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Virtual water content for meat and egg production through livestock farming in Saudi Arabia

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Abstract The concept of virtual water content (VWC) may facilitate an understanding of total water demand for commodity production. The water consumption for livestock production forms a significant fraction of freshwater demand in arid regions, i.e., Saudi Arabia. In this paper, VWC was estimated for different livestocks in the 13 regions of Saudi Arabia. The VWC for camel production was also estimated, which has not been investigated in the previous studies. The overall VWC for livestock in Saudi Arabia was about 10.5 and 8.9 billion m^3 in 2006 and 2010, respectively. This study shows the decreasing trend of overall VWC in producing livestock in Saudi Arabia. The VWC were highest in Riyadh followed by Eastern region, Qaseem, Hail, and Makkah with ranges of 3587–4112, 1684–2044, 1007–1331, 644–810, and 504–715 million m^3/year, respectively. The results demonstrate that a shift in diet from the high VWC meat to low VWC meat may reduce the overall VWC for livestock production. The findings of this analysis provide an assessment of the quantity and trend of water demand for livestock production in Saudi Arabia, which is useful to assess the development of an information-based agricultural water management strategy.

Keywords Virtual water content · Water saving · Water resources management · Arid region · Livestock farming · Water demand

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Introduction

The agricultural sector uses the largest share of freshwater resources worldwide. The average worldwide freshwater consumption per person was about 1385 m^3, of which agriculture, industry and domestic use consumed about 91, 5, and 4%, respectively (Ouda 2014). In the Middle East, agriculture accounts for over 75% of total water consumption. However, with increasing demand resulting from population growth coupled with higher living standards, water will be reallocated away from the agriculture sector to the domestic and industrial sectors (Karrou et al. 2011; Ouda 2014). A rational water resource management plan (WRMP) requires the estimate of direct and indirect consumptions of water. The concept of water footprint (WFP) has been increasingly used as an indicator of water consumption and it is an informative tool for comprehensive understanding of water demand at national level (Hoekstra 2003; Chapagain and Hoekstra 2003; Charchousi et al. 2015). Past studies reported that the major fractions of WFP were due to the agricultural and industrial consumptions, while agriculture consumed more than 80% of global freshwater supplies (Shiklomanov 2000; Mekonnen and Hoekstra 2011). Almost 30% of the global agricultural

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WFP was related to livestock animal production (Mekonnen and Hoekstra 2012). The WFP of many animal products is larger than the WFP of crop products with equivalent calorie value (Mekonnen and Hoekstra 2012). The average WFP per calorie for beef was 20 times larger than for cereals and starchy roots, while the WFP per gram of beef protein was 6 times larger than for pulses (Mekonnen and Hoekstra 2012). Earlier study reported that by replacing all meat with an equivalent amount of crop products, a 30% reduction of the food-related WFP per American citizen could be obtained (Mekonnen and Hoekstra 2012). However, there are several animal products, which have lower WFP than crop products when nutritional value is considered. The worldwide meat production has been projected to be double by 2050 in the developing countries, due mainly to the increase in production and consumption (IAASTD 2008; Steinfeld et al. 2006; Alexandratos and Bruinsma 2012; Ran et al. 2016), which is likely to intensify the freshwater crisis in the future (Rost et al. 2008; Ran et al. 2016).

An information-based water management strategy can support the development of an optimal management plan to reduce water demand-supply gap, especially in arid and semi-arid regions, such as Saudi Arabia. The development of an optimal WRM plan requires comprehensive understanding of water demand pattern, supply system, and the estimate of water quantities and trends (Allan 1997). The analysis of virtual water content (VWC), which is closely linked to WFP, provides an information-based understanding of water demand for agricultural commodities, including livestock production (Hoekstra and Chapagain 2007; Mekonnen and Hoekstra 2012; Gerbens-Leenes et al. 2013). Virtual water is defined as the volume of water required to produce a commodity or a service. This concept was first introduced when the option of importing virtual water (coming along with food imports) was examined as a partial solution to water scarcity problems in the Middle East countries (Allan 1993, 1994, 1997). To assess the national WFP, it is essential to quantify the VWC for the products that are produced and consumed locally in addition to the imported or exported VWC of the products that are leaving and entering a country (Hoekstra and Chapagain 2007). Quantification of VWC for the livestock production plays an important role in understanding the aspects of national WFP in Saudi Arabia. The livestock animal specific VWC identifies the type of animal responsible for greater fractions of water demand and thus provides an opportunity to optimize water use in livestock farming.

The water consumption of agricultural products used as feed items forms the major fractions of VWC for livestock farming (Rost et al. 2008; Mekonnen and Hoekstra 2012; Ran et al. 2016). The WFP of an agricultural product is defined as the sum of the blue, green, and grey WFP (Mekonnen and Hoekstra 2011). The blue WFP refers to water consumption from surface and groundwater sources, and green WFP refers to consumption of green water resources (e.g., rainwater in so far as it does not become run-off). The grey WFP refers to pollution and is defined as the volume of freshwater required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards. Worldwide, green water contributes about 80% of the consumptive water use (CWU) in agricultural production (Molden et al. 2010; Rockström et al. 2014). In livestock production, green water accounts for 90% of total CWU (Mekonnen and Hoekstra 2012), while only 2–8% of CWU is blue water used for drinking water, servicing, and feed mixing purposes (Steinfeld et al. 2006; Mekonnen and Hoekstra 2012; de Boer et al. 2013; Ran et al. 2016). In Saudi Arabia, there is no natural surface water flow system and the countrywide average annual rainfall is very low (< 70 mm/year) (Chowdhury and Al-Zahrani 2013; Al-Zahrani et al. 2015). The soil moisture content is low and evaporation rate is extremely high (Missimer et al. 2014). As a result, the contribution of green water to agricultural crop production is minimal (MOWE 2013; Chowdhury et al. 2016). The only dependable source of water for crop production is groundwater pumped from the non-renewable aquifers, which represented the blue water (MOWE 2013; USDA 2016). The agricultural farms typically pump the groundwater for irrigation (Chowdhury et al. 2016).

Different types of meat (e.g., camel, cow and dairy cow, goat, poultry) and egg are produced through the in-house and open grazing farming in Saudi Arabia (SSYB 2011). The VWC for these livestock products varies depending on the climatic conditions, the region and the applied farming practices. For example, Chapagain and Hoekstra (2003) predicted the VWC for 1 ton of beef and poultry meat in Saudi Arabia as 11,359 and 4146 m^3, respectively. In Egypt, these values were 15,752 and 2268 m^3/ton, respectively while in Germany, these were 7768 and 877 m^3/ton, respectively. The differences in VWC were related to production efficiency, including the genetic merit of animals and farming management practices. For example, the lower value of VWC for beef in Germany was due to higher growth rate than in Saudi Arabia. In Saudi Arabia, climatic variability between the northern and southern regions is significant, which affects VWC of livestock farms. Furthermore, farming practices and feed consumptions are likely to be variable. In addition, the country produces a large amount of camel meat, while camel is not the typical livestock in most countries, and the VWC for camel has seldom been investigated (Chapagain and Hoekstra 2003). As a result, data on VWC presented in the previous studies do not reflect the major livestock animals

and farming practices applied in Saudi Arabia (Chapagain and Hoekstra 2003; Mekonnen and Hoekstra 2010, 2011, 2012). Better understanding of VWC for livestock animals and egg production in different regions of Saudi Arabia is highly needed to guide the allocation of livestock farming and optimize water use.

The total water demand in Saudi Arabia was increasing for the last few decades, due mainly to the rapid population growth and urbanization, and the expanded agricultural activities (World Bank 2010; UNDP 2013). In 2010, the gap between water demand and sustainable water supply was about 11.5 billion m^3 (UNDP 2013). The water demand-supply gap was bridged through extensive use of non-renewable groundwater resources, desalinated water, and minimal use of treated wastewater (UNDP 2013). The depletion of groundwater volumes threatens the sustainable development plan of the country and raises significant water security issues. To optimize the agricultural water demand and minimize the water demand vs. supply gap, the country has completely phased out wheat production in 2015 and there is a plan to phase out the production of fodder crop by 2019. No doubts, these two measures could be very effective. It is to be noted that the agriculture sector is the largest consumer of freshwater, in which the share of the livestock farms is significant (Al-Zahrani and Baig 2011; Al-Shayaa et al. 2012; Mekonnen and Hoekstra 2012).

The importance of VWC for livestock farms in Saudi Arabia has not been previously investigated. This study assesses the VWC for camel, cow, dairy cow, sheep, goat, poultry, and egg production in the 13 regions of Saudi Arabia. In this study, the regional variability of VWC in the country is examined. Finally, the analysis provides recommendations towards the development of an information-based agricultural water management strategy that will optimize freshwater use in livestock industry by highlighting the limitations and future research needs.

Methodology

Saudi Arabia is divided into 13 administrative regions. The main farming animals are camel, cow (used for meat production), dairy cow (used for milk production), sheep, goat, and poultry. In addition, a large number of hens (used for eggs) are also produced. The livestock production analysis was based on data for the period of 2006–2010 (Table 1) obtained from the Saudi Statistical Yearbook (SSYB 2011). The details of productive animals and eggs for each year can be found in SSYB (2011). These data represent the total number of productive animals (e.g., slaughtered) and eggs (e.g., consumed) in the respective years. The feeding composition, style, and water consumption for

these animals prior to achieving the slaughtering ages were obtained through field survey and were validated through data obtained from the literature (Chapagain and Hoekstra 2003; Abdallah and Faye 2013).

To calculate the VWC, the WFP methodology of Mekonnen and Hoekstra (2012) was followed. The WFP was predicted as

$$\mathrm{WFP}[a,c,s] = \mathrm{WFP}_{\mathrm{feed}}[a,c,s] + \mathrm{WFP}_{\mathrm{drink}}[a,c,s] \\ + \mathrm{WFP}_{\mathrm{service}}[a,c,s], \quad (1)$$

where $\mathrm{WFP}[a,c,s] = $ WFP for category a animal in country c for production systems s. $\mathrm{WFP}_{\mathrm{feed}}[a,c,s]$, $\mathrm{WFP}_{\mathrm{drink}}[a,c,s]$, and $\mathrm{WFP}_{\mathrm{service}}[a,c,s]$ represent the WFP for category a animal in country c for production systems s related to feed, drinking water, and service water consumption purposes, respectively. In the current study, VWC was predicted in one country ($c = 1$: Saudi Arabia) for seven categories of farm products ($a = i = 1,2, ….7$, representing camel, cow, dairy cow, sheep, goat, poultry, and egg) following one production system ($s = 1$: mixed type). It should be noted that animal feed items are originated from domestic and imported products. To calculate the WFP for the feed items, Mekonnen and Hoekstra (2012) used the weighted average WFP for the domestic and imported products. The weighted average WFP was calculated as

$$\mathrm{WFP}^*[p] = \frac{P[p] \times \mathrm{WFP}[p] + \sum_{\mathrm{n_e}} (T_i[\mathrm{n_e},p] \times \mathrm{WFP}[\mathrm{n_e},p])}{P[p] + \sum_{\mathrm{n_e}} (T_i[\mathrm{n_e},p])}, \quad (2)$$

where $P[p] = $ domestic production of feed item p (ton/year); $T_i[\mathrm{n_e}, p] = $ imported amount of feed item p (ton/year) from exporting country $\mathrm{n_e}$; $\mathrm{WFP}[p] = $ WFP of feed item p for domestic production (m^3/ton); $\mathrm{WF}[\mathrm{n_e}, p] = $ WFP of feed item p for exporting country $\mathrm{n_e}$ (m^3/ton); and $\mathrm{WFP}^*[p] = $ weighted average WFP for feed item p (m^3/ton). The calculation of weighted average WFP for a feed item requires the amounts of imported feed item from the exporting countries, WFP of this item in the source countries, domestic production of this item, and the amount of this item used for livestock farms to feed these animals (Mekonnen and Hoekstra 2012). At national level, this calculation can be performed through the use of country-specific imported feed amounts and WFP, and total domestic production and domestic WFP. However, at regional level within a country, it is often difficult to obtain precise information on these data. To minimize the complexity and information gap at regional level, this study distributes the imported feed items among the regions based on population distributions. The total population in the country was estimated to be

Table 1 Summary of livestock production in Saudi Arabia (in million)

Region	Camel		Cow		Dairy cow		Sheep		Goat		Poultry		Egg	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
Riyadh	0.12	0.090	0.190	0.23	0.0729	0.1035	1.98	0.740	0.39	0.14	77.86	75.09	1096	1439
Makkah	0.021	0.020	0.01	0.007	0.0000	0.0000	0.42	0.39	0.24	0.20	182	80.62	831	881
Madinah	0.006	0.012	0.003	0.00	0.0000	0.0000	0.28	0.27	0.20	0.12	11.00	10.23	129	194
Qaseem	0.034	0.020	0.015	0.016	0.0005	0.0004	1.23	0.721	0.13	0.05	132	138	505	580
Eastern region	0.034	0.017	0.104	0.095	0.0270	0.0491	1.003	0.641	0.05	0.03	26.19	25.19	325	397
Aseer	0.013	0.007	0.014	0.012	0.0000	0.0000	0.86	0.66	0.41	0.13	46.86	56.19	95	255
Tabouk	0.003	0.001	0.003	0.003	0.0014	0.0014	0.063	0.043	0.08	0.05	3.49	4.67	59	67
Hail	0.022	0.018	0.004	0.006	0.0030	0.0027	0.64	0.42	0.11	0.05	19.41	25.56	20	59
Northern region					0.0000	0.0000	0.014	0.024			0.15	1.9		
Jazan	0.003	0.004	0.018	0.017	0.0000	0.0000	0.28	0.23	0.32	0.16	4.13	1.565		
Nazran	0.010	0.010	0.003	0.003	0.0009	0.0000	0.12	0.065	0.08	0.03	3.48	4.74	62	24
Al-Baha	0.004	0.007	0.003	0.004	0.0000	0.0000	0.15	0.13	0.17	0.05	6.64	0.41	24	16
Al-Jouf	0.010	0.006	0.002	0.000	0.0000	0.0000	1.06	0.891	0.08	0.04	2.04	1.58	16	74
Total	0.284	0.213	0.368	0.390	0.1058	0.1571	8.091	5.231	2.253	1.06	515.3	425.8	3161	3987

Empty cell no data due to very low numbers

around 27.1 million in 2010 (SSYB [2011](); City population [2016]()), in which Makkah, Riyadh, Eastern region, Aseer, Madinah, Jazan, Qaseem, Tabouk, Hail, Najran, Al-Jouf, Al-Baha, and Northern region had 25.5, 25.0, 15.1, 7.1, 6.6, 5.0, 4.5, 2.9, 2.2, 1.9, 1.6, 1.5, and 1.2% of the total populations, respectively. The imported feed items were distributed among these regions using the respective similar percentages (Table 2). Up on availability of region-specific production and source-specific import data for all feed items in a region, the WFP* calculations can be

updated in future. Using the data equation (2) and following equation (1), the VWC can be estimated as

$$\text{VWC}_i = \text{VWC}_{feed} + \text{VWC}_{drink} + \text{VWC}_{service}, \tag{3}$$

where VWC_i = virtual water content (VWC) for i category animal (m^3/animal), VWC_{feed} = VWC for feed consumed by an animal (m^3/animal), VWC_{drink} = VWC for drinking purposes (m^3/animal), and $\text{VWC}_{service}$ = VWC for servicing/cleaning purposes (m^3/animal). The VWC for feed was calculated based on the amount of feed consumed

Table 2 Weighted water footprint (m^3/ton) (WFP*) for feed items used in Saudi Arabia

	Riyadh	Makkah	Madinah	Qaseem	Eastern region	Aseer	Tabouk	Hail	Jazan	Najran	Al-Baha	Al-Jouf
Wheat	1123	1210	1070	951	965	849	944	851	1018	1142	1125	967
Oats	2081	1122	2114	1533	1770	990	1385	1575	1690	1170	1185	1653
Barley	669	835	555	444	718	610	539	704	496	679	564	548
Other grain	533	441	481	456	631	454	481	552	558	468	357	512
Maize/corn	1643	1403	1360	1909	2032	883	1637	1517	987	1279	1506	1849
Dry peas	1170	966	1081	1325	1328	661	1145	1485	845	1052	801	1333
Soya meal	1043	677	676	1012	1232	682	1071	1294	678	785	728	1074
Canola meal	933	655	655	983	1201	655	1037	1256	655	764	710	1037
Mill screen	1225	805	805	1208	1476	805	1275	1543	805	939	872	1275
Alfalfa	733	596	658	708	830	401	771	841	607	724	613	648
Dry hay	420	323	328	438	535	283	407	509	413	418	317	400
Silage	420	317	322	438	535	283	407	509	401	397	317	400
Other roughages	378	269	293	399	469	254	379	467	317	332	302	410

by an animal, water consumption in feed production, and slaughtering age (Chapagain and Hoekstra 2003). In many developing and developed countries, livestock feed is a mixture of crops, crop residues, and industrial products (Chapagain and Hoekstra 2003). To mix the feed items, additional water is required. The VWC for feed was estimated as

$$\text{VWC}_{\text{feed}} = (\text{CW} \times \text{SA} + \text{WFM}), \tag{4}$$

where CW = total VWC of feed crops per animal (m³/year), SA = slaughtering age (year), and WFM = volume of water for mixing of food items (m³/animal). The past studies have reported that WFM was approximately 50% of the feed volume consumed by a livestock animal (Chapagain and Hoekstra 2003; Mekonnen and Hoekstra 2012). To assess CW, the weighted WFP per ton of the feed items (WFP*) and the average feed amount are necessary (AFV). Abbas (2013) reported crop water requirements (CWR) for the major crops produced in different regions of Saudi Arabia. In this study, the CROPWAT software (Version 8), recommended by Food and Agriculture Association (FAO), was used (FAO 2009). In addition, historical rainfall and temperature data for different regions were obtained from the FAO database in the CLIMWAT 2.0 software (FAO 2012). As such, climatic variability in different regions was incorporated in this calculation (Abbas 2013; Chowdhury et al. 2016). The CWR represented the water consumption in addition to the supplements from seasonal rainfall events in these regions and it was satisfied from the non-renewable groundwater sources. The calculated CWR for different crops were divided by the crop yields to obtain the WFP for the domestic feed crops, which were used in Eq. (2) to calculate the weighted WFP (WFP*).

In Tables 3, 4, 5, and 6, indicative sample calculations along with the necessary data (e.g., feed items, amounts, slaughtering ages, live weights, etc.) are presented (Chapagain and Hoekstra 2003; Khan et al. 2003; Abdallah and Faye 2013). The feed intakes vary depending on animal type, purpose, and farming practices. The feed items are divided into grain (e.g., wheat, oats, barley, corn, dry peas, soyabean, canola, mill screen, and other grains) and non-grain (e.g., pasture, dry hay, silage, other roughages, etc.) fractions. Different animals are fed with different fractions of grain and non-grain feed items. Further details on the animal specific feed intakes are shown in Table 3. In Table 3, a VWC of feed crops sample calculation is presented for each category animal per year (CW = AFV × WFP*) in Riyadh. In Table 4, the total VWC is estimated for each category animal for up to the slaughtering age, where the CW from Table 3 and the VWC for drinking and service purposes for up to the slaughtering age are included. The animals produced through the grazing farming had lower weights than those

of the industrial farming. These data are used to calculate the VWC for unit weight of each category animal (Table 5). In Table 6, the VWC of a hen was divided into eggs and carcass. To obtain the unit VWC for egg, data on egg and carcass produced per hen and market values were collected through field survey in the local farms. The monetary fractions for egg and carcass of hen were estimated to be 0.854 and 0.146, respectively (Chapagain and Hoekstra 2003). These were multiplied by the VWC of hen (Table 4) to obtain the respective water share and then converted to a unit VWC (Table 6). Following a similar procedure and using the weighted WFP (WFP*) for the feed items from different regions (Table 2), the VWC was calculated for all regions.

The yearly water requirements for drinking and service purposes depend on local climatic conditions (i.e., temperature, humidity, rainfall etc.), farming practices, and the final farming product (e.g., meat or milk from cow; poultry or egg, etc.), which was estimated as

$$\text{VWC}_{\text{drink}} = ADD_{\text{d}} \times \text{SA} \times 365 \tag{5}$$

$$\text{VWC}_{\text{service}} = \text{ADD}_{\text{s}} \times \text{SA} \times 365, \tag{6}$$

where ADD_{d} = average water consumption per animal (m³/day) and ADD_{s} = average water demand for service purposes (e.g., cleaning) per animal (m³/day)

The unit VWC was estimated per unit weight of meat (e.g., per ton). Farming practices play an important role in predicting the unit VWC. In this analysis, a 'mixed' type, meaning the mixture of 'grazing' and 'industrial' feeding, as proposed by Chapagain and Hoekstra (2003) was considered. Gerbens-Leenes et al. (2012, 2013) reported that the livestock produced through industrial farming were heavier than those of 'grazing' farming' and, however, previously Chapagain and Hoekstra (2003) reported the opposite. Unit VWC per animal was properly calculated (Table 5).

The total VWC for each category of livestock animal (VWC$_{\text{ti}}$) was calculated as

$$\text{VWC}_{\text{ti}} = \text{VWC}_{\text{ui}} \times W_i, \tag{7}$$

where VWC$_{\text{ti}}$ = VWC for i category livestock animal (m³/year), VWC$_{\text{ui}}$ = VWC for one ton of animal, and W_i = total weight of i category livestock animal consumed in a year (ton/year). The value of W_i was calculated as

$$W_i = \text{LW}_i \times N_i, \tag{8}$$

where LW_i = live weight on an animal (ton/animal) in Table 5, and N_i = no. of livestock animal slaughtered in a year (Table 1). The total virtual water content (VWC$_T$) was finally calculated as

$$\text{VWC}_T = \sum_{i=1}^{n} \text{VWC}_{\text{ti}}. \tag{9}$$

Table 3 Indicative calculations of VWC for feed of a farm livestock animal in Riyadh (after: Chapagain and Hoekstra 2003; Mekonnen and Hoekstra 2012; Abdallah and Faye 2013; Abbas 2013; field survey)

Feed crop	WFP	Camel AFV	Camel CW	Cow AFV	Cow CW	Dairy cow AFV	Dairy cow CW	Sheep AFV	Sheep CW	Goat AFV	Goat CW	Poultry AFV	Poultry CW	Laying hen AFV	Laying hen CW
Wheat	1123	0.53	595	0.0069	8	0.055	62	0.000625	1			0.0054	6.1	0.0054	6.0
Oats	2081	0.12	250	0.0889	185	0.01	21	0.001875	4	0.0015	3				
Barley	669	0.237	159	0.1392	93	0.462	309	0.011125	7	0.0049	3				
Other grains	533			0.0042	2	0.0315	17	0.000375		0.0004	0				
Maize/corn	1643			0.0363	60	0.8495	1396	0.001625	3	0.00225	4	0.0051	8.4	0.0051	8.2
Dry peas	1170	1.2	1405	0.0048	6	0.0018	2	0.0015	2		0				
Soyabean meal	1043			0.009	9	0.1555	162	0.00075	1	0.00075	1	0.0017	1.8	0.0017	2.2
Canola meal	933			0.0077	7	0.06	56	0.000375	0	0.0004	0	0.001	0.9	0.001	1.1
Mill screen	1225			0.0195	24	0.13	159	0.000625	1		0	0.0009	1.1	0.0009	1.2
Total grain		2.087		0.3165		1.765		0.018875		0.0102	0	0.0141		0.0141	
Non grain portion	413			0.007	3	0.096	40	0.000375		0.0004	0	0.0033	1.4	0.0033	1.2
Pasture	733	1.26	923	1.123	823	0.41	300	0.11075	81	0.065	48				
Dry hay	420			0.8565	360	1.285	540	0.14175	60	0.03815	16				
Silage	420			0.4195	176	3.715	1560	0.0255	11	0.00065	0				
Other roughages	378			0.196	74			0.00225							
Total feed volume		3.347		2.303		5.41		0.2995		0.1144		0.0174		0.0174	
Total water for feed per year			3331		1829		4623		170		76		20		20

WFP weighted average water footprint for feed items (m³/ton), *AFV* average feed amount (ton/year), *CW* VWC of feed crops per animal (m³/year)

Table 4 Calculation of VWC for a livestock animal at the age of slaughtering

Animal	SA	VWC_drink ADD	VWC_drink TDD	VWC_service ADD	VWC_service TSD	VWC_feed VWC_FI VWC_FY	VWC_feed VWC_FI VWC_FT	VWC_feed VWC_M VWC_MY	VWC_feed VWC_M VWC_MT	VWC_i
Camel	4	30	43.80	6.5	9.49	3331	13324.4	1.67	6.69	13384.3
Cow	3	21.5	23.54	6.5	7.12	1829	5488.3	1.15	3.46	5522.5
Dairy cow[a]	8.83	33.9	109.3	4.3	13.9	4623	40823.4	2.71	23.9	40970.4
Sheep	1.5	3.98	2.18	3.5	1.92	170	254.6	0.15	0.23	258.9
Goat	2	2.09	1.53	2.5	1.83	76	151.1	0.057	0.11	154.6
Poultry	0.20	0.28	0.02	0.14	0.01	20	3.92	0.009	0.002	3.96
Hen	1.44	0.24	0.13	0.12	0.06	20	28.2	0.009	0.013	28.45

[a] Dairy cow total life time = 10 years [0–1 year = calves; 1–3 years = heifers; 3–10 years = dairy, equivalent to 8.83 years of dairy period

SA average slaughtering age (year), *ADD* average daily demand (l/day), *TDD* total drinking demand: (m³/animal), *TSD* total service demand (m³/animal), *VWC_drink* VWC for drinking, *VWC_service* VWC for servicing, *VWC_feed* VWC for feed, *VWC_FI* VWC for feed intake, *VWC_FY* VWC for feed intake in 1 year (m³/year), *VWC_FT* VWC for total feed intake (m³/animal), *VWC_M* VWC for feed mixing, *VWC_MY* VWC for feed mixing in 1 year (m³/year), *VWC_MT* VWC for total feed mixing (m³/animal), *VWC_i* overall VWC for *i* category animal (m³/animal)

Table 5 Calculation of VWC for unit weight of a livestock animal meat at slaughtering age

Type of animal/bird	LW_i			VWC_{ui}
	Grazing	Industrial	Mixed[+]	
Camel	0.63	0.726	0.678	19,741
Cow	0.4	0.545	0.4725	11,688
Dairy cow	0.27	0.45	0.36	113,807
Sheep	0.04	0.053	0.0465	5568
Goats	0.035	0.04	0.0375	4122
Poultry	0.0018	0.0022	0.002	1978
Hen	0.0015	0.002	0.00175	16,256

LW_i living weight of i category animal (ton/animal), VWC_{ui} unit VWC of i category animal (m³/ton)

Table 6 Dividing the VWC between the carcass and eggs of a hen

Product	W_E	M_P	M_V	T_P	V_F	W_S	VWC_{ui}^a
Egg	0.00882	13889	122.5	143.5	0.854	24.28 = (≈ 28.45 × 0.854)	2753
Carcass	0.00175	12,000	21		0.146	4.16	2379

W_E weight of egg (ton/hen), M_P market price (SR/ton), M_V monetary value of product (SR/hen), T_P total price (SR/hen), V_F value fraction, W_S water share (m³/product/hen), *Egg* each hen produces 210 of eggs in their life period; weight of an egg = 42 g; price of an egg = SR 0.58; 1 ton = 23,810 eggs, *Carcass* price of 1 kg of hen = SR. 12

[a] Data obtained by adjusting the VWC_i from Table 4 by the weights of mixed farming

Result

Production of livestock

From 2006 to 2010, production of camel, sheep, goat, and poultry was decreased by 24.3, 35.5, 54, and 17.4%, respectively, while production of cow, dairy cow, and eggs was increased by 6.5, 48.5, and 26.1%, respectively. The data demonstrate decreasing trends for camel in most regions (4.8–66.7%) except Madinah, Jazan, and Al-Baha, where camel production was increased by 33.3–100% (Table 1). Production of cow was increased in Riyadh, Qaseem, Hail, and Al-Baha by 6.7–33.3%. Production of dairy cow was also increased in Riyadh and Eastern region by 41.8 and 81.8%, respectively. In this period, sheep production was decreased in all regions except the Northern region, while goat production was decreased in all regions. Production of poultry was increased in Qaseem, Aseer, Tabouk, Hail, and Najran regions, while egg production was increased in all regions except Najran and Al-Baha (Table 1).

The percentile distributions of the livestock animals are shown in Fig. 1. Most of the camel was produced in Riyadh (42.5–42.9%) followed by Qaseem (9.4–12.1%) and Eastern region (8–12.1%). The cow was produced mostly in Riyadh (51.5–58.5%) and Eastern region

(24.2–28.2%). The dairy cow was also highest in Riyadh (65.9–69.0%) and Eastern region (25.5–31.3%). In 2006 and 2010, production of camel, cow, and dairy cow did not show significant shift in terms of the regions. The production of camel and cow was likely to have the major shares of VWC in the livestock farms, indicating that the regions with higher numbers of these animals might have sustained pressure on the groundwater resources.

Livestock feed and unit virtual water content

The regional-weighted WFP of the main feed items is shown in Table 2. Significant fractions of the grain items were imported from the other countries. For an example, Saudi Arabia imported 1.92 million metric tons (MMT) of corn in 2010–2011, which was increased to 2.9 MMT during 2014–2015, while the country consumed 3.1 MMT (CDSI (Central Department of Statistics and Information) 2012; USDA 2016). Most of the imported corn was used for animal feed processing (USDA 2016). Corn is a very important feed grain for the poultry farms, dairy farms, livestock meat products, and commercial feed items (USDA 2016). The country imported 2.36 MMT of wheat during 2010–2011, which was increased to 3.49 MMT during 2014–2015, while the national consumption was 3.35 MMT. Wheat is an important grain for producing

Fig. 1 Percentile distributions of livestock in different regions of Saudi Arabia. *C* camel, *B* cow (only for meat production), *MB* dairy cow, *S* sheep, *G* goat, *P* poultry. Notations 1 and 2 represent year 2006 and 2010
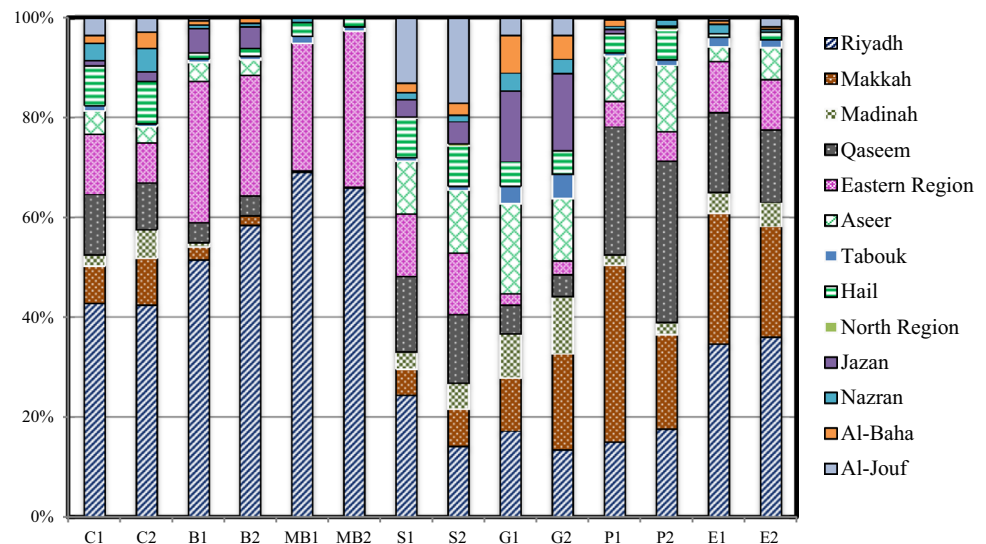
most of the livestock, poultry, and egg, while domestic wheat production was ended in 2015–2016, indicating possible increase in import in the future (CDSI 2012; USDA 2016). Domestic production of barley was terminated in 2003. In 2010–2011, 8.32 MMT of barley was imported, which was increased to 8.5 MMT in 2015–2016. About 80% of barley was used for feeding sheep, camels, and goats (USDA 2016). The country also imported 1.24 MMT of other grain crops (CDSI 2012). In 2010–2011, 46050 MT of dried chick peas were imported (CDSI 2012). In addition, production of domestic fodder crops is likely to be phased out by 2019, while fodder crops are an important feed item for producing livestock animals (USDA 2016). Further details on the import of different feed items and domestic productions can be found in the literature (CDSI 2012; SSYB 2011).

The feed compositions for camel, cow, dairy cow, sheep, goat, poultry, and hen are shown in Table 3. The corresponding feed amounts are 3.347, 2.303, 5.41, 0.2995, 0.1144, 0.0174, and 0.0174 ton/year, respectively (Table 3). On average, feed of one camel is equivalent to the feed of 1.5 cows (Table 5). The feed of a dairy cow is 2.4 times the feed of a cow. Among the feed of camel, cow, dairy cow, sheep, goat, poultry, and hen, approximately 62.4, 13.7, 32.6, 6.3, 8.9, 81, and 81% are grain or grain products, respectively. The unit VWC for these animals were predicted to be 19,741, 11,688, 113,807, 5568, 4122, 1978, and 16,256 m^3/ton, respectively. Worth to notice that a unit VWC for dairy cow included the VWC of producing milk for 7 years (3–10 years of life), while approximately 96% of the unit VWC was associated with milk production (Chapagain and Hoekstra 2003). The unit VWC for egg was calculated as 2753 m^3/ton. The calculation of a unit VWC for egg was performed using the average of 210 eggs per hen during its lifetime, and the weights of 0.042 and

1.75 kg per egg and hen, respectively (Abdallah and Faye 2013; Chapagain and Hoekstra 2003). On average, approximately 8.82 kg (210 × 0.042) of eggs are obtained from a hen. The total value of eggs and carcass of a hen was approximately SR 143.5 (US$ 38.3), in which 85.4% was attributed to eggs (Table 6). The unit VWC was highest for camel followed by cow, whereas poultry production needed the lowest VWC (Tables 4, 5, 6). Variability in the unit VWC for different livestock animals indicates that there might be a scope to allocate livestock in different regions for water saving purposes.

Total virtual water content

The total VWC were in the range of 8.9–10.6 billion m^3/year for the period of 2006–2010 (Table 7). The camel and cow had the highest fractions attributing 31.5–36.6% and 20.5–25.7% of total VWC, respectively. In 2010, the countrywide VWC for camel, cow, dairy cow, sheep, goat, poultry, and eggs were 2799, 2274, 996, 1341, 135, 1042, and 297 million m^3, respectively. These data showed an increase of VWC for cow, dairy cow, and egg in comparison with the VWC in 2006 (Table 7). The regional distribution of VWC is shown in Fig. 2. The VWC were highest in Riyadh followed by Eastern region, Qaseem, Hail, and Makkah with ranges of 3587–4112, 1684–2044, 1007–1331, 644–810, and 504–715 million m^3/year, respectively. The lowest VWC was calculated for the Northern region. Three regions (Riyadh, Eastern region, and Qaseem) contributed 69.5–72.4% of the total VWC in the country (Table 7).

In 2010, VWC for camel was highest in Riyadh (1204 million m^3). In this year, cow had the highest VWC in Riyadh (1269 million m^3) followed by Eastern region (679 million m^3). The dairy cow was mainly produced in Riyadh

Table 7 Trend of virtual water content (million m^3) for farm livestock production in Saudi Arabia

	Camel		Cow		Dairy cow		Sheep		Goat		Poultry		Egg		Major animal
Region	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	
Riyadh	1605	1204	1048	1269	421	597	512	191	60	21	200	192	87	113	Cow + camel
Makkah	198	189	39	27	0	0	77	71	26	22	329	146	46	49	Camel + poultry
Madinah	56	113	11	0	0	0	51	49	22	13	20	19	7	11	Camel + sheep
Qaseem	482	284	87	94	4	3	337	197	22	7	358	374	42	49	Poultry + camel
Eastern region	589	295	743	679	201	366	336	215	10	6	87	84	33	41	Cow + camel
Aseer	123	66	55	47	0	0	157	121	44	14	85	101	5	14	Sheep + poultry
Tabouk	45	15	18	18	10	9	18	12	13	9	10	13	5	6	Cow + camel
Hail	398	325	30	45	23	22	224	147	23	10	67	89	2	6	Camel
Northern region							4	7			0	6			Sheep + poultry
Jazan	28	38	70	66	0	0	51	42	35	17	7	3			Cow + sheep
Nazran	110	110	13	13	4	0	3	5	10	4	7	10	4	1	Camel
Al-Baha	41	72	12	17	0	0	30	26	20	6	13	1	1	1	Camel
Al-Jouf	149	89	12	0	0	0	306	257	13	7	6	5	1	7	Sheep
Total	3823	2799	2139	2274	662	996	2104	1341	298	135	1189	1042	234	297	

Empty cell no data due to very low numbers

Fig. 2 Regional VWC for livestock and eggs (million m^3) produced in 2006–2010 period
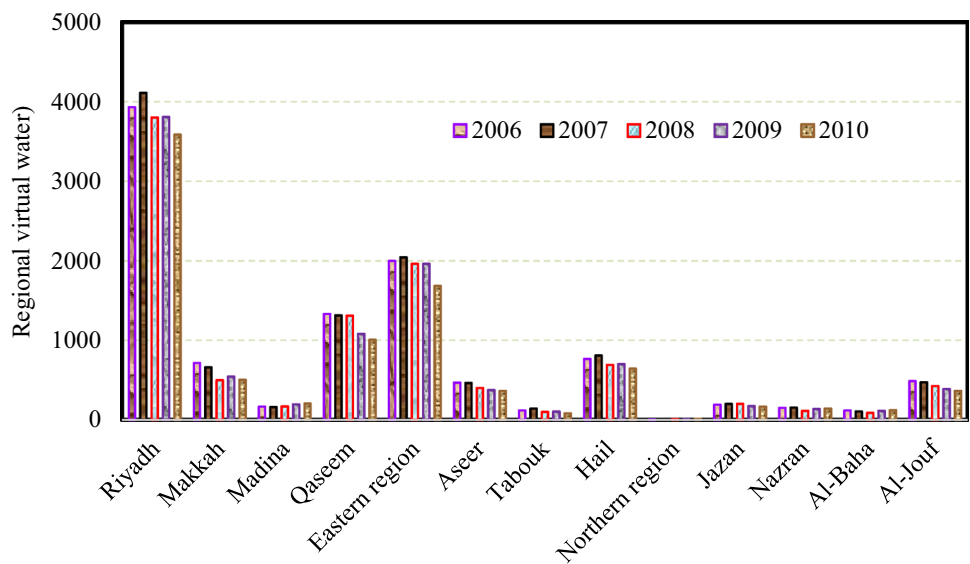
and Eastern region with VWC of 597 and 366 million m^3, respectively. VWC for sheep and goat were highest in Al-Jouf and Makkah, respectively. VWC for poultry were highest in Qaseem followed by Riyadh, Makkah, and Aseer (Table 7), while the VWC of egg were highest in Riyadh followed by Makkah, Qaseem, and Eastern region. The VWC distribution is explained in Fig. 3. In 2010, total VWC in Riyadh was 3587 million m^3, in which camel, cow, and dairy cow had 33.6, 35.4, and 16.6%, respectively. In this year, the second largest VWC was in Eastern region (1684.1 million m^3), where camel, cow, and dairy cow had the VWC of 18.1, 40.3, and 21.8%, respectively.

The third largest VWC was for Qaseem region (1007.1 million m^3), where poultry and camel were the main livestock attributing 37.2 and 28.2% of VWC, respectively (Table 7; Fig. 3). Further details on VWC can be obtained from Figs. 2 and 3 and Table 7.

The geographical distribution of VWC in 2006 and 2010 is shown in Fig. 4. In these years, the largest VWC for livestock farms were for Riyadh, Eastern region, Qaseem, Hail, and Makkah (> 500 million m^3/year). These five regions showed the decreasing trends for VWC during 2006–2010. The distributions of VWC were not consistent to the population distributions. The populations in Riyadh,

Fig. 3 Percentile distributions of product specific regional VWC in 2006 and 2010. *C* camel, *B* cow (only for meat production), *MB* dairy cow, *S* sheep, *G* goat, *P* poultry, *E* egg; subscripts 1 and 2 represents 2006 and 2010
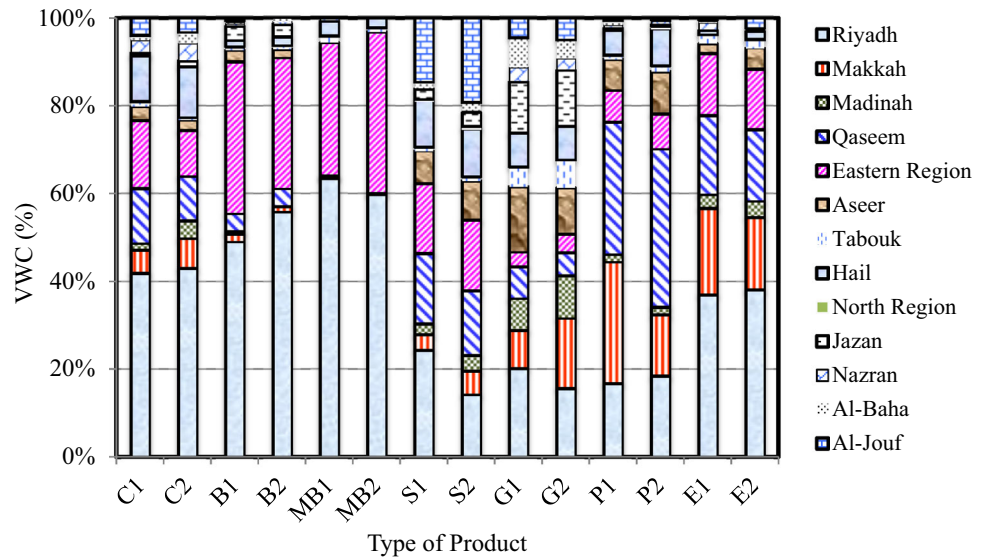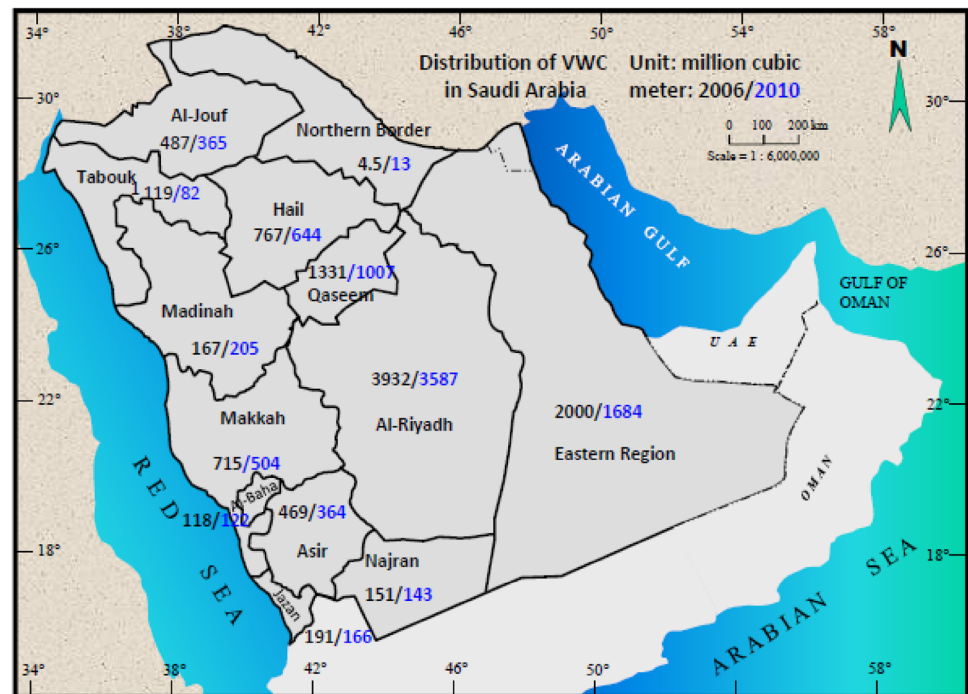

Fig. 4 Regional distribution of VWC for livestock farms in 2006 and 2010 (million m^3) (first value: VWC in 2006; second value: VWC in 2010)

Eastern region, Qaseem, Hail, and Makkah were 6.8, 4.1, 1.2, 0.6,. and 6.9 million, respectively (SSYB 2011). Makkah had more populations than Riyadh, while the VWC in Makkah were less than 20% of Riyadh (Fig. 4). The VWC in Eastern region, Qaseem, and Hail were higher (Fig. 4). It is to be noted that the higher VWC for livestock farms were consistent to the regions with higher agricultural crop productions (SSYB 2011; Abbas 2013). The higher levels of agricultural activities and livestock farms might have higher stress on the non-renewable groundwater sources, which deserves better understanding.

Trend of virtual water content

The highest and lowest VWC were estimated for 2007 and 2010 with the values of 10.6 and 8.9 billion m^3, respectively. The VWC for camel, sheep, goat, and poultry were decreased by 26.8, 36.3, 54.5, and 12.4%, respectively, from 2006 to 2010, while the VWC for cow, dairy cow, and egg were increased by 6.3, 50.4, and 26.7%, respectively (Fig. 5). In these years, VWC for camel were highest (2799–3823 million m^3/year), while a decreasing trend from 2006 to 2010 was observed (Fig. 5). In 2006, VWC for cow was 2139 million m^3, which was increased to 2464
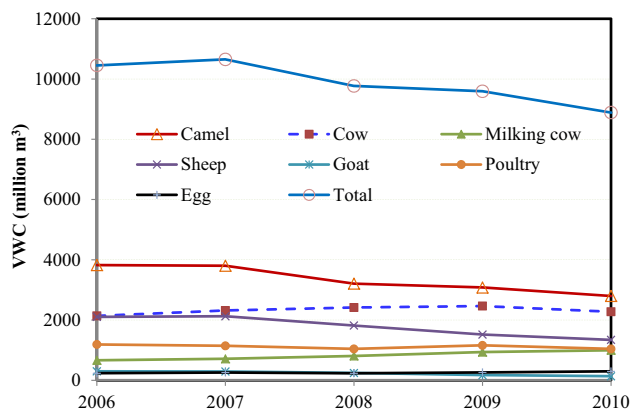
Fig. 5 Trends of VWC for livestock and egg produced in Saudi Arabia (million m³)

million m³ in 2009 and then decreased to 2274 million m³ in 2010. The VWC for dairy cow was increased from 662 to 996 million m³ during 2006–2010. VWC for sheep was decreased from 2104 to 1341 million m³ in this period. For egg, VWC showed variable trend (Fig. 5) with the values of 234, 258, 233, 261, and 297 million m³ in 2006, 2007, 2008, 2009, and 2010, respectively. VWC for goat was decreased from 298 million m³ in 2006 to 135 million m³ in 2010. Further details on VWC for each category of animal are shown in Table 7.

Comparative analysis

The unit VWC of camel was 1.7 and 3.5 times the unit VWC for cow and sheep, respectively (Table 8). One kg of camel and cow meat required 19.7 and 14.6 kg of feed supply, respectively. Production of 1 kg of sheep, goat, and poultry required 9.66, 6.1, and 1.65 kg of feed, respectively (Table 8). The dairy cow had the highest unit VWC, in which about 96% was due to milk production for 7 years (Chapagain and Hoekstra 2003). The VWC for some livestock animals in this analysis were different from the ones reported in the literature (Chapagain and Hoekstra

2003; Mekonnen and Hoekstra 2010). The variability in VWC might be attributed to several factors, including the way VWC, is estimated using the gross national income instead of field data, local feeding practices, and impact of local climatic conditions.

The decrease in production of some livestock animals was responsible for the reduced VWC in 2010. Camel production was decreased by 25% since 2006 and the corresponding VWC was reduced by 26.8%. Production of cow was increased by 6.0% and the related VWC was increased by 6.3%. Production of dairy cow and VWC was increased by 48.5 and 50.4%, respectively. During the same period, VWC for sheep, goat, poultry, and egg were changed by − 36.3, − 54.6, − 12.4, and + 26.7%, respectively, which were reflecting the changes in their productions (Table 1). The changes in livestock productions showed minimal variation with respect to the changes in VWC, indicating that significant technological improvements might have not been taken place during this period. However, it is to be noted that the temporal changes in farming practices were not considered in this study. The five regions (Riyadh, Eastern region, Qaseem, Hail, and Makkah) consumed 83.6–84.6% of total VWC during 2006–2010. In Riyadh, Eastern region, Qaseem, and Makkah, VWC were decreased by 8.8, 15.7, 24.3, and 29.5%, respectively, during this period. In Madinah and Al-Baha, VWC were increased from 2006 to 2010. In Madinah, camel and egg productions were increased, while in Al-Baha, camel, and cow productions were increased. The shift of livestock productions in different regions can have implications on the policy, water resources, and feed supplies.

Policy implications

The findings indicated that there were minimal technological and/or managerial developments for water conservation in livestock farms. Saudi Arabia should invest in

Table 8 Comparison of different livestocks in context to unit virtual water content (Riyadh region)

	Camel	Cow	Dairy cow[a]	Sheep	Goats	Egg	Poultry	Comment
VWC (m³/ton)	NR	11,359	148,223	5904	4179	NR	4146	Past study
VWC (m³/ton)	19,741	11,688	113,807	5568	4122	2753	1978	Current study
Slaughtering age (year)	4	3	10	1.5	2	1.44	0.20	Current study
Weight (ton/animal)	0.678	0.473	0.36	0.0465	0.038	0.00882	0.002	Current study
Feed consumption: ton/year/animal	3.347	2.303	5.41	0.2995	0.114	0.0174	0.0174	Current study
Feed consumed in lifetime (ton)	13.388	6.909	47.77	0.4493	0.229	0.0251	0.00331	Current study
Feed consumed (kg feed/kg product)	19.75	14.62	132.7	9.66	6.101	2.84	1.65	Current study

NR not reported

[a] The main product is milk (≈ 96%) during the lifetime (e.g., 3–10 years) and feed consumption for 10 years

technological and managerial water saving programs to reduce water consumption in these farms. Another possible move may be the shift of diet from high the VWC meat (e.g., camel, cow) to low VWC meat (e.g., poultry). However, such a shift needs to be assessed from social, cultural, and nutritional aspects. In particular, the needs of protein and energy should be compared. Future study is warranted on nutritional equivalency for substituting the meat intake habit.

In this study, VWC for few livestock animals was not calculated due to the lack of data. VWC for secondary products, such as cheese, butter, leather, etc. was not estimated in this analysis. Upon availability of data, future study may further improve these estimates. Effects of temperature variability in different regions were not explicitly evaluated. In addition, the previous studies have indicated that climate change might implicitly affect the VWC via the impacts on agricultural water demand (Papadopoulou et al. 2016). Future study is recommended to fulfill these limitations towards a better understanding of the overall and regional VWC in the livestock farms. The VWC trade balance in Saudi Arabia needs further investigation to identify the actual water consumption of livestock production in relation with VWC import/export. The authors are currently conducting a study to estimate the green, blue, and grey components of water footprint in livestock industry in Saudi Arabia. The economic and financial feasibility of water consumption in livestock production and the opportunity cost of this consumption need to be investigated. The findings documented in this study will form the foundation for an economic and financial feasibility study. Despite the limitations as noted above, the findings of this analysis shed light on water consumption in the livestock farming and egg production in Saudi Arabia.

Conclusions

In this study, VWC for livestock farms in the 13 regions of Saudi Arabia from 2006 to 2010 were predicted by comparing and analyzing the regional variability of livestock production. This study estimated the VWC for camel production through farming, which was not reported earlier. Camel production was associated with a large fraction of VWC. The analysis showed that the overall VWC for livestock production were 10.6 and 8.9 billion m^3/year in 2006 and 2010, respectively. Despite the decrease in overall VWC, VWC for cow, dairy cow, and egg were increased in the same period, which can be related to the high financial return of cow, dairy cow, and egg. This study shows that a shift in diet from the high VWC meat to low VWC meat may reduce the overall VWC for livestock

production. However, protein and energy equivalency need to be investigated for any shift of diet. Our findings highlight the value of VWC in understanding water consumption pattern in the livestock farming and identifying methods to increase its efficiency to save water through appropriate allocation of livestock farms in different regions and attribute control over the production of the high VWC animals as an integral part of a comprehensive agricultural water management strategy. In conclusion, future work should be paid to provide a compressive regional and national overview of VWC for livestock farming in Saudi Arabia to obtain the development of a knowledge-based agricultural water management strategy in the Kingdom towards the optimal management of water resources.

References

Abbas (2013) Implications of climate change on crop water requirements in Saudi Arabia. Masters thesis, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

Abdallah HR, Faye B (2013) Typology of camel farming system in Saudi Arabia. Emir J Food Agric 25:250–260

Alexandratos N, Bruinsma J (2012) World food and agriculture to 2030/50: The 2012 revision. FAO, Rome, p 32

Allan JA (1993) Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. Priorities for water resources allocation and management. ODA, London, pp 13–26

Allan JA (1994) Overall perspectives on countries and regions. In: Rogers P, Lydon P (eds) Water in the Arab World: perspectives and prognoses. Harvard University Press, Cambridge, pp 65–100

Allan T (1997) Virtual water': a long term solution for water short Middle Eastern economies? In: paper presented at the 1997 British Association Festival of Science, Roger Stevens Lecture, University of Leeds, Water and Development Session-TUE.51.14.45, 9 September 1997

Al-Shayaa MA, Gaig MB, Strquadine GS (2012) Agricultural extension in the Kingdom of Saudi Arabia: difficult present and demanding future. J Anim Plant Sci 22(1):239–246

Al-Zahrani KH, Baig MB (2011) Water in the Kingdom of Saudi Arabia: sustainable management options. J Anim Plant Sci 21(3):601–613

Al-Zahrani M, Chowdhury S, Abo-Monasar A (2015) Augmentation of surface water sources from spatially distributed rainfall in Saudi Arabia. J Water Reuse Desalination 5(3):391–406

CDSI (Central Department of Statistics and Information) (2012). Import Statistics of Saudi Arabia in 2012

Chapagain AK, Hoekstra AY (2003) Virtual water flows between nations in relation to trade in cattle livestock and livestock products. Value of Water Research Report Series No. 13. UNESCO-IHE, Delft, The Netherlands

Charchousi D, Tsoukala VK, Papadopoulou MP (2015) How evapotranspiration process may affect the estimation of water footprint indicator in agriculture? Desalination Water Treat 53(12):3234–3243

Chowdhury S, Al-Zahrani M (2013) Reuse of treated wastewater in Saudi Arabia: an assessment framework. J Water Reuse Desalination 03(3):297–314

Chowdhury S, Al-Zahrani M, Abbas A (2016) Implications of climate change on crop water requirements in arid region: an example of Al-Jouf, Saudi Arabia. J King Saud Univ Eng Sci 28:21–31

City population (2016) Saudi Arabia. https://www.citypopulation.de/SaudiArabia.html. Accessed 26 April 2017

de Boer IJM, Hoving IE, Vellinga TV, Ven GWJ, Leffelaar PA, Gerber PJ (2013) Assessing environmental impact associated with fresh water consumption along the life cycle of animal products: the case of Dutch milk production in Noord-Brabant. Int J Life Cycle Assess 18:193–203

FAO (Food and Agriculture Organization) (2009) CROPWAT software, Food and Agriculture Organization, Land and Water Division. http://www.fao.org/nr/water/infores_databases_cropwat.html

FAO (Food and Agriculture Organization) (2012) CLIMWAT: A climatic database for irrigation planning and management, FAO. http://www.fao.org/nr/water/infores_databases.html. Accessed 10 Sept 2012

Gerbens-Leenes PW, Van Lienden AR, Hoekstra AY, van der Meer TH (2012) Biofuel scenarios in a water perspective: the global blue and green water footprint of road transport in 2030. Glob Environ Chang 22:764–775

Gerbens-Leenes PW, Mekonnen MM, Hoekstra AY (2013) The water footprint of poultry, pork and beef: a comparative study in different countries and production systems. Water Resour Ind 1–2:25–36

Hoekstra AY (ed) (2003) Virtual water trade. In: proceedings of the international expert meeting on virtual water trade, delft, The Netherlands, 12–13 December 2002. http://www.waterfootprint.org/Reports/Report12.pdf

Hoekstra AY, Chapagain AK (2007) Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manag 21(1):35–48

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development) (2008) Agriculture at a crossroads: global report. IAASTD, Island Press, Washington

Karrou M, Oweis T, Benli B, Swelam A (2011). Improving water and land productivities in irrigated systems. Community-based optimization of the management of scarce water resources in agriculture in CWANA Report no. 10. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, pp. + 195

Khan BB, Iqbal A, Riaz M (2003) Production and management of camels. Department of Livestock Management, University of Agriculture, Faisalabad

Mekonnen MM, Hoekstra AY (2010) The green, blue and grey water footprint of farm animals and animal products. Volume I: Main Report, Value of Water Research Report Series No. 48, Delft, The Netherlands

Mekonnen MM, Hoekstra AY (2011) The green, blue and grey water footprint of crops and derived crop products. Hydrol Earth Syst Sci 15:1577–1600

Mekonnen MM, Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. Ecosystems 15(3):401–415

Missimer TM, Guo W, Maliva RG, Rosas J, Jadoon K (2014) Enhancement of Wadi dam recharge using dams coupled with aquifer storage and recovery wells. Environ Earth Sci 73(12):7723–7731

Molden D, Oweis T, Steduto P, Bindraban P, Hanjra MA, Kijne J (2010) Im- proving agricultural water productivity: between optimism and caution. Agric Water Manag 97:528–535

MOWE (Ministry of Water and Electricity) (2013) Annual report Riyadh, Saudi Arabia. http://www.mowe.gov.sa/ENIndex.aspx. Accessed May 2014

Ouda OKM (2014) Impacts of agricultural policy on irrigation water demand: case study Saudi Arabia. Int J Water Resour Dev 30(2):282–292

Papadopoulou MP, Charchousi D, Tsoukala VK, Giannakopoulos Ch, Petrakis M (2016) Water footprint assessment considering climate change effects on future agricultural production in mediterranean region. Desalination Water Treat 57(5):2232–2242

Ran YM et al (2016) Assessing water resource use in livestock production: a review of methods. Livest Sci 187:68–79

Rockström J, Falkenmark M, Folke C, Lannerstad M, Barron J, Enfors E, Gordon L, Heinke J, Hoff M, PahlWostl C (2014) Water resilience for human prosperity. Cambridge University Press, NY

Rost S, Gerten D, Bondeau A, Lucht W, Rohwer J, Schaphoff S (2008) Agricultural green and blue water consumption and its influence on the global water system. Water Resour Res 44(9):1–17

Shiklomanov IA (2000) Appraisal and assessment of world water resources. Water Int 25(1):11–32

SSYB (Saudi Statistical Year Book) (2011) Saudi statistical year book. http://www.cdsi.gov.sa/yb46/Pages/MixFPage.htm

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. FAO, Rome, p 390

UNDP (United Nations Development Programme) (2013) Water governance in the Arab region: managing scarcity and securing the future. UN Plaza, New York 10017, USA

USDA (2016) Saudi Arabia: Grain and Feed Annual. GAIN Report No. SA1602. https://gain.fas.usda.gov/Recent/GAIN/Publications/GrainandFeedAnnual_Riyadh_SaudiArabia_3-14-2016.pdf

World Bank (2010) Making the most of scarcity: Accountability for better water management results in the Middle East and North Africa Report, Washington. USA

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