planted Area (ha/yr) | Production (ton/yr) | Paddy Rice WF (m$^3$/ton) |
|------------|---------------------------|----------------------------------------|----------------------|---------------------|---------------------------|
|            | Blue Green Total          | Blue Green Total                       |                      |                     |                           |
| Diyala     | 11,745 357 12,102         | 22,424,850 681,605 23,106,455          | 1,909                | 5537                | 2.9                       |
| Babylon    | 15,933 67 16,000          | 16,353,631 68,769 16,422,400           | 1,026                | 5132                | 5.0                       |
| Najaf      | 15,155 22 15,177          | 492,993,746 734,222 493,727,968        | 33,480               | 143,965             | 4.3                       |
| Qadysia    | 14,391 42 14,433          | 255,588,957 745,934 256,334,891        | 17,760               | 106,562             | 6.0                       |
| Muthanna   | 14,032 14 14,046          | 12,201,332 12,045 12,213,377           | 869                  | 1,825               | 2.1                       |
| Dhi-Qar    | 15,486 121 15,607         | 10,500,541 81,978 10,582,519           | 678                  | 2,102               | 3.1                       |
| Misan      | 14,793 12 14,805          | 4,313,639 3,499 4,317,138              | 292                  | 729                 | 2.5                       |
| Total      |                          | 819,409,829 2,328,052 816,704,748      | 56,014               | 265,852             | 99.7% 0.3%                |
| Average    | 14,505 90.7 14,596        | 99.72% 0.28%                           |                      | 4.8                 | 3082.2 8.8 3072           |
Table 5. Comparison of the results of this research with the WFs values of the 13 major rice-producing countries by m$^3$/ton (Chapagain and Hoekstra, 2011).

| Country      | Green WF | Blue WF | Grey WF | Total WF |
|--------------|----------|---------|---------|----------|
| China        | 367      | 487     | 117     | 971      |
| India        | 1077     | 826     | 116     | 2,020    |
| Indonesia    | 583      | 487     | 118     | 1,187    |
| Vietnam      | 308      | 203     | 127     | 638      |
| Bangladesh   | 549      | 577     | 103     | 1,228    |
| Myanmar      | 846      | 378     | 50      | 1,274    |
| Thailand     | 942      | 559     | 116     | 1,617    |
| Philippines  | 844      | 423     | 78      | 1,345    |
| Japan        | 341      | 401     | 61      | 802      |
| USA          | 227      | 835     | 101     | 1,163    |
| Brazil       | 791      | 670     | 61      | 1,521    |
| Korea, R     | 356      | 388     | 84      | 829      |
| Pakistan     | 421      | 2,364   | 88      | 2,874    |
| World Average| 632      | 584     | 109     | 1,325    |
| Iraq (This study) | 8.8 | 3,082.2 | /       | 3,091    |

The high WF of the rice crop in Iraq can be explained in addition to the mismanagement of irrigation systems by the fact that southern Iraq's climate is hot and dry without rain in summer and water is lost in large quantities by evapotranspiration. Other causes include the using of continuous submergence throughout the rice cycle (flooded method) which is the conventional method of rice irrigation in Iraq that requires large quantities of water, farmers’ usual practice is to maintain standing water on the soil surface to a depth of 5-20 cm throughout the rice cycle (Hameed et al., 2011). The water footprint of the rice crop in Iraq can be reduced by the introduction of new high productivity varieties and the use of irrigation modern methods (like sprinkler irrigation) to reduce water waste, adding a high residue cover crop that expands soil organic can expand ET while reducing WF due to increased yield (Monaco and Sali, 2018).

Rice cultivation in Iraq can benefit from global experiences in this regard, in their study on India 2002 lowest level of precipitation, (Zampieri et al. 2018) proposed new indicators and compared them with observations of soil moisture from satellites. They combine all diagnoses with the reported yields, calculate long-term correlations, and suit the anomaly of 2002. They have highlighted the need for integration of non-local surface freshwater dynamics with local rainfall variability to determine the model and forecast soil moisture conditions in rice fields.

Zampieri et al. (2019) in Northern Italy found that the complete change of rice cultivation towards dry seeding is not consistent with the availability of seasonal water. Sustainable rice cultivation in the middle latitudes thus seems to be feasible in the sense of near-term climate change by combining conventional and dry-seeding.
In the provinces with a large water footprint and relatively little production (Muthanna, and Misan), the rice should be replaced with other crops requiring less water like vegetables. Applying the System of Rice Intensification (SRI) may contribute to reducing waste in water and increasing production.

Decreasing WF means decreasing water use per unit of crop yields to get more benefit from each drop of water. Increasing the productivity of water in agriculture, which reduces the WF per unit of production, will help to reduce the pressure on the limited freshwater resources (Mekonnen and Hoekstra, 2014).

It is worth mentioning that water shortage is not a worldwide problem, in certain regions is not and precipitation is going to increase with global warming, mainly in the tropics and in the high latitudes (Elliot et al., 2014; Zampieri et al., 2019). It was, therefore, appropriate to modify the traditional methods with advanced methods. The number of techniques recommended in regions suffering especially from water stress in the near future. Techniques such as direct seed rice, bed planting, mechanical transplantation, laser leveling, and soil matric potential dependent irrigation using tensiometers, etc. are recommended (Bahatt, 2020).

4. Conclusions

Given the growing need for water, it has become a commodity, a social good, a natural resource, and an economic good. The concept of ‘water footprint’ was therefore developed to provide a water consumption indicator (Hoekstra and Hung, 2002).

To understand the water footprint including its economic, social, environmental, and ethical dimensions, water needs to be understood in an integrated manner within the larger framework of sustainable development.

As a result of global warming and climate change, and increasing demand for food and other products, the availability of water for agricultural use is declining but the comprehensive approach including both supply and demand-side measures enables sustainability in water use.

Addressing water deficits by supply-side measures such as increasing irrigation facilities alone would be inadequate in addition to involving significant economic, social, and environmental costs. Increasing crop efficiency in water use by using improved varieties and hybrids, irrigation scheduling, optimizing the use of other inputs would help but need to be used over a large geographic area to have sufficient impact. These supply-side measures should, therefore, be complemented by demand-side measures to help reduce the water footprint of agriculture. Two demand-based strategies are possible. The first is to plan production taking into account regional WFs and the second is to induce a change in patterns and behavior of consumers.

The production planning must be based on the county water availabilities and understanding the crop water requirement, dependence on blue water and the economic value of water for the crops grown in Iraq are fundamental for planning sustainable agriculture.

Efficiency in water allocation can be increased through spatial and temporary planning of production. A crop’s economic value provides a useful indication for such planning as it can help optimize profits and optimize the allocation of water through appropriate crop selection. Rice production planning to minimize water footprint means growing rice in provinces where the average water requirement is low like Qadisiya Province and don’t grow the rice in
provinces where crop water requirement is high and replace it with crops that need less water and give better economic returns like vegetables.

Inducing change in consumer behavior and patterns by linking economic activity's impact on local water resources in which people are involved can help to reduce the pressure on the environment that it creates. Knowing a product's WF helps induce changes in consumption patterns and adopts water-saving behavior.

The whole building of the debate and action on climate change was built on the 'carbon footprint' measure. It has led to understanding the need for global climate governance and the purpose under the Kyoto Protocol has evolved into global institutions. There is also the potential for the concept of WF to induce such behavioral change. Over the two past decades, it has gained widespread attention and has the potential to bring about change just like the idea of carbon footprint.

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