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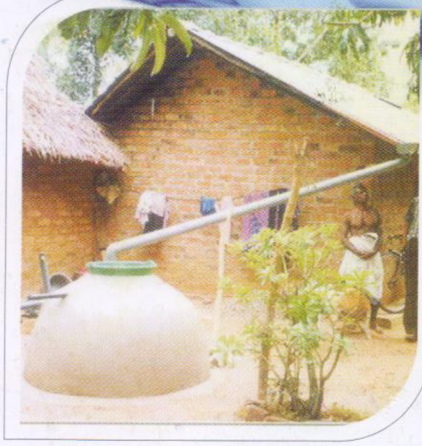

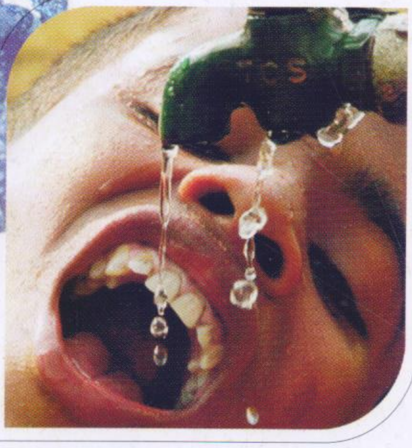

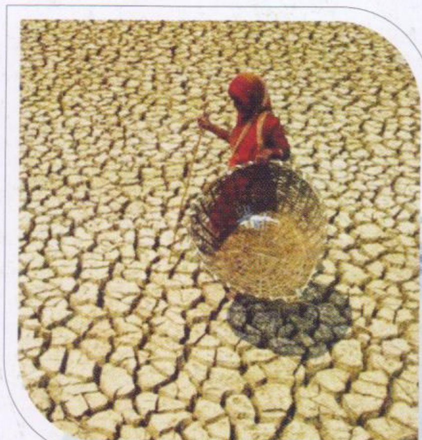

The Institution of Engineers (India)

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Best Paper Award

Civil Engineering Division Board of The Institution of Engineers (India) is pleased to present this Scroll of Honour to **Mrs Deepa Chalisgaonkar**, Scientist F, National Institute of Hydrology, Roorkee for her contributed article titled ***'Agricultural Water Footprint: A Way Forward for Water Conservation and Management'*** in the Annual Technical Volume on **"Water Conservation and Management in India"** awarded during 31st Indian Engineering Congress 2016 at Kolkata.

Agricultural Water Footprint: A Way Forward for Water Conservation and Management

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Abstract

Over the years, increasing population, growing industrialization, expanding agriculture and rising standards of living have pushed up the demand for water in India. Besides the obvious implications on the environment and the community, water scarcity will also generate important problems for Indian economies as the largest share of water consumption in India is used for food production. Limited water availability may lead to insufficient production of food, which may lead to food insecurity and malnutrition. From both the public and private sectors different initiatives have been launched to prevent and to mitigate water scarcity, emphasizing the priority to move towards a water-efficient and water-saving economy. Virtual Water (VW) and Water Footprint (WF) are two useful indicators to deal with water scarcity. The first one from the perspective of production; whereas the second one from the perspective of consumption. Water footprint is an emerging concept in the area of water conservation and management as it presents a wider perspective on how a consumer or producer relates to the use of water resources. It is defined as the total amount of water, external and internal, that is required for the production of a good or a service. The paper discusses the concept of water footprint and virtual water with the detailed methodology for estimating the agricultural water footprint and its different components. The paper also summarizes the agricultural WF and virtual water of NCT-Delhi which can facilitate the water resources planner and mangers for effective conservation and management practices. This will help in evaluating drought tolerance, water use efficiency, effective use of rainfall, and the significance of irrigation.

Keywords: Water footprint, Virtual water, NCT-Delhi

Introduction

India is an agrarian economy with more than 50% of its population dependent on agriculture for their livelihood. This sector is associated with India's water security, food security as well as energy security. Agriculture sector is the major consumer of water with around 85% of the share occupied by it alone. With the growing water crisis, there is an urgent need to bring effective reforms in the agriculture sector. Both surface and groundwater are used in a very non-scientific manner for irrigation. Even though agriculture has been the biggest consumer of water, urban water demands (domestic and industrial) are increasing rapidly in the last two decades. This increase in urban water demand is compelling the shift of regional water resources from rural to urban consumers to meet the cities' growing water needs. For any developing nation when the thrust will be on economic growth, the competition for water among various sectors (agriculture, domestic, industrial, and environmental uses) will always be on the rise, whilst the sources of water remain the same. The inadequate sources of water escalate the value of water and significance of efficient / scientific allocation of water among various sectors. Thus, it becomes increasingly relevant to implement demand-side management through increasing water use efficiency in agriculture sector, especially considering nation's goal of achieving food security for all.

From both the public and private sectors different initiatives have been launched to prevent and to mitigate water scarcity and drought situations, emphasizing the priority to move towards a water-efficient and water-saving economy. Virtual Water (VW) and Water Footprint (WF) are two useful indicators to deal with water scarcity. The first one from the perspective of production; whereas the second one from the perspective of consumption.

Water Footprint and Virtual Water

Water Footprint

The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. Water use is measured in terms of water volumes consumed (evaporated) and/ or polluted per unit of time. 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 or private enterprise).

The water footprint of a product is defined as "the volume of freshwater used to produce the product, measured over the full supply chain". It has three components:

- Blue Water Footprint: refers to the volume of surface water and groundwater consumed (i.e. evaporated or incorporated into the product) during production processes;
- Green Water Footprint: refers to the volume of rainwater consumed (i.e. evaporated or incorporated into the product) by the product; and
- Grey Water Footprint: refers to the amount of freshwater required to mix pollutants and maintain water quality according to agreed water quality standards.

Water foot print presents a wider perspective on how a consumer or producer relates to the use of water resources. It gives the clear picture of total water consumption (directly or indirectly). By using this concept some water scarce regions may import water intensive products and can save their water resources by using virtual water trade. Consequently, they can allocate their water in other activities. This concept may be very useful in reforming some water consumption pattern in future. The water footprint provides a water accounting framework for efficient and conservative water use.

Virtual Water

Virtual water is total water used to produce goods or services. Virtual water content of each commodity varies in regions due to differences in climate condition and water productivity. For instant, in arid and semi-arid regions of the country, high evaporative demand causes low water productivity to crop production. The virtual water concept is used for measuring the global distribution of water through trade. Some water scarce regions may import food that is water intensive to produce. Some studies about virtual water trade that show water is a key factor to produce water intensive products and regions can save their water resources due to using virtual water trade. Consequently, they will allocate water in other sections by virtual water import. This view can reform some water consumption pattern in future.

Virtual water trade is the hidden trade of water if commodities are traded from one place to another. For instance, it takes about 1,600 cubic meters of water on average to produce one metric tonne of wheat. The precise volume can be more or less depending on climatic conditions and agricultural practice. The water is said to be virtual because once the wheat is grown, the real water used to grow it is no longer actually contained in the wheat. In semi-arid and arid areas, knowing the virtual water value of a good or service can be useful towards determining how best to use the scarce water available.

Agricultural Water Footprint

Agricultural (including forestry) sector is a major water-consuming sector. In light of population growth, economic development, urbanization, dietary changes and climate change, the water demand in this sector is significantly increasing. The agricultural WF corresponds with the water use in the agricultural sector (i.e. in the form of crop evapotranspiration or water pollution). The agricultural WF measures the volume of evapotranspiration (ET) or water use of a crop per unit mass of yield.

The total water footprint of an agricultural production process (WFproc) is the sum of the blue (WFblue), green (WFgrn), and grey (WFgrey) water footprints (Hoekstra et al., 2008). Comparing water footprints of different management practices in agriculture can help in evaluating drought tolerance, water use efficiency, the effective use of rainfall, and the significance of irrigation.

Assessment of Agricultural WF

The agricultural WF has three components: Blue Water Footprint, Green Water Footprint, Grey Water Footprint. It is assessed by computing the environmental pressure exerted in the region in terms of the water it uses directly and indirectly. It can be assessed by following the methodology developed by Hoekstra's (2009) in Water Footprint Manual which provides several checklists, tables, and examples to help delineate these goals. The WF is computed based on the available data of direct (real) and indirect (virtual) water consumption.

Blue Water Footprint

The blue water footprint is the volume of freshwater that evaporated from the global blue water resources (surface water and ground water) to produce the goods and services consumed by the individual or community. The blue component of agricultural WF is almost negligible.

Green Water Footprint

The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture) during production or those incorporated in products. The green component in crop water use (CWU, m^3/ha) can be calculated by accumulation of daily evapotranspiration (ET, mm/ day) over the complete growing period.

$$CWU_{green} = 10x\sum_{d=1}^{lp} ET_{green} \quad (1)$$

Where, lp = crop growing period

The green component can be assessed by computing crop water requirements (CWR) for different crops in the region by estimating evapotranspiration rates for a specific crop, in the specific climate of the region. This computation can be done using the CROPWAT 8.0 and CLIMWAT 2.0 software of Food and Agriculture Organization (FAO) of the United Nation's. Precipitation data, crop growth inputs, and general soil data of the region is required for using CROPWAT to calculate crop water requirements.

Grey Water Footprint

The grey water footprint is the volume of polluted water that associates with the production of all goods and services for the individual or community. The latter can be estimated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains at or above agreed water quality standards. Computation of grey water footprint is a different segment of quantifying available water resources. Its calculations require much different data inputs than the blue and green counterparts. In an agricultural study such as this, it is important to include the grey water in the total water footprint because pollutants such as fertilizers, pesticides, and insecticides have a significant impact on the water demands of a farm. Often times, enforced water quality standards require pollutants to be diluted by freshwater to attain certain ambient legal levels.

The grey component in water footprint (WF proc,grey, m^3/ton) of growing a crop or tree has been calculated by using the formula given below:

$$WF_{proc,grey} = [(\alpha x AR)/(C_{max} - C_{nat})]/Y \quad (2)$$

Where,

AR = Chemical application rate to the field per hectare (kg/ha)

α = Leaching runoff fraction

C_{max} = Maximum acceptable concentration (kg/m^3)

C_{nat} = Natural concentration for the pollutant considered (kg/m^3)

Y = Crop yield (ton, ha)

Step-by-Step Computation of Agricultural WF

The computations of net water requirement per crop can be done based on the FAO 56 Penman-Monteith equation for reference ET in non-standard condition. In addition, crop coefficient variation as a function of the plant growth stage is calculated. Typical irrigation methods and irrigation efficiency has also been taken into consideration while calculating irrigation needs for different crops. Different steps involved in calculating the irrigation requirements using crop coefficient, crop evapotranspiration, effective rainfall and irrigation requirement of major crops are presented below:

- Using climate data, estimate Reference Evapotranspiration (ET_0) using Penman-Monteith method.
- Using rainfall data, to estimate effective rainfall using USDA Soil Conservation method.

- Inputs for soil parameters.
- Compute crop water requirement and irrigation requirement of all the major crops grown in the region by assigning relevant data values crop by crop.
- The Crop Water Requirement and Irrigation Requirement for all the crops of the region added together to obtain total Crop Water Requirement and Irrigation Requirement.
- Compute grey water footprint based on the application of Nitrogen (N) fertilizer to the region's crop fields. Lacking region-specific data, several assumptions regarding fertilizer use and transport can be made been made based on Hoekstra's Manual.

The total crop water requirement and grey WF added together gives agriculture WF.

A Case Study of NCT-Delhi

About the Region

Being the capital city of the country, Delhi has a distinct position in the Indian institutional system. Although, about 75% of the total geographical area (1483 km^2) is urbanized, the urban agglomeration of Delhi extends its limits out of the NCT, with satellite towns like

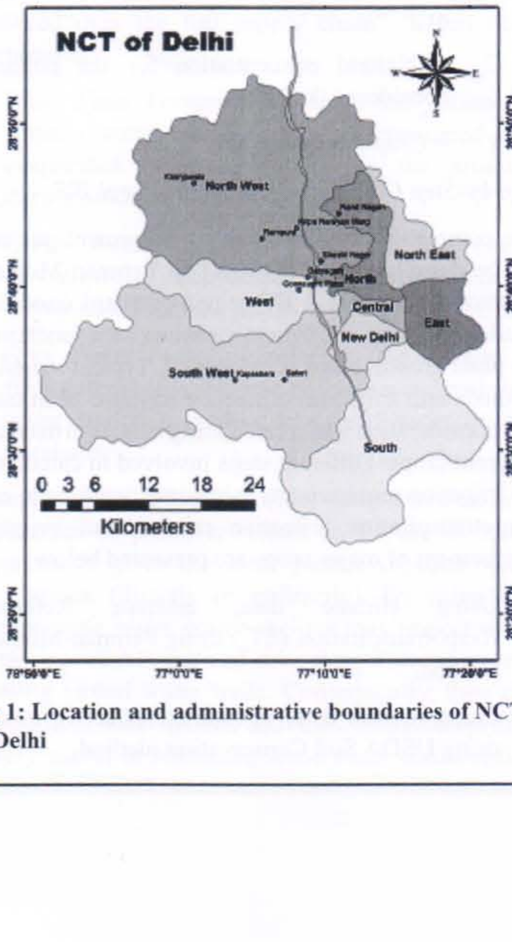

Fig 1: Location and administrative boundaries of NCT of Delhi

Gurgaon, Noida, Faridabad, and Ghaziabad, growing in the immediate vicinity of Delhi in the neighboring states of Haryana and Uttar Pradesh. The location of NCT of Delhi is shown in **Fig 1**.

The climate of the NCT of Delhi region is semiarid in nature. About 87% of the annual rainfall is received during the monsoon months viz. June to September. The average annual rainfall of the Delhi of NCT is about 800 mm. NCT of Delhi's population grew at an annual growth rate greater than 4% during the last decade. Although the NCT of Delhi is said to be 75% urban but the 25% rural area contributes a variety of livestock presence at Delhi. The travel and transport demands of NCT of Delhi are increasing with the growth of population and economic activities.

Agriculture in NCT of Delhi

Further, very fast growth of services sector is making agriculture less attractive. The agricultural activities in NCT of Delhi include (i) growing of field crops, fruits, seeds, and vegetables and (ii) management green area and forest plantations. As per forest department of NCT of Delhi, the tree cover area is 229.6 km^2 consisting of forest area of 85 km^2. There are more than 18000 parks and gardens in NCT of Delhi spread in about 8000 ha in various locations.

Agricultural WF of NCT of Delhi

The WF of the NCT of Delhi has been computed based on this data for the period 2006-2010. The related data has been collected from various sources, published reports from various departments of government of NCT of Delhi and from some other important websites and other reports. The virtual water content related data is available at country level not at NCT of Delhi level, so it was used for NCT of Delhi as well. Few of the data were not specifically available for NCT of Delhi. For those data available for India has been considered and if it was not available for India also then the global average has been used. The data which was not available at all has been assumed suitably. The WF has been computed based on the available data of direct (real) and indirect (virtual) water consumption of NCT of Delhi. The crop water requirement and irrigation requirement for different crops of NCT of Delhi are presented in **Table 1**. The basis of calculation and data assumed for agricultural grey water component is given in **Table 2**.

The agriculture water footprint has been computed as 779.72 MCM per annum. As shown in **Table 3** it has about 5% of grey water component. It also shows that

Table 1: Crop water requirement and irrigation requirement for different crops

Crop type	ETc mm/Annum	Eff rain, mm/ Annum	Irrigation Requirement mm/Annum	Area, Ha	CWR million litre/Annum
Wheat	303.7	34.8	269.5	20135	61150
Rice	807.1	470.2	608.5	6848	55270
Barley	345.8	107	292.5	70	242
Millet	351.4	348	143.1	1531	5380
Maize	470.5	426.1	187.8	40	188
Sorghum/ Jowar	414.4	426.1	160.9	3341	13845
Pulses	250.4	35.6	213.2	8	20
Potato	354.3	36.8	315.9	51	181
Sugarcane	2031.4	515.3	1522	3	61
Perennial grass	1192	515.3	750.1	8000	95360
Perennial shrubs	1182.6	515.3	858.7	29958	354283
Forest	1771.5	515.3	1302.2	8500	150578

Table 2: Data for computation of grey water component for major crops

Crop	Area in Ha	Production (MT)	Yield (Y) (ton/ha)	Av. fertilizer application rate (kg/ha)	Nitrogen leaching fraction (N)	USEPA water quality standard (mg/L)	Total WF_{grey} (m^3/ ton)
Wheat	21309	92480	4.34	143	0.1	10	329.49
Rice	6821	28512	4.18	148	0.1	10	354.07
Barley	76	214	2.82	50	0.1	10	177.3
Bajra	1586	2979	1.88	50	0.1	10	265.96
Maize	48	1054	21.96	125	0.1	10	56.92
Jowar	3240	31681	9.78	50	0.1	10	51.12
Gram	76	67	0.88	50	0.1	10	568.18
Potatoes	88	21999	249.99	50	0.1	10	2
Sugarcane	3	266	88.67	100	0.1	10	11.28

a significant part of the agriculture water component of NCT of Delhi (76%) is utilized by perennial grass, perennial shrubs and forests and very less part goes for the production of food grains and vegetables.

Virtual Water Import in NCT of Delhi

In this study, virtual water of 31 important agricultural products (m3/ton) is estimated based on crop water requirements and yields. These products are categorized in different groups such as cereals, fruits, industrial crops, oil seeds, summer crops, selected fodder crops. The selected crops which have more share in water import. In addition to the earlier discussed water consumptions, a huge quantity of virtual water is also being transferred to/from NCT of Delhi in the form of various goods, commodities and products etc. Based on the available data, the indirect WF has been assessed due to virtual water transfer of agricultural products (crop based), animal based products, petroleum products and electricity as 7037.18 MCM per annum as shown in **Table 4**.

The total agriculture WF of NCT of Delhi has been assessed as 7816.85 MCM per annum which is due to water consumption of agriculture sector and a major part of it is because of virtual water import.

Table 3: Agriculture water footprint of NCT of Delhi per season

Crop Type	CWR Million litre	CWR MCM	Grey WF (m^3/ ton)	Grey WF MCM	Footprint MCM
Million litre	61150	61.15	329.49	30.471	91.621
Rice	55270	55.27	354.07	10.095	65.365
Barley	242	0.242	177.3	0.038	0.28
Millet	5380	5.38	265.96	0.792	6.172
Maize	188	0.188	56.92	0.06	0.248
Sorghum/ Jowar	13845	13.845	51.12	1.62	15.465
Pulses	20	0.02	568.18	0.038	0.058
Potato	181	0.181	2	0.044	0.225
Sugarcane	61	0.061	11.28	0.003	0.064
Perennial grass	95360	95.360	NA	NA	95.36
Perennial shrubs	354283	354.283	NA	NA	354.283
Forest	150578	150.578	NA	NA	150.568
Agriculture WF		**736.558**		**43.161**	**779.719**

Table 4: Virtual water import

Virtual Water Import due to import of crop based products annually	5138.70 MCM
Virtual Water Import due to import of animal based products annually	1898.43 MCM
Total Virtual Water Import	7037.13 MCM

Conclusions

The present paper describes the insights of an evolving concept of water footprint and virtual water. Among the major water consuming sectors, agriculture is the primary consumer of water in India as well in the world. Around 85% of the water share is being occupied by agricultural use in India. With the growing water crisis, there is an urgent need to bring effective reforms, conservations and management measures in the agriculture sector for long term sustainability. In the paper a case study of NCT-Delhi has been presented, wherein agricultural WF and virtual water of the NCT region has been assessed. Water consumed per annum by various types of crops, grass, shrubs and forests in various forms as well as water consumed by other various activities including virtual water import have been assessed in the study. The total WF of NCT of Delhi has been assessed as 15,926 MCM per annum which is due to water consumption of 41% in domestic sector, 5% in agriculture sector, 5% in industrial sector and 49% because of virtual water transfers. The present assessment has been carried out based on the best possible available data sets related to virtual water transfer as the data of all the commodities was not available. The study reveals that the grey water footprint in agricultural sector is the major shareholder which implies that water is facing huge environmental problems in NCT of Delhi and the efforts should be taken to minimize the grey water footprint component. However, with the availability of more and refined data, the WF of NCT of Delhi has scope for revision. In future these kinds of studies pertaining to the assessment of WF will be helpful to the authorities to identify the sectors/commodity with large water footprint so that a check can be made in order to optimize the resources.

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