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Water footprint of horticultural crops

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Abstract
The world freshwater resources throughout the world have become scarcer during the past decades due to an increase in population and economic activity and a subsequent increase in water appropriation. The 'water footprint' concept was developed in order to have an indicator of 'water use' in relation to its consumption (Hoekstra, 2003). The water footprint concept, sources and methodology come from the Water Footprint Network (WFN). The concept was created by Dr. Arjen Hoekstra along with the others at the WFN. Water footprint is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted (Hoekstra *et al.*, 2011). Water footprint can help to identify products that can be risky to produce at a certain location due to water scarcity and to achieve a more sustainable and equitable use of freshwater. Water footprint can be grouped into three categories, *viz*., green, blue and grey. The amount of rainwater required (evaporated or used directly) to make an item is called green water footprint. The blue water footprint signifies the amount of surface water and ground water required (evaporated or used directly) to produce an item. The amount of fresh water required to assimilate pollutants to meet specific water quality standards is termed as grey water footprint. A water footprint can be calculated for any well-defined group of consumers (e.g. an individual, family, village, city, province, state or nation) or producers (e.g. a public organization, private enterprise or economic sector). One can also calculate the water footprint of a particular product. Per year water footprint of an Indian individual is 1089 m^3 compared to global average of 1385 m^3, whereas for an individual of the US, it is 2842 m^3. Consumption of agricultural products determines the global water footprint related to consumption (Mekonnen and Hoekstra, 2011). Among agricultural commodities, global water footprint of vegetables and fruits are 322 m^3/ t and 967 m^3/t, respectively. In India, the total water footprint for vegetables and fruits are 29 billion cubic meter and 13 billion cubic meters, respectively (Jayaram, 2016). Water footprints of some vegetables and fruits as well as their derived products are quite high, which is a matter of great concern. Water footprint of such exhaustive horticultural crops should be reduced for sustainability of water and horticultural crop production. This can be achieved by increasing production, reducing harmful evapotranspiration or enhancing effective use of rainfall. Organic farming and product substitutions are other options which can help in reducing water footprint of horticultural crops.

Keywords: WFN; sustainable; water footprint**;** crop production

Introduction
Global freshwater withdrawal has been increasing at an alarming rate. With a growing population, coupled with changing diet preferences, water withdrawals are expected to continue to increase in the coming decades (Liu *et al*., 2008) [8]. With increasing withdrawals, also consumptive water use is likely to increase.

The idea of considering water as 'a commodity' is highly debatable. The Dublin Conference of 1992 concluded that 'clean fresh water is scarce' and thus should be treated as an economic good. It leads to examining water from the supply and demand sides separately. The consideration also professes that water should best be left to market forces to take care of issues of distribution across space and time. Considering water as an 'economic and social good' slightly improves the scope but also proves inadequate (Iyer, 2003) [6] since the social benefits and costs are not easily quantifiable. Such utilitarian approaches fall short in accounting for the innumerable alternative uses of water and makes prioritising between them difficult. Economic valuation of water as a natural resource is difficult and the market mechanism fails to price it at socially optimal levels leading to huge social costs and price of water does not reflect the cost of water used for an activity. To encounter all these problems, the 'water footprint' concept was developed by World Footprint Network (WFN) in order to have an indicator of water use in relation to its consumption. The main person behind all this was Dr. Arjen Hoekstra, Professor in Water Management, University of Twente, the Netherlands.

Worldwide, the largest freshwater consumer is agriculture, consuming more than 70% of the world's freshwater (Lucrezia *et al*., 2014) [9]. Water resources have been heavily exploited by agriculture worldwide. Therefore, a proper knowledge on water footprint of agricultural products is quite necessary.

Water footprint

Water footprint can be defined as the total volume of fresh water that is used to produce the foods and services consumed by the individual, business or nation (Hoekstra, 2008) [4].
It is a measure of humanity's appropriation of fresh water in volumes of water consumed and/or polluted (Hoekstra *et al*., 2011) [5, 11].

Water footprint is a multi-dimensional indicator showing

- HOW MUCH (Volume)
- WHEN (Time of the year e.g. dry season)
- WHERE (Location)
- TYPE (Freshwater, rainwater, freshwater needed to dilute water pollution to an acceptable level) of water is used for the production of a product over the whole supply chain.

Necessity of water foot printing

Water is renewable and constantly total amount of water is cycling throughout the environment. But, Freshwater resources distribution is characterized by:

- Strong regional differences
- Annual and seasonal variation

Due to the dependency and temporary limitation of freshwater a water footprint can help

- Identify products that can be risky to produce at a certain location and definite period of time due to water scarcity
- Achieve a more sustainable and equitable use of freshwater

Categories of water footprint

There are three categories/types of water footprint, *viz*., Green, Blue and Grey water footprint.

1. Green water footprint

- The amount of rainwater required (evaporated or used directly) to make an item
- Relevant for agricultural, horticultural and forestry products
- It
  - evaporates & transpires from fields & plantations
  - incorporated into the harvested crop/product
  - does not run off
  - is stored in soil temporarily stays on top of the soil or vegetation

2. Blue water footprint

- The amount of surface water and ground water required (evaporated or used directly) to produce an item
- Irrigated agriculture, industry and domestic water use
  - It evaporates and transpires directly from soil
  - It is incorporated into the product through irrigation

3. Grey water footprint

- The amount of fresh water required to assimilate pollutants to meet specific water quality standards
- Pollution
  - By fertilizers, pesticides, etc.
  - During manufacture of a product
  - Domestic use

Direct and indirect water footprint

When one consumes a product one not only consumes the direct water in the product but also the indirect water accumulated for producing the product.

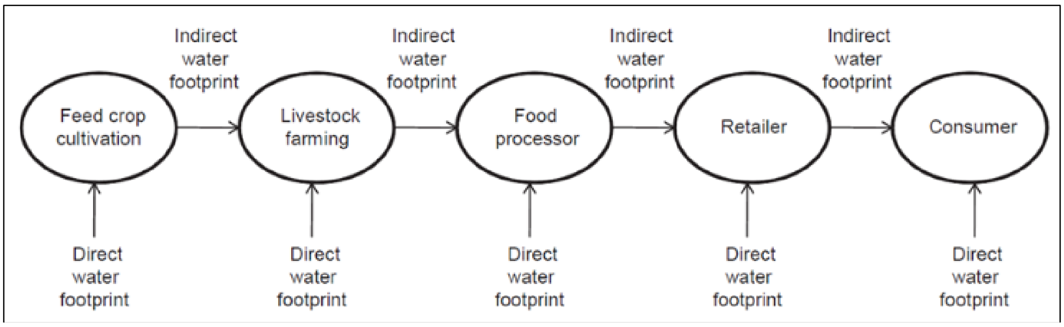

Fig 1: Water footprint in each stage of supply chain of an animal product

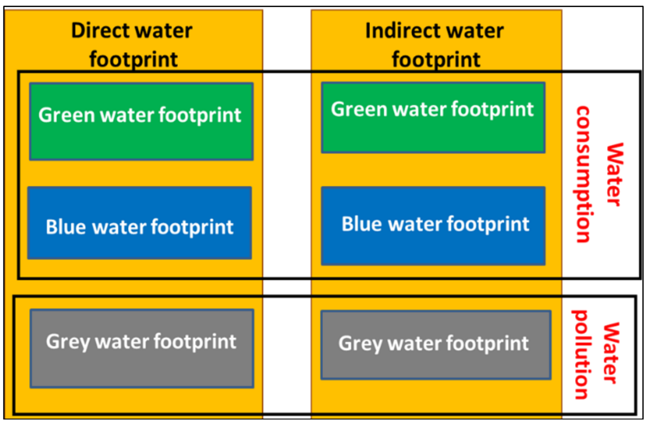

Fig 2: Components of water footprint

Application of water footprint

Water footprint can be applied to:

- Process step
- Product
- Person/consumer
- Community
- Producer/business
- Area
- Nation
- Humanity
- Crop
- Animal

Water footprint of products: The water footprint of a product is the total volume of freshwater used to produce the product, summed over the various steps of the production chain. The water footprint of a product refers not only to the total volume of water used; it also refers to where and when the water is used.

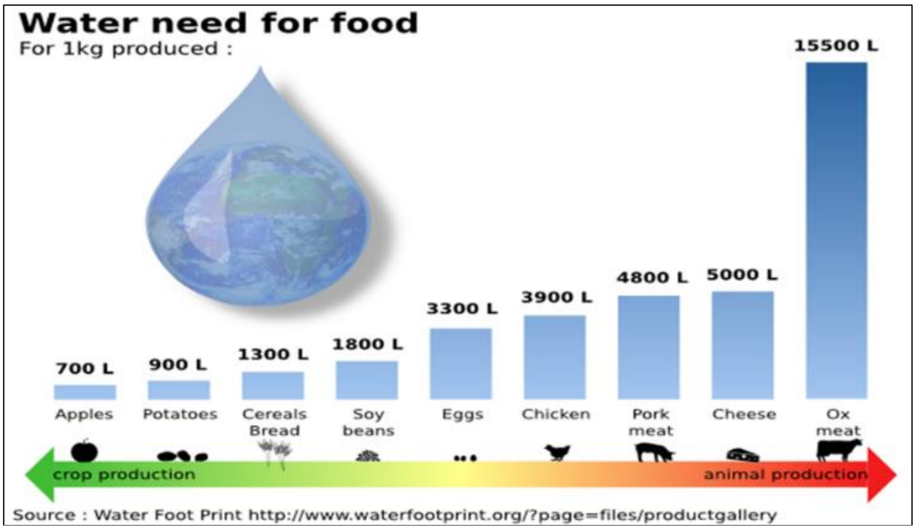

Fig 3: Water footprint of some products

Water footprint of companies: The water footprint of a business, the 'corporate water footprint', is defined as the total volume of freshwater that is used directly or indirectly to run and support a business. It is the total volume of water use to be associated with the use of the business outputs. The water footprint of a business consists of water used for producing/manufacturing or for supporting activities and the indirect water use in the producer's supply chain.

Water footprint of a nation: Total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation.

Calculation of crop water footprint

According to WFN Approach (Hoekstra *et al*., 2011) [5, 11] crop water footprint can be calculated as follows:

$$\text{Green water footprint} = \frac{[\text{Crop ET} - \min(\text{Crop ET}, \text{Irr})]}{\text{Yield}}$$

$$\text{Blue water footprint} = \frac{\min(\text{Crop ET}, \text{Irr})}{\text{Yield}}$$

Where, Crop ET = Crop evapotranspiration
Irr = Total irrigation from planting to harvesting
Yield = Fresh yield

$$\text{Grey water footprint} = \frac{\text{N Load}}{\text{Cmax} - \text{Cnat}} \text{ x FW}^{-1}$$

Where, C_{max} = Maximum concentration of pollutant
C_{nat} = Natural concentration of pollutant
N_{Load} = N concentration in the water
FW = Fresh Water

Total Water Footprint = Green Water Footprint + Blue Water Footprint + Grey Water Footprint

CROPWAT Model

Green and Blue water evapotranspiration during crop growth can be estimated with the Food and Agriculture Organization's CROPWAT model. The model offers two alternative options. The simplest but not the most accurate option is the 'CWR option'. In this option, it is assumed that there are no water limitations to crop growth. The model calculates-

1. Crop water requirements (CWR) during the full length of the growing period under particular climatic circumstances
2. Effective precipitation over the same period
3. Irrigation requirements

CROPWAT 8.0 for Windows is a computer program. If we feed the following data it calculates the water footprint

- Soil data
- climate data
- crop data

Case study

1. Global average of water footprint (FAO, 2008) [2]

In a study FAO found out the following water footprints for various agricultural produces.

Table 1: Global water footprint of primary crop categories (1996–2005)

Primary crop category	Water footprint (m^3/ t)			
	Green	Blue	Grey	Total
Sugar crops	130	52	15	197
Fodder crops	207	27	20	253
Vegetables	194	43	85	322
Fruits	727	147	93	967
Cereals	1232	228	184	1644
Oil crops	2023	220	121	2364
Pulses	3180	141	734	4055

From the Table 1, it is evident that total water footprint of fruit and vegetables are 967 m^3/t and 322 m^3/t, respectively in comparison to higher total water footprint of cereals, oilseeds and pulses.

2. Water footprint of vegetable crops (Hoekstra, 2008) [4]

Hoekstra (2008) [4] studied the water footprint of selected vegetable crops on the global average basis. He found that water footprint of potato was the highest followed by pumpkin and cucumber. Whereas, the water footprint of lettuce was the lowest among the studied vegetables.

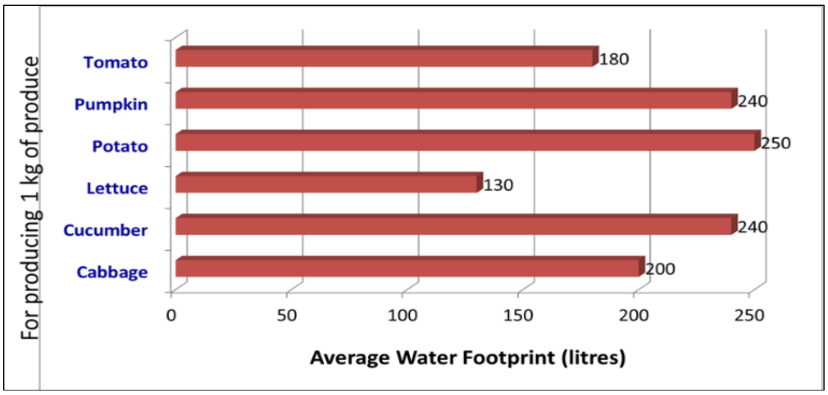

Fig 4: Global water footprint of vegetable crops

3. Water footprint of major spices and their derived products (Mekonnen and Hoekstra, 2010) [10]

In Table 2 a wide variation of water footprint was noticed by Mekonnen and Hoekstra (2010) [10] among various spices and their derived products. Vanilla beans exhibited unbelievably higher water footprint (126505 m^3/t) compared to other spices.

Table 2: Global average water footprint of spices and its derived products (1996 – 2005)

Product description	Global average Water footprint (m^3/ton)			
	Green	Blue	Grey	Total
Garlic	337	81	170	589
Garlic powder	1297	313	655	2265
Vanilla beans	86392	39048	1065	126505
Cinnamon	14853	41	632	15526
Cloves	59634	30	1341	61205
Nutmeg, cardamom	30683	2623	1014	34319
Coriander	5369	1865	1046	8280
Ginger	1525	40	92	1657

4. Water footprint of fruit crops (Hoekstra, 2008) [4]

In his study Hoekstra (2008) [4] found highest water footprint in olives (4400 l/kg), followed by dates. The lowest water footprint of 460 l/kg was recorded in oranges.

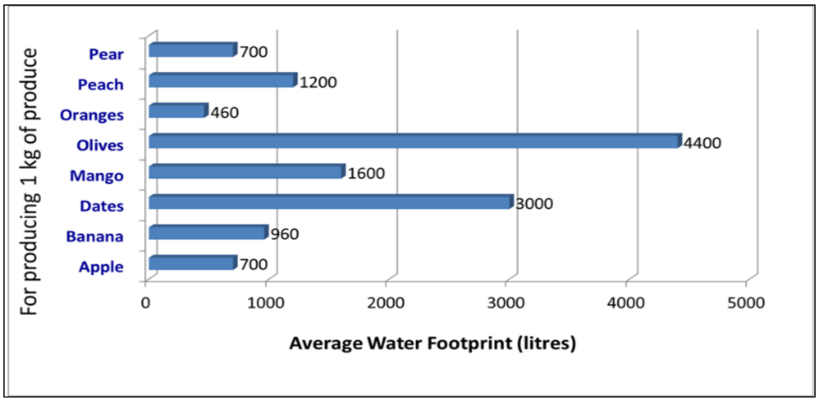

Fig 5: Global water footprint of fruit crops

5. Water footprint of agriculture in India (Jayaram, 2016) [7]

In Table 3 indicates that out of total water footprint of 962 BCM, vegetable accounts for 29 bcm and fruits accounts for 13 bcm.

Table 3: Water footprint for agriculture in India (2007 – 08)

Produce group	Internal water use (bcm)	Net virtual water flow (bcm)	Water footprint (bcm)
Cereals	619	27	647
Pulses	134	18	152
Oilseeds	96	7	103
Vegetables	29	0.51	29
Fruits	13	-0.2	13
Cash crops	17	-0.4	16
Total	911	51	962

*BCM: Billion cubic meter

6. Water footprint of major vegetable crops and their derived products (Mekonnen and Hoekstra, 2010) [10]

A wide variation of water footprint was noticed by Mekonnen and Hoekstra (2010) [10] among various vegetables and their derived products. The products showed higher water footprint compared to fresh produce. This might be due to reduction in volume and weight of the product compared to the fresh vegetables. Again, some extra water is also used in preparation of the vegetable products. (Table 4).

Table 4: Global average water footprint of vegetable crops and its derived products (1996 – 2005)

Product description	Global average Water footprint (m^3/ton)			
	Green	Blue	Grey	Total
Potatoes	191	33	63	287
Potato flour	955	165	317	1436
Potato flakes	694	120	230	1044
Potato starch	1005	173	333	1512
Sweet potato	324	5	54	383
Cassava	550	0	13	564
Flour of cassava	1833	1	44	1878
Dried cassava	1571	1	38	1610
Cassava starch	2200	1	53	2254
Taro	587	3	15	606
Yams	341	0	1	343
Chillies, green	240	42	97	379
Tomatoes	108	63	43	214
Tomato juice	135	79	53	267
Tomato juice, conc	539	316	213	1069
Tomato paste	431	253	171	855
Tomato ketchup	270	158	107	534
Tomato puree	360	211	142	713
Tomato, dried	2157	1265	853	4276
Onion, green	176	44	51	272
Onion, dry	192	88	65	345
Beans, green	320	54	187	561
Sugar beet	82	26	25	132
Cabbages	181	26	73	280
Artichokes	478	242	98	818
Asparagus	1524	119	507	2150
Lettuce	133	28	77	237
Spinach	118	14	160	292
Cauliflower, broccoli	189	21	75	285
Pumpkin, squash & gourds	228	24	84	336
Cucumber & gherkins	206	42	105	353
Egg plant	234	33	95	362

7. Water footprint of major fruit crops and their derived products (Mekonnen and Hoekstra, 2010) [10]

For fruits Mekonnen and Hoekstra (2010) [10] found a wide variation in water footprints, *viz*., in case of water melon (235 m^3/ton), pineapple (255 m^3/ton), papaya (460 m^3/ton), orange (560 m^3/ton), banana (790 m^3/ton), apple (820 m^3/ton), peach (910 m^3/ton), pear (920 m^3/ton), apricot (1300 m^3/ton), plums (2200 m^3/ton), dates (2300 m^3/ton), grapes (2400 m^3/ton), figs (3350 m^3/ton), etc.

Fruit products showed higher water footprint compared to fresh fruits. This might be due to reduction in volume and weight of the product compared to the fresh fruits. Again, some extra water is also used in preparation of the fruit products.

Table 5: Global average water footprint of fruit crops and its derived products (1996 – 2005)

Product description	Global average Water footprint (m^3/ton)			
	Green	Blue	Grey	Total
Cashewnuts	12853	921	444	14218
Almonds, with shell	4632	1908	1507	8047
Walnut, with shell	2805	1299	814	4918
Arecanut	10621	139	406	11165
Coconuts	2669	2	16	2687
Olives	2470	499	45	3015
Olive oil, virgin	11826	2388	217	14431
Olive oil, refined	12067	2437	221	14726
Bananas	660	97	33	790
Plantains	1570	27	6	1602
Apricots	694	502	92	1287
Oranges	401	110	49	560
Mandarins	479	118	152	748
Lemons & limes	432	152	58	642

Grapefruit	357	85	54	506
Apples	561	133	127	822
Pears	645	94	183	922
Cherries	961	531	112	1604
Peaches	583	188	139	910
Plums	1570	188	422	2160
Strawberry	201	109	37	347
Raspberry	293	53	67	413
Grapes	425	97	87	608
Grapes, dried	1700	386	347	2433
Grapes, juice	490	114	71	675
Grapes wines	607	138	124	869
Watermelons	147	25	63	235
Figs	1527	1595	228	3350
Mangoes, guavas	1314	362	124	1800
Avocados	849	283	849	1981
Pineapples	215	9	31	255
Dates	930	1250	98	2277
Papaya	399	40	21	460

8. Water footprint for vegetables in India (Jayaram, 2016) [7]

State-wise water requirement of selected vegetables were studied (Jayaram, 2016) [7] as depicted in the Table 6.

Table 6: Water requirement per ton of vegetables (m^3)

States	Tomato	Onion	Cabbage	Cauliflower	Potato	Brinjal	Okra	Sweet potato	Cassava
Andhra P.	308.36	251.37	372.60	-	354.90	246.87	207.06	223.46	111.79
Bihar	218.84	179.44	235.26	254.10	192.88	195.48	147.28	217.04	-
Gujarat	242.25	192.67	292.04	297.86	191.45	294.72	253.55	-	-
Haryana	444.69	160.37	276.54	327.33	171.75	359.75	313.70	-	-
J & K	192.64	91.88	170.48	201.53	293.08	285.26	98.45	-	-
Karnataka	172.23	303.51	228.32	251.95	644.93	178.03	335.76	371.42	282.51
MP	326.12	224.99	202.28	267.59	267.11	274.26	293.73	667.07	-
NE States	349.87	139.86	186.78	223.85	313.68	254.94	147.07	1079.13	1998.38
Punjab	213.82	102.73	167.89	211.11	113.46	260.62	24.32	1828.70	-
Rajasthan	1588.69	378.28	-	-	428.22	1530.91	806.21	-	-
All India	379.76	230.21	199.89	232.96	277.49	326.39	244.86	559.24	492.45

9. Share of various vegetables in water footprint in India (Jayaram, 2016) [7]

Jayaram (2016) [7] studied tomato, onion, potato, brinjal, cabbage, cauliflower, okra (ladies' finger), cassava and sweet potato as these vegetables account for close to 95 per cent of the total vegetables produced. Potato was the largest user of water with an estimated 9,712.71 bcm of water (33 per cent of water used in the production of all vegetables) followed by cassava with 4,904.72 bcm (17 per cent) and tomato with 3,344.99 bcm (14 per cent). Onion left a footprint of 2,746.05 bcm. Production of cabbage, cauliflower and okra used around 1100 bcm of water each. The total water footprint left from the production of these vegetables was 29,048.75 bcm.

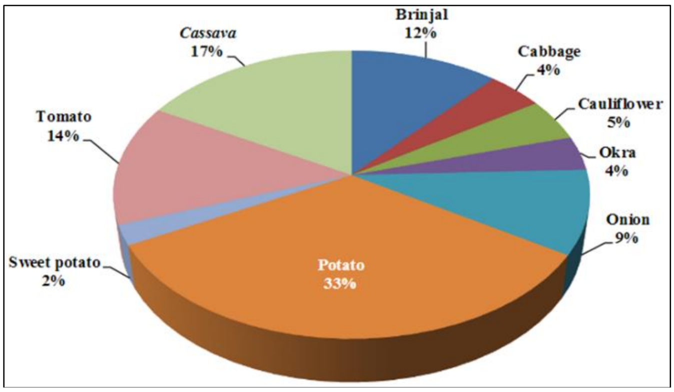

Fig 6: Share of various vegetables in water footprint

10. Share of various fruits in water footprint in India (Jayaram, 2016) [7]

Fruits included in the study were banana, mango, pineapple, citrus, apple, guava, litchi, sapota, grapes, papaya and pomegranate as they accounted for about 97.6 per cent of the total fruit produced in 2007- 08 (Jayaram, 2016) [7]. Mango was the largest user of water with an estimated use of 48,804.38 bcm (35 per cent).

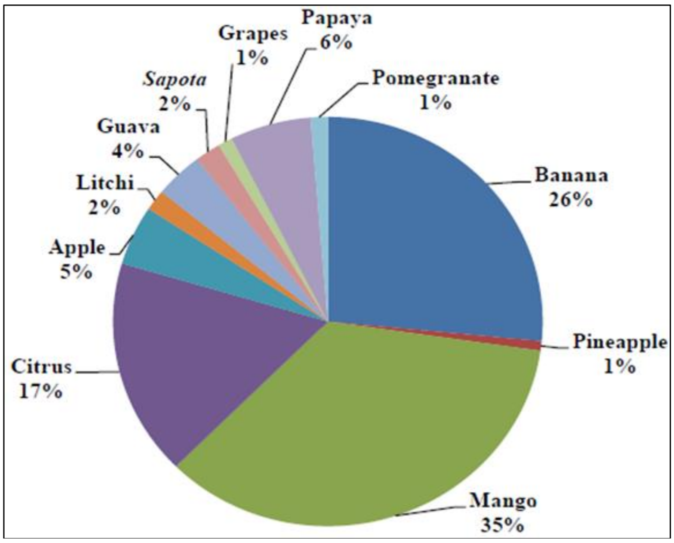

Fig 7: Share of various fruits in water footprint

11. Water footprint of irrigated and rainfed fruit (Mekonnen and Hoekstra, 2010) [10]

It was observed that the global average consumptive water footprint (Blue plus green water footprint) per ton of apple was lower for irrigated crops than for rain-fed crops (Table 7). This is because, on average, irrigated yields are larger than rain-fed yields (Mekonnen and Hoekstra, 2010) [10].

Table 7: Water footprint of rainfed and irrigated apples (1996 – 2005)

Farming system	Yield (t/ha)	Water footprint related to crop production (Gm^3/yr)				Water footprint per ton of crop (m^3/ton)			
		Green	Blue	Grey	Total	Green	Blue	Grey	Total
Rainfed	8.93	24	0	6	30	717	0	167	883
Irrigated	15.91	8	8	2	18	343	321	71	734
Global	10.92	33	8	7	48	561	133	127	822

12. Water footprint of horticultural crops in Hebei southern plain, north China (Chu *et al.*, 2007)

Chu *et al.* (2007) noticed higher total water footprint in vegetables (7.7m^3/t) compared to fruits (2.6 m^3/t) in Hebei Southern Plain, North China.

Table 8: Water footprint of fruits and vegetables in Hebei Southern Plain

Crop	WF_{green} (m^3/t)	WF_{blue} (m^3/t)	WF_{grey} (m^3/t)	Total WF (m^3/t)
Vegetables	1.3	4.9	1.5	7.7
Fruits	0.5	1.1	1.0	2.6

13. Water footprint of vegetables in South Africa (Nyambo and Wakindiki, 2015) five vegetables were studied by Nyambo and Wakindiki (2015) at South African conditions. They observed highest grey water in green beans cultivation (373 m^3/t) followed by spinach (214 m^3/t). This might be due to use of more inorganic fertilizer application in production of those two crops compared to other vegetables.

Table 9: Grey water footprint of vegetables in South Africa

Crops	Yield (t/ha)	Total WF_{grey} (m^3/t)
Cabbage	30	37
Potato	9	156
Tomato	19	132
Spinach	7	214
Green beans	1.5	373

14. Water footprint of vegetable soup in spain (Rivas *et al.*, 2017)

There is a famous chilled vegetable soup of Spain. Rivas *et al*. (2017) studied the water footprint of each of the ingredients and all the steps involved. They found that 580.40 litre of water is required to prepare 1 litre of that special chilled vegetable soup.

Table 10: Water footprint of 1 liter of a chilled vegetable soup in Spain

Ingredients	Green WF (L)	Blue WF (L)	Grey WF (L)	Total WF (L)
Tomato	34.1	31.8	26.1	92.0
Pepper	7.4	1.1	6.3	14.8
Cucumber	4.1	6.5	3.5	14.1
Onion	4.4	14.3	7.1	25.8
Olive oil	333.5	75.6	0.8	409.9
Vinegar	7.5	2.7	2.3	12.5
Garlic	0.5	0.5	0.4	1.4
Total ingredients	391.3	132.4	46.6	570.4
Packaging WF	6.9	0	2.6	9.4
Operational WF	-	0.6	-	0.6
Total	398.2	133.0	49.2	580.4

15. Water footprint of Rose (Mekonnen *et al.*, 2012)

A little work has been done in the field of floriculture with regards to water footprint. Mekonnen *et al*. (2012) studied the water footprint of rose in Lake Naivasha Basin, Kenya and observed the results as shown in Table 11.

Table 11: Water footprint of rose in Lake Naivasha Basin, Kenya

Weight of rose (g/stem)	Cut flower production (stem/m^2)	Water footprint by type (litre/stem)			
		Green	Blue	Grey	Total
20	134	1.6	3.3	2.5	7.3
25	107	2.0	4.1	3.1	9.2
35	77	2.8	5.8	4.3	12.8

Technology and practices to reduce water footprint in horticulture

First Approach

Water footprint for horticultural crops can be reduced increasing yield, reducing non beneficial evapotranspiration and enhancing effective use of rainfall.

A. Increasing yield

Yield can be increased through –

- Soil nutrient management
  - Optimizing crop rotation
  - The use of crop residues
  - Appropriate tillage
  - Proper and timely application of manures & fertilizers
- Precision irrigation
  - Synchronizing water application with crop water demand
- Weed and pest control
  - Crop rotation
  - Proper tillage
  - Biological control
  - Breeding of superior crop varieties with high yielding and stress resistance

B. Reducing non beneficial evapotranspiration

Evapotranspiration can be reduced through

- Crop scheduling to reduce evaporation during fallow period
- Plant spacing and row orientation
- Regulating canopy development through cultural practices and breeding
- Minimum tillage to reduce soil water evaporation and conserve soil water during fallow period
- Use of crop residue and mulches to reduce soil water evaporation and improve nutrient recycling
- Improve irrigation techniques (drip and subsurface irrigation)
- Effective control of weeds to reduce transpiration from weeds

C. Enhancing effective use of rainfall

Rainfall can be effectively used by

- Synchronizing crop scheduling and rainfall
- Water harvesting and supplemental irrigation

Second approach

Total water footprint can be reduced by reducing green, blue and grey water footprint as indicated below:

A. Green water footprint

Green water footprint can be reduced by adopting the following measures:

- Increase green water productivity in both rainfed & irrigated horticulture
- Increase total production from rainfed horticulture

B. Blue water footprint

Blue water footprint can be reduced through:

- Increase blue water productivity in irrigated horticulture
- Decrease ratio of blue/green water footprint

C. Grey water footprint

Reduction in grey water footprint can be achieved by following ways:

- Reduce use of artificial fertilizers and pesticides
- More effective use of synthetic inputs
- Follow organic farming

Conclusion

Discussion can be concluded with the following lines –

- Water footprint is increasing due to practice of intensive horticulture to feed increasing population
- WF should be reduced for sustainability of water and horticultural crop production
- Right crop should be chosen for right place based on water footprint
- Organic farming may provide an option to counteract the problem of excessive water footprint
- Product substitution is another option to reduce water footprint

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