META ANALYSIS OF WATER FOOTPRINT OF MAJOR MATERIAL FLOW IN URBAN AREAS.

ABSTRACT:

All water use in the globe is ultimately tied to consumer use. It is so interesting to learn about the precise water requirements of various consumer goods, particularly those that use a lot of water. Every commodity or good need water at some point throughout the manufacturing or distribution process. This data is useful not only for consumers, but also for food processors, retailers, and merchants. This study is aimed to focus at water footprint of such commodities based on cities major consumptions. For the purpose, cities water footprints are studied, and a basic set of equations are being developed for the city-based perspective for the researchers to bring about the requirement of incorporating water footprint concept in the conventional water flows. The study also focused on comparison of different states to use water for the same commodity. The states being water scarce and water surplus in nature, and using different irrigation practices and geological conditions have different water footprints of crops, animal products, cotton textile etc. This study will serve as a base for further studies to be done on the water footprint and shall try to bring to the notice of the authorities that there is a huge amount of water that is being neglected by the policy makers.

Keywords: Water footprint, Virtual water, Consumer goods, Water scarce regions, Water surplus regions, Commodity production, Sustainable water management, Urban water demand, Resource conservation

CHAPTER-1: INTRODUCTION

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Cities are considered as the most important base level aspect when it comes to commodities consumption. Both real and virtual water flows are affected by the users/ consumers, being the tail end of the supply. Their resource requirement affects almost all commodities manufacturing as well as flow. The major commodities consumed by almost every individual are Energy for e.g. electricity, Fuels such as diesel and petroleum, biofuels, bioenergy etc. Other basic requirements include food items such as milk, meat, fruits & vegetables, cereals etc. The consumption of these materials, when seen through hidden water concept plays a drastic role in increasing water consumption of any city, based on the size and population.

Considering convention water flows that are being calculated in various researched for certain cities, it does not include the Virtual/hidden water inside the most basic commodities. Water footprints are the indication of total amount of freshwater consumed during production along the whole supply chain.

1.1 Importance of project at city level and its importance

The concept of Virtual water as introduced by John Anthony Allan in the year 1993, deals with the water consumption by different commodities in its manufacturing, storage, travel and consumption by the user. The water flow through any city defines various aspects of people living in the area. Exact amount of flow if calculated may give critical information on major practices by the people, be it water intensive or water scarce. It will also improve the planning of cities on the basis of water consumption and water availability. These shall ultimately result in more sustainable water usage in any city and better governance and policy making as well.

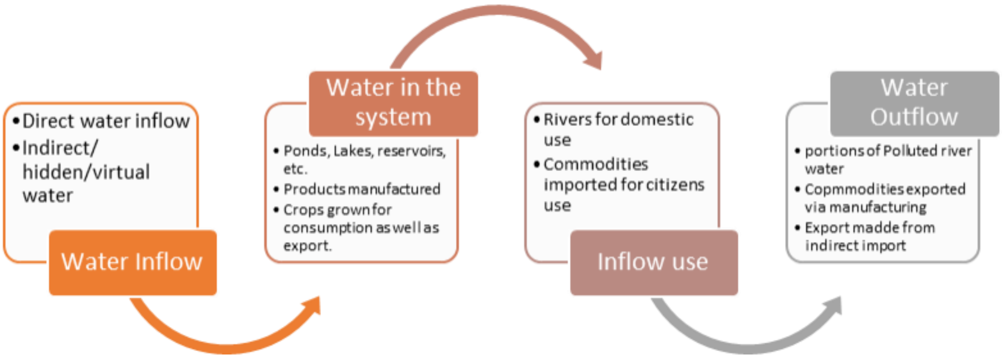

Figure 1: Derived water flow in accordance with conventional water flows, having both urban and rural areas

1.2 Commodity based water flow

From the above figure it is clear that in a water flow of a city, there can be products that are imported & exported, imported & used, manufactured & stored for use or manufactured & exported. Major domestic products have a direct impact on the water flow of any city. Calculation of water flow of any city shall hence, more importantly include the virtual water flow, as it holds a major amount to be counted, for a better management. Conventionally the calculation of water footprint of products has started with the emergence of studies by Hoekstra in 2003.

The idea of Life Cycle Assessment (LCA) is widely utilised for estimating potential environmental implications. Water usage has historically been left out of most LCA studies (Milà i Canals et al., 2009). LCA is a more contemporary tool for assessing impacts on water resources than the water footprint. The WFN (Water Footprint Network) strategy provides transparent information on water usage and related impacts at suitable time and spatial scales, which may be valuable in improving water efficiency and management. The LCA software programme tracks product flows between processes and scales the operations to final product output amounts. (P. W. Gerbens-Leenes et al., 2018)

1.3 Importance of the approach

Cities, it is becoming obvious, hold the key to achieving sustainability targets because of their ability to address and have an impact on global concerns such as climate change, biodiversity loss, and water resources. The water footprint is an important indicator that links consumer requirements and production demands to the planet's available resources.

Looking at the conditions of Indian cities living in water scarcity, there is a need to develop top-down approach, be it decision making and policy formulations at city level. Improvement in Hydrological performance by improving the rate of infiltration of storm water, reducing the frate of runoff and increasing the permeable layers in cities. In addition to that Material Flow analysis is also necessary to make a complete water balance for any city. A comprehensive view and government recognition for the hidden water in water balance is the need of the hour.

This study is an extension of already developed water balance for megacity like Delhi using conventional method of inflow & outflow measurements. Urban Water Security Assessment Using an Integrated Metabolism Approach. (Ghosh et al., 2019)

Research questions that are tried to be answered in the further sections of the report are: 1. Are Indian cities independent in terms of resource availability to its citizens. 2. If so, till what time they can sustain, moving ahead at this same rate of exploitation. How does Material flow analysis studies in a city, is going to help in the sustainable use of available resources. The future scope of the study shall include the combination of conventional water flow estimations with the updated material flow analysis.

Mass balance equation of any urban catchment when physical water is considered looks like:

$$\Delta S = (P+I) - (Ea + Rs + Rw)$$

P is precipitation; I is imported water; Ea is actual evapotranspiration; Rs is stormwater runoff; and Rw is wastewater discharge

Where, P + I is the inflow

Ea + Rs + Rw is the loss

ΔS is the change in storage.

Considering mass balance inclusive of commodity flow shall result in a more comprehensive outcome. The above equation may hence be derived as:

$\Delta S = WFi - (WFm + WFe)$

Where WFi = Water footprint of Imported material, adding to the storage

WFm = Water footprint of Manufactured goods depleting the amount of storage.

WFe = Water Footprint of exported materials subtracting the flow of water/ amount of storage

Considering Grey water footprint $\Delta Pc = (WFm + WFe) - WFi$

Where ΔPc is the change in pollutant concentration.

The purpose of the study is to have a complete analysis of a city's water footprint. The ways to calculate complete usage of water in a water scarce as well as water intensive cities. The further sections of the study deals with the statistical measures of different categories of commodities, relating them with the impact on water footprint individually on the basis of water availability as well as the method used for water footprint calculation.

The researches done in the past have focused on either water footprint calculation of a specific product, or have focused on the methods of water footprint calculation at global average using the existing water footprint assessment manual. Focus at the base level of water usage is missing somehow in the researches. The study is also focused towards complete assessment of the water balance of any city, which is the physical as well as hidden water in the form of water footprint flow.

The inclusion of water footprint calculation in a physical water flow, will give a complete and sustainable plan for a city to manage its water resources. It will help rephrasing the policies on water management and will bring to the notice of government, the gaps that exist in the policies. The future scope of the study includes suggestions on sustainable water governance. Research focusing specifically on calculating the complete water footprint with an analysis on available practices when considered for water usage, both physical as well as in the form of commodities. The improvements that are required to be made in the existing water demand management as a whole, inclusive of both governance as well as general public.

CHAPTER 2-:
LITERATURE REVIEW

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A water footprint is a consumption-based water usage indicator that takes into account both direct and indirect water use by a consumer, producer, or region. A person's, community's, or business's WF is defined as the entire volume of all forms of water used to generate the goods and services consumed or generated by the person, community, or business. It is measured in terms of water used (evaporated) and/or contaminated. It can be calculated for any well-defined group of consumers (such as a person, family, city, or nation) or producers (such as a business).(Chalisgaonkar et al., 2018)

Today, irrigated agriculture accounts for over 70% of total freshwater loss by humans (Kundzewicz et al., 2007). Agriculture accounts for approximately 86% of global freshwater use (Mekonnen & Hoekstra, 2014). Agriculture must compete with the other water using communities and industries for water (Rosegrant et al., 2009).

There are a lot of studies available for the review of Water Footprint at multi-level. Global water footprint calculations taking into account specific commodity for management at different levels has been done. In this regard very few studies have focused on a complete analysis of direct and indirect water at a city level as discussed earlier.

2.1 Review of existing studies on city’s Water Footprints.

City’s Water Footprint includes both direct and indirect usage of water. The Direct usage can be easily seen as:

1. Domestic usage
2. Agriculture
3. Construction
4. Electricity turbine
5. Industries
6. Maintaining the flow in the water bodies

The Indirect usage that is not seen but compose to a lot of water footprint can be listed as:

1. Domestic/user level of commodities
2. Indirect electricity generation

3. Indirect manufacturing use in commodities

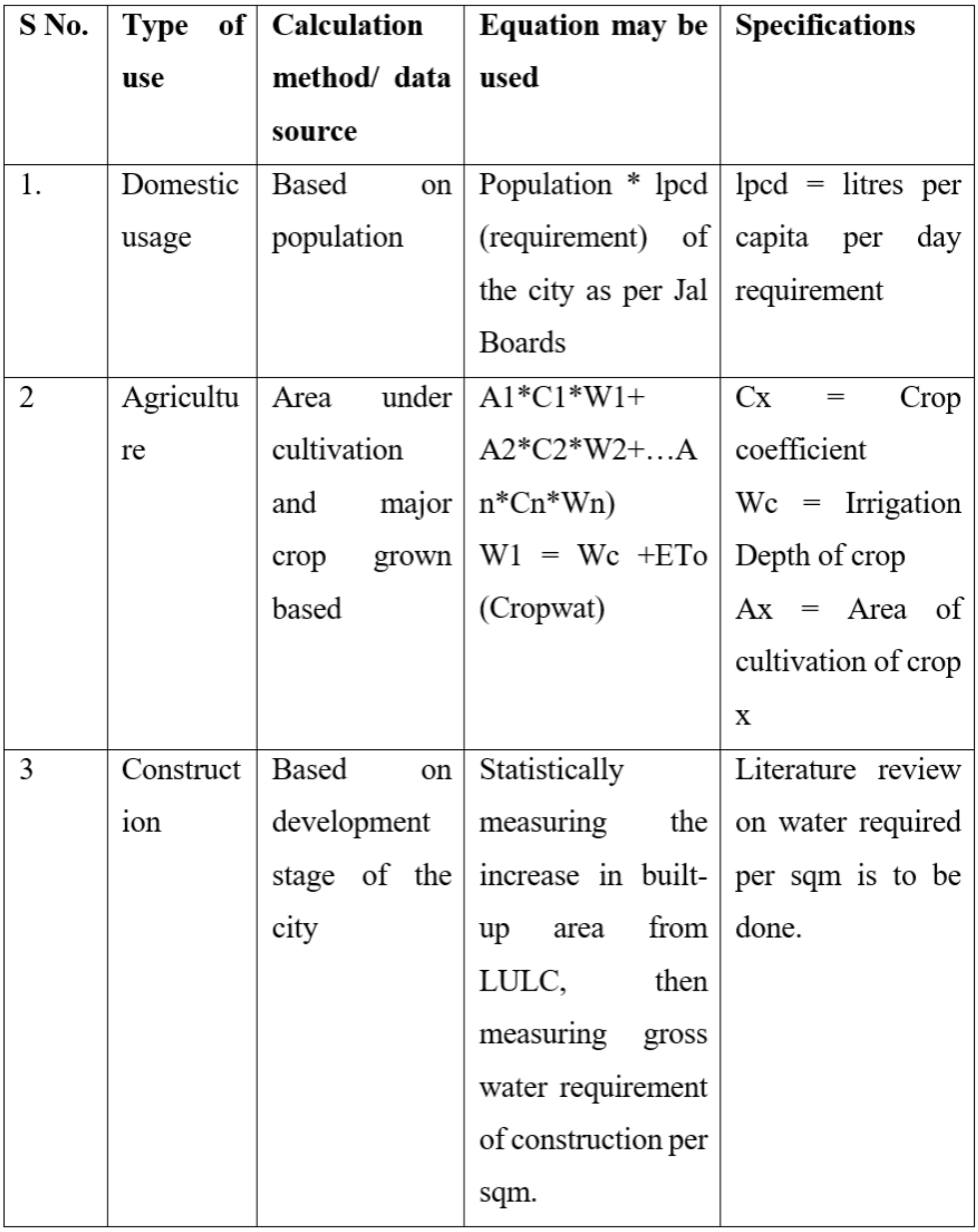
4. Indirect Food import and manufacture/ Export

5. Indirect water use in construction material manufacture

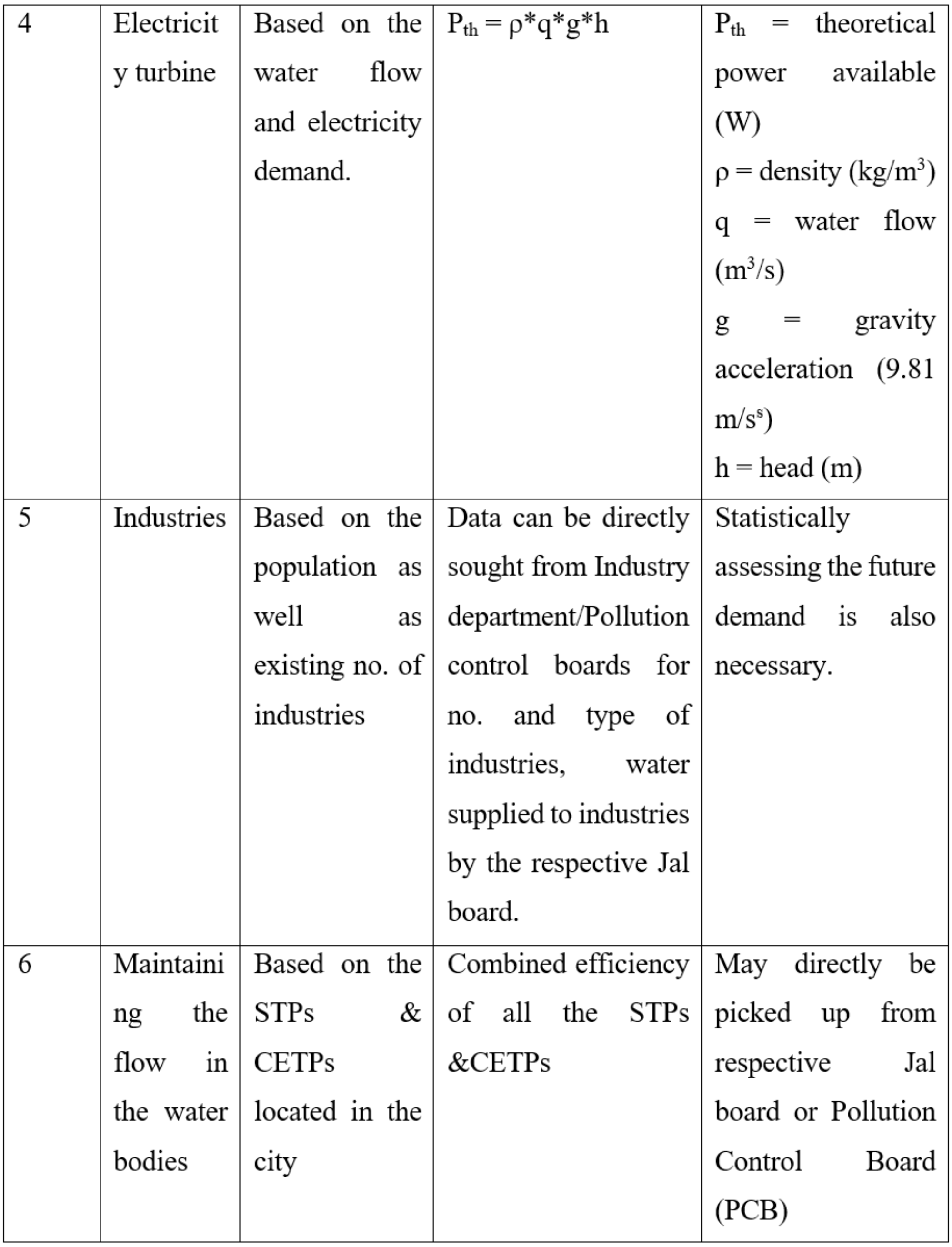
6. Indirect commodities import/manufacture/export, be it textiles like cotton, luxury goods like commute or normal food items (Packed as well as raw)

Calculating the direct usage has specified methods as well as calculations based on city population. The methods and equations may be used are listed in the table below:

Table 1:Calculation of direct water use.



S No.	**Type of use**	**Calculation method/ data source**	**Equation may be used**	**Specifications**
1.	Domestic usage	Based on population	Population * lpcd (requirement) of the city as per Jal Boards	lpcd = litres per capita per day requirement
2	Agriculture	Area under cultivation and major crop grown based	A1*C1*W1+ A2*C2*W2+…An*Cn*Wn) W1 = Wc +ETo (Cropwat)	Cx = Crop coefficient Wc = Irrigation Depth of crop Ax = Area of cultivation of crop x
3	Construction	Based on development stage of the city	Statistically measuring the increase in built-up area from LULC, then measuring gross water requirement of construction per sqm.	Literature review on water required per sqm is to be done.



4	Electricity turbine	Based on the water flow and electricity demand.	$P_{th} = \rho*q*g*h$	P_{th} = theoretical power available (W) ρ = density (kg/m^3) q = water flow (m^3/s) g = gravity acceleration (9.81 m/s^s) h = head (m)
5	Industries	Based on the population as well as existing no. of industries	Data can be directly sought from Industry department/Pollution control boards for no. and type of industries, water supplied to industries by the respective Jal board.	Statistically assessing the future demand is also necessary.
6	Maintaining the flow in the water bodies	Based on the STPs & CETPs located in the city	Combined efficiency of all the STPs &CETPs	May directly be picked up from respective Jal board or Pollution Control Board (PCB)

All of the above methods have been used in one or the other research to know the major physical water flow in the city. However, calculating the hidden water has different ways and types. To move further it is important to know what hidden water is, and when the concept gained importance.

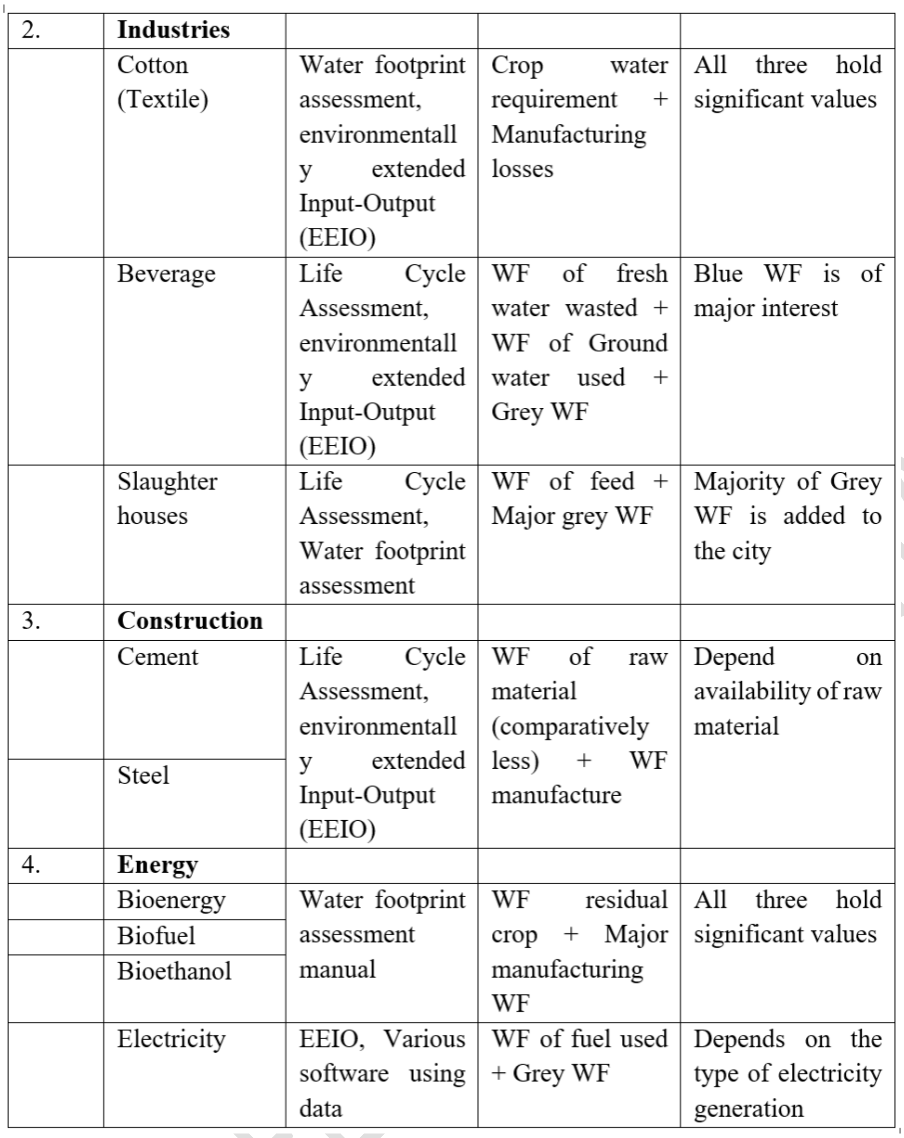
Hidden water is the basis of the concept of water footprint. It was introduced by Tony Allan in the early 1990s. It took over ten years for the concept's significance for achieving regional and global water security to become widely acknowledged. The Netherlands' Delft hosted the first global conference on the topic in December 2002. Using water along the supply chain has gained interests of people only after the introduction of water footprint concept by Hoekstra in 2002 ((Chapagain & Hoekstra, 2004). Virtual water is the amount of water required to manufacture a product from start to finish, and it is a mostly ignored and concealed component of manufacturing. (Lillywhite, Robert. (2010)

Moving back to the indirect water use in a city. Different methods have been defined by different researches. The study aim to quantify the ranges of the water footprint values of certain commodities grown in different topographies, based on water availability. It will also highlight the difference in water footprint of commodities when calculated from different methods of water footprint calculations, which are supposed to be either matching or near to each other.

The methods of calculation of water footprint of various sectoral commodities have been defined in the table below so as to have a gross idea water being imported virtually in a city, water used in commodities being manufactured and the commodities that are being exported:

Table 2: Calculation of Water footprint of Commodities

S No.	Commodities with major water footprint	Calculation method/ data source	Steps Involved	Comments
1	**Food products**			
	Wheat	Water Footprint Assessment	Developed software like CROPWAT, FAOSTAT etc.	Blue, green as well as grey WF can be known.
	Rice	Water Footprint Assessment	Developed software like CROPWAT, FAOSTAT etc.	Blue, green as well as grey WF can be known.
	Milk	Water footprint Assessment manual	Feed + Cooling, Storage & distribution units	Blue & Green WF are the major contributors
	Fruits, Vegetables			
	Meat	Water footprint assessment, environmentally extended Input-Output (EEIO)	WF feed + WF of slaughter house	Blue and grey WF hold significant values



2.	**Industries**			
	Cotton (Textile)	Water footprint assessment, environmentally extended Input-Output (EEIO)	Crop water requirement + Manufacturing losses	All three hold significant values
	Beverage	Life Cycle Assessment, environmentally extended Input-Output (EEIO)	WF of fresh water wasted + WF of Ground water used + Grey WF	Blue WF is of major interest
	Slaughter houses	Life Cycle Assessment, Water footprint assessment	WF of feed + Major grey WF	Majority of Grey WF is added to the city
3.	**Construction**			
	Cement	Life Cycle Assessment, environmentally extended Input-Output (EEIO)	WF of raw material (comparatively less) + WF manufacture	Depend on availability of raw material
	Steel			
4.	**Energy**			
	Bioenergy	Water footprint assessment manual	WF residual crop + Major manufacturing WF	All three hold significant values
	Biofuel			
	Bioethanol			
	Electricity	EEIO, Various software using data	WF of fuel used + Grey WF	Depends on the type of electricity generation

2.2 Hidden water Vs Water Footprint

Difference between the concept of hidden water of a crop & Water Footprint. Hidden water is the concepts that tells us about the water inside the commodity, rather the Water Footprint significantly define the water Inbuilt in the product throughout its manufacturing process. Water footprint hence being a broader term shall be used in the researches so as to broad up the approach. It will hence include all the water that is required by the product, at different levels of its manufacturing.

2.3 Calculations using Water Footprint Assessment Manual

2.3.1 Crop Water Footprint for a city

Crop water footprint shall be dependent on the type of crop, the topography of the area and the use of the crop, I.e. either it is limited to the crop itself or the crop being a perennial tree. The process of water footprint calculation shall be done throughout the cycle of the crop, when the water is being provided. Some crops start giving yield at the early stage and has a smaller life span, while others might have a much larger span of years before they come to use.

The manual has defined calculation of the water footprint in m3/ton equivalent to l/kg, which shall be based on the yield throughout the sowing process. Hence, the Process water footprint is defined at each stage for blue, green and grey water footprints.

The manual has defined the Blue/green water footprint as the function of Crop Water Use and the Yield. It can be defined as:

$$WF_{proc,\ Blue/Green} = CWU_{blue/green} / Y \ (\text{Volume/mass})$$

Where Y is the Yield and CWU is the Crop Water Use

Grey Water Footprint is calculated based on the fertilisers supplied to the crop. But that amount too is subjected to most harmful fertiliser pollutants as well as use subtraction of the amount of nutrients being taken up by the crop. So, the original flow of fertilisers shall be limited to the fraction that is being washed away. Hence the grey WF value depend majorly on the chemical application per hectare of the field, leaching and runoff ratio and the maximum acceptable concentrations of the pollutants. This can be stated as:

$$WF_{proc,grey} = [(\alpha \times AR)/ (c_{max} - c_{nat})]/ Y \ (\text{Volume/mass})$$

AR is the chemical application rate to the field per ha (kg/ha), α is the leaching runoff fraction, cmax is the max acceptable concentration in kg/m3 and cnat is the natural concentration of the concerned pollutant in kg/m3

Consumptive water use calculations require ET information, which then can be found out either through an empirical formula like Penman Monteith equation for reference evapotranspiration or can be known with some software like CROPWAT/AQUACROP developed by FAO. All the equations related to the formula can be found out using the manual. Calculation of ET using empirical formula can be typical sometimes, hence software that use climate data, rainfall as well as soil information to calculate the ET which is convenient and somehow more accurate.

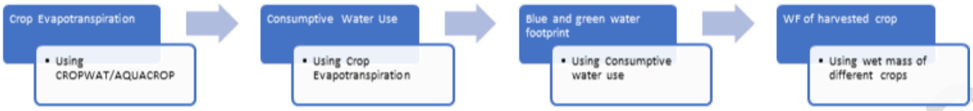


Figure 2: Steps defined by the manual in 2011 for different water footprint calculation

2.4 WF of other related commodities

Since food products are all somehow dependant on the vegetation, the process of calculating Total Blue/Green water footprint of products, start from the basic crop water requirement calculations. These then move upon other feeds for e.g. raising a cow for milk will include its feed as a grass in the calculation of its water footprint, along with the other cereal/ oil feeds will add up to the milk production. The total water footprint will also include the waste from the farm as well as the waste generated at storage, cooling and transport facilities. This will add upto the grey water footprint of the product(*Milk_production_by_states,* n.d.).

For a city the milk requirement can be calculated on the basis of population as well as market research on the daily consumption of milk in a city. The water footprints of animal products are determined by three major factors: the animal's feed conversion efficiency, feed composition, and feed provenance. The type of production system (grazing, mixed, or industrial) has an impact on all three elements.

When considering animal products, cities often lack the majority of water consumption in the sense that the manufacture have majorly been dependant on the rural areas of the country rather than urban. A limited no. of animal facilities or farms exists in the cities and that too are not involved with the packaging system, rather just produce for direct consumption of the people. An exception can rather be assigned to the chicken meat which is been increasing its production in the urban cities due to a probable reason of lifestyle change or lifestyle shift.

Moving back to calculating the water footprints of the animal products, keeping in mind the different manufacturing conditions like topographical difference, different production systems and different capacities of animals; the water consumption can be divided as:

WF total = WF feed + WF drink + WF service

Apart from this for a city, since it to be supplied with the use of a facility for storage, cooling and distribution. It needs to be added in the total water footprint. It again depends whether the city is only performing the storage or is manufacturing the animal products within the city.

In the latter case, Milk industry will then hence be possible for an increase in the grey water footprint due to no. of cooling & storage for the city. The water used in each of the listed category needs to be added to get the overall water footprint. WF of animal feed in any given city will depend on the no. of farms and the average no. of animals present in these farms. The water footprint of the feed is hence the grass used as feed multiplied by the population of the farms in the city. However exact no. of dairy can hardly be known because of an household practice of producing milk targeting a smaller population are being common in the cities these days. That water requirement shall be added to the domestic water use because these are the domestic units having 15-20 animals at the maximum extent.

The concept of feed conversion efficiency also plays a role in the estimation. Each group of animal population has a different energy conversion than the other. These conversions are helpful in knowing the exact WF of the animal feed. The city’s WF for milk can somehow be represented as the figure below:

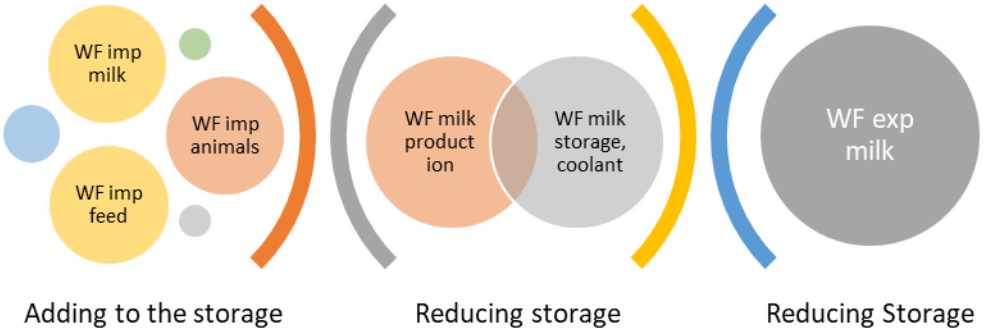


Figure 3:The city's WF for milk

2.5 Bioenergy

Another product that is related to crops is the bioenergy, generated from crop residue. That bioenergy shall involve water footprint of each residue and conversion of the same to biofuel, bioethanol or some pyrolysis oil(W. Gerbens-Leenes et al., n.d.).

For a city it majorly depends on whether the city is agriculture based or is imported its food products. In an agriculture-based city like Punjab, Haryana, Uttar Pradesh, West Bengal, Madhya Pradesh, Gujrat, assam, Karnataka, etc. Cities that are mentioned, shall have a lesser water footprint when bioenergy is considered because of a minimum water consumption in the import of the product, but it might be alleviated with the fact that the final product when exported from these states shall have a negative impact on the storage of the city's water. The same can be depicted in the figure below:

Figure 4: Water footprint for an agriculture-based city

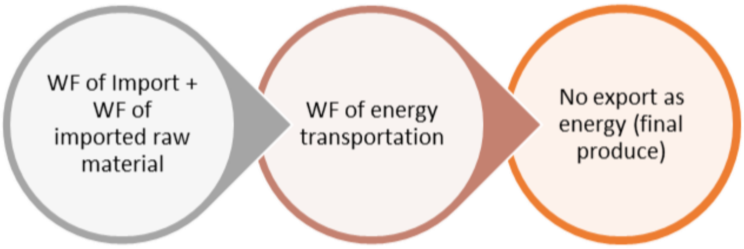


Figure 5: WF for a non-agriculture-based city

The water footprint for cities manufacturing Bioenergy through low fuel content crops have been higher as that of the more fuel containing crops. For example, if we talk about globally, Brazil being a top producer of sugarcane, is have much lesser bioenergy footprint because of plenty of raw crop residue. Also, it has been found that sugarcane is a major contributor in the bioenergy produce. Bioenergy when talked of crops can be obtained from every crop, but the major contributors are Jatropha carcus, maize, paddy rice, potato, sugar beet, Rapeseed, Casava, barley, soyabean etc.

2.6 Water Footprint of textile units

Taking of textiles lead us to the most demanded cotton fabric in India. Both urban as well as rural population of the country utilise cotton. In a city cotton may or may not be sown, but is either imported or exported for extensive utilisation and demand fulfilment of the product. Cotton is a water intensive product. Its production depends on the seed type, soil type and availability of favourable hydrological conditions. Cotton is grown in Punjab, Haryana, Rajasthan, Madhya Pradesh, Maharashtra and Gujarat. South zone comprises Andhra Pradesh, Telangana, Karnataka and Tamil Nadu.

When considering a city, cotton WF will depend on the availability of cotton, which will ultimately depend on the growing conditions of the crop in the area. According to the demand, if not manufactured, what amount of it is being imported is an important aspect to be considered. Apart from this crop water requirement is again used in the calculation of water required for the crop to be grown. The most interesting part of WF calculation of textiles is being covered in the water used by the manufacturer, because all the cotton that is obtained from the crop is not being converted to the final product. There are losses, sometimes tremendous. The manufacturing process also involves effluent discharge. Even after treatment, industries using dying colours tend to pose a serious threat to the nearby fresh water resource. Which sometimes for the interest of the government, as well as revenue generation is ignored, without seeking the overall interest of the city. One of the biggest examples of this could be dying and textile manufacturing industry hub near Noyyal River of Tamil Nadu.

Just for the reference of understanding the process of cotton manufacturing, given below is a chart representing, losses in the process of cotton fabric manufacturing.

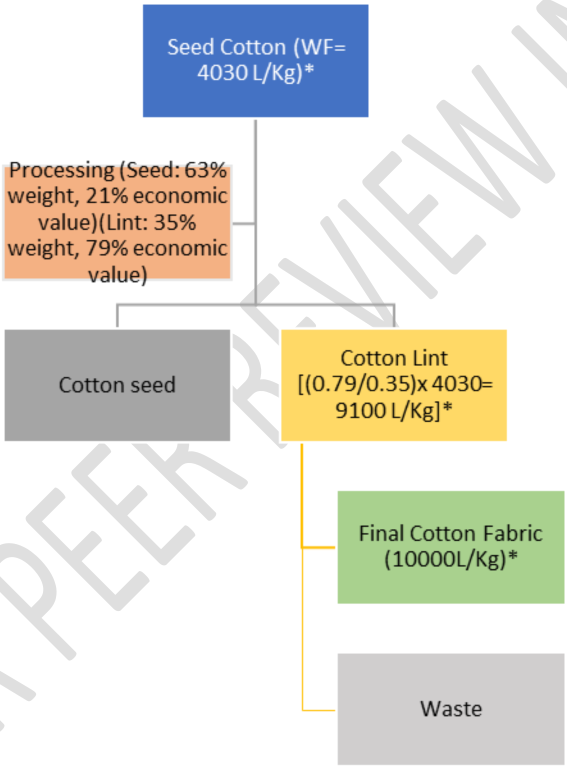


Figure 6: Cotton WF calculations

It has been claimed in researches that the Blue Water Footprint of cotton is higher in the regions of Rajasthan and Punjab, while looking at the green water footprint, it is higher in the regions of Gujrat, being the largest producer of cotton in India. Use of fertilisers in Gujrat indicate a higher value of grey water footprint as well. This can be justified through manufacture rate and more water footprint.

2.7 Other important commodities for a city

A city, apart from food to feed and clothes to wear, needs a shelter to live in. The urban cities occupy most of the space due to changing land use from agriculture to Built-up, due to rapid urbanisation and increasing population. Poverty, hunger and no shelters have become a new normal for major Indian cities. Buildings are being made at a rapid rate, as we talk about it on almost every platform defining it as the cause towards global warming.

Cement, sand and steel manufacturing also occupies a lot of water which will add upto a city's major water footprints. The manufacturing rate may be inferred from the population increase during the last two to three decades. This will enable us to average out the increasing physical as well as hidden water use. Looking at the Cement Information System (CIS), Department for Promotion of Industry and Internal Trade (DPIIT), almost every state has sufficient no. of cement manufacturing units. The raw materials involved, might be of importance if being imported or manufactured. Same is with the sand, if whether the sand mines are available or not depends on the geographical conditions of the area. Which ultimately decides the water footprint of sand for that particular city. City with raw material availability would have a cut off in capital cost as well as the resource cost, which will again have some water footprint. (Bardhan & Choudhuri, 2016)The water footprint increase shall cost a city more because the manufacturing of the same product will cost different at different locations, which is itself a resultant of water available.

The following depicts the direct and indirect use of a water in any urban construction:

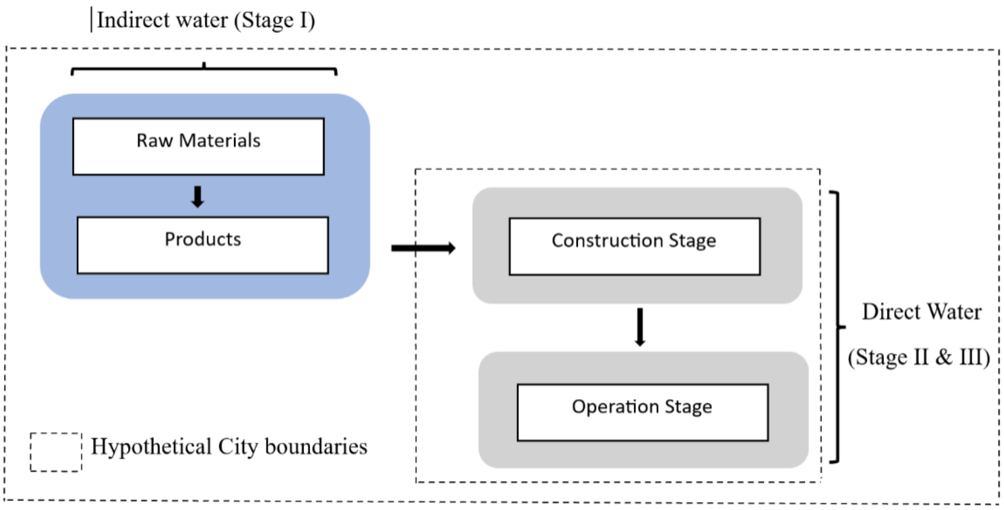


Figure 7:Direct and indirect use of a water in any urban construction

The above chart depicts the stages of construction in any urban city, w.r.t water usage, both Direct as well as indirect. City boundaries represent the difference in availability of raw materials in the city. It can also be termed as Life Cycle of water in construction, as is quoted in one of the related and cited literature(Pomponi & Stephan, 2021).

CHAPTER 3:- METHODOLOGY

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The methodology adopted for the study is majorly dependent on the Meta analysis of the data already available on the researches. The study is also based on the thorough understanding of the city's Indirect water flows in the form of water footprint of the commodities. For the purpose different categories have been chosen on the basis of major as well as basic yet necessary water consuming commodities. The water footprint of these commodities have been closely examined for statistically defining a range to its value over different regions of the Indian subcontinent.

Most of the information that have been collected have been tried to analyse on the basis of literature studied for the cities. Major contributor of the city's Water Footprint/ food as well as textile products have been given presence due to proper available literature. Analysis of the same have has been done so as to know the trend in any water scarce as well as water intensive city/ state. This will help analysing a better plan for cities with respect to total water consumption. The discussion and future scope of the study has tried to describe the same.

Methods involved or researched by various scientists in calculation of a city's Water footprint have been studied so as to make a conclusion on the variety of methods for different products used within a city. All the researches done on the cities have involved specific commodity used, which is relatable to the demographic details of the city. Almost each one of them are dependant on the Water Footprint Assessment manual, 2011, to define methods of calculation for basic commodities.

To understand the city's water balance in terms of Indirect water flow, the following chart is prepared. Relevant equations may be explained at later stages of methodology itself.

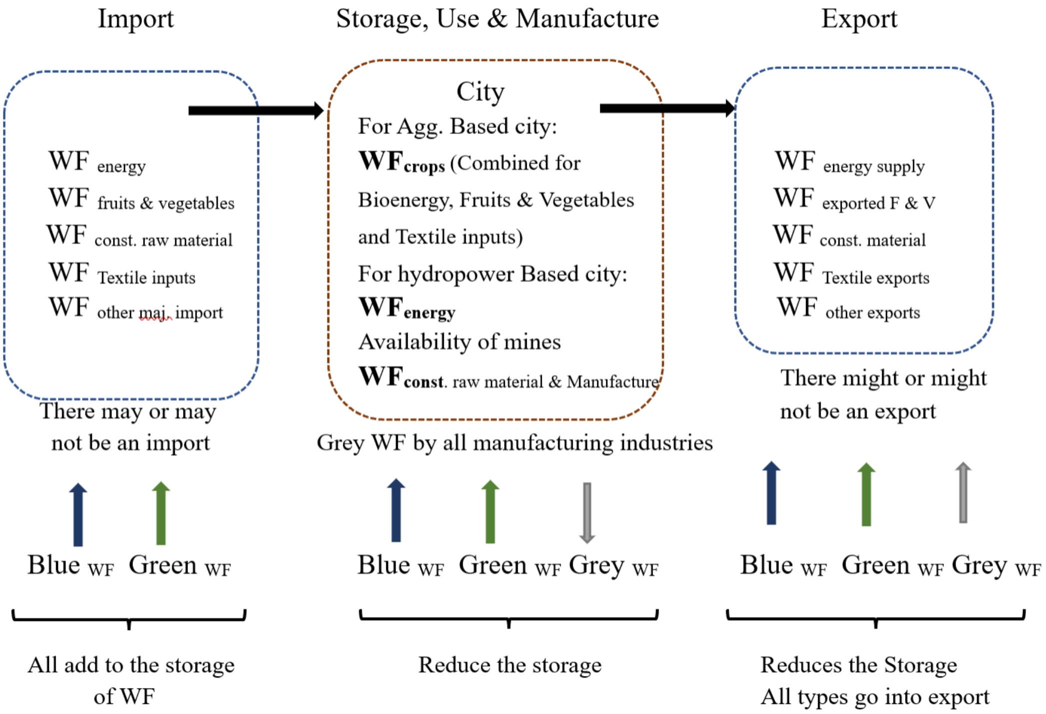


Figure 8: WF concept note for a city

The above chart can also be converted into equations, but in my opinion, charts are better understood. This shows how water may/may not be used in a city and how balance can be calculated via simply putting the values according to the manufactured quantity in the equations to get the total water footprint of the city. An example of equation modification can be seen below, for a city involved with importing, manufacturing, using as well as exporting the textile.

If the cotton lint is being imported:

ΔWFstorage = (Ci * WF cotton lint imported) – (Ci * 0.79/0.35 * WFlint to fabric) – (Cu * WFused fabric) – (Ce * WF fabric exported)

Where, Ci is quantity of Cotton lint imported, Cu is quantity of Cotton fabric used, Ce is quantity of Cotton fabric exported

If the cotton fabric is imported for use

ΔWFstorage = (Ci * WF cotton fabric imported) - (Cu * WFused fabric) - (Ce * WF fabric exported)

Where, Ci is quantity of Cotton fabric imported, Cu is quantity of Cotton fabric used, Ce is quantity of Cotton fabric exported.

Similarly, these may be adjusted as per the available records for the city. The WF for cotton lint and fabric manufactured has already been discussed for calculations. These shall start from calculation of crop water requirement, then the subsequent losses in the process, adding to increase the Water footprint for the final product to be prepared. Cotton lint possess 35% of weight, 79% economic value, leading to the calculation of WF as (0.79/0.35) x WF of cotton lint = WF of final Cotton fabric.

CHAPTER 4-:
RESULT

CHAPTER 4-: RESULT

The statistical analysis involves the comparison of Water Footprint of various commodities at different parts of the city so as to get an exact idea of how the WF are varying in the water intensive and water scarce areas, of the same commodity that is being discussed. Data compilation for different commodities is hence done from different researches so as to enable the comparison on the basis of geographical changes in the same commodity. A table comprising of details with respect to the literature that has been studies and data that is collected is given below. It has been used for various discussions in the study ahead. Four different categories of commodities are being looked at, namely Energy, Building material, Industries and Food, considering them to have a major impact on the Water Footprint of any Indian City.

Table 3: Raw data collected for various commodities for analysis.

Material	**Water Footprint**				**Methodology Used in calculation**	**Remarks**	**Reference**	**Region of Interest**
	Blue Water Footprint	**Green Water Footprint**	**Grey Water Footprint**	**Total Water Footprint**				
Energy								
Electricity	4241 l/GJ	-	-	4241 l/GJ	LCA software and databases	The study focused on the production of construction materials, excluding transportation	The blue and grey water footprint of construction materials: Steel, cement and glass P.W. Gerbens-Leenesa, A.Y. Hoekstra, R. Bosman(P. W. Gerbens-Leenes et al., 2018)	global weighted average
Crop residue for Bioenergy	0-20 m3/ton	60m3/ton (Sugar beet pulp)-1300 m3/t (Eucalyptus)	0-30 m3/ton	110 m3/t (Sugar beet pulp) – 1300 m3/t (Eucalyptus)	EROI	Different footprint for different crop material	The water footprint of second-generation bioenergy: A comparison of biomass feedstocks and conversion techniques V. Mathioudakis, P.W. Gerbens-Leenes, T.H. Van der Meer, A.Y. Hoekstra (Mathioudakis et al., 2017)	Indian Average
Bioethanol	0-40 m3/ton	500m3/ton (Sugar pulp)-10,000 m3/t (Pine)	0-50m3/ton	600-10000 m3/ton	EROI	Different footprint for different crop material	The water footprint of second-generation bioenergy: A comparison of biomass feedstocks and conversion techniques V. Mathioudakis, P.W. Gerbens-Leenes, T.H. Van der Meer, A.Y. Hoekstra	Indian average
Pyrolysis oil	0-40 m3/ton	600m3/ton (Sugar pulp)-10,000 m3/t (Pine)	0-50m3/ton	700-10000 m3/ton	EROI	Different footprint for different crop material	The water footprint of second-generation bioenergy: A comparison of biomass feedstocks and conversion techniques V. Mathioudakis, P.W. Gerbens-Leenes, T.H. Van der Meer, A.Y. Hoekstra	Indian Average
Building Material								
-Cement	2.17 l/kg	-	210 l/kg	212.17 l/kg	LCA software and databases	The study focused on the production of construction materials, excluding transportation	The blue and grey water footprint of construction materials: Steel, cement and glass P.W. Gerbens-Leenesa, A.Y. Hoekstra, R. Bosman	Global Average

OPC	0.54-0.68 L/Kg + 1.5 L/kg	-	210 L/Kg	212.18 L/kg	LCA software and databases	The study focused on the production of construction materials, excluding transportation	Water Footprint of widely used construction material-steel, cement, glass, A.Y. Hoekstra, Dr. Winnie Gerbans(Bosman, n.d.)	Global Average
PCC	0.44-0.58 L/Kg + 1.2L/Kg	-	210L/Kg	211.78 L/Kg	LCA software and databases	The study focused on the production of construction materials, excluding transportation	Water Footprint of widely used construction material-steel, cement, glass, A.Y. Hoekstra, Dr. Winnie Gerbans	Global Average
-Steel	24.9 MCM/year	0.122500 MCM /year (18 ha of greening)	15.2 MCM/year	40.2225 MCM/year	SimaPro8 software and Ecoinvent database	Grey WF calculated for pollutants TSS, NH3, CN, phenol, oil and grease, BOD5 and COD	A Review on Water Footprint Study for Steel Industry Madhuri. G1 , Ravi Tej Hegde2 , Sadashiva Murty BM3 , Srinivas rao RT(Murthy et al., 2017)	Jamshedpur
	69.735 m3/ton	-	2059.309 m3/ton	2129.04 m3/ton	LCA software and databases	The study focused on the production of construction materials, excluding transportation	The blue and grey water footprint of construction materials: Steel, cement and glass P.W. Gerbens-Leenesa,⁎ , A.Y. Hoekstrab,c , R. Bosman	Weighted Global average
Industries								
Cotton textile (Raw Products)					Water Footprint Assessment	WF of raw materials	Water Footprint of Cotton Textile Processing Industries; a Case Study of Punjab, Pakistan, Sohail Ali Naqvia, Dr Masood Arshadb, Farah Nadeem	Punjab, Pakistan
Caustic Soda	3.2 m3/t	-	-	3.2 m3/t	Water Footprint Assessment	WF of raw materials	Water Footprint of Cotton Textile Processing Industries; a Case Study of Punjab, Pakistan, Sohail Ali Naqvia, Dr Masood Arshadb, Farah Nadeem	Punjab, Pakistan
Sodium silicate	0.069 m3/t	-	-	0.069 m3/t	Water Footprint Assessment	WF of raw materials	Water Footprint of Cotton Textile Processing Industries; a Case Study of Punjab, Pakistan, Sohail Ali Naqvia, Dr Masood Arshadb, Farah Nadeem	Punjab, Pakistan

Soda ash	3.76 m3/t	-	-	3.76 m3/t	Water Footprint Assessment	WF of raw materials	Water Footprint of Cotton Textile Processing Industries; a Case Study of Punjab, Pakistan, Sohail Ali Naqvia, Dr Masood Arshadb, Farah Nadeem	Punjab, Pakistan
Dyes	4-9.5 m3/t	-	-	4-9.5 m3/t	Water Footprint Assessment	WF of raw materials	Water Footprint of Cotton Textile Processing Industries; a Case Study of Punjab, Pakistan, Sohail Ali Naqvia, Dr Masood Arshadb, Farah Nadeem (*Assessm_water_footprint_cotton_India*, n.d.)	Punjab, Pakistan
Cotton	3300 l/Kg	5400 l/Kg	1300 l/Kg	10,000 L/Kg	Water Footprint Assessment	stored irrigation water + effective rainfall + antecedent stored water	Towards sustainable water use in cotton supply chain, Sameer Safaya, Guoping Zhang, Ruth Mathews May 2016	Global Average
	372 m3/ha	5,985 m3/ha	496,657 m3/ha	503014 m3/ha	Water Footprint Assessment	stored irrigation water + effective rainfall + antecedent stored water	Towards sustainable water use in cotton supply chain, Sameer Safaya, Guoping Zhang, Ruth Mathews May 2016	Madhya Pradesh
	400 m3/ha	5493 m3/ha	4386 m3/ha	10279 m3/ha	Water Footprint Assessment	stored irrigation water + effective rainfall + antecedent stored water	Towards sustainable water use in cotton supply chain, Sameer Safaya, Guoping Zhang, Ruth Mathews May 2016	Gujrat
	123 m3/ha	5506 m3/ha	39504 m3/ha	45133 m3/ha	Water Footprint Assessment	stored irrigation water + effective rainfall + antecedent stored water	Towards sustainable water use in cotton supply chain, Sameer Safaya, Guoping Zhang, Ruth Mathews May 2016	Maharashtra
	5726 m3/ton	15837 m3/ton	1062 m3/ton	22625 m3/ton	Review of existing literatures	stored irrigation water + effective rainfall +	The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the	Indian average

						antecedent stored water	water resources in the cotton producing countries A.K. Chapagain, A.Y. Hoekstra b, H.H.G. Savenije, R. Gautam	
	150 m3/ton	2096 m3/ton	1938 m3/ton	4184 m3/ton	Water Footprint assessment	Water scarce regions of India are taken into account	Water Footprint for Different Industries-An Overview, Rushikesh G. Kakad, Dr. R. T. Pachkor	Gujrat
	42 m3/ton	2641 m3/ton	24291 m3/ton	26974 m3/ton	Water Footprint assessment	Water scarce regions of India are taken into account	Water Footprint for Different Industries-An Overview, Rushikesh G. Kakad, Dr. R. T. Pachkor	Maharashtra
	252 m3/ton	4021 m3/ton	333766 m3/ton	338039 m3/ton	Water Footprint assessment	Water scarce regions of India are taken into account	Water Footprint for Different Industries-An Overview, Rushikesh G. Kakad, Dr. R. T. Pachkor	Madhya Pradesh
Beverage, raw material (sugar)	156 m3/ton	85 m3/ton	15 m3/ton	256 m3/ton	Water Footprint assessment	water footprint of different ingredients and other inputs is calculated distinguishing the green, blue and grey water components	Corporate Water Footprint Accounting and Impact Assessment: The Case of the Water Footprint of a Sugar-Containing Carbonated Beverage, Ertug Ercin , Maite Martinez Aldaya , Arjen Y. Hoekstra(Ercin et al., 2011)	Indian average
Food								
-Wheat	453 m3/ton	128 m3/ton	290 m3/ton	871 m3/t	LCA approach based on the PAS 2050:2011 protocol	Data processing was performed using XLSTAT software	Carbon footprint and water footprint of rice and wheat production in Punjab, India Durba Kashyap, Tripti Agarwal(Kashyap & Agarwal, 2021)	Punjab
	1950 m3/ton	388 m3/ton	755 m3/ton	3093 m3/ton		Excludes the water requirement for dilution of waste flows.	The water footprint of India, Doeke Kampman. (Joe McCarthy, 2016a)	Delhi
		61.15 MCM/annum	30.47 MCM/annum	91.62 MCM/annum	Virtual Water Content based	CROPWAT is used for distributed water use	Quantification of Water Footprint of National Capital Territory (NCT) of Delhi,	Delhi

					on Crop water requirement		India, Sharad.K.Jain(Chalisgaonkar et al., 2018)	
	-	-	-	1523m3/ton	EROI	Crop WF calculated for bioethanol WF estimation	The water footprint of second-generation bioenergy: A comparison of biomass feedstocks and conversion techniques V. Mathioudakis, P.W. Gerbens-Leenes, T.H. Van der Meer, A.Y. Hoekstra (Mathioudakis et al., 2017)	Global Average
	1807 m3/ton	297.28 m3/ton	721.81 m3/ton	2826.09 m3 /ton	Self-derived equations	Crop Water requirement based	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
	1704 m3/ton	-	-	1704 m3/ton	Separately calculating for fuel and fuel wood and then adding them for total WF	For 6 regions and 35 provinces	The water footprint of food and cooking fuel: A case study of self-sufficient rural India K. Das, P.W. Gerbens-Leenes, S. Nonhebel (Das et al., 2021)	Rajasthan
	2711 m3/ton	-	-	2711 m3/ton	Separately calculating for fuel and fuel wood and then adding them for total WF	For 6 regions and 35 provinces	The water footprint of food and cooking fuel: A case study of self-sufficient rural India K. Das, P.W. Gerbens-Leenes, S. Nonhebel	Maharashtra
	1243.75 m3/ton	889.041 m3/ton	-	2132.79 m3/ton	Life Cycle Assessment based (LCA)	underestimate full variability of green and blue WFs due to local environmental factors and production systems.	The water use of Indian diets and socio-demographic factors related to dietary blue water footprint Francesca Harris a, Rosemary F Green a b, Edward J M Joy a b, Benjamin Kayatz c, Andy Haines a d, Alan D Dangour	Indian Average
	1162 m3/ton	643 m3/ton	294 m3/ton	2099 m3/ton	Water Footprint Assessment manual	Considers wheat as animal feed	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010(Thakur et al., 2018)	Indian Average 2005

-Rice	693 m3/ton	213 m3/ton	191 m3/ton	1097 m3/ton	LCA approach based on the PAS 2050:2011 protocol	Data processing was performed using XLSTAT software	Carbon footprint and water footprint of rice and wheat production in Punjab, India, Durba Kashyap, Tripti Agarwal	Punjab
	3902 m3/ton	3427 m3/ton	807 m3/ton	8137 m3/ton		excludes the water requirement for dilution of waste flows.	The water footprint of India, Doeke Kampman(Joe McCarthy, 2016b)	Delhi
	-	55.27 MCM/annum	10.10 MCM/annum	65.36 MCM/annum	Virtual Water Content based on Crop water requirement	CROPWAT is used for distributed water use	Quantification of Water Footprint of National Capital Territory (NCT) of Delhi, India, Sharad.K.Jain	Delhi
	136.3 Bm3/yr	104.5 Bm3/yr	14.7 Bm3/ yr	255.5 Bm3/yr	Crop water use calculated from CLIMWAT & CROPWAT	calculated as the sum of water evaporated from the crop fields and the volume of water polluted in the process	Assessing Energy and Water Footprints for Increasing Water Productivity in Rice Based Systems, R Tripathi, M Debnath, S Chatterjee, D Chatterjee, A Kumar, D Bhaduri, A Poonam, PK Nayak, M Shahid, BS Satpathy, BB Panda and AK Nayak	India
	-	-	-	1633 m3/ton	EROI	Crop WF calculated for bioethanol WF estimation	The water footprint of second-generation bioenergy: A comparison of biomass feedstocks and conversion techniques V. Mathioudakis, P.W. Gerbens-Leenes, T.H. Van der Meer, A.Y. Hoekstra	Global average
	653.173 m3/ton	1877.872 m3/ton	-	2531.042 m3/ton	Life Cycle Assessment based (LCA)	underestimate full variability of green and blue WFs due to local environmental factors and production systems.	The water use of Indian diets and socio-demographic factors related to dietary blue water footprint, Francesca Harris a, Rosemary F Green a b, Edward J M Joy a b, Benjamin Kayatz c, Andy Haines a d, Alan D Dangour(Harris et al., 2017)	Indian Average
-Dairy	-	-	-	1.48-61.42 m3/kg	Water Footprint assessment	Total WF for various states have been calculated	Water Footprint of milk production in Andhra Pradesh R Harika, D. Pandey, A Sharma and S Sirohi	Andhra Pradesh

	-	-	-	1-5 m3/Kg	Water Footprint assessment	Total WF for various states have been calculated	Water Footprint - A Tool for Sustainable Development of Indian Dairy Industry Ankaj Thakur , Anshuman Kumar , Brij Vanita , Girish Panchbhai4 , Narender Kumar, Anjali Kumari5 and Pardeep Kumar Dogra	Various Indian states
Vegetables	43 m3/ton	194 m3/ton	85 m3/ton	322 m3/ton	Water Footprint Assessment manual	All types of WF are analysed.	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Global Average
	81.6466 m3/ton	-	-	81.64 m3/ton	Life Cycle Assessment based (LCA)	underestimate full variability of green and blue WFs due to local environmental factors and production systems.	The water use of Indian diets and socio-demographic factors related to dietary blue water footprint, Francesca Harris a, Rosemary F Green a b, Edward J M Joy a b, Benjamin Kayatz c, Andy Haines a d, Alan D Dangour	Indian Average
Fruits	147 m3/ton	727 m3/ton	93 m3/ton	967 m3/ton	Process analysis	All types of WF are analysed.	The green, blue and grey water footprint of crops and derived crop products, M. M. Mekonnen and A. Y. Hoekstra(Mekonnen & Hoekstra, 2011)	Global average
	226.7962 m3/ton	-	-	226.7962 m3/ton	Life Cycle Assessment based (LCA)	underestimate full variability of green and blue WFs due to local environmental factors and production systems.	The water use of Indian diets and socio-demographic factors related to dietary blue water footprint, Francesca Harris a, Rosemary F Green a b, Edward J M Joy a b, Benjamin Kayatz c, Andy Haines a d, Alan D Dangour	Indian Average
	147 m3/ton	726 m3/ton	89 m3/ton	962 m3/ton	Water Footprint Assessment manual	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Global Average
-Chicken Meat (via grazing)	1536 m3/ton	11993 m3/ton	1369 m3/ton	14898 m3/ton	Process analysis	All types of WF are analysed, WF For	A Global Assessment of the Water Footprint of Farm Animal Products Mesfin M. Mekonnen and Arjen Y. Hoekstra	Indian Average

						grazing is high as it includes crop WF.		
Mixed	995 m3/ton	7676 m3/ton	876 m3/ton	9547 m3/ton	Process analysis	All types of WF are analysed. Mixed water footprint	A Global Assessment of the Water Footprint of Farm Animal Products Mesfin M. Mekonnen and Arjen Y. Hoekstra	Indian Average
Weighted average	873 m3/ton	6726 m3/ton	768 m3/ton	8367 m3/ton	Water Footprint Assessment manual	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Indian average 2010
Meat, Chicken	-	-	-	4498.67 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
Meat, Goat	-	-	-	13402.29 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
Meat, Goat , weighted average	393 m3/ton	4194 m3/ton	13 m3/ton	4600 m3/ton	Water Footprint Assessment manual	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Indian average 2010
Meat, Sheep	-	-	-	16018.67 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
Meat, Sheep, weighted average	582 m3/ton	7416 m3/ton	314 m3/ton	8312 m3/ton	Water Footprint Assessment manual	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Indian average 2010
Meat, Pig	-	-	-	15876 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
Meat, Pig, weighted average	1191 m3/ton	5415 m3/ton	554 m3/ton	7160 m3/ton	Water Footprint	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Indian average 2010

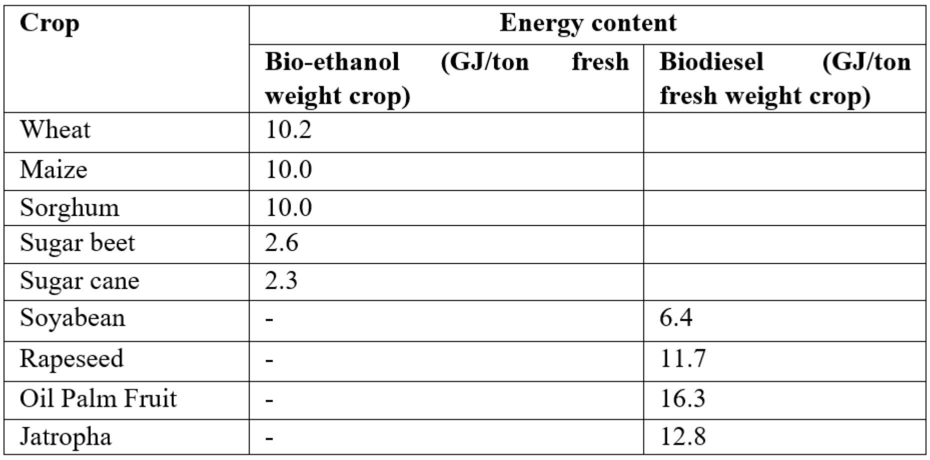
					Assessment manual			
Milk, Cow	-	-	-	5628 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
milk	130 m3/ton	885 m3/ton	63 m3/ton	1078 m3/ton	Water Footprint Assessment manual	Every detail is included in the calculation	The green, blue and grey water footprint of farm animals and animal products, M.M. Mekonnen, A.Y. Hoekstra 2010	Indian Average 2010
Milk, Buffalo	-	-	-	5212.50 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj
Milk, Goat	-	-	-	1303 l/kg	Self-derived equations	Animal feed, drinks and other services are added to the WF	Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India by Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra	Prayagraj

4.1 Analysis of bioenergy

Bio-energy carriers, Ethanol, Bio-diesel, Fuelwood, Charcoal, Bagasse, Biogas, etc.

Plants and trees contain a variety of elements such as carbohydrates, lipids, lignins, minerals, organic acids, and proteins. Because each of these building components has its own energy value, each type of biomass has a different energy content. The crop's WF in terms of m3/ton and the crop's energy content (GJ/ton) determine the WF of bio-energy in terms of m3/GJ. Biofuel Scenarios from the Perspective of Water: (P. W. Gerbens-Leenes et al., 2012)

Table 4: Bio energy provided by the energy crops.



Crop	**Energy content**	
	Bio-ethanol (GJ/ton fresh weight crop)	**Biodiesel (GJ/ton fresh weight crop)**
Wheat	10.2	
Maize	10.0	
Sorghum	10.0	
Sugar beet	2.6	
Sugar cane	2.3	
Soyabean	-	6.4
Rapeseed	-	11.7
Oil Palm Fruit	-	16.3
Jatropha	-	12.8

Water footprint of producing energy from a few well-known crops can be listed as:

Table 5:Water footprint per unit of energy

Water footprint per unit of energy				
Crops for **ethanol**	Green	Blue	Grey	Total (m3/GJ of ethanol)
Barley	119	8	13	140
Cassava	106	0	3	109
Maize	94	8	19	121
Potatoes	62	11	21	94
Rice, paddy	113	34	18	165
Rye	140	2	10	152
Sorghum	281	10	9	300
Sugar beet	31	10	10	51
Sugar cane	60	25	6	91
Wheat	126	34	20	180
Crops for **biodiesel**	Green	Blue	Grey	Total (m3/GJ of ethanol)
Groundnuts	177	11	12	200
Oil palm	150	0	6	156
Rapeseed	145	20	29	194
Seed cotton	310	177	60	547
Soybeans	326	11	6	343
Sunflower	428	21	28	477
Crop for **Electricity**	Green	Blue	Grey	Total (m3/GJ of Electricity)
Sugar beet	19	27	-	46
Maize	30	20	-	50
Sugar cane	23	27	-	50
Barley	31	39	-	70
Rye	42	36	-	77
Paddy rice	54	31	-	85
Wheat	39	54	-	93
Potato	58	47	-	105
Cassava	127	21	-	148
Soybean	78	95	-	173
Sorghum	102	78	-	180
Jatropha	165	231	-	396

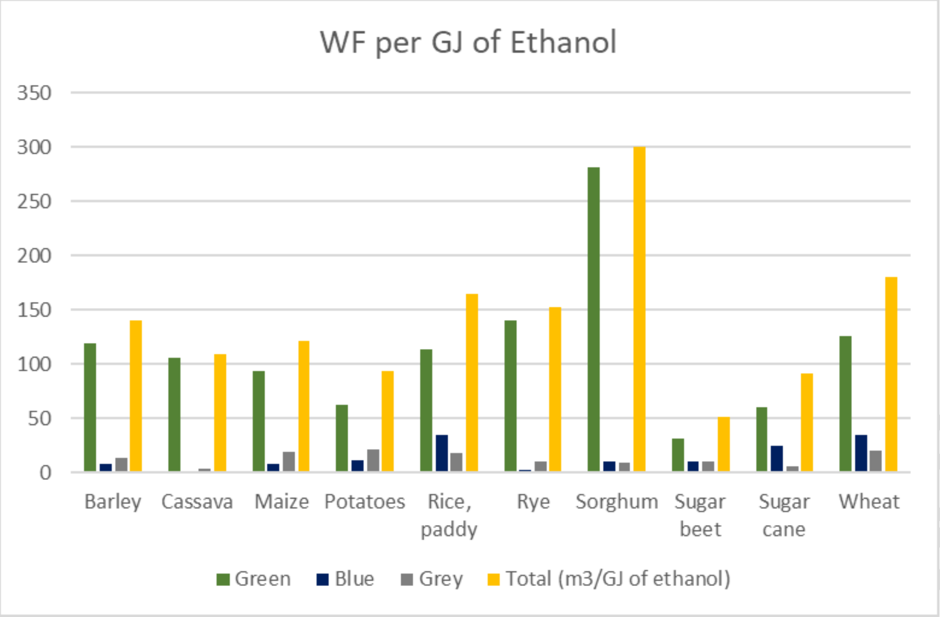


Figure 9: WF of crop residue per GJ of ethanol

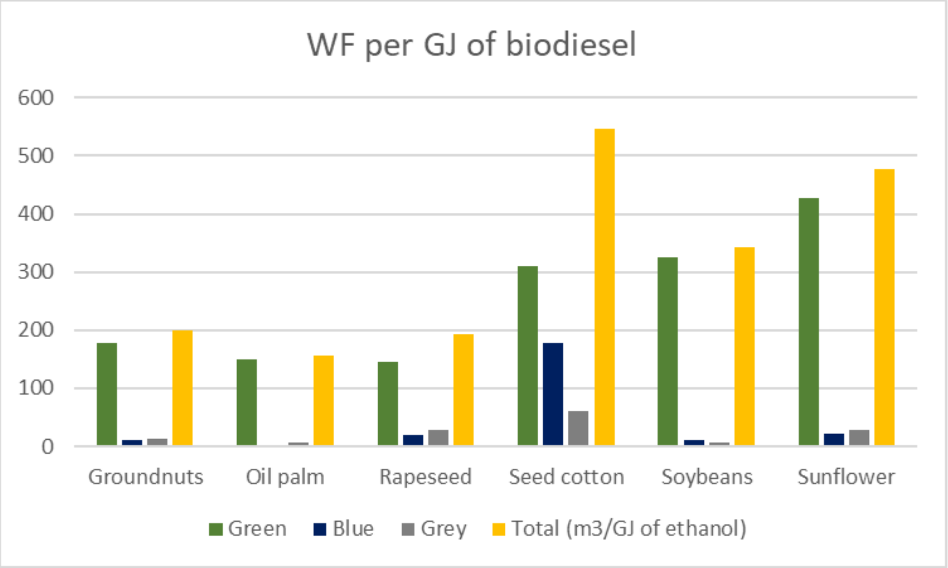


Figure 10: WF of crop residue per GJ of biodiesel

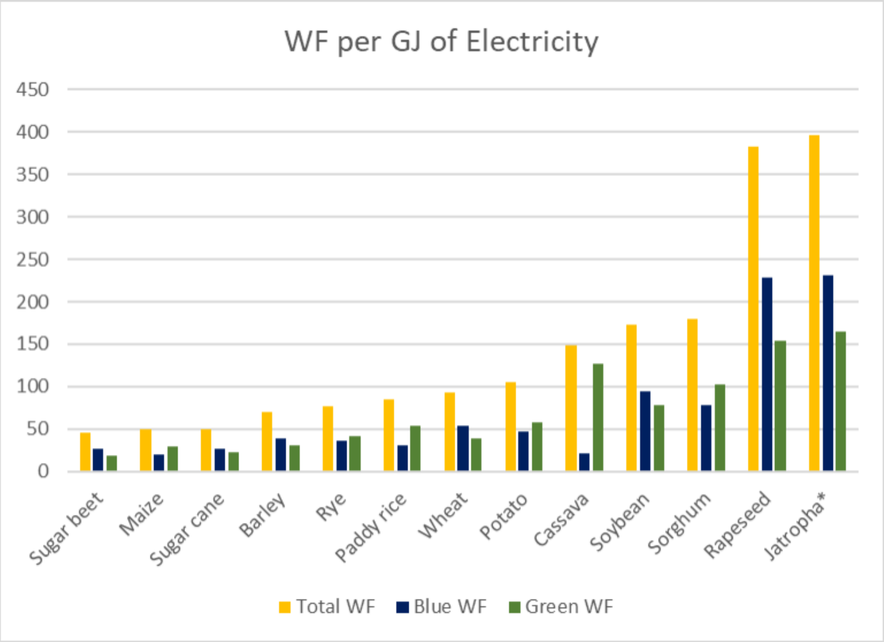


Figure 11: WF of crop residue per GJ of electricity

The depiction of all the three bioenergy products shows that a significant amount of green as well as blue water footprint add to the generation of the products. But on the other hand, being biofuels to be cleaner, and with much lesser grey water footprint, makes them a reliable option for energy generation. When compared between the crops rapeseed and Jatropha have proven to be richer in biofuel, but simultaneously due to high water footprint in Indian context, should be used only when the raw material is available.

4.2 Analysis of Crop Water Footprint

Table 6: Overall crop water footprint at different states of India

Sl. No.	State	WF (m3/ton)
1	Uttar Pradesh	28306
2	Himachal Pradesh	27889
3	Uttarakhand	27809
4	Tamil Nadu	27739
5	Bihar	26960
6	Gujrat	26692
7	Maharashtra	26460
9	Haryana	26337
10	Rajasthan	25860
11	Meghalaya	1900
12	Andhra Pradesh	18381
13	Orissa	20459
14	Chhattisgarh	22074
15	Punjab	22323
16	Jharkhand	22454
17	Jammu and Kashmir	23760
18	Karnataka	24100
19	Madhya Pradesh	24432
20	West Bengal	24467

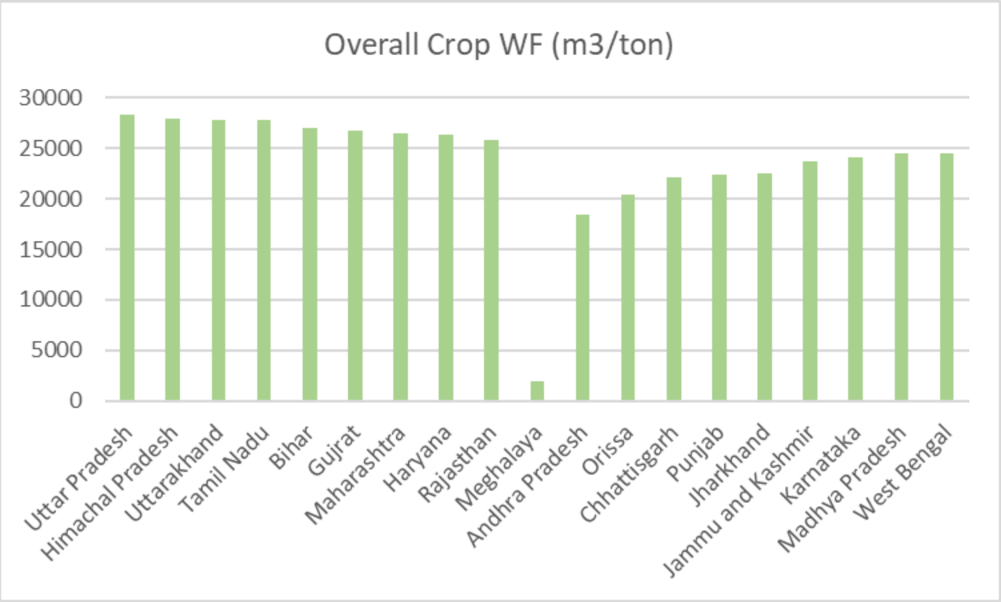


Figure 12: Overall crop water footprint at different states of India

The state wise comparison of total average crop water footprint has shown a peculiar behaviour in Meghalaya state, where the water footprint is significantly low. Agriculture practices, cropping patterns, soil qualities, temperatures, and many other factors could be the cause of the heterogeneity as described in the study. Irrigation/agricultural practices have been a major contributor of overall water footprint of the country. India stands ……….. in overall agriculture water footprint in the world. Looking at the commodity specific footprint is necessary for a city-based water footprint assessment. Researches based on commodities, majorly wheat and rice have been done on almost every state. A state specific analysis of data available has been done in the research to compare between the differences in water footprint in any water scarce area and a water surplus location. The results obtained from various studies for some areas for the same commodity have been compared using a t-score, to check whether the values are correlated and similar to each other. This will enhance the authenticity of the data and we can compare between the sates using the same data.

4.3 WF of Wheat

Wheat and rice are considered to be common crops being a basic food consumed at every household in India. Hence, a lot of researchers are interested in knowing the water footprint of particular commodity in various parts of the country. The same are collected and analysed in the study. Wheat water footprint from various researches have been studied and made into groups of two. One data set is from a single study, and the other has been combined from various other researches done on specific states using different methods for calculation.

While checking for the correlation between the values of both the tables, it indicates that both the series are strongly positively correlated with a value of correlation coefficient to be **0.926**. The larger correlation coefficient indicates that on an increase of one variable, the other variable will also increase. A Q-Q Plot is made to check whether the data distribution follows a normal distribution. The plot shows the data points to follow a normal distribution, hence a parametric T-test can be run to know the authenticity of the data. Apart from that Mann-Whitney-U test is also done to test the similarities and know whether there is a significant difference in the data.

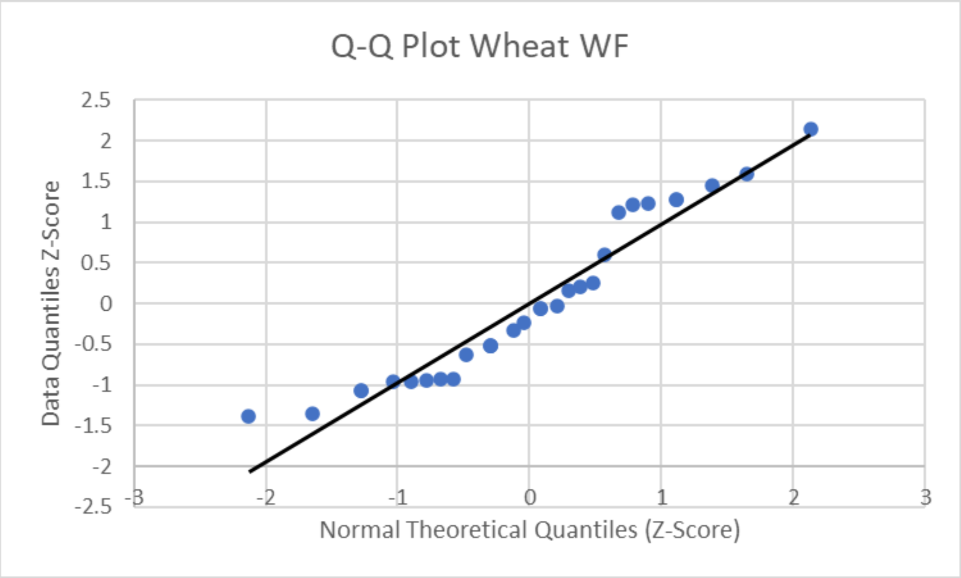
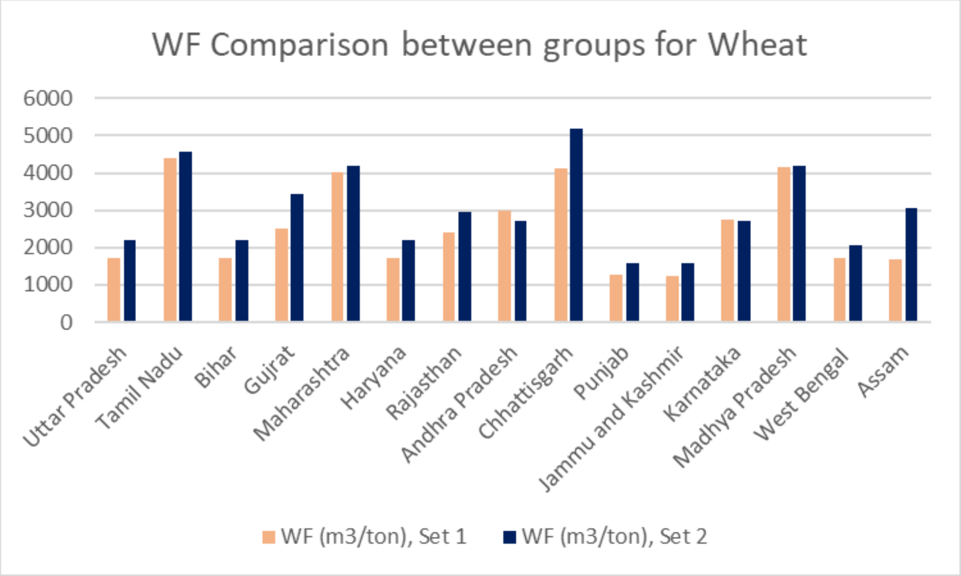


Figure 13: Q-Q Plot of WF data of wheat

The result shows that data has a t-score of **0.001964** indicating that the groups are highly similar. Mann Whitney U-Test also accepts the hypothesis that the data is similar with 95 % confidence level. This indicates that the studies can be relied and the data being collected from different sources is unidirectional and closer to reality, irrespective of the method used.



It can now be analysed from the data that Chhattisgarh, Tamil Nadu, Maharashtra and Madhya Pradesh have significantly high values of Water footprint. On the other hand, Punjab, Jammu & Kashmir, West Bengal and Bihar have lesser value of Water Footprints.

Going ahead with the details and while projecting the data of blue, green and grey water footprint, results show a varied use of water in the states. Some use precipitation water more like, Tamil Nadu, Assam, West Bengal while the others are dependent on fresh water resources as a whole for agriculture practices like Madhya Pradesh, Chhattisgarh, Maharashtra and Rajasthan. Some states have relatively high grey water footprint probably because of use of pesticides that are difficult to dilute. Tamil Nadu, Gujrat, Maharashtra and west Bengal are some of the same listed states.

Here is the graph showing details of each state:

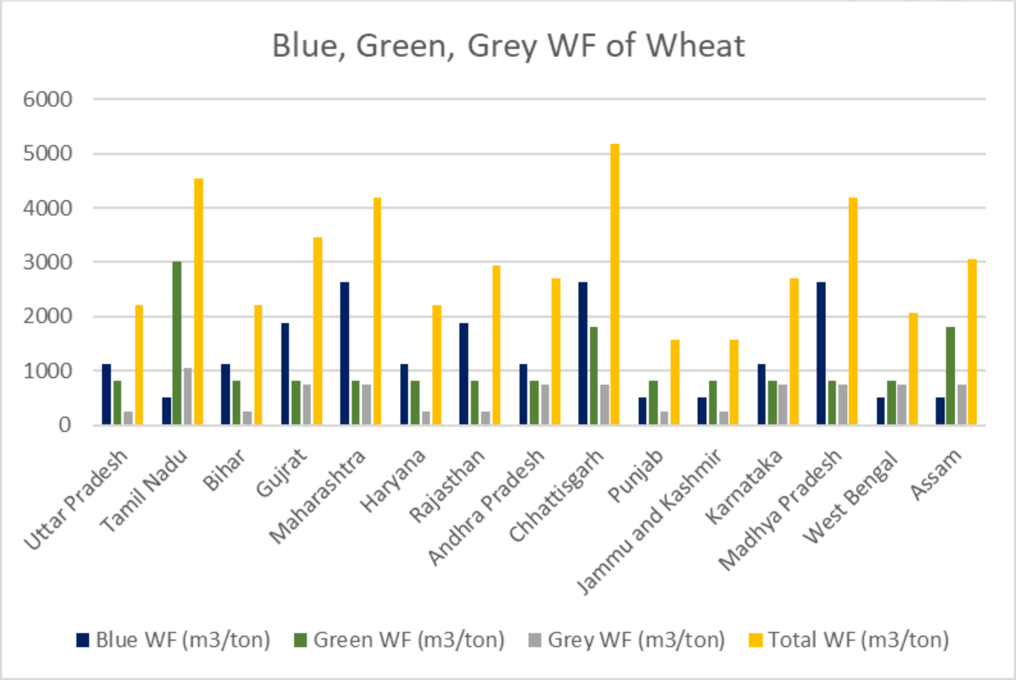


Figure 14: Blue Green Grey WF of wheat

4.4 WF of Rice

In case of Rice ironically, since the data obtained for set 2 was an average of all the data sets that were given in a research, the data doesn’t not corelate and a significant difference is easily visible in the values calculated. The Q-Q plot shows that the data follows a normal distribution when combined, hence both T-Test and Mann-Whitney test were run on the groups to test the authenticity of the data.

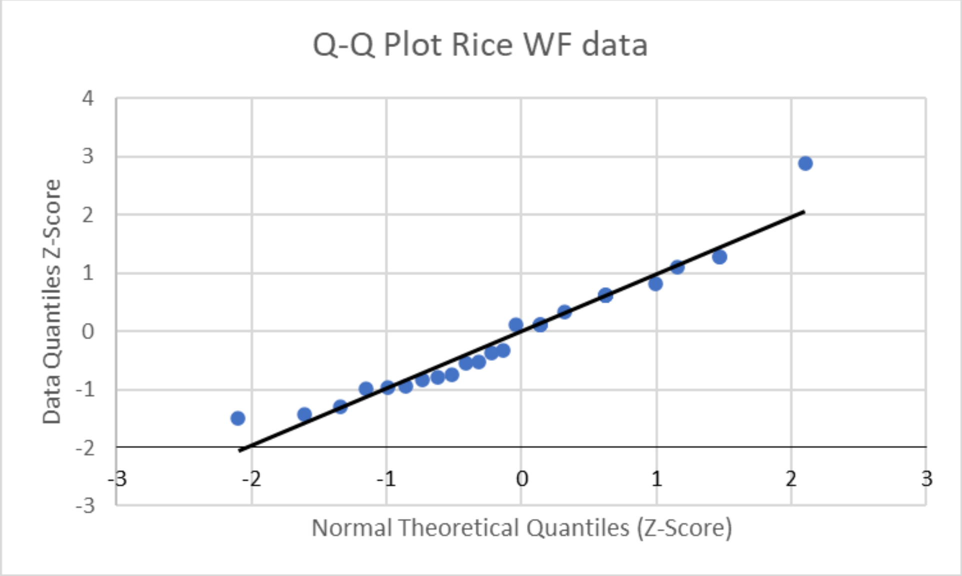


Figure 15: Q-Q Plot for WF data for Rice

Both the test shows that a significant difference is there in the data. Hence the set having same method for calculation is taken for further analysis of water footprint of Rice as a crop.

The comparison is seen in the graph below:

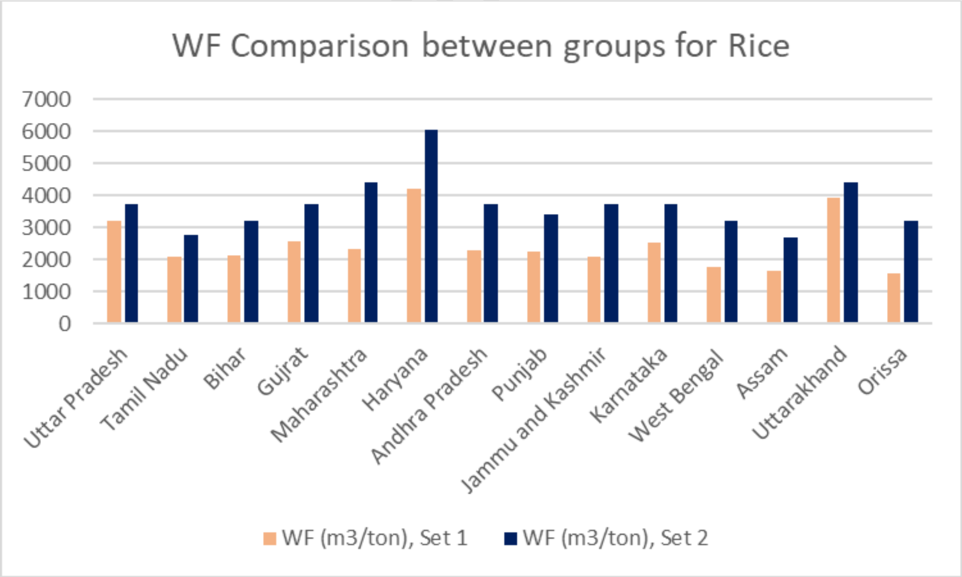


Figure 16: WF Comparison between groups for Rice

The Set 2 shows that there is a high water footprint of Rice at Haryana, Maharashtra, UP & Uttarakhand. While the least can be observed in Assam and Tamil Nadu. If we go on with the details of the set 2 usage as green, blue & grey water footprint, it can further be seen that there is a difference in usage of fresh water and green water sources between the states, that probably have an impact on their water availability vs yield.

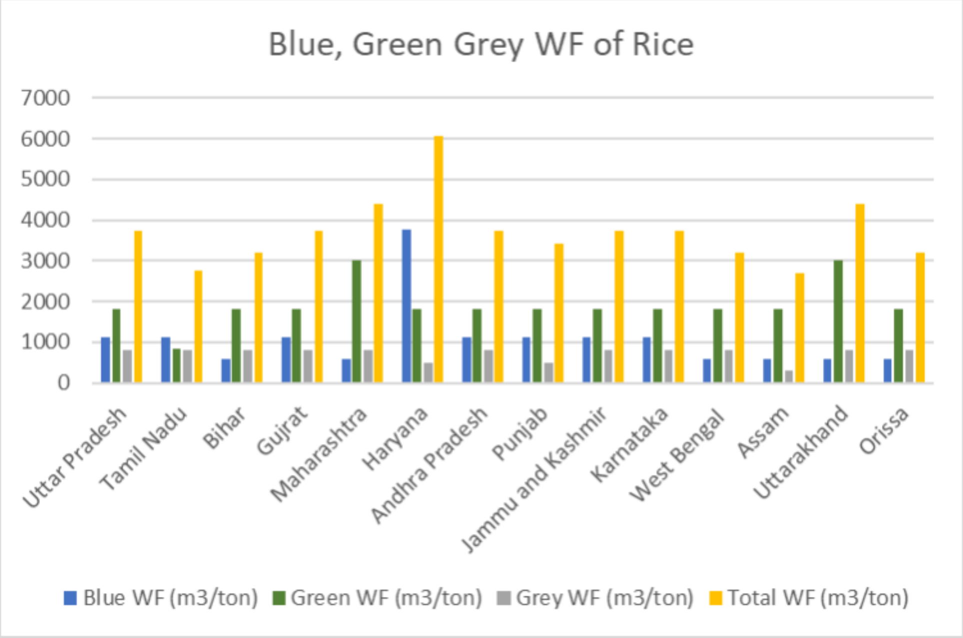


Figure 17: Blue, Green & Grey WF of Rice

As far as other major crops are concerned, Barley and Maize also contribute to the Indian Water footprint of crops in the country. Their percentage contribution is also analysed in the graph below:

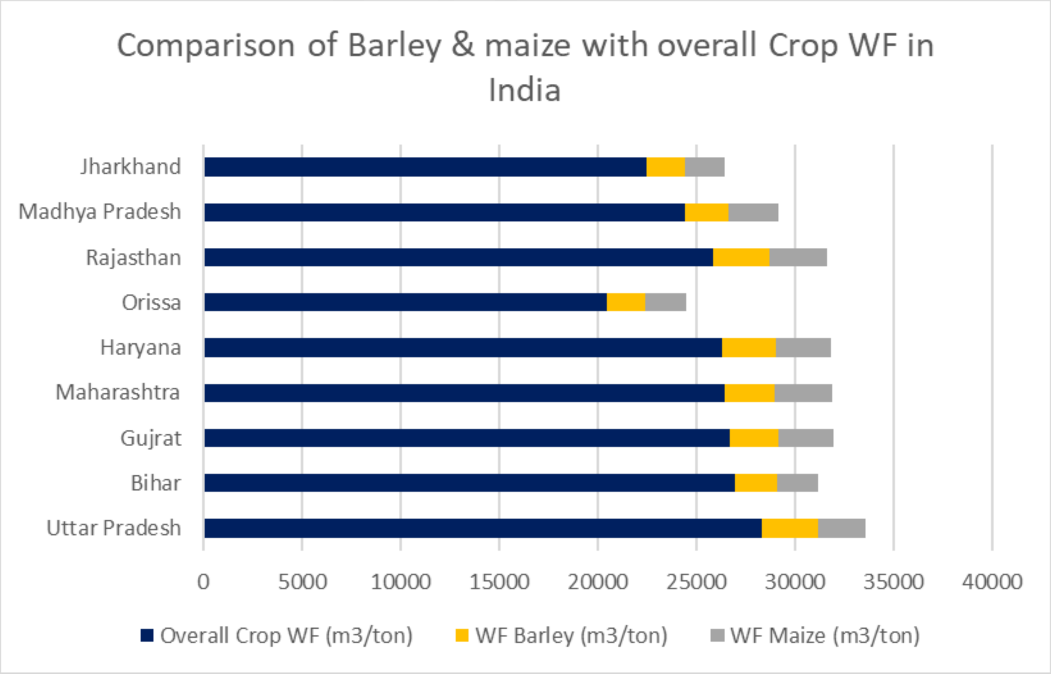


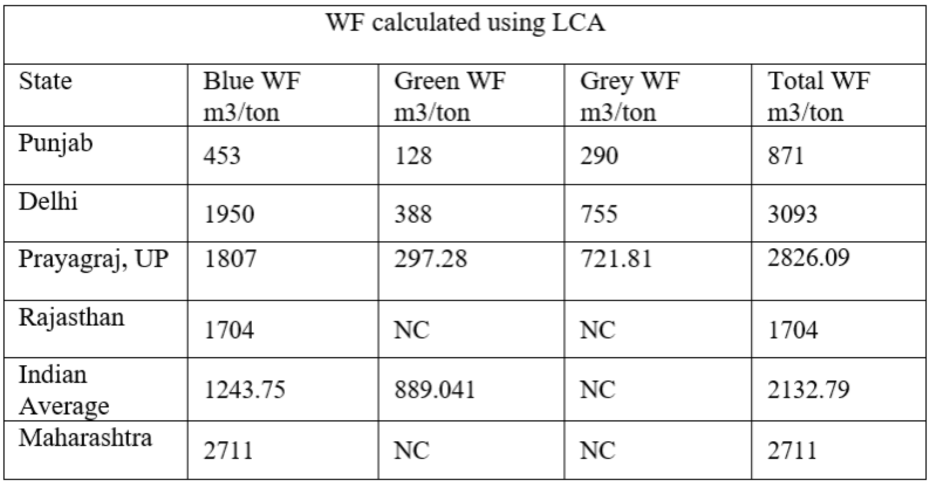
Figure 18: Comparison of Barley & maize with overall Crop WF in India

Barley is a major contributor to the animal feed as well, hence looking at it specifically is a mandate for the study. The comparison shows that it contributes around 10-15 % of overall crop water footprint in almost each state, which is a good number. However it can also be seen that Rajasthan has a higher water footprint, even being a water scarce region of the country. While comparing it with Orissa which has a lower WF and in a better condition in water availability than Rajasthan.

4.5 Comparison of LCA Vs WFA methods for selected states

Another objective that needs to be fulfilled by the study is to see whether using different methods of calculation for the same commodity in a specified area change the WF significantly or not. To measure the same since data availability for wheat is eaccurate for the purpose, wheat for some selected states have been analysed. To check the correlation among the data for different methods, coefficient of correlation is calculated so as to know variation.

Table 7: WF calculated using LCA



WF calculated using LCA				
State	Blue WF m3/ton	Green WF m3/ton	Grey WF m3/ton	Total WF m3/ton
Punjab	453	128	290	871
Delhi	1950	388	755	3093
Prayagraj, UP	1807	297.28	721.81	2826.09
Rajasthan	1704	NC	NC	1704
Indian Average	1243.75	889.041	NC	2132.79
Maharashtra	2711	NC	NC	2711

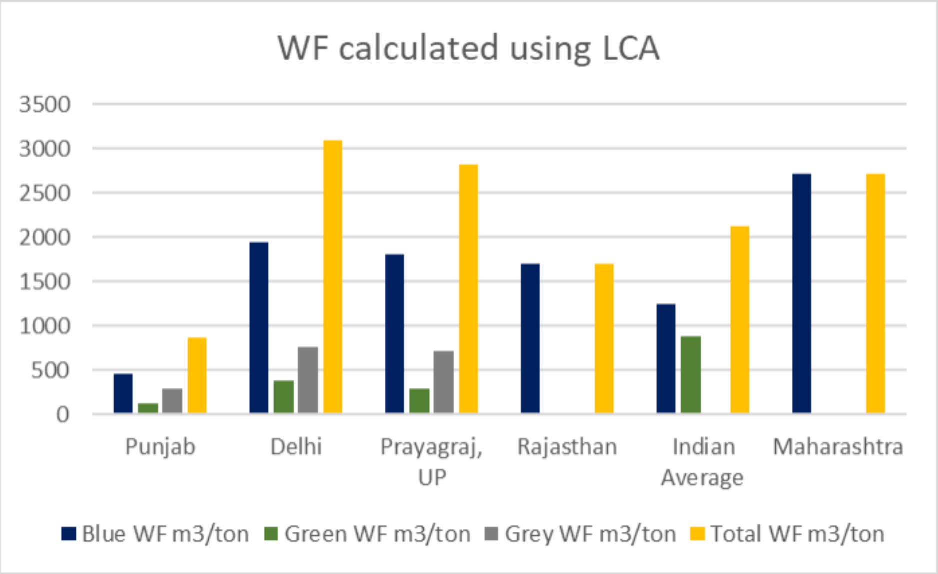


Table 8: WF calculated using WFA

WF calculated using WFA				
State	Blue WF m3/ton	Green WF m3/ton	Grey WF m3/ton	Total WF m3/ton
Punjab	633	891	230	1754
Delhi	1997	1002	822	3821
Prayagraj, UP	1125.5	813	279	2217.5
Rajasthan	1875.5	824	250	2949.5
Indian Average	1162	643	294	2099
Maharashtra	2625.5	824	750.5	4200

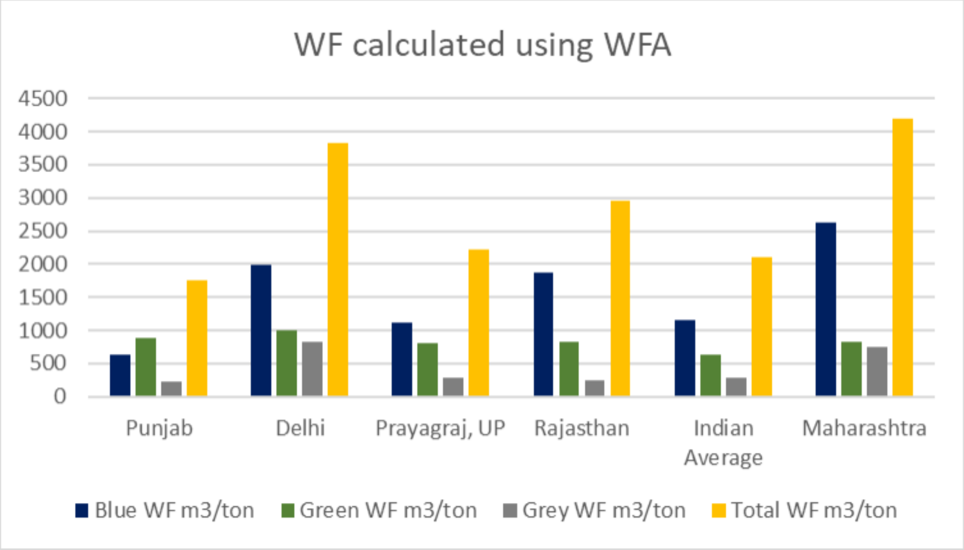


Figure 19: WF calculated using WFA

The correlation analysis of both the data shows that they are positively correlated with a correlation coefficient to be **0.633349908**. A positive correlation implies that both the data move in the same direction. Along with the same T-Test for paired data shows a t-score/s-score of **0.115798** indicating that the groups are similar. Also, a non-parametric test named Mann Whitney test is also done and with 95 % significance it shows that there is no significant difference in the data.

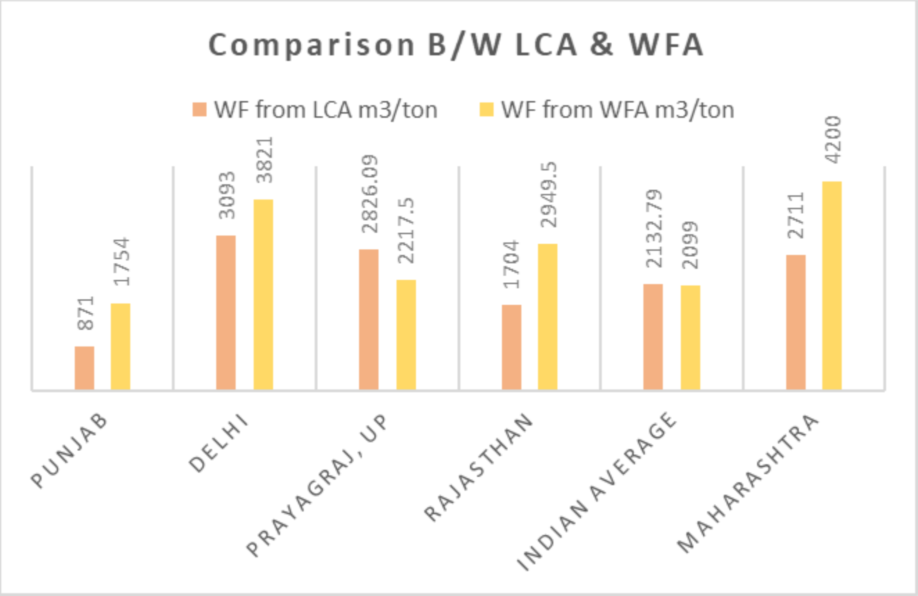


Figure 20: Comparison between LCA & WFA

These results show a few things about the method being used. To some places there might be a suitable difference and significance of the data that is being used, because it also depends on what type of irrigation practices are being done in the area. A city planner when taking care of the Water Impact assessment shall be able to analyse the type of method required for the area. A breakup of green blue and grey water footprint tells a lot about the nature of irrigation in the area.

4.6 Cotton as a textile industry input

Water Footprint of Cotton as is seen in the researches varied drastically from place as well as the methods used. Most of the time the methodology used by the researchers is dependent on the Water Footprint Assessment manual designed for all types of water footprint calculations and explanations. Accordingly, the Water Footprint is calculated based on the crop water requirement considering Crop Water Use to be same as that of the Crop Water Requirement in most of the cases.

The ways of expression in the researches have varied a lot, some of the researches have focused on the area in which the crop is grown and have calculated the footprint in m3 per hectare of land. While in some of the research the quantity produced is the prima facie, wherein the unit of Water Footprint then came out to be m3 of water used per ton of cotton generated/fabric made.

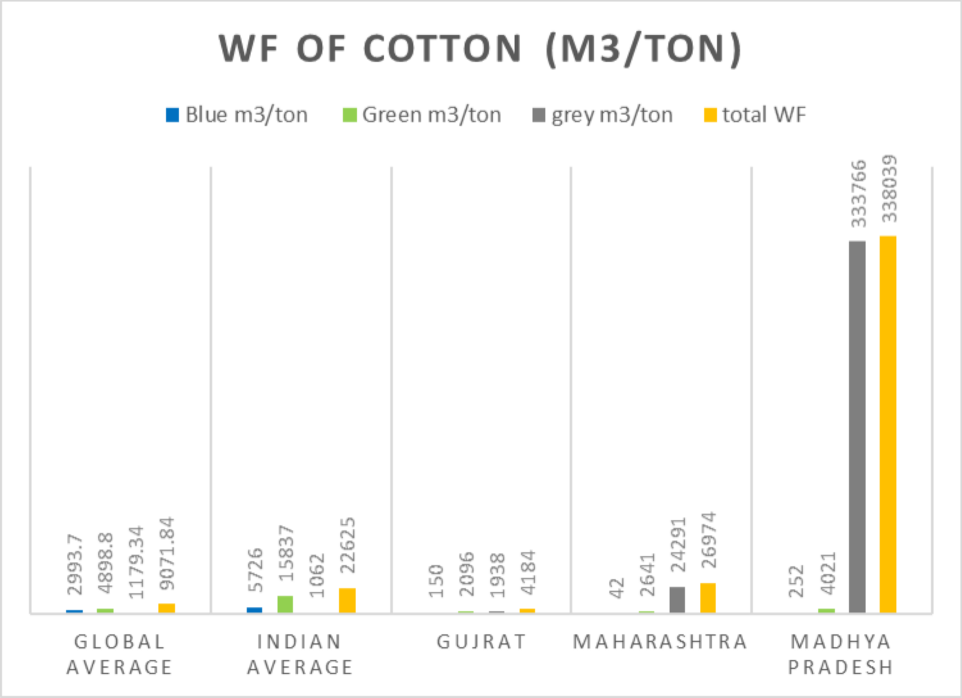


Figure 21: WF of cotton (m3/ton) of selected states

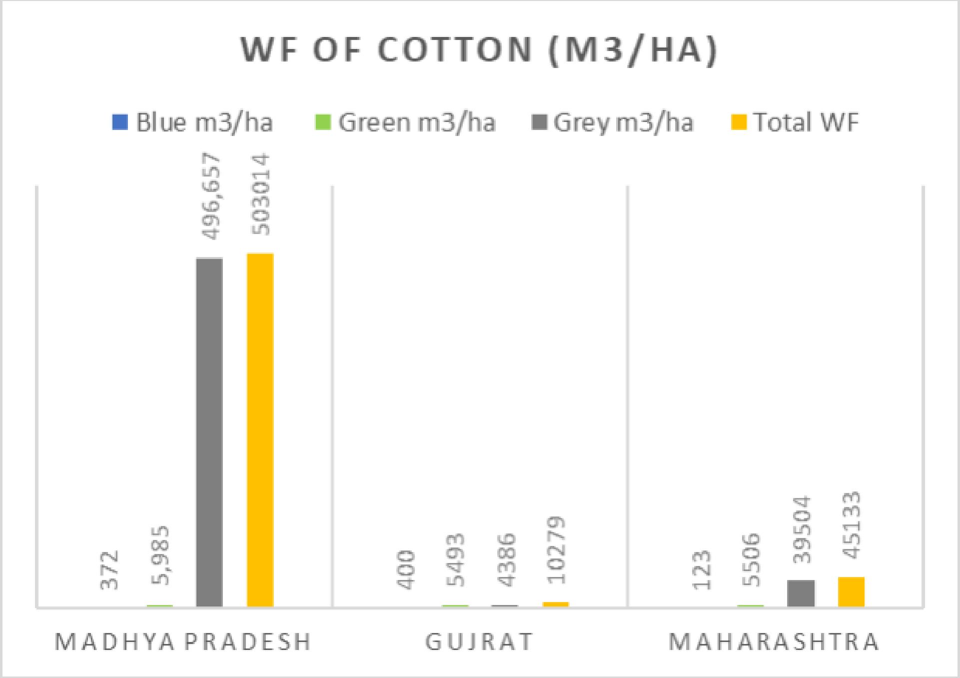


Figure 22: WF of cotton (m3/ha) for selected states

4.7 WF Analysis for Milk & Meat

Animal products have higher water footprints when compared to crops. Indian average of total water footprint of crops according to various researches lies between 2000-2500 m3/ton. Given below is Indian average of Chicken meat (14898 m3/ton), goat meat (4600m3.ton), sheep meat (8312m3/ton), and pig meat (7160m3/ton). However, the value of chicken meat from different studies is varying due to calculation based on grazing and other feeds provided to the chicken. There are differences due to method used as well. One thing that is certain is that for a city’s sustainable development, it is important to keep a diet according to the availability of water.

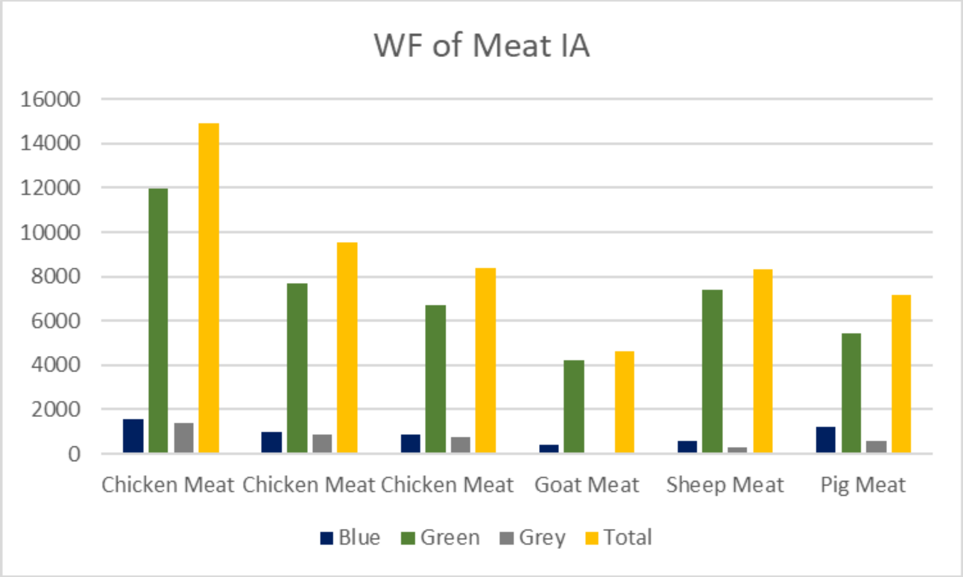


Figure 23: WF of meat, Indian average

Another study based on Prayagraj have also calculated the Water Footprint of Meat for UP. The method used for calculation is the authors self-derived equations from the base equations available for the calculation. According to the findings, the green component of WFP accounts for around 72 percent of total water, while the blue and grey components account for approximately 19 and 9%, respectively. Furthermore, soil regime and climate barriers influence the geographical variability of blue, green, and grey across states. Blue water is plentiful in locations with semi-arid or desert terrain. As a result, the current study recommends a balanced strategy to green and blue water consumption in order to handle future water demand.

Milk is another basic necessity of any city. Water footprint of India is almost double as that of global average for milk. Kerala, Karnataka and Punjab have been shown as the major contributor of WF of milk. Various other studies have been done on animal products. Animal products major water footprint is covered in the crops that are given as feed to them.

Table 9: WF of Milk (m3/ton) for selected states with global average

Sl. No.	State	WF (m3/ton)
1	Indian Average	1623.861
2	Punjab	2966.494
3	Gujrat	2086.52
4	Kerala	4408.918
5	Andhra Pradesh	1805.298
6	Karnataka,	2413.111
7	Haryana	1433.352
9	Global Average	925.3284

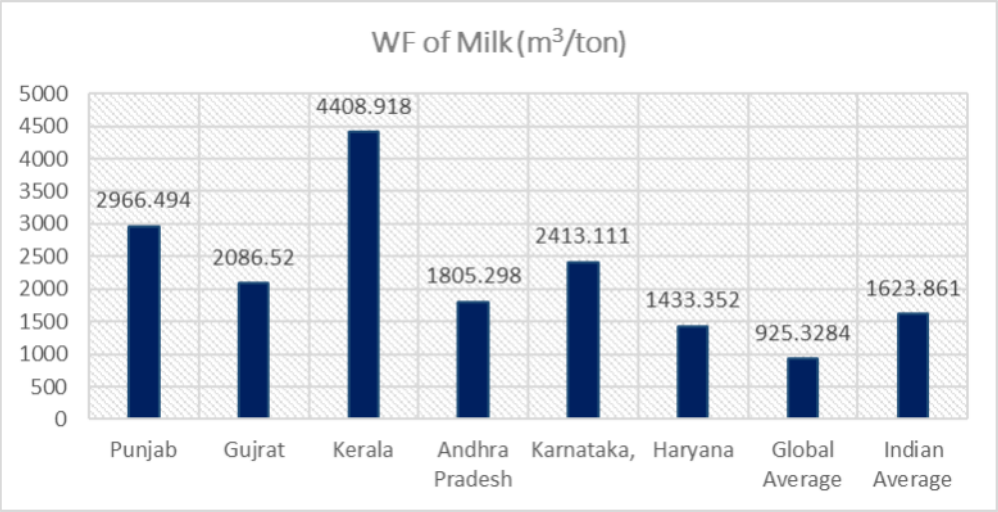


Figure 24: WF of Milk (m3/ton) for selected states

Chapter 5:- Conclusion

Chapter 5-: Conclusion

The results and discussion of the study have revealed some interesting facts about the water footprint of various commodities used in different areas. The study will serve as a base for further researches, for cities based on the total water flow calculations along with the conventional water flows. Being a city centric approach, the study has revealed various methods of calculations of Water Footprint. It has discussed upon the impact of Import, Storage, manufacture, usage and export of commodities having higher or lower water footprints.

A city, when looked at from different usage perspective shall be planned by the basic governance considering in mind its water resources available in terms of Fresh water from rivers & reservoirs as well as natural water flow from precipitation. While doing so virtual water that flows in the form of commodities when neglected leads to water shortages. Carbon footprint have gained a recognition of private sectors, to be used as a global trading to deal with carbon dioxide emissions on a larger scale. Water Footprint is yet to gain government attention. Neither the Ministry of Fresh water resource, nor the pollution control boards are aware and responsive towards the present scenario of misbalance in terms of water footprint, when indirect use is considered i.e. commodity trade.

Another important consideration is people recognition along with the government acknowledgement. General public shall be made aware that the commodity they buy and the one they discard has a lot to do with the overall water consumption of the city. A major impact is faced when the commodities imported in the city are misused. These add a burden to the fresh water resources available , either in the form of grey water, by increasing the pollution or by exploitation of the particular product by making it a pileup for dumpsites.

It is a serious issue that is globally accepted since a long time. The research will definitely help and form the basis of all the further researches and recognition of the concept at each stakeholder level. This is the beginning of the upcoming IEC (Information, Education & Communication) activities and institution-based ideas as well.

Chapter 6 :- Future Scope

6.1 Strengths

6.1.1. Conceptual and Analytical Strengths

The present study makes a significant contribution to understanding the concept of water footprint by linking it with urban consumption patterns and highlighting the hidden use of water in various commodities. It effectively brings forward the importance of virtual water, allowing a deeper insight into indirect water consumption that is generally neglected in traditional assessments. By adopting a city-based perspective, the study provides a practical and relevant framework for analyzing water demand in urban areas, especially in the context of rapid urbanization and increasing pressure on water resources. The comparative analysis between water-scarce and water-surplus states further strengthens the conceptual clarity by demonstrating how climatic conditions, irrigation practices, and geographical variations influence water consumption patterns.

6.1.2. Practical and Interdisciplinary Relevance

Another important strength of the study lies in its interdisciplinary approach, as it integrates aspects of agriculture, urban planning, and resource management. The development of basic equations for estimating city-level water footprint adds methodological value and provides a foundation for future research. The findings of the study are useful for multiple stakeholders, including policymakers, researchers, industries, and consumers, as they highlight the need for sustainable water management practices. By emphasizing the gap between actual water use and perceived consumption, the study contributes to raising awareness about efficient resource utilization and supports informed decision-making.

6.2 Limitations

6.2.1. Data and Methodological Constraints

Despite its valuable contributions, the study is limited by its dependence on secondary data sources, which may affect the accuracy, consistency, and reliability of the findings. Such data may not always reflect real-time conditions or localized variations, thereby limiting the precision of the analysis. Additionally, the models and equations developed for estimating the city-based water footprint are relatively basic and may require further refinement, calibration, and validation for broader applicability. The absence of primary data collection and field-based verification further reduces the empirical strength of the study.

6.2.2 Scope and Coverage Limitations

The scope of the study is restricted to selected commodities and does not cover all sectors contributing to water consumption, such as industrial processes and service sectors. This limits the comprehensiveness of the analysis. Moreover, the generalized nature of the data may fail to capture micro-level variations, seasonal fluctuations, and local practices that significantly influence water usage. The study also does not extensively address socio-economic, behavioral, and policy-related factors, which play a crucial role in determining water consumption patterns, thereby limiting the overall depth of the research.

6.3 Future Scope

6.3.1 Expansion and Technological Advancements

The study provides a strong foundation for future research and offers significant scope for expansion. Future studies can include a wider range of commodities and sectors, including industrial and service-based activities, to develop a more comprehensive understanding of water footprint. There is also potential to incorporate primary data collection through field surveys and case studies to improve the accuracy and reliability of findings. The use of advanced tools such as remote sensing, geographic information systems (GIS), and data analytics can further enhance the precision and depth of water footprint assessments.

6.3.2. Policy Integration and Awareness

Further research can focus on developing advanced and region-specific models that consider variations in climate, soil conditions, irrigation practices, and cropping patterns. These models can be integrated into urban planning and water resource management frameworks to support sustainable development. Additionally, studies can explore the role of policy interventions, economic incentives, and technological innovations in reducing water footprints. Increasing awareness among consumers, industries, and policymakers through education and outreach programs will also play a crucial role in promoting responsible water use. Future work should aim to bridge the gap between theoretical research and practical implementation to ensure effective incorporation of water footprint concepts into policy and decision-making processes.

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