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Article

Water footprint assessment of animal-based and plant-based products in Iran

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A B S T R A C T

In recent years, the majority of the Middle Eastern nations have been suffering from water scarcity, and Iran is not an expectation in this matter. The mean annual precipitation of the country is in the vicinity of 250 mm, which is considerably lower than the global rainfall average (almost 67% lower) and with a total internal renewable water resource (IRWR) of 128 billion cubic meters (BCM) which forms only less than 0.50% of the total global water resources. A number of critical waterbodies have already dried up or shrunk considerably. Therefore, Iran is suffering from both physical water scarcity and mismanagement of water resources. The agriculture and livestock sectors, as the most water-intensive industries in Iran, have difficulties meeting the water requirements in order to maintain their normal activities. In the past two decades alone, more than 50% of the nation's reservoir capacity was extracted and consumed in the agricultural sector. In this study, we evaluate the water footprint (Blue water footprint, Green water footprint, and Grey water footprint) of 11 main food categories and their production from 2010 to 2019, along with the annual population growth. During the decade, vegetables with 143.3603871 million liters was the most water-intensive product, followed by wheat and fruits production, 118.755447 million liters and 115.5299726 million liters, respectively. The results of this study indicate that animal-based products require the highest amount of water volume for production, but it is plant-based products (vegetables, fruits, and grains, in particular, that are consuming the highest amount of water in the country).

1. Introduction

Currently, malnutrition and hunger are among the most critical issues around the globe. For decades, the situation of world hunger was witnessing slightly more positive trends, but in recent years, the trends have been changed for the worse [1]. As a result of the COVID 19 pandemic, in 2020, between 720 and 800 million people in the world were undernourished. The numbers indicate a significant jump in comparison with the year 2014, in which 607 million people were affected by undernourishment [2]. However, malnutrition is much more complex than hunger, which is a result of a lack of access to food. Malnutrition in all its shapes, including hunger, deficiencies in vitamins and minerals, food insecurity, overweight, obesity, and over-consumption, is a concerning problem not only among developing nations but also among those in developed countries [3]. Among all the factors that could possibly affect the global food production patterns - for instance: land use, energy availability, technological advances, and farm management - freshwater resources directly determine the efficiency of the agricultural sector [4]. Forty percent of the total food production is made on irrigated farms [5]. With a constant increase in the population and income levels, it is projected that food demand will go up around 85% by the year 2050. It is often questioned whether there are adequate water resources to supply the immensely increasing food demand [6]. The vast majority of recent studies indicate water scarcity on a global level. Many parts of the world are facing difficulties in supplying the water required by different sectors [7, 8]. The water crisis is expected to expand as a result of climate change which leads to more severe weather conditions such as frequent floods and droughts and alterations in precipitation patterns [9]. Approximately 70% of the world's total freshwater is being consumed by the agricultural sector [5]. A large number of regions have already reached their natural resources limitations, especially for water resources, and thus in order to be able to produce the public dietary demand, some mitigation strategies are required [4].

Currently, the Middle East is considered one of the most vulnerable regions when it comes to the water crisis. The Consequences of the water shortage vary from economic issues to political tensions over the possession of groundwater resources [10-12]. Iran, as the second-largest nation in size and third largest in population in the Middle East, is dealing with serious water scarcity, which has caused water pollution, shrinkage or total dry up of water bodies, decrease in quality and quantity of crops, drinking water shortage, interruptions in the wildlife and ecosystems, and changes in migration patterns which often is considered the only option for the people living in the most water-stressed area. The mean annual precipitation in Iran is in the vicinity of 250 mm, which is considerably lower than the global rainfall average (almost 67% lower) and with a total internal renewable water resource (IRWR) of 128 billion cubic meters (BCM), which forms only less than 0.50% of the total global water resources [5]. The current drought trends in Iran decreased the precipitation when compared to the mean precipitation of the past four decades. Due to the climate of the country, the evaporation and transpiration rates are noticeably high; thus, only about one-quarter of the total precipitation finds its way to surface water resources [13], and because of that not many perennial streams with a steady flow throughout the year can be found in Iran. Moreover, the unbalanced timing and location of the precipitation can be considered another noteworthy factor. The North of Iran (provinces located near the Caspian Sea) enjoy more than three-fourths of the total precipitation, while these provinces include only a tiny part of the country, and to exacerbate the situation, only one-fourth of the precipitation happens in the crop-growing season [13]. This means that the majority of Iranians reside in regions in which their lives, from crop yields to potable water, highly depend on groundwater resources. The rapid growth of the population and its uneven distribution add more stress to the densely populated areas. Some water infrastructures in Iran date back to thousand years ago, and the country has a prominent history in this regard as a result of this fact, the access to the available groundwater is fairly easy, and it has already been consumed more than what it should have been [14, 15]. In fact, Iran can be mentioned as one of the leading groundwater consumers in the world [16].

By well over 60% of the total water supply, groundwater is the prominent supplier of freshwater in the nation. The largest share of this amount is used for agricultural purposes [17]. In the past two decades alone, more than 50% of the nation's reservoir capacity was extracted and consumed in the agricultural sector. Without changing the current consumption patterns for groundwater resources, in the near future, Iran will face a number of serious issues such as food deficit, social inequality, and internal and external conflicts over water resources [18]. On the other hand, the lack of proper water resources management is rising concern. Many old and new aquatic infrastructures are established without the adequate consideration, and there are more private and public organizations involved in decision making regarding the water resources than it should be, and it led to a very poor relationship between development and sustainability and often, the economic spectrum outweighs the resource preservation when it comes to water resources management [19]. A large number of studies emphasize the fact that the leading factor behind the current dry ups or shrinkage of some vital waterbodies in Iran is the lack of suitable freshwater management. The considerable shrinkage of Lake Urmia, which is located in the north west of the country and is regarded as the largest lake in the region, is a good example of poor management consequences in Iran [20, 21]. The issues that worsen the water crisis in the agricultural sector including, but are not limited to, more attention towards irrigated farming and less on rainfed crops, low levels of education among farmers, which leads to not adopting more advanced agricultural technologies, very low and affordable water price as well as energy price compared to other countries, heavy international sanctions which trigger the policymakers to choose food self-sufficiency over food import. From 1980 to 2010, food production increased by almost 170% to meet the needs of the ever-increasing population in the country. To make this decision into practice, providing the necessary water resources for the agricultural sector has been more focused on while the water consumption patterns and trends have mostly been neglected [22]. In this article, we evaluate the water footprint (WF) of the most produced items, both plant-based and animal-based groups, to detect the largest water consumers in the food industry during the last decade (2010-2019). The items are categorized in 11 main categories based on the frequency of consumption and the national production rates.

2. Literature Review

To date, most studies focused on a single crop when it comes to WF assessment, and there are few articles that evaluated the water footprint of the food production sector in Iran as a whole. Therefore, in this section of the paper, both studies were reviewed to provide a broad vision of what has been done so far. In a recent study in 2021 by Soltani et al., which is one of the largest studies on its kind in Iran, it was concluded that growing wheat has the highest WF among the crops and meat production has the highest WF among the entire food production items [23]. Another study used the WF data for 26 crops in 30 provinces from 1980 to 2010. The results of the study revealed a more than 120% jump in water consumption in the agricultural sector and a more than 170% increase in food production in those period and suggested special attention to the location and time of plantation could decrease the total WF of crops in Iran [22]. Another research paper done by Qasemipour et al., for South Khorasan as the case study indicated that food production (crops and livestock production) activities are the number one water consumer in this rigid area. More than 95% of the total WF goes to these two groups. The persistence of such activities has led to 200% water scarcity which is drastically higher than the global sustainability standards [24]. Movahednejad et al., which analyzed the water footprint of the poultry industry in Iran, believe the reason that the virtual water footprint of poultry production is far beyond the global mean is not in the white meat production systems and technologies but it is more related to the WF of the crops that are fed to domesticated birds and as a solution, importing poultry feed is suggested which provides more variety in choices and less stress on water resources [25]. D. Vanham analyzed the water footprint for Austrian dietary patterns. In this study, four different diet categories (the current diet, the healthy diet, the vegetarian diet, and the combined diet – which is a combination of healthy and vegetarian diets) were studied. The results revealed that all these dietary patterns when compared to the current diet, could decrease the water consumption for agricultural products significantly. Among all the analyzed diets, the vegetarian diet showed the least water consumption rate [26]. In the same year, in another study, Vanham et al. [27] analyzed the European Union diets in the same four categories and concluded that animal products require the highest amount of water for production, and the EU can shift from a net viral water importer with the current and the healthy diets to net viral water exporter with vegetarian and combination diets . In another study in India, five dietary patterns were analyzed: 1) rice and lower diversity, 2) rice and fruit, 3) wheat and pulses, 4) wheat, rice and oils 5) rice and meat. The results indicated that rice-oriented diets consume a higher amount of green water while wheat-oriented diets consume more blue water. Moreover, the rice and meat diet showed the highest blue and green water footprint [28]. A recent study done in Mexico demonstrated the relationship between different diets and water consumption. The study revealed a strong relationship between diets high in calories and high WF and also showed that Mexican diets are 55% higher in water footprint in comparison with the world's healthy diet [29]. Kassem et al. focused on Danish diets and revealed that animal-based consumption in Denmark is considerably higher than and fruit and vegetable consumption is lower than in the rest of the EU. The study suggested shifting from red meat to insects as a source of protein has a noticeable positive impact on the water footprint for agricultural products in Denmark [30]. Tom et al. [31] in their research indicated that reducing caloric intake from the current US diet to gain normal weight declines the blue WF by nine percent while shifting the current food mix to the USDA recommended dietary patterns increases the blue WF by 16% and the third scenario which is reducing caloric intake and shifting to USDA recommended food mix increases the blue WF by 10%. The reason behind this reverse increase is that USDA recommendations contain a higher amount of fruit, vegetables, and dairy products consumption [31]. The findings of research which was conducted to compare the WF of American and Mediterranean diets in the US and Spain demonstrated that regardless of the production's location, Mediterranean diet save water resources up to 29% in comparison with the American diet. Moreover, the study concluded that diets containing a higher amount of fruits, vegetables, and seafood could save more water resources [32].

3. Methodology

The dietary data used in this paper are collected from the Food and Agriculture Organization of the United Nations (FAOSTAT)'s Food Balance Sheets (FBS) [33] for the period 2010-2019. The total water footprint of 11 main food categories that have the highest impact on water consumption in the country was included in this study. Given the fact that it is not possible to have a precious estimation of water footprint related to fish and other seafood, all the seafood consumption was converted to poultry which is the closest to seafood regarding the nutrients value and affordability. In order to calculate the water footprint for a certain crop, the sum of blue water footprint, green water footprint, and grey water footprint must be calculated. In most similar recent studies, only blue and green water are summed as the total water footprint of a crop. The reason is, technically, nowadays, in many parts of the world, especially the water-stressed regions, grey water is being restored and used for other purposes [34]. However, since in Iran, still a considerable amount of grey water is not being restored for reuse purposes, grey water is also included in evaluating the total WF of products. The data used in water footprint calculation were taken from Water Footprint Assessment Manual [35].

$$Water_{proc} = Water_{proc\ green} + Water_{proc\ blue} \quad (1)$$

$$WF_{blue} = \frac{CWU_{blue}}{Y} \quad (2)$$

$$WF_{green} = \frac{CWU_{green}}{Y} \quad (3)$$

CWU_{green} is the green component in water use (m^3)

CWU_{blue} is the blue component in water use (m^3)

Y is the crop yield

4. Results and Discussion

What is critical in analyzing the trends of the water footprint of products in a country is to consider the population changes throughout the studied period. As Figure 1 indicates, Iran faced an upward trend each year from 2010 to 2019 period. In 2010 the population was estimated at 73 million, while at the end of the decade, the nation's population became more than 82 million. This is clear that population growth has a direct relationship with food demand.

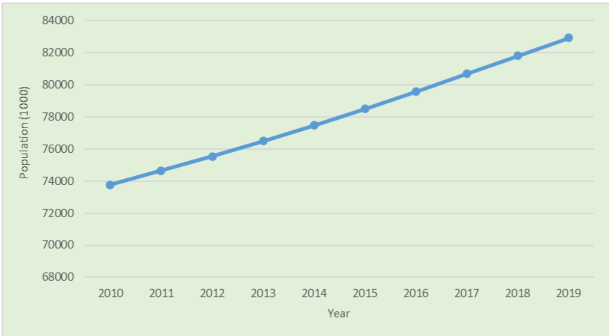

Figure 1. Population trend in Iran (1000) 2010-2019

In this study, 11 main categories were used for water footprint calculation. The division was based on the most consumed products and dietary habit of Iranians and some groups include other sub items in which the calculation was based on the dominant ingredient of that product. For instance, normally, in many countries pork production leaves the highest amount of WF impact or grapes for wine production is included because of the high amount of wine consumption in those countries. Since, Iranian dietary habits are heavily influenced by Islamic beliefs and the consumption of pork and wine are banned by the government, they are excluded from the final evaluation. Moreover, the sea food products were replaced by poultry products because of their similar nutrient values and affordability.

Figure 2 demonstrates the total WF, Blue WF, Green WF, and Grey WF of each studied group. A glance at the figure reveals that green water is considerably higher in each group compared with blue or grey water footprint. Furthermore, it makes it clear that animal-based products require a drastically higher amount of water than plant-based products. Bovine meat, followed by mutton and goat, and poultry products are the top three water-intensive products of the country.

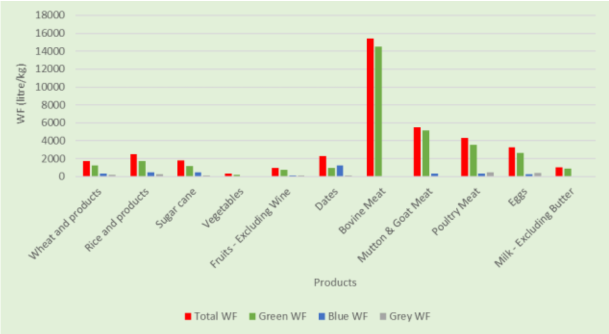

Figure 2. The water footprint of different products (liter/kilogram)

Table 1 (appendix) indicates the consumption rate of products per capita during the entire decade. As can be seen, consumption of vegetables decreased throughout the decade while bovine meat and wheat remained almost stable. Among grains, wheat and its products were consumed in higher quantities than rice which also requires less water for production. In other groups, no significant change in trends was observed. Moreover, among all, dates require the largest amount of blue water, followed by rice and products, sugarcane, and wheat and products. For green water footprint, the animal sources are significantly larger in water shares than field crops. To produce one kilogram of bovine meat, 14490.1 liters of green water is consumed, while the blue water footprint of this product is only 3.76 liter per kilogram.

Table 2 (Appendix) shows the total amount of production in each group broken down into years and the total water consumption in each year and each group separately. For each year, the population changes were considered. During the decade, vegetables with 143.3603871 million liters was the most water-intensive product, followed by wheat and fruits production, 118.755447 million liters and 115.5299726 million liters, respectively. Mutton and goat meat, bovine meat, and eggs left the least water footprint impact on the national water resources. As regards the water consumption trends in the decade, no relation was found. The total average food production WF fluctuated during this period, with 2014 being the most water-intensive year (49.5015487 million liters) for the agricultural sector during this period.

5. Conclusion

From the findings of this research, it can be concluded that food production is a heavy burden on the water resources in Iran. The green water footprint for animal-based products in most categories is higher than plant-based crops, while the blue water footprint for field crops is larger in portion in comparison with animal protein production. Despite the fact that animal-based sources have a higher overall water footprint compared with plant-based sources, the total water consumption in vegetables, fruits, and grains is considerably higher in Iran. The reason is the lack of affordability of such products by individuals with below the average incomes and also Iranian dietary patterns being rich in fibers and vegetables. One solution to minimize the water footprint in food production is to import these high demand products from less-stressed regions and to control the population growth as an overall strategy to decrease the environmental impacts of food production in the country.

Ethical issue

Authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. Authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

Authors' contribution

All authors of this study have a complete contribution to manuscript writing.

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Appendix

Table 1. Annual product consumption per capita (kilogram), water footprint (cubic meter), population (1000)

Population	**Products**	Wheat and products	Rice and products	Sugar cane	Vegetables	Fruits - Excluding Wine	Dates	Bovine Meat	Mutton & Goat Meat	Poultry Meat	Eggs	Milk - Excluding Butter
	Total WF	1727	2497	1782	322	967	2277	15415	5521	4330	3300	1020
	Green WF	1277	1698	1176	194	727	934	14490	5185	3551	2607	867
	Blue WF	342	499	481	43	147	1252	3.76	330	303	231	82
	Grey WF	207	275	107	85	93	91	0.12	6	476	429	71
73763	2010	150.63	43.14	10.54	215.26	151.53	10.7	7.46	5.35	22.81	9.39	23.66
74635	2011	139.5	38.29	10.86	217.73	162.7	10.8	6.88	5.34	24.56	9.05	22.75
75540	2012	145.93	39.28	9.86	210.47	165.68	11.6	5.85	5.04	24.99	11.2	22.91
76482	2013	142.23	45.25	17.26	228.17	168.72	10.6	6	4.92	25.7	10.9	25
77466	2014	155.66	41.25	10.09	207.79	143.93	9.7	5.78	5.18	26.98	9.63	23.02
78492	2015	158.48	40.95	3.06	198.76	149.3	9.86	6.36	4.44	26.54	9.01	17.63
79564	2016	158.42	42.25	4.59	183.83	129.23	10.6	6.96	4.79	28.27	9.27	18.04
80674	2017	156.62	42.55	13.56	127.39	128.11	10.1	7.47	4.83	27.14	7.6	20.47
81800	2018	154.81	42.38	9.69	119.53	138.74	12.3	6.61	4.24	26.82	8.29	19.78
82914	2019	155.95	40.29	11.13	138.74	144.19	12.1	6.75	3.42	27.04	8.33	23.24

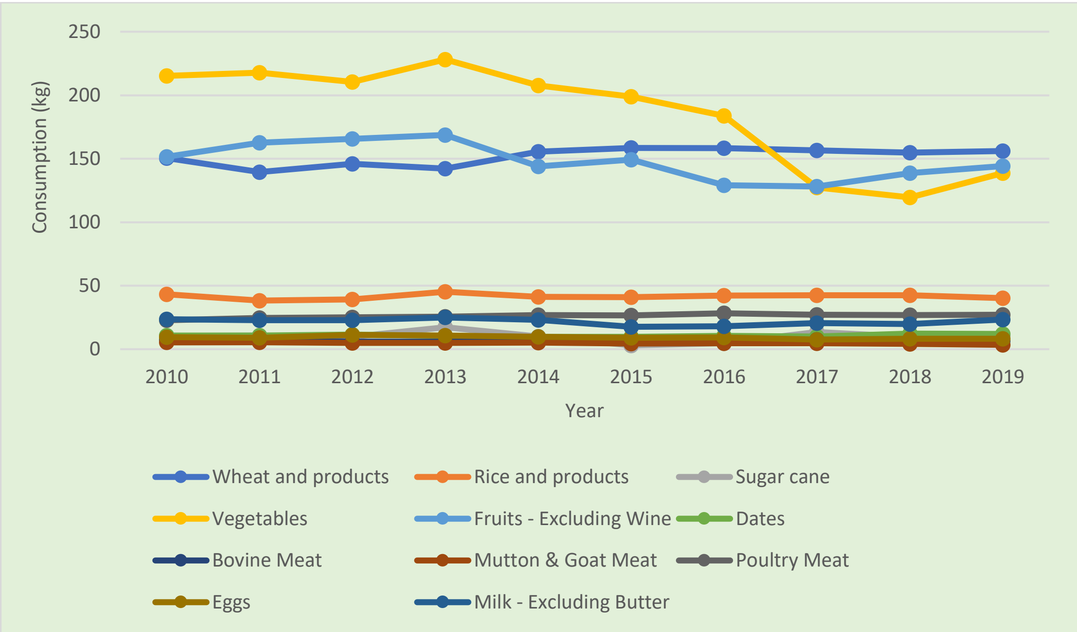

Table 2. Total water consumption of products (million liters)

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	**Product Mean**
Wheat and products	11.11	10.41	11.02	10.88	12.06	12.44	12.60	12.64	12.66	12.93	118.76
Rice and products	3.18	2.86	2.97	3.46	3.20	3.21	3.36	3.43	3.47	3.34	32.48
Sugar cane	0.78	0.81	0.74	1.32	0.78	0.24	0.37	1.09	0.79	0.92	7.85
Vegetables	15.88	16.25	15.90	17.45	16.10	15.60	14.63	10.28	9.78	11.50	143.36
Fruits - Excluding Wine	11.18	12.14	12.52	12.90	11.15	11.72	10.28	10.34	11.35	11.96	115.53
Dates	0.79	0.80	0.87	0.81	0.75	0.77	0.84	0.82	1.01	1.00	8.47
Bovine Meat	0.55	0.51	0.44	0.46	0.45	0.50	0.55	0.60	0.54	0.56	5.17
Mutton & Goat Meat	0.39	0.40	0.38	0.38	0.40	0.35	0.38	0.39	0.35	0.28	3.70
Poultry Meat	1.68	1.83	1.89	1.97	2.09	2.08	2.25	2.19	2.19	2.24	20.42
Eggs	0.69	0.68	0.85	0.83	0.75	0.71	0.74	0.61	0.68	0.69	7.22
Milk - Excluding Butter	1.75	1.70	1.73	1.91	1.78	1.38	1.44	1.65	1.62	1.93	16.88
Water Consumption	47.98	48.40	49.31	52.37	49.50	49.01	47.44	44.04	44.43	47.36