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Impact of nutritional sovereignty of red meat on water consumption in the agricultural sector

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Given the dependency of red meat production on water-depleting fodder crops, this research aimed to measure the impact of the nutritional sovereignty of red meat on water consumption in the agricultural sector. The most important findings of this study reveal that the total water used in the production of red meat amounted to 46.68 billion cubic meters, representing 10.14% of the total water consumption in the agricultural sector during the period 1995 to 2022. The volume of water used in red meat production depends on several factors; with the most significant being the ratio of the area dedicated to fodder crops to the total cropped area and the ratio of the area of green fodder to the total area of fodder crops. Additionally, a 10% increase in the estimated amount of water used in red meat production results in a marginal 0.22% increase in overall water usage in the agricultural sector. This is attributed to a reduction in the area of green fodder and the Agricultural Development Fund's adoption of initiatives to enhance sheep multiplication and improvement. To achieve sustainable development goals in the face of water scarcity, the following actions are required: (1) persisting in the cessation of green fodder cultivation to conserve water for future generations, (2) leveraging virtual water obtained from imports and Saudi agricultural investments abroad.

Key words: Food sovereignty, red meat, fodder crops, water resources.

INTRODUCTION

Throughout the course of human history, food has consistently ranked high among fundamental requirements. Making healthy choices in what we eat is of utmost importance. Due to the potential risks associated with food degeneration, proper food handling, application, and storage are equally crucial. Food spoilage not only poses health concerns but can also have implications for finances and credibility. The transportation of food is a critical issue for different countries, emphasizing the need for safe practices, especially when shipping over long distances, with consideration for environmental impacts.

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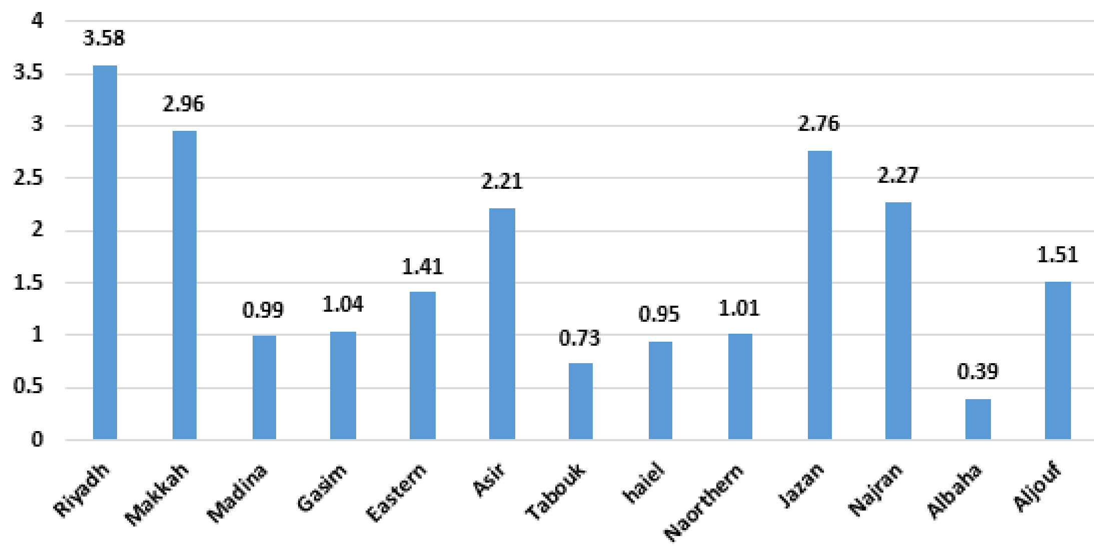

Figure 1. Geographical distribution of sheep numbers in million heads in 2022.
Source: Ministry of Environment, Water and Agriculture (2022). Statistical book.

In addition to the evident health risks, food spoilage significantly affects the financial aspects of the food industry, impacting customers and merchants globally. While the exact monetary cost of economic losses is challenging to quantify, its detrimental effects are a constant topic of discussion (Selamoglu and Memon, 2021; Imran et al., 2023).

Food sovereignty refers to the right of states to determine agricultural policies related to agricultural land use, labor, fishing, animal husbandry, and food. This determination should align with environmental, social, economic, and cultural considerations suitable for their circumstances. The principles of food sovereignty include prioritizing local agriculture for feeding citizens, providing landless farmers access to land, water, seeds, and financing. It also encompasses the right of farmers to produce food and consumers' right to determine the quality of what they want to consume. States have the right to adopt protective measures against low-priced agricultural and food imports, link prices of agricultural commodities to production costs, impose taxes on low-priced imports, and commit to sustainable production. Additionally, there is an emphasis on monitoring production in internal markets to avoid surpluses and involving people in the choices and directions of agricultural policies. Recognizing the rights of farmers and their role in agricultural and food production is fundamental to food sovereignty (Schligham, 2023). This concept covers six sectors: peasants and small farmers, traditional fishermen, pastoralists and livestock breeders, indigenous communities, agricultural labor, and consumers and urban movements (Yap, 2013).

The Kingdom of Saudi Arabia possesses livestock wealth (sheep, goats, cows, and camels) amounting to 30.9 million heads in 2022, of which about 21.8 million heads are sheep, accounting for 70.57%. This is followed by goats at 21.95%, then camels at 6.48%, and cows at 1.0%. Figures 1 to 4 indicate that livestock is concentrated in the Riyadh region, with a percentage of 15.78%, followed by Makkah Al-Mukarramah at 12.71%. The Asir, Jazan, Najran, Sharqiyah, Al-Jawf, and Medina regions have percentages of 11.51, 11.4, 10.81, 6.57, 6.17, and 5.17%, respectively. From the above, it is clear that the eight aforementioned regions own livestock wealth amounting to 80.11%, while the percentage of ownership in the rest of the regions will not exceed 19.89% in 2022.

According to Ghanem et al. (2014), relying on local agriculture to achieve food security entails several economic risks. The most important ones include (1) the depletion of water resources, characterized by relative scarcity, (2) a decline in the economic size of the agricultural sector due to directing a certain amount of water resources to grow crops with low productivity per unit of water, (3) a decrease in the area cultivated with the rest of the dominant crops in the crop structure, and (4) not benefiting from the virtual water gained from imports and Saudi agricultural investment abroad.

Ghanem and Abdul (2018) studied the current and expected situation of food security for red meat. This study showed that the strategic stock of red meat may reach 189.34 thousand tons at the end of the period 2018-2030. Considering the expected domestic consumption of red meat amounting to 510.3 thousand

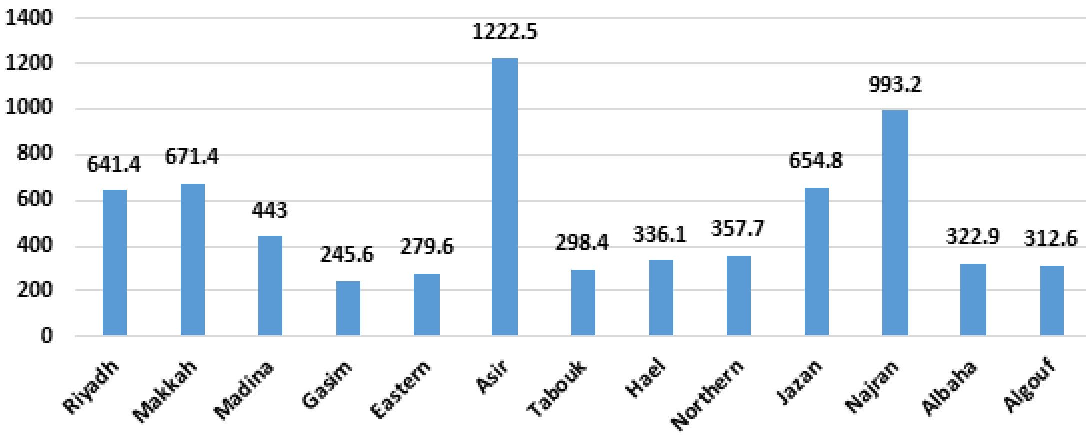

Figure 2. Geographical distribution of goat numbers in thousand heads in 2022.
Source: Ministry of Environment, Water and Agriculture (2022). Statistical book.

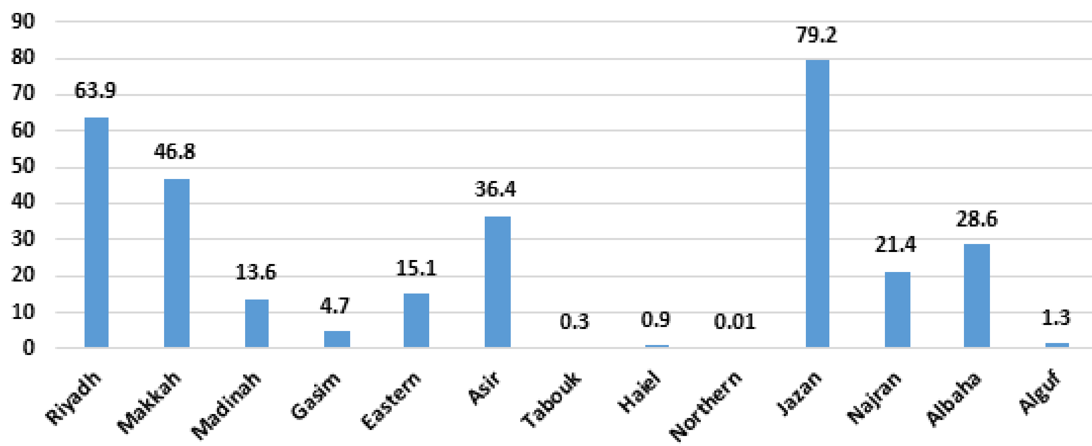

Figure 3. Geographical distribution of cows' numbers in thousand heads in 2022.
Source: Ministry of Environment, Water and Agriculture (2022). Statistical book.

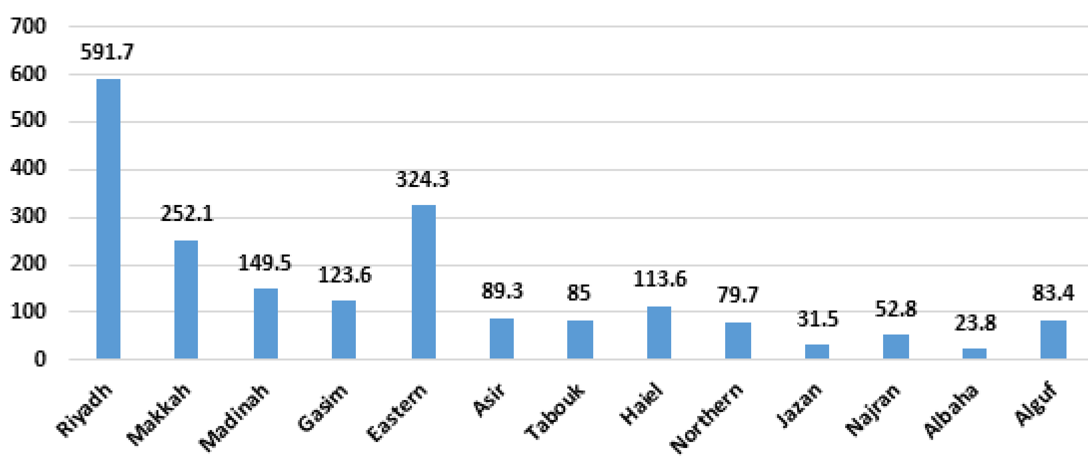

Figure 4. Geographical distribution of camels' number in thousand heads in 2022.
Source: Ministry of Environment, Water and Agriculture (2022). Statistical book.

tons in 2030, the food security coefficient for red meat is estimated at about 0.37 during the period 2018-2030. Finally, this study recommends the need to increase the strategic stock of red meat to be sufficient for local consumption for a period of no less than 6 months, in accordance with food security considerations. Schligham, (2023) explained that the state of Algeria suffered greatly from food dependency due to the deteriorating value of the import bill. Achieving food sovereignty requires adopting a long-term strategy, with all specialists in this field contributing to its development, along with the need to educate society about the importance of rationalizing consumption.

Due to the dependence of red meat production on fodder crops that deplete water, the area of green fodder increased from 305.3 thousand hectares in 1995 to 502.2 thousand hectares in 2016, then decreased continuously until it disappeared from the crop composition structure in early 2022. This was done with the aim of rationalizing water consumption in the agricultural sector (Ministry of Environment, Water, and Agriculture, 2022). According to World Bank data, the livestock production index (2004-2006=100) in the Kingdom of Saudi Arabia increased from 44.02 in 1995 to 144.3 in 2021, which means an increase in the amount of water used in the production of red meat.

Research objectives

The research mainly aimed to study the impact of the nutritional sovereignty of red meat on water consumption in the agricultural sector during the period 1995-2022, by studying the following objectives:

1. Study the current status of food sovereignty and the extent to which red meat production contributes to meeting local consumer needs.
2. Estimating the quantity and value of water used to achieve nutritional sovereignty for red meat and its ratio to the total water consumption in the agricultural sector.
3. Measuring the impact of achieving food sovereignty for red meat on water consumption in the agricultural sector.

MATERIALS AND METHODS

To achieve its objectives, this study relied on secondary data published in: (1) the website of the Food and Agriculture Organization (FAO), and (2) the statistical book issued by the Ministry of Environment, Water and Agriculture. In measuring the nutritional sovereignty indicators of red meat, this study also relied on the following economic equations:

1- Self-sufficiency ratio = (total domestic production ÷ total domestic consumption) x 100
2- The period of adequacy of production for domestic consumption = total domestic production ÷ daily domestic consumption (Ghanem and Kamara, 2010).

This study also relied on statistical analysis represented by the Bernoulli distribution, which is sometimes known as the binomial probability distribution indicators, and standard errors at 95% confidence in estimating the contribution of production to meeting local consumption needs for red meat during the period 1995-2022. Confidence intervals were estimated as follows:

Standard error of probability at 95% confidence = $\pm 1.96 * \sqrt{\frac{P(1-P)}{N}}$

95% confidence interval for probability = $P \pm 1.96 * \sqrt{\frac{P(1-P)}{N}}$

where, P represents the probability of contributing to meeting consumer needs, $(1-P)$ represents the probability of not contributing, N represents the length of time period 1995-2022 (William, 2003).

Finally, this study relied on the proposed model to achieve its objectives to study the impact of achieving food sovereignty for red meat on water consumption in the agricultural sector during the period 1995-2022. The proposed model consists of Equations 1 and 2:

$$\hat{Y}_1 = a_0 + a_1 X_1 + a_2 X_2 + e_1 \quad (1)$$

$$\hat{Y}_2 = b_0 + b_1 \hat{Y}_1 + b_2 X_3 + b_3 X_4 + e_2 \quad (2)$$

The proposed model aims to study the impact of achieving food sovereignty for red meat on water consumption in the agricultural sector during the period 1995-2022. The model comprises of the following:

The ratio of the area of fodder crops (barley, maize, sorghum, clover, rhododendrons, and other fodders) to the crop area (X1).

The ratio of the area of sustainable green fodder (alfalfa, rhododendrons, and other fodders) to the total area of fodder crops (X2). This variable reflects the environmental dimension, as green fodder crops are water-depleting crops. Therefore, the expansion of green fodder cultivation leads to an increase in the amount of water used in the production of red meat.

The crop intensification factor in Saudi agriculture (X3). The amount of water used in the production of the rest of the dominant crops in the crop structure in billion m^3 (X4).
The equations of the proposed model were estimated using the ordinary least squares method (Gujarati, 1979).

RESULTS AND DISCUSSION

The current status of food sovereignty for red meat in the Kingdom of Saudi Arabia

By studying the current situation of red meat food sovereignty during the period 1995-2022, it is evident from the data presented in Figures 5 and 6 and Table 1 that local production of red meat increased from 155.14 thousand tons in 1995 to 265.0 thousand tons in 2022, representing an annual growth rate of 1.4%. Sheep ranked first in red meat production at a rate of 42.45%, followed by camels at a rate of 26.33%, then cows and goats at rates of 17.17 and 14.05%, respectively, during the period 1995-2022.

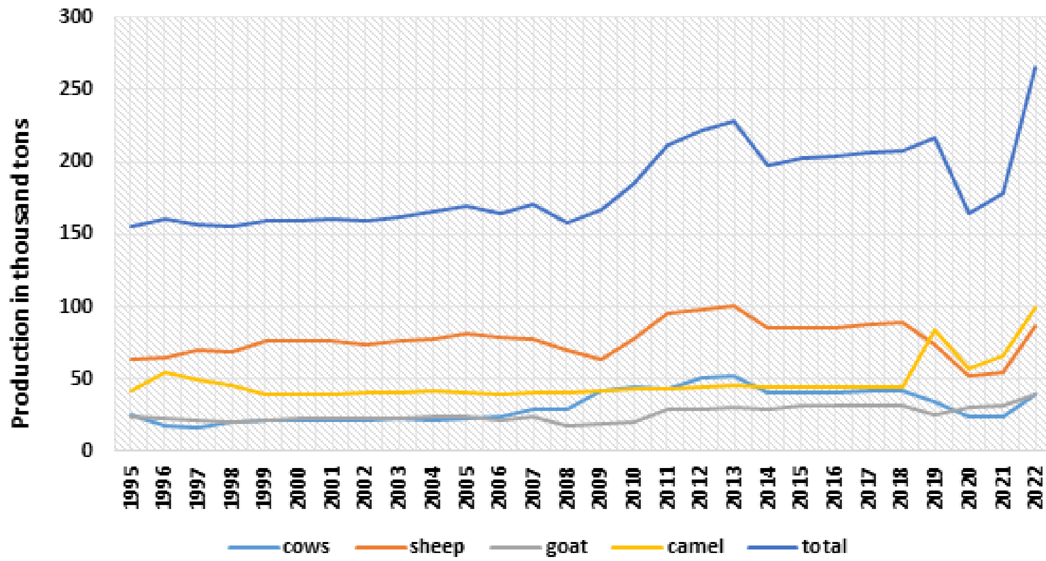

Figure 5. Red meat production in the Kingdom of Saudi Arabia, in thousand tons, during the period 1995-2022.
Source: Ministry of Environment, Water and Agriculture (2022). Statistical book; Food and Agriculture Organization, website (FAOSTAT).

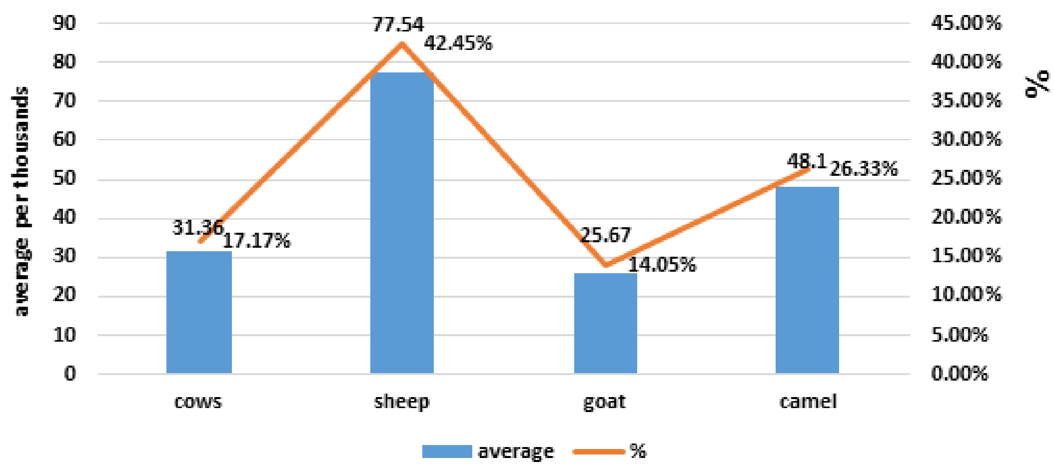

Figure 6. Average and relative importance of red meat production during the period 1995-2022.
Source: Data contained in Figure 5.

Table 1. General trend equations for the development of local red meat production during the period 1995-2022.

Production	Annual growth rate %	F	R^2	Equation
cows	2.9	23.48	0.47	$Ln\hat{Y}_1 = 2.967 + 0.029X$ $(29.85)^{**}(4.85)^{**}$
sheep	0.47*	4.75	0.28	$\hat{Y}_2 = 59.296 + 2.973X - 0.090X^2$ $(9.45)^{**}(2.98)^{**}(-2.70)^{**}$
goat	1.8	34.29	0.57	$Ln\hat{Y}_3 = 2.958 + 0.018X$ $(56.58)^{**}(5.86)^{**}$
camel	1.5	10.98	0.30	$Ln\hat{Y}_4 = 3.630 + 0.015X$ $(48.95)^{**}(3.31)^{**}$
total	1.4	36.04	0.58	$Ln\hat{Y}_5 = 4.998 + 0.014X$ $(132.29)^{**}(6.00)^{**}$

**Significant at the 1% probability level.
Source: Collected and calculated from the data presented in both Figures 5 and 6.

Table 2. Production, consumption, self-sufficiency rate, and period of production adequacy for local consumption of red meat during the period 1995-2022.

Year	Local production in thousands ton	Local consumption in thousands ton		Self-sufficiency ratio %	The production sufficiently period for consumption per day
		Annual	Daily		
1995	155.14	370.65	1.02	41.9	152.8
1996	161.14	377.69	1.03	42.7	155.7
1997	157.00	323.38	0.89	48.5	177.2
1998	155.02	286.27	0.78	54.2	197.7
1999	158.69	309.63	0.85	51.3	187.1
2000	159.64	322.18	0.88	49.5	180.9
2001	159.96	240.00	0.66	66.7	243.3
2002	158.67	410.90	1.13	38.6	140.9
2003	161.93	363.17	0.99	44.6	162.7
2004	165.84	358.80	0.98	46.2	168.7
2005	168.97	435.09	1.19	38.8	141.8
2006	164.08	398.78	1.09	41.1	150.2
2007	171.24	405.94	1.11	42.2	154.0
2008	158.24	356.25	0.98	44.4	162.1
2009	166.50	374.95	1.03	44.4	162.1
2010	185.30	366.95	1.01	50.5	184.3
2011	212.16	433.23	1.19	49.0	178.7
2012	222.00	469.64	1.29	47.3	172.5
2013	227.96	490.58	1.34	46.5	169.6
2014	197.20	467.71	1.28	42.2	153.9
2015	202.65	508.78	1.39	39.8	145.4
2016	203.39	444.41	1.22	45.8	167.0
2017	206.17	438.14	1.20	47.1	171.8
2018	207.89	403.71	1.11	51.5	188.0
2019	217.00	533.29	1.46	40.7	148.5
2020	165.00	550.00	1.51	30.0	109.5
2021	178.00	414.0	1.13	43.0	156.9
2022	265.00	441.7	1.21	60.0	219.0
average	182.56	403.42	1.11	46.02	167.94
Standard deviation	28.59	73.02	0.20	7.01	25.56
Coefficient of variation %	15.66	18.10	18.08	15.23	15.22

Source: Collected and calculated from: (1) data contained in Figure (5), (2) Food and Agriculture Organization (FAOSTAT), period 1995-2022.

Regarding local consumption of red meat, it increased from 370.65 thousand tons in 1995 to 550.0 thousand tons in 2020, then decreased to 441.7 thousand tons in 2022. In general, local consumption of red meat increased at an annual growth rate of 1.7% during the study period. The self-sufficiency rate for red meat ranged between a minimum of 30.0% in 2020 and a maximum of 66.7% in 2001, with an annual average estimated at about 46.02%. The production adequacy period for domestic consumption ranged between a minimum of 109.5 days in 2020 and a maximum of 243.3 days in 2001, with an annual average estimated at about 167.94 days during the study period. The food sovereignty indicators for red meat were characterized by relative stability, as the coefficient of variation ranged between a minimum of 15.22% for both the self-sufficiency rate and the period of adequacy of production for local consumption and an upper limit of 18.1% for local consumption of red meat during the study period (Tables 2 and 3).

Contribution of local production to meeting local consumption needs for red meat

By examining the relative importance of the contribution

Table 3. General trend equations for the development of local consumption of red meat during the period 1995-2022.

Local consumption	Annual growth rate%	F	R^2	Equation	
Annually	1.7	28.97	0.53	$Ln\hat{Y}_1 = 5.742 + 0.017X$	$(111.74)^{**}(5.38)^{**}$
Daily	1.7	29.20	0.53	$Ln\hat{Y}_2 = -0.158 + 0.017X$	$(-3.09)^{**}(5.40)^{**}$

**Significant at the 1% probability level.
Source: Collected and calculated from the data presented in Table 2.

Table 4. The minimum and maximum contribution of production to meeting local consumption needs for red meat during the period 1995-2022.

Statement	Self-sufficiency ratio %
Average for the period 1995-2022	46.0
probility to contribute to self-sufficiency	0.46
The possibility of not contributing to self-sufficiency	0.54
Standard error of the probability of contributing to self-sufficiency	0.09419
Standard error at 95% confidence	0.18461
Probability of contributing to self-sufficiency at 95% confidence	0.46 ± 0.18461
Upper limit	64.46
Lower limit	27.54

Source: Collected and calculated from the data presented in Table 2.

of local production to meeting local consumer needs for red meat during the period 1995-2022, it is clear from the data in Table 4 that the contribution of local production to meeting local consumer needs for red meat ranged between a minimum of 27.54% and a maximum of 64.46% at 95% confidence.

Estimating the quantity and value of water used to achieve nutritional sovereignty for red meat

The amount of water required to achieve nutritional sovereignty for red meat was estimated by multiplying the local production of red meat by the average water requirement per ton of red meat, which is 9.13 thousand m^3/ton (Table 5). The data in Table 6 reveals that the water used in red meat production increased from 1.42 billion m^3, constituting 9.56% of the total water used for agricultural purposes (14.82 billion m^3) in 1995, to 2.42 billion m^3, accounting for 31.92% of the total water used for agricultural purposes (7.58 billion m^3) in 2022. The cumulative water usage in red meat production reached approximately 46.68 billion m^3, making up 10.14% of the total water used for agricultural purposes (460.41 billion m^3) during the period 1995-2022. Considering the average cost of groundwater extraction at 0.482 riyals/m^3 with a discount rate of 10% (Nashwan et al., 2016), the value of water used in red meat production increased from 682.72 million riyals in 1995 to 1.17 billion riyals in 2022.

Measuring the impact of achieving nutritional sovereignty for red meat on consumption water in the agricultural sector

To study the impact of achieving food sovereignty for red meat on water consumption in the agricultural sector, the equations of the proposed model were estimated by successively applying the ordinary least squares (OLS) method during the period 1995-2022. The equations of the proposed model presented in Table 7 reveal the following:

1. A 10% change in both the ratio of the area of fodder crops (barley, sorghum, maize, white, and green fodder) to the crop area (X_1) and the ratio of the area of green fodder crops (alfalfa and rhododendron) to the area of fodder crops (X_2) leads to a change in the same direction in the amount of water used in the production of red meat, by 0.17 and 7.06%, respectively.
2. A 10% change in both the estimated amount of water used in the production of red meat ($\hat{Y}_1$) and the amount of water used in the production of the rest of the dominant crops in the crop structure (X_4) leads to a change in the same direction for the total water consumption in the

Table 5. Average water requirements for red meat in cubic meters/ton.

Meats	Water requirements	Source	Average
Sheep	6143	Hoekstra and Chapagain (2006)	8131.25
	13500	Zimmer and Renault (2003)	
	6978	Hoekstra (2003)	
	5904	Chapagainn and Hoekstra (2003)	
Goat	4043	Hoekstra and Chapagain (2006)	6739
	13500	Zimmer and Renault (2003)	
	5234	Hoekstra (2003)	
	4179	Chapagainn and Hoekstra (2003)	
Cows	15497	Hoekstra and Chapagain (2006)	12508.5
	13500	Zimmer and Renault (2003)	
	9678	Hoekstra (2003)	
	11359	Chapagainn and Hoekstra (2003)	
Average			9126.25

Source: Hoekstra and Chapagain (2006); Zimmer and Renault (2003); Hoekstra (2003); Chapagain and Hoekstra (2003).

agricultural sector, by 0.22 and 2.81%, respectively.

Regarding the crop intensification factor variable (X_3), its effect on water consumption in the agricultural sector was found to be non-significant due to the relative stability in its value during the study period. The behavioral equations of the proposed model are free from the problem of autocorrelation of the residuals, according to the Durbin-Watson (D.W.) test. The Arch Test values for the first and second equations were 0.58 and 0.09, respectively. These values are not statistically significant at the 1% probability level, indicating no autocorrelation in the variance of the series during the period 1995-2022. Finally, the equations of the proposed model are efficient, effectively representing the data used in estimation, as indicated by efficiency indicators, including the U-Theil inequality coefficient, whose value is close to zero (Table 8).

CONCLUSION AND RECOMMENDATIONS

The Kingdom of Saudi Arabia possesses livestock wealth (sheep, goats, cows, and camels), amounting to 30.9 million heads in 2022. It is well-known that red meat production relies on dry and green fodder crops, contributing to water depletion. Many farmers expanded the cultivation of green fodder, especially after the issuance of Resolution No. (335). The area of green fodder increased from 305.3 thousand hectares in 1995 to 502.2 thousand hectares in 2016. However, due to the relative scarcity of water, the depletion of water resources increased. In response to the continued waste of water, the Council of Ministers issued a decision on (12/8/2015) to halt the cultivation of green fodder within a period not exceeding three years. Consequently, the area of green fodder steadily decreased, disappearing from the crop structure by the beginning of 2022.

With the expansion of red meat production, water usage increased from 1.42 billion m^3, representing 9.56% of the total water used in the agricultural sector in 1995, to 2.42 billion m^3, representing 31.92% in 2022. The water used in red meat production depends on various variables, notably the ratio of the area of fodder crops to the cropped area and the ratio of the area of green fodder to the total area of fodder crops. It is observed that the increase in water used for red meat production leads to a slight percentage increase of 0.22% in the total water used in the agricultural sector. The reduced relative impact is attributed to the shift towards concentrated feed in animal raising and fattening. In addition, the Agricultural Development Fund adopted the initiative to multiply and improve sheep. It was also found that stopping the cultivation of green fodder led to a decrease in the amount of water used in the agricultural sector from 20.83 billion cubic meters in 2015, to approximately 7.58 billion cubic meters in 2022.

To achieve the goal of sustainable development in light of water scarcity, the following is required: (1) continue to stop the cultivation of green fodder and provide water for future generations, as a study (Ghanem et al., 2017) confirmed that the decision to stop the cultivation of green fodder is in the interest of the Saudi economy,

Table 6. The amount of water used in the production of red meat and its ratio to the total water consumption for agricultural purposes during the period 1995-2022.

Year	Water used in red meat production		Water used for agricultural purposes in billion m^3	Amount of water used in the production of red meat (%)
	Quantity in billion m^3	Value in million riyals		
1995	1.42	682.72	14.82	9.56
1996	1.47	709.12	15.32	9.60
1997	1.43	690.90	18.66	7.68
1998	1.42	682.19	18.05	7.84
1999	1.45	698.34	18.30	7.92
2000	1.46	702.52	18.00	8.10
2001	1.46	703.93	18.64	7.83
2002	1.45	698.25	18.28	7.92
2003	1.48	712.60	18.03	8.20
2004	1.51	729.81	19.85	7.63
2005	1.54	743.58	18.59	8.30
2006	1.50	722.06	17.00	8.81
2007	1.56	753.57	15.42	10.14
2008	1.44	696.36	15.08	9.58
2009	1.52	732.71	14.75	10.31
2010	1.69	815.44	14.41	11.74
2011	1.94	933.64	15.97	12.13
2012	2.03	976.95	17.51	11.58
2013	2.08	1003.17	18.64	11.17
2014	1.80	867.81	19.61	9.18
2015	1.85	891.79	20.83	8.88
2016	1.86	895.05	19.79	9.38
2017	1.88	907.28	19.20	9.80
2018	1.90	914.85	19.00	9.99
2019	1.98	954.94	10.50	18.87
2020	1.51	726.11	8.50	17.72
2021	1.63	783.32	10.08	16.12
2022	2.42	1166.17	*7.58	31.92
total	46.68	-	460.41	10.14

*Estimated.
Source: Collected and calculated from: (1) Data contained in Tables 2 and 5; (2) Ministry of Environment, Water and Agriculture, Statistical Book, period 1995-2022.

Table 7. Statistical estimation of the proposed model to measure the impact of achieving nutritional sovereignty for red meat on water consumption in the agricultural sector during the period 1995-2022.

Endogenous variable	Equation
The amount of water used in the production of red meat	$\mathrm{Ln}\,\hat{Y}_1 = -2.351 + 0.017\,\mathrm{Ln}\,X_1 + 0.706\,\mathrm{Ln}\,X_2$ $(-10.33)^{**}$ $(3.15)^{**}$ $(11.12)^{**}$ $R^2 = 0.87$ $F = 77.91$ $D.W = 1.38$
Total water consumption for agricultural purposes	$\mathrm{Ln}\,\hat{Y}_2 = 2.308 + 0.022\,\mathrm{Ln}\,\hat{Y}_1 + 0.281\,\mathrm{Ln}\,X_4 + 0.961\,AR(1)$ $(5.07)^{**}$ $(3.03)^{**}$ $(7.77)^{**}$ $(5.381)^{**}$ $R^2 = 0.86$ $F = 32.72$ $D.W = 1.47$

**Significant at the 1% probability level.
Source: Statistical analysis of the data included in the study.

Given that the total current value of groundwater availability (6.15 billion riyals) exceeds its estimated counterpart for sacrificed production (5.03 billion riyals), (2) benefiting from virtual water acquired from imports

Table 8. Indicators for measuring the efficiency of the proposed model to measure the impact of achieving nutritional sovereignty for red meat on total water consumption in the agricultural sector.

Indicator	First	Second
The square root of mean random error (R.M.S.E.).	0.046	0.337
Mean Absolute Error M.A.E.	0.035	0.317
Average Percentage Absolute Error M.A.P.E.	7.17	11.67
inequality Coefficient of Theil (U-Theil)	0.046	0.057

Source: Collected and calculated from the equations of the proposed model presented in Table 7.

and Saudi agricultural investment abroad, to cover local consumer needs and food security, in particular the contribution of local red meat production to meeting local consumer needs ranged between a minimum of 27.54% and a maximum of 64.46% at a confidence level of 95%.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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