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THE WATER FOOTPRINT OF INDIA: A STUDY ON RELATION TO CONSUMPTION OF AGRICULTURAL GOODS

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ABSTRACT

In various places in India, water scarcity has become one of the most pressing concerns affecting humanity. The Water Footprint is the recent concept to evaluate the water consumption by the people. Virtual water commerce evaluates the volume of water withdrawn from and received by a country to maintain sustainable development. This paper aims to analyse the pattern of water usage in the production of major agricultural commodities across the country and by analysing the virtual water trade, we assess the country's water footprint. It is essential because agriculture contributes a major part to the overall trade of the country, leading to the major of the water consumption from available freshwater resources. For the period 2015-2020, this study shows the water footprint varies between 551 m^3/cap/yr and 1456 m^3/cap/yr and with average of 640 m^3/cap/yr. Orissa and Chattisgarh in eastern India, and Rajasthan in western India, are the three states having the highest water footprint per capita. Because of the water production is poor and virtual water import is little, these states have a high water footprint. The Kerala and Tamil Nadu in the southern states of India, as well as in the Delhi, have the lowest water footprints. This study will serve as a foundation for future research on the true volume of water consumed by the agriculture industry. This will aid in the development of a long-term paradigm for addressing the water crisis by providing tools and a policy framework to protect water resources.

KEYWORDS: The Water footprint, water scarcity, virtual water trade, sustainable development.

1. INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

India, the world's second most populated country, is under mounting pressure on its water resources as a result food demand is rising to support the country's increasing population. Water resource management is requiredto sustain the limited amounts of water accessible in these locations while also achieving appropriate levels of development, stability and food security.

The water footprint of the product that can be used to inform policymakers about how much the water is traded through the product's exports and imports (Kar et. al., 2014). In order to fulfil the expanding demands for food while utilising the limited freshwater available resources, there is an increasing interest in enhancing crop water productivity.Therefore, the challenge is to produce more yields with less water and so reduce thewater footprint of each unit of the crops produced (Mekonnon and Hoekstra, 2104). To meet the growing demand for food, agricultural water productivity must be increased, especially in arid and semi-arid countrieswhere water resources are limited.

The total amount of freshwater utilised during the whole supply chain to generate the product is known as the product's water footprint. This multidimensional indicator shows water consumption rates by source as well as amounts and types of pollutants. The water footprint is divided into three categories: green, blue, and grey. Consuming green water resources is referred to as leaving a "green water footprint" (rainwater insofar as it does not become run-off). The usage of blue water resources (groundwater and surface) across a product's supply chain is referred to as the blue water footprint. The amount of fresh water needed to remove the pollutants from the environment given existing ambient water quality standards and natural background concentrations is known as the "grey water footprint," which also refers to pollution.(Hoekstra et. al.,2009).

In order to determine the effectiveness of management of water resources for the agriculture sector, this study analyses virtual water commerce to measure the water footprint of crops, primarily focusing on primary crops cultivation in India. Additionally, it contrasts the water footprint of agricultural crops with the water footprintworldwide.

1.2. LITERATURE REVIEW

Mekonnen and Hoekstra (2010) explained that based on the blue, green and grey water footprints of global crop production, vegetables (300 m3/tonne), fruits (1000 m3/tonne), cereals (1600 m3/tonne), and pulses (4000 m3/tonne) have the highest global average water footprints per tonne of crop. Kim and Kim (2019) added that food security necessitates demand-driven water systems of agriculture-related products utilising water footprints since food could not be grown without freshwater. Muratoglu (2020) explained that a number of nations are suffering water scarcity as a result of the uneven distribution of water supplies and rising demand.

Mekonnen and Lenses (2020) expected that by 2090, the effects of climate change and land use changes use might result in an increase in the water footprint of up to 22%. As a result, action needs to be taken to improve water sustainability and protect the ecosystems that depend on it. Among the activities are those to increase water productivity, set standards, limit each watershed's water footprint, switch meals to reduced foods, and decrease food waste. Hoekstra and Chapagain (2010) explained according to the findings, the average annual worldwide the water footprint is 7450 Gm3 or 1240 m3/cap/yr. The USA and China have very different average water footprints, with the USA's being 2480 m3/cap/yr and China's being 700 m3/cap/yr. Accordingto Chu et al.,(2017) cotton crops in the Hebei southern plains of North China had the greatest water footprint intensities, whilst vegetables had the lowest. Thaler et. al. (2017) found that sunflower, grain maize and winterwheat had the greatest WF in semi-arid regions. Additionally, colder weather were really the main factor limiting crop yield potential in more humid regions, where cold temperatures were the key factor limiting crop production potential and typically led to higher WFs as a result of lower yields. Kahramanog et al.(2020) says that sustainable development in agricultural production has become a global ambition. To be effective, researchers, farmers, policymakers, civic society, and the private sector must work together to develop an integrated, evidence-based approach. In the same way, In the same way, Reis et al.(2020) indicated that in the state of Sao Paulo in Brazil, sugarcane is the most significant crop. This crop had a low water footprint (166.2 m3/tonne) compared to other crops because of its high local yield. Additionally, the tomato crop displayed promising results when measured against global standards. This shows that the region around SaoCarlos is a good place to raise tomatoes and sugarcane. Contrarily, compared to worldwide norms, the water footprint of groundnut and rice crops is large. This can indicate a lack of certain crops in the area.

2. MATERIAL AND METHODS

2.1. Study area

India shares borders with China, Nepal, Bhutan, Pakistan, Bangladesh, and Myanmar in South Asia. The Arabian Sea on the west and the Bay of Bengal on the east encircle the southern region of India. India is located in the Himalayan Range in the north, bordering the Chinese border. The Indus, Ganges, and Brahmaputra rivers all originate in this hilly region.

In this study, all states of India were included except some administrative divisions are not included; Arunachal Pradesh, Chandigarh, Daman & Diu, Manipur, Dadra & Nagar Haveli, Goa, Lakshadweep Island, Nagaland, Sikkim, Tripura, Meghalaya because of little area for agriculture and not much data available andnot much precipitation reported.

2.2 Selected crops

In India, there are three seasons for cultivating crops and their production that Kharif, Rabi and Perennial crops. In this current study few crops have been taken into account, 11 selected crops which contribute to major agriculture production given in Table 1.

Table 1: Major Indian crops selected for the study.

Kharif Season	Rabi season	Perennial crops
Rice	Rice	Sugarcane
Maize	Wheat	
Groundnut	Maize	
Soyabean	Groundnut	
Cotton seeds	Rapeseed and mustard	

*2.3.*Climatic data

The data related to evapotranspiration was calculated in CROPWAT 8.0 (FAO). In this, it is calculated per month with the FAO Penman-Monteith method. Climatic data has been taken from CLIMWAT (FAO) which is the climatic database of CROPWAT. Total rainfall and effectiveness have been again taken fromCLIMWAT (FAO).

2.4.Crop parameters

Data on the length of the various growing stages, seeding and harvesting times, and crop coefficients aretaken from Allen et. al. (1998) and Agricultural statistics at a glance 2020. To make this analysis possible,only two sets of crop parameters for the entire country are created: wet season (Kharif), which runs from June to December, and dry season (rabi), it runs from December to April.

2.5.Methodology

In this study, the water footprint of selected crops of states was studied using the methodology of the Water Footprint Assessment manual given by Hoekstra et. al (2011). The total water footprint of the process of growing crops (WF_{proc}) is the sum of the green, blue and grey components:

$WF_{proc}[s]$ = $WF_{proc,green}[s]$ + $WF_{proc,blue}[s]$ + $WF_{proc,grey}[s]$ (volume/mass)

The green component in the process water footprint of growing crop ($WF_{proc,green}$,m^3 /ton) is calculated as the green component in crop water use (CWU_{green}, m^3/ha) divided by the crop yield (Y, ton/ha). Because there is no adequate data for calculating the grey water footprint, the natural quantity in the receiving water body is considered to be zero.

The blue component ($WF_{proc,blue}[s]$,m^3/ha) in a similar way:

$$WF_{proc,green} = \frac{CWU_{green}}{Y}$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y}$$

Crop water use (CWU, m^3 /ha) are calculated by the accumulation of daily evapotranspiration (ET,mm/day) over the complete growing period:

$$CWU_{green} = 10 * \sum_{d/0}^{lgp} ET_{green}$$

$$CWU_{blue} = 10 * \sum_{d/0}^{lgp} ET_{blue}$$

Which ET_{green} represents the green water evapotranspiration and the ET_{blue} represents the blue water evapotranspiration. In the above equation, factor 10 means to convert water depth in millimetres into water volume per land surface in m^3/ha. In addition, in the above equation, the summation is done from the first day of sowing till the day of harvesting “lgp” (length of the growing period).

Evapotranspiration from land can be quantified or calculated using an empirical formula-based model. CROPWAT8.0 model developed by the Food and Agriculture Organization of the United Nations was used to estimate the crop evapotranspiration, which is based on the Penman- Monthieth method described by Allen et al. The estimation was carried out in optimal conditions. Effective precipitation (P_{e11}), crop water requirements (CWR), and irrigation requirements are all calculated using the model (IR). The crop coefficient is multiplied by the reference evapotranspiration (ETo) to get the CWR (Kc):

$CWR = ET_2 * K_c$

The K_c values of the crops used in this study were taken by Allen et. al. and when the CWR are fully (optimal conditions or no water limitations to crop growth), ET_c the will be equal to CWR:

ET_c = CWR

Green and blue water evapotranspiration (ET_{green} & ET_{blue}) can be estimated as follows:

$ET_{green} = min(ET_c\ , P_{e11})$

$ET_{blue} = max(0, ET_c - P_{e11})$

Green water consumption ET_{green} is calculated by the amount of rainfall data that contribute to crop water usage (such that it reaches the plant's roots and the plant can benefit from it) is estimated. Bluewater consumption (ET_{blue}) includes the total crop water use (ET_c) minus the amount of effective rain. The CROPWAT model was used to estimate effective rain and also total (ET_c), and the model's results can beused to assess the pattern of green and blue waters, each of which is distinct.

3. RESULTS

The green water footprint and the blue water footprint of 11 crops have been calculated for the different states of India. Separately crops have been calculated in all states of India covering almost 80 % of the Indian states.

3.1. Virtual water content of rice crop

The virtual water content of rice crop is explained because in India, rice is only crop which has more contribution towards water use. Virtual water content of rice is explained here:

Virtual water content of rice varies 7465 m^3/ ton in Madhya Pradesh to 8588 m^3/ton in

Rajasthan, with an average of 8026 m3/ton. This difference in various states of India in crop output is due to the differences in crop yield which is correlated with the percentage of crop area under irrigation. As we can see, Delhi and Haryana have major differences in the virtual water content of rice, because in India there are two types of rice Basmati and Non – basmati rice, and in this study, we didn't make any differences betweenthese rice.

Mainly basmati rice requires more water than basmati rice. The total water footprint of rice in different states are shown in fig 1.

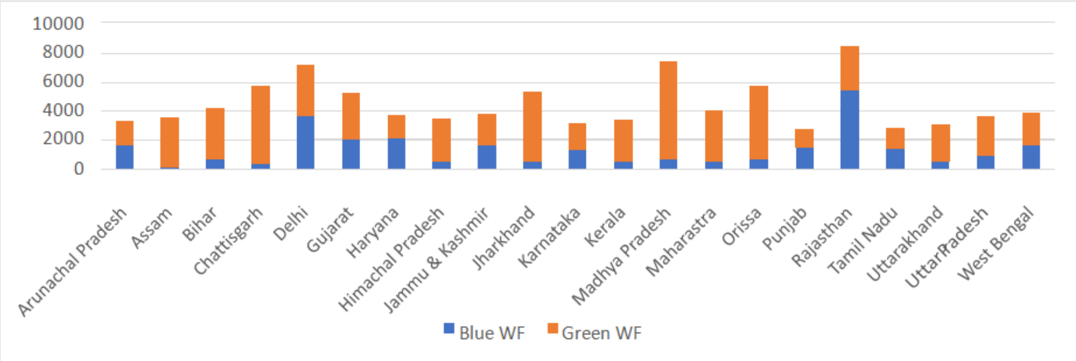

Figure 1: Virtual water content of rice in different states are shown in figure which is given in m3/ ton. In this study, virtual water content is equivalent to water footprint of crops.

3.2. Water footprint of India

The water footprint of India related to water consumption in agriculture crops is 640 billion m^3/ yr. Taking approximate one billion people living in India, the average water footprint is 640 billion m^3/year. The consumption of total water footprint is shown in Table 2.

Three states of India with the highest water footprint per capita are Orissa and the Chattisgarh in eastern India and the Rajasthan in western India. Few states with the lowest water footprint are in the southern states of Tamil Nadu and in Kerala and in Delhi. Especially, in the case of Kerala, the main reason for thelowest water footprint is the exclusion of coconut.

Due to the high number of people living in urban areas, Delhi has a small water footprint. The reported consumption is low and the intermediate consumption is high in Delhi because a big portion of the cropsis consumed as semi-processed and processed goods. The variation in the water footprint per capita is shown in figure 2.

Table 2: Component of water footprints related to the consumption of agricultural commodities.

States	Blue	Green	Total	Exp	SC
Arunachal Pradesh	27	49	76	6	70
Assam	0	17	17	0	17
Bihar	15	25	40	0	40
Chattisgarh	2	26	28	4	24
Delhi	0	0	0	0	0
Gujarat	12	27	39	7	32
Haryana	14	13	27	15	12
Himachal Pradesh	0	2	2	0	2
Jammu & Kashmir	2	4	6	0	6
Jharkhand	3	10	13	0	13
Karnataka	14	31	45	3	42
Kerala	0	4	4	0	4
Madhya Pradesh	15	46	61	16	45
Maharastra	17	59	76	10	66
Orissa	3	31	34	0	34
Punjab	18	15	33	23	10
Rajasthan	31	31	62	10	52
Tamil Nadu	15	19	34	4	30
Uttarakhand	3	4	7	6	1
Uttar Pradesh	57	64	121	21	100
West Bengal	11	33	44	4	40
Total	259	510	769	129	640

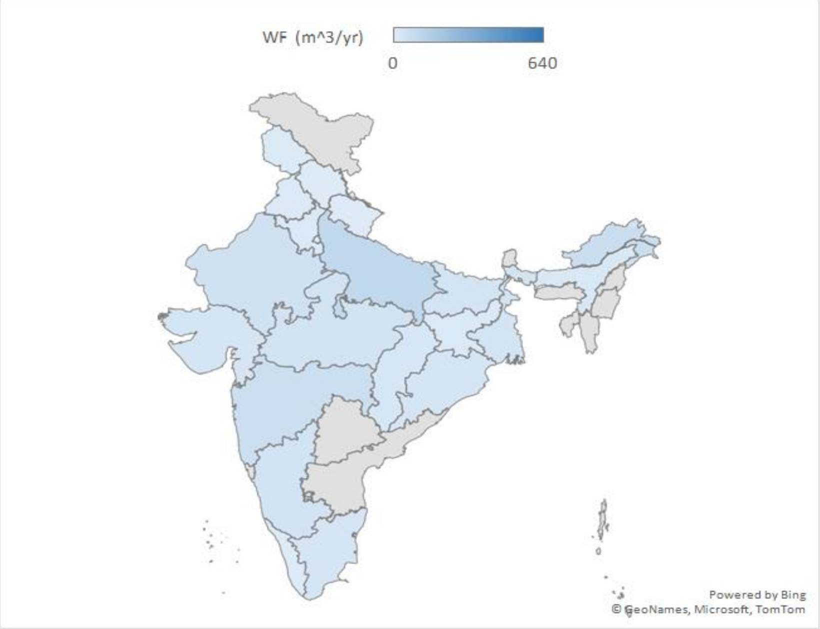

Figure 2: The water footprint of India in various states is shown in the figure. Variation in water footprintper capita in India in m^3/ cap/yr.

3.3.Water footprint by crops of states of India:

The entire water footprint can be broken down into the water footprints of the various crops in addition to the differentiation between the blue, green, and grey water footprints. The amount of rice or wheat consumed as a staple diet in a state, as well as the amount of oil and sugar consumed, all have a substantialimpact on the water footprint. The average virtual water content of the crops that are eaten in a state determines the size of its water footprint. The figure 3 shows the amount of water used and consumptionpatterns are related.

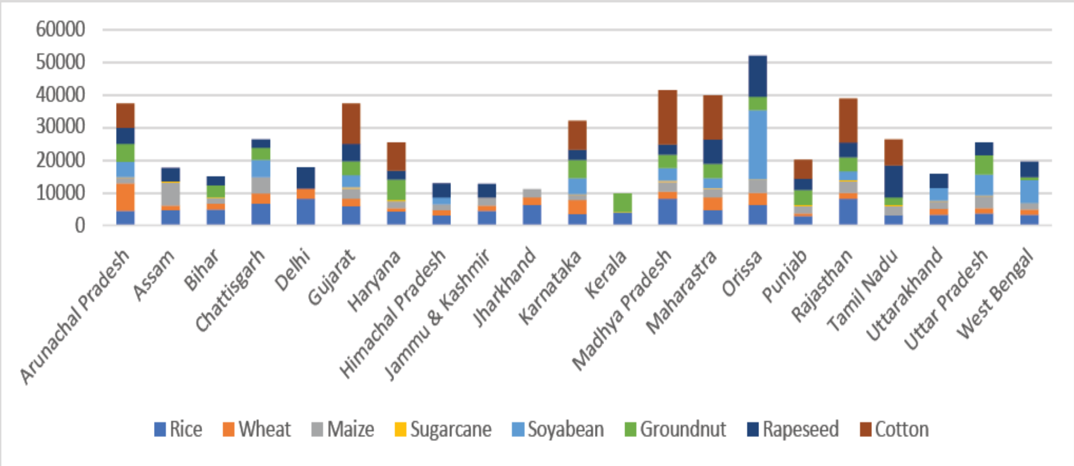

Figure 3: Water footprint of the various crops in various states of the India.

3.4.Comparison of $WF_{green3blue}$ of states of India with the global $WF_{green3blue}$

In this study, results obtained from the study of Mekonnen and Hoekstra for the results of the global water footprint of the agricultural crops are used in this study. For the comparison purpose, the average of globalwater footprint of green and blue water footprints of the crops are taken as shown in fig 4.

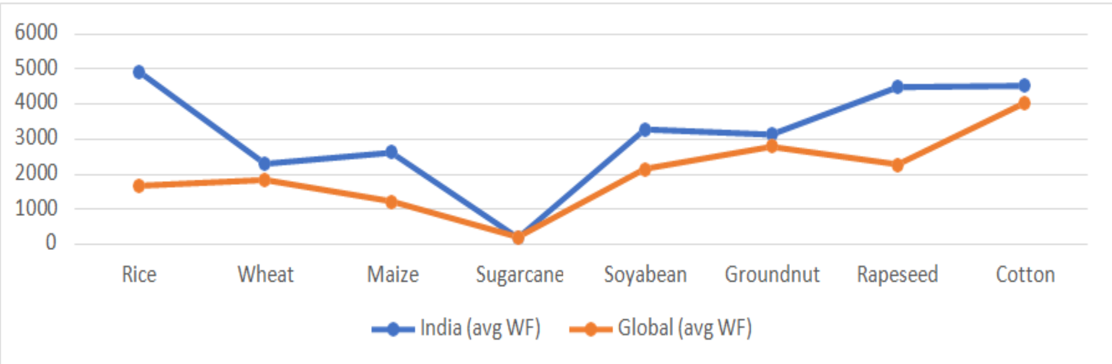

Figure 4: Comparison of $WF_{green3blue}$ of states of India with the global $WF_{green3blue}$.

Figure 4 shows the average water footprint of blue and green water footprints of agricultural crops of Indian crops found more than the global water footprint. On the other hand, there are few crops found with less water footprint than the global average water footprint such as sugarcane while some of them found more average water footprint than the global average water footprint such as wheat, rice, maize etc.

4. DISCUSSION

Agricultural land in India is mainly cultivated in two main seasons that is Kharif and Rabi season, and sometimes there is a third season which is perennial crops which is cultivated in a whole year, for example, sugarcane. The present cropping intensity in India is almost 136%. Approximately 51% of India's land surface is already under cultivation, compared to 11% of the global average.

This study mainly focuses on calculating the water footprint of selected primary crops for the season of both the Kharif and Rabi seasons and perennial crops. Table 2 summarizes the results of the green water footprint and the blue footprint of the agricultural crops. It is clear from the result that the value of WF_{green} ranges between 2 and 64 m^3/ton and the value of WF_{blue} ranges between 2 and 57 m^3/ton. The overall average of WF_{blue} is 25 m^3/ton and of the WF_{green} is 453 m^3/ton. In addition, found that WF_{green} have more values than the WF_{blue} for all selected crops and because of low rainfall, agricultural land is not fully irrigated in few states of India And because of shortage of rainfall, in few states of India WF_{green} have much higher values than WF_{blue}.

5. CONCLUSION

To fulfil the rising demand for food, it is crucial to increase agricultural water production, especially in the countries with the second largest populated country in the world i.e. India, which suffers from limitedwater resources. The aim of this present study is to assess the water footprint categorised into the blue andgreen water footprints of the Indian states. In addition, comparing the water footprint of blue and green WF with the global average water footprint as the results are found by the Mekonnen and Hoekstra. The methodology of assessment of the water footprint was adopted in this study from Hoekstra et. al. 2011. The study area covers almost 85% of the country's cultivated area.

Climatic data are taken from the CLIMWAT model which is the database of the CROPWAT 8.0 model. The evapotranspiration values haven taken from CROPWAT 8.0 model and as well as effective rainfall is also taken from CLIMWAT. In addition, crop parameters were taken from Allen et. al. and agriculturalstatistics at a glance 2020.

The results show that the average value of WF_{blue} and WF_{green} ranges between 25 m^3/ton and 453 m^3/ton. The water footprint of India related to water consumption in the selected agriculture crops is 640 billion m^3/ yr, as considering approx. one billion population of the country. In addition results shows thatthe highest water footprint per capita are Orissa and the Chattisgarh in eastern India and the Rajasthan in western India. Few states with the lowest water footprint are in the southern states of Tamil Nadu and inKerala and in Delhi.

In addition, result related to the comparing the average blue and the green water footprint of the Indian states with the global average blue and green water footprint, found that the average $WF_{green3blue}$ of Indian states of few crops found more values than the global average $WF_{green3blue}$ such as rice, wheat, maize, cotton seeds while few crops found less vlues than the global average $WF_{green3blue}$ such as sugarcane.

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