Water Footprint Assessment of Major Agricultural Products – A Case Study for Dhaka District in Bangladesh

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Abstract: Freshwater scarcity has become a serious concern for Bangladesh although the country is called the land of rivers. Water footprint shows how and where freshwater is used and/or consumed. About 92% of the global water footprint is contributed by agricultural products. Dhaka is one of the most densely populated areas of the world. The aim of the current study is the assessment of the water footprint for the major agricultural products in the Dhaka district in Bangladesh. In the current study, water footprints of the green water, blue water, and grey of different crops produced in the Dhaka district have been calculated. Since crop water uses highly depends on the climatic condition and soil type, they are considered using local data and CLIMWAT database. The CROPWAT model is used to calculate the evapotranspiration of the crops. The grey water footprint is calculated by estimating the main pollutant nitrogen-based fertilizer. The result indicates that the highest water footprint is contributed by green water, which is about 65.28% of the total water footprint. The blue water and grey water footprints are found to be about 34.45% and 0.25%, respectively. A large amount of water footprint is found for rice, jute, and pulse. Among all the crops, rice and pulse exhibit the highest blue water footprint. Blue water footprint indicates the amount of surface water and groundwater used for irrigation activities. With the increasing population, the amount of blue water used for irrigation has been increasing day by day. As the groundwater table is lowered, the current study suggests a more efficient use of green water in crop production. It is expected that the results of this study will be supportive of the effective management of water resources and agricultural practices in Bangladesh.

1. Introduction

Water is necessary for all aspects of life. But the freshwater resource covers only 2.5 percent of the global water stock. Most of the freshwater is used for irrigation activities and agricultural production. About 85% of the global blue water consumption is used in the agricultural sector (Shiklomanov, 2000). The world population is continuously increasing and it is expected to

reach approximately 8 billion at the end of 2022. Following this trend, the world population will reach about 9.7 billion in 2050. Accordingly, the demand for crops is increasing all over the world with the increasing population. In the last three decades, crop yield has increased by about 42%. It is estimated that the production of crops has to increase by 50% by 2050 to feed the additional population worldwide. Growing additional crops for the additional population requires more water. As a result, freshwater withdrawal has increased by seven folds over the past century (Gleick, 2000).

The water footprint is the indicator of the direct or indirect use of water of a consumer or products (Hoekstra et al., 2011). It can be divided into three categories such as green water footprint, blue water footprint, and grey water footprint. Green water footprint indicates the amount of precipitated water used by the plant. Blue water footprint is the water that comes from groundwater or surface resources. Grey water footprint is the amount of water required to digest pollutants. Hence, the water footprint of a crop indicates the total water used by the corresponding plant (Hoekstra et al., 2011).

Although three-quarters of the earth's surface is covered with water, the scarcity of usable freshwater has been continuously increasing. Changing climatic conditions are exacerbating the situation. As a result, nearly 4.0 billion people in the world have been facing severe water scarcity (Mekonnen and Hoekstra, 2016). Bangladesh is called a land of rivers, which is rich in water resources. However, uncontrolled pollution and natural arsenic contamination limit the amount of available freshwater resources. Hence, the effective utilization of water should be ensured for the sustainable development of the country. The current study is an attempt to estimate the virtual water footprint for different crops in the Dhaka district of Bangladesh.

2. Study Area and Data Used

Dhaka district is selected as the study area in this study based on the data availability, which is in central Bangladesh. The location of the study area is shown in Figure 1. The latitude and longitude of Dhaka district are 23.81°N and 90.33°E respectively. It covers an area of about 1464 sq. km. Dhaka is the densest district of Bangladesh with a population of about 8 million. The main water bodies around the study area include Buriganga, Kaliganga, Dhaleswari, Shitalaksha, and Ichamati.

The agricultural activities of the study area mainly depend on rainfall. Accordingly, the rainfall and climatic data are collected from Bangladesh Meteorological Department (BMD) and the CLIMWAT databases. It
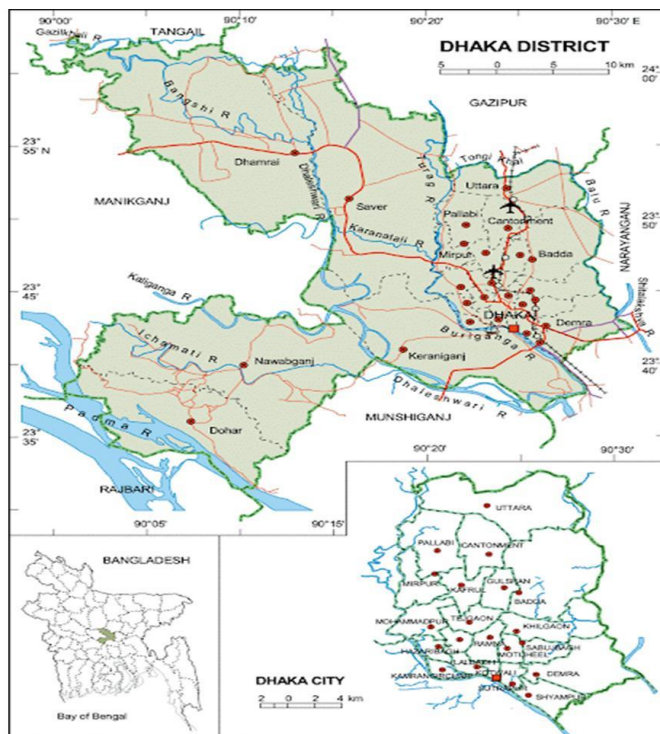

Figure 1: Location of the study area (Dhaka, Bangladesh)

combines with satellite data of at least 20 years. The values of crop coefficient and stages are collected from Chapagain and Hoekstra (2004). Other calculation parameters are collected from the food and agricultural organization of the United Nations (FAO) manual. In this study, only nitrogen fertilizer leaching is considered to calculate the grey water footprint. This is justified because the contribution of other fertilizers is very little. Data about areas of cultivatable land and crop yield are taken from the yearbook of agricultural statics of the Bangladesh Bureau of Statistics (BBS, 2022). For the grey water footprint, the maximum allowable limit for nitrate is collected from the United States Environmental Protection Agency (US-EPA). The amount of nitrate found in water is estimated to be 5.92 mg/L.

3. Methodology

The current study estimates the green, blue, and grey water footprint of Dhaka districts' agricultural products. Only major crops are considered, which include rice, wheat, pulse, maize, potato, cabbage, tomato, jute, mustard, groundnuts, and vegetables. The crop water requirement is estimated using the crop water models developed in the FAO CROPWATv8.0 software platform. The model considers local climatic conditions, soil conditions, crop yields and the rate of nitrogen products use in estimating crop water requirement. Evapotranspiration indicates the water uses of the plant, which depends on the climatic conditions of a certain area. The evapotranspiration of the crops is also calculated using the CROPWAT software.

The water footprint is calculated using the empirical formulation outlined in the water footprint assessment manual of Hoekstra et al. (2011). Green water footprint is the evapotranspiration of rainwater. The required rainfall is estimated from crop water models. It is calculated by dividing the estimated evapotranspiration by the total crop yield of the area using Equation (1).

$$WF_{green} = 10 \times ET_0/Y \qquad (1)$$

Where WF_{green} is the green water footprint in m^3/hec. ET_0 is the estimated green water requirement of crops in mm. Y is the total yield of the area, which is the crop production per unit area of land (ton/hec).

Blue water footprint is the consumption of irrigated water. Irrigated water is the difference between the total water required for the full growth of the crop and the water consumed from rainfall. The Blue water footprint is calculated using the same procedure as the green water footprint using Equation (2).

$$WF_{blue} = 10 \times ET_0/Y \qquad (2)$$

Where WF_{blue} is the blue water footprint in m^3/hec. ET_0 is the estimated blue water requirement of crops in mm. Y is the total yield of the area, which is the crop production per unit area of land (ton/hec).

In Bangladesh, the most used fertilizer is Urea in which nitrogen is the major component. Therefore, the amount of nitrate is considered for calculating the grey water footprint in this study. It is assumed that 10% of the used fertilizer will be leached and mixed with irrigated water. The grey water footprint is computed by using Equation (3)

$$WF_{grey} = L/C_{max} - C_{nat} \qquad (3)$$

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

Total water footprint of a crop is the total water consumed by the crop. Thus, the total water footprint is the summation of the green water footprint, blue water footprint, and grey water footprint, which can be expressed by Equation (4)

$$\text{Total water footprint} = \text{WF}_{green} + \text{WF}_{blue} + \text{WF}_{grey} \qquad (4)$$

Where WF_{green} is the green water footprint, WF_{blue} is the blue water footprint and WF_{grey} is the grey water footprint. Total water footprint generally varies with the types of crops and soil conditions. The soil type of the study area (Dhaka district of Bangladesh) is considered loamy in the current study.

4. Results and Discussion

The water footprint estimated for different crops in the Dhaka district of Bangladesh is shown in Figure 2. As can be seen from the figure, Pulse has the largest green and blue water footprints. It is found that the green water footprint of the pulse is 2144 m^3/hec whereas the blue water footprint of the pulse is 1150.09m^3/hec. After the pulse, jute and groundnut have larger amounts of green water footprint, which are 1650.5 m^3/hec and 1575.94m^3/hec, respectively. Rice and jute have a high amount of blue water footprint with 1045.13m^3/hec and 653m^3/hec, respectively. Among all crops, beans have the lowest blue water footprint of 110.76m^3/hec. The other two low blue footprint crops are tomato and cabbages, which have a blue water footprint of 148.98m^3/hec and 155.57m^3/hec, respectively. The green water footprint of rice, wheat, maize, beans, potato, tomato, and mustard are 1231.7m^3/hec, 747.52m^3/hec, 286.92m^3/hec, 316.25m^3/hec, 324.01m^3/hec, 165.23m^3/hec and 587m^3/hec, respectively. On the other hand, the blue water footprint of wheat, pulse, maize, potato, mustard, and groundnut are 499.56m^3/hec, 1150.09m^3/hec, 191.56m^3/hec, 246.09m^3/hec, 160.29m^3/hec and 486.82m^3/hec, respectively.
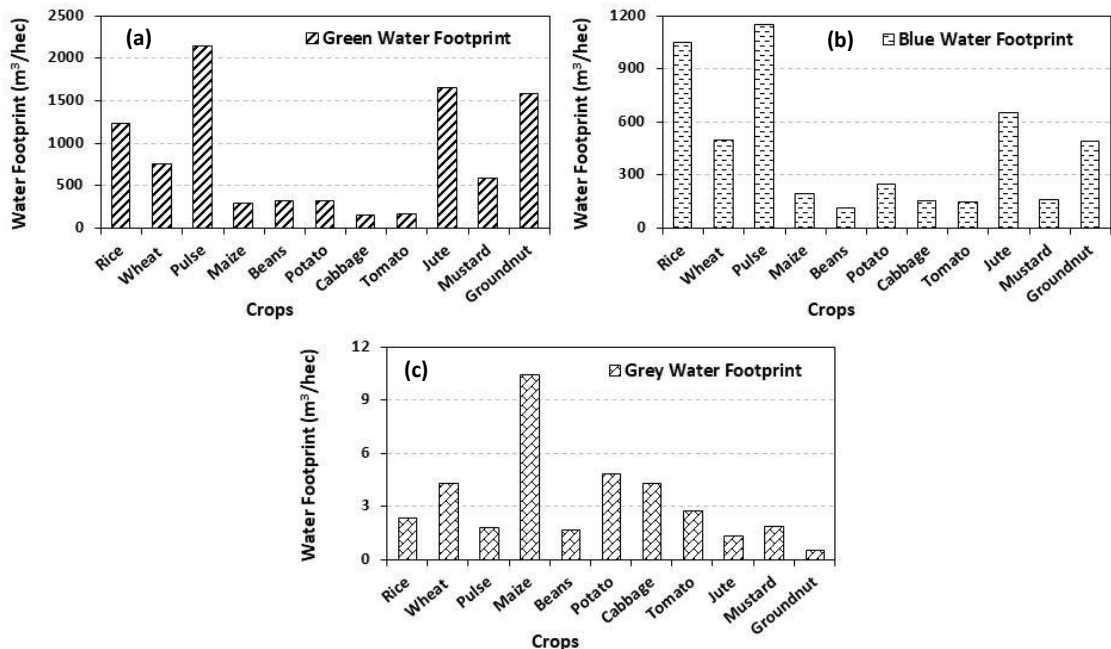

Figure 2: Estimated (a) Green water footprint (b) Blue water footprint and (c) Grey water footprint of different crops of Dhaka district in Bangladesh

It is also seen from Figure 2 that the grey water footprint for maize has 10.44m^3/hec, which is the highest of all. Groundnut has the lowest amount of grey water footprint, which is 0.54m^3/hec. Likewise, the grey water footprint of rice, wheat, beans, potato, cabbage, tomato, jute, and mustard are 2.4m^3/hec, 4.31m^3/hec, 1.76m^3/hec, 1.65m^3/hec, 4.58m^3/hec, 4.31m^3/hec, 3.25m^3/hec, 1.29m^3/hec, and 1.84m^3/hec, respectively. All the crops have a larger amount of green water footprint followed by blue and grey water footprints.

Figure 3 presents the percentage contribution of different crops in the study area's green, blue and grey water footprints. Pulse contributes the highest in green water footprint assessment, which amounts to 23.35%. The second highest contribution is 17.97%, which is obtained from jute. The contribution of rice, wheat, maize, beans, potato, cabbage, tomato, mustard, and groundnut is found to be 13.41%, 8.14%, 3.12%, 3.44%, 3.53%, 1.69%, 1.80%, 6.39%, and 17.16%, respectively. The lowest contribution in green water footprint is for cabbage, which indicates that cabbages require a relatively small amount of precipitated water. Based on the green water footprint assessment results, it can be also said that potato requires a very small amount of precipitated water compared to pulse and jute.
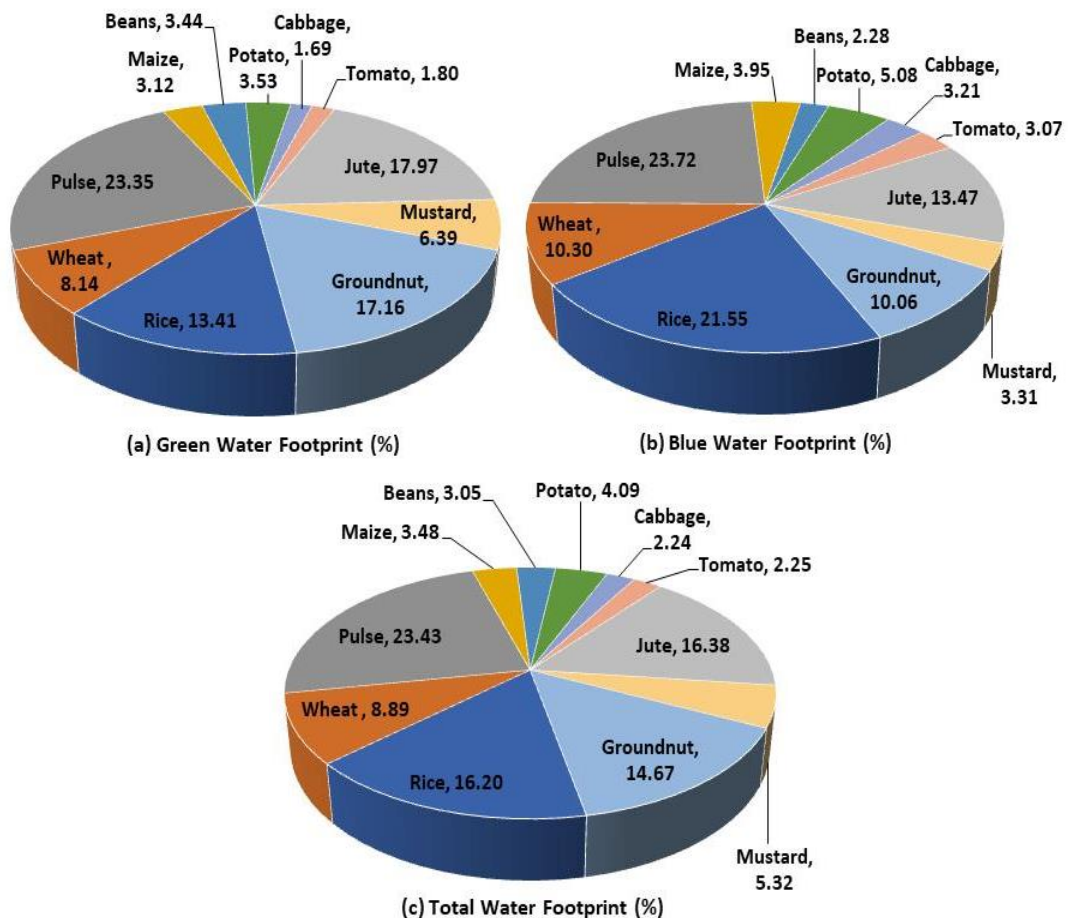

Figure 3: Percentage distribution of (a) Green water footprint (b) Blue water footprint and (c) Total water footprint for different crops of Dhaka district in Bangladesh

It can be also seen from Figure 3 that pulse contributes the most to blue water footprint which is equal to 23.72%. This is followed by rice which contributes 21.55%. Accordingly, wheat,

maize, beans, potato, cabbage, tomato, jute, mustard, and groundnut contribute 10.30%, 3.95%, 2.28%, 5.08%, 3.21%, 3.07%, 13.47%, 3.31%, and 10.06%, respectively. It is seen that beans contribute to the lowest in the assessment of blue water footprint. Therefore, it can be concluded that beans require less amount of irrigated water whereas pulse and rice require a higher amount of irrigated water. Figure 3 also shows the percentage of the total water footprint of different crops in the Dhaka district of Bangladesh. It shows that pulse has the highest total water footprint of all the crops. It contributes about 23.43% of the total water footprint. This is followed by rice and jute, which are contributing 16.20% and 16.38%, respectively. The contribution of wheat, maize, beans, potato, cabbage, tomato, mustard, and groundnut to the total water footprint of the crops in the study area is 8.89%, 3.48%, 3.05%, 4.09%, 2.24%, 2.25%, 5.32%, and 14.67%, respectively. Cabbage and tomato have the lowest contribution to the total water footprint assessment.

5. Conclusions

Based on the results obtained in the current study, the following conclusions can be drawn.

- The highest water footprint is contributed by green water, which is about 65.28% of the total water footprint of crops in the Dhaka district of Bangladesh.
- The blue water and grey water footprints are found to be about 34.45% and 0.25%, respectively of the total water footprint of crops in the study area. Rice and pulse exhibit the highest blue water footprint among all the crops in the study area.
- The water footprint obtained for rice, jute, and pulse has been found as the highest for green, blue and grey water footprints.
- The grey water footprint is found to be very small compared to the green and blue water footprint because the most commonly used nitrogen-based fertilizer (urea) in the study area is considered for grey water footprint assessment. Other pollutants like phosphorus, potassium, and pesticides are not considered, which might introduce some uncertainties in the grey water footprint assessment.

References

BBS, Yearbook of Agricultural Statistics 2021, 33rd Series, Bangladesh Bureau of Statistics (BBS). May 2022, pp. 41-47.

Chapagain, A.K., Hoekstra, A.Y., Water Footprint of Nations, Volume 2: Appendices, Value of Water Research Report Series No.16, UNESCO-IHE, Delft, The Netherlands. 2004, 34-37.

Gleick, P.H., The Changing Water Pattern Paradigm: A Look at Twenty-first Century Water Resources Development, Water International. 2000, 25(1); 127-138. https://doi.org/10.1080/02508060008686804.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan, London, United Kingdom. 2011, pp. 40-43

Mekonnen, M.M., Hoekstra, A.Y., Four Billion People Facing Sever Water Scarcity, Science Advances. 2016, 2(2): e1500323; https://doi.org/10.1126/sciadv.1500323.

Shiklomanov, I.A., Appraisal and Assessment of World Water Resources, Water International. 2000, 25(1); 11-32. https://doi.org/10.1080/02508060008686794.