

Original Article

From Plate to Planet : Analyzing the Dietary Water Footprint — A Cross-sectional Study

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Abstract

Background : The Water Footprint (WF) is an environmental indicator that measures the volume of freshwater (l or cu. mm) used throughout the entire production chain of a consumer item or service. India is the World's largest user of freshwater due to its rapid development and massive population; the major contributor to this is the food system. The per capita Water Footprint (WF) of India is approximately 1,089 cubic meters per year, agriculture being the major contributor accounts for approximately 90% of the resource.

Aims and Objectives : To analyze the dietary pattern of the participants and to quantify the Water Footprints associated with the production of different food groups.

Materials and Methods : A cross-sectional study, was done among 130 employees of a Tertiary Care Center in Vijayapura district from May, 2024 to July, 2024. Data was collected by 116-item semi-quantitative FFQ to assess the food intake, which was later segregated into 31 food groups based on similarity in nutritional content. The Water Footprint for each food group was calculated using India-specific WF data. Data was analyzed using SPSS Software version 26.0.

Results : The mean \pm SD of total dietary energy was 2368 ± 827 kcal/capita/day. The mean \pm SD blue WF of diets in the study population was 1008 ± 342 l/capita/day, and the mean \pm SD green WF of diets was 3236 ± 1216 l/capita/day. Rice and wheat being the main staple cereals contributed to about 380 l/capita/day of dietary green WF and 133 l/capita/day of dietary blue WF.

Conclusion : Substituting wheat and rice with lower water demanding crops like sorghum and millet, consuming more fruits and less meat can lower the Water Footprint. The shift to such diets could be a key step in mitigating the environmental impacts of current consumption patterns in India.

Key words : Water Footprint, Green WF, Blue WF, Food Frequency Questionnaire (FFQ), Dietary pattern.

The Water Footprint (WF) is an environmental indicator that measures the volume of freshwater (l or cu. m) used throughout the entire production chain of a consumer item or service. It is estimated by adding the water consumed to the water present in imported goods and deducting it from the water exported. Arjen Hoekstra first put forward the idea of a "Water Footprint" in 2002 during the International Expert Meeting on Virtual Water Trade in Delft, Netherlands. The recent National Water Policy (2012) of India placed a strong emphasis on evolving Water Footprints and water audit benchmarks on the use of water resources to encourage efficient use of water. The Water Footprint may be viewed as a complete indication of freshwater resource appropriation¹.

Water Footprint (WF) consists of three components :

- Blue WF refers to the volume of surface and groundwater utilized for irrigation, industrial usage, and residential use during the manufacturing process (groundwater and surface water),
- Green WF refers to the amount of rainwater utilized

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Editor's Comment :

- This study highlights that Indian diets have a high-water footprint, largely driven by poultry and staple cereals such as rice and wheat. Promoting less water-intensive grains and more plant-based foods can help reduce pressure on freshwater resources and support sustainable nutrition. Such sustainable dietary transitions are essential to protect freshwater resources while supporting long-term food and nutrition security in India.

during production, especially in agriculture (soil moisture and rainfall),

- Grey WF refers to the volume of freshwater required to dilute the pollutants produced during manufacturing (waste, polluted, and recycled water)².

With a total WF of 1047 Billion Cubic Meters (BCM) annually, India has the highest WF among all nations, followed by China (967 BCM/year) and the United States (826 BCM/year). India has a per capita Water Footprint of 1089 cubic meters, which is less than the Global average of 1,243 cubic meters per capita. India's 1.2 billion population accounts for a substantial 12% of the World's total Water Footprint³.

Almost 90% of India's annual freshwater usage is by the agricultural sector. These are likely to increase in the future as agriculture attempts to keep pace with India's growing population and changing dietary preferences. In the last few decades, the World has seen a significant shift in

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food consumption patterns towards more animal products such as meat, milk, and eggs, mainly due to growing economies and rising individual incomes.

Considering India's present water productivity and its anticipated food demand for 2050, it is inevitable that the country will have to import virtual water. This is because in the near future, India's average (utilizable) water availability per capita will fall below the minimal quantity required to sustain a person's diet. This indicates that India's water shortage is a national as well as a local problem⁴.

"The water-use impacts of food production should be a key consideration of sustainable diets. But until now, little has been known about the water scarcity demands of diets - especially the diets of individuals," Diego Rose⁵.

A sustainable diet is defined by the Food and Agriculture Organization of the United Nations as "diets with low environmental impacts that contribute to food and nutrition security and the healthy life for present and future generations"⁶. Thus, the study of regional dietary Water Footprint will help in better understanding and suggestion of sustainable diet choices.

AIMS AND OBJECTIVES

- (1) To analyze the dietary patterns of the participants.
- (2) To quantify the Water Footprints associated with the production of different food groups based on the dietary patterns of the participants.

MATERIAL AND METHODS

This is a cross-sectional study conducted among 130 employees of a Tertiary Care Center in Vijayapura district. After obtaining Institutional Ethical Clearance, the study was conducted in May, 2024 to July, 2024. The participants were selected using the Convenient Sampling Technique. The participants were selected among Consultants, Residents, and Non-teaching staff. Data was collected after obtaining informed consent, using a 116-item semi-quantitative FFQ⁷ and Socio-demographic profile by interview technique to assess the food intake, which was later segregated into 31 food groups based on similarity in nutritional content⁸. Blue and Green Water Footprint for each food group was calculated using India-specific WF data quantified by The Water Footprint Network. The following formulae was used to calculate the Water Footprint (WF) for each food group:

$BWF/GWF \text{ of a food group (L/kcal/day)} = BWF/GWF \text{ of that particular food group (L/kcal)} \times \text{Energy obtained from the food group (kcal/day)}$ ⁹

The data thus obtained was entered into Microsoft Excel.

STATISTICAL ANALYSIS

To statistically analyze the collected data a Statistical package for the Social Sciences (Version 26) was used. The findings were displayed as Mean, Standard Deviation, and percentages through charts and tables. To compare the variables a One-way ANOVA with the Kruskal-Wallis test was implemented. The correlation between Socio-demographic variables and the mean Blue and Green Water Footprint was studied using the Chi-square test. A p-value of <0.05 was considered statistically significant.

RESULT

Table 1 displays the descriptive characteristics of the study population. A total of 130 individuals, between the age of 25 to 64 years were included in the study (the majority ie, 44.6% being from the 25-34 age group). The majority of participants (83.1%) were Hindu, and there were more Females (56.9%) in the sample. 57.7% of participants lived in Urban areas, and a majority (54.6%) of them belonged to the Upper Class according to Modified BG Prasad classification.

Dietary Characteristics :

The mean \pm SD of total dietary energy was 2368 ± 827 kcal/capita/day. The main staple cereals were rice and wheat with a mean consumption of 634 Kcal/capita/day and 563 Kcal/capita/day respectively.

Diet and Water Footprints :

Fig 1 shows the mean \pm SD dietary blue and green Water Footprints. The mean \pm SD blue WF of diets in the study

Table 1 — Socio-demographic Profile

Variables		N (%)
Gender	Male	56 (43.1%)
	Female	74 (56.9%)
Age (in years)	25 - 34	58 (44.6%)
	35 - 44	48 (36.9%)
	45 - 54	18 (13.8%)
	55 - 64	6 (4.6%)
Residency	Rural	55 (42.3%)
	Urban	75 (57.7%)
Religion	Hindu	108 (83.1%)
	Muslim	12 (9.2%)
	Christian	10 (7.7%)
Education	Illiterate	2 (1.5%)
	Primary School	14 (10.8%)
	High School	17 (13.1%)
	Pre-university	20 (15.4%)
	Graduation	32 (24.6%)
	Post-graduation	45 (34.6%)
Occupation	Teaching staff	77 (58.8%)
	Non-teaching staff	53 (40.5%)
Marital status	Married	98 (75.4%)
	Unmarried	32 (24.6%)
Socio-economic status (Acc to Modified B G Prasad classification)	Lower middle class	31 (23.8%)
	Middle class	23 (17.7%)
	Upper middle class	5 (3.8%)
	Upper class	71 (54.6%)

population was 1008 ± 342 l/capita/day, and the mean \pm SD green WF of diets was 3236 ± 1216 l/capita/day. Rice and wheat being the main staple cereals contributed to about 380 l/capita/day of dietary green WF and 133 l/capita/day of dietary blue WF. Fig 2 shows the top 5 contributors of energy among the study participants. Fig 3 shows the top 5 food groups contributing to the blue and green Water Footprint.

Water Footprints of Food Groups :

The highest contributor to dietary Water Footprint was found to be Poultry, which was about 40% and 35% of total Dietary green WF and Dietary blue WF respectively. This was followed by the food group ‘Other Vegetables’ which contributed to 12% and 10 % of total Dietary GWF and BWF respectively. Fruits like Orange and Guava contributed the least in contrast to Mango which contributed to 6% of Dietary GWF and BWF. This was in line with the fact that Mango was the seasonal fruit during the study period. Fig 3 shows the top 5 food groups contributing to the blue and green Water Footprint.

Figs 4 & 5 show the Dietary Blue and Green water footprints of all the 31 food groups respectively.

Associations between dietary blue & green water Footprint and Socio-demographic characteristics:

Except for age, the study revealed that Blue and Green WFs had a significant association with all variables analyzed. Gender and Dietary WF were significantly associated, with males having higher Water Footprints than females ($p=0.05$). Furthermore, the Water Footprints and Socio-economic level were found to be statistically related, with WF being greater among participants from the upper class ($p<0.05$). Blue and Green WFs strongly correlated with education, with illiterates, graduates, and post-graduates having larger footprints. Residence was a highly reliable indicator of dietary WFs. Dietary Blue and Green WF were higher in the urbanized region.

DISCUSSION



Fig 1 — Mean \pm SD of Dietary Green and Blue WF (N=130)

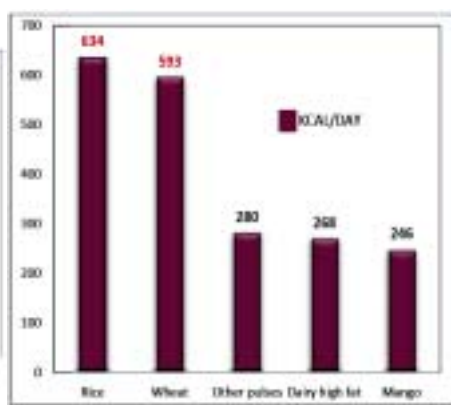


Fig 2 — Top 5 Energy Contributors

Table 2 — Association Between the BWF and GWF with Socio-demographic Profile

WF		N	Mean (SD)	Median	95% CI	p
GENDER						
BWF	Male	56	2382 (832)	1038	514-2177	0.05*
	Female	74	1800 (345)	897	514-2177	
GWF	Male	56	3466 (1196)	3300	1450-7156	
	Female	74	3000 (1219)	2952	1368-7156	
SOCIO-ECONOMIC STATUS						
BWF	Lower middle class	31	878 (402)	741	514-2128	0.004*
	Middle class	23	850 (244)	768	547-1499	
	Upper middle class	5	1094 (313)	1038	707-2177	
	Upper class	71	1321 (112)	1329	1139-1434	
GWF	Lower middle class	31	2498 (1015)	2020	1368-5321	0.001*
	Middle class	23	2630 (976)	2727	1368-4950	
	Upper middle class	5	3320 (831)	3195	2048-4858	
	Upper class	71	3678 (1150)	3380	2132-7156	
EDUCATION						
BWF	Illiterate	2	1117 (0)	1117	1117-1117	0.024*
	Primary school	14	895 (355)	677	547-1499	
	High School	17	915 (478)	741	514-2128	
	Pre-university	20	769 (158)	746	608-991	
	Graduation	32	1053 (226)	1065	707-1434	
	Post-graduation	45	1148 (349)	1038	853-2177	
GWF	Illiterate	2	3676 (0)	3677	3677-3677	0.05*
	Primary school	14	2606 (1083)	2438	1368-4950	
	High School	17	2666 (1166)	1972	1760-5321	
	Pre-university	20	2198 (500)	2020	1519-2952	
	Graduation	32	3894 (694)	3658	3090-4858	
	Post-graduation	45	3620 (1366)	3260	2131-7156	
BWF	Urban	75	1080 (254)	1065	707-2177	0.0
	Rural	55	910 (419)	743	514-2177	
GWF	Urban	75	3643 (1003)	3380	2132-7156	
	Rural	55	2681 (1280)	2020	1368-7156	

This study provides an individual-level estimate of the Blue and Green Water Footprints of various Indian food groups. It was found that there was a vast difference in the Water Footprints across various Socio-demographic groups due to differences in consumption patterns. This factor should be considered while recommending a sustainable diet. According to the United Nations Food and Agriculture Organization (FAO), the average minimum daily energy requirement is approximately 2533 Kcal. The average energy intake in this study was 2368 ± 827 Kcal/day, which could probably be due to the underestimation of energy

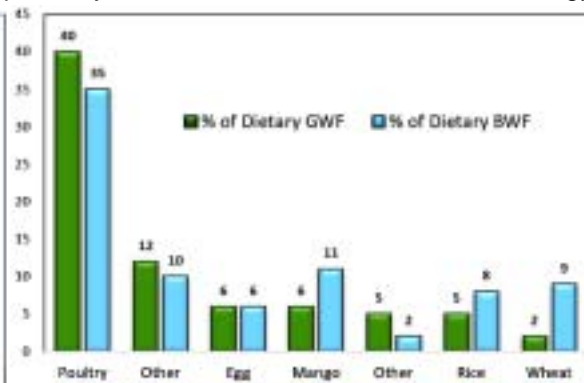


Fig 3 — Top 5 Contributors to Dietary WF

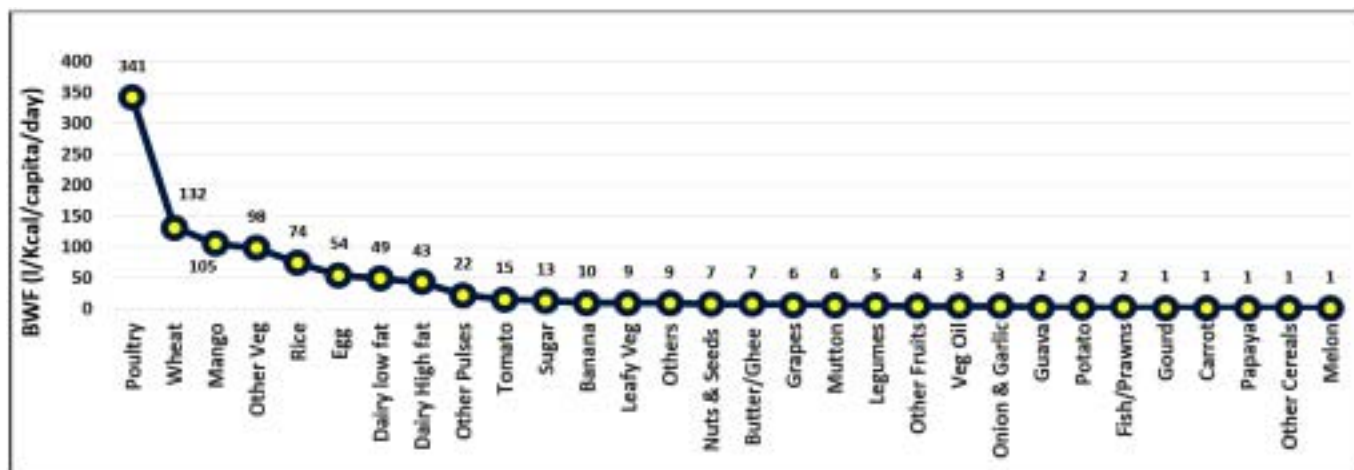


Fig 4 — Blue Water Footprint of 31 Food Groups (Lkcal/day)

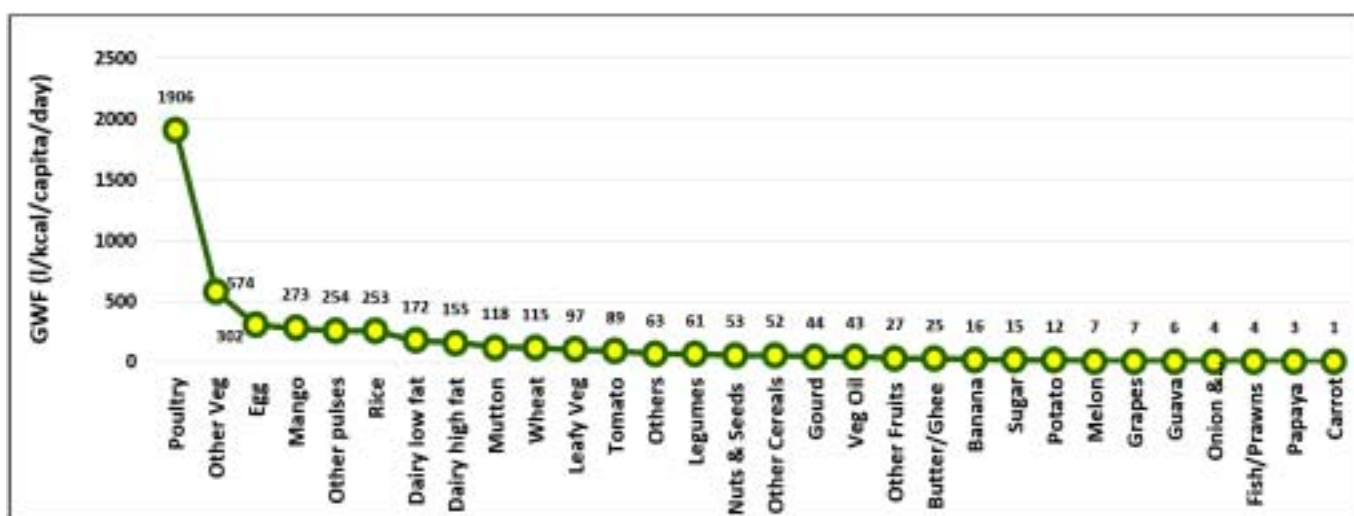


Fig 5 — Green Water Footprint of 31 Food Groups (Lkcal/day)

intake using FFQ. There are currently no comparable middle-income country data available, however, the combined Green and Blue Water Footprint (4244 l/capita/day) was higher than the South European vegetarian diet (3176 l/capita/day), and lower than the average South European diet (5364 l/capita/day) according to a study done by Vanham *et al.*¹⁰. The mean blue WF of this study (1008 l/capita/day) was found to be considerably higher than that found for the European diet (299 l/capita/day) and the UK diet (160 l/capita/day) in a study by Vanham *et al.*, and Hess *et al.*¹¹. These differences in dietary WFs are attributed to the difference in dietary patterns and also to the variation in WFs of various food groups due to climate and yield at the location of production. High dietary blue WF indicates that the Indian diet depends on ground and surface water resources. The groundwater tables are being depleted rapidly hence farmers face greater costs to extract irrigation water (Ahmed *et al.*)¹². Therefore, the high dependency of Indian diets on blue water has a tremendous impact on economic, social and environmental sustainability. In this study, the foods with

the highest Blue and Green WF were poultry which is consistent with global averages as per study done by Mekonnen and Hoekstra *et al.*⁸. Socio-demographic groups were significantly associated with dietary blue and green WF, due to the amount and type of food consumed. The strongest predictor of dietary blue WF was place of residence, which is significant given India's present water crisis. The blue WF of Urban diets was about 1.4 times higher than that of Rural diets, ie, 1080 l/capita/day compared to 910 l/capita/day while the green WF of Urban diets was approximately 1.2 times higher than that of Rural diets, or ie, 2681 l/capita/day compared to 3643 l/capita/day. Dietary modifications, such as replacing rice and wheat with alternative cereal crops that require less water (sorghum and millet), might be a significant adaptation to the restricted availability of groundwater resources. Dietary blue WF was lower in female participants, mostly as a result of reduced overall energy consumption. According to research by Bowen *et al.*¹³, urbanization and rising Socio-economic levels may be connected to the nutritional shift in India. Dietary WF rose with a higher quality of living

and was higher in Urban diets than in more traditional, Rural diets. This is linked to a decrease in the intake of grains and pulses and an increase in the consumption of processed foods, vegetable oils, and animal products (particularly dairy and poultry) (Misra, *et al*)¹⁴. According to this study, dietary modifications that result in higher overall calorie intake and animal product consumption; as they do in many Western nations, may raise dietary WFs and have an impact on water stress.

CONCLUSION

According to the United Nations Food and Agriculture Organization (FAO), Sustainable diets are those with low environmental impacts, contributing to food and nutrition security and a healthy life for current and future generations. In the context of this study, the high dietary blue Water Footprint (WF) highlights the heavy reliance of Indian diets on ground and surface water resources. This presents a sustainability challenge, as these resources are under increasing stress. A shift towards less water-intensive food items is essential for ensuring the sustainability of water resources for future generations. Specifically, by substituting wheat and rice with other cereal crops with lower water demand like sorghum and millet. Incorporating more fruits and less meat into the diet can also lower the water footprint as meat production is water-intensive as compared to plant-based foods. This approach can help safeguard water resources for future generations, supporting both environmental sustainability and long-term food security. The shift to such diets could be a key step in mitigating the environmental impacts of current consumption patterns in India.

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