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Research Article

Evaluation of Tehran Province Livestock Production from Water Footprint Prospective

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Abstract
In Tehran, Iran's most populous province, there has been a notable surge in livestock production in recent years, prompting a critical examination of water resource allocation through the water footprint indicator. This study uniquely concentrates on livestock productions at a provincial level, specifically within four key counties boasting the highest production rates in Tehran province. Employing the methodology introduced by Mekonnen and Hoekstra (2012), a comprehensive analysis of the water footprints (WFs) associated with various livestock productions is conducted. The results underscore that milk production holds the highest average water footprint at 13,007 cubic meters per ton, significantly surpassing other products. Conversely, lamb exhibits the lowest water footprint at 2,266.7 cubic meters per ton among livestock productions. Evaluation of fresh water sources in relation to animal water footprints highlights unsustainable conditions in southern counties, particularly Islamshahr, due to a pronounced disparity between their product water footprint and available water resources. In contrast, northern counties demonstrate lower water footprints, aligning with their abundant water resources. A scrutiny of water resources reveals vulnerability in Tehran's dams, approaching long-term minimum water volume despite the escalating levels of livestock production. While Varamin features a wastewater treatment unit contributing substantial volume (160 million cubic meters) and recycled water to the system, wells and Qanats play a role in water provision but prove inadequate. Given the substantial productions and water resource scarcity, a recommendation is made to discontinue all livestock production; however, if production persists, focusing solely on sheep meat (lamb) in northern counties is deemed a feasible strategy.
Keywords: Livestock Water Footprints, Water Scarcity, Water Resources, Sustainability, Resource Allocation

Introduction

Sustainable production of animal products in international assemblies has been widely considered for two main reasons, 1) Demand increasing for animal products due to the population growth and urbanization (Raney et al., 2009; Steinfeld et al., 2013; Wirsenius et al., 2010); and 2) Nations try to find more efficient ways to produce products (Aiking, 2014; Johnston et al., 2014). One relation that has a main influence on livestock production is water

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availability. Therefore, understanding some issues such as water resources distribution and water consumption of production chain is very important.

In fact, water has a critical role in food production (Ridoutt et al., 2009) so many methods developed to identify foods water portions. One of these facilities is water footprint concept. The purpose of water footprint is quantified and qualify water consumption (Lu et al., 2016a). Water footprint concept defined by Hoekstra (2003). Water footprint stands on carbon footprint and ecological footprint basis (Galli et al., 2012). It consists of three parts that the mixture of them shape water footprint of goods. These parts are green water (soil moisture and precipitation which used in crops evapotranspiration), blue water (surface and underground water resources that used in irrigation) and gray water (volume of water that is polluted in production processes (Hoekstra et al., 2011).

These terms contain a specific time scale and location. Blue water footprint (WF_{blue}) and green water footprint (WF_{green}) are volumetric value which shows how much water used for produce a specific good while gray water footprint (WG_{gray}) point to volume of water that cause environmental pollution or water needed to dilute pollutants (Jeswani & Azapagic, 2011). Because of this complexity, WF shows possible strikes of various different water consumption on environment (Hoekstra, 2003). This concept considers direct water usage in production chain and water use influence on environment together. Limitation in access to freshwater resources is main factor to prevent the boom of agricultural and livestock production. Calculation and determination the water footprint (WF) of agricultural products and water consumption in product supply chain, hence, is initial ploy to diminish the pressure on available water resources, while the end user's information recognized simultaneously. Livestock production is one of the most important sectors in water consumption (Murphy et al., 2017). Therefore, WF of their product should be considerable.

Several studies have been done about livestock production. Mekonnen & Hoekstra (2012), analyzed water footprint of farm animal products in global scale. In this regard, eight farm animals categorize were chosen and then water footprint content in three main parts of WF were calculated. Result showed animal products in industrial system, impose more pollutants to environment by decrease the ground and surface water quality in compare to other systems. Their study also revealed that cattle and ships have significant water footprint among other animals.

Harding et al. (2017), studied the impact of Africa location on blue water footprint of commercial beef. They utilized top-down approach in their study. For this target, feed cultivation, primary production, feedlots and abattoirs were considered and after water footprint calculation, the WF sensitivity analyzed in several scenarios to find the best-feasible scenario to pursue in order to reduce the WF of commercial beef. According to results, the base case water footprint of commercial beef in South Africa was 437 L/kg. The sensitivity analysis showed that in the best case the equivalent WF for commercial beef in South Africa could be as low as 105 Leq/kgCW. In another study by Pahlow et al. (2015), blue and green water footprint of livestock production considered, it was found that meat has a large share in water consumption (about 12000 m^3) that green water footprint has main role in this value. The study conducted by Murphy et al. (2018) focused on the water footprints of pasture-based beef and sheep farms in Ireland during 2014 and 2015. Their findings revealed that green water, primarily sourced from pasture production, played a pivotal role in water consumption for both beef (88%) and sheep (87%). Notably, the impact of beef production on global water stress was measured at 91 liters per kilogram, while for sheep, this impact was significantly lower at 2 liters per kilogram. The results indicated that increases in productivity in Ireland were correlated with higher green water use and improved grass yields per hectare on these farms. In another study by Ibidhi & Ben Salem (2018) assessed water footprint and economic water productivity (EWP) of sheep meat in humid and semi-arid regions of Tunisia. Semi-arid farms had a higher

WF (9.07 m^3/kg sheep body weight (BW)) with most water used for feed production, while humid region farms had a lower WF (6.98 m^3/kg BW)) with 17.3% of WF from off-farm feed. Humid region showed 20% better water efficiency and 60% higher gross margin return per m^3 of water, making it more suitable for sheep rearing, especially in the context of climate change and rangeland degradation in the semi-arid region.

In the study by Sawalhah et al. (2021), the water footprints of the New Mexico beef cattle industry, considering blue (surface and ground) and green (precipitation) water, were calculated. The weighted average WF was found to be 28,203 L/kg_{meat}, with 82% (23,063 L/kg_{meat}) attributed to green water, mainly used by rangeland forages. Blue water accounted for 18% (5140 L/kg_{meat}) of the total beef WF, varying significantly across different production phases, where cow-calf operations heavily relied on green water (99.5%), while backgrounding and feedlot stages were predominantly associated with blue water (100%). Palhares et al. (2021) assessed the water footprint of a tropical cattle production system, emphasizing individual-animal performance and diet types. The study, involving 52 Nelore bulls, revealed individual-animal WF ranging from 29,923 to 32,569 L/kg carcass weight (CW) and 16,803 to 18,279 L/kg live weight (LW), with diet type significantly influencing green and total water footprints ($p < 0.05$). In Van province, Turkey, a study by Yerli & Sahin (2022) from 2004 to 2019 calculated water footprints. The province exhibited an average WF of 8.73 billion m^3/year, with 62.5% attributed to WF_{blue} and 7.5% to WF_{green}. Livestock ($WF_{livestock}$) accounted for 4.9% of the total. The per capita water footprint was 889.9 m^3/year, categorizing Van province as experiencing severe water scarcity (257%). The study emphasizes the need to address the high WF_{blue} by adjusting agricultural practices for sustainable water resource management. Velarde-Guillén et al. (2023) investigated the water footprint of dairy production in Peru's arid central coast. Globally, dairy consumes 19% of livestock sector water, but specific data for Latin America, especially arid zones, is lacking. The study found that 99% of the WF came from feed production, urging a need to prioritize and optimize local resources with lower water requirements. The overall WF for these systems was 0.66 m^3/kg fat and protein corrected milk (FPCM), production. Grobler et al. (2023) study underscores the critical role of water in beef cattle production. It concludes that accurate assessment of the blue water footprint requires considering total production cycle measurements, revealing significant water consumption variations and culminating in a calculated footprint of 27,147 liters. emphasizing the potential for reducing water usage in dairy farming by focusing on feed

According to the study background and prior research, comprehending water usage in the agricultural sector and its intricate relationship with water resources is a crucial imperative for effective supply and demand management. Meat and milk constitute indispensable components of the Iranian diet, underlining the significance of understanding the water footprint associated with cattle, cow, and sheep productions. In light of this, the primary objective of our study is to meticulously determine the water footprint of these livestock productions. The aim of this study is to unravel the dynamic interplay between water resources—specifically, the contributions from Dams, Wells, and Qanats—and the requisite water supply for sustaining cattle, cow, and sheep productions in Tehran province. This investigation seeks to provide nuanced insights into the water footprint dynamics of these essential food sources, thereby informing sustainable water resource management practices in the context of Tehran's agricultural landscape.

Material and Methods

System boundaries

Due to the Iran's climatic condition, livestock production systems suffer water deficiency and drought. Tehran also located in semi-arid region. In one hand Tehran province with Tehran

County centrality and in the other hand with developed animal husbandry has especial problem in water supply. No previous studies have been conducted on livestock production water footprint in Iran. Important criteria for the study were availability of flock and production data for 2017. The system boundary was livestock nutrition to their production. Freshwater that included in this kind of studies (livestock production) has various components in compare to WF of agricultural productions. Energy consumption and production in issues that are related to farmland is remarkable but here according to the study purpose, an energy subject was neglected.

Data Collection

This study was carried out on Tehran province which is located in the northern part of the Iran (1190 m above sea level, 34°-36° 50′ N, 50° - 53° E) (Figure 1). Average of annual precipitation in this area is 237 mm. Southern regions such as Varamin and Eslamshahr county have more appropriate condition for holding the cattle according to smoothed ground and higher temperature while northern counties are cooler than south and topographic property makes this area feasible for holding the sheep. The data set used in this study for agricultural and livestock production were obtained from the Ministry of Agriculture (IMAJ, 2015) and information for water resources obtained from (IWRM, 2014). Information in agricultural section has close connection to livestock diet. So first of all, based on the type of livestock, their diet recognized and then main data such as crop yield in agricultural part survived.

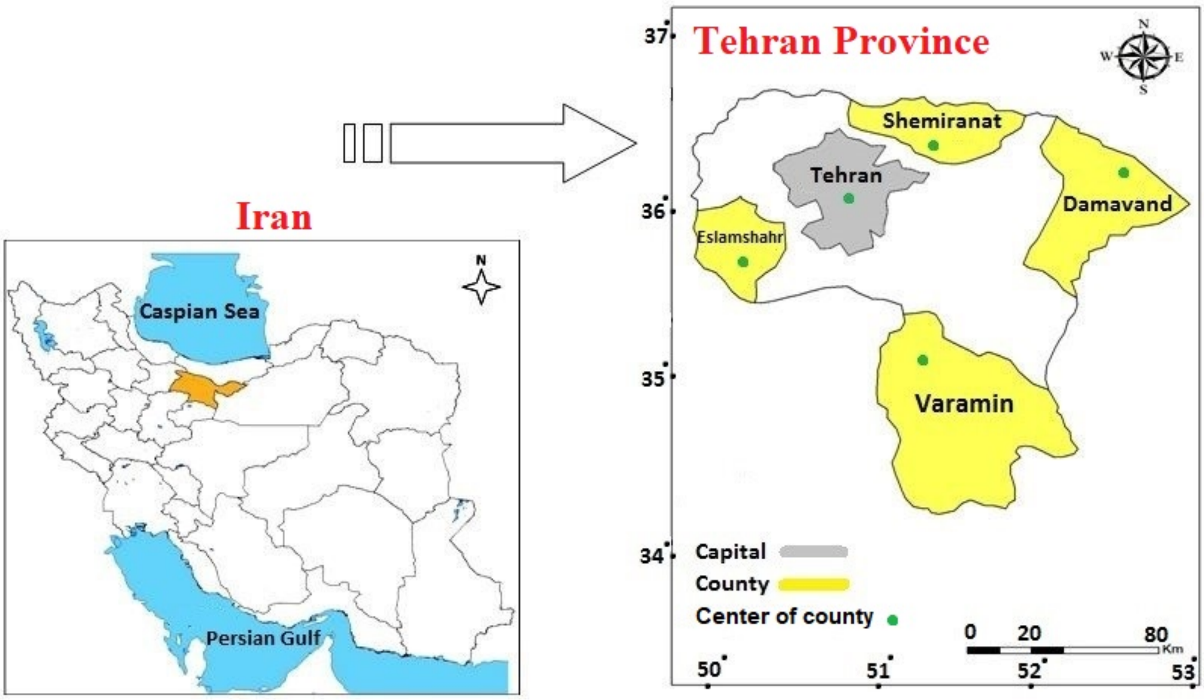

Figure 1. Spatial location of studied area

Animal Water Footprint

Livestock production include three components (Figure 2) which defined as a water footprint of crops that is in animal nutrition diet (WF_{feed}), volume of water that used by animal as a drinking water (WF_{drink}) and volume of water which is used for animal services (WF_{serv}). Related equation represented by (Mekonnen & Hoekstra, 2012) as equation 1.

$$WF_{animal} = WF_{feed} + WF_{drink} + WF_{serv} \tag{1}$$

WF_{feed} is indirect water consumption but both WF_{drink} and WF_{serv} are direct water consumption. The order of WF_{serv} is a volume of water that is needed for washing the animal or other ordinary tasks that are necessary to maintain the animal environment quality. Animal water footprint expressed in m^3/y/animal.

Animals same as other alive creatures, need water for drinking that is different for each type of animals. These two components of equation 1, is given in Table 1.

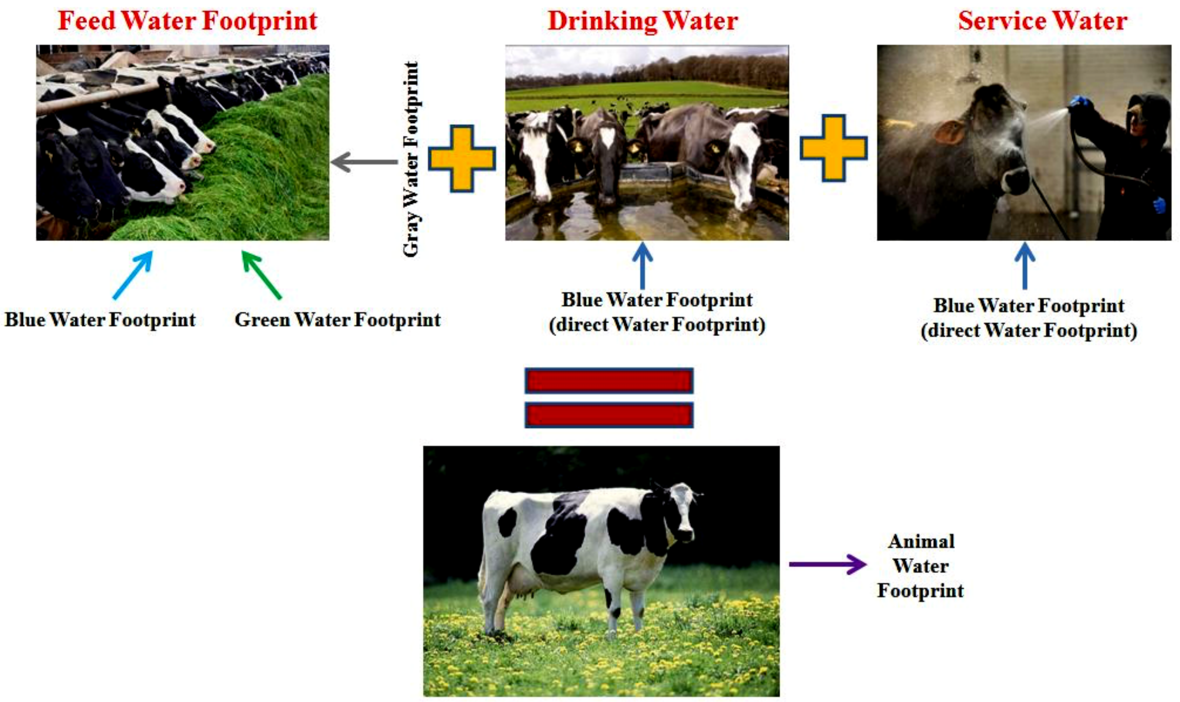

Figure 2. Schematic animal water footprint components

Table 1. Drinking and service water footprint per animal (Mekonnen & Hoekstra, 2010)

Livestock type	Drinking water (L/day)	Servicing water (L/day)
Cattle	27	7.1
Cow	52	12
Sheep	6.1	1.8

The water footprint content in the animal feed at the end of their growth period consists of two main parts, the actual water that used for livestock feed combination and second is crops water footprint. So, WF_{feed} calculates as equation 2 (Mekonnen & Hoekstra, 2012):

$$WF_{prod} = \frac{\sum_{p=1}^{n}\left(Feed_a \times WF_{crop}\right) + WF_{mixing}}{Pop_a} \qquad (2)$$

Where $Feed_a$ is amount of feed which is consumed by animal during a year (ton/y), WF_{crop} is water footprint of consumed crops (m^3/ton), WF_{mixing} is volume of water that used for combining animal feed (m^3/y) and Pop_a is number of slaughtered animals for cattle or number of cows in a year.

In the context of the amount of food consumed by livestock, a factor is called the feed conversion factor proposed as follow (Mekonnen & Hoekstra, 2012):

$$Feed_a = FCE \times P \qquad (3)$$

Where FCE is food conversion (kg dry mass/kg product) (Table 2) and P is the total amount of animal product (ton/y).

As mentioned in equation 2, the water footprint of consumed crops by livestock should be known, therefore in next step crops water footprint will be expressed.

Table 2. Global average feed conversion efficiency per animal category and production system (Mekonnen & Hoekstra, 2010)

Livestock type	FCE (kg dry mass /kg product)
Cattle	46.9
Cow	1.9
Sheep	30.2

Crops Water Footprint

Blue, green and gray water footprint of crops calculated using the framework which provided by (Hoekstra & Chapagain, 2008)) and (Hoekstra et al., 2009). In this context, water footprint is considered as an indicator in which water allocation for human consumption is considered and ecosystem costs are not being considered (Hoekstra et al., 2011). Effective precipitation (P_{eff}) and water requirement calculated using Netwat software. This model is native version of CropWat software that in this model, evapotranspiration is calculated by the Penman–Monteith equation, and P_{eff} is adapted from the USDA-SCS model. Total water footprint in crops consist of three components in equation 4 (Lu et al., 2016b):

$$WF_t = WF_{green} + WF_{blue} + WF_{gray} \tag{4}$$

Green water footprint

Water consumption in this stage is considered by calculating the evapotranspiration of the plant during the growth period, which is ultimately expressed in per cubic meter in per kilogram. The green water footprint of the product is calculated by the relationship 5 (Hoekstra et al., 2011):

$$WF_{green} = \frac{CWU_{green}}{Y} \tag{5}$$

Where CWU_{green} is crop water usage (m^3/ha), Y is crop yield (kg/ha). Crop water usage calculates as follow (Lu et al., 2016b):

$$CWU_{green} = 10 \times \sum_{d=1}^{T} ET_{green} \tag{6}$$

That 10 coefficient converts evapotranspiration from millimeter to volume of water (m^3/kg). In this equation T is plant's growth duration (day) and ET_{green} is green water evapotranspiration that determine as following equation (Lu et al., 2016b):

$$ET_{green} = min(ET_c.P_{eff}) \tag{7}$$

Where Et_c is amount of evapotranspiration (mm) and P_{eff} is amount of effective precipitation (mm) that affects from several factors such as rainfall, temperature, wind speed, type of plant, soil condition and planting time (Wei et al., 2016).

Blue water footprint

Blue water evaluation (Equations 8 and 9) is quite same as green water footprint whereas blue water evapotranspiration calculates as equation 10:

$$WF_{blue} = \frac{CWU_{blue}}{Y} \tag{8}$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{T} ET_{blue} \tag{9}$$

$$ET_{blue} = max\ (0. ET_c - P_{eff}) \tag{10}$$

Gray water footprint

In this study, nitrogen manure considered as a source of releasing the pollution in environment. Information about average of nitrogen fertilizer usage (NAR kg/ha) obtained from the Ministry of Agriculture (IMAJ, 2014). Computing method described by Chapagain et al. (2006) and Hoekstra et al. (2011). According to Chapagain et al. (2006), united states environment agency (USEPA) mentioned maximum allowable concentration of nitrogen in water resources is 10 (mg/l). Since no information was available about the natural concentration of nitrogen in water and environment, this value assumed zero in this study.

$$WF_{gray} = \frac{\propto_{Irr} \times NAR_{Irr}}{C_{Max} - C_{Nat}} \times \frac{1}{Yield_{Irr}} \tag{11}$$

Where α were assumed to be equal to the values applied by (Chapagain et al., 2006) and Hoekstra et al., 2011), that is different for each crop. NAR_{Irr} is amount of used fertilizer (kg/ha), C_{Max} is maximum allowable nitrogen (mg/l), C_{Nat} is natural nitrogen concentration (mg/l) and $Yield_{Irr}$ is crop yield in irrigated cultivation (kg/ha).

Results and Discussion

General farm characteristics

In 2017, the average study farm was 44026 ha, produced 958403 ton (Table 3). Tables 4 and 5 indicates the food composition and their water footprint components in cubic meter per ton.

According to Table 3, most production occurs in Varamin county and lowest related to Shemiranat. This condition indicates that southern areas have higher contribution in supplying animal feed.

Table 3. Agricultural properties of studied counties

County	Cultivated area (ha)	Production (ton)
Varamin	27843	531782
Eslamshahr	12888	329708
Damavand	3295	96913
Shemiranat	0	0

Livestock feed water footprint

In Tables 4 and 5, water footprint of animal feeds, calculated according to their diet. In these tables, cow and cattle feed composition relied on maize so its water footprint is higher than others while for sheep this condition occurred for alfalfa. Totally one-unit feed for sheep has higher water footprint in compare to cow and cattle.

Table 4. Feed water footprints in cattle and cow diet

Feed type	Composition (%)	WF_{blue}	WF_{green}	WF_{gray}
Alfalfa	3	18	21.5	26
Fodder corn	6	31	31	13
Maize	75	110	111	34
Wheat	8	51	78.5	19
Soybean	3	2	61	1
Rapeseed	3	7	51	10
Other*	2	-	-	-
Sum	100	219	354	103

Table 5. Feed water footprints in sheep diet

Feed type	Composition (%)	WF_{blue}	WF_{green}	WF_{gray}
Alfalfa	40	240	286	347
Maize	30	44	45	14
Straw	25	7	52	5
Other*	5	-	-	-
Sum	100	291	383	366

Livestock production properties and water footprint

Livestock population in Varamin county is more than others that is shows this area has most demand or water and feed (Table 6). Among counties, in Shemiranat for cow and cattle and in Eslamshahr for sheep have lowest population.

Table 6. Livestock production properties (IMAJ, 2015)

County	Animal type	Total number of animals (head)	Annual meat production (ton)	Annual milk production (ton)
Damavand	Cow and Cattle	5643	127	28000
	Sheep	58128	498	0
Varamin	Cow and Cattle	117442	4097	110000
	Sheep	244872	6412	0
Eslamshahr	Cow and Cattle	31817	873	154374
	Sheep	25556	1402	0
Shemiranat	Cow and Cattle	1323	105	5347
	Sheep	45890	175	0

As it is obvious from table 7, Damavand has the lowest footprint of beef production and the largest water footprint associated with cow's milk. It should be noted that among the components of the water footprint, the green footprint in cow's milk is more than other components, and its meaning is that the role of the green footprint in feeding cows in this area is more than other factors in the production of milk. In Varamin, the lowest water footprint belongs to sheep's meat (lamb) production of 943 cubic meters per ton. This is despite the fact that the water footprint of cow's milk is 3630 cubic meters per ton and there is no priority for milk production in this county. It is noteworthy that, in the case of livestock production in this county, the water footprint of lamb is lower than other products and milk water footprint is higher than the others.

Table 7. Water footprint calculation for livestock productions

County	Animal type	Meat production Water Footprint (m^3/ton)			Sum	Milk production Water Footprint (m^3/ton)			Sum
		Blue	Green	Gray	-	Blue	Green	Gray	-
Damavand	Cow and Cattle	346	559	163	1068	6230	10071	2930	19231
	Sheep	86	113	109	308	-	-	-	-
Varamin	Cow and Cattle	536	866	252	1654	1176	1901	553	3630
	Sheep	264	347	332	943	-	-	-	-
Eslamshahr	Cow and Cattle	421	681	198	1300	6092	9848	2865	18805
	Sheep	535	728	696	1959	-	-	-	-
Shemiranat	Cow and Cattle	1634	2642	769	5045	3357	5425	1580	10362
	Sheep	60	79	76	215	-	-	-	-

Small livestock products produced in the Shemiranat have far less water footprints than large livestock products. Cow's milk production has high gray water footprint, which is why milk cows play an important role in environmental pollution than other products. In Eslamshahr cow milk by allocating 18,805 cubic meters per ton of water footprint, has highest water footprint content among other products. It should mention that in the milk production, the gray water footprint is allocated high proportion to itself, which can be a factor in preventing the production of cow's milk in this area too.

According to precipitation and temperature properties, Tehran province has a descending gradient in recent years. So, at first glance it can be said that this area will suffer from lack of water for its products.

As noted in previous sections, water footprints of an animal consist of animal feed, drinking required water and water for services. First is indirect water consumption and two last being direct water consumption.

As it is clear from Figure 3, in most counties, great livestock have much larger water footprint in compare to small livestock and also great dairy livestock have greater water footprint in all counties (Figure 3). In the case of great dairy livestock, each head of this livestock in Shemiranat, with the allocation of 6.8 million cubic meters of water, has the lowest water footprint and in the Eslamshahr, with the allocation of 198 million cubic meters of water, had the highest water footprint. In the case of great fleshy livestock, Varamin with an allocation of 130 million cubic meters of water and Shemiranat with an allocation of 3.3 million cubic meters of water to these animals, had the highest and lowest water footprint in this group, respectively.

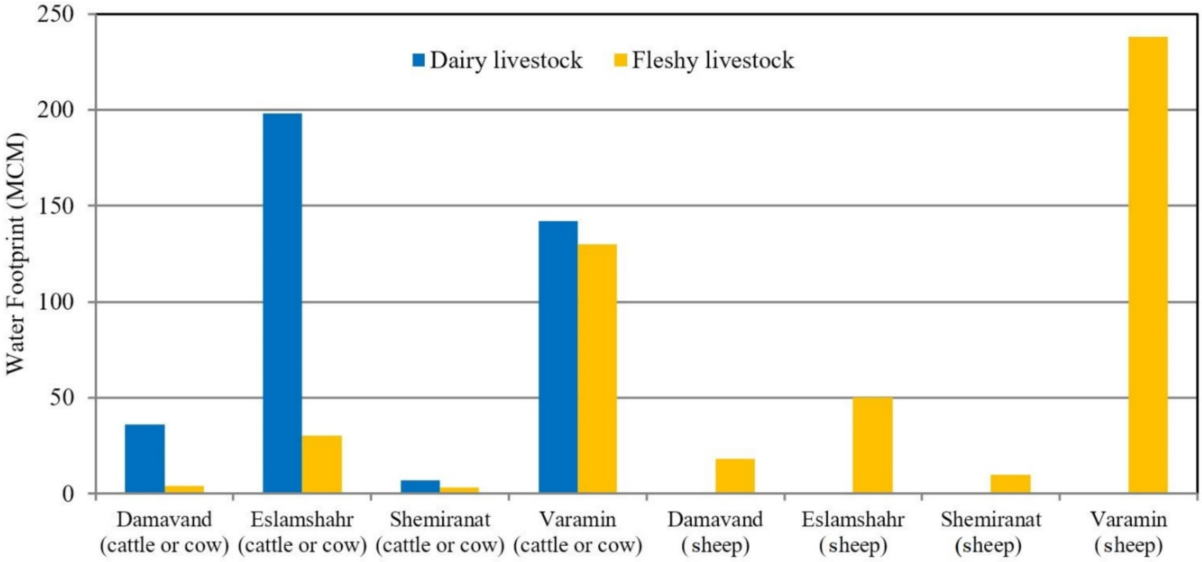

Figure 3. Water footprint of animal productions during a year

In relation to small livestock, each head in Varamin devoted 238 million cubic meters to itself then this type of animal has the most water footprint and each head of livestock in Shemiranat with an allocation of 10 million cubic meters of water footprint had the least water footprint among the others (Figure 3). The difference between these numbers arises from the fact that, for example, in Equation 2, for the calculation of the water footprint, the amount of production (meat / milk) of the livestock and the number of killings varies in each region, therefore, despite the fact that the amount of feeds water footprint of livestock is equal, there can be no expectation of equal livestock water footprint.

Tehran province water resources

Dams

Tehran province has three dams which supplies water for users in all socio-economic sections. In present study drinking and manufacturing usage of Tehran city are not considered. In following diagrams (Figure 4) dams condition from water volume prospective represented. Unfortunately, their average water volume in long term has descending trend. Lar Dam is one of the important dams of the province located in the east of Tehran province. The purpose of this dam was to supply water to the east of the province, especially Damavand county. The dam's reservoir volume significantly decreased in average in compare to long term maximum exactly in summer season (Figure 4). Latian dam located in the north of Tehran which has more desirable climate than other dams. As the Figure 5 shows, the difference between long term minimum and long-term average is lower than other dams. Mamloo dam located in east of Tehran and it is used to supply the water for Varamin and Eslamshahr counties. According to livestock population in these two areas, increasing the pressure on this water source is not unpredictable.

As Figure 4 shows, maximum water supplied by Lar dam for Tehran province but the highest decrease in water volume has been occurred for this dam. Lar and Latian dams as mentioned, provide water for Damavand and Shemiranat and according to table 6, these two areas don't have remarkable livestock in compare to others, so most pressure is on Eslamshahr and Varamin livestock production if their water just supplies from Mamloo dam. Volume of water supplied by mentioned dams noted in Table 8.

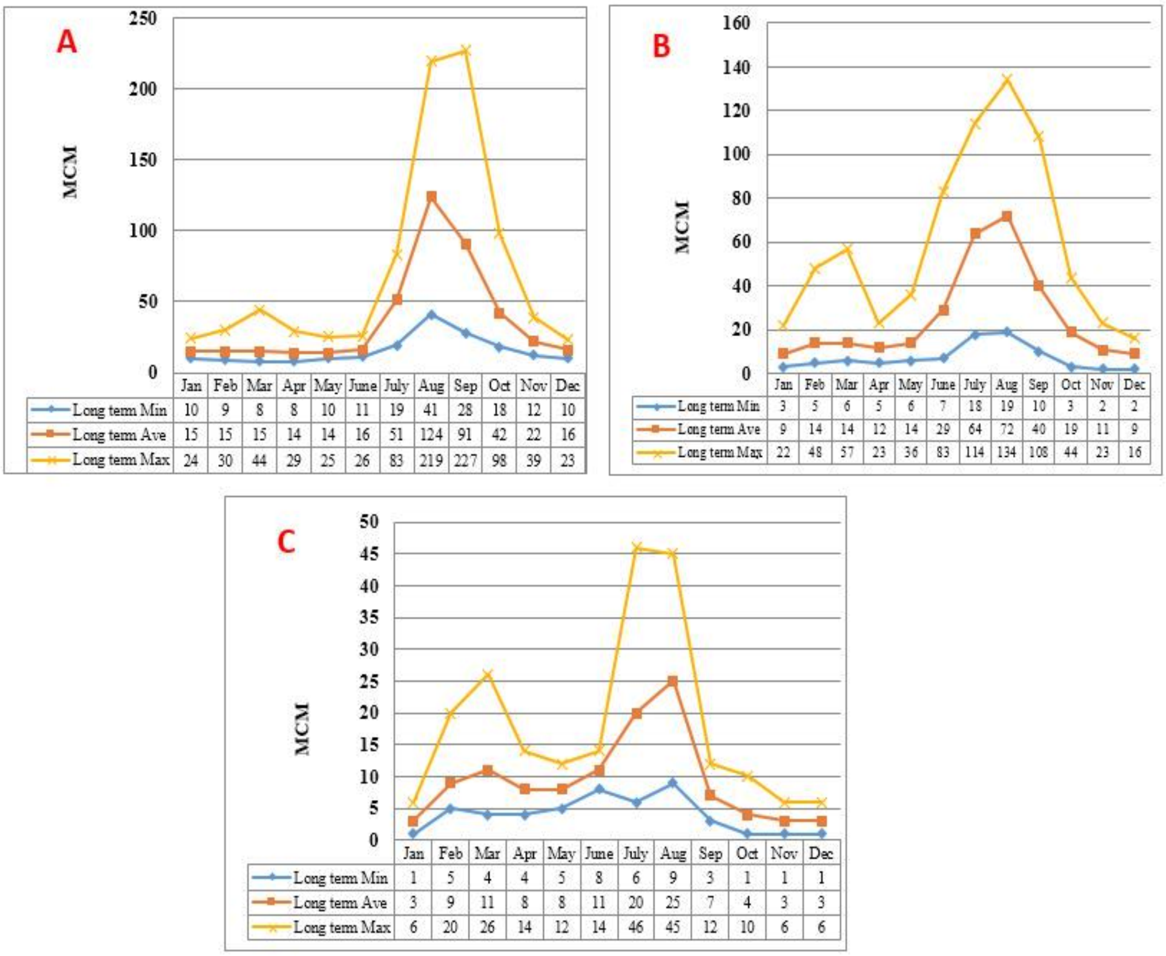

Figure 4. Fluctuations of the dams water volume (A) Lar; (B) Latian; (C) Mamloo

Table 8. Water Supply Volume from Designated Dams

Dam	Volume of water (MCM)	Covered County
Lar	435	Damavand – Shemiranat
Latian	307	Varamin – Shemiranat – Eslamshahr – Damavand
Mamloo	112	Varamin

Wells, Qanat and Waste Water Treatment Plants

In studied counties, 111 wells and Qanat exist that have vital function to provide water for agriculture and domestic consumption (Table 9). So, it is necessary to survey them as sources for providing water. Only in Varamin one waste water treatment unit exists that singly provides 160 MCM treated water for agricultural usage which mainly used for Varamin's cultivated areas. In compare to wells and Qanat output this volume is remarkable and this value shows the importance of developing these sectors.

In order to have a comprehensive assessment about available water resources and livestock water footprint, Figure 5 displayed.

The sum of water consumption in the Damavand is 71.2 million cubic meters, which is 677.8 million cubic meters less than the mentioned water resources, which indicates the proper conditions of water consumption in this county. Required water provides by two dams and several wells and Qanat and according to the animal's water footprints, there is no limitation on this level of production. It is necessary to mention that both dams that this county is using, shared between other counties so it is need to evaluate other counties situation.

Table 9. Wells, Qanat, and Waste Water Treatment Units in Studied Counties

County	Wells and Qanat		Waste water treatment (MCM)
	Quantity	Volume of water (MCM)	
Damavand	21	6.9	0
Varamin	30	19.7	160
Eslamshahr	51	33.7	0
Shemiranat	9	4.9	0

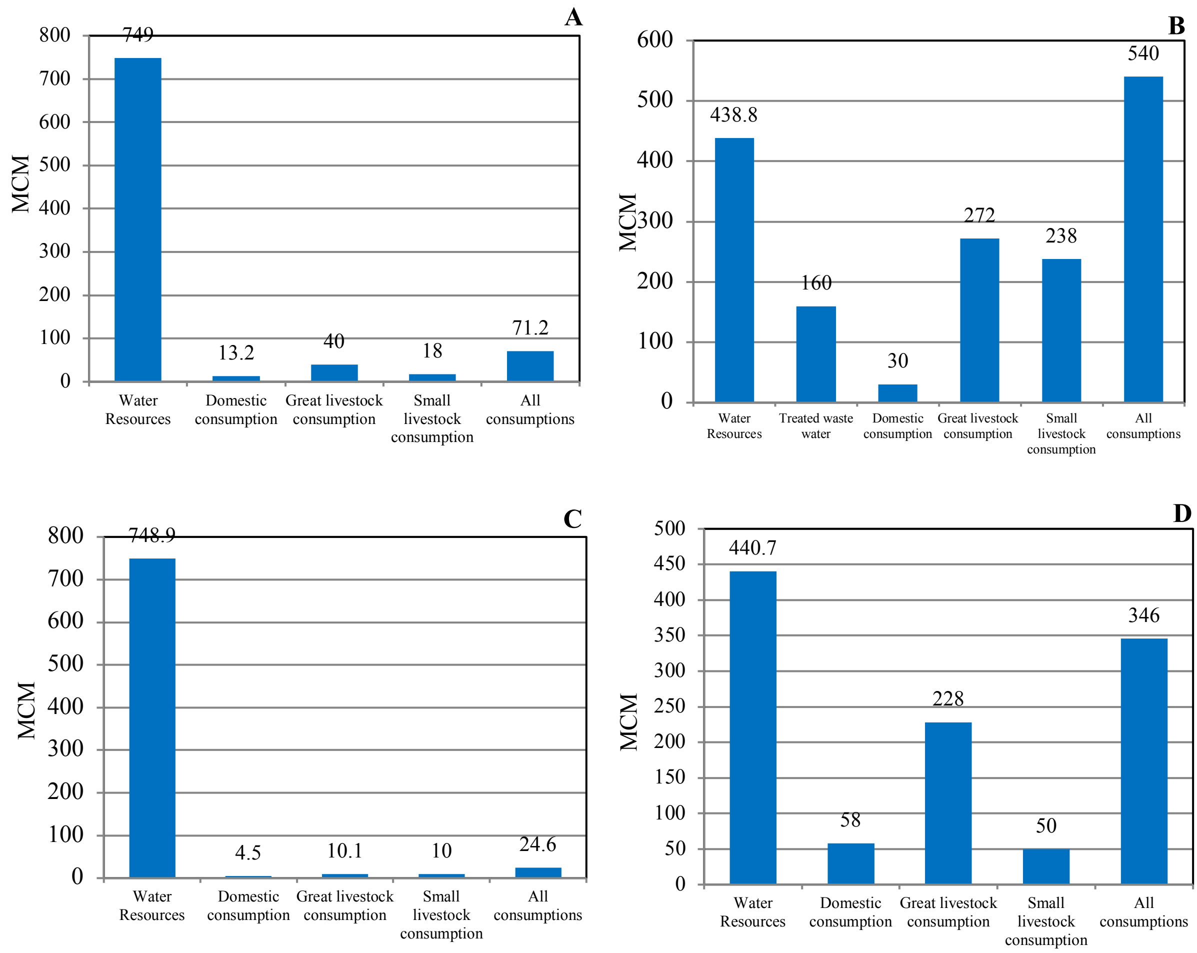

Figure 5. Comparison of available water resources and animals water consumptions (A) Damavand; (B) Varamin; (C) Shemiranat; (D) Islamshahr

About Varamin, In the event that the volume of recycled water is not considered, water consumption is 101.2 MCM more than available water resources volume but when recycled water enters the usage system, there is no problem in water providing. Varamin is using two dams which one of them is Latian. This dam is common between all counties and this matter put high pressure on this dam. Though Mamloo dam is another source for water supply in this area, it is better to use this dam only in order to diminish pressure on Latian dam. To reach this goal, it could be possible to decrease production quantity with water resources consideration.

Shemiranat is a low population county in Tehran province, as other studied areas, domestic water consumption has lowest amount among other sectors. So, this kind of usage is not the problem. In addition to supplied water by wells and Qanats this county has dependency to Lar and Latian dams in water. According to Shemiranat physiographical properties (topography and climate), increasing in small livestock production seems possible. It is suggested that just Lar dam to be used for providing water for this area. In regard to Eslamshahr, water resources condition is at risk. It means 78.5% of available water used. The only dam which supplies water for this county is Latian dam so the priority is to use this dam with the Eslamshahr.

Conclusion

In the present study, the water footprint of livestock production in one of Iran's most significant provinces was evaluated. The importance of this subject lies in the fact that Iran's capital is located in this province with the highest population. Despite limitations in water resource availability, livestock productions are at a high level. This study aimed to comparatively analyze the water footprint of livestock production and the available water resources in Tehran province. The results showed that, in all products, the green water footprint was higher than other footprints, indicating that precipitation has the most influence on livestock production. This finding has also been confirmed in studies by (Mekonnen & Hoekstra, 2010; Mekonnen & Hoekstra, 2012; Murphy et al., 2017).

Regarding meat production, beef in Shemiranat has the highest water footprint (5045 m^3/ton), while lamb in Semiranat has the lowest water footprint (215 m^3/ton) among counties. In milk production, the highest water footprint is related to Damavand (19231 m^3/ton), and the lowest was found in Varamin (3630 m^3/ton). The average values were 4167 m^3/ton for beef, 2266.7 m^3/ton for lamb, 856.2 m^3/ton, and 13007 m^3/ton for milk. Thus, lamb and beef production have favorable conditions from a water footprint viewpoint, but deciding whether to continue their production process requires an assessment of water resource status. For this purpose, water resources such as dams, wells, and Qanats were analyzed. Results revealed that livestock productions have had a significant impact on water use, with the best conditions in water resources and production ratio recognized for northern and eastern counties.

Damavand and Shemiranat have the most sheep, and this type of animal has a low water footprint, making water consumption sustainable for these areas. In Islamshahr, production quantity, especially in milk, is high, and this county is also using water resources that have the most shares in the province, causing inequality between water availability and consumption. Surely, these areas obtain water from outside their boundaries. Although Varamin is located south of Tehran and also has a high contribution to water consumption, the animal water footprint in this county is more appropriate than in Islamshahr. In summary, it can be said that meat production in the southern counties of Tehran may not be sustainable, and they may need to consider stopping production and importing their needs from beyond their boundaries, or at least significantly decreasing their production quantity. There is high potential to use recycled water, and if wastewater treatment units develop, the chance to increase the rate of meat production will rise.

Wells and Qanats have considerable discharge, but they are mainly used for drinking purposes due to their quality, making them an unreliable source for livestock production. If the focus be on reducing the water footprint of production, there are options available. Deficit irrigation could reduce wheat blue water footprint by about 38%. Organic or synthetic mulching practices decreased WF_{blue} by 8% and 17%, respectively (Zhuo & Hoekstra, 2017). Reducing the gray water footprint by decreasing pesticide and fertilizer usage is another possibility (Lovarelli et al., 2016). However, it should be noted that the domestic consumption of Tehran city is affiliated with the mentioned dams. Therefore, the actual water available for the studied products is less than what has been studied, and the cities and villages of Tehran province probably get their water from other sources such as unauthorized wells and recycling of water resources (from methods such as biological, chemical, etc. purification)(Yousefi et al., 2023).

In general, it is advisable to consider stopping livestock production in Tehran province at this level and instead import them from other provinces.

Recommendations for Future Research

In conclusion, our study has delved into the water footprint of livestock production in Tehran province, a region of paramount importance due to its status as Iran's capital with the highest population. Despite limitations in water resources, the province sustains a high level of livestock production. The comparative analysis of water footprints and available water resources has revealed valuable insights that warrant further exploration in future research. To enhance our understanding and guide future studies, the following avenues are proposing:

1. Advanced Water Management Strategies: Future studies could investigate the efficacy of advanced water management strategies in mitigating the impact of livestock production on water resources. This may include the exploration of precision irrigation technologies, water-efficient farming practices, and innovative water recycling methods tailored to the unique conditions of Tehran province.
2. Integrated Socioeconomic Analysis: Future research should integrate socioeconomic factors into the analysis, exploring the economic and social implications of potential shifts in livestock production. Understanding the impact on local economies, livelihoods, and employment opportunities will contribute to the development of holistic and sustainable water management policies.
3. Optimizing Recycled Water Usage: Given the potential for recycled water use in livestock production, further studies should investigate the optimization of wastewater treatment units. Assessing the feasibility and scalability of such units, as well as identifying barriers to implementation, will provide practical insights for enhancing water sustainability in the livestock sector.
4. Exploration of Alternative Water Sources: Investigating alternative water sources beyond dams, wells, and Qanats is essential. Future research could explore the feasibility of tapping into unconventional sources, such as rainwater harvesting or treated urban wastewater, to supplement the water needs of livestock production and alleviate pressure on existing resources.
5. Evaluation of Sustainable Farming Practices: Conducting research on the adoption and impact of sustainable farming practices, such as organic or synthetic mulching, deficit irrigation, and reduced pesticide and fertilizer usage, would be beneficial. This can contribute to identifying environmentally friendly and water-efficient approaches that align with both agricultural and water conservation goals.
6. Policy and Governance Analysis: Examining the effectiveness of existing policies and governance mechanisms in promoting sustainable water management in the livestock sector is crucial. Future studies should assess the alignment of current regulatory frameworks with the goal of minimizing water footprints while ensuring food security and economic stability.

By addressing these research directions, future studies can build upon the foundation laid by our investigation and provide actionable insights for policymakers, stakeholders, and communities in Tehran province. These efforts will contribute to the development of robust and sustainable water management strategies in the face of increasing livestock production and water scarcity challenges.

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