SPATIAL EXPLICIT ASSESSMENT OF WATER FOOTPRINT FOR RICE PRODUCTION IN BANGLADESH

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ABSTRACT
This study is a quantitative assessment of the green, blue and grey water footprint of rice in Bangladesh. It concentrates on three fiscal years ranging from 2011 to 2014 and covers all the three types of rice produced in Bangladesh, namely Aus, Aman and Boro. This is a pioneering study in this kind in Bangladesh and has the novelty in using localized data. Rainfall data is taken from 35 rainfall measuring stations of Bangladesh Meteorological Department whereas yield data is taken from Bangladesh Bureau of Statistics. CLIMWAT 2.0 and Harmonized World Soil Database 1.21 are used to extract climate and soil information respectively. Lastly, CROPWAT 8.0 is used for estimating the actual crop evapotranspiration. The grey water footprint is calculated based on the application rate of Nitrogen based fertilizers. The three distinct water footprints are analyzed for each district of Bangladesh. This very first study, using local data finds the green and blue water footprint of Boro rice in Bangladesh to be 147 cubic meter/M. ton and 1162 cubic meter/M. ton respectively. Maximum total water footprint is found for Aus rice. Results from such analyses will help in regional water resource management in a more efficient way.

Keywords: Bangladesh; blue water; green water; grey water; water footprint.

INTRODUCTION
Terrific economic development results loss of natural resources on the earth and amid those loss gradual depletion of available freshwater throughout the world has become one of the major concerns in the recent years. An efficient and effective distribution of water with other economic resources has become instrumental to ameliorate the crisis. Along this line, the concept of "water footprint" was coined by Hoekstra in 2002 (Hoekstra, 2003). The water footprint of an individual or community is defined as the total volume of freshwater that is used directly and indirectly to produce any goods and services consumed by the individual or community. The water footprint is therefore a consumption based indicator of freshwater use (Hoekstra et al., 2008). The assessment of the water footprint, from a hydrological, ecological, and economic perspective, is very significant to facilitate an efficient allocation of water resources as it can provide a transparent and realistic guidance for optimizing the water policy decisions. In the recent years of water scarcity in many parts of the world, water footprint and virtual water trade have received much attention as both policy instrument and practical means to balance the local, regional, national and global water budget.

Water footprint assessment includes both direct and indirect water footprint as suggested by Hoekstra et al. (2011). In case of assessment of water footprint of a crop there exists two stages, namely- crop processing and crop to product processing. In crop processing, direct water footprint includes direct blue, green and grey water footprint, on the other hand, indirect water footprint comprises of water use associated with fertilizers, pesticides, machineries etc. The green water is defined as that part of the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or momentarily stays on top of the soil or vegetation and ultimately, evaporates or transpires through plants. In monetary perspective, the blue water is of foremost importance because it costs higher than the other types and it is a major concern to limit the use of blue water i.e. the surface water and the ground water. In crop processing, the blue water refers to the amount of water supplied to the crop by irrigation. The last type is the grey water footprint, which is an indicator of water pollution, associated in the crop processing and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards.

A number of studies were carried out so far in some developed and developing countries e.g. USA, China, Indonesia, India etc. to explore the facts regarding water resource management that were not in concern before the introduction of water footprint concept. A study on consumption perspective (Chapagain et al., 2010) reveals that the green water footprint is noticeably larger than blue water footprint in India, Indonesia, Vietnam, Thailand, Myanmar and the Philippines for rice whereas USA and Pakistan showed larger blue water footprint compared to green water footprint. In recent past, a study on the past and future trends of grey water footprint of anthropogenic nitrogen (N) and Phosphorus (P) exhibits terrible condition of river due to increasing grey water footprint. The study was conducted over 1000 rivers within a time period of 1970 to 2000 and found that the pollution assimilation capacity of these rivers have been fully disbursed (Liu et al., 2011). Majority of these well-recognized studies on water footprint are conducted on large area basis where corresponding data are extracted predominantly from international database. However, analyses based on such dataset may not be reliable enough because of difference between local and international data set. The novelty of the current study lies here. Perception of the significance of water footprint of one of the most water intensive crops, rice in Bangladesh and the absence of assessment with local data leads to this study. This paper estimates the direct water footprint of main three types of rice (Boro, Aus, Aman) crop processing stage which is candid as per the guideline in "The water footprint assessment manual (Hoekstra et al., 2011)" to simplify the study and prevent it from being intricate.

METHODOLOGY AND DATA

This assessment is a level B spatial explication, which estimates the direct water footprint of rice processing (planting to harvesting) in Bangladesh conforming "The Water footprint Assessment manual" by Hoekstra et al. (2011). There are two popular systems of rice cultivation in Bangladesh, namely up land system and wet land system; however, wet land system is the practice in Bangladesh. The wetland system follows preparation of field by tillage & puddling. A standing water layer is also maintained throughout the cultivation period to saturate the soil. The study covered altogether the districts in Bangladesh. It also used data predominantly from local sources and checked with global database to reassure right assessment. The assessment of water footprint of rice processing (planting to harvesting) could be depicted in Eq. 1.

$$WF_{proc.\ rice} = WF_{blue} + WF_{green} + WF_{grey} \quad (1)$$

Assessment of the blue and green water footprint

Both green and blue water is consumed by rice in the form of evaporation, incorporation in crop and change of catchment area. Quantitative assessment of loss of water due to change of location of water between different catchment areas is not feasible and a cumbersome task therefore it is neglected along with the incorporated water which is found usually as maximum as 1% of evapotranspiration. The study computed only the water that evaporates. Table 1 shows planting and harvesting dates of three major types of rice namely Aus, Aman and Boro.

Table 1: Major types of rice and their planting and harvesting date for Bangladesh

Rice Type	Planting Date	Harvesting Date
Boro	15-Dec	13-Apr
Aus	1-May	28-Aug
Aman	15-Aug	12-Dec

The green and blue water footprint (m^3/ton) of rice is obtained by dividing the corresponding evapotranspiration (m^3/ha) by yield (M.ton/ha). Yield data is obtained from Bangladesh Bureau of Statistics (BBS, 2013). Evapotranspiration was estimated using CROPWAT 8.0 model developed by the Food and Agriculture Organization of the United Nations (FAO, 2010b). CROPWAT 8.0 offers two different options to compute evapotranspiration, namely crop water requirement option and irrigation requirement option. Crop water requirement option is based on optimal condition and gives comparatively unrealistic results compared to irrigation requirement option. This study obtained actual evapotranspiration (ET_c) using irrigation requirement option. The monthly rainfall data for the 35 stations over Bangladesh is collected from Bangladesh Meteorological Department and the effective rainfall is computed using USDA SCS (United States Department of Agriculture, Soil Conservation Service) method which calculates effective rainfall according to the Eq. (2) and (3).

$$P_{eff} = P_{month} * (125 - 0.2 * P_{month}) / 125 \text{ for } P_{month} <= 250 \text{ mm} \qquad (2)$$

$$P_{eff} = 125 + 0.1 * P_{month} \text{ for } P_{month} > 250 \text{ mm} \qquad (3)$$

where, P_{eff} = effective rainfall and P_{total} = total rainfall in the concerned period. In Bangladesh wet land method is utilized in which the standing water layer comes with a constant percolation and seepage loss varies from 2 mm/day (heavy clay) to 6 mm/day (sandy soil) (Chapagain et al., 2010). An average of 3 mm/day is used in this study as percolation loss. In last 15 days of rice cultivation the field is left to dry for harvesting. Factors like soil moisture prior to land preparation, contribution from shallow ground water through capillary rise and outflow of the overland runoff from adjacent rice fields are neglected in this study. The value of k_c is taken from Allen et al, (1998). Soil data for 64 districts is formatted with the help of FAO's Harmonized World Soil Database Viewer 1.2 and Soil Water Characteristics 6.02.74.

The crop water requirement is obtained by multiplying reference evapotranspiration (ET_o) with crop coefficient (K_c). It is assumed that the water stress co-efficient K_s=1, which means water requirements (CWR) are fully met. Therefore, CWR= ET_c where, ET_c= Actual crop evapotranspiration. Reference crop evapotranspiration (ET_o, mm/day) is taken from CLIMWAT 2.0 model output in monthly basis. Actual crop evapotranspiration and effective rainfall calculated with the help of climate file, rainfall file, crop file and soil file are used to determine green and blue water footprint. Green water footprint is the minimum of actual crop evapotranspiration (ET_c) and effective rainfall (P_{eff}) while blue water footprint is either zero or the difference between actual crop evapotranspiration and effective rainfall.

$$ET_{green} = \text{Min.} (ET_c, P_{eff}) \qquad (4)$$

$$ET_{blue} = \text{Max.} (0, ET_c - P_{eff}) \qquad (5)$$

Assessment of grey water footprint

Numerous formulations are found in literature to calculate of grey water requirement for point sources of water pollution but in case of crop processing the source of pollution is diffuse. To overcome the unfeasibility of apportioning the measured concentrations to different sources, "The Water Footprint Assessment Manual" (Hoekstra et al., 2011) recommends to estimate the fraction of applied chemicals that enters the water system by using simple or more advanced models. The simplest model assuming that a certain fixed fraction (Leaching Run-off Fraction, α) of the applied chemicals (AR kg/ha) finally reach the ground- or surface water gives a simple and workable formula shown in Eq. (6).

$$WFproc, grey = \frac{\alpha * AR}{(C\max - Cnat)} * \frac{1}{Y} (\frac{Volume}{Mass}) \qquad (6)$$

where, C_{max}=Maximum acceptable concentration for the pollutant considered (kg/m^3), C_{nat}=Natural concentration for the pollutant considered (kg/m^3), Y=Crop yield (kg/ha). Since a number of chemical components are present in fertilizers and pesticides, selection of a certain or all the chemicals for the grey water footprint calculation becomes a question. The answer comes from another assumption: grey water footprint will be calculated only for the "Critical Pollutant", which creates most severe effect on environment. This work assumes Leaching-run-off fraction, α to be 10% and Nitrogen-based fertilizers to be the Critical Pollutant (Chapagain et al. 2006b).

RESULTS AND DISCUSSIONS

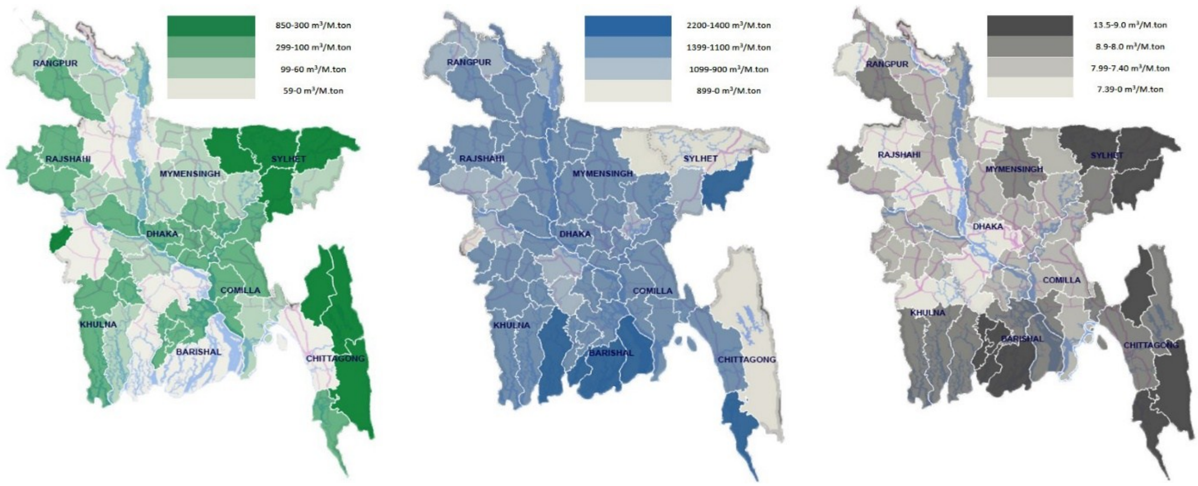
Water footprint of 64 districts in Bangladesh of three different type of crops is shown in Table 2. A number of districts located in the south east, south west, north and north east part of the country is greatly facilitated by the moon soon rain during the rainy season. As a result Aus and Aman growing in this season show a large amount of green water footprint and small or no blue water footprint.

Table 2: Green, blue and grey water footprint of Boro, Aman and Aus rice of 64 districts in Bangladesh

Water footprint (m^3/M.ton)

District	Boro			Aus			Aman		
	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey
Bagerhat	32.0	1414.8	8.8	2817.8	0.0	15.2	2694.8	0.0	16.5
Bandarban	547.6	814.8	9.5	2760.4	0.0	15.7	1768.0	0.0	12.4
Barguna	4.8	2126.4	13.2	2734.7	0.0	15.4	2702.0	0.0	17.0
Barisal	178.3	1137.7	8.2	3160.9	0.0	17.8	2453.2	0.0	15.4
Bhola	33.1	1403.0	8.9	3340.8	0.0	18.8	2536.5	0.0	15.9
Bogra	49.0	1318.5	8.0	2815.2	297.4	14.6	1953.0	210.8	13.1
Brahmanbaria	153.9	1110.2	7.8	2910.1	133.2	17.1	2150.5	153.6	14.8
Chandpur	136.6	1106.7	7.7	2462.9	0.0	13.8	2706.1	0.0	17.3
Chittagong	47.0	1235.1	9.0	2237.4	0.0	12.7	1679.3	0.0	11.8
Chuadanga	55.6	1257.7	7.8	2336.2	812.0	13.0	1690.5	343.9	11.8
Comilla	154.4	1113.8	7.9	2278.4	104.3	13.4	1858.2	132.7	12.8
Cox's Bazar	179.3	1408.5	9.3	2337.7	0.0	11.5	1797.0	0.0	10.5
Dhaka	103.3	1276.5	7.2	4344.7	28.8	20.8	3047.8	549.1	20.7
Dinajpur	104.5	1190.2	8.0	2706.6	0.0	13.3	1854.7	0.0	11.9
Faridpur	81.5	1076.2	7.2	5865.6	0.0	33.7	2260.3	34.5	15.4
Feni	88.4	1347.1	8.9	2518.6	0.0	14.1	1675.0	0.0	10.6
Gaibandha	48.3	1299.6	7.8	3054.3	322.7	15.9	1908.6	162.9	12.4
Gazipur	106.6	1317.5	7.4	3559.6	23.6	17.1	1630.0	293.6	11.1
Gopalgonj	53.3	1022.6	6.7	5882.4	0.0	33.1	3962.8	0.0	24.9
Hobigonj	419.9	928.7	8.6	2415.0	0.0	12.9	1986.4	0.0	12.7
Jamalpur	46.7	1167.0	7.6	3895.0	204.4	20.2	2046.8	197.4	13.7
Jessore	111.2	1154.9	7.4	2603.1	0.0	12.9	2000.9	0.0	12.4
Jhalakathi	197.6	1260.8	9.0	2924.7	0.0	16.4	2721.2	0.0	17.1
Jhenaidah	54.8	1260.8	7.7	2344.9	292.8	13.0	1651.9	208.9	11.5
Joypurhat	44.4	1195.1	7.2	2969.5	313.8	15.4	1771.8	191.2	11.9
Khagrachari	524.9	781.1	9.1	2654.0	0.0	15.1	1488.0	0.0	10.4
Khulna	73.2	1284.7	8.3	3867.5	0.0	20.8	1981.1	256.1	13.7
Kishoregonj	74.8	1114.0	7.4	2973.0	0.0	14.7	1527.5	272.9	11.0
Kurigram	93.8	1078.8	7.6	4178.7	0.0	21.0	1867.6	244.7	13.2
Kushtia	53.2	1089.1	7.4	2489.3	728.3	13.8	1883.1	315.4	13.1
Lakshmipur	103.7	1192.2	8.4	3494.6	0.0	17.6	2110.4	276.5	14.9
Lalmonirhat	56.7	1122.4	7.3	3851.8	0.0	21.5	1865.8	0.0	11.8
Madaripur	59.2	1138.8	7.4	5780.0	0.0	33.2	3597.3	0.0	24.2
Magura	119.2	1163.3	7.9	2157.9	0.0	12.4	1838.9	0.0	12.3
Manikgonj	104.3	1288.3	7.3	6342.3	42.0	30.4	4178.8	752.8	28.4
Maulavibazar	69.7	1427.7	9.8	2344.2	685.8	13.0	1622.3	271.7	11.3
Meherpur	377.8	835.6	7.8	2286.5	0.0	12.2	1862.5	0.0	11.9
Munsigonj	109.6	1353.6	7.6	4362.6	28.9	20.9	3791.8	683.1	25.8
Mymenshing	85.0	1265.5	8.4	3200.7	0.0	15.8	1970.9	352.1	14.2
Narail	103.9	1255.2	7.2	5375.1	899.7	25.7	2125.6	746.7	16.2
Narayangonj	114.0	1184.8	7.6	3223.8	0.0	15.9	3476.5	0.0	21.5
Narsingdi	107.9	1065.7	7.5	3648.5	0.0	18.3	1889.2	287.0	12.9
Natore	94.4	932.1	6.6	3365.5	0.0	16.9	2071.0	314.6	14.1
Nawabgonj	198.5	1276.9	8.3	2386.3	987.4	15.1	1774.3	263.2	11.8
Netrokona	612.7	625.5	7.7	3299.6	0.0	16.3	2150.6	0.0	13.1
Nilphamari	81.9	1016.8	7.7	3009.0	0.0	14.4	1867.4	0.0	11.5
Noagaon	104.6	1263.0	7.3	2660.9	445.4	12.7	1489.5	523.2	11.4
Noakhali	61.0	1208.6	7.9	3380.3	0.0	18.9	2606.2	0.0	16.5
Pabna	178.0	1145.0	7.4	3704.6	1532.9	23.5	2203.5	326.8	14.7
Panchagar	82.9	1028.3	7.7	8074.2	0.0	38.6	2007.6	0.0	12.3
Patuakhali	4.5	1989.2	12.4	2910.6	0.0	16.4	2834.6	0.0	17.8
Perojpur	197.7	1261.5	9.0	2752.8	0.0	15.5	2671.6	0.0	16.8
Rajbari	84.5	1115.4	7.4	6030.8	0.0	34.7	2081.8	31.8	14.2
Rajshahi	110.1	1063.8	7.6	2681.5	300.3	12.8	1481.4	416.8	11.3

Rangamati	483.7	719.8	8.4	3412.3	0.0	19.4	1688.2	0.0	11.8
Rangpur	97.3	1175.0	7.9	8418.8	0.0	41.4	1630.0	152.3	11.5
Satkhira	162.4	1223.0	8.5	2264.5	0.0	12.2	1843.6	0.0	11.3
Shariatpur	59.9	1374.9	7.5	7126.3	0.0	33.9	4059.9	0.0	23.4
Sherpur	74.1	1103.7	7.4	3119.6	0.0	15.4	1846.5	329.9	13.3
Sirajgonj	80.6	1226.4	7.3	3260.2	604.3	17.3	1898.4	614.5	14.6
Sunamgonj	721.3	602.6	9.1	1588.4	1327.1	20.0	2031.0	0.0	12.5
Sylhet	831.3	694.6	10.5	2703.8	0.0	14.2	2121.2	0.0	13.1
Tangail	84.7	1290.0	7.7	5014.3	929.5	26.7	2050.2	663.7	15.8
Thakurgaon	94.7	1078.5	7.3	2638.3	0.0	13.0	1743.4	0.0	11.2
Bangladesh	**146.7**	**1162.2**	**8.0**	**3146.9**	**168.5**	**16.8**	**2060.0**	**156.6**	**13.7**



Green Water Footprint　　Blue Water Footprint　　Grey Water Footprint

Fig. 1: Graphical representation of water footprint of Boro rice

Absence of rainwater in most part of the country during Boro cultivation is making the average blue water footprint of Boro rice of Bangladesh (1162.2 m^3/M.ton) larger than that of Aman rice (156.6 m^3/M.ton) and Aus rice (168.5 m^3/M.ton). In some districts, the green water footprint of Aus and Aman show larger values compared to corresponding average green water footprint of the country, the reason behind this is the small yield values in these districts compared to others. At the same time, some districts show zero blue water footprint indicating sufficient rainfall and zero irrigation. Fig. 1 shows graphical representation of water footprint of Boro rice.

The primary aim of water footprint assessment is to plan to reduce the green, blue and grey water footprints. The green water footprint is to be kept as low as possible because an efficient use of green water confirms greater chance of storage of blue water. Again, if the blue water footprint can be lessened, there exists a greater chance of surplus storage of blue water, which will certainly give a greater freedom of reallocation to policy makers. A lower grey water footprint represents a lower degree of pollution and vice versa. Forthrightly, steps should be taken before disposal of effluent to lower the grey water footprint and mitigate the severity of the situation. Recycling and Reuse of effluent could be a good instrument to reduce the grey water footprint. Desalination of seawater or brackish water may seem to be an alternative solution for water scarcity; but desalination and transportation of the desalinated water to the lands far from the coastal belts consume huge energy; and the earth cannot fight one scarce resource with another scarce resource, energy. Although water is a renewable resource, there lefts no better solution than sustainable water budgeting. Furthermore, being renewable resource does not mean that it is always available anywhere. The water footprint assessment helps the allocation of proper amount of proper type (green, blue and grey) water at proper place at proper time.

CONCLUSIONS

With the limited resources, this study finds the green, blue and grey water footprint for Boro rice in Bangladesh to be 146.7, 1162.2 and 8.0 m^3/M.Ton respectively. The footprints are found to be 3147, 168.5 and 16.8 m^3/M.Ton respectively for Aus rice. And the Aman rice gives the footprints as 2060, 156.6 and 13.7 m^3/M.Ton respectively. In the modern era when rivers are running dry, lake and ground water levels are dropping, species are endangered by contaminated water, source of safe drinking water is shrinking, Bangladesh is not an exception. In this circumstances, water footprint concept can be utilized to discover the links between the problems and probable solutions to achieve a more sustainable and equitable use of the limited fresh water resource. To achieve additional perspective from the water footprint of rice, concentration should go to the assessment of water footprint of other main crops like wheat, potato etc. as well. Such assessment over main crops will help to understand the efficiency of different crops over each other based on nutritional values and water consumption. With the help of comparative assessment, decision on sustainable water allocation could be taken. Further study considering water availability in the catchment area could help identify environmentally endangered areas and make meticulous policy for achieving water-based environmental sustainability. In the present days, water may be available in Bangladesh to grow water extensive crops like rice, but a benchmark should be introduced to achieve a sustainable water allocation. Additional study over future and past trends could help to setup such benchmark for rice production.

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