SPATIAL ASSESSMENT OF AGRICULTURAL WATER FOOTPRINT IN DHAKA DIVISION OF BANGLADESH

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ABSTRACT

Agriculture is the main source of ensuring food security, industrial growth, and sustainable development in Bangladesh. This is also regarded as the major water-consuming sector in the country. According to the government's policy on achieving flood self-sufficiency following rising demand from increasing populations, the production of crops is also increasing. This growing number of crops will also increase the amount of water needed. The water footprint is a calculator for direct and indirect uses of water. It indicates the total amount of water needed to produce a product or for a consumer. The water footprint of a product comes from three different sectors. The green water footprint is the amount of precipitated water used for production. The blue water footprint is the amount of ground or surface water, and the gray water footprint is the amount of polluted water. Dhaka division is one of the important divisions of Bangladesh, where the country's capital is situated. The demand for water in Dhaka is increasing due to growing populations. Thus, the objective of the current study is to assess the amount of water used for agricultural purposes in the Dhaka division of Bangladesh. Several crops, including rice, wheat, maize, potatoes, sugarcane, pulses, jute, and mustard, were considered in the current study because they are the major crops cultivated in this area. All three different types of water footprints were calculated individually for each district of the Dhaka division for a period of one year from January 2022 to December 2022. Then they were put together to estimate the total water footprint of an area. The CropWat models were created in the FAO CropWat software platform for green and blue water footprints, taking into account local climate and soil types. Furthermore, only nitrogen fertilizers were considered for the gray water footprint because they are the major pollutants. The spatial variation maps of green, blue, and gray water footprints were developed using the ArcGIS software. The results show that the water footprint of different districts in the Dhaka division varies spatially, and Rajbari has the highest total water footprint among all the districts. As for the crops, sugarcane is the highest water consumer because it uses a large portion of blue water. The result of this study is expected to be supportive of policymakers and water managers in developing better water-saving policies and thereby minimizing the wastage of water.

Keywords: *Green water footprint, Blue water footprint, Gray water footprint, CropWat, ArcGIS*

1. INTRODUCTION

Agriculture is a vital sector of the economy of Bangladesh, providing food, fiber, and other important commodities. It contributed to the 14.2% GDP of Bangladesh in 2017 and employs 42.7 percent of the workforce (CIA, 2022). The production of crops is increasing due to the increasing population and modern technology. Food grain production went from 8 million tons to 13 million tons between 1950 and 1970 (Saha, 2016). However, agricultural production also has a significant impact on the environment, particularly in terms of water availability. About 70% of global water consumption is used in the agricultural sector (Faurès et al., 2002). The importance of water management to improve agricultural productivity in Pakistan without adverse environmental effects is detailed by Khan et al. (2016). This aspect is particularly true for the Dhaka division of Bangladesh because the water scarcity has been continuously increasing with the growing crop production caused by the exponential growth of the population (Ahmed et al., 2018). Excessive pumping of groundwater in Dhaka has caused the lowering of groundwater levels to more than 200 feet over the last 50 years (Roberts, 2016). The use of different fertilizers and pesticides in agricultural activities also pollutes surface water bodies. Furthermore, the seepage from agricultural fields increases the pH, biological oxygen demand, chemical oxygen demand, total dissolved solids, etc., which results in increasing threats to the sustainable management of water resources.

Estimating the water footprint of crops is a vital step to knowing the water use efficiency of different crops, which helps to develop options to reduce the water footprint of agricultural products. The vulnerability of different agricultural practices to water scarcity was revealed by a study of the water footprint of crops in water-stressed areas (Chico et al., 2010). The water footprint of an agricultural crop refers to the total volume of water consumed in its production, including rainwater, irrigation water, and polluted water (Hoekstra et al., 2017). With the initial concept of agricultural water footprints given by Hoekstra et al. (2011), Mekonnen and Hoekstra (2011) extended the concept to analyze the water footprints of various crops and livestock products on a global scale. Hoekstra and Hung (2005) emphasized the global interconnection of water use patterns in their study of virtual water trade. The water footprint is usually categorized into three components: blue water, green water, and gray water footprints (Chapagain and Hoekstra, 2008). The green water footprint is the estimation of the consumption of rainwater by plants, whereas the blue water footprint is the amount of groundwater and surface water withdrawal. Furthermore, the gray water footprint is the amount of water needed to dissolve the pollutants existing in the water. Thus, the total water footprint of a specific area can be estimated by making a sum of all three aforementioned types of water footprints (Hoekstra et al., 2011). The goal of the current study is to estimate the water footprint of major crops in the Dhaka division of Bangladesh. It is expected that the outcome of the study will be supportive of minimizing excessive usage of water for agricultural activities.

2. METHODOLOGY

2.1 Study Area and Data Used

The Dhaka division of Bangladesh is taken as the study area in the current study, which is shown in Figure 1. The division consists of thirteen districts, which consist of Dhaka, Narayanganj, Faridpur, Gazipur, Gopalganj, Kishoreganj, Madaripur, Manikganj, Narsingdi, Rajbari, Shariatpur, and Tangail. Dhaka is the most populated division of Bangladesh, with 44 million people. This division is surrounded by four major rivers, which are the Buriganga, the Dhaleshwari, the Shitalakshya, and the Turag. Rice, wheat, maize, potatoes, sugarcane, pulses, jute, and mustard are considered the main agricultural products because they grow in large amounts in the Dhaka Division.

The water footprint is calculated separately for each district based on their specific conditions. Thus, all the data are collected individually for each specific area for a period of one year from January 2022 to December 2022. Minimum and maximum temperature, rainfall, relative humidity, wind speed, and sunshine hours for each region were collected from the Bangladesh Meteorological Department (BMD).

Crop parameters of all major crops in Bangladesh used for the CLIMWAT models were collected from Chapagain and Hoekstra (2004), which are presented in Table 1.

Table 1: Crop parameters of main crops in Bangladesh

Crop Name	K_c (Initial)	K_c (Mid)	K_c (End)	Initial Stage (Days)	Dev. Stage (Days)	Mid Stage (Days)	Late Stage (Days)
Rice	1.05	1.20	0.60	30	30	80	40
Wheat	0.30	1.50	0.30	15	25	50	30
Pluses	0.40	1.15	0.35	20	30	40	20
Maize	0.30	1.20	0.50	20	35	40	30
Potato	0.50	1.15	0.75	30	35	50	25
Jute	0.35	1.10	0.25	20	50	60	35
Mustard	0.70	0.90	0.85	10	15	20	10
Sugarcane	0.40	1.25	0.75	30	50	180	60

The soil type for each area was determined from the study of Islam et al. (2017), which was validated by the Soil Resource Development Institute (SRDI) Report. The crop yield for every crop was obtained from the yearbook of agricultural statistics of the Bangladesh Bureau of Statistics (BBS, 2022). For gray water footprint, only nitrate was considered because it is the main pollutant in the water. The amount of ammonia fertilizer used in farmlands is assumed from a study by Ahmmed et al. (2018). In this study, it is assumed that 10% of the used fertilizer is leached from the ground and found as nitrate in water. The maximum allowable limit for nitrate in water was set by the United States Environmental Protection Agency (US-EPA), which is 10 mg/L. The amount of nitrate found in water was estimated to be 5.92 mg/L.

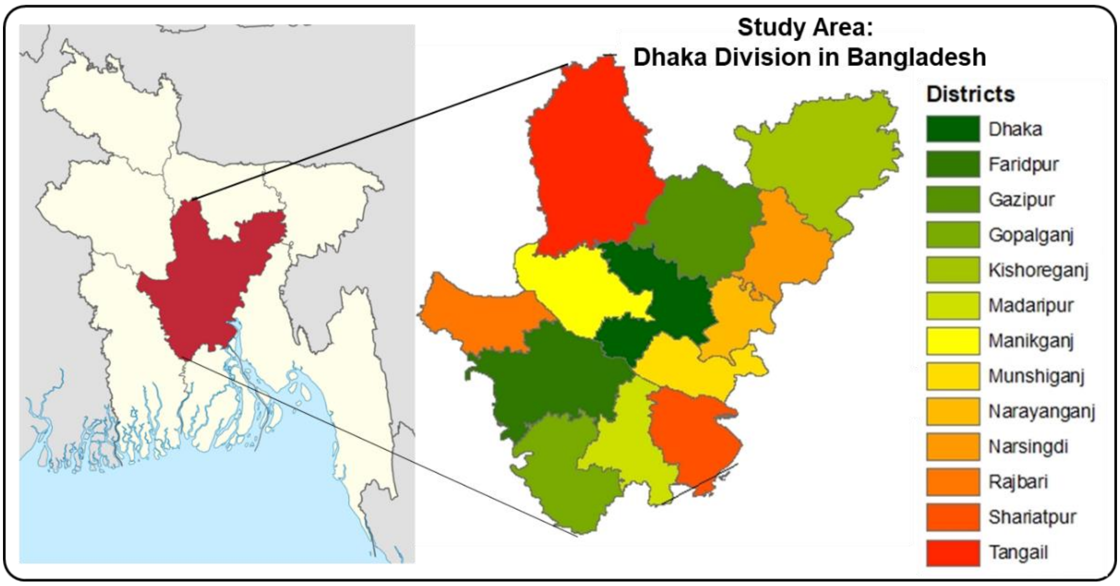


Figure 1: Location of Dhaka Division in Bangladesh

2.2 Assessment of Water Footprint of Crops

In this study, the green, blue, and gray water footprints were calculated using the method detailed in the water footprint assessment manual of Hoekstra et al. (2011). The calculation of green and blue water footprints depends on the amount of evapotranspiration in the area. The amount of evapotranspiration is estimated using the FAO CropWat8.0 model, which uses the Penman-Monteith Equation as expressed by Eq. (1) in the following.

$$ET_o = \frac{0.408\Delta(R_n - G) + (900/T)\gamma u_2 \delta e}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

where, ET_o = evapotranspiration (mm/day), Δ = rate of change of saturation specific humidity with air temperature. (Pa K^{-1}), R_n = net radiation at the crop surface (MJ/m^2/day), G = ground heat flux (MJ/m^2/day), T = mean daily air temperature at 2 m heights (°C). u_2 = wind speed at 2 m height (m/s), δe = vapor pressure deficit (kPa), γ = Psychrometric constant. Crop water requirement is obtained by the CropWat model. Figure 2 represents the major steps of the CropWat model to calculate crop water evapotranspiration.

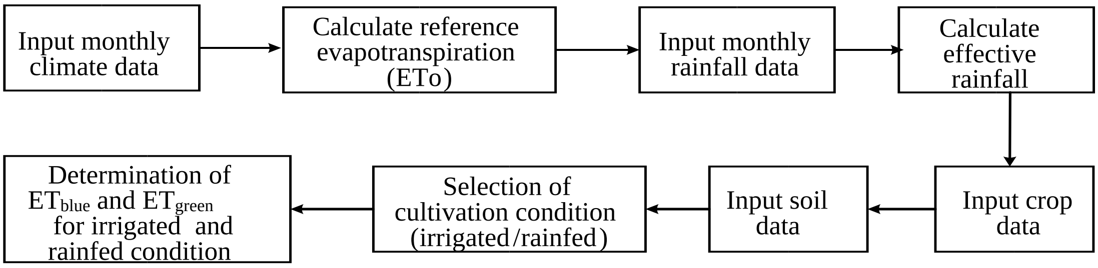


Figure 2: Estimation steps of the FAO CropWat model to calculate crop water requirement

Then the required green water footprint was calculated by dividing the estimated evapotranspiration by the total crop yield of the area using Eq. (2). Rainfall in mm was converted to water volume in m^3/ha by using a factor of 10.

Green water footprint, $WF_{green} = 10 \times ET_0 / Y$ (2)

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 was calculated in the similar way of the green water footprint by using Eq. (3).

Blue water footprint, $WF_{blue} = 10 \times ET_o / Y$ (3)

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 in ton/ha.

The gray water footprint calculation is different from the blue and green water footprint. In order to calculate the 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. The gray water footprint was calculated by using Eq. (4).

Gray water footprint, $WF_{gray} = 10 \times \frac{L}{Cmax - Cnat}$ (4)

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

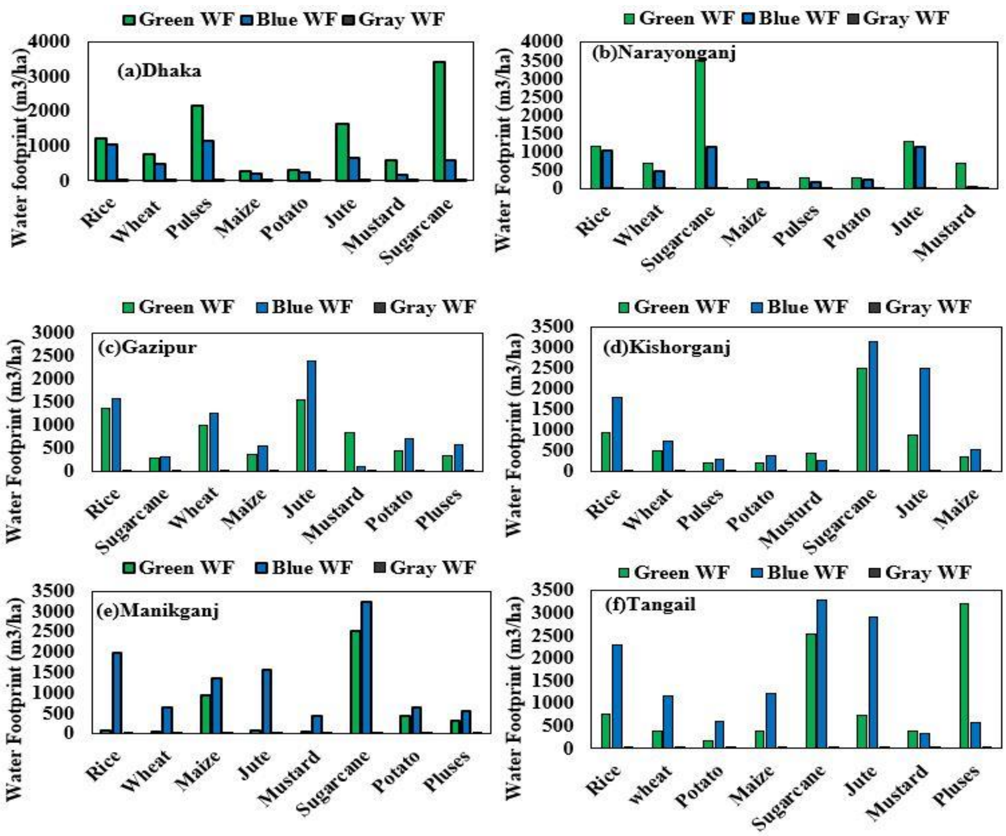
The total water footprint of a crop is the summation of blue, green, and gray water footprints, which is given Eq. (5).

Total water footprint, $WF_{tatal} = WF_{blue} + WF_{green} + WF_{gray}$ (5)

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

Figure 3 represents the blue, green, and gray water footprints of eight districts in the study area. From the figure, it is clear that, in Dhaka, sugarcane consumes the highest amount of green water, which is about 3500 m^3/ha. On the other hand, maize has the lowest green water footprint of less than 300 m^3/ha. As for the blue water footprint, pluses have the highest amount, which is 1150 m^3/ha. Mustard has the lowest amount of blue water footprint, which is 160 m^3/ha. Maize produces the highest amount of gray water footprint, slightly more than 10 m^3/ha, while pluses have the lowest gray water footprint, which is less than 2 m^3/ha. In Narayonganj, sugarcane consumes the highest amount of green water. It is around 3500 m^3/ha. Maize has the lowest amount of green water footprint, which is more than 250 m^3/ha. Sugarcane also has the highest amount of blue water footprint, which is more than 1000 m^3/ha. The lowest amount of blue water-consuming crop is pluses. It has a blue water footprint of less than 200 m^3/ha. Similarly, in this district, maize produces the highest amount of gray water footprint. It is 10.44 m^3/ha. Pluses is the lowest gray water consumer. For Gazipur district, the highest green water consumer is jute, which consumes little more than 1500 m^3/ha. Sugarcane has the lowest amount of green water, which is less than 300 m^3/ha. The highest blue water consumer is also jute, which is more than 2300 m^3/ha, and the lowest amount belongs to mustard. It is less than 100 m^3/ha. Maize produces the highest amount of gray water footprint, which is around 10 m^3/ha. Pluses are the lowest gray water consumer, and it is about 1 m^3/ha.



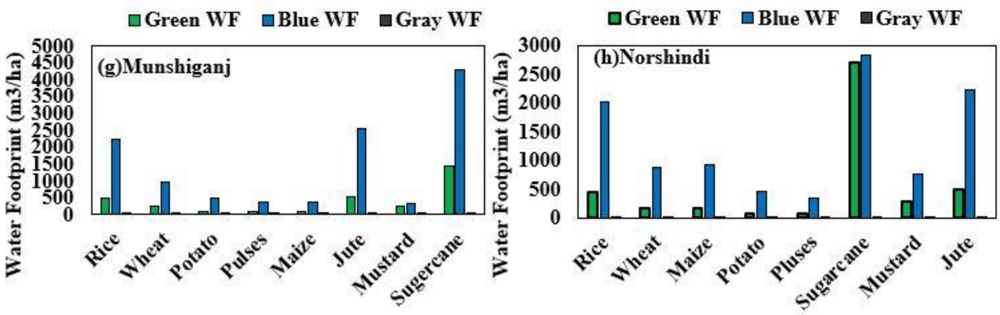


Figure 3: District-wise Green water, blue water, and gray water footprints of different crops

In Kishorganj, sugarcane is the highest green water consumer. It consumes more than 2500 m^3/ha of green water. Pulses have the lowest amount of green water, which is slightly more than 200 m^3/ha. The highest blue water consumer is also sugarcane, which is a little less than 3200 m^3/ha, and the lowest amount belongs to mustard. It is more than 250 m^3/ha. Maize produces the highest amount of gray water footprint. It is 10.44 m^3/ha. Pluses are the lowest gray water consumer, which is about 1.76 m^3/ha. For Manikganj, sugarcane has the highest green water footprint, which is slightly higher than 2500 m^3/ha. Mustard has the lowest amount of green water, which is less than 40 m^3/ha. The highest blue water consumer is also sugarcane, which is more than 3000 m^3/ha, and the lowest amount belongs to mustard. It is slightly less than 450 m^3/ha. Maize produces the highest amount of gray water footprint of about 10 m^3/ha. Pluses are the lowest gray water consumer, which is about 1.50 m^3/ha**.** The highest number of green water consumers is sugarcane in the Tangail district, which is more than 2500 m^3/ha. Potatoes have the lowest amount of green water footprint less than 200 m^3/ha. The highest blue water consumer is also sugarcane, which is slightly more than 3200 m^3/ha, and the lowest amount belongs to mustard. It has a blue water footprint of about 331 m^3/ha. Maize produces the highest amount of gray water footprint, and it is around 10 m^3/ha. Pluses are the lowest gray water consumer, which is about 2 m^3/ha**.** For Munshiganj, the highest green water consumer is sugarcane, which has about 1428 m^3/ha green water footprint. Maize has the lowest amount of green water, which is around 100 m^3/ha. The highest blue water consumer is also sugarcane, which is more than 4000 m^3/ha, and the lowest value belongs to mustard. It is less than 350 m^3/ha. Maize produces the highest amount of gray water footprint, which is around 10 m^3/ha. Pluses is the lowest gray water consumer, which is a little less than 2 m^3/ha**.** Sugarcane is the highest green water consumer in Narshingdi. It has a green water footprint of a little higher than 2700 m^3/ha. Pulse has the lowest amount of green water. It is about 67 m^3/ha. The highest blue water consumer is also sugarcane, which is less than 3000 m^3/ha and the lowest amount belongs to the pluses, which is almost 345 m^3/ha. Maize produces the highest amount of gray water footprint, which is little more than 10 m^3/ha. Pluses are the lowest gray water consumer, which is about 1.50 m^3/ha**.**

Figure 4 represents the green water, blue water, and gray water footprints of different crops for the rest of the five districts in the study area. From the figure, it can be noticed that, in Faridpur, sugarcane has the highest amount of blue water footprint, which is a little less than 6000 m^3/ha. Pluses has the lowest amount of blue water footprint, which is 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 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 more than 2000 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 a little less than 4000 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.

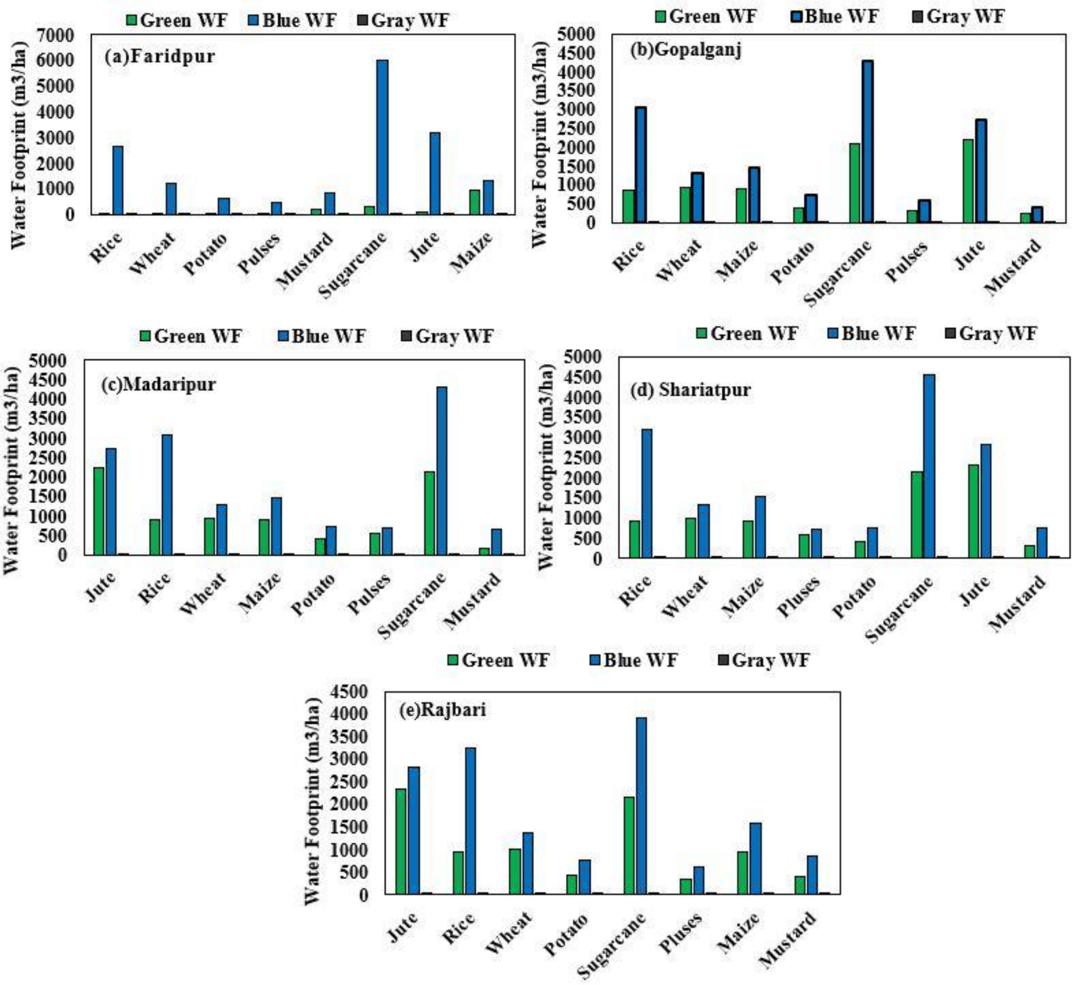


Figure 4: District-wise Green water, blue water, and gray water footprints of different crops

Figure 5 represents the total water footprint of eight districts in the Dhaka divisiono of Bangladesh. In Dhaka district, sugarcane has the highest quantity of total water footprint, which is slightly more than 4000 m^3/ha. Then comes pulse, which has a water footprint of 3296 m^3/ha. Maize has the lowest total water footprint of less than 500 m^3/ha. For Narayanganj, sugarcane has the highest total water footprint and is a little higher than 4500 m^3/ha. In this district. maize has the lowest total water footprint, which is 450 m^3/ha. Jute has the highest total water footprint in Gazipur, which is slightly less than 4000 m^3/ha. Surprisingly, in this district, Sugarcane has the lowest amount of total water footprint. It is almost 606 m^3/ha. In Kishorganj, sugarcane has the highest total water footprint of more than 5500 m^3/ha. Pulses have the lowest total water footprint, which is about 500 m^3/ha. For Manikganj, sugarcane has the highest value of total water footprint of more than 5500 m^3/ha. Mustard has the lowest total water footprint of all, which is less than 500 m^3/ha. Sugarcane has the highest amount of total water footprint in Tangail. It consumes more than 5500 m^3/ha of water. Mustard and potato both have the lowest amount of total water footprint, which is about 722 m^3/ha. In Munshiganj, sugarcane has the highest total water footprint, which is a little less than 6000 m^3/ha. Pluses have the lowest water footprint and it is about 478 m^3/ha. Sugarcane has the highest amount of water footprint in Narshingdi. It is a little less than 6000 m^3/ha. Pluses have the lowest total water footprint, which is slightly more than 500 m^3/ha.

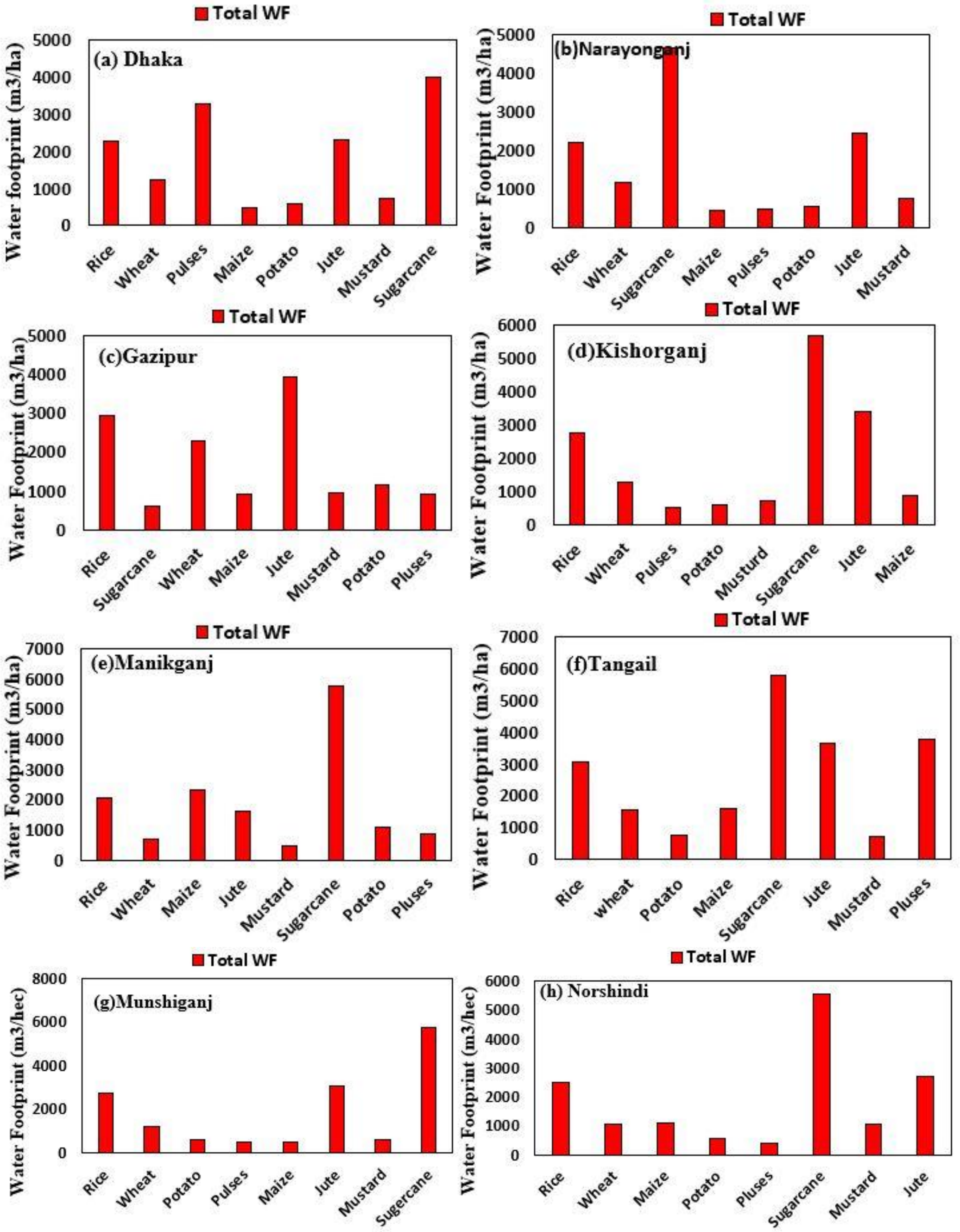


Figure 5: District-wise total water footprints of different crops in the study area

Figure 6 shows the total water footprint of the remaining five different districts. In Faridpur, sugarcane has the highest water footprint, which is a little bigger than 6300 m^3/ha. Pluses have the lowest total water footprint, which is less than 500 m^3/ha. It can also be seen from the figure that sugarcane has the highest magnitude of water footprint for Gopalganj, which is almost 6400 m^3/ha. Mustard has the lowest water footprint, which is found be to less than 700 m^3/ha. Sugarcane has the highest value of water footprint in Madaripur, which is slightly less than 6500 m^3/ha. Mustard has the lowest water footprint, which is found to be almost 800 m^3/ha. Shariatpur exhibits the highest amount of water footprint for sugarcane, which is about 6700 m^3/ha. Mustard also has the lowest amount of water footprint, 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. Pluses have the lowest water footprint, which is about 976 m^3/ha.

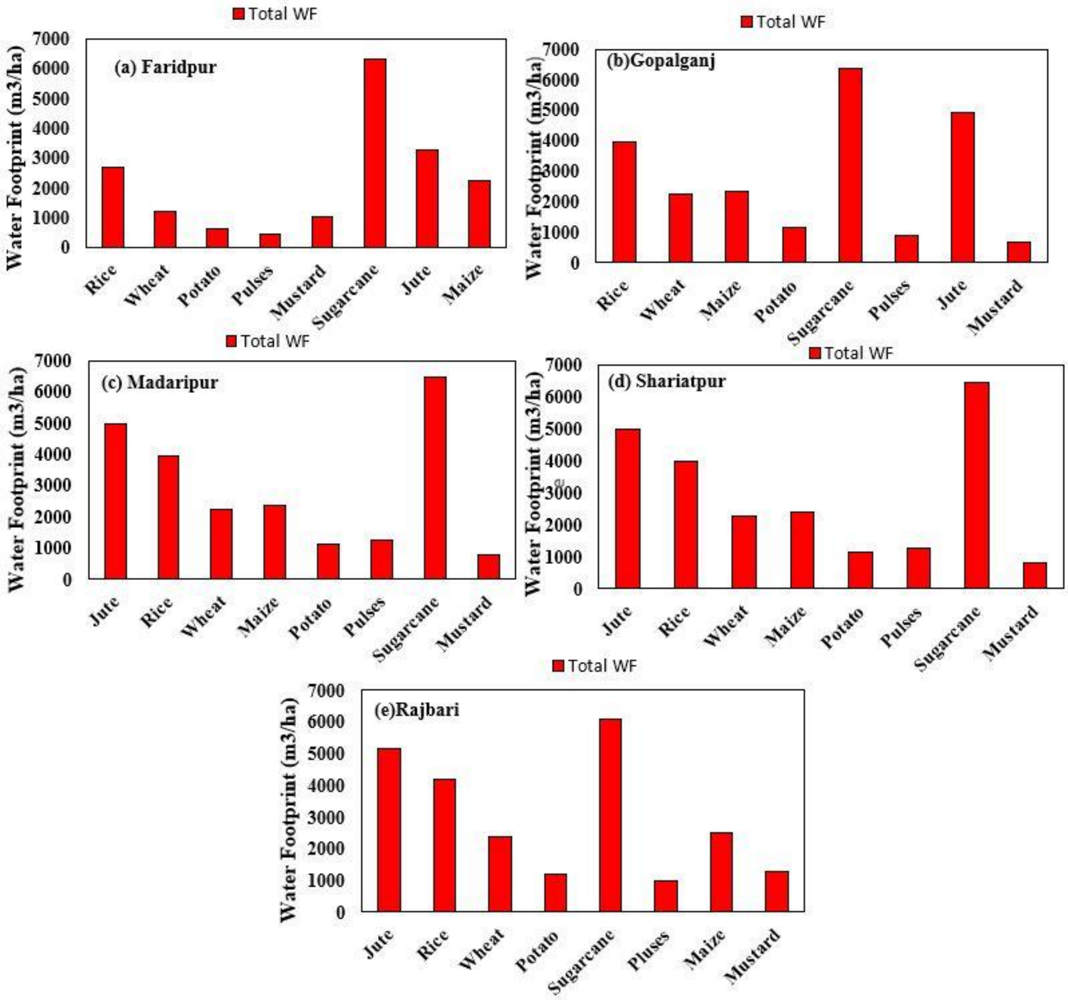


Figure 6: District-wise total water footprints of different crops in the study area

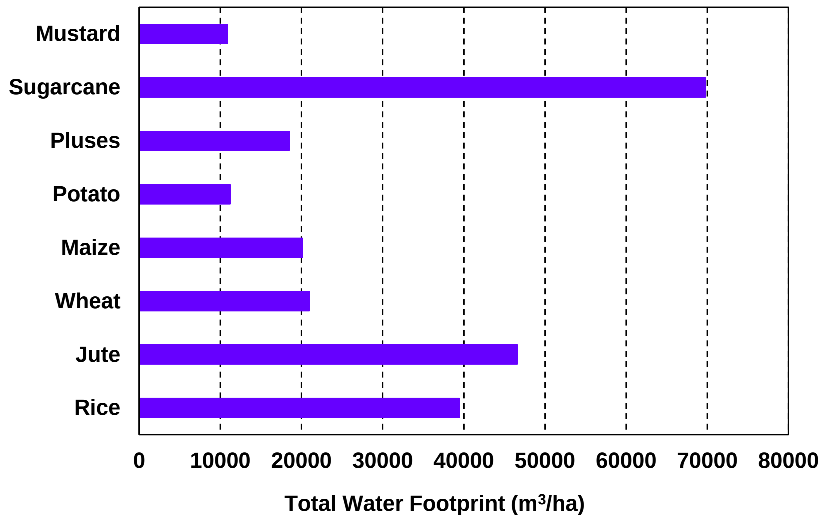


Figure 7: Total water footprints of different crops in the Dhaka division of Bangladesh

Figure 7 describes the total water footprint of different crops in the Dhaka division. The highest total water footprint of the Dhaka division belongs to sugarcane, which is about 69770 m^3/ha. Then comes jute. It has a water footprint of more than 46500 m^3/ha. Rice has a water footprint that is slightly less than 40000 m^3/ha. The water footprint of wheat is almost 21000 m^3/ha. Maize has a similar footprint as wheat. Further potato has a water footprint of a little more than 11000 m^3/ha. Pluses has a water footprint of about 19000 m^3/ha. Mustard has the lowest water footprint. It is a little more than 10500 m^3/ha. Hence, sugarcane, jute, and rice have large water footprint values among all the crops cultivated in the study area. On the other hand, potatoes, mustard, and maize have small water footprints.

Figure 8 shows the variations in green water consumption between different districts of the Dhaka division. Dhaka district has the largest amount of green water footprint, with a little less than 10400 m^3/ha, followed by Tangail, which has a green water footprint of slightly more than 8500 m^3/ha, and Shariatpur, which has about 8600 m^3/ha of green water. Narayanganj has a water footprint of more than 8100 m^3/ha. Madaripur has a slightly larger water footprint than Narayanganj, which is 8200 m^3/ha. Gopalganj has a water footprint of more than 7800 m^3/ha. Kishoreganj and Gazipur have an almost similar green water footprint of more than 6000 m^3/ha. Manikganj and Narsingdi have a green water footprint of almost 4400 m^3/ha. Munshiganj has a green water footprint of more than 3200 m^3/ha. Faridpur has the lowest amount of green water. It consumes almost 1600 m^3/ha of them.

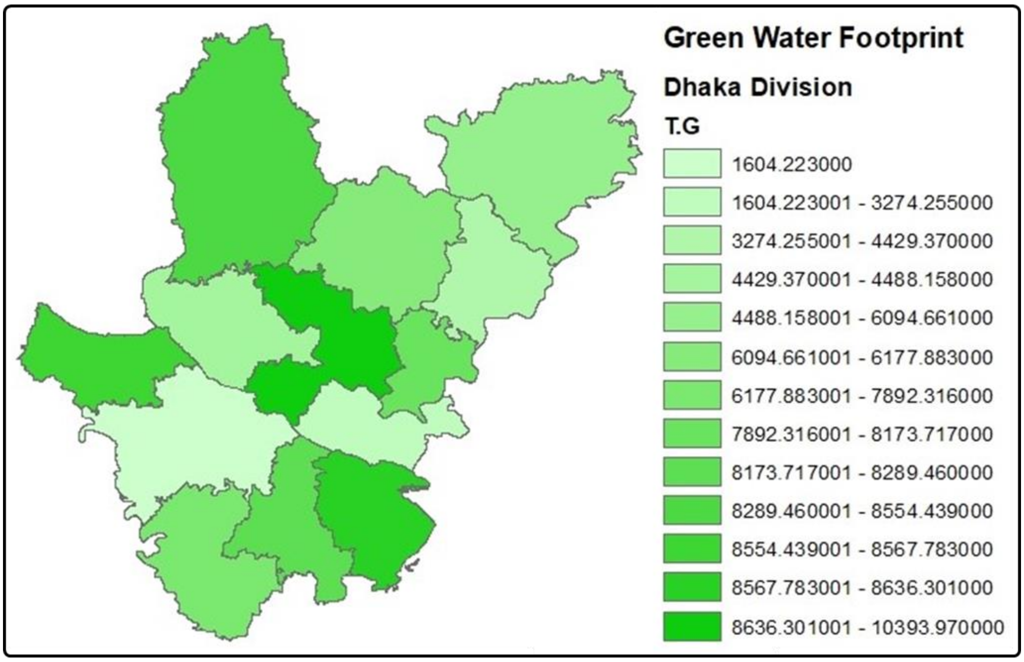


Figure 8: Green water footprint of Dhaka division in Bangladesh

Figure 9 describes the variations in blue water footprints among different districts of the Dhaka division. Faridpur is the largest consumer of blue water, with a blue water footprint of more than16000 m^3/ha. Shariatpur and Rajbari both have a blue water footprint of more than 15000 m^3/ha. Madaripur and Gopalganj both have a water footprint that is very close to each other. Tangail has a blue water footprint of more than 1200 m^3/ha. Manikganj and Norsingdi have a water footprint of 1000 m^3/ha. The blue water footprint of Kishorganj is slightly less than these two. Gazipur has a water footprint of little more than 5900 m^3/ha, and Dhaka has a water footprint of more than 4500 m^3/ha. Narayonganj is the lowest consumer of blue water footprint, with a water footprint of about 4470 m^3/ha of blue water.

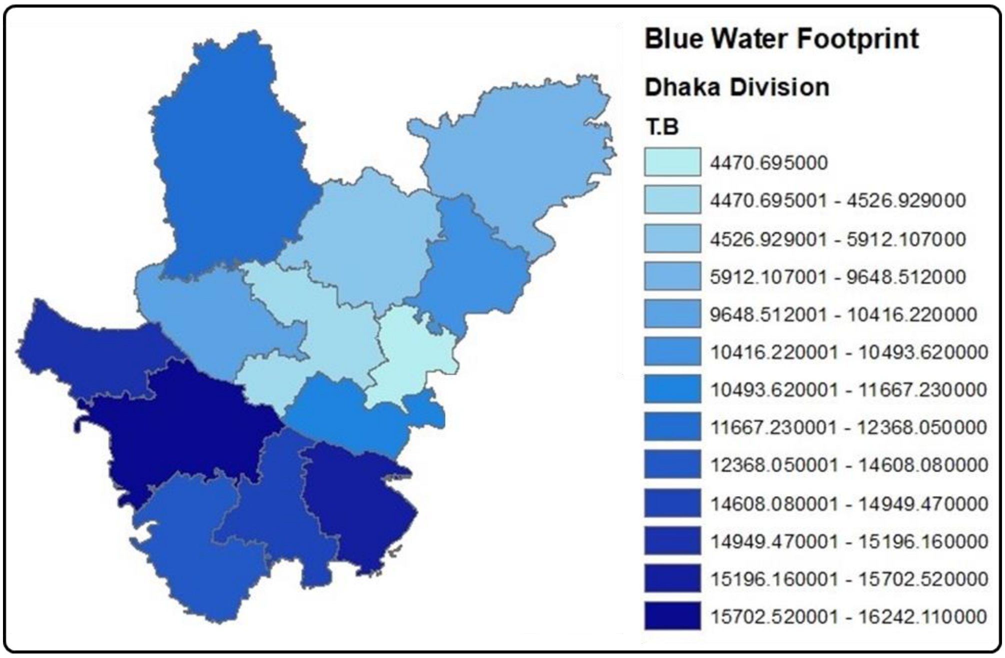


Figure 9: Blue water footprint of Dhaka division in Bangladesh

Figure 10 implies the intensity of water consumption in different areas of Dhaka district. Rajbari is the highest water consumer district of the Dhaka division with a total water footprint of 30000 m^3/ha. Madaripur and Shariatpur have very similar total water footprints. Then comes Gopalganj, which has a total water footprint smaller than the above two districts. Tangail has a total water footprint of 20000 m^3/ha. Faridpur and Kishorganj have a total water footprint of almost 17000 m^3/ha and 15000 m^3/ha, respectively. Manikganj and Munshiganj have similar total water footprints. Dhaka has a total water footprint that is slightly less than 15000 m^3/ha. Gazipur has a total water footprint which is slightly less than Dhaka. Narayanganj is the least total water consumer district. The total water footprint of Narayanganj is 12674 m^3/ha.

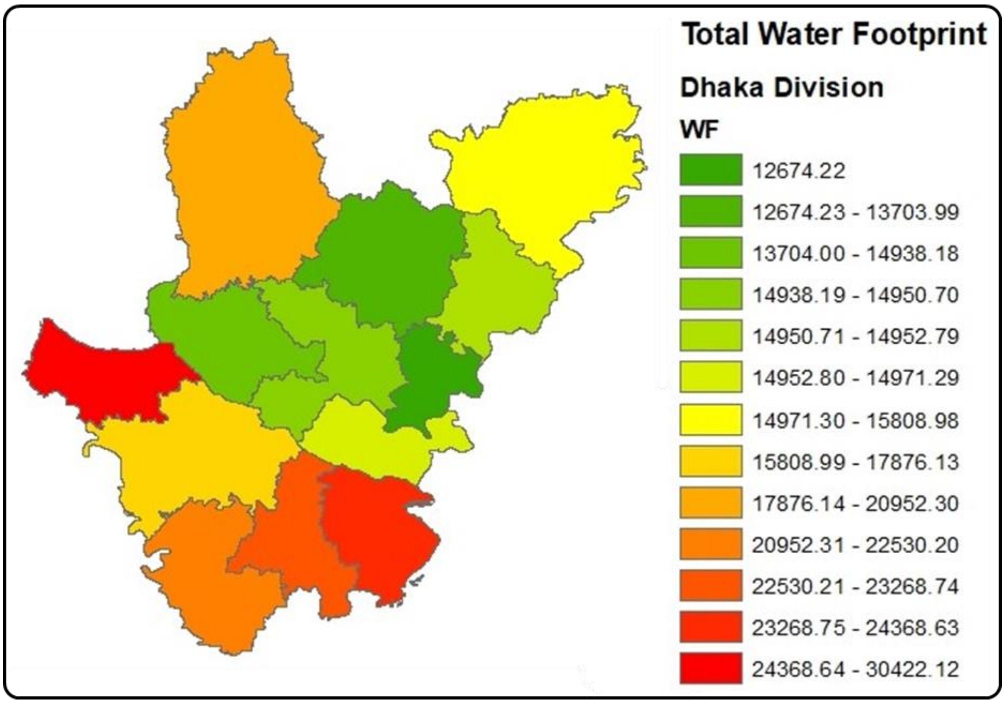


Figure 10: Total water footprint of Dhaka division in Bangladesh

4. CONCLUSIONS

Based on the findings obtained in the current study, the following conclusions can be drawn:

- Sugarcane, jute, and rice are relatively higher water consumers in the Dhaka division of Bangladesh when compared to other crops. However, the highest water footprint consumer crop is sugarcane, which consumes about 69770 m^3/ha.
- Dhaka has the highest consumption of green water, whereas Faridpur is the highest consumer of blue water. This demonstrates the underlying cause of groundwater scarcity in the study area.
- The gray water footprint is found to be very small compared to the green and blue water footprints because the most commonly used nitrogen-based fertilizer (urea) in the study area is considered for the gray water footprint. Other pollutants, such as phosphorus, potassium, and pesticides, were not considered. This might introduce some sort of uncertainty in the gray water footprint assessment.
- The highest total water footprint of crops was found in Rajbari and Shariatpur districts. This demonstrates that these two districts are at risk of excessive water withdrawals for agricultural activities and crop production.

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