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Valuing Water Used for Food Production in India

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Abstract

With an estimated water footprint of 790 billion cubic metres for food production in India in the year 2007-08 and given the high average requirement of producing one kilogram of the major staples consumed in the country, assuring the sustainability of the national water resources is a matter of concern in the country. The present research study attempts to provide an analytical estimate of the water footprint along with the average quantity of water required for the production of major cereals, pulses, oilseeds, vegetables, fruits and sugarcane. The economic value of the water used in their production is estimated to serve as a pointer to the optimal use of water. A value added approach has been used to do so and water requirements for different crops have been estimated using the crop water requirement model.

Keywords: Water valuation, agriculture, evapotranspiration, water footprint

Water is a basic human need and a complex natural system. Understanding water as a natural resource is evolving in both academics and applications. However, considering water as an 'economic and social good' helps simplify the value of a complex resource. The concept can be of help in decision making, though inadequate since the social benefits and costs are not easily quantifiable (Iyer, 2003).

Fresh water has domestic, agricultural and industrial uses. These are alternative sectors competing for water. They have different objectives and are prioritized, temporally and spatially based on need and demand. The economic value of water used varies across its use in these sectors. Water use in domestic and industrial sectors is easier to quantify, since there is no other natural /biological system that operates between the input and output stages. In the case of agriculture water use by biological systems like crops, the influence of environmental factors needs to be accounted for while estimating water use.

Three measures are generally used, namely Withdrawal, Application and Evapo-transpiration but these are not inter-changeable. Withdrawal is the quantity of water drawn from surface or ground water sources for the purpose of irrigation. Application is the quantity of water delivered to the field for irrigation. The latter includes loss of water during storage and transport but not the application losses. Evapotranspiration is the quantity of water actually used by the plant for evaporation, transpiration and growth and is estimated through water requirement models. It has been found that the crop water requirement (CWR) amount of evapo-transpiration that takes place is a better indicator of water used for production than the other measures (Hoekstra, 1998).

The volume of fresh water used to produce a product, measured at the place where it is produced, is also its water footprint (Hoekstra and Hung, 2002) or the virtual water content of the product (Allan, 1998). It acts as a measure of water productivity in agriculture and indicates the efficiency in allocation of water. The CWR also provides a simple means by which to arrive at the economic value of water used for crop production. Linking CWR to consumption patterns indicates the environmental impact of consuming a product.

This study has lead to a question of whether 'a return to traditional pattern of production and consumption of food in terms of production areas/regions and seasons imply greater sustainability for our water resources'. This paper attempts to find a logical answer by way of estimating the water footprint of food production in

India. The average quantity of water required has also been estimated and an economic value attached to such water use.

Database and Methodology

The water used for production of a crop is its specific water demand. Specific water demand (SWD) for each crop is estimated as the average water required for producing the crop in a state and as per crop type (Hoekstra and Hung, 2003).

$$SWD_C = CWR_C / Y_C \quad (1)$$

CWR is the crop water requirement (m^3ha^{-1}) calculated from the accumulated crop evapo-transpiration, ETc (mm/day) over the complete growing period. The crop evapotranspiration ETc follows from multiplying the reference crop evapotranspiration ET0 with the crop coefficient Kc

$$ETc = K_C * ET_0 \quad (2)$$

The only factors affecting ET_0 are climatic parameters. The reference crop evapotranspiration ET_0 is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 12 cm, a fixed crop surface resistance of 70 sm-1 and an albedo of 0.23. This reference crop evapotranspiration closely resembles the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water (Smith, Allen, Monteith, Perrier, Pereira and Segeren, 1992). Reference crop evapo-transpiration is calculated on the basis of the FAO Penman-Monteith equation (Allen, Smith, Perrier and Pereira, 1994). The crop coefficient accounts for the actual crop canopy and aerodynamic resistance relative to the hypothetical reference crop. The crop coefficient serves as an aggregation of the physical and physiological differences between a certain crop and the reference crop.

The economic value of water used for food production has been estimated through a value added method suggested by Agudelo and Hoekstra (2001). Considering each crop as an individual sector, the economic value of specific water demand was estimated as

$$EVW_C = (Y_C * P_C)/CWR_C \quad (3)$$

Where c is the crop considered, EVW is the economic value of water (₹/tonne), Y is the actual yield (tonne/ha), P is the price (₹/tonne) and CWR is the crop water requirement for crop production (m^3/tonne).

The climatic data required was accessed from FAO databases. CLIMWAT is a climatic database published jointly by the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO. There are 167 Stations from India for which climate data has been made available through CLIMWAT database. The Stations are distributed across the country in 22 States/UTs and cover almost all agro-climatic zones in the country. It provides data for seven climatic parameters, namely mean daily maximum and minimum temperature, mean relative humidity, mean wind speed, mean sunshine hours per day, mean solar radiation, monthly rainfall, and monthly effective rainfall. The crop water requirement was calculated from CROWAT using the reference evapotranspiration and climatic data extracted from CLIMWAT.

The staples along with important vegetable and fruit crops have been taken up for the study. Crops included are rice, wheat, maize among cereals; Bengal gram, *tur* and soybean among pulses; groundnut, sesamum, rapeseed and mustard and sunflower among oilseeds; onion and potato among vegetables; mango and banana among fruits and sugarcane. These cover an average of around 80 per cent of the gross cropped area during the five years between 2004-05 and 2008-09. They also constitute the major component of a vegetarian diet in India. The data for area, and production of these crops during the above mentioned period was accessed from the Department of Agriculture and Cooperation, Ministry of Agriculture and National Horticulture Board databases. Prices for the year 2008-09 for all crops were collected from the Department of Agriculture and Cooperation. Wherever required the Minimum Support Price for crops was also used. Prices for horticulture crops were based on their wholesale prices in major markets collected and disseminated by the National Horticulture Board.

Results and Discussion

Every kilogram of rice was produced using an average of 3465 litres of water. A kilogram could be produced in Karnataka with 1581 litres of water, whereas it required 8235 litres in Madhya Pradesh. An average of 1854 litres of water was required to produce a kilogram of wheat and 2092 litres to produce a kilogram of maize. These quantities are the water footprint of these products in their production location. It also is a measure of efficiency of water use in the production of these crops. The most efficient water user in rice, wheat, potato and mango was found to be Punjab. Himachal Pradesh used the least amount of water in the production of Bengal gram and soybean. Onion and rapeseed and mustard were found to require the least amount of water in Jammu and Kashmir. Every kilogram of maize was produced with just 761 litres of water in Goa, and 2478 litres was used to produce a kilogram of groundnut in Tamil Nadu. Table 1 indicates the quantity of water required to produce a kilogram of various food produces. A significant difference in quantity of water used for the same crop can be observed between states. The range varies from a low of 400 litres in onion and a high of 39,557 litres in soybean.

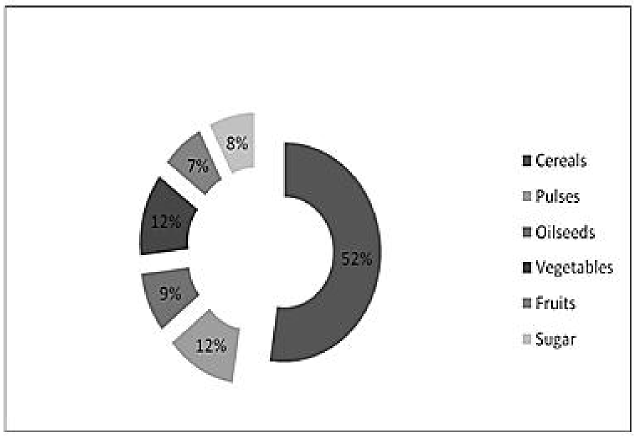

Fig. 1: Shares in water footprint

The footprints of individual produces can be converted into the water footprint for food production in the country. Food production in India used around 791.10 billion cubic metre (BCM) of water in 2007-08. Figure 1 depicts the share of crop produce groups in the total water footprint of food production. More than half the water used in producing food (52 %) was used for producing cereals (415 BCM). Pulses and vegetables used around 95 BCM each (12 %), followed by oilseeds (70 BCM or 9 %), fruits (56 BCM or 7 %) and sugar (60 BCM or 8 per cent). Uttar Pradesh was found to account for around 12 % to the water used for food production, followed by Maharashtra (10 %). Andhra Pradesh, Madhya Pradesh and Bihar accounted for 8 % each. With a population of 1.20 billion, the per capita water footprint of food production in 2007-08 was estimated at 65,925 litres.

The economic value of water in its use for crop production depends on the yield of the crop, the price of the product and the CWR. Yield and price positively influence the economic value, whereas a higher CWR reduces the economic value. Economic value of water was the highest when used for production of onion. The value of water was lowest when used for sugarcane production. Water was valued ten times more when used in the production of onion than when used for production of any of the cereals, pulses or oilseeds. The economic value of water used in producing food crops is presented in Table 2.

Water availability for agriculture use is expected to decrease as a result of global warming and climate change which are expected to exacerbate the vagaries of monsoon. Increasing demand for food and other products is bound to increase and so is demand for agricultural water. Addressing water deficits through supply side measures like increasing irrigation facilities would prove inadequate besides involving substantial economic, social and environmental costs. Increasing water use efficiency of crops through means like use of improved varieties and hybrids, scheduling of irrigation, optimizing use of other inputs would help but would be required to be used over a large geographical area to have sufficient impact. Hence, these should also be complemented with demand side measures that will help to reduce agricultural water footprint.

There are two possible and feasible demand based strategies. First is to plan production taking into consideration regional water availabilities and second is to change consumption patterns and behaviour. Understanding the water requirement for growing crops and their economic value in a particular location in a particular season forms the basic building block for both. Efficiency in allocation of water can be increased by planning production, spatially and temporally. The economic value of a crop provides useful indication for such planning, since it can help optimize profits and allocate water optimally through appropriate choice of crops that can be grown. Knowing the water footprint of a product and the impact it leaves on local water resources can be used to induce changes in consumption patterns that are favourable for water savings.

Planning for rice production with the objective of minimizing water footprint implies growing rice in the States where the average water requirement is small. The evidence from this research points to Punjab, Karnataka, Tamil Nadu, Andhra Pradesh and West Bengal. It is known that these are States on river basins and are endowed with surface water resources. The seasonal difference in water requirement also indicates that *kharif* rice in Punjab and *rabi* rice in other States is favourable for water efficiency. They also prove to be the season in which rice has been traditionally cultivated in these regions. The economic value of water in these States is also higher for rice than in others, proving to be remunerative from the farmers' view point. Similar assessment in other crops also points in this direction.

Table 1: Average water requirement per unit production

State	Rice	Wheat	Maize	B. gram	Tur	S.bean	G.nut	Rape and Mustard	S.flower	Sesame	Onion	Potato	Mango	Banana	S.cane
Andhra Pradesh	2340	4779	1143	2986	13179	2589	4265	6077	4703	15881	251	355	2613	844	194
Bihar	7717	1847	1855	3523	5345		7225	2290	1814	3468	179	193	2061	587	331
Chhattisgarh	4865	3515	2654	4351	11755	3386	3135	5724	4466	8068	230	296	4777	852	4868
Goa	2230	—	761	—	—	—	2557	—	—	—	—	—	3588	2299	223
Gujarat	4273	1578	4651	4807	7815	8759	2928	2059	—	9627	193	191	3120	519	220
Haryana	2749	726	1930	4013	6586		6162	1636	1270	8590	160	172	2707	—	239
Himachal Pradesh	3172	830	1653	1563	11550	2087	3872	2389	—	4472	113	152	10697	4753	422
Jammu & Kashmir	3116	649	2862	3202	—	—	5393	1177	—	6591	92	293	3935	—	2671
Jharkhand	4667	1818	2129	—	8309	41644	—	3698	13509	8022	191	347	2782	1132	367
Karnataka	1581	5133	1477	7687	10583	6156	5922	8862	5817	4804	304	645	1847	1020	158
Kerala	2439	—	—	—	—	—	4215	—	—	7069	—	160	2674	2885	95
Madhya Pradesh	8235	1809	2980	3609	8521	3781	3768	2186	4734	7036	225	267	1870	477	325
Maharashtra	3819	2588	1948	5615	8901	3507	3729	14145	4942	10726	282	439	12185	435	194
NE States	2948	1825	1917	3471	5207	2564	2738	2751	2097	12475	140	314	1911	1329	221
Odisha	4127	2498	1947	5538	8012	—	3468	22130	2539	8725	427	303	6559	1860	214
Punjab	1999	466	1328	2112	6852	—	4932	3977	1472	12481	103	113	1193	—	201
Rajasthan	5719	1167	3789	5047	11335	3950	3423	5351	2406	7767	378	428	1382	1045	284
Tamil Nadu	2236	—	1710	5697	10558		2478	—	2038	14451	492	404	3323	504	131
Uttar Pradesh	2967	1009	1869	3116	6684	5572	5342	4330	1261	10043	203	133	1285	681	208
Uttarakhand	2605	1027	2307	2335	6823	2467	2849	5962	—	2834	208	186	4131	—	167
West Bengal	2465	1265	1126	3031	6816	6113	2482	4087	1611	3861	203	156	2052	884	139
All India	**3632**	**1918**	**2102**	**3983**	**8602**	**7121**	**4044**	**5491**	**3645**	**8349**	**230**	**277**	**3652**	**1300**	**565**

Table 2: Economic value of water

State	Rice	Wheat	Maize	B.gram	Tur	S. bean	G.nut	Rape and Mustard	S.flower	Sesame	Onion	Potato	Mango	Banana	S.cane
Andhra Pradesh	4.2	2.1	7.0	7.2	2.1	5.4	5.5	3.0	4.7	2.2	53.3	11.8	7.3	10.3	10.1
Bihar	0.8	5.2	4.1	6.8	4.2	—	3.1	9.0	12.2	5.7	86.7	29.9	9.3	16.2	4.8
Chhattisgarh	2.6	3.8	3.2	5.9	4.1	5.4	7.6	5.1	4.7	5.3	61.7	36.7	5.7	6.8	0.4
Goa	3.1	—	11.0	—	—	—	8.2	—	—	—	—	—	5.3	3.8	4.4
Gujarat	2.1	7.0	1.6	4.5	3.6	1.6	8.0	10.7	—	6.6	77.0	43.4	8.5	19.1	8.8
Haryana	6.7	15.3	4.9	5.4	4.3	—	3.7	13.9	20.6	3.4	94.2	36.7	5.4	—	9.3
Himachal Pradesh	3.4	12.7	5.3	21.2	1.7	16.8	9.4	14.9	—	12.7	156.0	84.0	2.7	2.4	1.9
Jammu & Kashmir	7.4	16.9	3.7	5.0	—	—	7.4	24.2	—	8.3	203.7	39.4	5.2	—	0.5
Jharkhand	1.7	5.5	3.9		0.0	0.3		4.9	1.6	3.4	79.9	12.1	8.8	9.1	2.2
Karnataka	6.1	2.6	5.6	2.7	2.8	2.8	3.9	2.0	3.9	9.9	51.9	18.3	5.8	8.7	8.3
Kerala	3.9	—	—	—	—	—	5.0	—	—	3.9		26.1	7.2	5.1	15.8
Madhya Pradesh	1.5	6.3	2.6	6.0	3.8	5.0	5.8	9.6	4.7	6.6	58.8	30.8	16.4	14.0	5.5
Maharashtra	2.3	4.2	3.7	3.6	3.0	5.5	4.6	1.3	4.3	4.1	51.8	9.6	2.9	17.2	4.2
NE States	2.9	6.2	4.6	11.5	7.5	10.3	7.7	8.0	10.6	4.1	188.8	36.7	17.2	7.0	4.7
Odisha	1.9	4.8	4.0	2.9	2.5	—	6.7	1.3	8.7	3.5	36.9	14.0	4.1	7.5	4.4
Punjab	6.7	20.7	6.3	11.3	2.9	—	4.3	6.0	15.0	2.9	152.9	36.9	20.0	—	13.0
Rajasthan	1.4	16.3	2.0	4.6	3.2	3.5	6.3	4.3	9.2	7.1	31.2	20.2	14.4	6.7	7.8
Tamil Nadu	3.9	—	4.9	4.7	2.8	—	9.8	—	10.9	2.6	35.9	28.2	5.7	43.2	15.7
Uttar Pradesh	2.8	9.7	3.4	6.7	4.8	3.1	4.8	5.0	17.6	5.2	73.5	31.0	13.4	8.3	6.4
Uttarakhand	3.1	9.7	3.6	6.9	2.9	5.6	7.4	3.0	—	9.7	53.7	22.5	4.1	—	4.9
West Bengal	3.1	9.4	7.5	9.3	2.9	2.3	8.5	6.2	13.8	7.1	84.1	37.9	11.3	6.7	14.4
All India	**2.2**	**5.2**	**4.0**	**4.0**	**2.3**	**2.0**	**5.2**	**3.3**	**6.1**	**3.3**	**63.3**	**15.1**	**5.3**	**6.7**	**1.4**

For the production of high value crops like fruits and vegetables, such strategies would prove to be especially profitable for the farmer and beneficial for the environment.

Conclusion

In view of the above discussion, it may be logically concluded that the production of crops that were traditionally grown in a region during an appropriate season and emphasis on the consumption of such locally produced seasonal crops would result in reducing the per capita water footprint. Such systems of production and consumption will be more sustainable in terms of water use. Tweaking the price support system taking this into consideration would prove beneficial, both for the farmer and the environment. It could be used not only as a tool for ensuring remunerative prices but also for increasing efficiency in allocating water for food production.

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