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The Impact of Food Sovereignty of Cereal Crops on Water Consumption in the Agricultural Sector in the Kingdom of Saudi Arabia

Adel M. Ghanem[1], Khalid N. Alrwis[1], Othman S. Alnashwan[1], Suliman A. Almojel[1], Sattam F. Almodarra[1], Sharaf Aldin B. Alaagib[1], Nageeb M. Aldawdahi[2]

King Saud University, Food Security Unit, Agricultural economics department, College of food and Agricultural Sciences[1]
Department of Agricultural Extension and Rural Society, King Saud University, Saudi Arabia[2]

Corresponding author: 2*

ABSTRACT— The research aimed to measure the impact of food sovereignty of grain crops on water consumption in the agricultural sector during the period 1990-2020. This study resulted in a set of results, the most important of which is, the total amount of water used in the production of grains amounted to 136.32 billion m3, representing 27.0% of the total amount of water used in the agricultural sector during the period 1990- 2020. Increases of 10% in the ratio of grain area to area yield and the summer grain area to its winter counterpart resulted in increases of 10.7% and 3.66 % in the amount of water utilized in grain production, respectively. Furthermore, a 10% increase in the expected amount of water required in grain production results in a 2.8 % increase in the water used in agriculture. In light of the scarcity of water resources, expanding the cultivation of the most significant winter cereal crops (wheat) while reducing the area of summer cereal crops with high water requirements, the most important of which is sorghum, is required to reduce water use.

KEYWORDS: Food sovereignty; Grain crops; Water resources.

1. INTRODUCTION

Food sovereignty means the right of peoples and countries to determine their policies regarding land, agriculture, employment, fishing, and food, in an environmentally, socially, economically, and culturally appropriate manner according to their circumstances. Food sovereignty was based on several principles: (1) the priority of local agriculture in feeding citizens and the access of landless farmers to land, water, seeds, and finance, (2) the right of farmers to produce food and the right of consumers to determine what they want to consume, (3) the right of states In following protectionist measures from low-priced agricultural and food imports, (4) the necessity of linking agricultural commodity prices to production costs, so that countries have the right to impose taxes on low-priced imports, and their commitment to sustainable production and to control the production in internal markets to avoid surpluses, (5) Participation of peoples in the choices and directions of agricultural policies to be applied, (6) recognition of the rights of farmers and their role in agricultural and food production [10].

Food sovereignty is concerned with six sectors: (1) peasants and small farmers, (2) traditional fishermen, (3) pastoralists and herders, (4) indigenous communities, (5) agricultural labour, (6) consumers, and urban movements [13].

Food sovereignty differs from self-sufficiency, as some countries were able to increase self-sufficiency rates in grains by using fertilization techniques and the heavy use of pesticides, which negatively affected the environment. Local seeds have also been abandoned, harming biodiversity and seed sovereignty. Food sovereignty varies from food security in that it prioritizes locally produced food, while Food security entails obtaining food from a range of sources, including local production, imports, food aid, and agricultural investment overseas.

Food sovereignty is also concerned with producers, the production method, and the production environment, which takes into account all the processes and individuals related to the food production and consumption chain, while the concept of food security focuses on the overall results represented in the availability of healthy and safe food from anywhere and in any conditions [10]. Grains occupied a very economical place in the structure of the cropping structure, as the percentage of the area of grain crops reached 70.94% of the total cropped area of 1.38 million hectares in 1990. The cropping area was restructured, to rationalize water consumption, which resulted in a decrease in the percentage of the grain area to 31.87% of the total cropped area of 771.92 thousand hectares in 2020. The study of [7] indicated that reliance on local agriculture in achieving food security entailed several economic risks, the most important of which were (1) the depletion of water resources, which are relative scarcity, (2) The decline in the economic size of the agricultural sector, due to direct a certain amount of water resources to the cultivation of crops with low productivity per unit of water, (3) the decrease in the cultivated area with the rest of the crops prevailing in the structure of the crop structure, (4) the failure to benefit from the virtual water gained from import and Saudi agricultural investment abroad.

Finally, a study by [4] found that increasing the planted area with palm trees by 10% and increasing the average summer temperature by 10% increased the quantity of water necessary to attain food sovereignty for dates by 9.5% and 0.35 %, respectively. Furthermore, a 10% increase in the estimated amount of water used in the production of dates and the estimated amount of water used in the production of other crops that are dominant in the cropping structure led to a 0.72 % and 9.24 % increase in the total amount of water used for agricultural purposes, respectively.

Research Objectives:

This research aimed to study the relationship between the food sovereignty of grain crops and the consumption of water for agricultural purposes during the period 1990-2020 by studying the following objectives:

1- The current status of food sovereignty for cereal crops (wheat, barley, millet, sorghum, maize, sesame, and other cereals).

2- Estimation of the amount of water used to achieve food sovereignty for grain crops and its proportion to the total water consumption in the agricultural sector.

3- Measuring the impact of achieving food sovereignty for grain crops on water consumption in the agricultural sector.

2. Materials and Methods

In achieving its objectives, this study relied on secondary data published in: (1) the website of the [2], (2) the statistical yearbook issued by the General Authority for Statistics, (3) the statistical book issued by the Ministry of Environment, Water and Agriculture, (4) Annual statistics issued by [12]. This study also relied on quantitative economic analysis represented by:

(1) Indicators for measuring the food sovereignty of cereal crops, the most important of which are:

Self-sufficiency ratio = (total domestic production ÷ total domestic consumption) x 100

The period of production sufficiency for domestic consumption = total domestic production ÷ daily domestic consumption [5].

(2) Bernoulli distribution, which is sometimes known as the binomial distribution, and standard errors at 95% confidence in estimating the percentage or probability of contributing to meeting the domestic consumption needs of grain during the period 1990-2020. Confidence intervals were estimated as follows:

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

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 1990-2020 (William, 2003)).

(3) The proposed model to study the impact of achieving food sovereignty for grain crops on water consumption in the agricultural sector during the period 1990-2020. The proposed model consists of the following behavioral equations:

$$\hat{Y}_1 = a_0 + a_1 X_1 + a_2 X_2 + e_1$$
$$\hat{Y}_2 = b_0 + b_1 \hat{Y}_1 + b_2 X_3 + b_3 X_4 + e_2$$

The proposed model equations include the following variables: (1) Endogenous Variables ,and their number are two variables: the amount of water used in grain production in billion m3 ($\hat{Y}_1$), the total amount of water used for agricultural purposes in billion m3 ($\hat{Y}_2$), (2) Exogenous Variables There are four variables: the ratio of the area planted with grain crops to the total cropped area (X_1), the ratio of the area of summer grain crops (millet, sesame, sorghum, sorghum and other grains) to its winter counterpart (wheat and barley) (X_2) and this variable reflects the environmental dimension, where that in the summer the temperature rises and thus the water needs of grain crops increase, the crop intensification coefficient in Saudi agriculture (X_3), the amount of water used in the production of the rest of the crops prevailing in the cropping structure in billion m3 (X_4). The equations of the proposed model were estimated using the ordinary least squares method [9].

3. Results and Discussion

3.1 The current status of the food sovereignty of grain crops in the Kingdom of Saudi Arabia

By studying the relative importance of the area and production of grains in Saudi agriculture during the period 1990-2020, it is clear from the data in table (1) and figure (1) that wheat is one of the most important grain crops in Saudi agriculture, with an average wheat area of 371.56 thousand hectares, representing 65.14% of the average total area of the grain. Wheat production represented 74.46% of the total cereal production during the study period. The relative importance of the area and production of sorghum was 19.33% and 7.42% for each, respectively. As for the barley crop, it ranked third, with the relative importance of barley area and production reaching 10.82% and 15.15% for each, respectively. In general, the ratio of the grain area to the total cropped area ranged between a minimum of 25.05% in 2018 and a maximum of 71.74% in 1991, with an annual average estimated at 48.42% during the period 1990-2020.

Table 1: Statistical analysis of the development of the area and production of grain crops during the period 1990-2020.

Statement		Minimum	Maximum	Average	standard deviation	Variation coefficient %	Area and production percentage %
Wheat	Area	83.82	924.41	371.56	244.09	65.69	65.14
	Production	426.20	4123.66	1841.88	1073.99	58.31	74.46
Millet	Area	2.63	7.94	5.37	1.69	31.51	0.94
	Production	4.49	13.52	8.80	2.52	28.59	0.36
Sorghum	Area	42.10	183.64	110.27	50.23	45.55	19.33
	Production	105.38	283.86	183.47	51.62	28.14	7.42
Maize	Area	2.27	29.50	9.37	8.73	93.17	1.64
	Production	4.26	163.45	46.05	49.78	108.09	1.86
Barley	Area	1.50	315.94	61.72	111.09	111.09	10.82
	Production	11.27	2010.50	374.72	117.10	117.10	15.15
Sesame	Area	1.39	3.74	2.41	23.69	23.69	0.42
	Production	1.25	5.35	3.32	38.44	38.44	0.13
other cereals	Area	0.05	26.18	9.54	119.22	119.22	1.67
	Production	0.18	89.29	34.05	117.67	117.67	1.38
Total cereals	Area	193.16	1132.61	570.42	50.55	50.55	100
	Production	886.36	5044.68	2473.63	47.83	47.83	100
Crop area		694.60	1596.40	1114.55	248.75	22.32	-
Ratio of cereals area to crop area %		25.05	71.74	48.42	15.24	31.48	-

Source: Compiled and calculated from: (1) [11]. Statistical Book, (2) General Authority for Statistics, Statistical Yearbook, Miscellaneous Issues, 1990- 2020, (3) Saudi Central Bank, Annual Statistics 2020,

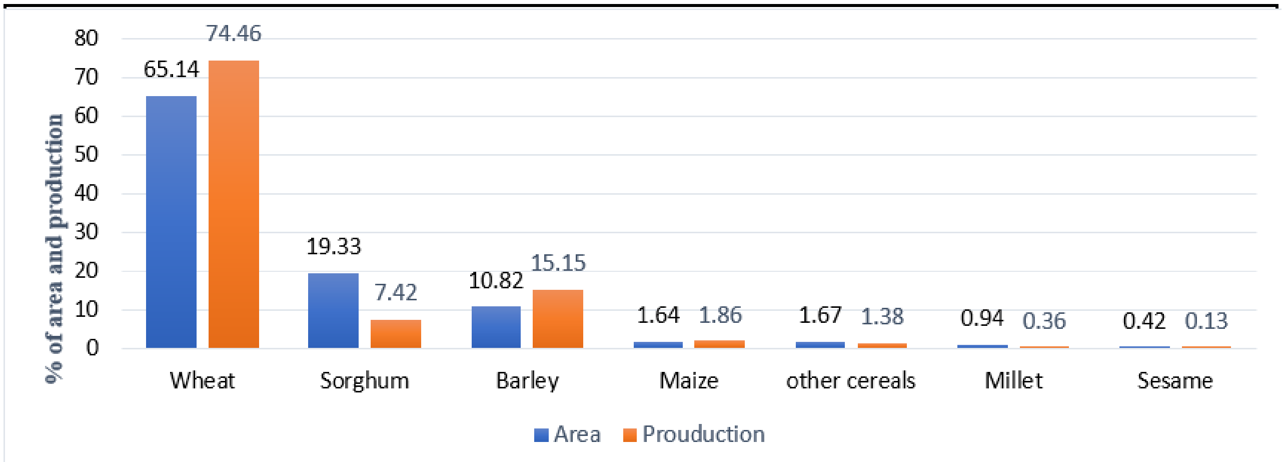

Figure 1. The relative importance of the area and production of grain crops during the period 1990- 2020. Source: The data in Table (1).

3.2 Self-sufficiency Ratio for Cereal Crops

Figure (2) and Table (2) show that the self-sufficiency rate of most grain crops (wheat, barley, and millet) decreased from 1990 to 2020, while the self-sufficiency rate of other grain crops increased from 2.1 % in 1990 to 134.5 % in 2020, by 10.5 % annual increase during the study period. The sorghum crop came in best, with an average self-sufficiency rate of 98.8%, followed by wheat (81.3%), millet and other grains, barley, and maize (59.1%, 33.6%, 7.3 %, and 3.0%, respectively). During the period 1990-2020, the average production sufficiency duration for local consumption of grain crops ranged from a low of 11.1 days for maize maximum of 360.7 days for sorghum (Figure,3).

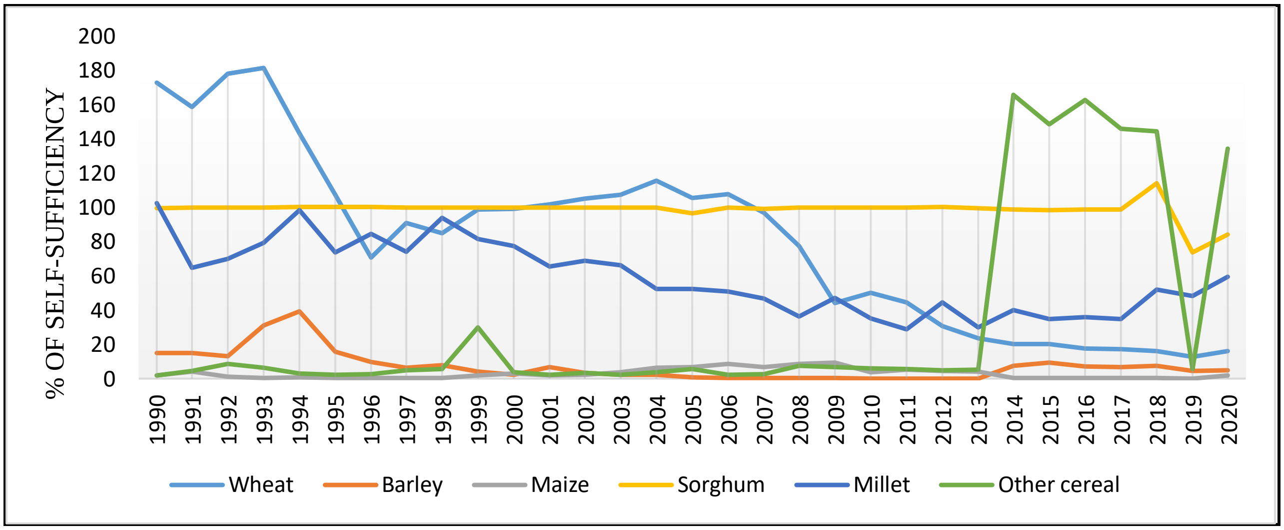

Figure 2. The development of the self-sufficiency rate of cereal crops during the period 1990- 2020

Source: Compiled and calculated from: (1) [11]. Statistical Book, (2) General Authority for Statistics, Statistical Yearbook, Miscellaneous Issues, 1990-2020, (3) Saudi Central Bank, Annual Statistics 2020, 5/31/2021.

Table 2. Equations of the general trend of the development of the self-sufficiency rate of cereal crops during the period 1990-2020.

Statement	**Growth rate %**	***F***	R^2	Equation
Wheat	-8.5	155.35	0.84	$Ln\ \hat{Y}_1 = 5.481 - 0.085T$ $(43.67)^{**}\ (-12.46)^{**}$
Barley	-8.0	6.67	0.19	$Ln\ \hat{Y}_2 = 2.344 - 0.080T$ $(4.12)^{**}\ (-2.58)^{**}$
Maize	0.7*	7.53	0.35	$\hat{Y}_3 = -1.400 + 0.757T - 0.023T^2$ $(-1.03)^{ns}\ (3.86)^{**}\ (-3.84)^{**}$
Millet	-3.1	46.77	0.62	$Ln\ \hat{Y}_4 = 4.519 - 0.031T$ $(53.66)^{**}\ (-6.84)^{**}$
Other Cereal	10.5	19.72	0.40	$Ln\ \hat{Y}_5 = 0.512 + 0.105T$ $(1.18)^{ns}\ (4.44)^{**}$

** Significant at the 1% probability level, ns not significant.

* The growth rate was calculated using the following formula: $r = (\frac{dY}{dT} \div \overline{Y}) \times 100$

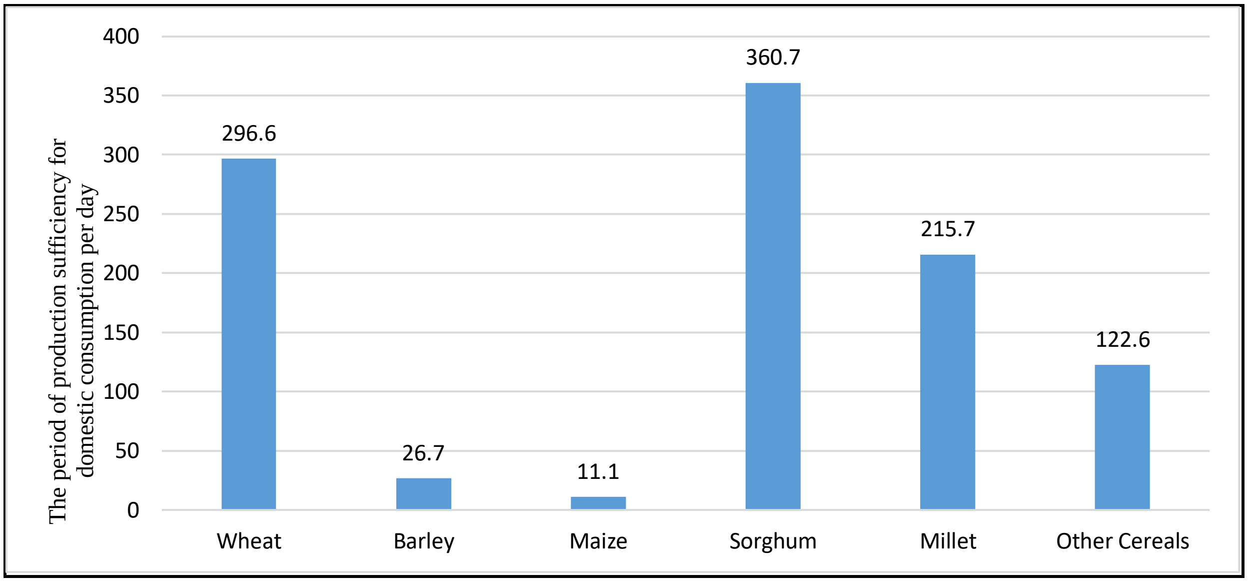

Figure 3. The average period of production sufficiency for domestic consumption per day for grain crops during the period 1990-2020

Source: compiled and calculated from: (1) General Authority for Statistics, Statistical Yearbook, miscellaneous issues, period 1990-2020, (2) Food and Agriculture Organization, website (FAOSTAT), period 1990-2020.

3.3 Contribution of Grain Production to Meet Domestic Grain Consumption Needs:

The minimum and maximum contribution of production to meet the domestic consumption needs of cereals during the period 1990-2020 were estimated. It is clear from the data in the table (3) that the upper limit of the production's contribution to meeting the local consumption needs of grains ranged between 9.01% for the maize crop and 102.63% for the sorghum crop at a confidence level of 95%. At a 95% confidence level, the minimal contribution of production to meeting local grain consumption ranged from - 3.01 % for maize to 94.97 % for sorghum.

Table 3. The extent to which production contributed to meeting the consumption needs of grain crops during the period 1990-2020.

Statement	Wheat	Barley	Maize	Sorghum	Millet	Other Cereals
Contribution potential	0.813	0.073	0.03	0.988	0.591	0.336
Possible not to contribute	0.187	0.927	0.97	0.012	0.409	0.664
standard error	0.070	0.0467	0.0306	0.0196	0.0883	0.0848
standard error at 95% confidence	0.1373	0.0916	0.0601	0.0383	0.1731	0.1663
Contribution probability at 95% confidence level.	0.813 ± 0.1373	0.073 ± 0.0916	0.03 ± 0.0601	0.988 ± 0.0383	0.591 ± 0.1731	0.336 ± 0.1663
Contribution percentage at 95% confidence level:						

Minimum	67.57%	1.86% -	%-3.01	94.97%	76.41%	16.97%
Maximum	95.03%	16.46%	9.01%	102.63%	41.79%	50.23%

Source: It was collected and calculated from the data presented in Figure (2).

3.4 Estimating the Amount of Water Used to Achieve Food Sovereignty for Grain Crops

During the period 1990-2020, the amount of water utilized to attain grain crop food sovereignty was calculated by multiplying the area planted with grain crops by the average water requirements per hectare or multiplying the locally produced grain quantity by the average unit water requirements (ton). It is clear from the data in Table (4) that the area planted with grain crops decreased from 978.33 thousand hectares in 1990 to 262.62 thousand hectares in 2020, i.e. the area planted with grain crops decreased at a rate of 5.5% annually. The local production of cereal crops decreased from 4138.08 thousand tons in 1990 to 1254.97 thousand tons in 2020, i.e., the local production of cereal crops decreased at a rate of 4.4% annually. The decrease in the area and production of grain crops is due to Cabinet Resolution No. 335 of 11/11/1428 AH, which includes the rules and procedures for rationalizing water consumption and regulating its use in agricultural fields, which directed the gradual stop of purchasing local wheat over a period of eight years at an annual rate of 12.5% [6].

In light of the cultivated area and the average water needs of cereal crops of 7.78 thousand m 3 / hectare [1], the amount of water used in the production of cereals was estimated at 7.61 billion m3, representing 67.54% of the total amount of water used for agricultural purposes in 1990. Given the structural changes in the cropping structure, the area planted with grain crops has decreased, and thus the amount of water used in grain production decreased to 2.04 billion m3, representing 24.04% of the total amount of water used for agricultural purposes in 2020. Between 1990 and 2020, the total amount of water used in grain production was 136.32 billion m3, accounting for around 27.0 % of the complete water used in the agricultural sector (Fig. 4). During the period 1990-2020, the amount of water used in the production of grain crops and its percentage to the total amount of water used for agricultural purposes dropped at a rate of 5.5 % and 5.9 % annually, respectively. The average water needs of the producing unit (ton) dropped from 1.84 thousand m3 tons in 1990 to 1.63 thousand m 3 / tons in 2020, indicating a 1.1 % annual decrease in the average water needs of the produced unit (tons) (Table 5).

Table 4. Estimation of the amount of water used in the production of grain crops and its proportion to the total water consumption for agricultural purposes during the period 1990-2020.

Year	Grain area and production		Water used in grain production, billion m3	Water requirements per unit of production thousand m3 / ton	Water used for agricultural purposes In billion m3	Percentage of water used in grain production %
	Cultivated area in thousand hectares	Domestic production in thousand tons				
1990	978.33	4138.08	7.61	1.84	11.27	67.54
1991	1090.33	4575.52	8.48	1.85	11.38	74.54
1992	1124.60	4704.84	8.75	1.86	12.42	70.45
1993	1132.62	5044.68	8.81	1.75	13.05	67.52
1994	1071.17	4861.31	8.33	1.71	13.06	63.81
1995	707.83	2670.89	5.51	2.06	14.82	37.16
1996	565.86	1933.58	4.40	2.28	15.32	28.74
1997	658.73	2340.72	5.12	2.19	18.66	27.46
1998	624.13	2204.53	4.86	2.20	18.05	26.90
1999	693.23	2488.56	5.39	2.17	18.30	29.47
2000	618.90	2171.56	4.82	2.22	18.00	26.75

2001	660.98	2594.03	5.14	1.98	18.64	27.59
2002	706.77	2856.34	5.50	1.93	18.28	30.08
2003	699.22	2952.14	5.44	1.84	18.03	30.17
2004	685.35	3195.00	5.33	1.67	19.85	26.86
2005	631.65	3005.38	4.91	1.64	18.59	26.43
2006	602.70	3042.00	4.69	1.54	17.00	27.58
2007	582.10	2967.00	4.53	1.53	15.42	29.37
2008	468.80	2438.00	3.65	1.50	15.08	24.19
2009	328.30	1592.00	2.55	1.60	14.75	17.32
2010	286.90	1571.00	2.23	1.42	14.41	15.49
2011	260.30	1418.00	2.03	1.43	15.97	12.68
2012	211.90	1085.00	1.65	1.52	17.51	9.42
2013	165.80	883.00	1.29	1.46	18.64	6.92
2014	321.25	1595.11	2.50	1.57	19.61	12.75
2015	305.86	1630.08	2.38	1.46	20.83	11.42
2016	291.45	1524.83	2.27	1.49	19.79	11.46
2017	277.95	1509.23	2.16	1.43	19.20	11.26
2018	268.58	1459.66	2.09	1.43	19.00	11.00
2019	237.44	966.52	1.85	1.91	10.50	17.59
2020	262.62	1254.97	2.04	1.63	8.50	24.04
Total	-	-	136.32	-	505.05	26.99

Source: Compiled and calculated from: (1) [11]. Statistical Book (2) General Authority for Statistics, Statistical Yearbook, Miscellaneous Issues, 1990-2020, (3) Saudi Central Bank, Annual Statistics 2020, 5/31/2021.

Table 5. Annual growth rates in the area and production of grains and the amount of water used and their ratio to the total amount of water used for agricultural purposes during the period 1990-2020.

Statement	growth rate%	F	R^2	Equation
The area planted with grain crops	-5.50	137.38	0.83	$Ln\ \hat{Y}_1 = 7.082 - 0.055T$ $(81.87)^{**}\ (-11.72)^{**}$
Total grain production	-4.40	65.92	0.69	$Ln\ \hat{Y}_2 = 8.407 - 0.044T$ $(84.72)^{**}\ (-8.12)^{**}$
The amount of water used in grain production	-5.50	137.48	0.83	$Ln\ \hat{Y}_3 = 2.226 - 0.055T$ $(25.75)^{**}\ (-11.73)^{**}$
Total water used for agricultural purposes	0.47[1]	9.46	0.40	$\hat{Y}_4 = 10.373 + 0.908T - 0.026T^2$ $(7.08)^{**}\ (4.30)^{**}\ (-4.02)^{**}$
The percentage of the amount of water used in the production of grain	-5.90	82.21	0.74	$Ln\ \hat{Y}_5 = 4.135 - 0.059T$ $(34.26)^{**}\ (-9.07)^{**}$
Water requirements per unit of grain production (tons)	- 1.10	23.90	0.45	$Ln\ \hat{Y}_6 = 0.727 - 0.011T$ $(17.08)^{**}\ (-4.89)^{**}$

** Significant at the 1% probability level.

Source: It was collected and calculated from the data in Table (4).

[1] The growth rate was calculated using the following formula: $r = (\frac{dY}{dT} \div \overline{Y}) \times 100$

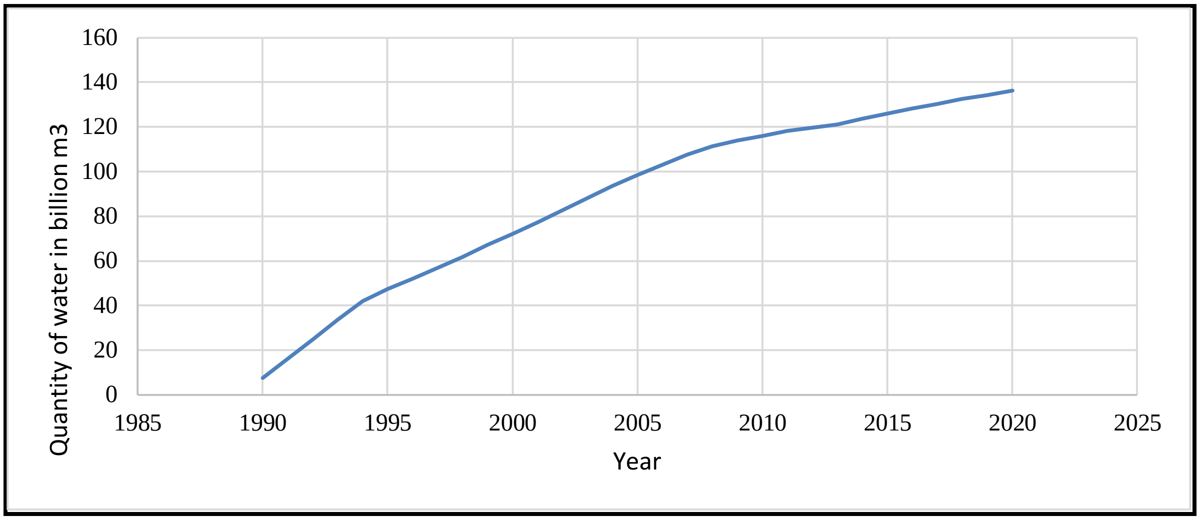

Figure 4. Cumulative water used in grain production during the period 1990-2020.
Source: The data in Table (4).

3.5 Measuring the Impact of Achieving Food Sovereignty for Grain Crops on Water Total Consumption in the Agricultural Sector

The equations of the proposed model were evaluated using the Ordinary Least Squares (OLS) method for the period 1990-2020 to investigate the impact of obtaining food sovereignty for cereal crops on overall water consumption in the agricultural sector. It is clear from the equations of the proposed model in Table (6) that: (1) A change of 10% in each of the ratio of the area of grain crops to the total cropped area (X1) and the summer grain crops area to their winter counterpart (X2) leads to a change in the same trend for the amount of water used in grain production by 10.7% and 3.66% for each of them, respectively, (2) a change of 10% in each of the estimated amount of water used in grain production ($\hat{Y}_1$) and the amount of water used in the production of the rest of the crops prevailing in the crop composition (X_4) leads to a change in the same direction for the total water consumption in the agricultural sector by 2.8% and 6.35% for each, respectively. About the coefficient of crop intensification (X3), its effect on water consumption in the agricultural sector was not significant, given the relative stability of its value during the study period. Also, the equations of the proposed model became free from the problem of autocorrelation of residuals, according to the Durbin - Watson test. The equations of the proposed model have good efficiency in representing the data used in the estimation, according to the indicators of measuring the efficiency of the model. The most important of which is the inequality coefficient of U-Theil, whose value is close to zero - Table (7).

Table 6. Statistical estimation of the equations of the proposed model to measure the impact of achieving food sovereignty for grain crops on the total water consumption for agricultural purposes during the period 1990-2020.

Endogenous Variables	Equation
The amount of water used in grain production	$\text{Ln}\,\hat{Y}_1 = -1.457 + 1.069\,\text{Ln}\,X_1 + 0.366\,\text{Ln}\,X_2 + 0.768\,AR(1)$ $(-2.33)^{*}\quad(3.56)^{**}\quad(5.16)^{**}\quad(3.14)^{**}$ $R^2 = 0.97\quad F = 232.34\quad D.W = 1.68$
Total water consumption for agricultural purposes	$\text{Ln}\,\hat{Y}_2 = 0.873 + 0.280\,\text{Ln}\,\hat{Y}_1 + 0.003\,\text{Ln}\,X_3 + 0.653\,\text{Ln}\,X_4 + 0.923\,AR(1)$ $(3.87)^{**}\quad(2.62)^{**}\quad(1.23)^{ns}\quad(12.01)^{**}\quad(6.59)^{**}$ $R^2 = 0.92\quad F = 72.65\quad D.W = 1.71$

** Significant at 1% probability level, * Significant at 5% probability level, ns not significant.
Source: Statistical analysis of the data included in the study.

Table 7. Efficiency indicators of the proposed model equations to measure the impact of achieving food sovereignty for grain crops on the total water consumption for agricultural purposes.

Indicator	First	The second
root mean square error R.M.S. E	0.147	0.163
Mean absolute error M.A.E.	0.119	0.140
Mean Absolute Error Percentage M.A.P. E	13.69	5.12
Coefficient of un equality (U-Theil)	0.052	0.028

Source: It was collected and calculated from the equations of the proposed model in Table (6).

4. Conclusion

Due to the scarcity of water resources, and the concentration of wheat, barley and maize cultivation in the sedimentary shelf areas (Riyadh, Qassim, Sharqiah, Hail, Al-Jawf, Tabuk and the northern borders), with ancient geological waters of limited renewal, the Ministry of Environment, Water and Agriculture restructured the crop structure, which resulted in a decrease in the area of grain crops from 70.94% in 1990 to 31.87% in 2020. Agricultural companies and projects stopped cultivating wheat, especially after the issuance of Resolution 335, as they turned to Saudi agricultural investment abroad, leaving small producers to grow grain crops in accordance with the concept of food sovereignty.

In light of the increasing consumer needs, the self-sufficiency rate of most cereal crops (wheat, barley and millet) decreased, which led to an increase in dependence on imports from abroad, especially for wheat and barley. The percentage of local production's contribution to meeting the consumption needs of grain crops ranged between a minimum of -3.01% for the maize crop and a maximum of 102.63% for the sorghum crop at a confidence level of 95%. The amount of water used in the production of grain crops and its proportion to the total amount of water used for agricultural purposes decreased at a rate of 5.5% and 5.9% annually for each, respectively, during the period 1990-2020.

Through econometric analysis during the period 1990-2020, it was found that the expansion of the area planted with grain crops, especially during the summer season, leads to an increase in water consumption in grain production, and thus an increase in the amount of water used in the agricultural sector. In light of the scarcity of water resources, the goal of rationalizing water consumption requires expanding the cultivation of the most important winter cereal crops (wheat) and reducing the area of summer cereal crops with high water requirements, the most important of which is sorghum.

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