



Original Research Paper



Assessment of Water Footprint in Selected Crops: A State Level Appraisal

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Abstract

Every commodity or goods has intake of water i.e. either in processing or furnished stage. Thus, the present study propensities macro-level (states-level) water footprint (WFP) assessment of selected eight crops namely, Wheat, Barley, Maize, Millets, Rice, Sorghum, Soybeans and Tea. The aim of present research is to assess water use in selected crops at field level. In addition, the spatial evaluation at state level also considered as one of the significant objective to understand regional disparity and/or similarly. Methodology and approach of assessment was adopted from Water Footprint Assessment Manual (2011). Data was collected from state Agricultural Directorate, National Bureau of Soil Survey and landuse, published reports and online database such as FAOSTAT, WMO, WFN, and agriculture census. Results show that green component of WFP contributes large fraction as about 72 percent, while blue and grey component amounted of about 19 and 9 percent of the total water consumption, respectively. Moreover, spatial variability of blue, green and grey among the states assimilated by soil regime and climate barriers. Supply of blue water is high where the region imparted to semi-arid or arid land. Consequently, a balanced approach between green and blue water use has been recommended in the present study to address increasing water demand in the future.

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1 INTRODUCTION

Enormous amount of water is available in the Earth's natural environment. However, fresh water accounts nearly 2.5 percent of total available water (Rao, 1971; Shiklomanov, 1993, 1996 and 1998; Falkenmark and Lundqvist, 1995) which stored in rivers, lakes, ponds, under the surface and sub-surface as groundwater. There are several indications about high volume of water consumption and exceed the rate of pollution more than to a sustainable level (Moon, 2008). Reported accounts of groundwater depletion, rivers running dry and worsening pollution levels form an indication of the growing water stress (Nace, 1967). The availability of resources, especially water, becomes a pertinent question among the policymakers and institutions (Falkenmark and Widstrand, 1992). Severity level exaggerated in the regions where water already was

absent or depleted to the critical level (Gleick, 1993 and 1998; Shiklomanov, 1993; 1996 and 2000; and UNESCO, 2003). Human use huge amount of water for drinking, cooking and washing, but even more for producing goods such as food, paper, cotton, clothes and so on, popularly known as 'water footprint'. The concept of water footprint have been nurtured and nourished after the term 'Virtual water' put forwarded by J A Allan (1993) at SOAS (Allan, 1997). Allan quoted "more water flows into the Middle East each year as 'virtual water' than flows down the Nile into Egypt for agriculture" (Allan, 2001). It enhances the understanding of virtual water and provides an extremely operational solution with no apparent downside. Similar, attempt had also been stated in Falkenmark (1989) writings as he referred the water to evident (blue water) and non-evident (grey water) on the

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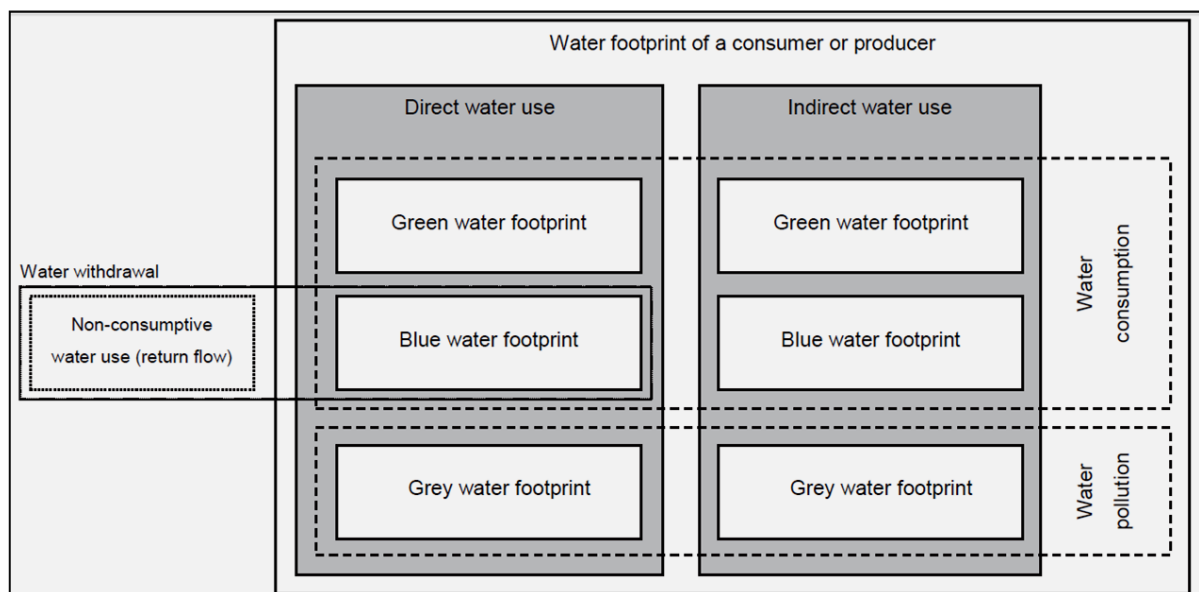
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basis of water use. Evident water is that water of which users are aware, for example, water comes from rivers and streams, springs or aquifers. While, non-evident water stored in the soil profile as soil moisture, and it is only utilized if vegetation and crops make use of it (Falkenmark, 1989). Until the recent past, it is evident that very few thoughts in the science and practice of water management along with water consumption and pollution studied. Even though, the consideration of production and supply chains is also scarce. Consequently, there is little awareness regarding the fact that the organization and characteristics of a production and supply chain strongly influence the volumes, paradoxically both temporal and spatial domain. Further, the distribution of water consumption and pollution that can be associated with a final consumer product. Virtual Water, which was earlier coined by Allan (2001), is defined as the volume of water required to produce a commodity or service. In addition, the transfer of products or service from one place to another also contribute significantly to water transfer in terms of hidden form. The reason lies in the processing or development stage of commodity or service by the consumption of volume of water. For example, one pair of shoes (bovine leather) required if processed and prepare in the efficient way, about 8000 liters of water to produce, while One glass of milk (200 ml) necessitate about 200 liters of water in hidden form to bring into being (Guardian, 2013). Moreover, one cup of tea (250

ml) and one cup of coffee (125 ml) have to need of 35 and 140 liters of water to processed and distil in proficient way respectively (Guardian, 2013). Similarly, One kg of grains used in animal feeds requires 1.2 m³ water (Verdegem *et al.*, 2006). However, virtual water focuses only direct use as recommend by Allan. Further significant explanation has been proposed by Hoekstra (2002) (Hoekstra, 2003) in this concept as the concept of “water footprint”. Subsequently elucidation of Chapagain and Hoekstra (2008) also noteworthy by which a clear framework to analyze the link between human consumption, and the appropriation of the globe’s freshwater established. It can be considered as an indicator of freshwater use that articulates not only direct water use of a consumer or producer, but also the indirect water use along the whole supply chain. But, the extensions in terms of Blue, Green and Grey water provide a rational approach to analyzing indirect water use in an efficient way (Figure 1).

It is proved as a multidimensional indicator that provide reasonable estimates of water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint can be specified geographically and temporally. From the manual of water footprint, blue water footprint refers to the volume of surface and groundwater consumed by the goods during production. Moreover, the green water footprint alludes to the rainwater stored in the soil as soil moisture. The grey water footprint of a product



- 1) The non-consumptive part of water withdrawal (return flow) is not part of water footprint.
- 2) Adopted from [Water Footprint Assessment Manual \(2011\)](#).

Figure 1. Concept diagram of water footprint

indicates to the volume of freshwater that is required to understand the load of pollutants based on existing ambient water quality standards. Recently, the release of Water Footprint Assessment Manual-2011 (Hoekstra *et al.*, 2011) provides a clear cut methodology and assessment approach in this regard. It can be applied as an instrument to save scarce domestic water resources by importing water-intensive products and exporting commodities that require less water. While, water-abundant countries can profit by exporting water-intensive commodities. Consequently, the national and international trade of agricultural goods is increasingly recognized as a mechanism to save domestic water resource and is a way to achieve national water security.

1.1 Significance in Indian Context

Today most water resource experts admit that water conflicts are not caused by the physical water scarcity, but they are mainly due to poor water management. In this perspective, the concept of water footprint guides towards improvements in water use efficiency, to achieve water security between/within country, and water deficit and surplus regions. India is a country with vast agricultural sector besides a considerable amount of water resources, both underground and surface. It is evident that the economy of India depends on agriculture based output and wheat constitutes main cereal crop together with rice, maize, barley and others commodities. Still India is a country where a sizeable section of the population is suffering from malnutrition and hunger. Principal cause for this could be the suboptimum use of agricultural and water resources resulting in low productivity and non-viable agriculture. Water resource management needs special attention as in India floods and droughts, seemingly paradoxical situations, occur frequently.

The problem is compounded by the inappropriate institutional support and poor implementation of the programs and inability to revise the plans based on the changing situations that can be successfully sorted out from water footprint approach. As several studies remarks that almost 4 to 5 times extravagant water are used in wheat cultivation and 2 to 3 times in rice cultivation (Falkenmark, 1997). Similarly, water used in production of animal feeds could be minimized significantly by aquaculture rather than to feed cattle, pigs, poultry and others (Verdegem *et al.*, 2006). In such critical juncture, questions can arise as how can demand of water met in future? What is a reasonable estimate of average water consumption? And to what extent will it provide the solution for water scarcity problem? These are few, among other, burning questions in the present context. Prime concern should be the management of water resource effectively so that inclusiveness would be ensured. Present study will help to understand and enhance the concept of water footprint and economic value of water as no or little have been done in this

regard. Objectives of the present study have been taken as:

- To quantify overall water footprint (WFP) and its fluxes at provincial level
- To quantify the spatial pattern of blue, green and grey water footprint in the study area
- To trace the ways of water sustainability through the concept of 'water footprint'.

Eight commodities i.e. Barley, Maize, Millets, Rice, Sorghum, Soybeans, Tea, and Wheat have been selected for water footprint assessment at provincial scale for entire India except Kerala. The state of Kerala was excluded from the present study due to non-availability of reliable and sufficient database. The study covers entire India for the period of 1999-2006 average water flow.

2 DATABASE AND METHODOLOGY

To fulfil the objectives of the study and derive general conclusion, both primary and secondary data have been used. Data had collected from various reports, international organizations such as FAOSTAT, WMO, WFN, and agriculture census as collected and compiled by government publications. A rational assessment approach towards the estimation of water footprint of selected commodities has been applied with the consideration of blue, green and grey water components. The water footprints are calculated following the methodology developed by (Chapagain and Hoekstra, 2008) and subsequently elaborated by (Aldaya and Llamas, 2008). A concise methodological description is provided below while a more comprehensive one can be found in WFN manual 2011. As defined above, the total water footprint (equation 1) is the sum of blue, green and grey water footprints (Table 1).

$$WFP_{Total} = WFP_{Blue} + WFP_{Green} + WFP_{Grey} \quad (1)$$

In addition, blue water footprint of a given goods or commodity is the volume of freshwater used for production, which in turn depends on the water use in the various steps of the production chain. In the present study, this fundamentally refers to primary crops, i.e. crops as they come from the land, without having undergone any secondary processing, and measured in m³/ton. The estimated amount can be understood as the ratio between the volume of water used (crop water use) during the entire period of crop growth from planting to harvest, and measured as m³/ha and the corresponding to crop yield in ton/ha. The Blue and Green water can be written as follows (equation 2 and 3):

$$WFP_{Blue} = \frac{CRU_{Blue}}{Y} \quad (2)$$

$$WFP_{Green} = \frac{CRU_{Green}}{Y} \quad (3)$$

Here, *CRU* and *Y* represent crop water use and yield, respectively.

Table 1. Water footprint (WFP): Blue, Green, and Grey

States	Wheat (%)			Rice (%)			Barley (%)			Maize (%)		
	Blue	Green	Grey	Blue	Green	Grey	Blue	Green	Grey	Blue	Green	Grey
Andhra Pradesh	48.1	37.0	14.9	26.6	64.1	9.3	NA	NA	NA	4.7	87.2	8.1
Arunachal Pradesh	0.0	73.3	26.7	2.0	83.2	14.8	6.3	93.7	6.3	0.0	89.4	10.6
Assam	0.0	75.3	24.6	0.9	86.2	12.9	5.0	95.0	5.0	0.0	91.0	9.0
Bihar	50.0	33.3	16.7	20.5	69.0	10.5	4.2	95.0	4.2	0.2	92.2	7.5
Chandigarh	38.3	43.1	18.6	35.7	55.0	9.2	9.1	71.8	9.1	1.7	91.6	6.7
Chhattisgarh	57.0	31.6	11.5	9.7	77.2	13.1	5.1	94.9	5.1	0.0	90.4	9.6
Dadra and Nagar Haveli	NA	NA	NA	9.2	82.0	8.7	NA	NA	NA	NA	NA	NA
Daman and Diu	1.0	67.3	31.6	1.5	89.2	9.4	NA	NA	NA	0.0	91.3	8.7
Delhi	40.8	37.6	21.6	46.1	45.9	8.0	4.1	53.1	4.1	4.6	88.7	6.7
Goa	0.0	77.5	22.5	4.6	86.2	9.3	NA	NA	NA	0.0	93.2	6.8
Gujarat	66.5	20.7	12.8	29.6	61.4	9.0	3.7	62.0	3.7	4.6	86.8	8.6
Haryana	56.9	27.7	15.4	46.7	45.8	7.5	3.5	45.4	3.5	1.8	91.4	6.8
Himachal Pradesh	9.3	69.6	21.1	21.3	68.7	10.0	4.7	84.1	4.7	1.1	92.1	6.8
Jammu and Kashmir	6.4	71.2	22.4	37.4	52.0	10.6	10.1	89.9	10.1	2.5	90.2	7.3
Jharkhand	26.6	49.3	24.2	2.3	84.5	13.1	4.5	95.3	4.5	0.2	91.8	8.0
Katakana	52.4	32.8	14.8	29.7	61.0	9.3	NA	NA	NA	14.7	78.9	6.4
Madhya Pradesh	67.6	24.3	8.1	6.0	81.4	12.7	4.4	82.3	4.4	0.4	90.8	8.8
Maharashtra	66.5	25.2	8.3	11.0	78.1	10.9	4.4	95.6	4.4	6.5	86.4	7.1
Manipur	0.0	79.1	20.9	5.8	81.1	13.1	NA	NA	NA	0.0	90.7	9.3
Meghalaya	7.8	68.2	24.0	2.2	85.8	12.0	0.0	100	0.0	0.0	89.5	10.5
Mizoram	0.0	81.8	18.2	0.4	87.3	12.3	NA	NA	NA	0.0	90.2	9.8
Nagaland	17.7	67.0	15.3	10.8	76.2	13.0	NA	NA	NA	0.0	90.9	9.1
Orissa	53.2	30.6	16.2	7.5	78.2	14.3	4.5	95.5	4.5	0.2	91.9	7.8
Puducherry	0.0	73.2	26.8	16.4	75.2	8.4	NA	NA	NA	0.0	93.7	6.3
Punjab	37.8	41.6	20.6	45.2	45.8	9.0	8.9	66.3	8.9	7.5	86.0	6.6
Rajasthan	69.8	18.3	11.9	43.1	47.0	10.0	3.3	44.7	3.3	4.6	86.7	8.7
Sikkim	1.0	74.9	24.1	15.1	76.8	8.1	4.7	95.3	4.7	0.0	91.4	8.6
Tamil Nadu	0.0	76.0	24.0	49.6	39.7	10.6	NA	NA	NA	6.2	87.4	6.4
Tripura	0.1	77.6	22.3	7.2	83.9	8.8	NA	NA	NA	0.0	91.1	8.9
Uttar Pradesh	53.2	30.9	15.9	28.5	62.2	9.3	6.4	47.6	6.4	2.4	90.9	6.7
Uttarakhand	27.7	53.3	19.0	17.1	73.0	10.0	7.9	85.3	7.9	1.5	91.9	6.5
West Bengal	42.3	39.6	18.2	7.5	80.1	12.4	4.4	95.6	4.4	0.0	91.6	8.4
National average	55.8	30.2	14.0	21.8	67.3	10.8	4.5	58.7	4.5	4.1	88.2	7.7
World Average	18.7	69.9	11.4	20.4	68.5	11.1	9.2	85.2	9.2	6.6	77.5	15.9

NA: Data Not Available.

Moreover, the grey water is the pollutant equivalent water consumption for a particular commodity. It calculated (WFP_{Grey} , m^3/ton) as the chemical application rate per hectare (AR, kg/ha), times the leaching factor (α) divided by the maximum acceptable

concentration (C_{max} , kg/m^3) minus the natural concentration for pollutant considered (C_{nat} , kg/m^3) and then finally divided by the crop yield (Y, ton/ha). It can be understood as (equation 4):

$$WFP_{Grey} = \frac{(\alpha \times AR) (C_{max} - C_{nat})}{Y} \quad (4)$$

Crop water use has estimated using Food and Organization's CROPWAT 8.0 (FAO, 2003) model¹ for blue and green water components. For further guidelines see at www.fao.org/nr/water/infores_databases_cropwat.html.

The crop water use was calculated by the following equations (5 and 6):

$$CWU_{Blue} = 10 \times \sum_{d=1}^{l_{gp}} ET_{Blue} \quad (5)$$

$$CWU_{Green} = 10 \times \sum_{d=1}^{l_{gp}} ET_{Green} \quad (6)$$

Here, l_{gp} and ET refer to the length of growing period and evapotranspiration, respectively. However, the blue and green components in crop water use (CWU , m^3/ha) are calculated by accumulating of daily evapotranspiration (ET , mm/day) over the complete growing period for a particular commodity or crops.

3 RESULTS AND DISCUSSION

Total average water footprint along with Blue, Green and Grey have been calculated for growing eight leading commodities at state level for India except for Kerala. While a comparative statement have also been prepared in terms of the average water footprint consumption in selected commodities between Indian states and global average. Detailed share of the water footprint consumption as a percentage to the total WFP is shown in Table 1. Figures 2, 3, 4, 5, 6, 7, 8, and 9 have also been prepared in GIS environment for total WFP as well as its sub-components in terms of cubic meter per ton of water consumption in each commodity, respectively. Finding shows that tea is the highest WFP consumer followed by Sorghum, Soybeans, Millets, Maize, Barley, Wheat and Rice due to crop phenology and growing cycle of the crops. In addition, total average WFP consumption of Indian states are much higher for Sorghum (6026), Soybeans (4410), Maize (2537), Barley (2124), Wheat (2100) and Rice (2070) than the global total WFP average of 3048, 2145, 1222, 1423, 1827 and 1673 cubic meter per ton, respectively. While, tea (6471) and millets (4029) are in an advantageous position from the world WFP average as total WFP of 8856 and 4478 cubic meters per ton, respectively. However, spatial variability also estimated among Indian states. Uttar Pradesh (28306 m^3/ton) is the highest total WFP consumer followed by Himachal Pradesh (27889 m^3/ton), Uttarakhand (27809 m^3/ton), Tamil Nadu (27739 m^3/ton) Bihar (26960 m^3/ton), Gujarat (26692 m^3/ton), Maharashtra (26460 m^3/ton), Haryana (26337) and Rajasthan (25860 m^3/ton). While, lowest total WFP consumption are embodied in North-Eastern states, except Meghalaya as an average of 1900 m^3/ton , followed by Andhra Pradesh (18381 m^3/ton), Orissa (20459 m^3/ton), Chhattisgarh (22074 m^3/ton), Punjab (22323 m^3/ton), Jharkhand (22454 m^3/ton), Jammu and Kashmir (23760 m^3/ton), Karnataka (24100

m^3/ton), Madhya Pradesh (24432 m^3/ton) and West Bengal (24467 m^3/ton). Possible reason for such variability could accompany by agriculture practices, cropping patterns, soil properties, climates and many other factors.

Apart from spatial variability in total WFP, commodity-wise variability also exists for selected crops. Significantly Tamil Nadu contributes highest in wheat (4401 m^3/ton) WFP. Almost 76 percent of total WFP contributed by green WFP in Tamil Nadu that is supplied with soil moisture and remaining amount contributed by fertilizer application used. Total wheat related WFP of Madhya Pradesh (4151 m^3/ton) is the second highest after Chhattisgarh (4133 m^3/ton), Maharashtra (4032 m^3/ton), Andhra Pradesh (3004 m^3/ton), Karnataka (2747 m^3/ton), Gujarat (2504 m^3/ton) and Rajasthan (2414 m^3/ton) (Figure 2). These are the states that are consuming more water in wheat production as compared to global average (1827 m^3/ton); the possible reason to this could be rain-fed agriculture and large growing season of the crops. However, main wheat producing states like Jammu and Kashmir (1228 m^3/ton), Punjab (1261 m^3/ton), Assam (1696 m^3/ton), Uttar Pradesh (1702 m^3/ton), Haryana (1722 m^3/ton), Bihar (1728 m^3/ton) and West Bengal (1734 m^3/ton) are much below than the global average of WFP. It could be a positive approach due to scientific and efficient agriculture practices significantly after the green revolution policy adaptation. Contribution of wheat related Blue, Green and Grey WFP as percentage to the total WFP have summarized in Table 1.

¹ <http://www.fao.org/nr/water/docs/cropwat8.0example.pdf>

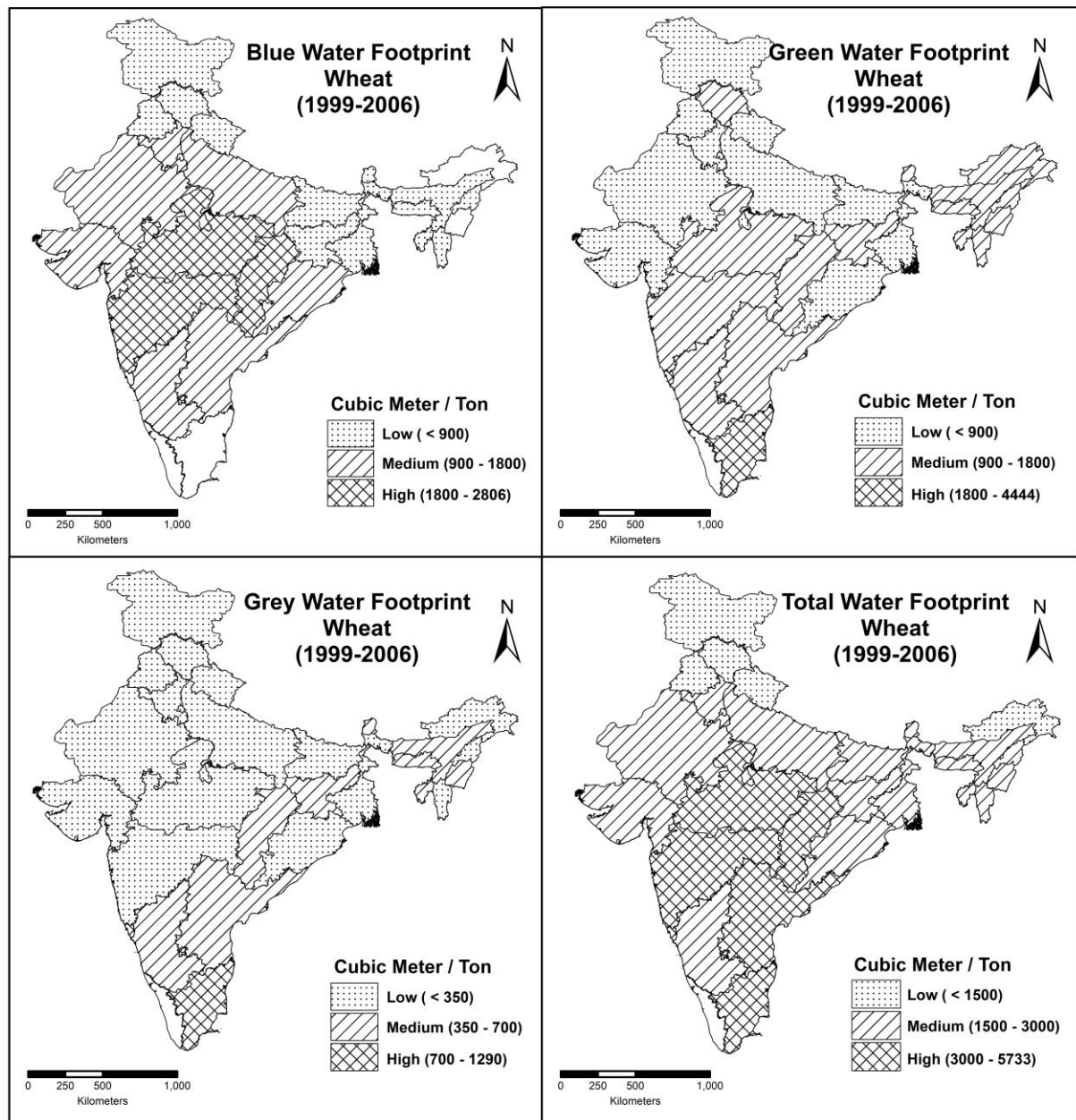


Figure 2. Water footprint: Wheat

Moreover, the average WFP for Rice also varies significantly (Figure 3), as Haryana (2657 m³/ton) is the largest WFP consumer followed by Gujarat (2551 m³/ton), Karnataka (2518 m³/ton), Uttarakhand (2495 m³/ton), Maharashtra (2324 m³/ton), Andhra Pradesh (2282 m³/ton), Uttar Pradesh (2274 m³/ton), Punjab (2228 m³/ton), Bihar (2117 m³/ton), Jammu and Kashmir (2091 m³/ton), and Tamil Nadu (2070 m³/ton). These are the states where the total WFP consumption for rice is not only much high than India average (2070 m³/ton) but also global average (1673 m³/ton). In

addition, the states like West Bengal (1745 m³/ton), Assam (1626 m³/ton), Orissa (1553 m³/ton), and few North-Eastern states are performing well as compare to the national average. Subcategory wise contribution of total WFP in terms of percentage contribution of Blue, Green and Grey are given below in Table 1. It is evident that soil moisture (Green WFP component) is significantly, more than 65 percent as an average, contributed to the rice cultivation. It can also be considered from the table that states have high WFP with less soil moisture contribution or vice-versa.

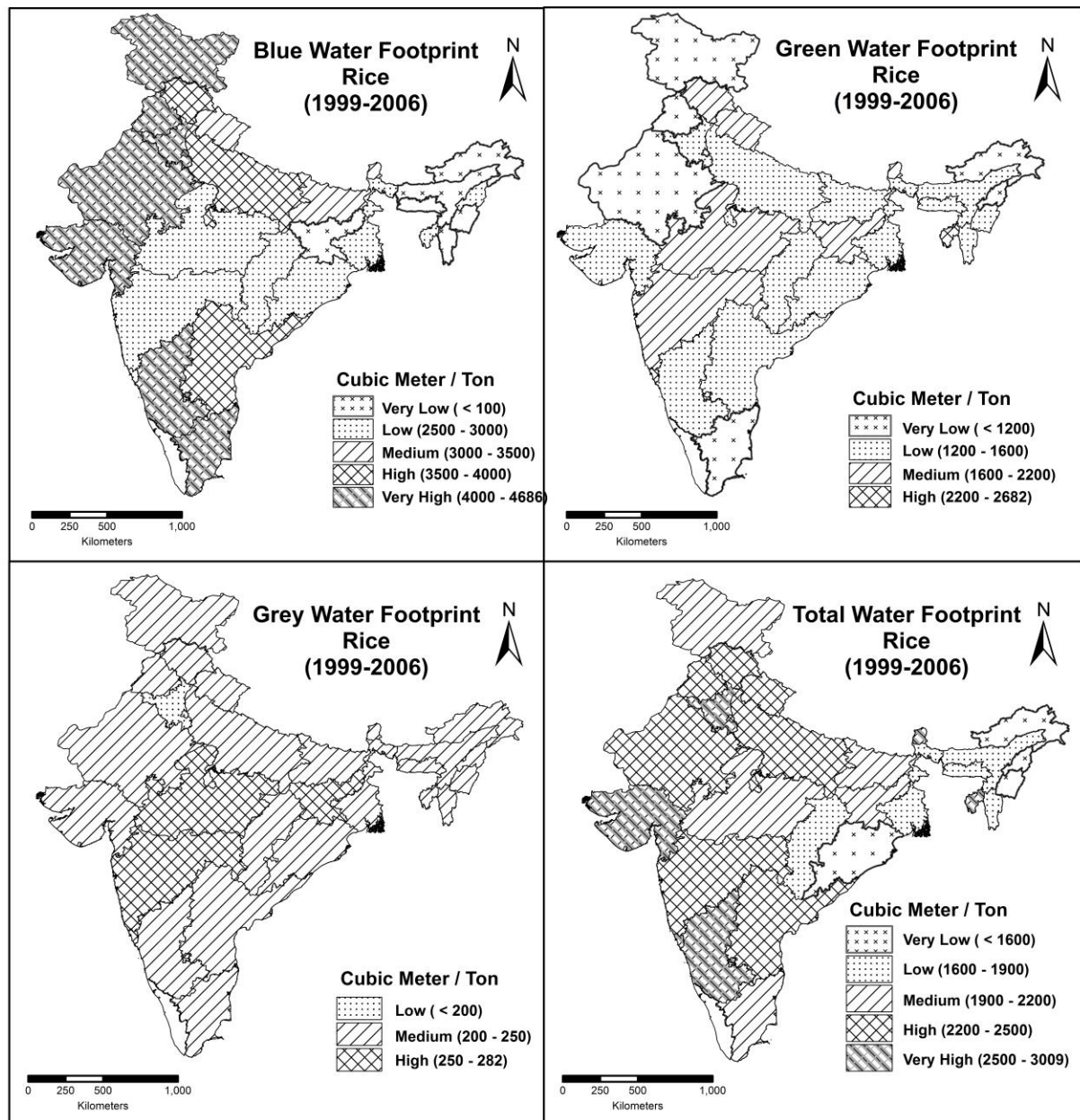


Figure 3. Water footprint: Rice

While in the case of barley (Figure 4), Rajasthan has highest WFP with an amount of 2846 m³/ton. The second highest WFP added by Haryana (2675 m³/ton) after Gujarat and Maharashtra with equal contribution with an amount of 2492 m³/ton. States like Madhya Pradesh (2227 m³/ton) and Bihar (2133 m³/ton) along with above states consume more water than national

average (2124 m³/ton). Remaining states like, West Bengal (2005 m³/ton), Jharkhand (1993 m³/ton), Chhattisgarh (1991 m³/ton), Orissa (1976 m³/ton) and Uttar Pradesh (1480 m³/ton) are below the national average while Punjab (1004 m³/ton) is the only states below the world average as well as national average in terms of embodied water in Barley crops.

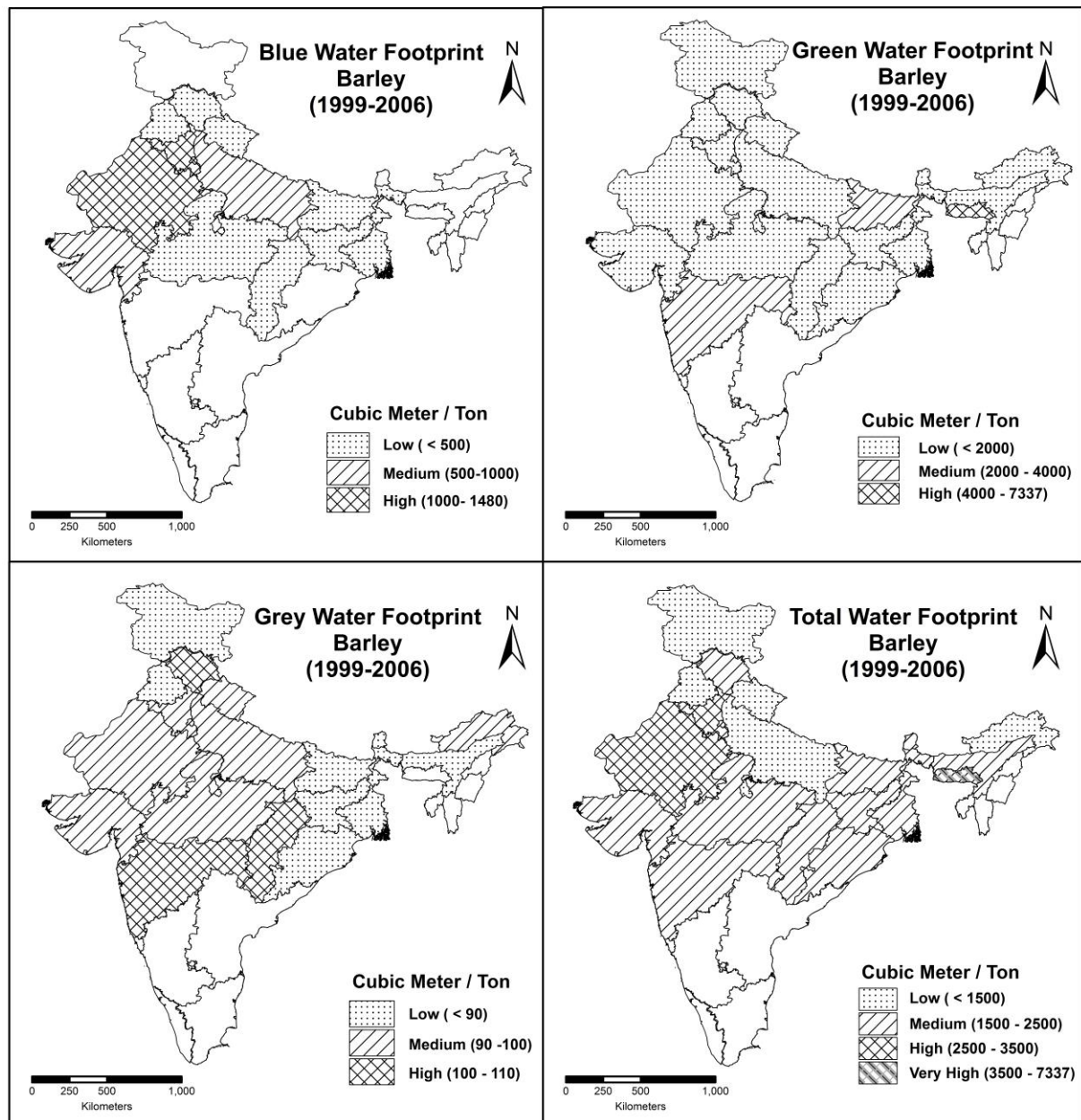


Figure 4. Water footprint: Barley

However, Karnataka (3072 m³/ton), Rajasthan (2912 m³/ton), Maharashtra (2911 m³/ton), Haryana (2806 m³/ton), Gujarat (2805 m³/ton), Tamil Nadu (2778 m³/ton) and Punjab (2590 m³/ton) are exceeding than the national average (2537 m³/ton) as well as world average (1222 m³/ton), in terms of total WFP embodied in Maize crop (Figure 5). While, Madhya Pradesh (2516 m³/ton), Uttarakhand (2491 m³/ton), Uttar Pradesh

(2408 m³/ton), Bihar (2098 m³/ton), Andhra Pradesh (2073 m³/ton), Orissa (2064 m³/ton), Jharkhand (1982 m³/ton), West Bengal (1911 m³/ton) and North-Eastern states are below than the national average but higher than global average as shown in figure. The possible reason for such variation could be growing the period of the crop and high potential evaporation rate as compare to other Maize growing region of the world.

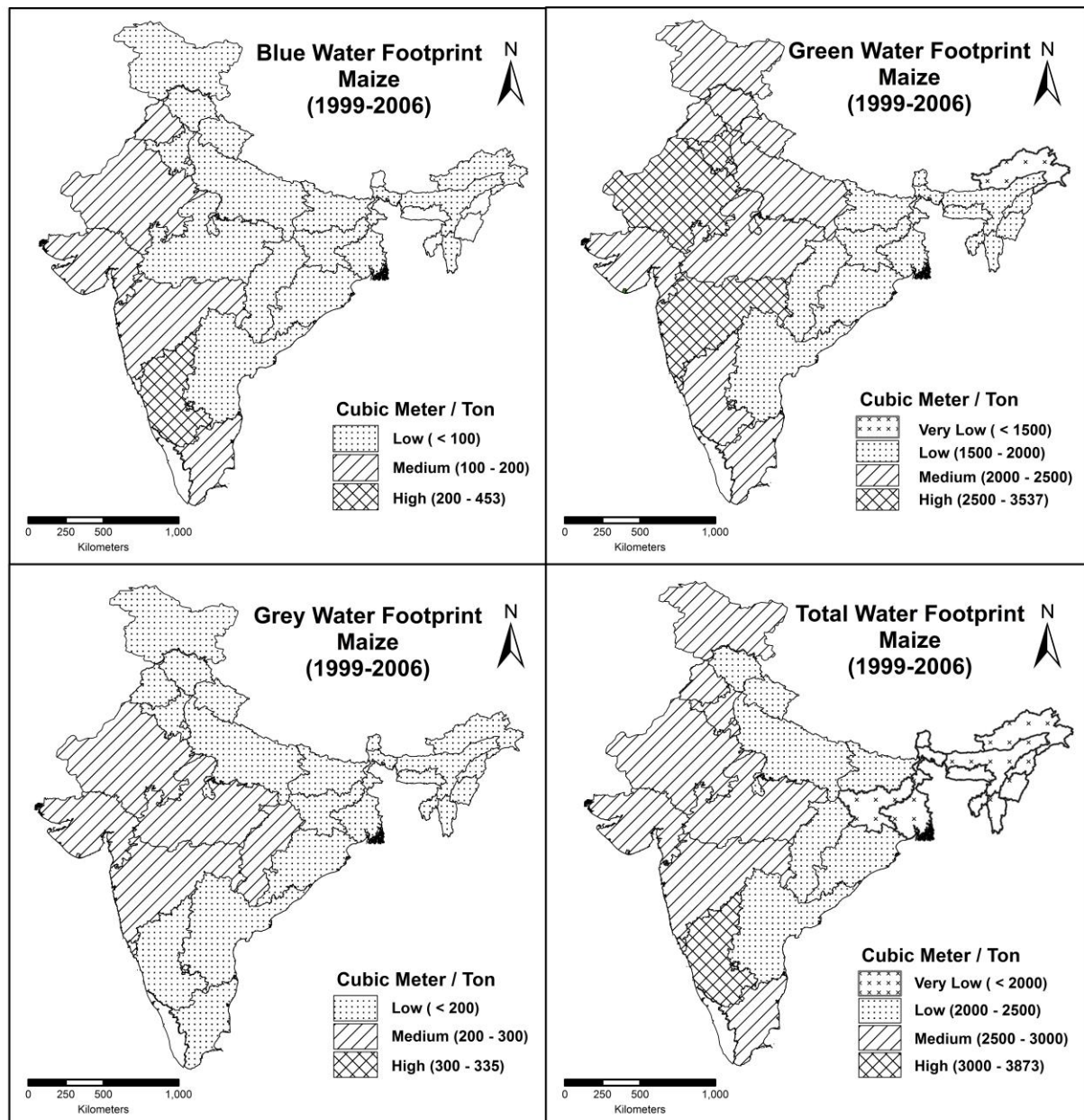


Figure 5. Water footprints: Maize

Another principal crop of India is millets that grown throughout the country with various potential and third largest water intensive crop after Sorghum and Soybean in terms of water consumption for a ton yield. It is significant to note that entire India is much below than the global average in Millets related WFP whether Blue, Green or Grey. The states above the national average (4029 m³/ton) estimated are Karnataka (4204), Rajasthan (4145 m³/ton), Maharashtra (4130 m³/ton)

and Tamil Nadu (4126 m³/ton). Nonetheless, Punjab (3981 m³/ton), Uttar Pradesh (3552 m³/ton), Uttarakhand (3405 m³/ton), Madhya Pradesh (3370 m³/ton), Bihar (3359 m³/ton), Orissa (3266 m³/ton), Andhra Pradesh (3220 m³/ton), West Bengal (3014 m³/ton) and North-Eastern state (average 2950 m³/ton) are embodied less than the national average WFP for Millets (Figure 6).

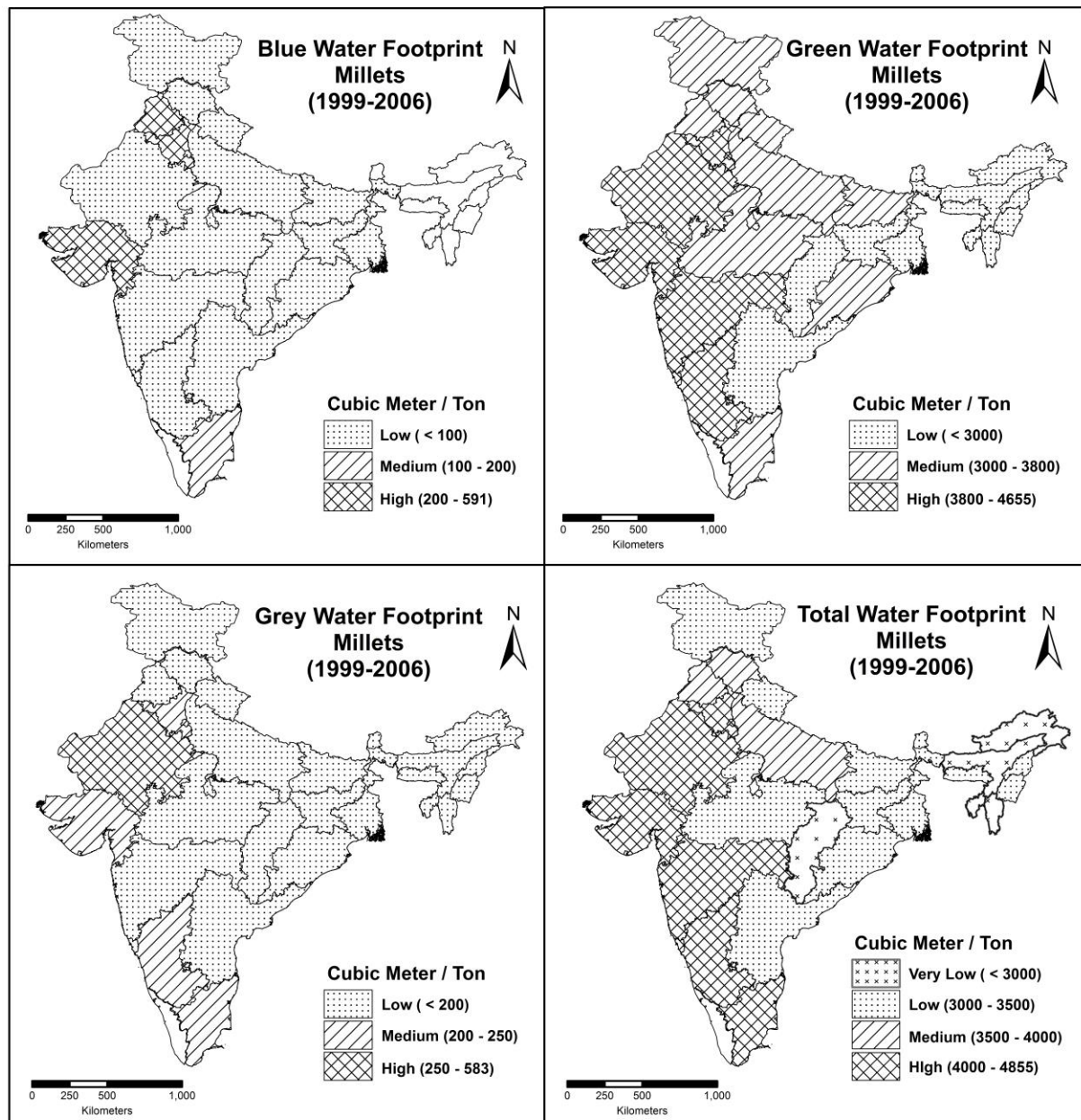


Figure 6. Water footprint: Millets

In addition, most of the states are higher than the global average in Sorghum related WFP. Tamil Nadu ($7571 \text{ m}^3/\text{ton}$), Haryana ($7317 \text{ m}^3/\text{ton}$), Gujarat ($7152 \text{ m}^3/\text{ton}$), Punjab ($6682 \text{ m}^3/\text{ton}$), Uttarakhand ($6554 \text{ m}^3/\text{ton}$), Rajasthan ($6391 \text{ m}^3/\text{ton}$), Uttar Pradesh ($6371 \text{ m}^3/\text{ton}$), Maharashtra ($6154 \text{ m}^3/\text{ton}$) and Karnataka ($6031 \text{ m}^3/\text{ton}$) are higher than the national average ($6026 \text{ m}^3/\text{ton}$) of Sorghum related WFP (Figure 7 and Table 1).

The WFP of Soybeans is higher than the global average ($2145 \text{ m}^3/\text{ton}$) in the entire country. However,

Karnataka, Gujarat, Rajasthan, Haryana, Punjab, Uttarakhand and Maharashtra are higher than the national average ($4410 \text{ m}^3/\text{ton}$), with an amount of 4788, 4775, 4674, 4578, 4444 and $4417 \text{ m}^3/\text{ton}$, respectively (Figure 8). While, Madhya Pradesh ($4364 \text{ m}^3/\text{ton}$), Uttar Pradesh ($4338 \text{ m}^3/\text{ton}$), Bihar ($3972 \text{ m}^3/\text{ton}$), Orissa ($3956 \text{ m}^3/\text{ton}$), Chhattisgarh ($3925 \text{ m}^3/\text{ton}$), Andhra Pradesh ($3854 \text{ m}^3/\text{ton}$), West Bengal ($3469 \text{ m}^3/\text{ton}$) and North-Eastern state are contributing less than the national average in Soybean related WFP.

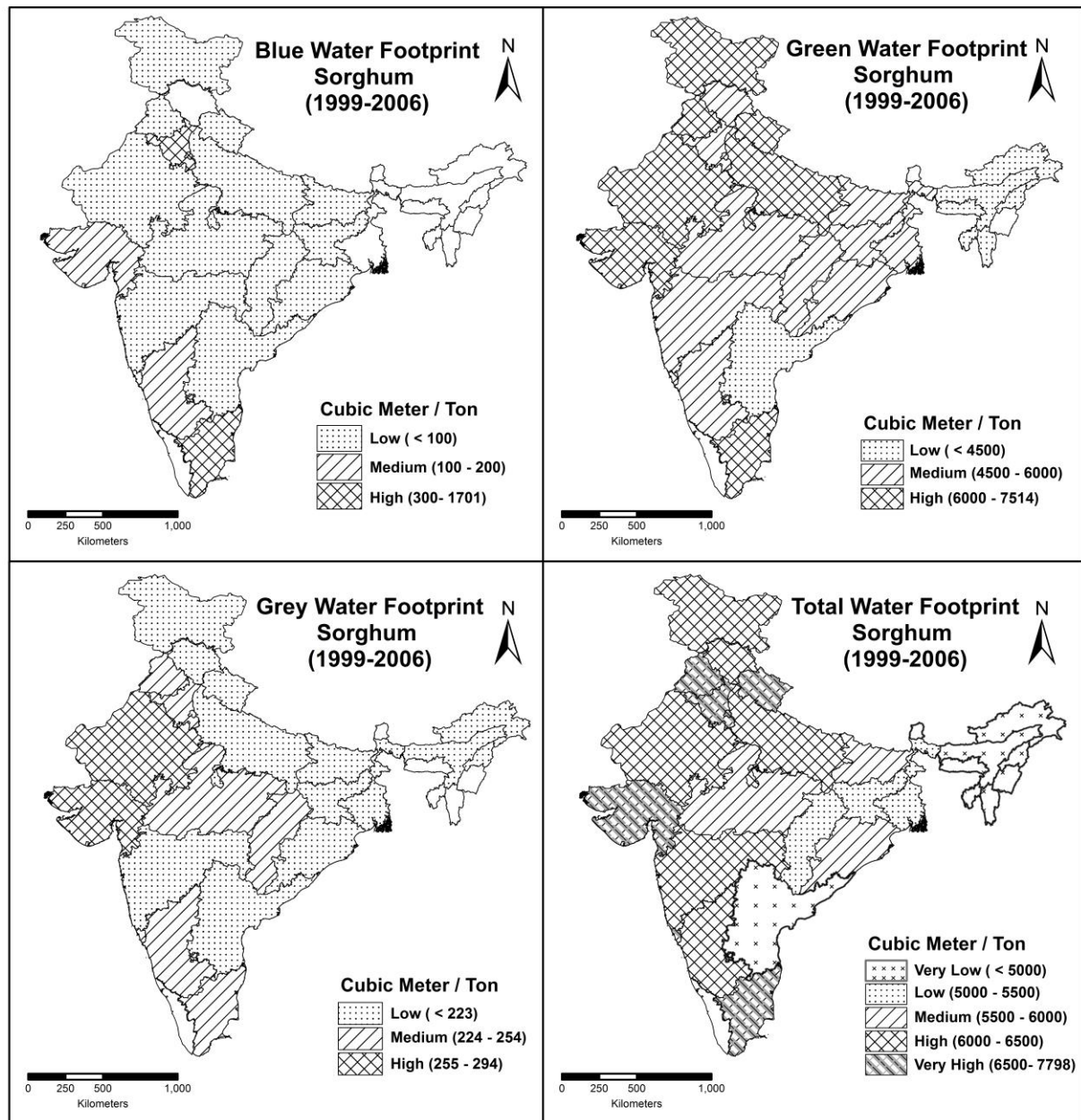


Figure 7. Water footprint: Sorghum

Like Sorghum, tea also has less than global average (8856 m³/ton) WFP throughout the country. It is significant to note that, except Tamil Nadu (6793 m³/ton), all the states including Uttar Pradesh (6180 m³/ton), Uttarakhand (5791 m³/ton), West Bengal (5461 m³/ton) and North-Eastern states (less than 5000 m³/ton)

are contributing less amount of water in their production respectively (Figure 9). This variation could be due to high yield and climate efficiency particularly for tea cultivation. Potential evapotranspiration is the main contribution factor in less water use as the whole cultivation region lies in low or mid-latitude.

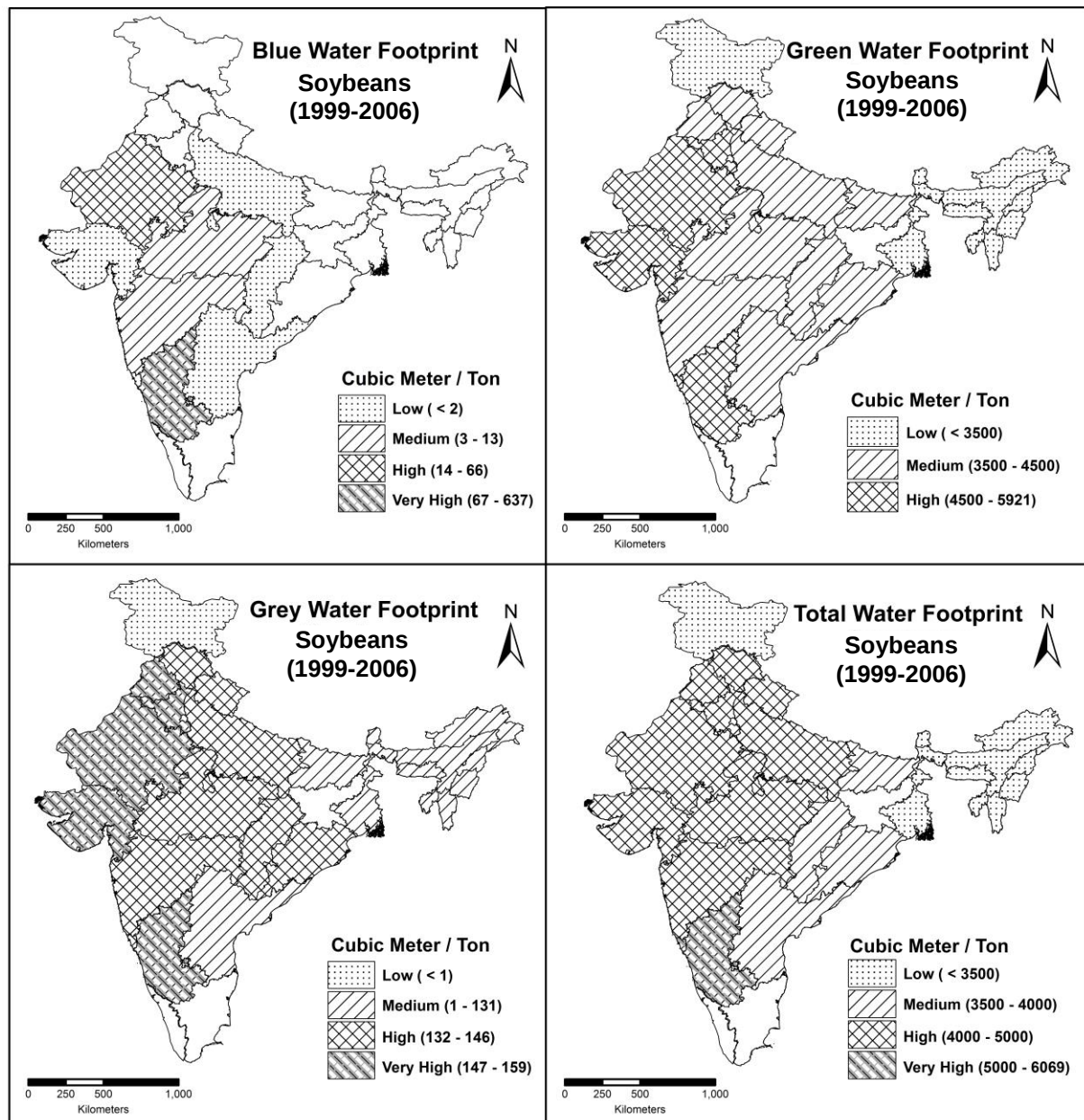


Figure 8. Water Footprint: Soybean

However, plenty of fresh water, blue water, in Indo-Gangetic plain provides opportunity to exploit water for agriculture use. Both, Rice and wheat cultivation require plenty of water during the primary stage. It is the main reason for suitability of both crops in such a vast plain. However, soil moisture (Green water component) is much important for rice cultivation as compared to wheat due to capillary requirement of rice as evident from Table 1. The percentage share of green WFP to total WFP is nearly two-third in all the states for rice because wheat contributes more or less

half or more to total WFP. Similarly, Maize and Barley's cultivation also based on green WFP because the need of blue and grey water is less than the rice and wheat crop. Further, percentage wise share of blue, green and grey WFP has been given in Table 1 for wheat, rice, maize and barley. However, northern region states are more susceptible than the southern states because of high water use and severe water-related problems. The cases of lowering water table, pollution, land subsidence and many more frequently reported from several locations.

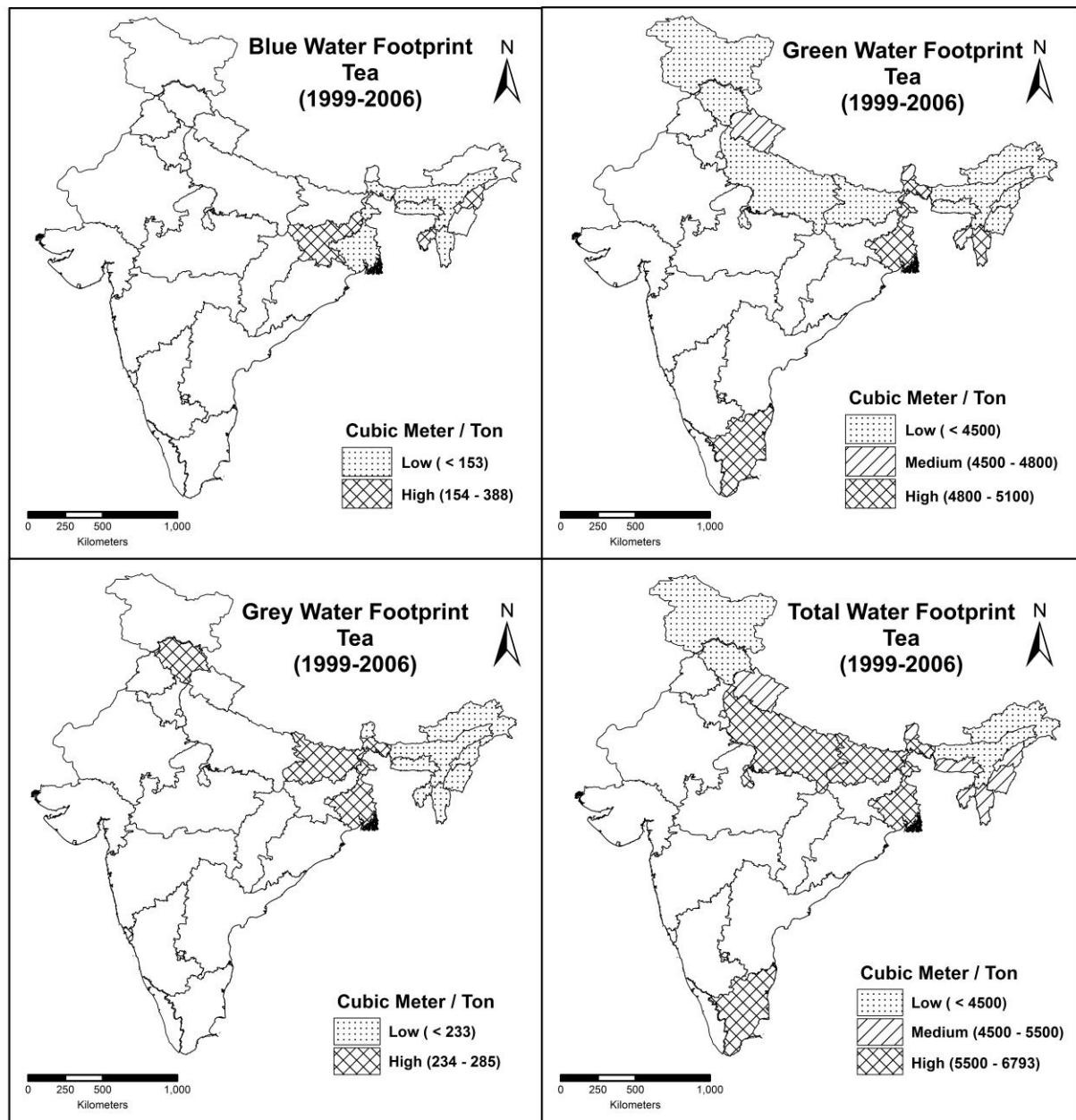


Figure 9. Water footprint: Tea

4 CONCLUSION

Present study represents the nationwide WFP of eight selected crops, i.e. Barley, Maize, Millets, Rice, Sorghum, Soybeans, Tea and Wheat at production level for the period of 1999-2006 estimated along with blue, green and grey categories as suggested by [Hoekstra \(2003\)](#) and further elaborated by [Chapagain and Hoekstra \(2008\)](#). Findings have been presented for entire India except Kerala state in terms of embedded water for a particular crop for a ton of yield. Subsequently, study reveals importance of green WFP as a large fraction of green water approximately 72 percent consumed by the crops apart from blue water. While blue water contribute less than the green water with the amount of 19 percent of the total and remaining

share imparted by grey water. However, spatial variability of blue, green and grey among the states assimilated by soil regime and climate barriers. Supply of blue water is high where the region imparted to semi-arid or arid land as suggested by [Mekonnen et.al. \(2011\)](#). Therefore, Tamil Nadu along with Rajasthan, Andhra Pradesh, Maharashtra, Karnataka, Orissa, Bihar, Gujarat, Haryana and Madhya Pradesh have hefty share of blue WFP ([Table 1](#)). In addition, the share of grey WFP is relatively low because the estimated share imparted by nitrogen only because phosphorous and pesticides applications leaving out. Consequently, a balanced approach between green and blue water use has been suggested which would be efficient to address increasing water demand in the future. Present study also opened new vistas towards economic value of water

as evident from various examples. However, there are a number of expert comments could be applied to improve water efficiency and WFP estimates, these are as follows:

1. Present model has a limitation with planting and harvesting dates that contribute to variation in estimated results.
2. Length of the growing period also adversely affects water consumption. Present study exploits few expert guess or literature derived estimates in growing period of the crops, thus do not reflect possible variation.
3. Another aspect can be to enhance crop productivity and decrease the length of growing period by various hybrid seeds and technical assistance.
4. The availability of sufficient database also limits the scope of the study and future estimates. Further, pilot study has been recommended to improve database, reliability of the estimates and prediction strategy.
5. However, soil regime is the primary determinant that influences rooting depth of the crops. It is very significance in rain-fed agriculture land where water holding capacity defined growth of the plants.
6. Fertilizer statistics is not sufficiently available for most of the crops. Thus, estimation of grey WFP has uncertainties. However, data have been collected a number of sources that itself has variation. Data received from such sources has generalization in terms of the average value for a region. Thus, consistency of data effects present results. It is apparent that southern states or rain-fed agriculture zone have a low rate of fertilizer application. While, the Northern part of India particularly Punjab, Haryana, Uttar Pradesh, Bihar and some part of West Bengal are in vice-versa.
7. It is evident that multi-cropping and intercropping are practiced more or less throughout the world. It could not possible to incorporate those practices explicitly in the present study. For this reason, it is recommended that WFP at smaller scale should interpret cautiously.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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ABBREVIATIONS

CRU: Crop Water Use; **WFP:** Water Footprint; **FAOSTAT:** Food and Agriculture Organization

Statistics; **WMO:** World Meteorological Organization; **WFP:** Water Footprint Network.

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