Water Footprint Analysis of Delhi to Understand it's sustainability

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Abstract - *India's ambition to meet SDGs (Sustainable Development Goals) like zero hunger and access to clean water depends upon the strategic use and management of limited freshwater resources. To do so, water consumption in various sectors must be established rather than using the traditional water withdrawal method. Water footprint (WF) is an indicator used to find the volume of fresh water being used in product, process, by a consumer, community, or nation directly and indirectly. It is based on the concepts of material flow analysis (MFA) and life cycle assessment (LCA). It traces all the processes and the direct water being consumed in them, giving virtual water content (VWC, water required to produce a unit product) of a particular product.*

In this study, it was found WF of Delhi in litres per capita per day (lpcd) for the year 2011 and forecasted for the year 2021 using water footprint assessment (WFA). The average water footprint of a person living in Delhi in the year 2011 came out to be 2913 lpcd broken down as crop WF: 1868 lpcd; livestock WF: 561 pcd; miscellaneous (comprises of products necessary in urban living such as petrol, liquor, etc.) WF: 207 lpcd and direct WF: 277 lpcd. It was found in the year 2021; crop WF is going to increase marginally because of higher dairy products and meat consumption along with lower consumption of cereals. Increase of 12.8% in total WF from 2011 to 2021 is primarily because of direct WF. There are many projects underway by the Delhi Jal Board (DJB) such as Renuka Dam, Kishau Dam and Lakhwar Vyasi Dam which aim to increase direct water supply by 66% i.e. 258 lpcd in 2011 to 430 lpcd in 2021.

Interestingly ~85-90% of WF of a person in Delhi is due to indirect consumption in the form of crop and livestock products which are being imported since there are no agricultural practices in Delhi. Remaining ~10-15% is in the form of direct WF, most of it comes from places which are not in geographical boundaries of Delhi (although they are a part of Delhi Hydrometric Area (DHA)). Delhi is almost entirely dependent on direct and indirect WF even though Delhi receives ~ 1 m of average rainfall every year.

***Key Words*: Environmental footprint; Water footprint; Water footprint assessment; Virtual water**

1. INTRODUCTION

Cities are the congested economic hubs of any nation; it is likely that many cities will face challenges in meeting the increasing demands of land, energy, water and other limited resources (UN, 2018). Freshwater use in agricultural, industrial, and household processes is increasing, which makes sustainable water use and management irrefutable. Stress on limited freshwater water resources is rapidly increasing in cities due to increasing population density, changing lifestyle, and urbanization (Gleick, 2000). The total urban population in India grew from 17.97% in 1961 to 31.16% in 2011 (Bhagat, 2011).

Freshwater resources are unevenly distributed all around India and the world with some areas being water scarce, while some are abundant. However, through the trade of goods and services, freshwater is being exchanged inter-regionally and internationally. This is known as virtual water (or indirect water) trade (Allan, 1996). Virtual water became a building block of an indicator known as "Water Footprint" (WF) developed by Hoekstra and Hung in 2002. Water footprint network (URL 1) has been developed over the years with a dedicated group of researchers working on water footprint. The water footprint is used to account actual or true water consumption for a product, process, consumer, community, business, or a nation (Hoekstra, Chapagain, & Aldaya, 2011).

1.1 Classification of Water Footprint

There are two classifications of water footprint. First, it is classified as direct and indirect to distinguish between the natures of the WF. Direct WF is water consumed directly, such as drinking, washing, etc. and indirect WF is water consumed indirectly through the purchase of goods or services such as buying foods, clothes, etc. Second, it is divided into blue, green, and grey WF to account for various water sources and water quality levels. The blue WF refers to the water taken up from groundwater and surface water resources during the production of a commodity. The green WF is an indicator of the precipitated water that does not run off or recharge the groundwater but gets stored as moisture in the soil and ultimately taken up by plants for their growth or gets evaporated. The grey WF is the water required to dilute the water, coming out from a production line of a product, according to water quality standards

(Mekonnen & Hoekstra, 2011). It is important to understand the difference between the water footprint of production (WF_{prod}) and the water footprint of consumption (WF_{cons}). The former is the sum of direct and indirect water use of regional water resource used in the process of production and latter is the sum of direct and indirect water use of regional and foreign water resource through domestic consumption (Vanham, Hoekstra, & Bidoglio, 2013).

1.2 Assessment Techniques

WF traces the flow of direct water consumed in every process involved. WF uses the concepts of material flow analysis (MFA) and life cycle assessment (LCA). However, WF measures on one attribute/unit, i.e., the volume of water and do not measure impact (Hoekstra et al., 2011). Common environmental impacts associated with excessive freshwater use are groundwater depletion, biodiversity loss, and freshwater pollution (Gleick, 2006).

1.3 Water Footprint of a city

WF studies now are being more focused on the city scale, such as Zhang et al., 2011, Feng et al., 2010 and (Ahams et al., 2017). Studies at city level give information about the allocation of water resources at a local scale. This allows taking appropriate measures and changes to optimize freshwater use. Cities are a good market place to sell goods which are not locally produced. Thus, cities use local water sources mostly for direct water consumption while putting burden and stress for indirect consumption on water resources somewhere else where they are being manufactured. Water saving in cities can be created by trading from a place which requires lesser Virtual Water Content (VWC, water required to produce or manufacture a unit of a particular product) than from a place having higher VWC for the same product (A. K. Chapagain, Hoekstra, & Savenije, 2006).

1.4 Scope of the study

In this study, we applied WFA (Water Footprint Assessment) to find per capita consumption of water in Delhi as direct and indirect WF. WF of consumption can then help to find which sector or activities have higher water utilization and how can it be reduced.

In India's fight against poverty and hunger and to achieve food and water security, WF can play a huge role in the future, particularly in the agricultural sector (URL 2).

Around 80% of fresh water is being used in agriculture (K Bharat & B Dkhar, 2018). Both food and water security are interconnected, and they should be looked with a more holistic approach at a local level. Current water productivity in agriculture in India is lower than that of the global average. With rapid population growth, it seems inevitable for India to become a water scarce nation (Rockstrom, Lannerstad, & Falkenmark, 2007). To tackle the situation, some possible ways are like increasing crop productivity, changing consumption patterns, or decreasing wastes and losses of agricultural products, all of which must go hand in hand.

Similar to other environmental indicators, water footprint does not give a complete picture of every environmental aspect. Therefore, it should be integrated with other relevant indicators to get social, economic, and environmental insights. The WF can act as a partial tool in the decision-making process (Hoekstra et al., 2011).

2. METHODOLOGY AND DATASETS

2.1 Method

This section describes the approach followed to determine and forecast the total water footprint in litres per capita per day (lpcd) and the losses as virtual water in different agricultural products for Delhi for the years 2011 and 2021.

2.2 Water Footprint Calculation

The summation of the footprint of the individual product gives the total water footprint within the geographical boundaries of Delhi as given by equations below.
where,

$$WF_{Delhi} = WF_{direct} + WF_{indirect} \quad [1]$$

WF_{direct} = Direct WF = Water being supplied by DJB (Delhi Jal Board) and groundwater used by households and industries in Delhi

$WF_{indirect}$ = Indirect WF = Water being used indirectly in products such as food, clothes, petrol etc.

$$WF_{direct} = \sum_{i=1}^{n} DW_i \quad [2]$$

where,
DW_i= Direct water through i^{th} source
i = 1, 2….n

$$WF_{indirect} = \sum_{p=1}^{m} WF_p \quad [3]$$

WF_p= VWC_p * w
where,
WF_p = Water footprint of p^{th} product
p = 1, 2…m
VWC_p = Virtual Water Content of product p (m^3/ton or l/kg)
w = weight of product p consumed (ton or kg)

2.3 Forecast

The trend of consumption of crop and livestock products for Delhi is assumed to be the same as for average India. The trend of consumption of various products was found out by using the FAO database. Also, virtual water content for any product p (VWC_p) is estimated to remain constant temporarily.

Time series curves were developed for each agricultural product from the data collected from FAO (as shown in Appendix figures). Outliers were identified by using box plot of residuals.

The equation used to find consumption for the year 2021:

$$C_{2021,p} = \frac{C, NSSO_{2011,p}}{C, FAO_{2011,p}} \times C, Estimated\ FAO_{\ 2021,p}$$

where,
$C_{2021,p}$: Consumption for product p (Delhi 2021)
$C,NSSO_{2011,p}$: Consumption for product p (Delhi, 2011) (Source: NSSO, 2014)
C, FAO2011, p: Consumption for product p (Indian average, 2011) (Source: URL C)
C, Estimated, FAO2021, p: Consumption for product p (Indian average, 2021).
It was found out by using the best fit trend line for product p using FAO data from 1961 to 2013 (Source: URL C).
Note: While forecasting, we excluded miscellaneous WF from our system boundary.

2.4 Virtual Water Content (VWC) of Various Crops and Products

Virtual water content (VWC) values were majorly taken from various Water Footprint Network (WFN) sources.

2.5 Datasets

All the data collected to calculate the water footprint of Delhi were for the year 2011-12. The main reason being, the last census report was published in 2011 and hence, better accuracy on per capita consumption. Data was collected from different sources, suitable assumptions were made, and it has been reported in detail in the supplementary material. No primary data and industrial data were collected. The system boundary for this study is shown in figure 1.

Fig -1: System boundaries for this study

2.5.1Direct Water Use and its Footprint

Direct water consumed in Delhi comprises of surface water from various rivers and groundwater.

Total direct water footprint in Delhi in 2011:

WF_{direct}= 1020 MGD (Surface and Ground Water Use) + 0.34 MGD (Virtual water associated with the treatment of water, Neglected as it less than 0.03% of direct water use)
= 1020 MGD
= 3861MLD
= 277 litres per day per capita
(Population of Delhi in 2011 = 16.7 million)

2.5.2Indirect Water Use and its Footprint

A total of 104 products were considered in this report to find the water footprint of Delhi. 75 products in crops, 13 products in livestock, and 16 miscellaneous products, which are important in urban living were included in this study. Agricultural Products considered are as follows:

Rice – P.D.S., Rice – other sources, Chira/Flattened rice, Khoi, lawa(puffed rice), Muri(puffed rice), Other rice products, Wheat/atta – P.D.S., Wheat/atta – other sources, Maida/wheat flour, Bread: bakery, Other wheat products, Jowar(sorghum) and its products, Bajra(pearl millet) and its products, Maize and its products, Barley and its products, Small millets and its products, Ragi(African millet) and its products, Other cereals, Arhar/Pigeon pea , tur, Gram: split, Gram: whole, Moong/Green Gram, Masur/Red Lentil, Urd/Black lentils, Other pulses, Gram products, Besan or gram flour or chickpeas flour, Other pulse products, Sugar – PDS, Sugar – other sources, Gur/brown sugar, Mustard oil, Groundnut oil, Coconut oil, Refined oil, Edible oil: others, Potato, Onion, Tomato, Brinjal, Carrot, Palak(spinach)/other, Green chillies, Cauliflower, Cabbage, Gourd, pumpkin, Peas, Beans, barbate, Lemon, Other vegetables, Banana, Watermelon, Pineapple, Coconut , Green coconut, Papaya, Mango, Apple, Grapes, Groundnut, Dates, Cashewnut, Walnut, Other nuts, Pears/nashpati, Berries, Ginger, Garlic, Dhania/Coriander, Turmeric , Black pepper , Dry chillies, Oilseeds, Other spices, Milk: liquid, Milk: powder, Curd,
Livestock Products:

Ghee/hard fat, Butter, Cheese(kg), Eggs (no.), Fish, prawn, Goat meat/mutton, Beef/ buffalo meat, Pork, Chicken, Others: birds, crab, etc.,

Miscellaneous Products:
Tea cups (no.), Coffee cups (no.), Cold drinks (L), Fruit juice and shake (no.), Bidi(no.), Cigarettes(no.), Tobacco(gm), Liquor (litre), Electricity (std units), Kerosene (litre), Petrol (litre), Coal (kg), L.P.G. (kg), Leather footwear (pair), Total no. of clothes (T Shirt equivalent), Bed sheet (no.)

*All products were considered in kilograms unless mentioned otherwise.

2.6 Losses

The virtual water loss due to inefficiencies in production, processing, packaging, and distribution has been calculated using data from FAO for the South and Southeast Asia in the year 2007 to 2009. The rate of losses and waste was assumed to remain the same during the period 2011 to 2021.

3. RESULTS

3.1 Water Footprint of Delhi in 2011 and 2021

The average water footprint of a person living in Delhi in the year 2011 came out to be ~2913 lpcd with ~858 grams of average food consumption in a day. Detailed flow of WF from different products within system boundaries of this study is shown in figure 2. Food products (crop and livestock products) contribute ~ 85% of total WF.

It was found crop WF as 1868 lpcd, 64% of total WF. Consumption of cereals, pulses, and edible oil takes ~84% of crop WF. Cereals alone contribute to ~60% of crop WF. Consumption of rice products and wheat products has a 91.7% share in cereals and contribute to ~18% and ~21% of total indirect WF respectively.

WF of livestock products is 561 lpcd, which is ~19% of total WF. High consumption of milk (~166 grams/day) leads to high WF of dairy products. WF of meat per unit consumed is relatively high (~ 7000 l/kg) but lower consumption of meat results in lower WF, i.e. 192 lpcd.

Miscellaneous products take about 7% of total WF, i.e. 207 lpcd. WF of energy requirement in 2011 through petrol, kerosene, coal, and electricity is ~ 70 litres per person per day. This is lower than average WF of clothes bought, i.e. 106 lpcd.

Direct water received in Delhi in 2011 was about 277 lpcd through various rivers and groundwater sources.

Fig -2: Water footprint(lpcd) of Delhi in 2011

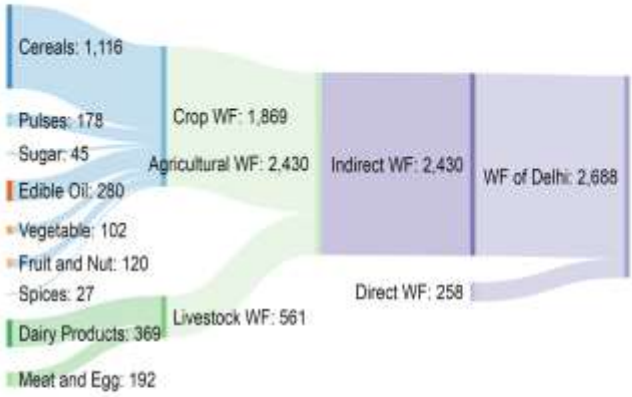

Fig- 3: Water footprint flow in Delhi 2011 in lpcd (excluding misc. products and groundwater)

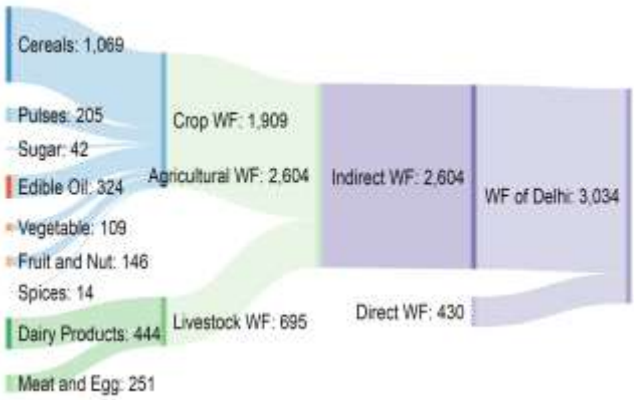

Fig- 0: Water footprint flow in Delhi 2021 in lpcd (excluding misc. products and groundwater)

The present study estimates WF of Delhi as ~ 3034 lpcd in 2021, based on projected input data of food products adapted from FAO database and neglecting miscellaneous products due to its insignificant contribution.

The results of this study have shown a 12.8% increase in total WF and ~6.5% increase in per day consumption from 858 grams per day in 2011 to 914 grams in 2021.

A ~4% decrease in WF was found in cereals, a product with the highest individual contribution. Spices and sugar consumption and WF has shown a marginal decrease. All other product categories have shown increased WF.

The WF of overall crop sector has been found to remain the same or increase marginally. Livestock WF is going to increase due to a shift in dietary patterns. Several projects are underway to increase direct WF by 66% in Delhi by DJB. Relative contribution of WF for year 2011 and 2021 is shown in figures 3 & 4. Comparison of the flow of WF through various product categories in the year 2011 and 2021 has been made in figure 5 and figure 6.

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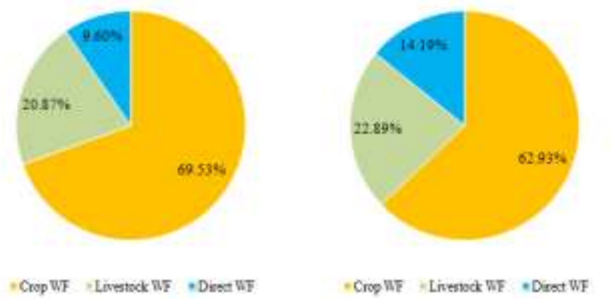

Fig -5: Sectoral water footprint in Delhi in (a)2011 and (b)2021

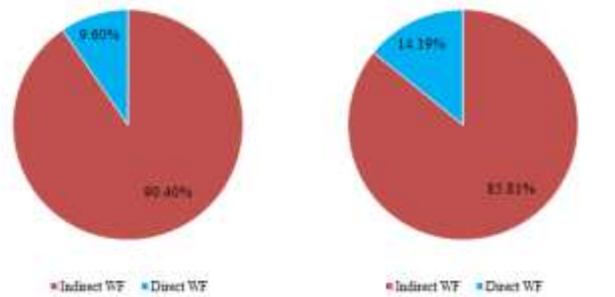

Fig -6: Distribution of types of WF in Delhi in (a) 2011 and (b) 2021

3.2 Losses

Due to inefficiencies in agricultural practices, the average virtual water lost in the year 2011 was 11239 million litres per day (MLD), which is going to increase to 12057 MLD in the year 2021. Average virtual water lost due to food wasted after consumption was 1243 MLD in the year 2011 and will become 1268 MLD in the year 2021. Average virtual water lost for different products has been tabulated in table 1.

Table -1: Losses of Virtual water in agricultural products (MLD) in 2011 and 2021 according to loss rates given by FAO

	Delhi 2011		Delhi 2021	
Agricultural Product	Virtual Water lost before consumption (MLD)	Virtual Water lost after consumption (MLD)	Virtual Water lost before consumption (MLD)	Virtual Water lost before consumption (MLD)
Cereals	3289	533	2845	461
Oilseeds & pulses	2377	82	2816	97
Fruits & vegetables	3275	389	3703	439
Meat	369	85	369	85
Fish & seafood	92	5	122	6
Milk & Cheese	1280	60	1539	72
Spices & Nuts	285	46	309	50
Sugar	134	22	156	25
Eggs	139	22	197	32
Total	11239	1243	12057	1268

3.3 Sensitivity Analysis

It was found that out of 38 categories of products, 5 products were contributing 73% of indirect WF, and the rest 33 products contributed the remaining 27%. Two scenarios were made to find sensitivity:

Scenario A: Variation in total WF due to variation in the water footprint of 33 products (contributing 27% of indirect WF) was studied. Other 5 products were assumed to have exact values of their WF.

Scenario B: Variation in total WF due to variation in the water footprint of 5 products (contributing 73 % of indirect WF) was studied. Rest 33 products were assumed to have exact values of their WF.

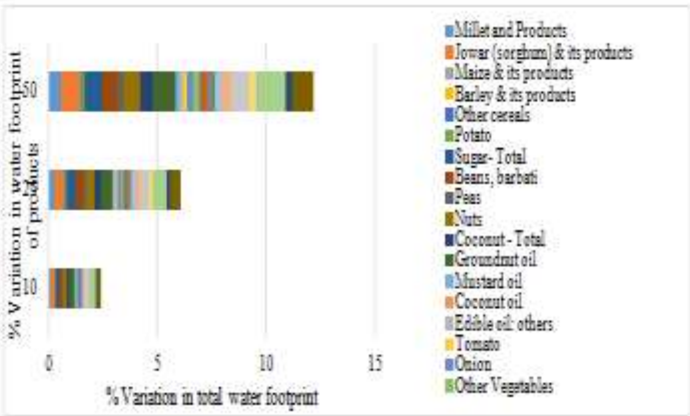

Chart -1: Percent variation in total WF with different percent variations in products according to scenario A

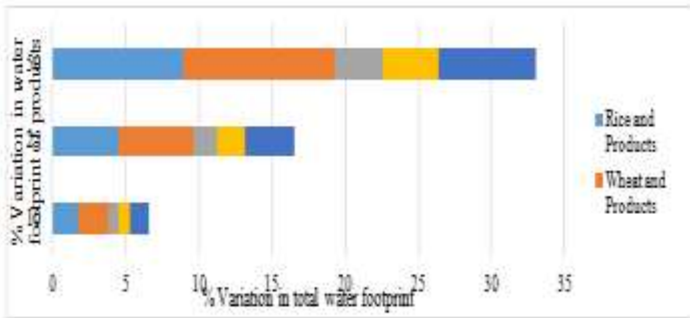

Chart -2: Percent variation in total WF with different percent variations in products according to scenario B

3.4 Validation

1. The data from NSS 68 of consumption of various agricultural products shows a correlation with the data given by FAO for the year 2011. The variation in data may be attributed to:
   - The difference in sampling methods by FAO and NSSO
   - FAO database uses January to December as a reference period of one year while NSSO conducted interviews from June'11 to July'12.
2. According to 'Water footprints of nations' by Chapagain & Hoekstra, 2004, average Indian internal agricultural and livestock WF of production = 2485 lpcd using analysis period as 1997–2001. This study gives agricultural and livestock WF of consumption in Delhi= 2429.2 lpcd in the year 2011-12.
3. According to 'The water footprint of India' by Kampman, 2007, the average Indian internal agricultural of production = 1802 lpcd using analysis period as 1997–2001. This study gives agricultural of consumption in Delhi = 1868 lpcd in the year 2011-12.

4. CONCLUSIONS

Food products (agricultural and livestock) have a major contribution (~ 90%) in WF of consumption for a person in Delhi. Rice and wheat products are the major contributors in crop water footprint due to high consumption. Our estimations showed that cereals' consumption could decrease by ~4.2% from 2011 to 2021. Overall consumption of livestock products is estimated to increase by ~24%, chicken consumption might increase by ~45%.

Results suggest, increase of 12.8% in total water footprint of Delhi from 2011 to 2021 is primarily because of direct and livestock water footprint increase. Direct water footprint is estimated to increase by 66% in this period. Results suggest indirect water footprint will have a marginal rise of ~7% from 2011 to 2021. It was found there is no significant water footprint contribution (less than 8%) of products essential in urban living as discussed in this report (in per capita scale). This is because the relative contribution of food products is much higher than the products required in urban living. 5 major food products were identified which contributed 73% of the total indirect WF and scenario based sensitivity analysis.

It was estimated 1243 MLD of virtual water was lost in Delhi by food wastage in the year 2011. It was estimated 11239 MLD of virtual water was lost in the year 2011 in production, storage and transportation phases. It was found virtual water lost due to inefficiencies in post-harvest practices such as storage and transportation is more than what Delhi needs (direct water) in a day.

It can be concluded enormous potential of water savings is there in Delhi as well as in India by reducing the losses in sowing, storage and transportation phases as well as by reducing the food wasted. It can ultimately lower the pollution levels in the streams by higher dilution.

For rural regions, emphasis should be on sowing seasonal crops according to climatic conditions, soil productivity and water availability. Cities can play a crucial role in decreasing indirect losses by connecting them with rural areas through efficient transportation systems. Proper storage facilities for agricultural products can be used as an indicator for sustainable cities and can aid in water savings.

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