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Evaluation of water footprint and economic water productivities of dairy products of South Africa

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ABSTRACT

Assessment of water footprint sustainability indicators and economic water productivities is regarded as a cornerstone of the world's sustainability goal and the reduction of the fresh water scarcity risk. These assessments are gaining much prominence because about four billion people face severe water scarcity, globally. Attaining sustainable and economically efficient water use goals requires a thorough assessment of all the existing sectors that use water. This paper examined the water footprint and economic water productivities of dairy products in South Africa for the periods 1996–2005 and 2006–2013 using the water footprint network assessment methodology. We found the total water footprints of all the selected dairy products in South Africa to be higher than the global averages are. During the period of 1996–2005, South African dairy producers utilized more green water in their dairy production. The production of butter and cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds had the highest total water footprints among all the dairy products in South Africa. Dairy production under a sole grazing system has high water footprints and low economic water productivities, relative to mixed production systems, for the period 2006–2013. With blue water becoming scarcer in South Africa, it is time for dairy livestock producers to shift their production to a system that is highly productive and has low water footprints. The water footprints of most of the dairy products for period 2006–2013 have reduced by varying amounts, relative to 1996–2005, which shows that water users along the dairy industry chains are managing water cautiously. Our findings have revealed dairy products that have high economic water productivities, and suggest that profit maximising and environmentally sustainable dairy producers and water users should integrate both blue water sustainability and economic water productivity indicators in their production decisions.

1. Introduction

In recent years, ecological and environmental sustainability assessments have been gaining much prominence, globally. The global water scarcity phenomenon has become a major issue of distress to governments, policy-makers, water users and water managers as well as private and non-governmental organisations and professional bodies interested in environmental and sustainability issues. It is estimated that about four billion people across the globe face severe water scarcity (Mekonnen and Hoekstra, 2016). An assessment of water sustainability indicators across various sectors of the global economy identified that, the greatest share of the world's freshwater is utilized in food production (IWMI, 2007). About 86% of all the freshwater resources in the world are consumed in food production (IWMI, 2007). This implies that the relative importance of water to food production and human survival cannot be overlooked. As a result of that, researchers and policy makers in recent years are interested in the study of sustainable and economical water utilization in the food sector.

Water footprint assessment is one of the ways of assessing water utilization in the food sector. The water footprint assessment gives an account of the quantity of fresh water utilized in the production of a particular food commodity (Hoekstra et al., 2011). Accounting for green (rainwater), blue (surface and groundwater) and grey (related to assimilating water pollutant) water consumption along the whole product value chain. Sustainability assessment of how water is utilized for food production reveals how producers along the food production chain behave with regards to the blue water available to them; as to whether they are using the available water resources sustainably or not. An important pillar of fresh water allocation is economic water productivity, which quantifies the value obtained by producers per unit of water used in producing a particular product (Hoekstra, 2014). The economic water productivities are calculated after the estimation of

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physical water productivities.

Water footprint sustainability assessments of livestock production systems and products have received some attention in recent years in countries such as Ireland (Murphy et al., 2013), Australia (Ridoutt et al., 2014) and China (Huang et al., 2014). Regarding dairy products, water footprint of assessments of milk and milk products have received much attention in developed countries such as Germany (Drastig et al., 2010), Argentina (Manazza and Iglesias, 2012), New Zealand (Zonderland-Thomassen et al., 2014) and in India (Amarasinghe et al., 2010). Animals and animal products' water footprints across the globe have also been explored based on global averages (Mekonnen and Hoekstra, 2012).

These assessments employed different methods such as the water footprint assessment methodology (Drastig et al., 2010; Mekonnen and Hoekstra, 2012), and life cycle assessment methodology including direct and virtual water consumption (Manazza and Iglesias, 2012; Murphy et al., 2013; Huang et al., 2014; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014). Most of these studies have focused on developed countries (Drastig et al., 2010; Huang et al., 2014; Murphy et al., 2013; Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014), with little emphasis placed on water-scarce African countries including South Africa. Existing studies that focus on assessing water utilization in the agricultural sector in South Africa are limited to the work of Jordaan and Grové (2012) who assessed the cumulative value added to water along the value chain of small-scale raisin and vegetables in order to determine the point along the value chain where most value is added to water.

Scheepers and Jordaan (2016) recently examined the blue and green water utilization for producing lucerne, used as feed for dairy cows. Owusu-Sekyere et al. (2016) recently quantified water utilization for milk production and processing in South Africa. However, this study focused only on milk with 4% fat and 3.3% protein. At the national level, information on water footprints of some dairy products was available from work of Mekonnen and Hoekstra (2012). However, these studies are limited to the quantification of water footprint indicators only, without accounting for economic water productivities, which is a strong pillar of fresh water allocation.

Nonetheless, some authors have assessed economic water productivities of products in the food sector. For instance, in Tunisia, assessments of some key crops were done to ascertain how productive the country is, in terms of water and land utilization (Chouchane et al., 2015) Schyns and Hoekstra (2014) conducted similar studies for some predominant crops produced in Morocco. Mekonnen and Hoekstra (2014) further assessed water conservation through trade in Kenya. Zoumides et al. (2014) conducted an economic water productivity assessment for crop production in Cyprus. All these studies focused on economic water productivities of crops, but with no similar studies being done on livestock products.

This study aims to assess the water footprint and economic water productivity of primary and derived dairy products for different production systems and periods in South Africa. This contributes to the limited knowledge on economic water productivities in the livestock sector and, to the best of our knowledge, this will be the first step taken towards assessing economic water productivities for dairy products in the dairy industry, particularly in Africa. Findings from this study can potentially assist water and environmental sustainability policy makers to understand whether, how and why consumers, water users and dairy producers along the dairy value chain might shift their consumption and production patterns to more sustainable and economically efficient ones. Insights from this study can further contribute to the current debate on the economic dimension of water footprint assessment.

2. Materials and methods

2.1. The study area

The study was conducted in South Africa. South Africa is one of the driest areas in the world and is ranked 30th in terms of freshwater water scarcity (DWA, 2013). The mean rainfall of the country is about 450 mm (DWA, 2013). According to DAFF (2012), approximately 80% of South Africa's agricultural land is suitable for livestock farming. The main source of water supply in the country is surface water (DWA, 2013). Ground water is widely used in rural and arid areas. A significant volume of water originates from return flows from major urban and industrial developments to streams. South Africa irrigates 1.5% of its total landmass to produce 30% of the total crops produced (DWA, 2013). Backeberg (2005) recounted that irrigated agriculture in South Africa utilizes about 40% of the utilizable runoff whiles agricultural production in general use more than 60% of the available water (DWA, 2013). In the dairy industry sector, large quantities of water are utilized for feed production. About 98% of all the water used along the dairy value chain in South Africa goes into feed production (Owusu-Sekyere et al., 2016).

The South African dairy industry is handled by Milk South Africa (Milk SA) and South African Milk Processors' Organisation (SAMPRO). These bodies consist of dairy farmers, producers and processors, who produce different dairy products for the local and international market. Dairy producers in South Africa do not import composite animal feeds (DAFF, 2015). However, some quantities of feed ingredients such as soya oilcake, yellow maize and fish meal are imported. It must be emphasised that there was no import of fish meal over the past ten years in the dairy industry (DAFF, 2015). There are three main systems of feeding dairy cows. These include: (i) Semi-intensive farm-based ration obtained from available crops, pastures and crop residues with minimal rations purchased. (ii) An intensive, zero-grazing dairy system using a total mixed ration. (iii) A traditional, extensive or dual-purpose system (Milk SA, 2014).

About 56% of dairy cows in South Africa rely on pasture, 38% rely on total mixed ration (TMR) and 6% rely on mixed or dual purpose system (Ercole, 2013; Milk SA, 2014). Table 1 presents production differences between the grazing (pasture) and mixed ration systems of feeding dairy cows for 300 days lactation period. This survey was done as part of a scheme towards dairy cattle improvement in the South African dairy industry. Average milk yield for total mixed ration is higher that grazing system, with a significant mean difference of 1463 kg of milk per cow for 300 days lactation period. In terms of fat content, the survey revealed that the butter fat content per kilogram for the mixed system is significantly higher than that of the grazing system.

Table 1
Mean production differences between grazing and mixed systems of dairy feeding.
Source: Dairy Cattle Improvement Scheme (Milk SA).

System	Milk (kg)	Butter fat (kg)	Protein (kg)	Butter fat (%)	Protein (%)
Mixed	7411 (1489)	310(61)	256(50)	4.26(0.36)	3.48(0.21)
Grazing	5949(1285)	245(50)	203(42)	4.23(0.33)	3.46(0.22)
Mean difference	1463***	65**	53**	0.04	0.02

Values in brackets are standard deviations.
**Indicates significant mean difference at 95% confidence interval.

This is indicated by the significant mean difference of 65 at 5% level. Additionally, the protein content of mixed system of feeding dairy cows is higher than that of the grazing system, as shown by the significantly positive mean difference of 53.

2.2. Data sources and description

The paper used secondary data from 1996 to 2013. An overview of the data inputs, sources and duration are described in this section. Mekonnen and Hoekstra (2012) provided data on water footprints of derived products from animals for different countries for the periods of 1996–2005. It must be emphasised that the data reported by these authors are weighted averages estimated at the global level for the stated period. The data pertaining to South Africa were extracted for the selected dairy products from grazing and mixed systems, for the stated period. The volumes of blue, green and grey water utilization in the dairy industry for the periods of 2006–2013 were obtained from the South African Milk Processors' Organisation (SAMPRO) and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market. Data on producer prices of daily products and production quantities were obtained from SAMPRO and FAOSTAT (FAO, 2015).

Part of the data on feed production and water usage for feed crops used in the dairy industry were attained from the work of Van Rensburg et al. (2012). Data on crop water use, irrigation, evapotranspiration, drainage and rainfall for different catchment areas and irrigation schemes for feed and forage crops production were obtained from Van Rensburg et al. (2012). This information was utilized in the estimation of the feed and forage crops' water footprints. Data on feeding (composition and quantities) were obtained from commercial dairy producers and processors who have electronic feed calculation systems with good recordkeeping. This electronic feed calculation system keeps records of feed ration, moisture content, dry matter, the nutritional content of feed inputs and the complete ration for the lactating cows. The data obtained from different producers and production areas for the period of 2006–2013 were aggregated and used in the calculations of blue, green and grey water footprints of the primary and derived products.

2.3. Methodological and empirical framework

In the calculations of the water footprints, the paper adopted the terminologies and empirical procedures outlined by Hoekstra et al. (2011). The methodology outlined by these authors for quantifying water footprint has been adopted by researchers in recent years to distinctly quantify the proportion of the total water footprint that is blue, green or grey in a particular product value chain. Conceptually, the surface and groundwater utilized for producing any of the selected dairy products is quantified as the blue water footprint of that product. The rainwater utilized for producing any of the selected dairy products is also quantified as the green water footprint of that dairy product. Hoekstra et al. (2011) iterated that the green water footprint excludes the rainwater that runs off. The quantified amount of water used to fine-tune the water quality to its acceptable standard becomes the grey water footprint. Grey water footprint deals with water contamination.

The stepwise accumulative procedure was applied in our quantifications of water footprints of the dairy products since the focus was on a variety of dairy products (Hoekstra et al., 2011). The empirical specification employed by Chapagain and Hoekstra (2004) to calculate live animals' water footprints was employed to quantify the water footprint of live animals. The quantification of the service water footprint in our analysis was based on the procedure set out by Hoekstra et al. (2011). In calculating the water footprint of various feed crops and dairy products, the estimation procedures employed by Mekonnen and Hoekstra (2012) were followed.

Additionally, the water footprint estimates of dairy products reported by Mekonnen and Hoekstra (2012) for the period of 1996–2005 were utilized and compared with our estimates for 2006–2013 because we applied the same models, parameters, assumptions and guidelines used by the authors. Also, the dairy products and production systems considered in our study and that of Mekonnen and Hoekstra (2012) are the same. The proportion of imported feed ingredients that were incorporated into rations formulated for dairy animals was approximated to be about 1.5%. Hence, the weighted average water footprint based on the relative volumes of local production and imports were taken in the calculation of the water footprint of animal feed ingredients (Mekonnen and Hoekstra, 2012). For the different field and forage crops, their blue and green water footprints were calculated using the formula specified in equation (1):

$$WF_{proc,blue,green} = \left(\frac{CWU_{blue}}{Y_t}\right) + \left(\frac{CWU_{green}}{Y_t}\right) \tag{1}$$

where $WF_{proc,blue,green}$ represents the blue and green water footprint of a particular feed crop. The first part of equation (1) represents blue water footprint. CWU_{blue} denotes the blue component in feed crops water use and Y_t is the feed crop yield (Hoekstra et al., 2011). The second part of equation (1) represents the green water footprint. Similarly, CWU_{green} denotes the green component in feed crops water use (Hoekstra et al., 2011). The crop water use components of equations (1) is defined as the sum of the daily evapotranspiration over the complete growing period of the feed crops (Hoekstra et al., 2011). This is empirically specified in equation (2):

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{lgp} ET_{blue,green} \tag{2}$$

$ET_{blue,green}$ represents the blue and green water evapotranspiration. The water depths are changed from millimetres to volumes per area by using the factor 10. The summation is done over the complete length of the growing period from day one to harvest (Hoekstra et al., 2011). The grey water footprints of the feed crops are calculated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically in equation (3):

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y_t} \tag{3}$$

It is worth noting that the fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. In line with the stepwise accumulative procedure, the water footprint of the main product Υ is assumed to be produced from x inputs or feed crops. Let x inputs be numbered from i = 1…. x. Assuming that x inputs are used to produce y dairy products, let the different dairy output products be represented as Υ = 1….y. The dairy products' (Υ) water footprints are represented in equation (4):

$$WF_{prod}[\Upsilon] = \left(WF_{proc}[\Upsilon] + \sum_{i=1}^{x} \frac{WF_{prod}[i]}{f_{\Upsilon}[\Upsilon, i]}\right) * f_v[\Upsilon] \tag{4}$$

where $WF_{prod}[\Upsilon]$ denotes total water utilized in order to produce Υ. The water footprint of input i is represented by $WF_{prod}[i]$. $WF_{proc}[\Upsilon]$ is the processing water that was used to process x inputs to y output products. The product and value fractions are denoted by $f_p[\Upsilon, i]$ and $f_v[\Upsilon]$, respectively. Details regarding the product and value fraction are outlined in Hoekstra et al. (2011). After calculating the dairy products' footprints for different production regions, weighted averages were calculated in order to determine total, blue, green and grey water footprints at the national level. The calculation of the weighted averages follows the formula specified in equation (5):

$$WWF = \frac{\sum_{l=1}^{n} x_l \times w_l}{\sum_{l=1}^{n} w_l} \quad (5)$$

where the weighted average water footprint is denoted by WWF. x_l is the water footprint value of a given dairy product from production region l and w_l represents the weight assigned to the given dairy product from production region l. The weights were assigned in line with the contribution of the different regions to total dairy output. Given that $WF_{prod}[\Upsilon]$ is measured in cubic m^3/tonne, the physical water productivity (PWP) of a particular dairy output product Υ measured in kilograms per metre cubed and expressed in equation (6):

$$PWP = \frac{1}{WF_{prod}[\Upsilon]} * 1000 \quad (6)$$

After calculating the physical water productivity, economic water productivities are further calculated. The economic water productivity for a particular dairy output product is then attained by multiplying the physical water productivity by that particular dairy product's value per kilogram. The producer prices are expressed in price per kilogram of the output product Υ. We denote the price of Υ by Υ_{Price}. We express the economic water productivity (EWP) in equation (7):

$$EWP = PWP * \Upsilon_{Price} \quad (7)$$

The monetary value attained from every cubic meter of water used in producing any of the dairy products then becomes the economic water productivity of that product (Chouchane et al., 2015). Economic water productivities were estimated for all the dairy products considered in the study. The water footprints and water productivities of the selected products were separated for grazing and mixed systems of raising dairy cows in the study area because water utilization (Mekonnen and Hoekstra, 2012) and milk yields from these production systems differ (Scholtz et al., 2014).

3. Results and discussions

3.1. The water footprints of South African dairy products versus the global averages from the year 1996–2005

The water footprints of South African dairy products were compared the global averages for the period 1996–2005 to understand the water use pattern and how dairy producers are behaving in terms of water utilization (Table 2). The findings point out that the average blue water footprints for all the dairy products in South Africa are lower than the global average blue water footprints are. This implies that in terms of blue water usage, water users in the South African dairy industry are performing better, compared with the global blue water footprint indicators. Regarding green water utilization, the 1996–2005 estimates by Mekonnen and Hoekstra (2010) show that South Africa's green water footprints are higher than the global average green water footprints for the dairy products considered, suggesting that green water use along the dairy industry chain in South Africa is higher, compared with other parts of the world. However, the grey water footprints for the dairy products in South Africa are lower than the global estimates for the same dairy products.

Although South Africa's blue and grey water footprints were revealed to be lower, the 1996–2005 estimates indicate that the overall water footprints for the selected dairy products in South Africa are higher than the global average total water footprints are. The high total water footprint indicators for dairy products in South Africa are attributable to the higher green water footprints. This further indicates that the highest proportion of water utilized along the dairy chain in South Africa during the 1996–2005 periods was accumulated from the farm level, since green water was not utilized at the processing and marketing stage of the dairy value chain. This is supported by Owusu-Sekyere et al. (2016) who iterated that the largest proportion of water used along the dairy value chain in South Africa is green water.

The high green water footprints for South Africa could be attributed to low milk yield associated with sole grazing system of dairy production under which relies on rainfall for field and forage crops production for feeding livestock (Scholtz et al., 2014). The low milk output could be explained by the low yield of rain-fed field and forage crops largely used dairy producers in South Africa, compared to the global average. For both South Africa and the world, the highest total water footprint was found to be associated with the production of butter. This is followed by the various cheese products, whether as grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds. The high water footprints of all these products are as a result of the conversion factors (product/value fractions) used (Mekonnen and Hoekstra, 2012).

The lowest water footprints among all the dairy products were associated with the production of whey and non-concentrated and unsweetened milk not exceeding one per cent fat, respectively. The next product with low water footprint was non-concentrated and unsweetened milk and cream with more than 6% fat. Comparing the water footprint estimates of South Africa for the period of 1996–2005 to other African countries where water footprint is gaining much prominence, the estimates show that the water footprints of butter and the assorted cheese products in South Africa are about 31 and 8% lower than that of Tunisia and Kenya, respectively for the same time period (Mekonnen and Hoekstra, 2010).

Similarly, the water footprint of whey and milk (non-concentrated and unsweetened) not exceeding one per cent fat in South Africa are about 64, 31 and 8% lower than that of Morocco, Tunisia and Kenya, respectively for the same time period (1996–2005) (Mekonnen and Hoekstra, 2010). Given that the South African estimates are higher than the global averages, but lower than these African countries, there is therefore the need for South Africa to have its country-specific benchmarks based on the country's available freshwater resources and for which the water footprints of products in that country can be related to. This benchmark will help South Africa by serving as a reference and assist in establishing water footprint reduction targets. This is in agreement with recent findings by Zhuo et al. (2016) in China.

3.2. Water footprints of dairy products under different dairy production systems in South Africa for the period 2006–2013

The average water footprints of the selected dairy products were estimated for sole grazing (extensive) and mixed systems (intensive and extensive) of production and the estimates are provided in Table 3. The estimates indicate that the blue water footprints for the selected dairy products produced under sole grazing system, is higher than the blue water footprints under the mixed production system, with the exception of whey (whether or not concentrated or sweetened), which had the same blue water footprints under the two production systems. This is concurs with the findings of Srairi et al. (2009) in an assessment of water productivities for dairy and meat cows kept under irrigation scheme in Morocco. The authors found that significant variability in milk and meat outputs placed substantial influence on water productivities.

Given the blue water scarcity situation in South Africa, it is vital for dairy livestock producers to decide whether to keep dairy animals solely on grazing or under the extensive system of production. Regarding green water use, the results show that green water footprints for the

Table 2
The average blue, green and grey water footprint of dairy products for the period 1996–2005 adapted from Mekonnen and Hoekstra (2012).

Product description	South Africa (m^3/tonne)				Global average (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	41	1019	40	1100	86	863	72	1021
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	42	1053	41	1136	88	891	75	1056
Milk and cream not concentrated and unsweetened exceeding 6% fat	76	1896	74	2046	159	1605	134	1898
Milk powder not exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder unsweetened exceeding 1.5% fat	190	4739	185	5114	398	4011	336	4745
Milk and cream powder sweetened exceeding 1.5% fat	200	4739	185	5124	408	4011	336	4755
Milk and cream unsweetened,	62	1576	63	1701	132	1334	112	1578
Milk and cream sweetened	81	1896	74	2051	164	1605	134	1903
Yogurt concentrated, unsweetened	48	1185	46	1279	99	1003	84	1186
Buttermilk, curdled milk & cream	64	1597	62	1723	134	1352	113	1599
Whey whether or not concentrated or sweetened	26	646	25	697	54	547	46	647
Products consisting of natural milk constituents sweetened	48	1185	46	1279	99	1003	84	1186
Butter	223	5546	217	5986	465	4695	393	5553
Cheese, fresh unfermented, and curd	128	3174	124	3426	266	2687	225	3178
Cheese, grated or powdered, of all kinds	218	5038	197	5453	439	4264	357	5060
Cheese processed, not grated or powdered	218	5038	197	5453	439	4264	357	5060
Cheese, blue-veined	218	5038	197	5453	439	4264	357	5060
Cheese (others)	218	5038	197	5453	439	4264	357	5060

grazing system are higher than that of mixed production system for all the dairy products. In terms of total water footprints, the results suggest that the total water footprints of all the dairy products produced under the grazing system alone are higher than the total water footprints of the same products produced under mixed production systems. The high green water footprints under the grazing or extensive system of production are as a result of the preponderance of indirect water usage for forage production. This might also be attributed to low milk yield associated with the extensive system of raising dairy cattle in South Africa (Scholtz et al., 2014). The low milk yield from this system can be attributed to poor pasture and forage output, mainly due to erratic rainfall. MacDonald et al. (2007) opined that low milk yield from cows kept on grazing system can be attributed to the inability of cows to eat sufficient metabolizable energy for high production owing to feed intake constraints.

Low milk yield affects water footprints estimates in the sense that lower yield from a particular production system directly increases the water footprint values of that particular system (Bosire et al., 2015). The high water footprints may also be attributed to low feed conversion efficiencies of animals kept on grazing system (Bosire et al., 2015). Therefore there is the need for dairy livestock producers to review their pastures and rangelands management strategies to increase feed availability and quality. This will increase dairy output, which in turn will reduce water footprints. For both grazing and mixed production systems, dairy livestock producers should breed animals with better growth rates and milk yield per cow, with the aim of enhancing feed conversion efficiency. This will reduce water footprints and enhance water productivities.

In terms of individual dairy products, the results reveal that the highest total water footprints are associated with butter for both grazing and mixed systems of production. Cheese products, whether grated or not grated, powdered or not powdered, blue-veined and cheese of all kinds recorded the next highest water footprints for both systems of production. Also, products such as milk powder with fat content not above 1.5%, milk and cream powder (unsweetened) exceeding 1.5% fat were found to have the third-highest total water footprints for both grazing and mixed systems of production.

The high water footprints of these products raise major concerns for sustainability policy-makers. Producers of these products should consider an investment in technologies that minimize water usage and

Table 3
The average blue, green and grey water footprint of dairy products for different production systems in South Africa (2006–2013).

Product description	Grazing system (m^3/tonne)				Mixed system (m^3/tonne)			
	Blue WF	Green WF	Grey WF	Total WF	Blue WF	Green WF	Grey WF	Total WF
Milk not concentrated and unsweetened not exceeding 1% fat	69	1289	40	1398	68	1180	39	1287
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	70	1263	41	1374	69	1185	41	1295
Milk and cream not concentrated and unsweetened exceeding 6% fat	75	1914	74	2063	68	1583	73	1724
Milk powder not exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder unsweetened exceeding 1.5% fat	187	4784	185	5156	171	3369	183	3723
Milk and cream powder sweetened exceeding 1.5% fat	197	4784	185	5166	181	3369	183	3733
Milk and cream unsweetened	62	1591	62	1715	57	1383	61	1501
Milk and cream sweetened	80	1914	74	2068	73	1583	73	1729
Yogurt concentrated, unsweetened	47	1196	46	1289	43	1137	46	1226
Buttermilk, curdled milk & cream	63	1612	62	1737	58	1396	62	1516
Whey whether or not concentrated or sweetened	25	625	25	675	25	599	23	647
Products consisting of natural milk constituents sweetened	47	1196	46	1289	43	1137	46	1226
Butter	219	5599	217	6035	200	3876	214	4290
Cheese, fresh unfermented, and curd	125	3204	124	3453	115	2386	123	2624
Cheese, grated or powdered, of all kinds	215	5086	197	5498	198	3557	195	3950
Cheese processed, not grated or powdered	215	5086	197	5498	198	3557	195	3950
Cheese, blue-veined	215	5086	197	5498	198	3557	195	3950
Cheese (others)	215	5086	197	5498	198	3557	195	3950

Authors' calculations, 2016.

Table 4
Physical and economic water productivities for different production systems in South Africa (2006–2013).

Product description	Grazing system			Mixed system		
	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/$m^3$)	Total WF (m^3/tonne)	Physical Water productivity (kg/m^3)	Economic water productivity (US$/$m^3$)
Milk not concentrated and unsweetened not exceeding 1% fat	1398	0.72	0.21	1287	0.77	0.23
Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat	1374	0.73	0.22	1295	0.78	0.23
Milk and cream not concentrated and unsweetened exceeding 6% fat	2063	0.48	0.15	1724	0.58	0.17
Milk powder not exceeding 1.5% fat	5156	0.19	0.14	3723	0.27	0.20
Milk and cream powder unsweetened exceeding 1.5% fat	5156	0.19	0.10	3723	0.27	0.13
Milk and cream powder sweetened exceeding 1.5% fat	5166	0.19	0.13	3733	0.27	0.18
Milk and cream unsweetened	1715	0.58	0.74	1501	0.66	0.85
Milk and cream sweetened	2068	0.48	0.13	1729	0.58	0.15
Yogurt concentrated, unsweetened	1289	0.78	0.42	1226	0.82	0.44
Buttermilk, curdled milk & cream	1737	0.58	0.39	1516	0.66	0.45
Whey	675	1.48	0.59	647	1.55	0.62
Butter	6035	0.17	0.19	4290	0.23	0.30
Cheese, fresh unfermented, and curd	3453	0.29	0.38	2624	0.38	0.51
Cheese, grated or powdered, of all kinds	5498	0.18	0.25	3950	0.25	0.34
Cheese processed, not grated or powdered	5498	0.18	0.23	3950	0.25	0.32
Cheese, blue-veined	5498	0.18	0.31	3950	0.25	0.43
Cheese (other)	5498	0.18	0.25	3950	0.25	0.34

Authors' calculations, 2016.

increase dairy product outputs, especially for butter and cheese processing. Another alternate will be the importation of such products with high water footprints from countries with enough water resources and where the same products are produced with minimal water usage. The results reveal that whey (whether or not concentrated or sweetened) has the lowest water footprints under both systems of production. Yoghurt (concentrated and unsweetened) and other dairy products containing some milk components (sweetened) were among the dairy products with low water footprints for both grazing and mixed systems of production.

3.3. The water productivities (physical and economic) of the selected dairy products in South Africa

Table 4 presents the water productivities of the dairy products for different production systems in South Africa. The water productivities were expressed in physical and economic terms. For both systems of production, the results show that whey, yogurt (concentrated and unsweetened), milk (unsweetened and unconcentrated) with fat content greater than 1 per cent but not higher than 6% fat and milk (unsweetened and unconcentrated) with fat content higher than 1 per cent have physical water productivities, respectively. However, it is worth noting that expressing water productivities in the physical context does not provide much insight when water utilization is assessed from an economic viewpoint (Pereira et al., 2009). Hence, it was imperative to focus on economic water productivities. Additionally, profit maximising firms are more interested in maximising the value attained from the quantity of water utilized in their production, in lieu of focusing on physical water productivities (Molden et al., 2010). This is because blue water is directly associated with production cost and as such; firms aim at gaining more value to cover the cost of water and other production inputs.

Under the grazing system of production, the results show that higher economic water productivities are associated with milk and cream (unsweetened) and whey, as 0.74 and 0.59 US dollars are attained per every cubic metre of water used to produce one kilogram of these dairy products, respectively. This is followed by yogurt (concentrated and unsweetened) and buttermilk (curdled milk and cream), respectively. Milk (unsweetened) and cream powder with fat content exceeding 1.5%, milk and cream (sweetened), milk and cream powder (sweetened) with fat contents higher than 1.5% and milk powder with fat content not above 1.5% have the lowest economic water productivities, respectively. Under the mixed system of production, the results show that milk and cream (unsweetened), and whey have high economic water productivities, respectively. This is followed by cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened), respectively.

On the other hand, milk and cream powder (unsweetened) with a fat content higher than 1.5% has the lowest economic water productivity of 0.13 US$/$m^3$. This is followed by milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6%, respectively. In general, the results show that economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. The difference in economic water productivities is the result of the difference in water use or footprints for the two systems. The higher water footprints observed for the grazing system resulted in low physical water productivities and hence the low economic water productivities. This provides the justification for stakeholders in the dairy sector to consider which system is economically efficient in terms of water use.

The contributions of different provinces to total dairy production in South Africa are presented in Fig. 1. The Western Cape province is the highest contributor to the total dairy production for the 2012/2013 production season. The Eastern Cape and KwaZulu-Natal provinces are the second-highest contributors to the total dairy production of the country, with 24% contributions each. Thirteen per cent of the country's dairy products come from the Free State province, with the North West and Mpumalanga provinces contributing 5% and 4%, respectively to the total dairy production of the country. The remaining provinces contribute 3% to the total dairy production. The high contributions from the Western and Eastern Cape provinces, as well as KwaZulu-Natal province, are probably attributable to the favourable climate and good pasture regimes for livestock production.

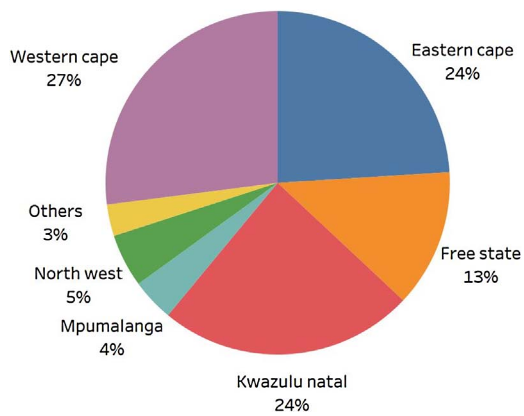

Fig. 1. Contributions of different provinces to total dairy production in South Africa.

4.1. Average water use behaviour in dairy production between the period 1996–2005 and 2006–2013

Table 5 presents the estimates of average water footprints of the dairy products calculated for the periods 1996–2005 and 2006–2013 in South Africa. The 1996–2005 estimates by Mekonnen and Hoekstra (2010) were compared to our 2006–2013 estimates because the same models, parameters, assumptions and guidelines as outlined in the water footprint assessment manual were employed in both estimations. Also, the analyses for the two time periods were conducted for the same dairy products and production systems and as such the estimates are comparable. This comparison is critically important to understand the degree of sustainability with which freshwater is used in the dairy industry in recent years. This will accurately and effectively inform water managers and water users towards the sustainable use of freshwater in dairy production.

Comparing the water footprint of the dairy products between the periods of 1996–2005 and 2006–2013, it was revealed that the production of milk (unconcentrated and unsweetened) with fat content not higher than 1% recorded the highest increase in water usage. This is followed by the same product with fat content exceeding 1% but not higher than 6%. The implication from these findings is that the water usage in the production of these dairy products has increased. This can be ascribed to our qualitative information which revealed that some of these unsweetened and unconcentrated milk products are produced by dairy producers who are not processors and as such their capacity to recycle blue water is limited compare with the other products which are mainly produced by dairy processing companies with good water recycling systems in recent years.

The production of the remaining dairy products saw significant improvements in terms of water saving, comparing the water footprints between the two periods. For instance, the highest reduction in water usage was associated with the production of butter. Similarly, there were somehow moderate reductions in water use for the production of cheese products, which were found to be among the dairy products with high water consumption. Between the periods of 1996–2005 and 2006–2013, the production of dairy products such as milk powder with fat content not above 1.5%, unsweetened milk and cream powder with fat content higher than 1.5%, as well as milk and cream powder (sweetened) with above 1.5% fat content, saw reductions in water usage of about 13%.

The remaining dairy products also recorded some reductions in water use between the two periods, which is a good indication that water users in the dairy industry recognise the need for water management and saving strategies to sustain their business and the environment in the long run. The reductions in water footprints for the dairy products vary from product to product. This provides the rationale for awareness creation and campaigns on sustainable water management aimed at imparting water-saving attitudes among South Africans because our findings indicate that water use behaviour in the dairy industry has improved since actors along the dairy value chain have become conscious of the water scarcity situation in the country.

Our study is not without limitations; firstly, our analysis focused only on dairy production under the grazing and mixed production system due to unavailability of data for other production systems such as the intensive, zero-grazing and traditional dual-purpose dairy system. Secondly, the study focused only on dairy outputs without considering meat output. Thirdly, we acknowledge the lack of consistency in input variables and data sources. For instance, the data extracted from Mekonnen and Hoekstra (2012) are averages of a global assessment and as such using it in the context of a national assessment has pros and cons.

Facilitating consist, reliable and frequent livestock surveys at provincial and national levels in South Africa would be essential to safeguard precision of future studies that focus on productivities and efficient use of resources in different livestock production systems. Similar

Table 5
Comparison of the average water footprints of the dairy products for the periods 1996–2005 (Mekonnen and Hoekstra, 2012) and 2006–2013 in South Africa (authors' calculations, 2016).

Product description	Water footprint in m^3/tonne (2006–2013)	Water footprint in m^3/tonne (1996–2005)	Mean difference (m^3/tonne)	Percentage change
Milk not concentrated and unsweetened not exceeding 1% fat	1343	1100	243	22
Milk not concentrated & unsweetened exceeding1% not exceeding 6% fat	1335	1136	199	17
Milk and cream not concentrated and unsweetened exceeding 6% fat	1894	2046	−153	−7
Milk powder not exceeding 1.5% fat	4440	5114	−675	−13
Milk and cream powder unsweetened exceeding 1.5% fat	4440	5114	−675	−13
Milk and cream powder sweetened exceeding 1.5% fat	4450	5124	−675	−13
Milk and cream unsweetened	1608	1701	−93	−5
Milk and cream sweetened	1899	2051	−153	−7
Yogurt concentrated, unsweetened	1258	1279	−22	−2
Buttermilk, curdled milk & cream	1627	1723	−97	−6
Whey whether or not concentrated or sweetened	661	697	−36	−5
Products consisting of natural milk constituents sweetened	1258	1279	−22	−2
Butter	5163	5986	−824	−14
Cheese, fresh unfermented, and curd	3039	3426	−388	−11
Cheese, grated or powdered, of all kinds	4724	5453	−729	−13
Cheese processed, not grated or powdered	4724	5453	−729	−13
Cheese, blue-veined	4724	5453	−729	−13
Cheese (Other)	4724	5453	−729	−13

studies should be conducted for dairy production under the systems not considered in this study when data is available. Future research in South Africa should consider the development of country-specific water footprint benchmarks for different product categories and production systems to serve as a reference and assist in establishing water footprint reduction targets. Additionally, future studies should consider water footprints and economic water productivities for different meat production systems in South Africa.

5. Conclusions

Generally, it is concluded that South Africa's total water footprints for the dairy products considered in this study are higher than the global average total water footprints in the period 1996–2005 are. Nonetheless, it can be concluded that South Africa's average blue water footprints for all the dairy products considered are lower than the global average blue water footprints in the period 1996–2005. Additionally, it can be concluded that during the period of 1996–2005, South African dairy producers were utilizing more green water in their dairy production. We suggest that current dairy producers should make efficient use of green water.

Regarding the dairy products, we conclude that butter and cheese products (whether grated or not grated, powdered or not powdered, blue-veined) and cheese of all kinds had the highest total water footprints in South Africa for both periods. In the 2006–2013 period, we conclude that the total water footprints for all the dairy products produced solely under grazing systems are higher than the total water footprints of the same products produced under the mixed production systems. We also conclude that blue water footprints under the grazing system are higher, relative to the blue water footprints under the mixed production system. We also conclude that the water footprints for most of the dairy products in the 2006–2013 period have reduced compared with the 1996–2005 estimates.

Regarding water productivities, we conclude that the economic water productivities for all the dairy products under the mixed system of production are higher than those of the grazing systems are. Among the dairy products, we conclude that dairy products such as milk and cream (unsweetened), whey, cheese (fresh unfermented and curd), buttermilk (curdled milk and cream) and yoghurt (concentrated and unsweetened) had the highest economic water productivities, respectively. Milk and cream powder (unsweetened) with fat content above 1.5%, milk and cream (sweetened) and milk and cream (unconcentrated and unsweetened) with a fat content higher than 6% had the lowest economic water productivity.

Given that there are low blue water footprints and high economic water productivities in the mixed production system, this system appears to be a better alternative, relative to the sole grazing system. Farm management options to boost water productivities under the various systems of livestock production include increasing dairy output, improving feed conversion efficiency of cows, animal health improvement, investment in water saving technologies and adoption of pasture management practices that increase forage availability and quality. Additionally, forage and pasture management practices that circumvent land degradation to reduce the quantity of water needed for field and forage crops.

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