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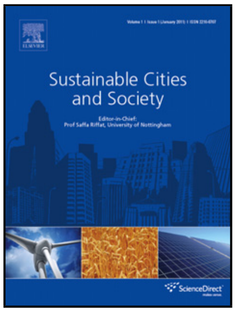

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Quantifying the water footprint of an urban agglomeration in developing economy

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Highlights:

- Provides information on dependency of urban cities on external water resources to alert the governments.
- Helps to monitor consumption WF of urban dwellers based on economic status and consumption quantity to plan VW trade policies for water intensive products.
- Helps to frame water policies and strategies to reduce WFs, based on consumption of water intensive goods.
- Assists policy makers to make foreign trade policies for highly consuming and water intensive products by affluent and non-affluent population.
- Resolves transboundary water conflicts and releases pressure on water resources by sharing water virtually or in the form of VW trades.

Abstract

[1]Sustainable conservation of natural resources has become a primary concern for urban cities, globally as they are centers of consumption and economy. Due to population growth, cities depend more on imports of food, energy, water, and services from all over the globe, and

consume more virtual water than direct water, because of their food habits and lifestyle. Most of the imported goods are water intensive and pose challenges in tracing the source of virtual water. The goal of this research is to develop a general framework to assess the water footprint (WF) of a typical city in India using existing databases. A consumer-centric approach has been adopted for assessing WF in Hyderabad Metro Development Area (HMDA). The variation of the WF across economic classes of consumers is also analyzed. The WF is estimated based on four broad categories: 1) food consumption, 2) fossil fuels based energy, 3) electric power, and 4) direct water. Average WF of HMDA region is 1041m^3/cap/year (2852 LPCD), in which 70% (1986 LPCD) of WF was consumed by food, 25% (744 LPCD) by electric power, only 4% (121 LPCD) is from direct water consumption and surprisingly the contribution from fossil fuel WF to total per capita WF of HMDA area is less than 1%.

List of Abbreviations

WF	- Water Footprint
VWF	- Virtual Water Footprint
VW	- Virtual Water
LPCD	- Liters per Capita per Day
MGD	- Million Gallons per Day
MCM	- Million Cubic Meters
MPCE	- Monthly per Capita Expenditure
LPG	- Liquid Petroleum Gas
HMDA	- Hyderabad Metro Development Authority
GHMC	- Greater Hyderabad Municipal Corporation
HMWSSB	- Hyderabad Metro Water Supply and Sewerage Board
RWSS	- Rural Water Supply and Sewerage
NSSO	- National Sample Survey Organization

Keywords:Urban water footprint, urban agglomeration, virtual water, consumption footprint, trade policy.

1 Introduction

[2]Virtual water (VW) concept was initiated in the 1990s (Allan, 1998) and took several decades to gain focus from researchers. Chapagain and Hoekstra (Chapagain & Hoekstra, 2004; Hoekstra & Hung, 2002) initiated the concept of WF by accounting the VW content and VW trade for 172 agriculture crops in 210 countries over the globe. They assessed WF and VW by considering national average climatic variables without considering the spatial variations. Later, Siebert and others (Siebert et al., 2010) accounted for green, blue VWF of crops globally, by considering the spatial variations in climatic conditions. Based on these data, Mekonnen and others accounted green, blue and grey WF of crops, crop-derived products, and farm animals, animal products, this is a global scale study (Mekonnen & Hoekstra, 2011; Mekonnen & Hoekstra, 2010; Mekonnen & Hoekstra, 2012;). Also, there are several studies at the national, regional level, and river basin scales to address WF, but there is no much research on WF at the city scale concerning socio-economic aspects of consumers. Fulton and Gleick (Fulton & Gleick, 2012) assessed the WF of California based on the top-down approach, while Feng and Klaus (Feng et al., 2012) assessed the regional WF of yellow river basin using multi-regional input-output (MRIO) assessment.

[3]In past studies of city level WF assessment, previous authors talked about WF of agricultural products imported into the cities, considering the cities from developed (Berlin from Germany), developing(Delhi from India) and underdeveloped countries (Lagos form Nigeria)

(Vanham et al., 2017, Vanham, 2013b, 2013a, Zhao et al., 2015). Vanham and others (Vanham et al., 2017; Vanham & Bidoglio, 2014) assessed the WF of Milan, Hong Kong and suggested diet to conserve embedded water in food efficiently and this study was done not only at the city scale but also at regional levels (Vanham et al., 2018b, 2018a). Zhao (Zhao et al., 2015) addressed the WF of Leshan city (3,326 m^3/cap/year) in China and concluded that this city targeted to export water-intensive products to other cities since it is rich in water resources. McCallum (McCallum et al., 2016) assessed the direct WF in 33 cities, indirect WF in 74 cities of United Staes and found that average direct WF (600 lit/cap/d) of urban cities dominated by average indirect WF (13,877 lit/cap/d) of the United States. These studies follow the approach of Hoekstra and others (Hoekstra et al., 2011) by considering FAO STAT food balance sheet data, census data and regional statistics from government departments.

[4]Most of the studies indicated that urban cities are consuming 20 times more VW than physical water (McCallum et al., 2016). The water embedded food, agricultural, energy, and commercial products were imported from all over the globe and from both water scarce and water-rich regions (McCallum et al., 2016). These imports are building pressure on water resources in the source regions. In this scenario, there is a necessity for strict water policies and constructive water governance infrastructure for virtual and physical water quantification. Generally, when framing the water policies or riparian rights of riverfront waters, only physical water alone considered in demand and VW is not included. However, humans are consuming more virtual water than physical water. Due to this ignorance, only regionally available water has given importance and the volume of VW floating between the regions is not considered in water budgeting. Due to this, the source regions becoming arid and arid with rigorous pumping of water for goods production. This practice leads to putting local water resources under pressure

and pushes regional and national water resources under crises (Vanham et al., 2018). This disparity between local and national water resources will trigger global unsustainability.

[5]In the literature, most of the studies, constructed on a top-down approach and also there are studies based on the bottom-up approach using regional and multi-regional input and output method. These approaches require massive trade data at the city level, which is not possible for every sector of a city. There has been much research on managing the direct WF of cities at global, national boundaries and also for India (Manzardo et al., 2016, Rathnayaka et al., 2016, Shaban and Sharma 2007a and B. A. George et al., 2009). However, there are significant gaps in our understanding of cities' indirect WF and its management for Indian cities, in particular. A major hindrance in this regard is the lack of adequate trade data. To apply the methodology, suggested by Hoff et al (Hoff et al., 2014), data on imported goods are essential, but it cannot be applied here, due to lack of enough trade data at city scale. This issue seeks the attention of researchers and policymakers to focus not only on physical water management but also on VW trade management.

[6]In this study, we mainly tried to address this issue by showing some alternatives for data other than city level trade data and developed a framework using this alternative dataset and these datasets are generally available on public forums. Here we followed a consumption-based approach in this study and presented a protocol for assessing the WF of a typical Indian city. Besides that, the authors also focused on WF across economic classes, which has not explored earlier. Previous studies have not tried to understand the gaps between WF of different economic strata, except for the study of Vanham and others (Vanham et al., 2018b). Considering economic levels is likely an essential source of information for policy purposes.

[7]This protocoled framework in this study helps in monitoring and managing VW, and to know how cities are dependent on external water resources by accounting and balancing consumption WF and production WF. Consumption WF is the amount of direct and indirect/virtual water consumed by the consumers of a region. Production WF is the volume of water from local or domestic resources used for the production of goods, which is used by consumers anywhere in the world. In previous studies, authors considered only trade data without considering the economic gradients of consumers. City level trade (import/exports) data may have leakages, which means that this trade may go out of cities as exports to another region. These leakages lead to inaccuracy of WF assessment. However, in the present study, we focused on consumer level consumption data of food, energy (fossil fuels and electric power) and direct water. This study is specific to consumers' consumption and their economic status. Also, assessed green, blue and grey WFs of food consumption and blue WF of energy and direct water consumption. Green WF is the amount of water comes from precipitation and water stored in soil moisture, blue WF is the amount of water in surface water bodies and aquifers, grey WF is the amount of fresh water required to dissimilate the polluted water (Hoekstra et al., 2011).

[8]In this study consumption WF is assessed based on the consumer level trade data concerning their economic status, which has taken from consumer expenditure survey report provided by the National Sample Survey Organization(NSSO and MSPI, 2012). Production WF will be assessed using process-based assessment methods/tools. Difference between these production and consumption WF shows the importing and exporting status of the region/study area. If the difference is negative, then the region or city is net VW exporter. If it is positive, then the city is net VW importer. We applied this framework to agriculture products only. This framework can be applied to any sector, whether it is food, energy, agriculture, or to any water

sector to know the import/export status of virtual water. The authors have limited the study only up to consumption WF of urban agglomeration for economic gradients of consumers.

[9]The scope of this work is to plan strategies for reducing WFs by understanding how purchasing power, consumption behavior of consumers will influence the WF of urban cities, which is not shown in previous researches except the study of Vanham (Vanham et al., 2018b). In the context of mission smart cities (Anand et al., 2018), this framework helps in water governance, planning and design of sustainable water infrastructure in cities that can sustain for future water crisis (Fialkiewicz et al., 2018; Haie et al., 2018). Also, it helps policymakers to understand and account environmental footprints to maintain balance in ecology. The proposed framework in this study is unique and helps policymakers and researchers to understand the WF of urban cities concerning change in economic growth and to plan the strategies for reducing the WF of different commodities groups and sectors in urban cities.

2 Study area

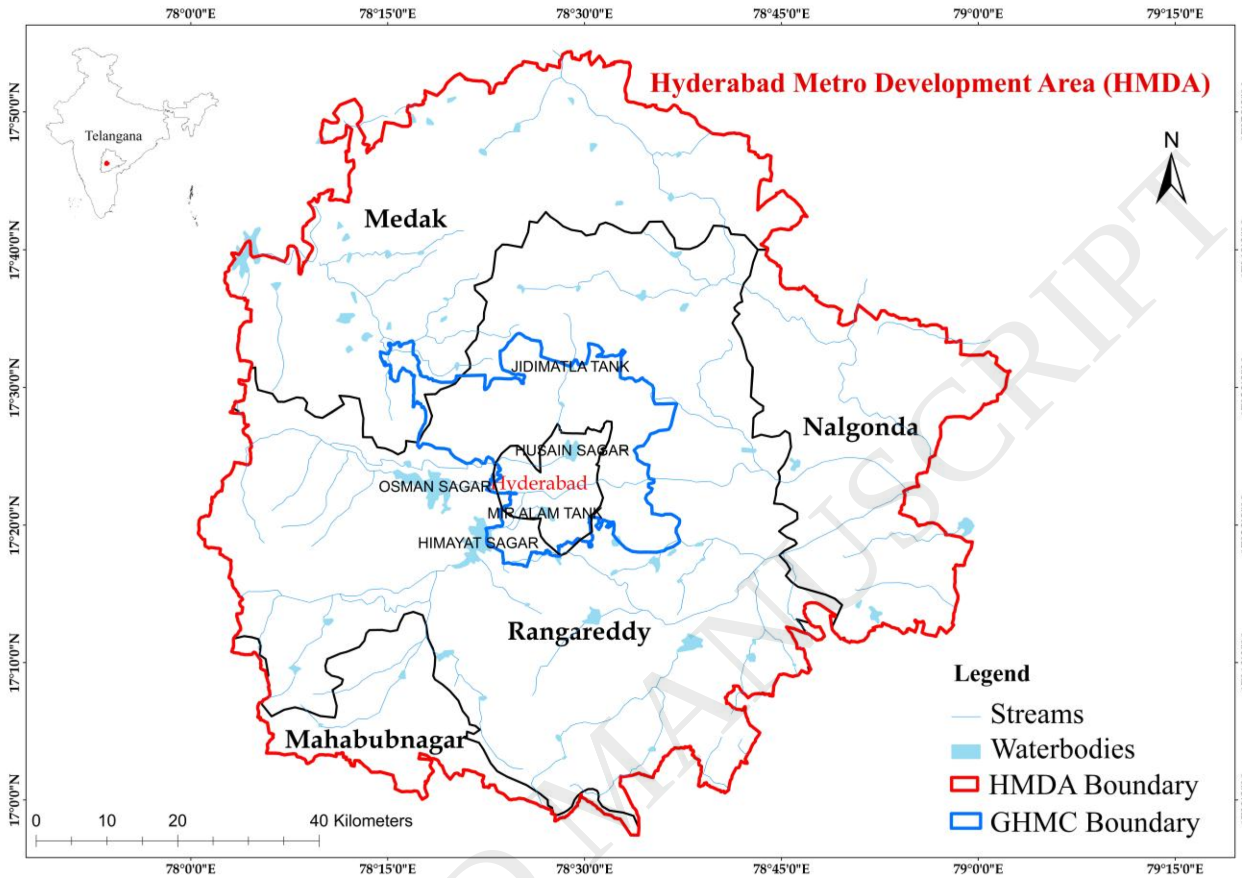


Figure 1: Jurisdictions of HMDA region, boundaries of GHMC and parts of five districts Hyderabad, Rangareddy, Nalgonda, Medak, Mahabubnagar included in study area.

[10]In this work, our study area is Hyderabad Metro Development Authority(HMDA) region (figure 1). HMDA is a cosmopolitan city and it is a combination of five districts, i.e., Hyderabad, Rangareddy, Medak, Mahabubnagar and Nalgonda districts and 54 mandals before the re-organization of Telangana state(Telangana social development report (TSDR - 2017)). In the earliest, Hyderabad is only up to the boundary of erstwhile Hyderabad, with the rapid growth of the migrated population, it encroached up to the boundaries of Greater Hyderabad municipal corporation (GHMC). Hyderabad is the central hub for cyber and manufacturing infrastructure, pharmaceutical, textile, food processing industries, commercial complexes and business centers with the massive demand for water for their production process and services. HMDA is an

amalgamation of urban, surrounding rural regions and Hyderabad is a part of HMDA region, which has a population of 9.4 Million. HMDA is the 6th populous urban agglomeration in India

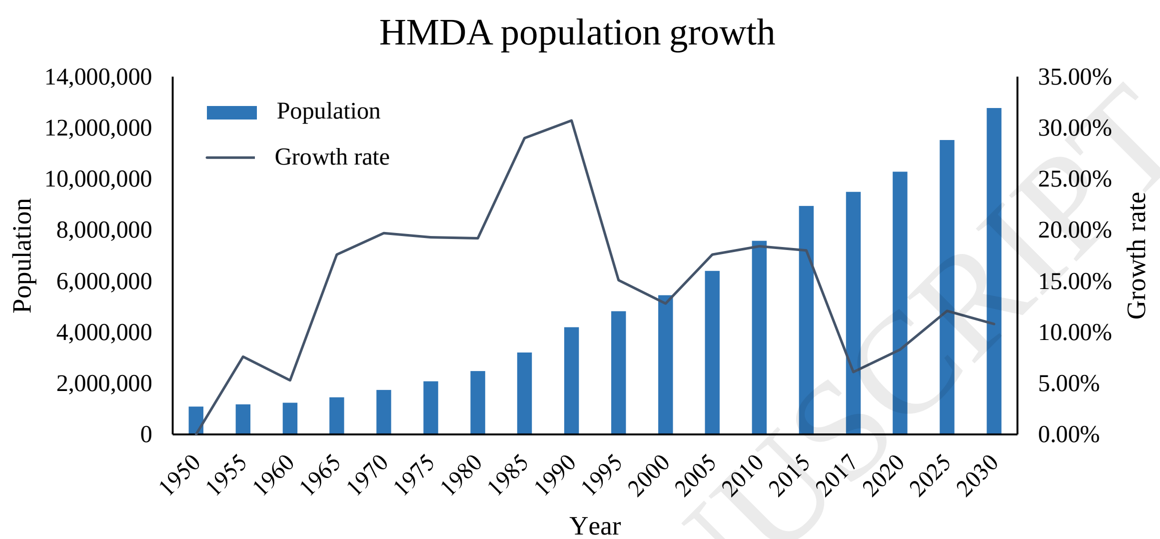


Figure 2: Urban population growth of Hyderabad (Reference: World population review- 2017)

and it is

going to reach 12.7 Million by the year 2030, according to world population review 2017 (figure 2). The annual average rainfall of Hyderabad region is 961 mm, with an annual maximum temperature of 45^0 C and annual minimum temperature of 6^0 C with hot and wet tropical climatic conditions.

[11]With the industrial and infrastructural development, Greater Hyderabad extended beyond the boundaries of GHMC and combined with the rural areas nearby to form HMDA region. The total spread of HMDA is 7,257 sq. Km (Boundaries of Hyderabad, GHMC, and parts of the five districts included in HMDA region are mentioned in figure 1). From the collected data (source: HMWS & SB) domestic water supply up to GHMC within the boundary of HMDA is 272 MGD (GHMC boundary shown in figure 1), commercial and industrial water demands of Hyderabad is 68 MGD. These demand quantities are only up to the boundary of GHMC and we have not mentioned the total water consumption of HMDA. HMWS & SB supplies drinking

water up to GHMC only. For drinking water supply, HMDA initially depended on Osman Sagar and Himayath Sagar. Due to the rapid growth of population, water supply from the local watershed (Musi) is dominated by water supply from Krishna and Godavari basins, and they are major water sources for HMDA region. In the HMDA region, water supply is controlled by the Hyderabad Water Supply & Sewerage Board (HMWSSB) up to GHMC. For the rural areas outside the GHMC, water supply is regulated by the Rural Water Supply and Sanitation department (RWSS), for the areas nearer to the district headquarters, the respective municipalities will regulate water supply.

3 Methodology and material

[12]WF methodology demands more data. The accuracy of WF results depends on the quality and quantity of data available. WF assessment can be done using either bottom-up or top-down approaches (Feng et al., 2011). As mentioned in the introduction, in this study, we proposed a framework to assess net/actual WF of HMDA region. Net/actual WF of a city is the

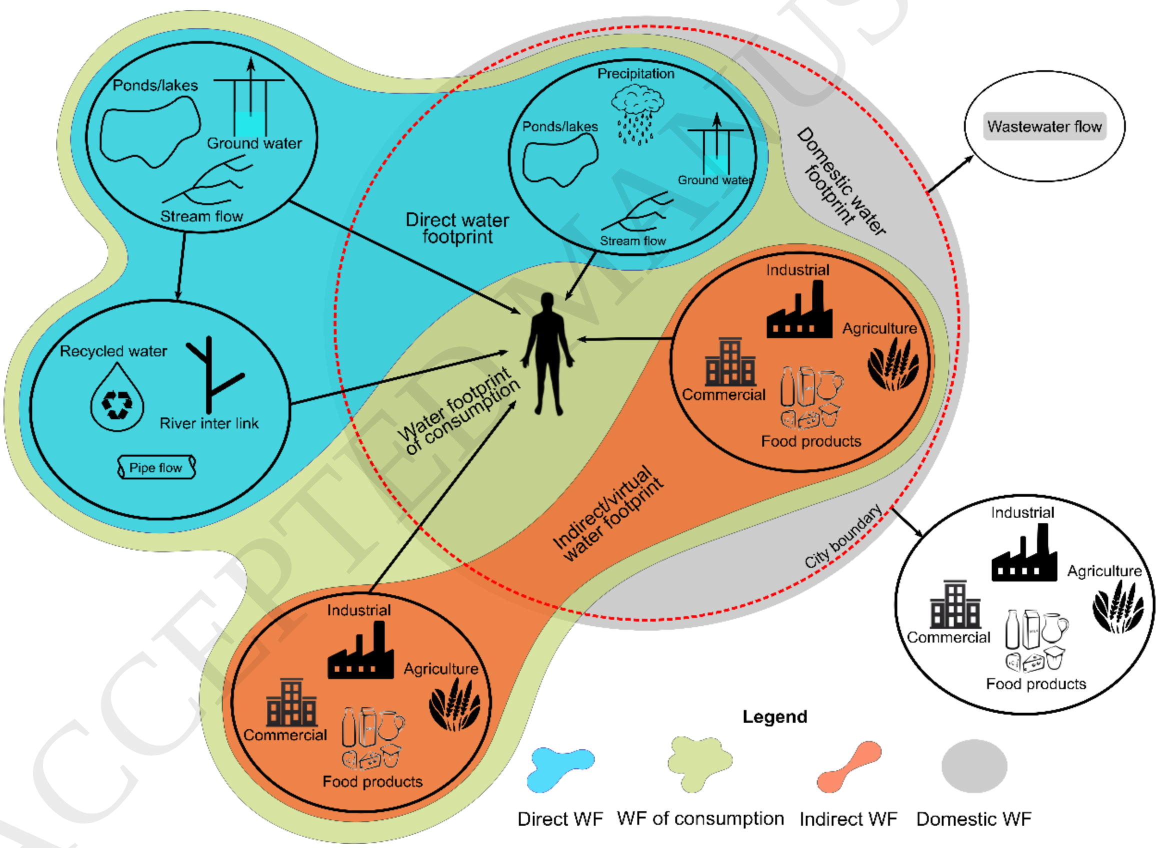


Figure 3: Conceptual figure showing components of city WF, virtual water (red layer), direct water (blue layer), consumption footprint (green layer) and domestic WF (grey layer) with in city boundary

total amount of fresh water consumed directly and indirectly by the habitants of the region (figure 3) (Dagani et al., 2018). This framework supports policymakers to know the dependency of urban cities on external water resources by quantifying the difference between consumption

WF and production WF. However, in this study, we presented a methodology to assess the consumption only, which includes food, energy (electric power, fossil fuels: petrol, diesel, kerosene, LPG, and coal) and direct water.

[13]In general urban cities consume more resources like food, energy, commodities, etc. besides water. When we are talking about the WF of urban cities, there are two faces for this coin. One is consumption WF(domestic), the other one is production WF. A city can have the upper hand in any one of the WF or both. HMDA region is giving its huge contribution to global industrial production through different sectors - pharmaceutical, infrastructural, apparel, electronics, etc.

3.1 Water footprint of food, energy and physical water

[14]To assess WF of any urban city, commodity-trading data is important. This data gives some information about the dependency of urban cities on external sources. However, at the city level (a small spatial scale), it is not easy to get the trade information. City level trade data contains many leakages; it may not be accurate. In this study, monthly per capita consumption expenditure is considered, as an alternative for city-level trade data of every economic class and their ranges of consumption expenditure from NSSO (MPCE ranges of every economic class was presented in Table 1 in supporting information). MPCE data provides information on quantity (in kgs) of food and non-food commodities consumed by consumers in all urban and rural regions in India based on the economic class of consumers(quantity of food commodities consumed by every fractile class is presented in supporting information Table 2). Table 1 shows the list of commodities considered for WF assessment in the present study. Here we have considered MPCE data from the 68th round of survey report, which was published by the NSSO in the year 2014. More information on survey procedure and methodology is given in 68th round

survey report of NSSO(Appendix-B), detailing of NSSO survey methodology and procedure is out of the scope of this work.

Table 1: List of commodities considered for assessment of WF(Reference: NSSO, 2012)

Food commodity group	Energy commodity group
1. Cereal grains 2. Pulses 3. Sugar & jaggery 4. Milk & milk products 5. Fats & oils 6. Vegetables 7. Fruits 8. Animal products: meat & eggs 9. Beverages: coffee & tea	1. Electric power: hydro & thermal 2. Coal 3. Kerosene 4. Diesel 5. Liquid petroleum gas 6. Petrol

MPCE data with respect to their economic classes from NSSO and census data of HMDA(HMDA, 2012), coupled with distribution of population in every economic class (Table 1 in supporting information), and WF of crops and crop derived products considered from the study of Mekonnen and Hoekstra (Mekonnen & Hoekstra, 2011, 2012)(Table 2 represents the data used in WF assessment and their sources).

Table 2: Data used for WF assessment and their references

Data Used	Reference
WF of crops & crop-derived products	Mekonnen & Hoekstra, 2011

WF of livestock	Mekonnen & Hoekstra, 2012
WF of energy products	Gleick, 2015
Consumers commodity data	NSSO and MSPI, 2012
Consumers economic class data	NSSO and MSPI, 2012
Census data of HMDA region	HMDA, 2012
Population distribution of every economic class	NSSO and MSPI, 2012

To assess the WF of energy we followed the approach proposed by Mekonnen (Mekonnen et al., 2015) and production WF of energy is considered from the study of Peter Gleick (Gleick, 2015). In the energy category, we have electric power (from hydro and thermal generations), fossil fuel-based energy: petrol, diesel, kerosene, LPG, and coal also. In the Indian energy sector, production and usage of thermal power are very prominent. In this study, we assumed that 80% of domestic power produced by thermal power plants. Equation (i) is developed to calculate the WF of food consumption in every economic class.

$$WF_{U\_C} = \sum_{p=1}^{n} \sum_{ec=1}^{12} ((Q_p^{ec} * WF_p)_{ct} * (D_p * p)) \quad \text{(i)}$$

where, WF_{U_C} will be WF of urban consumption, ‘Q_p^{ec}’, quantity of food product(p) consumed by every economic class(ec) consumer, ‘WF_p’ water consumed for the production of every product, ‘ct’ is commodity type(ct) consumed by the consumer(Food, Energy, and Water), ‘D_p’ distribution of population in every class and ‘p’ population.

[15]Domestic WF of GHMC is quantified using daily water supply data and population of GHMC. For areas other than GHMC direct WF is assessed based on information provided by RWSS engineers in personal interviews. Based on unpublished daily water supply data in GHMC (272 MGD) provided by HMWSSB for the year 2012, and population data of GHMC

from census 2011, the per capita direct WF in GHMC was assessed. Direct WF of GHMC and areas other than GHMC are assessed separately and considered the average of these two regions, as direct WF of HMDA.

4 Results

[16]The total per capita WF of HMDA region is 1041 m^3/cap/year, out of which 70% contribution is from food consumption and 25% is from electric power, 0.09% is from fossil fuels (petrol, diesel, kerosene, LPG, and coal) and only 5% is from direct consumption of water for daily activities.

4.1 Water footprint of food:

[17]Here we assessed WF of per capita at individual economic classes and total WF volume over the HMDA region after coupling with the population. Figure 4(a) shows the per capita WF volume that every individual food group contributed to total WF of every economic class. It ranges from 493 to 952 m^3/cap/year from lower to higher economic classes, respectively. Figure 4(b) shows total WF volume over the HMDA region after including the population. It ranges from 65 to 1029 MCM/year. From this figure, we can see WF of food consumption and the influence of consumer's economic status on the WF of urban dwellers. Per capita and absolute values of food consumption in the HMDA region has presented in Table 3 of supporting information.

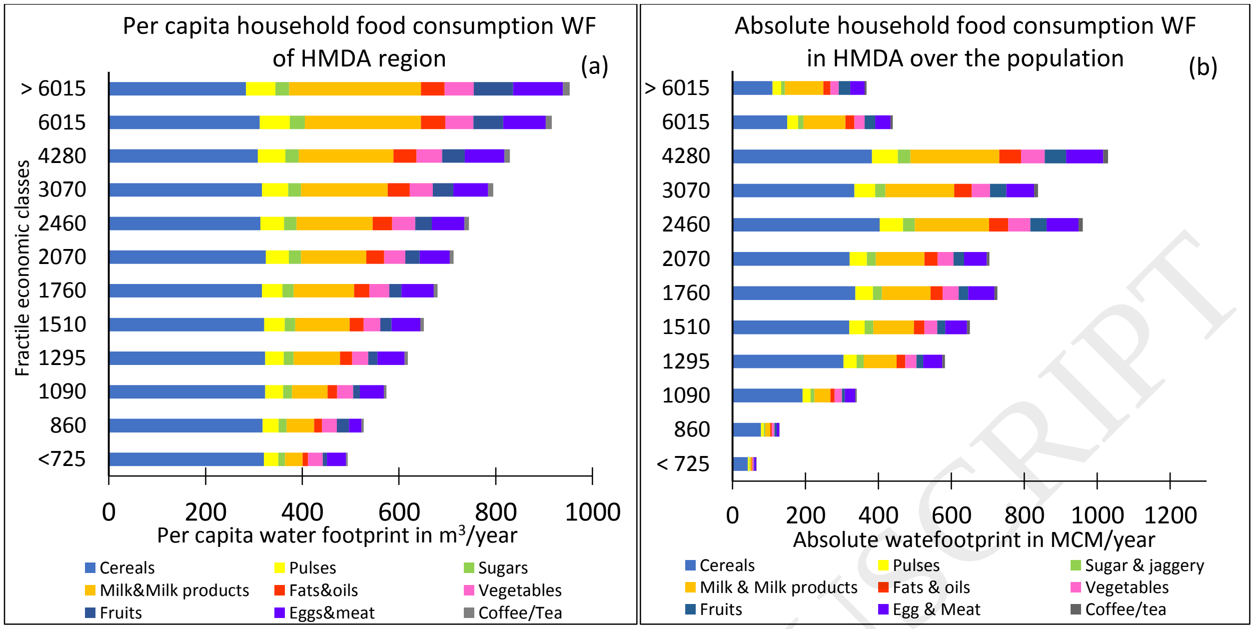


Figure 4: Plots showing annual per capita consumption WF of HMDA region (in cubic meters (left panel)) and absolute WF over HMDA region in million cubic meters (right panel) with quantity of wf on x-axis and consumer economic class on y-axis.

[18]In HMDA region, per capita WF of food consumption is 725 m^3/cap/year. It is contributing 70% of WF to the total WF of HMDA. However, in figure 4(b), WF over the HMDA region is changing its trend from lower to higher economic classes. Tenth and eight economic classes are at the top of the list with maximum WF of 1029 and 960 MCM/year. From figure 4 (a)&(b) WF of cereals, milk & milk products, eggs & meat products are following the same trend in contributing maximum to the total WF. In the HMDA region, cereals are primary food in their diet. WF of cereals are in the top of the list with a volume of 2973 MCM/year. Milk & milk products, eggs & meat products are next to the cereals with the volumes of 1387 MCM/year and 633 MCM/year. Moreover, we can observe that half of the food consumption WF of every economic class filled with cereals contributing 43% of WF to the total WF in HMDA region. WF of milk & milk products, eggs & meats are contributing 20%, and 9% of WF to the total food consumption WF, respectively and the WF contribution of pulses, vegetables, fruits, sugars is 453, 411, 319, 229, 82 MCM/year, respectively. This evaluation shows the

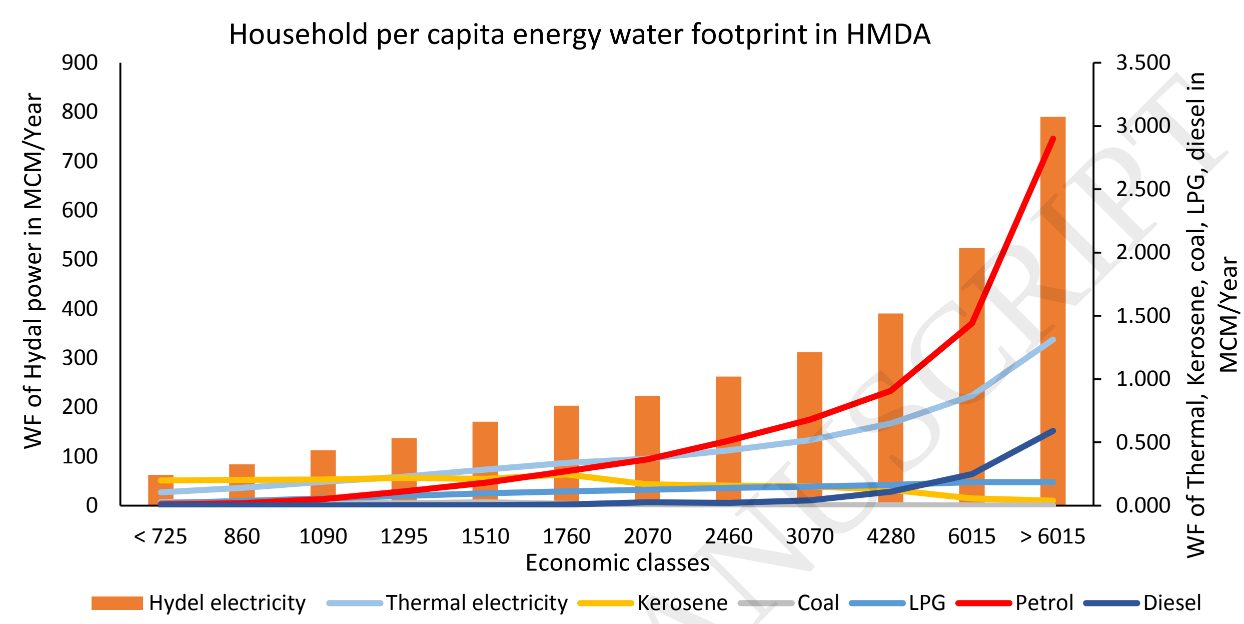
influence of consumers purchasing power/economic class and population density on WF volumes in cities.

4.2 Water footprint of energy:

[19]After WF of food consumption, energy consumption WF takes the major portion in total WF of HMDA region. Annual WF of energy consumption is 2550 MCM/year and only 10 MCM/year in total energy WF is from fossil fuels: petrol, diesel, kerosene, LPG and coal. In energy WF, maximum part is occupied with WF of electric power. In WF of electric power, maximum weight is given to thermal power, because in this region, thermal power production is more dominant than hydropower. So, we assumed that 80% of electric power comes from thermal power production and 20% is from hydropower. WF of thermal power and hydropower per unit of production is 0.0017 and 4.09 m^3/Kwh. WF of energy in urban areas in HMDA region is, nearly 1900 MCM/year and 640 MCM/Year in rural areas. Which means that urban area is consuming nearly three times the WF than the rural areas lying outside GHMC.

[20]In figure 5(a), (b) we see per capita, absolute WFs of electric power (Hydro and Thermal), kerosene on bar plots and WF of coal, LPG, petrol, and diesel in line plots with primary and secondary axes. This trend shows the potential impact of the socio-economic status of consumers on the WF of electric power. WF of electric power is high in 8^{th} and 10^{th} economic class for both thermal, hydropower consumption; it ranges between 8.23 MCM /year to 485 MCM/year for hydropower and 0.013 MCM/year to 0.8 MCM/year for thermal power. WF of petrol and diesel are also following the same trend. However, WF of petrol is high. In WF of kerosene and LPG, they are low in higher economic classes, and WF of kerosene is high in 4^{th} and 6^{th} economic classes. WF of LPG is following the same trend as electric power, petrol, and

diesel, but it is decreasing in higher economic class. WF of coal is almost negligible in higher economic classes and a minimal amount of coal WF contributed from lower economic classes.



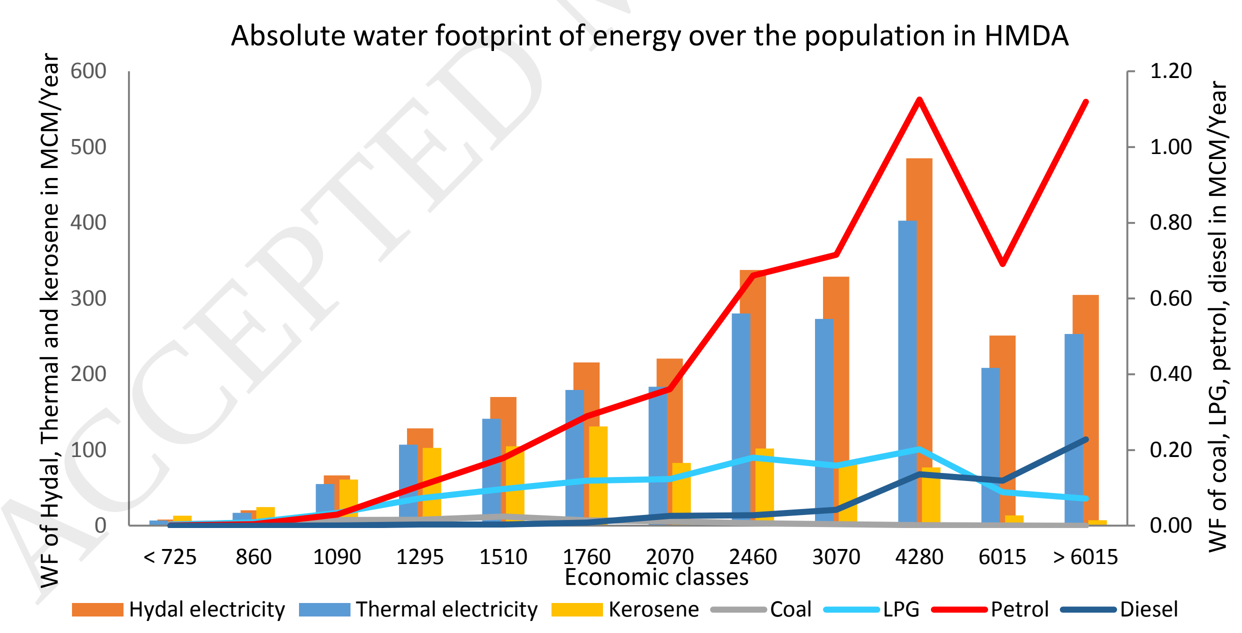


Figure 5(b): This absolute WF of electric power(hydro and thermal), kerosene in bar plot with quantities on primary axis at left side of plot and WF volume of coal, LPG, petrol and diesel (all together considered as energy) on secondary axis at right side of the plot and with economic class details on x-axis.

All together per capita, WF consumption of energy in HMDA region is more than 270 m^3/cap/year. Per capita and total amounts of energy WF values were presented in supporting information in Table 4(a), (b).

4.3 Water footprint of direct water

[21]Most of the urban cities depend on ground and external surface water resources for its drinking and habitation needs. However, here we have considered direct WF of HMDA from surface water resources only, we have not considered WF of groundwater. To assess the direct WF of HMDA, we adopted a simple averaging method over the total population in HMDA because it is hard to get the direct water consumption details based on the economic classes of the consumers. As per the Bureau of Indian Standards, IS:1172-1993, a minimum quantity of 200 LPCD should be provided for domestic consumption in cities with a full flushing system. The ninth five-year plan advocated that water requirement in urban areas as 125 LPCD with the planned sewerage system, 70 LPCD for cities without planned sewerage system and 40 LPCD for those collecting water from public stand posts. To lead a hygienic existence, National Commission on Urbanization has recommended to have 90-100 LPCD of water. However, many municipal corporations are fixing their own value of demand requirements based on industrial and commercial developments as water requirements will vary in cities and towns with variation in industrial and commercial developments. Direct WF in urban areas of HMDA region is 375 MCM/Year, and per capita consumption WF is 53 m^3/cap/year. In rural areas, consumption WF of direct water is 41 MCM/Year, and per capita consumption WF is 17 m^3/year. Total per capita consumption WF of HMDA region is 97 lit/day, i.e., we are in the recommended quantity of supply of 90-100 LPCD by National Commission of Urbanization.

5. Discussion

5.1. Key findings from HMDA WF assessment

[22]India is an agricultural nation; most of its agriculture practices depend on green water. Green water is a form of water, sourced from precipitation and stored as soil moisture. HMDA region is a metropolitan city from India. In HMDA's food consumption, 67% is occupied by green WF, 23% by blue WF, and only 10% by grey WF.

[23]In 8th and 10th affluent classes have maximum WF because the maximum population of HMDA lies in these classes. In Indian diet, the major part is occupied with cereals, and it consumes maximum water and causes environmental stress with maximum WF (Green et al., 2018; Harris et al., 2017). Cereals also occupy the major part of HMDA's food consumption WF. WF of milk products, livestock, pulses, vegetables, oils &fats, fruits, sugars, coffee/tea are next to the cereals, respectively. This trend can be seen in every economic class. Therefore, food consumption WF pattern of every food group is also similar in all classes.

[24]Coming to green, blue and grey WF, consumption trend shown in figure 6 (a), (b), (c) is changing for every food group and the pattern of food consumption WF remains same in all classes as in figure 4(b). Contribution of green WF is high in all food groups. Blue, grey WFs are next in order (figure 7). In total WF, cereals (green 22%, blue 16%, grey 5%) and milk products (green 17%, blue 2%, grey 1%) are consuming maximum percentage of green WF. Blue and green WF of oils & fats (0.1%, 0.2%) and livestock products (0.8%, 0.6%) are negligible. However, 8th & 10th economic classes have maximum green, blue and grey WFs.

[25]This study emphasizes WF of HMDA region in two different directions. First, it is showing food consumption WF of different economic classes, based on consumer purchasing capacity. Moreover, it is also depicting the impact of food consumption behavior and dietary

habits of urban cities on WFs. WF assessment based on the economic status of fractile classes gives scope to plan VW trade strategies to import water-intensive products, by considering the regional water availability. It is necessary for governments to have an account on domestic consumption WF and dependency of cities on external water resources. Second, it emphasizes the status of green, blue and grey water extraction/consumption from its natural resources and its impact on ecology because of giving higher priority to particular food groups in dietary habits(also for producing) of urban cities.

[26]Coming to energy WF, only the blue WF of energy for every class is assessed. In energy WF, maximum part contributed by electric power consumption (270 m^3/cap/year) and WF of fossil fuels is only 1 m^3/cap/year. In the HMDA region after electric power, WF of kerosene is high in below middle-class groups (6^{th}, $5^{th,}$ and 4^{th} classes). WF of diesel is gradually increasing from lower to upper economic classes. Surprisingly, WF of LPG is decreasing in upper economic classes, which tells that upper economic classes depend less on homemade food. Consumption WF of coal is negligible in HMDA region.

[27]When coming to direct WF, it contributes only 4% (45 m^3/cap/year) to the total WF of HMDA. In 4% of direct WF 90% (40.5 m^3/cap/year) is concentrated in urban areas and only 10% (4.5 m^3/cap/year) is concentrated in rural areas. Here a simple averaging method was considered (based on the daily demand and supply of domestic water in HMDA region) over the population to assess the direct WF. However, we have not assessed direct WF based on purchasing power due to lack of data for every economic class.

[28]Understanding regional/city level WF in different sectors helps in planning water requirement of urban cities. For cities under severe water crisis, VW trade strategies between wet and dry regions can release from water stress. VW transfer can resolve the transboundary issues

on sharing water virtually. It needs quantification and balancing of consumption WF and production WF at a region level/water basin level (Wu et al., 2019). Moreover, water stewardship and cooperation between governments is essential to achieve sustainable water consumption through VW trade policies, with mutual cooperation.

[29]In HMDA's WF, 95% is contributed to virtual water (VW) in the form of food and energy. This VWF is more than 20 times the direct WF. This evidence, again shows that urban cities consume 20 times more virtual water than direct water, which is supported by previous researches (Hoff et al., 2014; McCallum & Shanafield, 2016).

5.2. Comparing WF of HMDA with other cities

[30]Cities from developed nations have high WF (Blas et al., 2018; Hoff et al., 2014; McCallum & Shanafield, 2016; Vanham & Bidoglio, 2014). In this section, the difference between WF of HMDA and cities from developed, developing and under-developed nations is compared. The data for these cities were taken from past researches (Hoff et al., 2014; Vanham & Bidoglio, 2014), and reasons for WF difference were mentioned in table 3. In this comparison, we considered cereals and pulses as primary food products for comparison because these are common food products in these cities.

[31]Hoff (Hoff et al., 2014) accounted only imported agricultural WF of Delhi, Berlin and Lagos cities(not included livestock products). HMDA's food consumption WF included WF of livestock, coffee/tea, and sugars products (725 m^3/cap/year). Here, we compared only agricultural WF of HMDA with Delhi, Berlin and Lagos cities. After excluding the coffee/tea, sugars, milk products, and livestock (for the similarity in products comparison between the cities), WF of HMDA is 391 m^3/cap/year. However, Delhi (434 m^3/cap/year) has higher WF than HMDA. Reason for the difference between Delhi and Hyderabad WF is, the average per capita

cereals and pulses consumption of Hyderabad and Delhi are 56, 66 Kg/year with average VW content of 3530 and 2400 Liters/Kg (Hoff et al., 2014). Delhi's per capita consumption of cereals and pulses is higher than Hyderabad. In most of Hyderabadi's diet, rice consumption is higher than wheat. Due to much population weight for wheat consumption in Delhi, its food consumption WF is high, even though wheat has very less production WF than rice. Figure 8 represents the primary food products in cities considered for this comparison, such as cereals, pulses, oils and fats, cassava, sorghum, soya, coffee are primary food products. In Hyderabad and Delhi's food consumption maximum part is occupied with cereals and pulses because they are primary food in their diet but not in the case of other cities.

[32]Milan (Vanham et al., 2014) is a Europian city with high WF. Milan's food diet consists of more cereals, coffee, and less quantity of crop oils, fats. However, annual WF of crop oils and fats are at the top of the list even though they are consumed in very less quantity, because of its high VW content.

[33]Lagos (Hoff et al., 2014) food diet consists of more cassava, sorghum, and soy products and less amount of imported rice. It's food diet consist of a good amount of livestock which is fed with sorghum and soya. Soya and sorghum are water intensive and imported. As an underdeveloped nation, where technology is not used in farming practices, its agricultural productivity is low, and most of the food products to Nigeria are imported from surrounding countries (Mekonnen and Hoekstra 2014).

[34]Berlin's (Hoff et al., 2014) food diet is occupied with more wheat, soya, and coffee. Most of the Europian cities food diet consists of more livestock products and to feed this livestock, soya will be imported from the surrounding regions in Europe (Hoff et al., 2014; Vanham et al., 2013). Most of the cities food diet mentioned above depends on their regional

availability and priority. In Indian food diet cereals, pulses are more in quantity, some of these are water intensive. However, in city diets of western nations, these quantities are substituted with regionally available products.

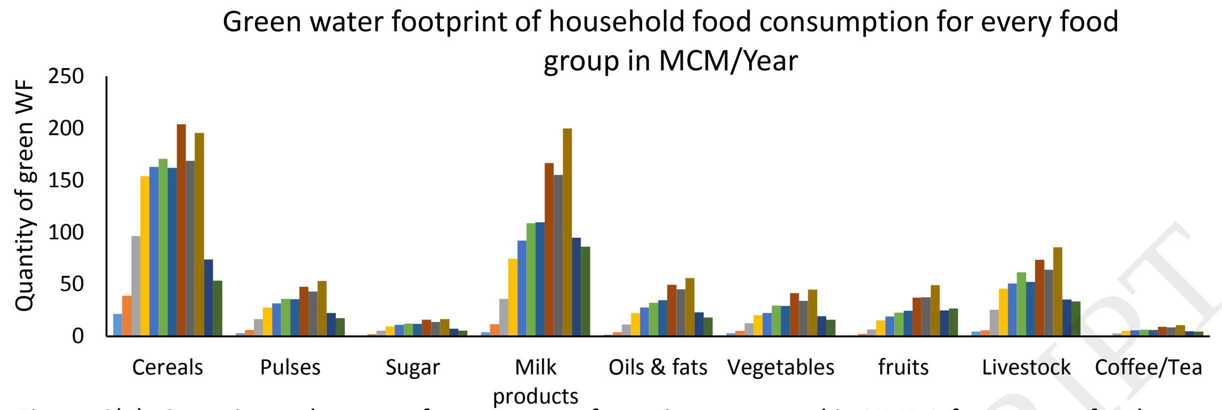


Figure 6(a): Quantity and patter of green water footprint consumed in HMDA from every food group consumption

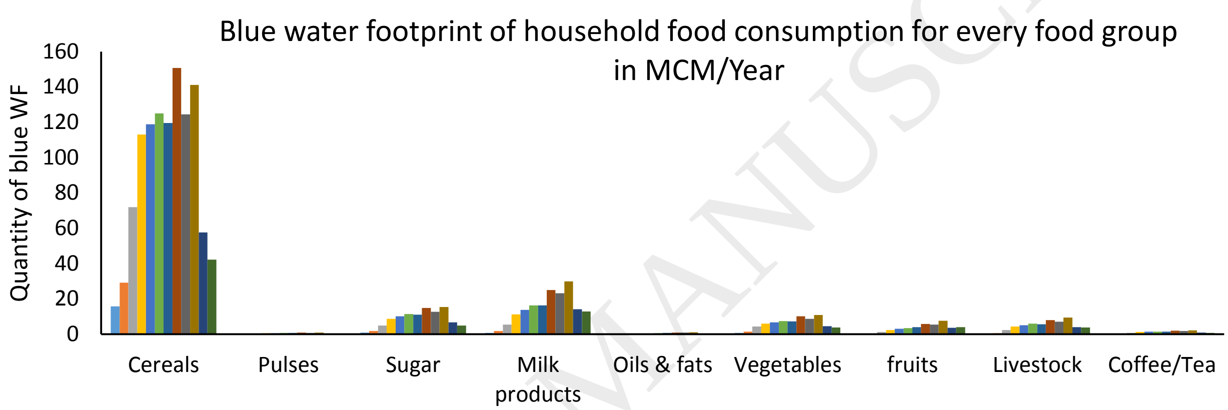


Figure 6(b): Quantity and pattern of blue water footprint consumed in HMDA from every food group consumption

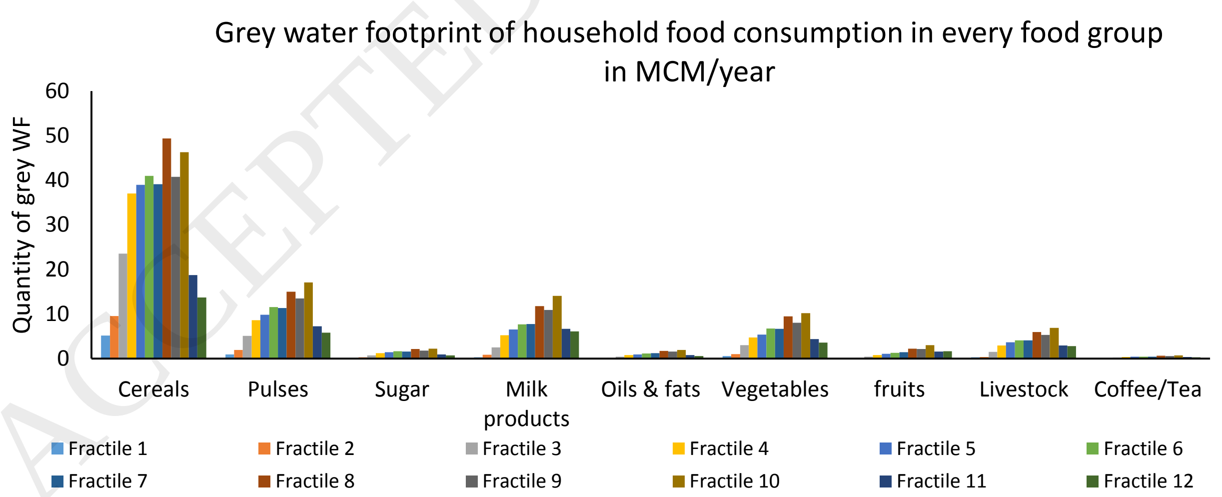


Figure 6(c): Quantity and pattern of grey water footprint consumed in HMDA from every food group consumption

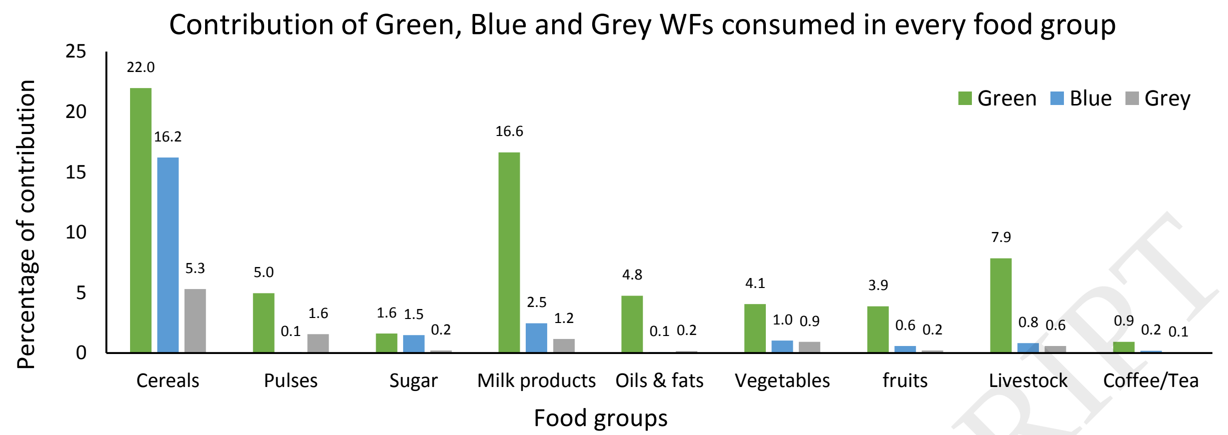


Figure 7: Percentage of green, blue and grey water footprint consumed in every food group

[35]From the overall observation, Hyderabad's WF is 60% of Berlin, 32% of Lagos and 20% of Milan. Based on local climatic conditions and food availability, priority is given to their food diet in cities (figure 8). Hyderabad and Delhi's food diet contains water-intensive products. These cities are from the agricultural nation (India) whose climatic conditions are suitable to produce water-intensive products, and these cities get food products from surrounding agricultural regions. It is different for Lagos and Berlin; they are low in water productivity and imports products (soya, sorghum) from larger distances. However, Cassava is primary food in Lagos diet because of its low VW content. Coffee and cocoa are also common stimulants in European city's diet(Berlin and Milan), which are high in VW content (figure 8)(Hoff et al., 2014). Moreover, population density with water-intensive dietary habits also adds up to the reasons for more WF in these cities.

[36]From the above comparison, it is clear that food consumption the local climatic conditions influence WF of cities, availability of food, and dietary habits. Consumption of less water-intensive products can contribute more weight to the conservation of water resources, and urban cities should depend more on locally available products.

[37]In this study, we assessed WF of domestic power only, not considered the commercial and industrial WF of power consumption. Average consumption WF of energy in HMDA is 270

Hyderabad(391 M3/Y)	Kg/Year	Liters/Kg	M3/Year
Cereals	102	2840	290
Pulses	11	4220	46
Vegetables	21	930	20
Fats & Oils	7	4330	30

Milan(1878 M3/Y)	Kg/Year	Liters/Kg	M3/Year
Cereals	130	1440	187
Pulses	20	2730	55
Oils & Fats	40	18250	730
Coffee	230	1260	290

Lagos(1210 M3/Y)	Kg/Year	Liters/Kg	M3/Year
Cassava	227	983	223
Sorghum	50	5700	285
Rice	33	3800	125
Soya	3	6800	20

Delhi(434 M3/Y)	Kg/Year	Liters/Kg	M3/Year
Rice	122	1900	232
Wheat	66	2100	139
Pulses	12	3200	38
Soya	5	4200	21

Berlin(643 M3/Y)	Kg/Year	Liters/Kg	M3/Year
Wheat	164	498	82
Soya	53	1755	93
Coffee	9	15000	135
Cocao	3	20000	60

Figure 8: The annual consumption quantities (in Kg/Year) of primary food products, along with the VW (in Liters/Kg) content embedded and total WF of product (in m^3/year) of cities Hyderabad (HMDA), Milan, Lagos, Delhi, and Berlin.

m^3/cap/year and WF of fuel(petrol, diesel, kerosene, LPG, coal) is 0.9 m^3/cap/year. WF of LPG consumption is less in higher classes which means that consumers of the higher economic class depend more on processed food products or ready-made products, which may be another reason for high per capita food consumption WF in higher classes. WF for coal based thermal energy is negligible in HMDA region. Whereas, WF of kerosene and coal consumption is higher in below middle classes and less in higher classes. WF of petrol consumption is high when compared with the WF of diesel, it is increased from the lower to higher economic class.

[38]In the HMDA region, VWF is dominating direct WF, and these results show that physical water consumption is negligible when compared with virtual water embedded in food and energy. Direct WF of Hyderabad is less than the European cities and cities in the United States. Average direct WF of Milan is 529 Liters/cap/day, average direct WF of United State

urban cities are 600 Liters/cap/day (Vanham et al., 2014; Chini et al., 2016). Whereas direct WF of HMDA is 120 Liters/cap/day, it is only 5% in HMDA's footprint. However, while assessing the direct WF, we have not assessed based on the economic gradients of consumers, due to data limitation of direct water consumption with respect to economic gradients of consumers, as in HMDA region for drinking water, consumers depend on several sources including groundwater, municipal water, and private water distribution sector. Assessing direct WF based on economic gradients alone is laborious and requires more data. It requires an enormous amount of effort and time. For now, we assessed using general averaging method over the population, and the obtained value of direct WF in urban is nearer to the values published from previous researches (Shaban, 2008; Shaban & Sharma, 2007b). Above results illustrate how the purchasing power of consumer can influence the WF of urban cities and it is demanding consciousness in consuming urban utilities.

6 Conclusion:

[39]We assessed WF of HMDA region based on economic classes using a consumer-centric approach. It helps to understand the consumption behavior of the different economic class population and to monitor products/goods consumption, which is more consumed by the affluent and non-affluent population. These assessments were required, to assess and plan foreign (out of HMDA boundary) VW, trade policies for water intensive and high consumables from water abundant regions. In addition, this approach helps to policymakers to plan strategies to reduce VWF of these goods (highly consuming goods) in the production phase, if they are importing from within the national territories.

[40]Securing regional water resources alone will not fulfill the sustainability of water resources; it is the duty of all nations and regions. Cooperation between the nations/regions with

strong water stewardship is essential to satisfy the water needs between transboundary regions. Exporting/importing of water-intensive goods between water abundant and dry regions through VW trade can help to resolve transboundary water conflicts and release pressure on water scarce regions. Assessing WF of one city will not serve the purpose of water resources sustainability; it demands this kind of assessment for more cities to achieve future water resources sustainability.

[41]In this study, we have quantified the HMDA region's WF at the consumer level by considering economic gradients of consumers. Out of total WF consumption, 95 percentage (997 m^3/cap/year) is from indirect WF, only 5% (44 m^3/cap/year) is from direct WF. In the HMDA region's WF, virtual WF dominated the direct WF. Here, we have not included the industrial, commercial WFs and temporal variations these WFs, which requires an enormous amount of information on commodity trades and its consumption WFs, this can be the future scope of this work.

Conflict of Interest: Authors declare that, they have no conflict of interest

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Table 3: Comparing agricultural WF of urban cities (Berlin, Delhi, Lagos, Milan,) with WF of Hyderabad Metro Development region (after excluding livestock products)

Study area	WF in m^3/cap/y	WF in L/cap/d	Reason for the difference in consumption WF
HMDA region	725	1986	Hyderabad's average per capita WF is 391 m^3/year, after excluding livestock products. It is doubled to actual WF 725 m^3/cap/y, which includes meat, milk & milk products in total footprint and average per capita consumption of cereals, pulses is 56 Kg/Year with an average virtual water content of 3530 L/Kg. Rice is the primary product in cereals consumption of Hyderabad. (Reference: Present study)
Delhi	434	1189	Delhi's average per capita consumption WF is 434 m^3/year without livestock products average per capita consumption of cereals and pulses is 66 Kg/year, with average virtual water content of 2400 L/Kg. it is more than Hyderabad's average cereals and pulses consumption (56 Kg/year) and total consumption footprint (391 CUM/year) but less in rice consumption. Reference: (Hoff et al., 2014)
Berlin	643	1761	Berlin's average per capita consumption footprint is 643 CUM/year, which is more than 63% consumption WF of Hyderabad and Delhi's on average. Berlin's average per capita cereals and pulses consumption is 108 Kg/year with a maximum consumption of wheat, soya which is produced locally with an average virtual water content of 1122 L/Kg in advantageous climatic conditions but this virtual water consumption is more than Delhi and Hyderabad. (Hoff et al., 2014)
Lagos	1210	3315	Lago's average per capita consumption WF is 1210 CUM/year, with average cereals, pulses consumption of 30 Kg/year with an average virtual water content of 5433 L/kg because of low water productivity of neighboring countries. With more virtual water consumption of soya(6800 L/Kg) in Lago's than Berlin(1755 L/Kg) and cassava is very common food in this region contributing more virtual WF of 983 L/kg with per capita consumption of 227 Kg/cap which is 7 times to the cereals and pulses consumption. (Hoff et al., 2014)
Milan	1878	5150	Milan's average per capita WF consumption is 1878 CUM/year which is more than doubled to the Hyderabad's WF in which 54% (1024 CUM/year) is WF from meat and milk, milk products which is nearly equal to the Lago's WF. The average WF of Milan by excluding meat, milk and milk products is 854 CUM/year with average cereals, pulses consumption of 77 Kg/year with a virtual water content of 1095 L/Kg. (Reference: Vanham et al., 2014).

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