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Estimating Water Footprint of Crops for a Selected Area in Dhaka Division of Bangladesh

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Abstract

The water footprint is an indicator of direct and indirect water consumption by a product or person and the pollution it causes. Bangladesh is mainly an agricultural-based country. The objective of the current study is to assess the water footprint of crops in the Dhaka division of Bangladesh. The area covered by Faridpur, Gopalganj, Madaripur, Shariatpur, and Rajbari districts was taken as the study area. Rice, wheat, maize, potatoes, sugarcane, pulses, jute, and mustard were considered for the water footprint assessment. The blue, green, and gray water footprints for each district were calculated separately. As the water footprint of a crop depends upon the climate, soil type, and precipitation of an area, local data were collected and used for the analysis. The CropWat model was used for estimating the water footprints of crops. The gray water footprint was calculated based on the use of nitrogenous fertilizers. The results indicate that maize has the highest amount of green and gray water footprints, and sugarcane has the highest amount of green water footprints in Faridpur. For Gopalganj, jute and sugarcane are the highest contributors to green and blue water footprints, respectively. For Madaripur, rice has the highest amount of green water footprint, and sugarcane has the highest amount of blue water footprint. The condition of Shariatpur is found to be the same as that of Madaripur. Rajbari district also exhibits the highest amount of green water footprint, while sugarcane has the highest amount of blue water footprint. The current study finally suggests that effective means of irrigation should be practiced in the study area for sustainable agricultural practices.

Keywords: *Water footprint; CropWat Model; Blue water; Green water; Gray water*

1 Introduction

Bangladesh is one of the most populated countries in the world. According to the UNDP report, the population of the country is expected to be 24 Crores by 2050, with a growth rate of 1.1%. Agriculture is the main source of food and raw materials for industrial development. In order to meet increasing demand, more production is necessary. The production of crops is dependent on land and water. Increasing production means increasing the number of water withdrawals. In the past decades, withdrawals of global freshwater have increased seven times (Gleick, 2000). Water withdrawal is expected to continue increasing in the upcoming decades (Rosegrant and Ringler, 2000; Liu et al., 2013). Water withdrawals larger than water availability led to a shortage of water in natural reservoirs. In Dhaka, pumping has caused groundwater levels to drop more than 200 feet over the last 50 years (Khan et al., 2016). In present times, the agriculture sector consumes about 85% of the world's blue water (Shiklomanov, 2000). Around 70% of the world's water withdrawals are also used for agriculture (Faurèsa et al., 2002). The increase in water withdrawals, especially in agricultural sectors, is the key driver of water scarcity for areas with 57.5% of the world's population (Huang et al., 2021).

The concept of water footprint was introduced by Hoekstra in 2002, which is a process of calculating the human application of freshwater in volume (Hoekstra et al., 2011; Hoekstra et al., 2017). Water footprints calculate both the direct and indirect use of water. The green water footprint is the amount of rainwater consumed, and the blue water footprint is the amount of surface water or groundwater used. The gray water footprint was not included in the water footprint calculation until some recent studies. It is the amount of water needed to dissolve pollutants. The water footprint of an area is equal to the sum of the water footprints of all processes taking place in that area (Hoekstra et al., 2011). In Bangladesh, the agricultural sectors consume a huge amount of water resources, and thus the water table is declining severely (Hoque et al., 2021). Therefore, the aim of the current study is to assess

the water footprint of crops in the Dhaka division of Bangladesh. It is expected that the outcome of this study will be supportive of understanding the amount of water used for different crops and thus will lead to the development of policies for sustainable utilization of water resources for agricultural purposes.

2 Methodology

2.1 Study Area and Data

In the current study, the area covered by Faridpur, Gopalganj, Madaripur, Shariatpur, and Rajbari districts in the Dhaka division was taken as the case study area, which is shown in Figure 1. The study area is separated from other parts of the Dhaka division by the Padma River. Rice, wheat, maize, potatoes, sugarcane, pulses, jute, and mustard were considered for the water footprint assessment. The water footprint of crops was estimated separately for each district in the study area. Hence, primary data were collected separately for each station and district. All the meteorological data were collected from the Bangladesh Meteorological Department (BMD), and the CLIMWAT database for various stages of different crops was collected from Chapagain and Hoekstra (2004). The soil type was determined from the study of Islam et al. (2017). Data on crop yield were obtained from the yearbook of agricultural statistics of the Bangladesh Bureau of Statistics (BBS, 2022). In this study, the gray water footprint was calculated only for nitrogen-based pollutants. Other types of pollutants are so small in number that they can be ignored. The amount of nitrogen-based fertilizer used in cultivable lands is assumed (Ahmmed et al., 2018). It is estimated that 10% of the used fertilizer is leached and found as nitrate in water. The maximum allowable limit for nitrate in water was taken from the United States Environmental Protection Agency (US-EPA), which is 10 mg/L. The amount of nitrate found in water was considered to be 5.92 mg/L.

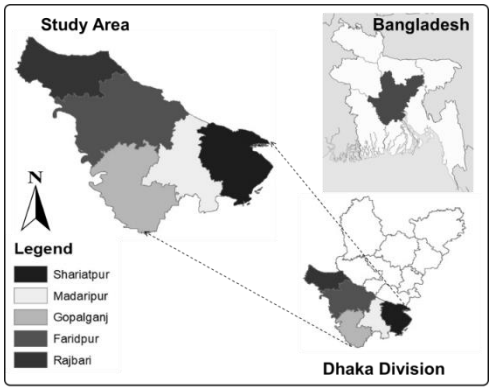

Fig 1: Location of the study area

2.2 Estimating Water Footprint of Crops

In this study, the green, blue, and gray water footprints were calculated separately using the method outlined in the water footprint assessment manual of Hoekstra et al. (2011). Then all three were summed up to determine the total water footprint. Rice, wheat, potatoes, pulses, mustard, sugarcane, jute, and maize are the main eight crops that are grown a huge amount in the study area. Hence, they were selected for this study. The calculation of green and blue water footprints depends on the amount of evapotranspiration. The process of evaporation and transpiration together is called evapotranspiration. The amount of evapotranspiration is estimated using the FAO CropWat 8.0 model. These models are created by taking into account local climatic conditions, soil types, and crop varieties.

The green water footprint is the calculation of rainwater used by crops. The water needed for evapotranspiration was simulated from crop water models. Then the green water footprint was calculated by dividing the estimated evapotranspiration by the total crop yield of the area using Equation (1). For converting rainfall in mm to water volume in m^3/ha a factor of 10 was used.

$$\text{Green water footprint, } WF_{green} = 10 \times \frac{ET_0}{Y} \quad (1)$$

Where WF_{green} is the green water footprint in m^3/ha. ET_0 is the estimated green water requirement of crops in mm, and Y is the total yield of the area in ton/ha.

The blue water footprint is the quantity of groundwater or surface water used for the growth of crops at every stage. The blue water footprint was estimated in the same way as the green water footprint by using Equation (2).

$$\text{Blue water footprint, } WF_{blue} = 10 \times \frac{ET_0}{Y} \quad (2)$$

Where WF_{blue} is the blue water footprint in m^3/ha, ET_o is the estimated blue water requirement in mm, and Y is the total yield of the area (ton/ha).

The gray water footprint is the calculation of the pollutant present in water. For estimating gray water footprint, the pollutant load (L) was divided by the difference between the water quality standard (C_{max}) for the pollutant and its natural concentration (C_{nat}) in the water body. In the current study, only nitrogenous fertilizer was taken as the pollutant. The gray water footprint ws calculated by using Equation (3).

$$\text{Gray water footprint, } WF_{gray} = 10 \times \frac{L}{C_{max} - C_{nat}} \quad (3)$$

Where L is the amount of pollutant load, C_{max} is the maximum permissible pollutant, and C_{nat} is the pollutant found in nature.

The total water footprint of a crop is a combination of blue, green, and gray water footprint.

$$\text{Total water footprint, } WF_{Total} = WF_{blue} + WF_{green} + WF_{gray} \quad (4)$$

Where WF_{green} is the green water footprint, WF_{blue} is the blue water footprint, and WF_{gray} is the gray water footprint.

3 Results and Discussion

The blue, green, and gray water footprints estimated for various crops in the study area is shown in Fig. 2.

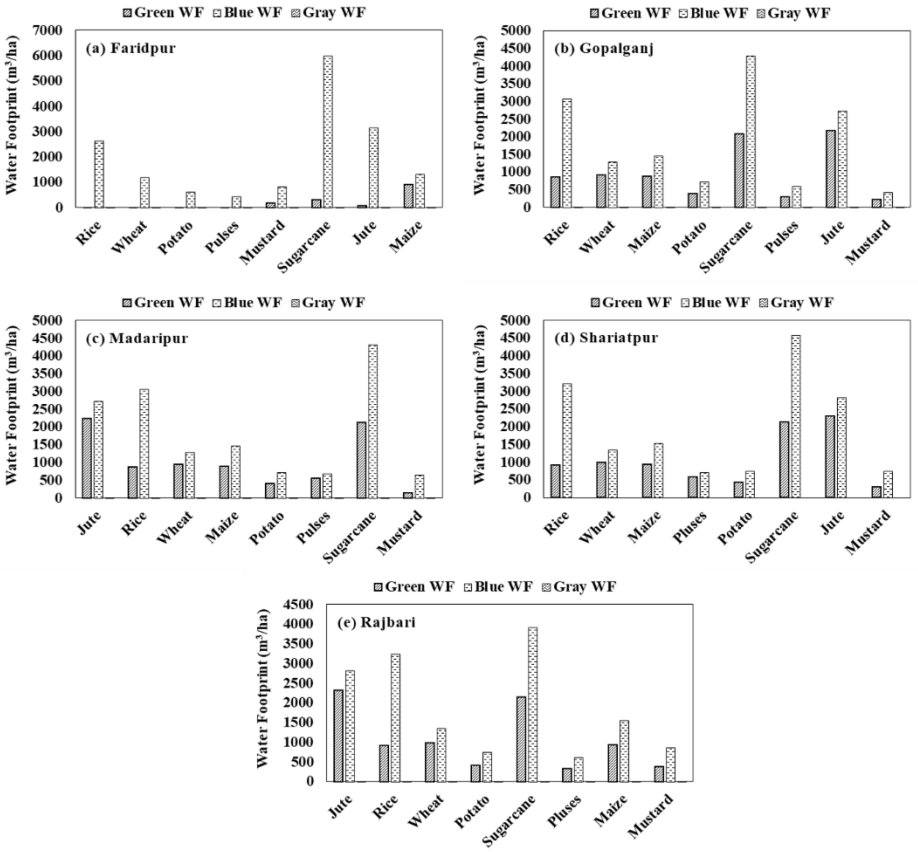

Figure 2: Estimated green water, blue water, and gray water footprints of different crops in the study area

As can be seen from the figure, in Faridpur, sugarcane has the highest amount of blue water footprint, which is a little below 6000 m^3/ha. The lowest amount of blue water footprint belongs to pluses, which are around 450 m^3/ha. As for the green water footprint, the highest amount is for maize, which is a little higher than 930 m^3/ha. Pulses exhibit the lowest green water footprint. It is a little less than 5 m^3/ha. For Gopalganj, sugarcane also has the highest amount of blue water footprint, which is about 4200 m^3/ha. However, the highest amount of green water footprint belongs to jute, which is a little lower than 2200 m^3/ha. Mustard has the lowest amount of both blue and green water footprints. It is about 423 m^3/ha for the blue water footprint and a little less than 230 m^3/ha for the green water footprint. As for Madaripur, the highest green water consumer is sugarcane, which is a little greater than 4600 m^3/ha, and mustard has the lowest amount of green water footprint, which is about 150 m^3/ha. On the other hand, the highest blue water consumer is also sugarcane, which is a little greater than 4310 m^3/ha, and the lowest amount also belongs to mustard, which is about 650 m^3/ha.

The highest green water consumer is sugarcane in Shariatpur. It is 2139.5 m^3/ha, while mustard has the lowest amount, which is about 308 m^3/ha. As for the blue water footprint, the highest consumer is also sugarcane, which is a little lower than 4600 m^3/ha, and the lowest amount belongs to the pluses. It is slightly higher than 714 m^3/ha. For Rajbari, the highest green water footprint belongs to jute, which is about 2330 m^3/ha, and pulses have the lowest amount, which is a little less than 344 m^3/ha. The highest blue water consumer is sugarcane, which is around 3916 m^3/ha, and the lowest amount belongs to the pluses, which are slightly less than 622 m^3/ha. The gray water footprint is approximately the same for all districts. Maize produces the highest amount of gray water footprint, which is 10.44 m^3/ha. The lowest amount of gray water footprint belongs to jute, which is about 1.3 m^3/ha.

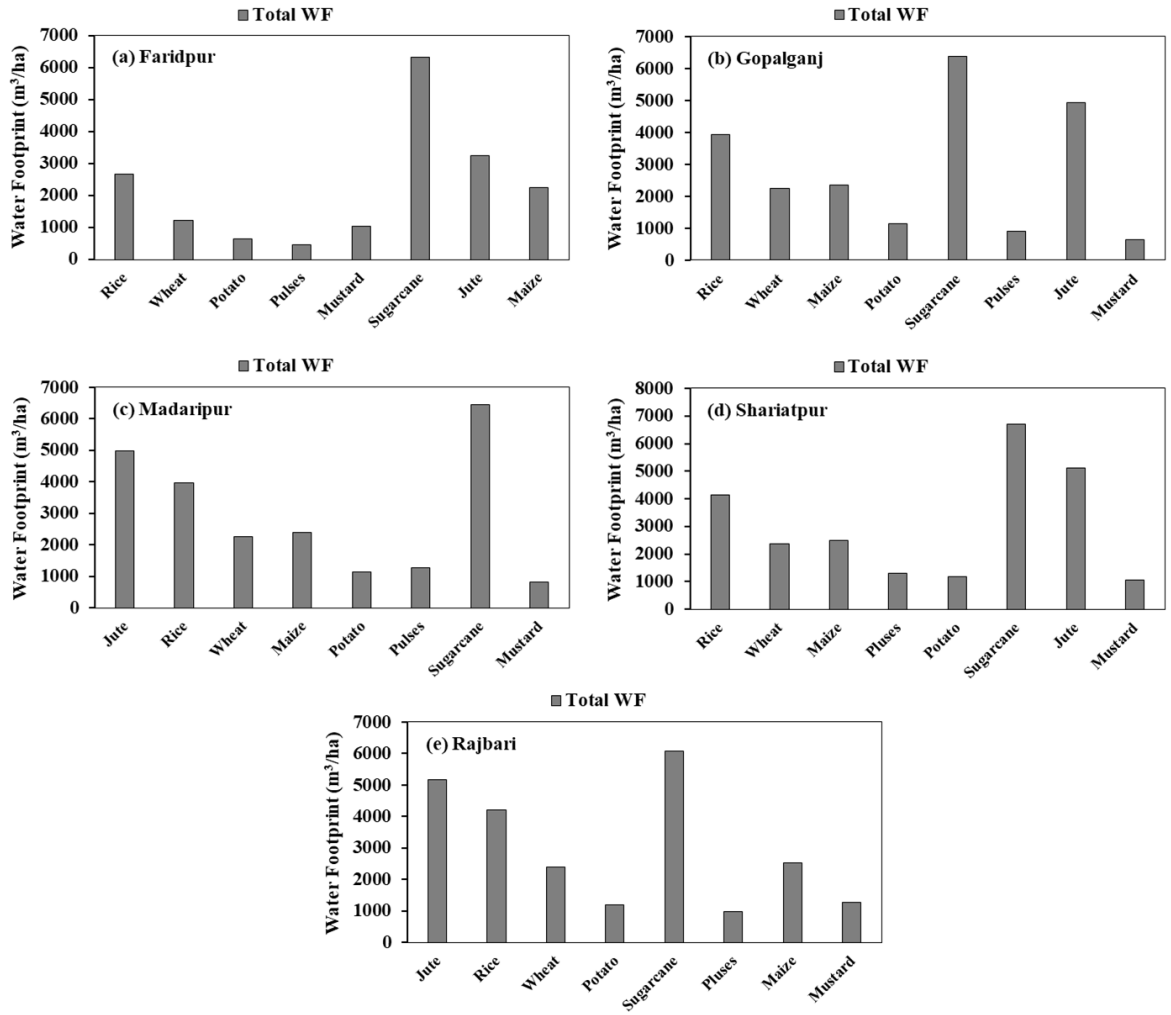

Figure 3: Estimated total water footprint of different crops in the study area

Fig. 3 shows the total water footprint of these five different districts. In Faridpur, sugarcane has the highest water footprint, which is a little bigger than 6300 m^3/ha. This is followed by jute, which has a water footprint of a little

less than 3300 m^3/ha. The water footprint of rice is about 2674 m^3/ha. Maize has a water footprint lower than 2300 m^3/ha. Wheat has a water footprint of about 1219 m^3/ha. The water footprint of mustard is about 1037 m^3/ha. Potato has a water footprint of about 638 m^3/ha. Pluses have the lowest water footprint, which is about 456 m^3/ha. It can also be seen from the figure that sugarcane has the highest amount of water footprint for Gopalganj, which is less than 6400 m^3/ha. Jute has a water footprint of 4923 m^3/ha. The water footprint of rice is about 3943 m^3/ha. Then maize has a water footprint of about 2353 m^3/ha. Similarly, wheat has a water footprint of about 2236 m^3/ha. The water footprint of pluses is about 906 m^3/ha. Potato has a water footprint of about 1133 m^3/ha. Mustard has the lowest water footprint, which is found be to lower than 700 m^3/ha.

Sugarcane has the highest amount of water footprint in Madaripur, which is about 6450 m^3/ha. After that, jute has a water footprint of a little less than 5000 m^3/ha. The water footprint of rice is around 3970 m^3/ha. This is followed by maize, which has a water footprint of a little less than 2400 m^3/ha. Wheat has a water footprint of about 2256 m^3/ha. The water footprint of pluses is about 1263 m^3/ha. Potato has a water footprint of about 1145 m^3/ha. Mustard has the lowest amount of water footprint, which is found be little higher than 800 m^3/ha.

Shariatpur exhibits the highest amount of water footprint for sugarcane, which is a little higher than 6700 m^3/ha. Then comes jute, which has a water footprint of around 5120 m^3/ha. The water footprint of rice is about 4150 m^3/ha. Maize has a water footprint of a little less than 2500 m^3/ha. Wheat has a water footprint of about 2350 m^3/ha. The water footprint of pluses is about 1300 m^3/ha. Potato has a water footprint of a little less than 1200 m^3/ha. Mustard also has the lowest amount of water footprint in Shariatpur, which is about 1050 m^3/ha. For Rajbari, sugarcane has the highest amount of water footprint, which is a little higher than 6000 m^3/ha. This is followed by jute that has a water footprint of about 5160 m^3/ha. The water footprint of rice is a little less than 4200 m^3/ha. This is followed by maize, which has a water footprint of about 2527 m^3/ha. Wheat has a water footprint of about 2381 m^3/ha. The water footprint of potatoes is about 1200 m^3/ha. Mustard has a water footprint of about 1267 m^3/ha. Pluses have the lowest amount of water footprint, which is about 976 m^3/ha.

Fig. 4 shows the comparison of water footprints among the five districts in the study area. As can be seen from the figure, Rajbari has the highest amount of water footprint, which is around 3000 m^3/ha. After that, Shariatpur has a water footprint of 2500 m^3/ha. Madaripur and Gopalganj have water footprints very close to each other. It is a little less than 23300 m^3/ha for Madaripur, and it is about 22500 m^3/ha for Gopalganj. For Faridpur, the number is about 1700 m^3/ha. It is found from the comparison of water footprints among five districts in the study area that Rajbari has the highest amount of water footprint, whereas Faridpur has the lowest amount of water footprint.

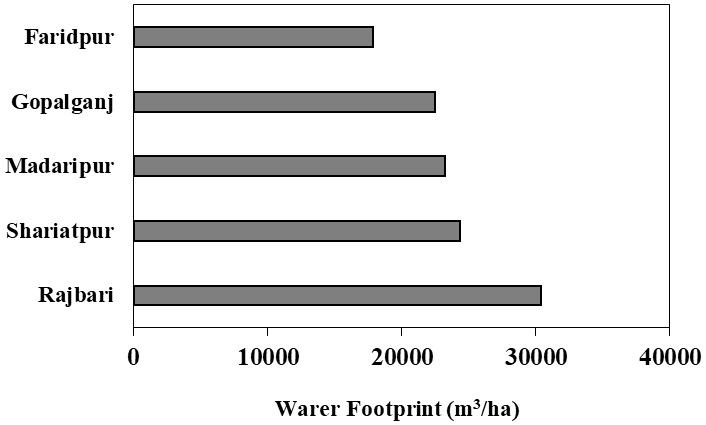

Figure 4: Comparative assessment of the estimated water footprints of five districts in the study area

4 Conclusions

Based on the results of the current study, the following conclusions can be drawn:

- Sugarcane has the highest amount of blue water footprint in all five districts. In Faridpur, Shariatpur, and Rajbari, pulses have the lowest amount of blue water footprint, and mustard has the lowest amount in the other two districts.
- Jute is the highest green water consumer in Gopalganj and Rajbari. In the other three districts, sugarcane has the highest green water footprint. As for the lowest amount in Faridpur and Rajbari, pulses exhibit the lowest amount of green water footprint, and mustard has the lowest water footprint in the remaining districts.

- Maize has the highest amount of gray water footprint, whereas jute has the lowest amount of gray water footprint.
- Sugarcane has the highest amount of total water footprint for all five districts. In Faridpur and Rajbari, pulses have the lowest amount of total water footprint, whereas mustard exhibits the lowest total water footprint for the remaining three districts in the study area.
- Considering the estimated green, blue, and gray water footprints for different crops in the study area, the study concludes that Rajbari district has the highest amount of water footprint, while Faridpur district has the lowest water footprint.

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