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The Role of Virtual Water Imports in Groundwater Protection- Case Study: Saudi Arabia

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Abstract: The virtual water is the amount of water required to produce a given good or service. Also the virtual water was introduced by Allen in 1997 as an economic tool and an alternative means of measuring the global distribution of water through trade. The average global volume of virtual water flows related to the international trade in agricultural products was 1263 Gm3/yr in the period 1997-2001. This estimate is based on the virtual water content of the products in the exporting countries. The virtual water needs to be considered in water balance calculations in arid countries. Saudi Arabia is an arid country with limited water resources and about 80-85% of water supplies come from groundwater which is classified as a nonrenewable water resource. Excessive use of groundwater has created major problems such as depletion of aquifers and deterioration of groundwater quality. Some of these problems are already occurring and others are expected to occur. Therefore, immediate public action is imperative to prevent or minimize the impacts of the depletion of groundwater resources. This paper provides a brief overview of groundwater condition in Saudi Arabia; discusses some impacts of groundwater depletion and this study is quantify, analyses and suggests the virtual water imports as major alternative to protect the groundwater resources, so, the virtual water imports will be used as a main item in water resources balance equation in Saudi Arabia by using data on crop water requirements over the growing season, evapotranspiration rates, the annual yield and the amount of water used in processing the crop.

Key words: Virtual water • Groundwater depletion • Foodstuffs

INTRODUCTION

The virtual water is the amount of water required to produce a given good or service [1-3]. Also the virtual water was introduced by Allen in 1997 as an economic tool and an alternative means of measuring the global distribution of water through trade [1,4]. The average global volume of virtual water flows related to the international trade in agricultural products was 1263 Gm3/yr in the period 1997-2001 [3]. This estimate is based on the virtual water content of the products in the exporting countries. The virtual water needs to be considered in water balance calculations in arid countries. Saudi Arabia is an arid country with limited water resources and about 80-85% of water supplies come from groundwater which is classified as a nonrenewable water resource. Groundwater extraction from Saudi Arabia's finite nonrenewable reserves has been unrestrained since the start of the country's foray into agricultural production in the early 1980s. The volume of water extraction from nonrenewable aquifers, according to the Saudi Ministry of Agriculture and Water, reached a peak of slightly more than 14 billion cubic meters in 1993 and 1994. In 1995, the extraction volume dropped to 12.5 billion cubic meters and in 1996, it dropped further to 12 billion cubic meters. In 2006, the overall volume of agricultural water use from all sources was 17 billion cubic meters.

Problem Identification: Excessive use of groundwater in Saudi Arabia has created major problems such as depletion of aquifers and deterioration of groundwater quality, some of these problems are already occurring and others are expected to occur, these results may be adverse economic consequences coupled with negative environmental and social effects.

Objective and Methodology: Saudi Arabia faces severe water problems and needs active water policies to achieve sustainable development; therefore, it should prevent or minimize the depletion of groundwater

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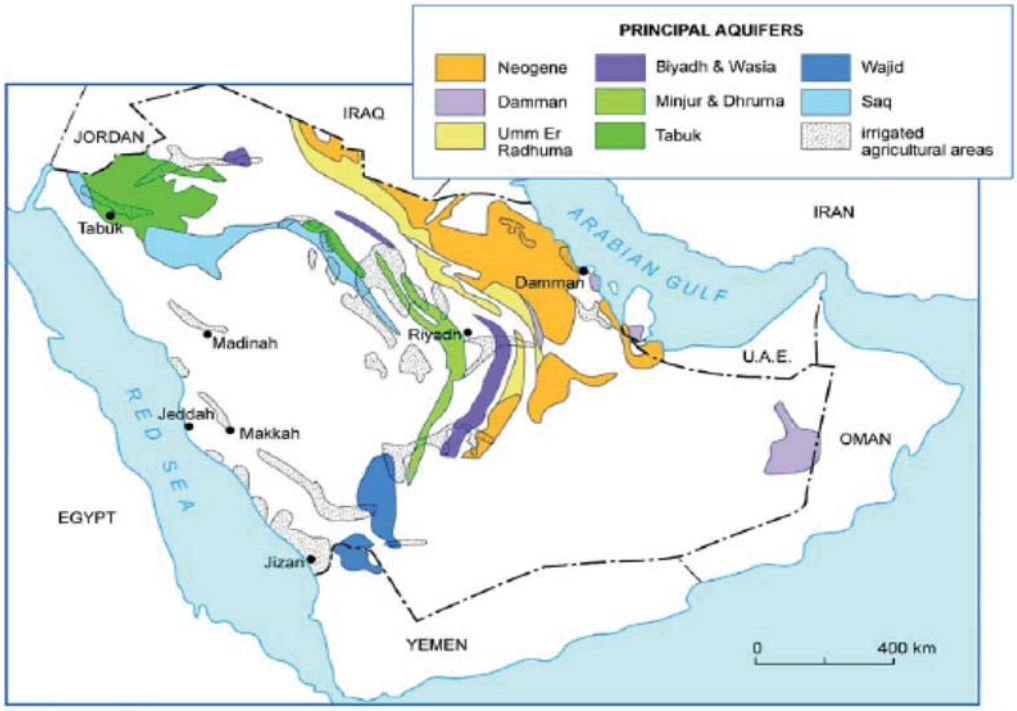

Fig. 1: The principles aquifers of Saudi Arabia

resources. This study is quantify, analyses the virtual water imports and exports as a major alternative to protect the groundwater resources and this objective has been achieved by:

- Providing a brief overview of water resources and groundwater condition in Saudi Arabia.
- Calculating the crop water requirement using the methodology developed by FAO [1] and Hung [5,6] and Chapagain and Hoekstra [3,7].
- Discuss the impossibility of Saudi Self –Sufficiency in Foodstuffs.
- Quantify the virtual water imports and exports in Saudi Arabia.

Water Resources in Saudi Arabia: The annual runoff in Saudi Arabia is estimated to be about 2,230 MCM. There are about 185 dams, with a total storage capacity of 775 MCM, for groundwater recharge and flood control, Groundwater in Saudi Arabia is found almost entirely in the many thick, highly permeable aquifers of large sedimentary basins of the Arabian Shield [8, 9]. Figure 1 shows the principles aquifers of Saudi Arabia.

Groundwater is stored in more than twenty layered principal and secondary aquifers of different geological ages [9], with groundwater quality varying between sites and aquifers. The estimated groundwater reserves to a depth of three hundred meters below ground surface are about 2,185 billion cubic meters with a total annual recharge of 2,762 MCM [10, 11]. The renewable groundwater resources are mainly stored in shallow alluvial aquifers and in basalt layers of varying thickness and width, which are found mostly in the southwest. These aquifers store about 84 billion cubic meters with an average annual recharge of 1,196 MCM.

Groundwater is supplemented by desalinated water and treated wastewater. Saudi Arabia has become the largest desalinated water producer in the world. The total annual water production from desalination plants has increased from about 200 MCM in 1980 to over 1287 MCM by 2002 [12]. The present production represents about 50% of the total current domestic and industrial demands and most of the rest is met from groundwater resources.

In addition, it is estimated that about 1,000 MCM of wastewater were generated in the country in 1996 and this is expected to increase to about 1,500 MCM by the year 2,000, About 41 per cent of municipal wastewater is treated and in 1997, about 185 MCM or 18.5 per cent of the treated wastewater was recycled for irrigating agricultural crops and landscape plants and for use in refineries, Table 1 shows water supply in Saudi Arabia, 1990–1997 (millions of cubic meters).

Table 1: Water supply in Saudi Arabia, 1990–1997 (millions of cubic meters)

Items	1990	%	1992	%	1997	%
Surface water and shallow aquifers (renewable)	2,100	13.0	2,140	7.0	2,140	12
Groundwater (non-renewable)	24,489	83.0	28,576	90.0	15,376	83
Desalination	540	3.0	795	2.0	795	4
Treated wastewater effluents	110	0.7	185	0.6	185	1
Total	27,239		31,696		18,496	

Sources: MOP 1990 estimate; Dabbagh and Abderrahman [11] (1992 total)

Table 2: Growth of water use in Saudi Arabia, 1980–2010 (millions of cubic meters)

Domestic and industrial			Agricultural		Total
Year	M M^3	%	M M^3	%	M M^3
1980	502	21.30	1,850	78.70	2,352
1990	1,650	6.06	25,589	93.94	27,239
1992	1,870	5.90	29,826	94.10	31,696
1997	2,063	11.17	16,406	88.83	18,469
2000	2,900	20.57	11,200	79.43	14,100
2010	3,600	19.67	14,700	80.33	18,300

Sources: MOP 1990; Dabbagh and Abderrahman 1997 (agricultural and total use, 1990 and 1992)

Table 3: Cumulative number of public wells according to type

Type of wells	1998	1999	2000	2001	2002	2003
Tube water wells	2261	2265	2296	2355	2410	2423
Dug water wells	1663	1663	1668	1701	1740	1804
Observation wells	775	775	773	788	788	788
Test wells	356	356	356	356	356	356
wells (Agricultural irrigation)	290	290	290	290	290	290
Total	5345	5349	5383	5490	5584	5661

Source: Ministry of Water and Electricity

Table 4: Cumulative number of private wells licensed for different purposes by region

Type of wells	1998	1999	2000	2001	2001
Riyadh		41067	42042	43899	45905
Makkah – Medina	5780	5917	6075	6266	6461
Eastern Province	7664	8154	8512	8988	9373
Qassem – Hail – Tabuk – Jouf – Northern Frontier		34898	35947	37345	39070
Baha – Assir – Nejran – Jizan	5006	5105	5169	5364	5561
Total		95141	97745	100000	100000

Source: Ministry of Water and Electricity

Table 5: Water footprints, water scarcity, water self-sufficiency and water dependency of Saudi Arabia (1995-1999)

Population (million)	20239432
Water withdrawal (10^6 m^3/year)	5092.0
Water availability (10^6 m^3/year)	8760.0
water footprint (10^6 m^3/year) per capita	789.0
Water scarcity %	58.1
Water self sufficiency %	31.9
Water Dependency %	68.1

Source: A.K. Chapagain, A.Y. Hoekstra, UNESCO-IHE., August 2003

Table 6: Saudi self sufficiency in Foodstuffs for major food commodity Group (2000- 20007)

Item	2000-2004	2005	2006	2007
	S.S.R. %	S.S.R. %	S.S.R. %	S.S.R. %
Wheat and Flour	98.62	97.44	97.56	97.56
Maize	3.34	6.88	8.69	8.69
Rice	-	-	-	-
Barley	2.51	0.79	0.41	0.41
Potatoes	94.26	100.26	101.55	101.55
Pulses (total)	-	-	0.00	-
Vegetables (total)	83.98	82.56	77.66	77.66
Fruits (total)	64.89	66.08	64.50	64.98
Sugar (Refined)	-	-	-	-
Fats & Oils (total)	1.22	1.12	0.42	0.42
Red Meat	58.83	55.63	48.44	48.44
Poultry Meat	63.43	55.33	58.28	58.28
Fish	43.22	38.73	43.96	60.40
Eggs	104.26	106.21	104.18	103.86
Milk & Dairy Production	42.97	40.04	27.98	28.45

Source: Arab Organization for Agriculture Development (AOAD)

Irrigation and Water Demand Management: The Kingdom of Saudi Arabia has an area of about 2.25 million km^2, most of which is located in arid regions. The available surface water and groundwater resources are limited, precipitation rates are low and evaporation is high. The average annual rainfall is less than 150 mm in most of the country. During the last two decades, Saudi Arabia has experienced comprehensive development in all sectors coupled with high growth rates in population and living standards. The annual national water demand has increased from 2,352 million cubic meters (MCM) in 1980 to about 27,239 MCM in 1990 and to more than 30,000 MCM in 1992., The cultivated area in Saudi Arabia has increased from less than 0.4 million Ha in 1971 to 1.62 million Ha. in 1992 [13] and total consumption of irrigation water has increased from about 1,850 MCM in 1980 to 29,826 MCM in 1992, Table 2 shows the growth of water use in Saudi Arabia, 1980–2010 (millions of cubic meters).

The total number of drilled wells increased from about 26,000 in 1982 to about 52,500 in 1990 and hundreds or even thousands of production wells were thickly clustered in some agricultural areas, Table 3 shows cumulative number of public wells (for different purposes) according to type up to 2003 G. and Table 4 shows cumulative number of private wells licensed for different purposes by region until 2002G.

The Impossibility of Saudi Self Sufficiency in Foodstuffs: Saudi Arabia's food independence is impossible to sustain, Saudi renewable water resources are insufficient and the country's population growth is among the highest in the world. Between 1975 and 2004, Saudi population grew by an average annual rate of 4.1 percent; compared with Arab countries, 2.6 percent; the Saudi population is forecast to increase from its size in 2006 of 24 million to reach 40 million in 2025.

Given such a high rate of growth and, regardless of how large Saudi water reserves might be, Saudi food independence is impossible to sustain in the long-run. It is only a matter of time before irrigation exhausts the recoverable contents of the aquifers. An individual needs about 1,000 cubic meters of water each year to raise the food requirement of that individual. Table 5 shows Water footprints, water scarcity, water self-sufficiency and water dependency of Saudi Arabia (1995-1999).

Saudi Arabia's population of 24 million people in 2006 would need an estimated 24 billion cubic meters of water for self-sufficiency in foodstuffs. As the Saudi population reaches 40 million around 2025, Saudi water consumption embedded in foodstuffs would reach 40 billion cubic meters. Even if and this is a very big if the volume of irrigation water were to remain unchanged from the 17 billion cubic meters in 2006, the proportion of food produced domestically to total Saudi food requirements would be 43 percent. Under the more likely scenario, however, as Saudi nonrenewable aquifers get depleted and Saudi agriculture becomes reliant on renewable water sources only, the ratio of Saudi food self-sufficiency in 2025 would be 12.5 percent--given MAW's estimate of the country's renewable water sources of about 5 billion cubic meters per annum, Table 6 shows Saudi self

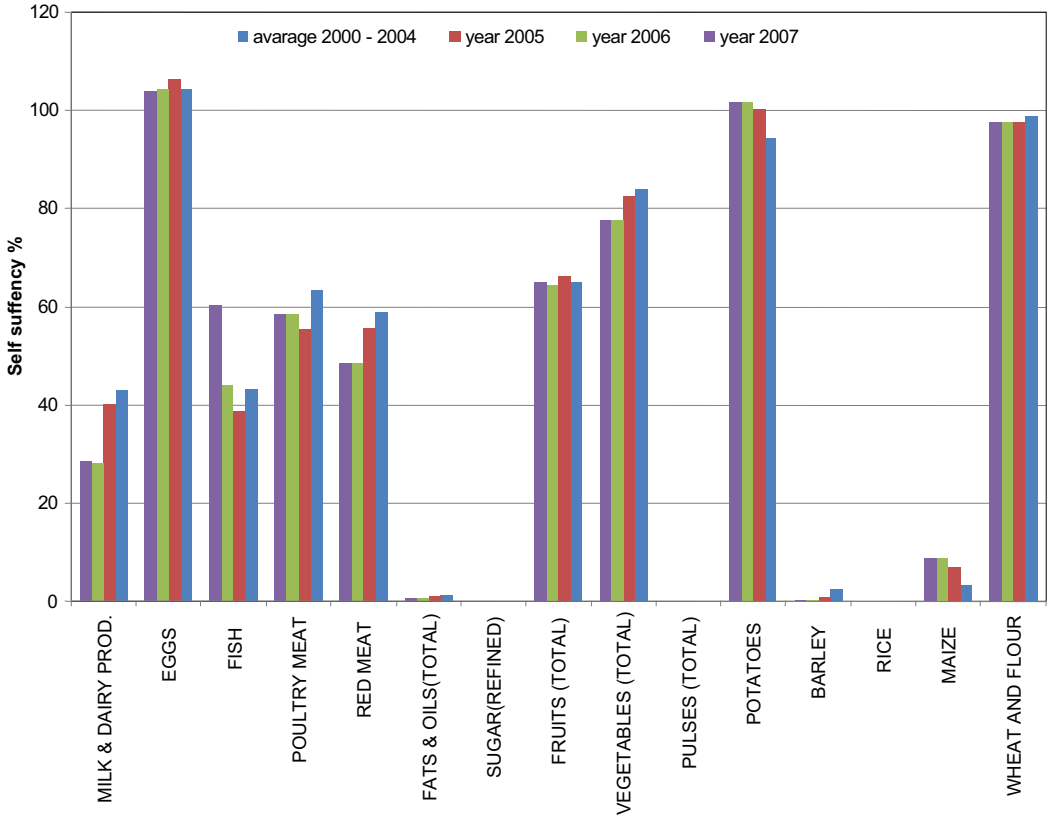

Fig. 2: Saudi self sufficiency in Foodstuffs for major food commodity Group (2000- 20007)

sufficiency in Foodstuffs for major food commodity Group from 2000- 20007 and Figure 2: represents Saudi self sufficiency in Foodstuffs for major food commodity Group (2000- 20007) from this figure is noticed that self sufficiency of maize, Rice, Sugar, Fats and Oils less than 10%.

Saudi Virtual Water Trade: In 2006, Saudi agriculture used 17 billion cubic meters of water from all sources, leaving a gap of 7 billion cubic meters, or 30 percent, to be imported. Between 2002 and 2006, Saudi foodstuffs imports added up to $35 billion--an average of $7 billion for each of the five years involved During the previous five years (1997-2001), Saudi food imports added up to $24 billion, an annual average of almost $5 billion. As Saudi Arabia's population grows, the water sufficiency ratio will correspondingly decline and food imports will increase.

Saudi Arabia not only increased the production of water-using foodstuffs for domestic consumption, but it has also been exporting to neighboring city-states animals, animal products, vegetables, animal and vegetable fats and oils, beverages and other high-water-using agro-commodities, though the export of alfalfa was stopped in 2000.

Foodstuffs are an encapsulation of water, Food is virtual water. Saudi food exports are synonymous with shipping away the country's finite water resources. For the five years between 1997 and 2001, the volume of Saudi water used to produce the exported foodstuffs averaged 1.054 billion cubic meters per year, Table 7: Virtual water flows for Saudi related to international trade of crop, livestock and industrial products (1997-2001), During the ten-year period between 1997 and 2006, an arid Saudi Arabia exported around 37.5 billion cubic meters of its finite water endowment, most of which was nonrenewable.

Estimation of Virtual Water Export and Import: The code is developed by the Food and Agricultural Organization of the United Nations (FAO), The climate parameters and crop coefficients required for estimating crop water requirements are available in the FAO databases (FAO, 1986).

Table 7: Virtual water flows for Saudi related to international trade of crop, livestock and industrial products (1997-2001)

Gross virtual water flows ($10^6 m^3/yr$)

Crop products		livestock products		Industrial products		Total		Net virtual water
Export	Import	Export	Import	Export	Import	Export	Import	Import
362	10598	556	2006	136	1703	1054	14308	13254

Source: A.K. Chapagain, A.Y. Hoekstra, UNESCO-IHE., August 2003,

Table 8: Virtual water content for major food commodity group

Item	Minimum Virtual water $M^3/100$ kg	Maximum Virtual waterc $M^3/100$ kg	Average Virtual water $M^3/100$ kg	Average Virtual water M^3/Ton
Wheat and Flour	115	144	129.5	1295
Maize	71	190	130.5	1305
Rice	108	170	139.0	1390
Barley	115	144	129.5	1295
Potatoes	14	22	18.0	180
Pulses (total)	167	300	233.5	2335
Vegetables (total)	20	22	21.0	210
Fruits (total)	40	50	45.0	450
Sugar (Refined)	125	200	162.5	1625
Fats & Oils (total)	500	800	650.0	6500
Red Meat	875	1750	1312.5	13125
Poultry Meat	188	375	281.5	2815
Fish	75	150	112.5	1125
Eggs	300	600	450.0	4500
Milk & Dairy Production	69	138	103.5	1035

Source: Hoekstra and Hung [14, 6]

Applying the CROPWAT model, Hoekstra and Hung [14, 6] estimated CVWC for major food crops in different countries. Given the crudeness of the available data and the complexity of cropping systems in different countries, errors are inevitable in the estimation.

Nevertheless, improving the estimation requires more accurate data at the country and sub-country levels, which are not currently available for all the countries. For this reason, our study uses the CVWCs (Crop Virtual Water Contents) estimated by Hoekstra and Hung [14, 6] in the calculation of the volumes of virtual water flows.

The "gross volume of virtual water import" (GVWI) to a country is the sum of "crop imports" (CI) multiplied by their associated crop virtual water content (CVWC) in that country:

$$GVWI = (CI \times CVWC) \quad (1)$$

Similarly, the "gross volume of virtual water export" (GVWE) from a country is the sum of "crop exports" (CE) multiplied by their associated crop virtual water content (CVWC) in that country:

$$GVWE = (CE \times CVWC) \quad (2)$$

Various Sources of Data Have Been Utilized:

- The annual food balance sheets from FAO were the major source of data: this data base contains information related to production, imports, exports and stock changes for most countries in the world. In addition, it also provides data related to the type of use of most food products; uses are split into the following categories: food, feed, seed, processing, waste and other uses. Data are available for the period 1961 to 1999.
- A few data available in various publications were also utilized. In general these data confirmed that the FAO data were quite accurate, table 8: shows virtual water content for major food commodity group.

Table 9 shows Saudi Exports and Imports for major food commodity Group from 2000 to 20007 which used to calculate Saudi Virtual water exports and virtual water Imports for major food commodity group during the period from 2000 to 2007., table 10 shows Saudi virtual water exports and virtual Water Imports for major food commodity group from 2000 to 2007.

Table 9: Saudi exports and Imports for major food commodity group from 2000 to 20007(1000 Ton)

	Exports (1000 Ton)				Imports (1000 Ton)			
ITEM	2000-2004	2005	2006	2007	2000-2004	2005	2006	2007
Wheat and Flour	1.96	2.56	1.19	1.19	34.21	72.25	67.03	67.03
Maize	0.40	0.25	0.21	0.21	1086.09	1226.50	1322.58	1322.60
Rice	4.57	6.02	10.42	10.42	795.60	999.00	968.00	968.00
Barley	1.92	6.43	2.48	2.48	4345.09	5979.70	7590.97	7591.00
Potatoes	36.33	42.70	60.68	60.68	57.67	41.50	53.50	53.50
Pulses (total)	2.83	5.14	3.62	3.62	70.84	70.58	80.88	80.88
Vegetables (total)	57.61	68.72	113.10	113.06	453.53	611.88	731.00	731.00
Fruits (total)	44.50	65.34	72.78	72.78	743.04	909.66	925.23	925.23
Sugar (Refined)	58.55	184.10	184.10	184.06	451.49	70.34	959.39	959.39
Fats & Oils (total)	20.97	27.62	39.52	39.56	117.15	202.29	548.96	548.96
Red Meat	5.11	2.41	15.58	15.58	132.54	137.17	195.39	195.39
Poultry Meat	12.05	17.37	33.00	33.00	281.95	450.84	416.63	416.63
Fish	3.75	9.39	13.94	13.94	82.39	127.71	110.00	110.00
Eggs	9.90	12.67	10.06	10.06	4.79	3.66	3.72	3.72
Milk & Dairy Production	240.33	218.30	218.30	218.34	1757.13	2039.60	2579.12	2579.10

Source: Arab Organization for Agriculture Development (AOAD)

Table 10: Saudi virtual water exports and virtual Water Imports for major food commodity group from 2000 to 2007

	Virtual water EXPORTS (10^6 M^3/year)				Virtual water IMPORTS(10^6 M^3/year)			
ITEM	2000-2004	2005	2006	2007	2000-2004	2005	2006	2007
Wheat and Flour	2.54	3.32	1.54	1.54	44.3	93.6	86.8	86.8
Maize	0.53	0.33	0.27	0.27	1417.0	1601.0	1726.0	1726.0
Rice	6.36	8.37	14.48	14.48	1105.0	1389.0	1346.0	1346.0
Barley	2.49	8.33	3.21	3.21	5627.0	7744.0	9830.0	9830.3
Potatoes	6.54	7.68	10.92	10.92	10.4	7.5	9.6	9.6
Pulses (total)	6.62	12.00	8.44	8.44	165.4	164.8	188.9	188.9
Vegetables (total)	12.10	14.43	23.74	23.74	95.2	128.5	153.5	153.5
Fruits (total)	20.02	29.40	32.75	32.75	334.4	409.3	416.4	416.4
Sugar (Refined)	95.14	299.10	299.10	299.10	733.7	114.3	1559.0	1559.0
Fats & Oils (total)	136.30	179.50	256.90	257.20	761.5	1314.9	3568.3	3568.3
Red Meat	67.07	31.63	204.50	204.50	1739.6	1800.4	2564.5	2564.5
Poultry Meat	33.92	48.90	92.91	92.91	793.7	1269.1	1172.8	1172.8
Fish	4.22	10.56	15.69	15.69	92.7	143.7	123.8	123.8
Eggs	44.57	57.02	45.27	45.27	21.5	16.5	16.7	16.7
Milk & Dairy Production	248.74	225.98	225.98	225.98	1818.6	2111.0	2669.4	2669.4
total	687.18	936.55	1235.69	1235.95	14761.1	18306.7	25431.8	25431.8

Table 11: Saudi virtual water balance for major food commodity group from 2000 to 2007

	Virtual water Balance (10^6 M^3/year)			
ITEM	2000-2004	2005	2006	2007
Wheat and Flour	41.8	90.2	85.3	85.3
Maize	1416.8	1600.2	1725.7	1725.7
Rice	1099.5	1380.6	1331.3	1331.3
Barley	5624.4	7735.4	9827.1	9827.1
Potatoes	3.8	-0.2	-1.3	-1.3
Pulses (total)	158.8	152.8	180.4	180.4
Vegetables (total)	83.1	114.1	129.8	129.8
Fruits (total)	314.3	379.9	383.6	383.6
Sugar (Refined)	638.5	-184.8	1259.9	1259.9
Fats & Oils (total)	625.2	1135.4	3311.4	3311.1
Red Meat	1672.5	1768.7	2360.0	2360.0
Poultry Meat	759.8	1220.2	1079.9	1079.9
Fish	88.5	133.1	108.1	108.1
Eggs	-23.0	-40.5	-28.5	-28.5
Milk & Dairy Production	1569.9	1885.0	2443.4	2443.4
Total	14074.0	17370.2	24196.0	24195.8

Table 12: Saudi Virtual water trade for major food commodity Group from 2000 to 2007

Year	Virtual Water Exports (10^6 M^3/year)	Virtual Water Imports (10^6 M^3/year)	Virtual water Balance (10^6 M^3/year)
Average 2000-2004	6872	14761	14074
2005	9365	18306	17370
2006	1236	25432	24196
2007	1236	25432	24196

During the eight-year period between 2000 and 2007, Saudi Arabia exported around 6.156 billion cubic meters for major food commodity group, during the same period Saudi Arabia imported around 84 billion cubic meters for major food commodity group with average 10.5 billion cubic meters for major food commodity group Table 11 shows Saudi virtual water balance for major food commodity group from 2000 to 2007. and Table 12 shows Saudi virtual water trade for major food commodity group from 2000 to 2007.

CONCLUSION AND RECOMMENDATIONS

- In 2006, Saudi agriculture used 17 billion cubic meters of water from all sources, leaving a gap of 7 billion cubic meters, or 30 percent, to be imported. Between 2002 and 2006, Saudi foodstuffs imports added up to $35 billion--an average of $7 billion for each of the five years involved During the five years (1997-2001), Saudi food imports added up to $24 billion, an annual average of almost $5 billion.
- During the eight-year period between 2000 and 2007, Saudi Arabia exported around 6.156 billion cubic meters for major food commodity group, during the same period imported around 84 billion cubic meters for major food commodity group with average 10.5 billion cubic meters for major food commodity group.
- The most direct positive effect of virtual water trade is the water savings it generates in the countries or the regions that import the products. This effect has been widely discussed in virtual water studies since the nineties (Allan, 1999; Hoekstra, 2003).
- The agricultural exports generated inefficiently economical benefits at the national level, consequently at the farmer's level, the value of agricultural product exports is not beneficial to reflect the real cost of water, by continuing to export virtual water, Saudi is reducing the volume of real water available for alternatives, more profitable or sustainable use.
- Currently, the water situation is unsustainable and the demand greatly exceeds water supply. Also the projected demand is expected to increase with population growth. Agricultural water policies are needed by increasing water use efficiency to get "More crop per drop" and effectively allocate the water to get "More jobs per drop".
- Saudi Arabia can used food trade as an active policy instrument to mitigate local and regional water scarcity. Rather than striving for food self-sufficiency, water-short countries should import food from water-abundant countries. Trade in virtual water as an answer to water shortages, Groundwater depletion and further environmental degradation is appealing.

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