8th International Conference on Water Resources and Arid Environments (ICWRAE 8): 121-133
22-24 January 2019, *Riyadh, Saudi Arabia*

Meat and Egg Production in Saudi Arabia: an Analysis on Virtual Water Content for Livestock Farming

[1]Shakhawat Chowdhury, [2]Omar K.M. Ouda and [3]Maria P. Papadopoulou

[1]Department of Civil and Environmental Engineering,
King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[2]Civil and Environmental Engineering Department,
Prince Mohammad Bin Fahd University, Al-Khobar 31952, Saudi Arabia
[3]School of Rural and Surveying Engineering National Technical University of Athens (NTUA), 9 HeroonPolytechniou, University Campus Zografou 15780 Greece

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 livestock in the thirteen regions of Saudi Arabia. The VWC for Camel production was also estimated, which has not been investigated in 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.

Key words: Virtual water content・Water saving・Water resources management・Arid region・Livestock farming・Water demand

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 [1, 2]. 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 [2, 3, 4]. A rational water resources 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 [5, 6, 7]. 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 [8, 9]. Almost 30% of the global agricultural WFP was related to livestock animal production [10]. The WFP of many animal products are larger than the WFP of crop products with equivalent calorie value [10]. 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 [10]. 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 [10]. However, there

Corresponding Author: Shakhawat Chowdhury, Department of Civil and Environmental Engineering,
King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia.
Tel: +966-13-860-2560, Fax: +966-13-860-2879, E-mail: Schowdhury@kfupm.edu.sa.

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 [11, 12, 13, 14], which is likely to intensify the freshwater crisis in future [13, 15].

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 [16, 17]. 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 [18, 19, 20]. Virtual water is defined as the volume of water required to produce a commodity or a service. This concept was first introduced when the optionof importing virtual water (coming along with food imports) was examined as a partial solution to water scarcity problemsin the Middle East countries [16, 17, 21]. In order to assessthenational 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 [17, 22]. 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 productsused as feed items forms the major fractions of VWC for livestock farming [9, 13, 15]. The WFP of an agricultural product is defined as the sum of the blue, green and grey WFP [23]. 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, greenwater contributes about 80% of the consumptive water use (CWU) in agricultural production [24, 25]. In livestock production, green water accounts for 90% of total CWU [9] while only 2-8% of CWU is blue water used for drinking water, servicing and feed mixing purposes [12, 26, 27, 28]. In Saudi Arabia, there is no natural surface water flow system and the countrywide average annual rainfall is very low (<70 mm/year) [29, 30, 31]. The soil moisture content is low and evaporation rate is extremely high [29]. As result, the contribution of green water to agricultural crop production is minimal [4, 31]. The only dependable source of water for crop production is groundwater pumped from the non-renewable aquifers, which represented the blue water [4, 32]. The agricultural farms typically pump the groundwater for irrigation [16].

Different types of meat (e.g., camel, cow anddairy cow, goat and poultry) and egg are produced through the in-house and open grazing farming in Saudi Arabia [33, 34, 35]. The VWC for these livestockproducts varies depending on the climatic conditions, the region and the applied farming practices. For example, Chapagain and Hoekstra [5, 7] predicted the VWC for 1 ton of beef and poultry meat in Saudi Arabia as 11, 359 and 4, 146 m^3 respectively. In Egypt, these values were 15, 752 and 2, 268 m^3/ton respectively while in Germany, these were 7, 768 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. Further, 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 [5]. 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 [5, 9, 23]. 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 [36, 37]. In 2010, the gap between water demand and sustainable water supply was about 11.5 billion m^3 [36]. The water demand-supply gap was bridged through extensive use of non-renewable groundwater resources, desalinated water and minimal use of treated wastewater [36]. 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 [7, 23, 38].

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 thirteen regions of Saudi Arabia. In thisstudy, 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.

MATERIALS AND METHODS

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, 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 [33, 34, 35]. The details of productive animals and eggs for each year can be found in literature [33, 34, 35]. 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 literature [5, 39].

To calculate the VWC, the WFP methodology of Mekonnen and Hoekstra [28] was followed. The WFP was predicted as:

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

where $WFP[a,c,s]$ = WFP for category a animal in country $c$for production systems s. $WFP_{feed}[a,c,s]$, $WFP_{drink}[a,c,s]$ and $WFP_{service}[a,c,s]$ 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) forseven 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 importedproducts. To calculate the WFP for the feed items, Mekonnen and Hoekstra [28] used the weighted average WFP for the domestic and imported products. The weighted average WFP was calculated as:

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

	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

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

where, $P[p]$ = domestic production of feed item p(ton/yr); $T_i[n_e, p]$ = imported amount of feed item p(ton/yr) from exporting country n_e; $WFP[p]$ = WFP of feed item p for domestic production (m^3/ton); $WF[n_e, p]$ = WFP of feed item p for exporting country n_e (m^3/ton); $WFP^*[p]$ = 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 [5, 7]. 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 around 27.1 million in 2010 [12, 33, 40], 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 andsource-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:

$$VWC_i = VWC_{feed} + VWC_{drink} + VWC_{service} \quad (3)$$

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), $VWC_{service}$= VWC for servicing/cleaning purposes (m^3/animal). The VWC for feed was calculated based on the amount of feed consumedby an animal, water consumption in feed production and slaughtering age [5, 7]. In many developing and developed countries, livestockfeed isa mixture of crops, crop residues and industrial products [5, 7]. To mix the feed items, additional water is required. The VWC for feed was estimated as:

$$VWC_{feed} = \left(CW \times SA + WFM\right) \quad (4)$$

where, CW = total VWC of feed crops per animal (m^3/year), SA = slaughtering age (yr); and WFM = volume of water for mixing of food items (m^3/animal).Past studies have reported that WFM was approximately 50% of the feed volume consumed by a livestock animal [5, 7, 20]. To assess CW, the weighted WFP per ton of the feed items (WFP^*) and the average feed amount are necessary (AFV). Abbas [1] 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 [27, 28]. In addition, historical rainfall and temperature data for different regions were obtained from the FAO database in CLIMWAT 2.0 software [18]. As such, climatic variability in different regions was incorporated in this calculation [1, 30, 31]. 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 equation (2) to calculate the weighted WFP (WFP^*).

In Tables 3-6, indicative sample calculations along with the necessary data (e.g., feed items, amounts, slaughtering ages, live weights, etc.) are presented [5, 39, 41]. 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 ($CW = AFV \times WFP^*$) 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

Table 2: The 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

Table 3: Indicative calculations of VWC for feed of a farm livestock animal in Riyadh

		Camel		Cow		Dairy cow		Sheep		Goat		Poultry		Laying hen	
Feed crop	*WFP**	AFV	CW	AFV	CW	AFV	CW	AFV	CW	AFV	CW	AFV	CW	AFV	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 (m^3/ton), AFV: average feed amount (ton/yr); CW: VWC of feed crops per animal (m^3/yr);

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 [5]. 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 depends on local climatic conditions (i.e. temperature, humidity, rainfall etc.), farmingpractices and the final farming product (e.g., meat or milk from cow; poultry or egg, etc.), which was estimated as:

$$VWC_{drink} = ADD_d \times SA \times 365 \quad (5)$$

$$VWC_{service} = ADD_s \times SA \times 365 \quad (6)$$

where, ADD_d = average water consumption per animal (m^3/day), ADD_s = average water demand for service purposes (e.g., cleaning) per animal (m^3/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 [5, 7] was considered. Gerbens-Leenes et al. [18, 42] reported that the livestock produced through industrial farming were heavier than those of 'grazing' farming'; however previously Chapagain and Hoekstra [5, 7] reported the opposite. Unit VWC per animal was properly calculated (Table 5).

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

		VWC_{drink}		$VWC_{service}$		VWC_{feed}				
						VWC_{FI}		VWC_M		
Animal	SA	ADD	TDD	ADD	TSD	VWC_{FY}	VWC_{FT}	VWC_{MY}	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*	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

SA: Average slaughtering age (yr); ADD: Average daily demand (l/day); TDD: total drinking demand: (m^3/animal); TSD: total service demand (m^3/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 (m^3/year); VWC_{FT} = VWC for total feed intake (m^3/animal); VWC_M = VWC for feed mixing; VWC_{MY}: VWC for feed mixing in 1 year (m^3/year); VWC_{MT} = VWC for total feed mixing (m^3/animal); VWC_i = Overall VWC for *i* category animal (m3/animal). 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;

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

	LW_i			
Type of animal/bird	Grazing*	Industrial*	Mixed+	VWC_{ui}++
Camel	0.63	0.726	0.678	19741
Cow	0.4	0.545	0.4725	11688
Dairy cow	0.27	0.45	0.36	113807
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	16256

LW_i = Living weight of *i* category animal (ton/animal); VWC_{ui} = Unit VWC of *i* category animal (m^3/ton);

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

sProduct	W_E	M_P	M_V	T_P	V_F	W_S	VWC_{ui}++
Egg*	0.00882	13889	122.5		0.854	24.28 =(≈28.45×0.854)	2753
Carcass**	0.00175	12000	21		0.146	4.16	2379

W_E = weight of egg (ton/hen); M_P = market price (SR/ton); MV = monetary value of product (SR/hen); T_P = total price (SR/hen); V_F = value fraction; W_S = water share (m^3/product/hen); Egg*: each hen produces 210 of eggs in their life period; weight of an egg = 42 gm; price of an egg = SR. 0.58; 1 ton = 23810 eggs; Carcass*: price of 1 kg of hen = SR. 12; ++: data obtained by adjusting the VWC_i from Table 4 by the weights of mixed farming

The total VWC for eachcategory of livestockanimal (VWC_{ti}) was calculated as:

$$VWC_{ti} = VWC_{ui} \times W_i \quad (7)$$

where, VWC_{ti} = VWC for *i* category livestock animal (m^3/yr), VWC_{ui} = VWC for one ton of animal, W_i = total weight of *i* category livestock animalconsumedin a year (ton/yr). The value of $W_i$was calculated as:

$$W_i = LW_i \times N_i \quad (8)$$

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

$$VWC_T = \sum_{i=1}^{n} VWC_{ti} \quad (9)$$

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 by33.3%-100% (Table 1). Production of cowwere increased in Riyadh, Qaseem, Hail and Al-Baha by 6.7% - 33.3%. Production of dairy

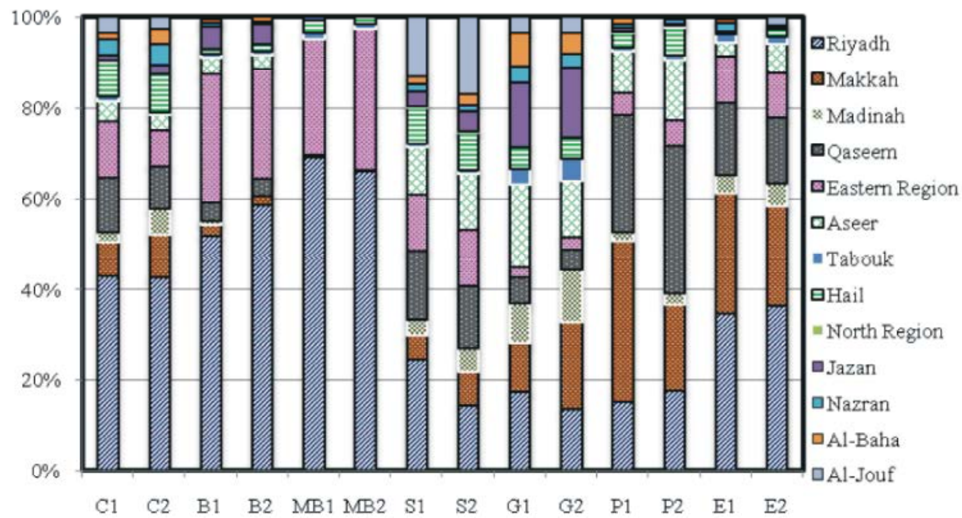

Fig. 1: Percentile distributions of livestock in different regions (C: Camel; B: Cow [only for meat production]; MB: Dairy cow; S: Sheep; G: Goat; P: Poultry. Notations 1 and 2 represent year 2006 and 2010

cow werealso increased in Riyadh and Eastern region by 41.8% and 81.8% respectively. In this period, sheep production were decreased in all regions except the Northern region while goat production were decreased in all regions. Production of poultry were increased in Qaseem, Aseer, Tabouk, Hail and Najran regions while egg production were increased in all regions except Najran and Al-Baha (Table 1).

The percentile distributions of the livestock animals are shown in Figure 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 anddairy cow did not show significant shift in terms of the regions. The production of camel and cow were 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 are 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 [33, 37]. Most of the imported corn was used for animal feed processing [37]. Corn is a very important feed grain for the poultry farms, dairy farms, livestock meat products and commercial feed items [37]. 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 most of the livestock, poultry and egg while domestic wheat production was ended in 2015-2016, indicating possible increase in import in future [33, 37]. 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 [43]. The country also imported 1.24 MMT of other grain crops [33]. In 2010-2011, 46050 MT of dried chick peas were imported [33]. In addition, production of domestic fodder crops are likely to be phased out by 2019 while fodder crops is an important feed item for producing livestock animals [37]. Further details on the import of different feed items and domestic productions can be found in literature [33, 34, 35].

The feed compositions for camel, cow, dairy cow, sheep, goat, poultry and henare 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/yr 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 ere predicted to be 19741, 11688, 113807, 5568, 4122, 1978

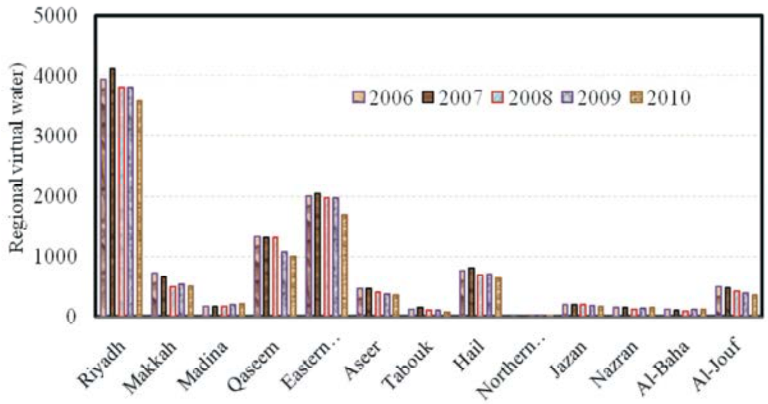

Fig. 2: Regional VWC for livestock and eggs (million m^3) produced in 2006-2010 period.

and 16256 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 [5, 7]. The unit VWC for egg was calculated as 2753 m^3/ton. The calculation of a unit VWC for eggwas performed using the average of 210 eggs per hen during its lifetime andthe weights of 0.042 and 1.75 kg per egg and hen respectively [5, 7, 39]. 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 where as poultry production needed the lowest VWC (Tables 4-6). Variability in theunit 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/yr 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 to the VWC in 2006 (Table 7). The regional distribution of VWC is shown in Figure 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 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 Figure 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 2nd largest VWC was in Eastern region (1684.1million m^3), where camel, cow and dairy cow had the VWC of 18.1%, 40.3% and 21.8% respectively. The 3rd 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; Figure 3). Further details on VWC can be obtained from Figures 2-3 and Table 7.

The geographical distribution of VWC in 2006 and 2010 are shown in Figure 4. In these years, the largest VWC for livestock farms were for Riyadh, Eastern region, Qaseem, Hail and Makkah (> 500 million m^3/yr). These five regions showed the decreasing trends for VWC during 2006 - 2010. The distributions of VWC were not consistent to the populationdistributions. The populations in Riyadh, Eastern region, Qaseem, Hail and Makkah were 6.8, 4.1, 1.2, 0.6 and 6.9 million respectively [39]. Makkah had more populations than Riyadh while the VWC in Makkah were less than 20% of Riyadh (Figure 4). The VWC in Eastern region, Qaseem and Hail were higher (Figure 4). It is to be noted that the higher VWC for livestock farms were consistent to the regions with higher agricultural crop productions [1, 34, 35]. The higher levels

Table 7: Trend of virtual water content (million m³) for farm livestock production in Saudi Arabia

	Camel		Cow		Dairy cow		Sheep		Goat		Poultry		Egg		
Region	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	Major Animal
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

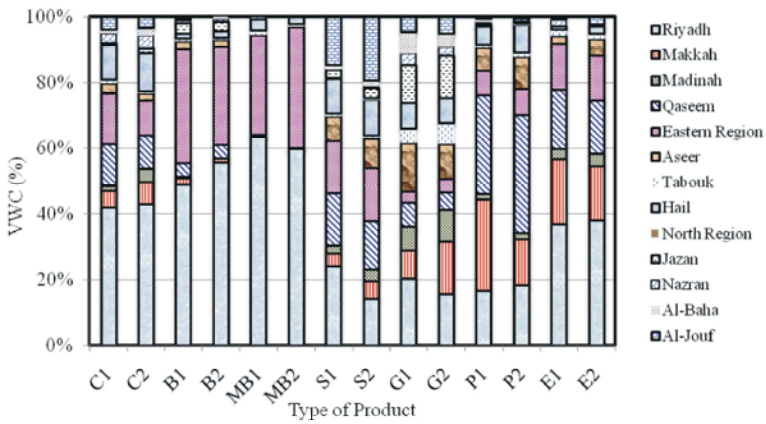

Fig. 3: Percentile distributions of regional VWC in 2006 and 2010. [C: camel; B: cow; MB: dairy cow; S: sheep; G: goat; P: poultry; E: egg; Subscripts 1 and 2 represents 2006 and 2010]

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 m³ 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 (Figure 5). In these years, VWC for camel were highest (2799-3823 million m³/year), while a decreasing trend from 2006 to 2010 was observed (Figure 5). In 2006, VWC for cow was 2139 million m³, which was increased to 2464 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 (Figure 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 ofcamel 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, goatand 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 [5, 7]. The VWC for some livestockanimals in this analysis were different from the ones reported in literature [5, 7, 8]. The variability

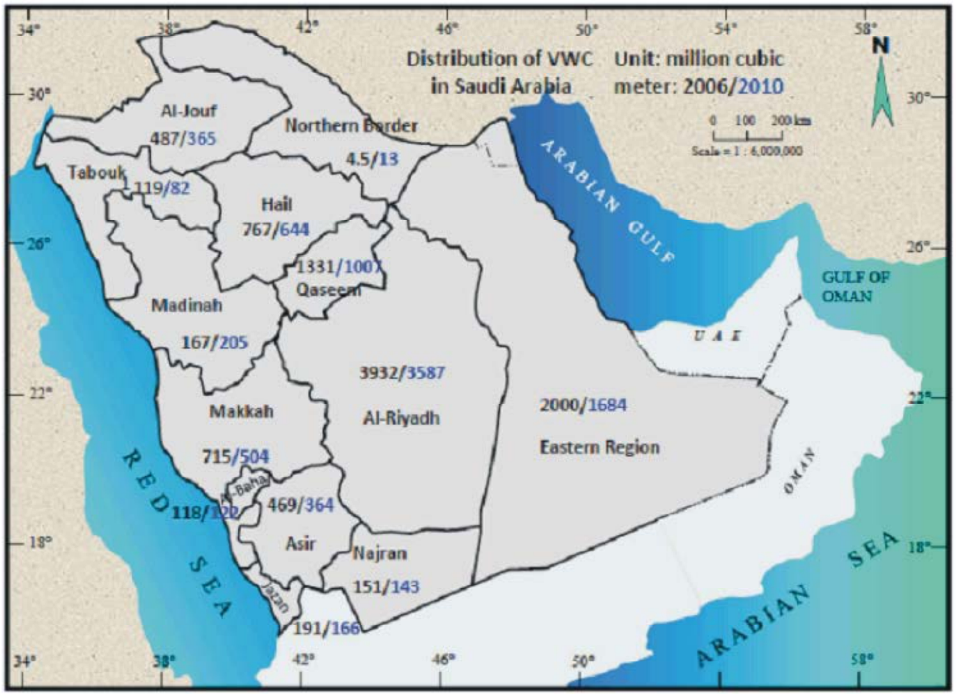

Fig. 4: Regional distribution of VWC for livestock farms in 2006 and 2010 (million m^3) [1st value: VWC in 2006; 2nd value: VWC in 2010]

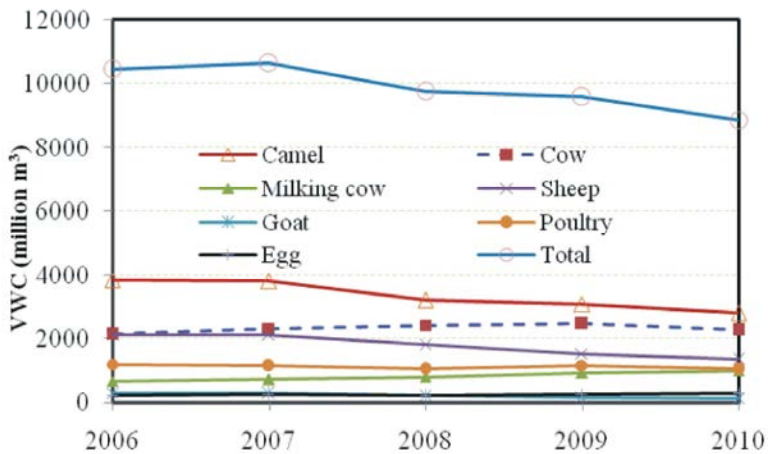

Fig. 5: Trends of VWC for livestock and egg produced in Saudi Arabia (million m^3)

in VWC might be attributed to several factors, including the wayVWC 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 somelivestockanimals were 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 wereincreased 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

Table 8: Comparison of different livestock in context to unit virtual water content [Riyadh region]

	Camel	Cow	Dairy cow*	Sheep	Goats	Egg	Poultry	Comment
VWC (m^3/ton)	NR	11359	148223	5904	4179	NR	4146	Past study
VWC (m^3/ton)	19741	11688	113807	5568	4122	2753	1978	Current study
Slaughtering age (yr)	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/yr/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

*The main product is milk (≈96%) during the lifetime (e.g., 3-10 years) and feed consumption for 10 years; NR: Not reported

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

In this study, VWC for fewlivestockanimals was not calculated due to the lack of data. VWC for secondary products, such as, cheese, butter, leather, etc.was not estimatedin 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, previous studieshave indicated that climate change mightimplicitly affect the VWC via the impacts on agricultural water demand [43, 44, 45]. Future study is recommended to fulfill these limitations toward 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 to VWC import/export. The authors are currently conducting a study to estimatethe 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 livestockfarming and egg production in Saudi Arabia.

CONCLUSIONS

In this study, VWC for livestock farms in the thirteen 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/yr 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 in order 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.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by the Deanship of Scientific Research (DSR) at King Fahd University of Petroleum & Minerals (KFUPM) for funding this work through project No. RG 1410-1 & 2.

REFERENCES

1. 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.
2. Ouda, O.K.M., A. Shawesh, T. Al-Olabi, F. Younes and R. Al-Waked, 2013. Review of Domestic Water Conservation Practices in Saudi Arabia. Applied Water Science, 3: 689-699.
3. Hoekstra, A.Y. and A.K. Chapagain, 2007. Water footprints of nations: water use by people as a function of their consumption pattern, Water Resources Management, 21(1): 35-48.
4. MOWE (Ministry of Water and Electricity), 2013. Annual Report. Riyadh, Saudi Arabia; http://www.mowe.gov.sa/ENIndex. aspx (accessed May 2014).
5. Chapagain, A.K. and A.Y. Hoekstra, 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.
6. Charchousi D., V.K. Tsoukala and M.P. Papadopoulou, 2015. How Evapotranspiration Process May Affect the Estimation of Water Footprint Indicator in Agriculture? Desalination and Water Treatment, 53(12): 3234-3243.
7. Hoekstra, A.Y., 2003. Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12-13 December 2002. Available online at: www.waterfootprint.org/Reports/Report12.pdf.
8. Mekonnen, M.M. and A.Y. Hoekstra, 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
9. Mekonnen, M.M. and A.Y. Hoekstra, 2012. A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems, 15(3): 401-415.
10. Shiklomanov, I.A., 2000 Appraisal and assessment of world water resources. Water International, 25(1): 11-32.
11. Alexandratos, N. and J. Bruinsma, 2012. World Food and Agriculture to 2030/50: The 2012 Revision. FAO, Rome, Italy, pp: 32.
12. Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales and C. De Haan, 2006. Livestock's long shadow: environmental issues and options, Rome: FAO, pp: 390.
13. Ran, Y.M., *et al*., 2016. Assessing water resource use in livestock production: A review of methods. Livestock Science, 187: 68-79.
14. IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development), 2008. Agriculture at a Crossroads: Global Report, IAASTD, Island Press, Washington, D.C., US.
15. Rost, S. Gerten, D. Bondeau, A. Lucht, W. Janine, J. Rohwer and S. Schaphoff, 2008. Agricultural green and blue water consumption and its influence on the global water system. Water Resources Research, 44(9): 1-17.
16. Allan, J.A., 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, Massachusetts, pp: 65-100
17. Allan T., 1997. Virtual water': a long term solution for water short Middle Eastern economies?. 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.
18. Gerbens-Leenes, P.W., A.R. Lienden, A.Y. Van Hoekstra and T.H. Van Der Meer, 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.
19. Hoekstra, A.Y., 2003. Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12–13 December 2002. Available online at: www.waterfootprint.org/Reports/Report12.pdf.
20. Hoekstra, A.Y. and A.K. Chapagain, 2007. Water footprints of nations: water use by people as a function of their consumption pattern, Water Resources Management, 21(1): 35-48.
21. Allan, J.A., 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: Priorities for water resources allocation and management, ODA, London, pp: 13-26.

22. Al-Shayaa, M.A., M.B. Gaig and G.S. Strquadine, 2012. Agricultural extension in the Kingdom of Saudi Arabia: Difficult present and Demanding Future. The Journal of Animal & Plant Sciences, 22(1): 239-246.
23. Mekonnen, M.M. and A.Y. Hoekstra, 2011. The green, blue and grey water footprint of crops and derived crop products. Hydrol Earth Syst Sci., 15: 1577-1600.
24. Molden, D., T. Oweis, P. Steduto, P. Bindraban, M.A. Hanjra and J. Kijne, 2010. Im- proving agricultural water productivity: between optimism and caution. Agric. Water Manag., 97: 528-535.
25. Rockström, J., M. Falkenmark, C. Folke, M. Lannerstad, J. Barron, E. Enfors, L. Gordon, J. Heinke, M. Hoff and C. PahlWostl, 2014. Water Resilience for Human Prosperity. Cambridge University Press, NY, USA.
26. De Boer, I.J.M., I.E. Hoving, Y.V. Vellinga, G.W.J. Ven, P.A. Leffelaar and P.J. Gerber, 2013. Assessing environmental impact sassociated 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.
27. FAO (Food and Agriculture Organization), 2009. CROPWAT software, Food and Agriculture Organization, Land and Water Division; Available at: http://www.fao.org/nr/water/infores_databases_cropwat.html.
28. 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 on Sep 10, 2012).
29. Al-Zahrani, M., S. Chowdhury and A. Abo-Monasar 2015. Augmentation of Surface Water Sources from Spatially Distributed Rainfall in Saudi Arabia, J. Water Reuse and Desalination, 5(3): 391-406.
30. Chowdhury, S. and M. Al-Zahrani, 2013. Reuse of Treated Wastewater in Saudi Arabia: An Assessment Framework. J. Water Reuse and Desalination, 03(3): 297-314
31. Chowdhury, S., M. Al-Zahrani and A. Abbas, 2016. Implications of Climate Change on Crop Water Requirements in Arid Region: An Example of Al-Jouf, Saudi Arabia. Journal of King Saud University-Engineering Sciences, 28: 21-31.
32. USDA, 2016. Saudi Arabia: Grain and Feed Annual. GAIN Report No. SA1602, Available at: https://gain.fas.usda.gov/Recent GAIN Publications/Grain and Feed Annual_Riyadh_Saudi Arabia_3-14-2016.pdf.
33. CDSI (Central Department of Statistics and Information) (2012). Import Statistics of Saudi Arabia in 2012.
34. SSYB (Saudi Statistical Year Book) (2010). Saudi Statistical Year Book. Available at: http://www.cdsi.gov.sa/yb46/Pages/MixFPage.htm
35. SSYB (Saudi Statistical Year Book) (2011). Saudi Statistical Year Book. Available at: http://www.cdsi.gov.sa/yb46/Pages/MixFPage.htm
36. UNDP (United Nations Development Programme), 2013. Water Governance in the Arab Region: Managing Scarcity and Securing the Future. UN Plaza, New York 10017, USA.
37. USDA, 2016. Saudi Arabia: Grain and Feed Annual. GAIN Report No. SA1602, Available at: https://gain.fas.usda.gov/Recent GAIN Publications/Grain and Feed Annual_Riyadh_Saudi Arabia_3-14-2016.pdf.
38. Al-Zahrani K.H. and M.B. Baig, 2011. Water in the Kingdom of Saudi Arabia: Sustainable Management Options. The Journal of Animal & Plant Sciences, 21(3): 601-613.
39. Abdallah, H.R. and B. Faye, 2013. Typology of camel farming system in Saudi Arabia. Emirates J. Food Agric., 25: 250-260.
40. City Population, 2016. Saudi Arabia: Available online at: https://www.citypopulation.de/SaudiArabia.html (accessed on 26/04/ 2017)
41. Khan, B.B., A, Iqbal and M. Riaz, 2003. Production and management of camels. Department of Livestock Management, University of Agriculture, Faisalabad.
42. Gerbens-Leenes, P.W., M.M. Mekonnen and A.Y. Hoekstra, 2013. The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. Water Resources and Industry, 1-2, pp: 25-36.
43. Ouda, O.K.M., 2014. Impacts of agricultural policy on irrigation water demand: case study Saudi Arabia. International Journal of Water Resources Development, 30(2): 282-292.
44. Papadopoulou, M.P., D. Charchousi, V.K. Tsoukala, C.H. Giannakopoulos and M. Petrakis, 2016. Water Footprint Assessment Considering Climate Change Effects on Future Agricultural Production in Mediterranean Region. Desalination and Water Treatment, 57(5): 2232-2242
45. World Bank, 2010. Making the most of scarcity: Accountability for better water management results in the Middle East and North Africa Report, Washington. USA.