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Blue and Grey Water Footprints of Dairy Farms in Kuwait

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Abstract

In Kuwait, dairy farming faces challenges due to its significant water demands. The current study assessed seasonal patterns of water use to estimate the blue water footprint (WF) and grey WF per kg of fat protein corrected milk (FPCM) for confined dairy farming systems in Kuwait. Blue and grey WFs were evaluated using data from three operational farms. The average blue WF ($L \cdot kg^{-1}$ FPCM) was estimated to be 54.5 ± 4.0 $L \cdot kg^{-1}$ in summer and 19.2 ± 0.8 $L \cdot kg^{-1}$ in winter. The average grey WF (generated from milk house wastewater) was assessed on bimonthly basis and determined based on its phosphate (PO_4) concentration (82.2 ± 14.3 $mg \cdot L^{-1}$) which is the most limiting factor to be 23.0 ± 9.0 $L \cdot kg^{-1}$ FPCM d^{-1}. The outcomes indicate that enhancing the performance of dairy cows and adopting alternative water management strategies can play a role in minimizing the impacts of confined dairy farming systems in Kuwait on water quality and quantity.

Keywords

Kuwait, Blue Water Footprint, Grey Water Footprint, Fat Protein Corrected Milk, Dairy Farming System

1. Introduction

Globally, there is an expansion in the dairy industry due to population growth and consumer preference toward high protein diets [1], which has created pressure on freshwater resources [2]. The dairy sector has a high-water demand [3] and uses water directly for drinking and cleaning, and indirectly for animal feed production and pollutant assimilation [4].

One of the greatest challenges accompanied with milk production is the limited awareness about the management of freshwater resources [5] and the unsustainable considerations in a water scarce country such as Kuwait.

One of the tools used to explore the total amount of utilized water along the milk production cycle is the water footprint (WF). The WF is a multi-dimensional indicator that clarifies the time and location of water use and quantifies the amount of water required to assimilate chemicals in water bodies [6]. The WF can help reverse the trend in water depletion, as it provides information about the association between the effect of production on water quantity and quality [7]. The WF reflects the total water use by its components, which include the blue WF (surface and ground water depletion), and the grey WF (the water needed to dilute polluted water).

On dairy farms, water is mainly used for drinking to maintain the productivity, cooling (thermoregulation), and cleaning of barns and milking centers. Even though the cleaning of milking equipment is critical to produce high-quality milk, it generates effluent water that has a negative impact on the environment due to the use of detergents that are high in their nitrate (NO_3-N), and phosphate (PO_4) contents.

In Kuwait there have been no previous studies that have evaluated the amount of water utilized on dairy farms. This data provides an opportunity to assess water use and seek sustainable production strategies based on local conditions [8]. Accordingly, the objectives of this study were to estimate the blue WF, assess the seasonal patterns of water use, determine the volume and composition of milk house wastewater, and estimate the grey WF of confined dairy production systems in Kuwait.

2. Material and Methods

2.1. Dairy Farm Management and Data Description

The study was performed over two-years from Jan 2018 through Dec 2019. Data collection represent the direct water utilized on three confined dairy farms in the Sulaibiya area (29˚28'56.0"N, 47˚81'80.0"E) of Kuwait. The coordinates and management description of each farm are shown in **Table 1**.

Type of animal housing systems, feed ration composition, water source and environmental conditions were almost identical among all three farms. In general, the differences between the farms were mainly represented by the sources of imported animals (Holland or Germany), stock replacement intervals, the frequency of introducing local born calves to the milking herd and the sale of the male animals.

Lactating Holstein cows were housed in traditional free-stall barns that are equipped with fans and water misters on the roof along with evaporative cooling pads on both ends of each barn to create a thermal comfort zone especially during the summer from May to Nov (average ambient Temperature (Temp) 31.8˚C).

Table 1. The coordinates and detailed operational information for the three dairy farms in Kuwait.

Farm	Farm (A)	Farm (B)	Farm (C)
Lat./Long.	29˚15'41.5"N 47˚47'45.6"E	29˚16'15.5"N 47˚48'04.0"E	29˚16'17.0"N 47˚48'40.0"E
Housing system	Confined (zero grazing system)/Sand bedding		
Cooling system	Fans, cooling pads, and water spray		
No. of barns	4	8	2
Barn size	15 m × 60 m	10.7 m × 107 m	49 m × 20 m
Life span of lactating cows	Lactating cows raised until 5 years (depending on the health condition). Lactating cows sold if the milk yield is 10 L or less & if the cow is not pregnant.		
Herd size	Lactating cows: 83 Non-lactating animals: 59.0	Lactating cows: 477 Non-lactating animals: 118.0	Lactating cows: 123 Non-lactating animals: 92.0
Milking frequency per day	2	3	2
Milking parlour	12 (rows) × 2 (lines)		
Cow breed	Holstein Friesian (imported from Europe)		
Water nozzle	Used	Used	Not used

Desalinated potable water from a municipal source was the main water supply to all barns. Water flow meters (Ningbo Water Meter (NWM)) were fixed in different locations on each farm to measure the amount of water intake (WI) by lactating cows, spray water for cooling, and the amount of wash water generated. The water meters were calibrated based on VanderZaag *et al.* [9] which was repeated every six months until the end of the study period. The occasional loss of data occurred due to water meter failure or modifications in the farm(s). Data were imputed by linear regression, which aimed to preserve the relation between the missing data and the existing data under the same class [10]. In addition, outlier values were removed if they exceeded 1.5 of the interquartile range (IQR). The water meter data were used to calculate the amount of water consumed per cow per day.

The blue WF reflects the amount of water used for washing, cooling or as potable water relative to milk production, while the grey WF reflects the amount of polluted water especially that generated from the cleaning processes of the milk house after each milking event. Potable WI by the lactating cows was measured on a biweekly basis by the water meters that were installed adjacent to the troughs. The amount of water delivered to the troughs was limited to their capacity which was controlled by a float valve. During the data recording period, the replacement of the lactating herds was monitored to calculate the consumption per cow per day.

For the entire monitoring period, the average WI for other animal categories including dry cows, heifers and calves was predicted from the average amount of drinking water in temperate conditions such as Ontario (ON)-Canada. This was achieved by referring to the fact that in arid environment the WI is two to four times that being consumed in moderate environment with Temp between 2˚C - 10˚C [11] [12].

In confined dairy farming systems in ON, the average WI of calves, heifers and dry cows was 12.0, 22.0, and 35.0 L cow^{-1} d^{-1}, respectively [13]. Ward and McKague [14] found that the average water consumption of calves, heifers and dry cows in ON was 9.1, 25.4 and 41.5 L cow^{-1} d^{-1}, respectively.

The predicted WI for calves, heifers and dry cows in the summer under heat stress was calculated using the average of the following two equations:

$$WI_{\text{heat stress}} = K * WI_w \quad (1)$$

where, $WI_{\text{heat stress}}$ = Water intake in summer under heat stress; K = Multiplicative constant (Gonzalez Pereyra *et al.* [15] reported that heat stress (THI 74.91 - 83.95) increases drinking water of Holstein dairy cows by 53.2%, thus K = 1.532); WI_w = Water intake in winter.

$$WI_s = K * WI_w \quad (2)$$

where, WI_s = Water intake in summer; K = Multiplicative constant (Arias and Mader [16] stated that beef cattle drink 87.3% more water in summer ($P \leq 0.01$) compared to winter, thus K = 1.873).

In the calculation of the amount of water consumed, it is important to include the dietary water (water present in the feed consumed). Dietary water is the difference between the "as-fed" and dry matter intake (DMI). However, metabolic water (water produced through oxidation of ingested food [17]) will be ignored as it represents a negligible amount compared to dietary water and WI [18] [19]. Moisture content of the feeds, along with the DMI and dry matter content (DMC) of the feed ration for lactating, dry cows, heifers and calves in Kuwait's dairy farms are shown in **Table 2**.

Table 2. Indicative calculations of seasonal dietary water (DW, kg) of feed rations for different animal categories in Kuwait's confined dairy farming systems.

Ingredient	Season	As Fed (kg)	DMI (kg)[d]	DMC%[e]	DW (kg)
Lactating Cows	Winter[a]	29.0	21.0	72.4	8.0
	Summer[b]	27.0	19.0	70.4	8.0
Dry Cows	Winter	25.0	16.5	66.0	8.5
	Summer	23.0	16.0	69.6	7.0
Heifers (3 - 24 mo)	Winter	14.5	11.3	77.9	3.2
	Summer	14.0	10.3	73.6	3.7
Calves[c] (1 - 3 mo)	Winter	3.7	3.3	89.2	0.4
	Summer	3.7	3.3	89.2	0.4

[a] December to April. [b] May to November. [c] Moisture content of calves' diet 10.8%. [d] Dry matter intake. [e] Dry matter content.

The average daily milk yield (MY) and the milking herd size during the study period was provided by the farmers. The concentrations of fat and protein in milk samples were obtained on a monthly basis after being analyzed by the milk analyzer (Lactoscan) via cooperation with a local lab in Kuwait. The average monthly MY (L cow^{-1} d^{-1}), fat and protein contents (%) of milk samples for the two-year period are shown in **Table 3**.

Table 3. The average monthly milk yield (MY, L cow^{-1} d^{-1}), fat (%) and protein (%) contents of milk samples*.

	Farm (A)			Farm (B)			Farm (C)		
Month	**MY**	**Fat**	**Protein**	**MY**	**Fat**	**Protein**	**MY**	**Fat**	**Protein**
January	19.6	3.2	4.3	22.1	2.2	4.3	19.7	2.2	4.1
February	21.0	3.1	4.1	21.6	3.4	4.1	19.4	2.2	4.1
March	20.6	3.1	3.9	21.5	3.4	4.1	17.9	2.0	4.1
April	17.6	2.9	3.9	19.9	2.9	4.0	17.1	1.5	3.3
May	17.6	2.9	3.9	19.7	3.0	4.0	16.1	1.6	3.8
June	17.6	2.9	3.9	18.8	2.8	4.0	11.7	1.8	3.5
July	17.4	3.0	3.9	18.6	3.4	4.1	10.6	2.4	3.5
August	17.1	3.0	3.9	17.9	2.8	4.0	9.1	2.4	3.7
September	15.7	3.0	4.0	18.2	2.9	4.0	7.1	2.6	3.8
October	15.5	2.9	4.0	18.0	2.8	4.0	9.5	2.5	3.7
November	16.6	2.8	4.0	20.7	3.1	4.0	11.1	2.5	3.8
December	17.0	3.0	3.9	20.8	2.9	4.0	13.4	2.4	4.1

*Average of two-year period (2018-2019).

Data of the wash water used for the cleaning of parlour/tank and holding area in addition to the data of spray water that operated only during the summer months (May to Nov) were recorded by water meters along the duration of the study.

Weather data for the study period including the average Temp (˚C), relative humidity (RH) and precipitation (PPT, mm) were obtained from the Kuwait International Airport Station (KIAS) which is 20 km away from the locations of the dairy farms. Temperature (˚C) and RH were used to calculate the Temperature Humidity Index (THI) according to the equation of Lefcourt and Schmidtmann [20]:

$$\text{THI} = 0.80 \times \text{Temp} + \text{RH} \times \left(\text{Temp} - 14.30\right) + 46.30 \quad (3)$$

where, Temp: Dry Bulb Temperature (˚C); RH: Relative Humidity in decimal form.

The reduction in THI due to the use of cooling systems (e.g. fans and sprinklers) during the summer season in the confined dairy farming system in Kuwait was estimated by the use of St-Pierre *et al.* [21] equation as follows:

$$THI_{adj} = -17.6 - (0.36 * Temp) + (0.04 * RH) \quad (4)$$

where, THI_{adj}: Adjusted Temperature Humidity Index.

2.2. Blue WF Calculation

The blue WF was calculated per unit of one kg of FPCM by dividing the total on farm water utilization (wash water, spray water for cooling and drinking water) in addition to water content of milk by the FPCM [13] [22].

The blue WF ($L \cdot kg^{-1}$ FPCM) is expressed as:

$$\text{Blue WF} = \frac{W_{drinking} + W_{washing} + W_{spray} + W_{prod}}{FPCM} \quad (5)$$

where, Blue WF = blue water footprint ($L \cdot kg^{-1}$); $W_{drinking}$ = drinking water (L cow^{-1} d^{-1}); $W_{washing}$ = milking parlour wash water (L cow^{-1} d^{-1}); W_{spray} = cooling water (L cow^{-1} d^{-1}); W_{prod} = water in milk that estimated to be 87% per kg of milk based on Ward and McKague [14]; FPCM = fat protein corrected milk (kg cow^{-1} d^{-1}) that expressed by IDF [23] to adjust the fat and protein contents of milk to 4.0% and 3.3%, respectively.

$$FPCM = M_{yield} \times \left[0.1226 \times (M_{fat\%}) + 0.0776 \times (M_{protein\%}) + 0.2534\right] \quad (6)$$

where, M_{yield}: Milk yield ($kg \cdot d^{-1}$); $M_{fat\%}$: Fat content of milk (%); $M_{protein\%}$: Protein content of milk (%).

2.3. Grey WF Calculation

Grey WF is a quantification of water volume required to restore water quality. Typical milk house effluent water consists of surplus milk, water, detergent, acid and manure generated from the washing after each milking event to clean and disinfect the floor, cows and equipment accessories.

Samples of the milk house effluent water were collected to quantify the nutrient content of the grey water. The pollutants considered are the nitrate (NO_3-N) and the total phosphate (PO_4) due to the use of cleaning agents that are rich in their PO_4 content [24] along with milk residue. The presence of milk in effluent water, at a 1% concentration, increases the PO_4 by 12 $mg \cdot L^{-1}$ and N by 55 $mg \cdot L^{-1}$ [25]. Likewise, the NO_3-N in effluent water could be detected due to the manure loss [26] [27].

From each dairy farm, three samples were collected from the drain of the milk house at the end of milking and washing event and another three samples from the inlet (clean water) on bi-monthly basis between Jan to the end of Nov 2019 with a total of 108 samples for each farm. These samples were analysed in triplicate for their NO_3-N and the PO_4 contents to ensure the precision of measurements. The analyses were done by a certified lab, using the ISO 7890-1-1986, and EPA 365.2+3 [28] [29] standard methods for the analysis of NO_3-N and PO_4, respectively. The grey WF was calculated using the concentration of each nutrient in the effluent water if it exceeds the maximum acceptable level of 10 $mg \cdot L^{-1}$ for NO_3-N based on ON drinking water quality standards [30] and Jordanian standard [31]; and 30 $mg \cdot L^{-1}$ for total PO_4 based on Kuwait Environmental Protection Agency (KEPA) [32].

The grey WF ($L \cdot d^{-1}$) is expressed by Franke *et al.* [33] as:

$$\text{Grey WF} = \frac{C_{\text{efflu}} - C_{\text{water}}}{C_{\max} - C_{\text{nat}}} \times E_{\text{efflu}} \tag{7}$$

where, E_{efflu}: Effluent volume ($L \cdot d^{-1}$); C_{efflu}: Concentration of pollutants (NO_3-N or PO_4) in effluent water ($mg \cdot L^{-1}$); C_{water}: Concentration of inlet (clean) water ($mg \cdot L^{-1}$) that was assumed to be zero; $C_{\max}$: Maximum standard (acceptable) concentration ($mg \cdot L^{-1}$); C_{nat}: Inlet water concentration ($mg \cdot L^{-1}$) that was assumed to be zero.

2.4. Statistical Analysis

The statistical analysis was conducted using R statistical software 3.4 for Windows [34] to show the overall effect of farm, season and THI_{adj} as independent variables on the average WI, MY, wash water, FPCM, total water and the blue WF as dependent variable(s).

The linear regression model is:

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3 + e \tag{8}$$

where, Y (dependent variable): the average WI, MY, wash water, total water use, FPCM, and blue WF, B_0: coefficient of constant term (intercept), B_n: slope of regression line, X_n: independent variable value, and e: error term. A P-value ≤ 0.05 was considered significant.

For the grey WF, linear regression analysis was conducted to show the effect of farm and sample collection period (month) as independent variables on the amount of effluent water, nutrient content (PO_4 or NO_3) and grey WF as dependent variable(s).

The linear regression model is:

$$Y = B_0 + B_1 X_1 + B_2 X_2 + e \tag{9}$$

where, Y (dependent variable): effluent water, nutrient content (PO_4 or NO_3) and grey WF, B_n: slope of regression line, X_n: independent variable value, and e: error term. A P-value ≤ 0.05 was considered significant.

2.5. Results and Discussion

2.5.1. Weather Conditions

During the study (Jan 2018 through Dec 2019), the average Temp and RH of the

Sulaibiya area was 27.6 ± 2.8˚C and 38.1 ± 5.1%, respectively. The average THI was 72.1 ± 2.7 and the average THI_{adj} during the summer season was 44.5 ± 1.7. The average monthly Temp (˚C), RH (%), PPT (mm), THI and THI_{adj} are shown in Figure 1. During the month of July in summer season, the maximum Temp was 40.1˚C, THI 82.1 and THI_{adj} 50.3, while during the short winter season (Dec to April) Temp reach 14.5˚C and THI 58.0. The average monthly PPT in Kuwait varied from 0.0 to 133.7 mm.

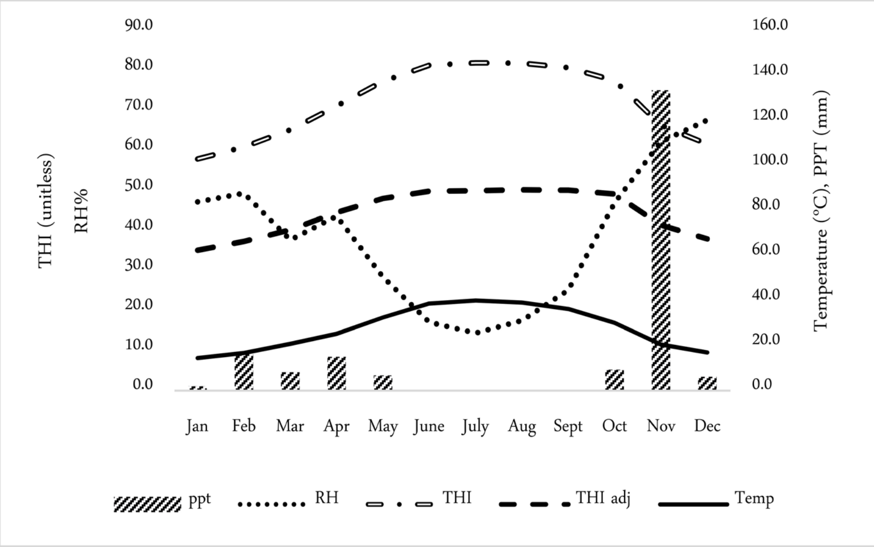

Figure 1. Average monthly Temp (˚C), RH (%), THI, THI_{adj} and PPT (mm) in Kuwait (2018-2019).

2.5.2. Water Intake of Different Animal Categories

The average daily WI per animal category was measured for lactating cows and estimated for all other categories. The average WI including dietary water was 100.6 ± 1.8 $L \cdot d^{-1}$ for lactating cows, 66.1 ± 0.5 $L \cdot d^{-1}$ for dry cow, 40.3 ± 0.3 $L \cdot d^{-1}$ for heifers (1 year), and 17.9 ± 0.1 $L \cdot d^{-1}$ for calves (Table 4). The WI for lactating cows is comparable with Shapasand *et al.* [35] who estimated the WI under average THI of 82.0 to be 118.2 $L \cdot d^{-1}$ and Solomon *et al.* [36] who found that WI in a region with an average Temp of 37.5˚C to be 128.0 $L \cdot d^{-1}$. In addition, the WI values for other animal categories agree with the estimated values as shown in Table 4. The high rate of water consumption is critical for the dairy cows to cope with the heat stress in Kuwait. In summer, the average Temp and THI in Kuwait were 34.0˚C ± 0.70˚C, and 78.4 ± 0.6, respectively which are beyond the thermal comfort zone of dairy cows (26˚C) [36]. Under this high heat stress cows consume more water to compensate for high dehydration rates [37]. Dairy cattle to acclimatize with Temp of 32˚C compared with 2˚C - 10˚C need to drink two to four times more water [12]. Studies have shown that WI is positively correlated with Temp [38], given the preference of cows for warmer water [39] [40].

Table 4. Estimated and measured water intake (WI, L cow^{-1} d^{-1}) of different animal categories on confined dairy farming systems.

	Measured	Estimated				
	WI[a]	WI[b]	WI[c]	WI[d]	DW[e]	Overall[f]
Dairy cows	100.6 ± 1.8	-	-	-	8.0	-
Dry cows	-	66.1 ± 0.5	59.4	72.6	7.6	67.1 - 80.3
Heifers (1 year)	-	40.3 ± 0.3	36.3	44.3	3.5	39.7 - 47.8
Calves	-	17.9 ± 0.1	16.1	19.7	0.4	16.5 - 20.1

[a] Measured WI of Holstein dairy cows (n = 689) in Kuwaiti dairy farms during the period of 24 month (mean ± SE). [b] Computed by the use multiplicative adjustment factor to the average WI values of Le Riche *et al.* (2017) and Ward and McKague (2019) which are 10.52, 23.67 and 38.75 L cow^{-1} d^{-1} for calves, heifers and dry cows, respectively. [c] WI is estimated by increasing the average WI values of Le Riche *et al.* (2017) and Ward and McKague (2019) by 53.20% based on Equation (1) [15]. [d] WI is estimated by increasing the average WI values of Le Riche *et al.*, (2017) and Ward and McKague (2019) by 87.30% based on Equation (2) [16]. [e] Dietary Water based on the feed rations of dairy farms in Kuwait. [f] Estimated WI values and DW.

2.5.3. Seasonal Effect on Milk Production, Total Farm Water Utilization and Blue Water Footprint

1) Milk Production

During the study, the average number of lactating cows was 83.0 ± 2.0, 477.0 ± 0.4 and 123.0 ± 1.5 for farms A, B and C, respectively. The average number of non-lactating animals (calves, heifers and dry cows) was 59.0 ± 12.7, 118.0 ± 22.4 and 92.0 ± 21.5 for farm A, B and C, respectively as shown in Table 1. Throughout the study, the average milk production was 17.0 ± 0.4 L cow^{-1} d^{-1} (Table 5) and ranged from 15.5 ± 0.6 L cow^{-1} d^{-1} in the summer to 19.3 ± 0.4 L cow^{-1} d^{-1} in the winter. The effects of farm ($P < 0.0001$) and season ($P < 0.001$) were significant. These results agree with Razzaque *et al.* [41] who studied the MY of 25 locally born and adapted Holstein lactating cows and found that it was 16.9 L cow^{-1} d^{-1}. Milk production of imported pregnant Holstein heifers in Kuwait ranged from 8.2 to 14.8 L cow^{-1} d^{-1} [42] [43]. Another investigation evaluated the performance of dairy heifers in Kuwait over 8 years and found that the average MY of lactating cows was 10.7 L cow^{-1} d^{-1} [44], which revealed an adaptation problem to Kuwait's climate when compared with the performance of these cows in their country of origin [45].

The low rate of MY in summer compared to winter is consistent with the recognized seasonal pattern of MY [46]. Geers *et al.* [47] reported that milk production decreased when Temp was >16˚C. In the current study, the average fat and protein contents of milk produced in Kuwait was 2.7% ± 0.0% and 3.9% ± 0.0% with similar values between seasons. Our milk fat content was lower than that reported by Razzaque *et al.* [41] which was 3.1%, while the milk protein content was higher compared with 3.1% reported by the same study. These differences could be due to the effect of Temp on milk composition [48] along with other reasons including the genetic factors, farm management practices, the components of feed rations or water quality and its availability to the herd. The overall average of FPCM was calculated to be 15.3 ± 0.4 kg cow^{-1} d^{-1} over the 24-month period (Table 5).

2) Whole Farm Water Utilization

The overall average water utilized on the confined dairy farms was 505.2 ± 22.6 L cow^{-1} d^{-1} of which 218.9 ± 2.5 L cow^{-1} d^{-1} (43.3%) was for drinking, 194.7 ± 22.9 L cow^{-1} d^{-1} (38.5%) was for spray and 58.9 L cow^{-1} d^{-1} (11.7%) was for cleaning of milk house (**Table 5**). The farm management ($P < 0.001$), season ($P < 0.0001$) and THI_{adj} ($P < 0.0001$) had a significant effect on the total amount of water used on the farm which was higher in summer (636.8 ± 31.1 L cow^{-1} d^{-1}) compared to the winter (314.3 ± 4.4 L cow^{-1} d^{-1}).

In winter, the main components of water use were associated with WI (69.5%) followed by washing of milking parlour (19.4%), dietary and milk water (11.8%). However, during the summer, most of the water used on the farm was associated with the cooling system (either in the barns or milking parlour). In the summer, the cooling (spray) water accounted for about 51.7% of the daily water use, followed by WI (34.4%) and wash water (9.0%). The volume of the wash water was varied based on the farm ($P < 0.0001$) and THI_{adj} ($P < 0.001$), which is consistent with the conclusion of Harner *et al.* [19] and Janni *et al.* [49] who reported that water used on 14 dairy farms in Minnesota was between 8.6 to 35.3 L cow^{-1} d^{-1} and was varied from 140% to 400% due to several reasons including animal performance and weather conditions.

Average WI of dairy livestock ranged from 218.4 ± 2.6 L cow^{-1} d^{-1} in winter to 219.2 ± 3.8 L cow^{-1} d^{-1} in summer which is consistent with the results of the NRC [50] and with the findings of Murphy *et al.* [51] and West [52]. Additionally, Gorniak *et al.* [53] found that as THI increased over 30, the WI by lactating cows increased. The high WI of cows in Kuwait is likely due to the high Temp combined with the THI value (78.4 ± 0.6), which was adjusted to 48.5 ± 0.3 based on the use of cooling pads and spray water systems to reduce the effect of heat stress on the cows. Similarly, VanderZaag *et al.* [9] reported a high rate of WI by lactating cows in summer compared to winter. However, in the current study, the water used in washing the milking parlour was 58.9 ± 2.3 L cow^{-1} d^{-1} (ranged from 57.5 ± 3.0 in summer to 60.9 ± 3.4 in winter), which is higher than the average values in temperate conditions. Robinson *et al.* [54] reported that the average wash water for tie stall barns in ON was 30.2 L cow^{-1} d^{-1}. VanderZaag *et al.* [9] reported an average value of 28.1 L cow^{-1} d^{-1} for washing the milking system. The high rate of water utilized for washing in Kuwait could be due to the use of the high volume hoses (without a trigger valve) to clean the milking parlour, equipment and milk tank throughout the milking event, coupled with the harsh weather conditions and the design of the housing system that governs the cleaning process.

3) Blue WF

The average whole farm blue WF (L·kg^{-1} FPCM) was estimated to be 40.1 ± 2.8 L·kg^{-1}. On a seasonal basis, the blue WF (L·kg^{-1}) was 19.2 ± 0.8 in the winter and 54.5 ± 4.0 in the summer. The effect of farm, season and THI_{adj} ($P < 0.0001$) was significant. The blue WF was affected by changes in water utilization and milk production. The blue WF was negatively correlated with milk production ($r = -0.73$) and positively associated with the total farm water utilization ($r = +0.74$).

Our findings showed that the whole farm water utilization was higher in summer as water spray and WI increased. Armstrong [45] and Fuquay [55] concluded that hot weather conditions especially during summer depressed the performance and milk production of lactating cows. However, to reduce the effect of heat stress a protocol of cooling by ventilation, shade, spray and fans were implemented on Kuwait dairy farms in Kuwait. This cooling program aims to reduce the effects of heat stress that were conveyed in the value of THI_{adj}, which proved to be successful in alleviating the effect of high ambient THI.

The increase in WI during the summer was not accompanied by an increase in milk production. Murphy *et al.* [51], found a positive correlation between milk production, WI and the minimum Temp. Likewise, the same relationship was found by Cardot *et al.* [56]. However, for Kuwait's dairy farms, the quality of water and the level of total dissolved solid (TDS) could negatively affect the rate of milk production and the effectiveness of WI under heat stress condition as identified by Shapasand *et al.* [35] and Challis *et al.* [57].

Table 5. Milk production, weather conditions, seasonal water utilization and the blue WF of confined dairy farming systems in Kuwait.

Season[a]	Winter	Summer	Overall Average	SE
		Milk Production & Weather Conditions		
Milk production ($L\ cow^{-1}\ d^{-1}$)	19.3 ± 0.4[b]	15.5 ± 0.5	17.0	0.4
Fat (%)	2.7 ± 0.1	2.7 ± 0.1	2.7	0.0
Protein (%)	4.0 ± 0.0	3.9 ± 0.0	3.9	0.0
FPCM[c]	17.3 ± 0.4	13.9 ± 0.5	15.3	0.4
Temp (˚C)	18.9 ± 0.5	34.1 ± 0.7	27.9	0.8
RH (%)	49.1 ± 1.5	29.8 ± 1.9	37.7	1.5
THI	63.5 ± 0.7	[78.4 ± 0.6]	63.5	0.7
THI_{adj}[d]	-	48.5 ± 0.3	48.5	0.3
		Farm Water Utilization & the Blue WF		
Average WI[e]	218.4 ± 2.6	219.2 ± 3.8	218.9	2.5
Total spray water[f*]	0.0 ± 0.0	329.0 ± 31.5	194.7	22.9
Wash water[f]**	60.9 ± 3.4	57.5 ± 3.0	58.9	2.3
Dietary water[f]	22.0 ± 0.0	19.0 ± 0.0	19.4	0.0
Water from milk[f]	15.0 ± 0.4	12.1 ± 0.4	13.3	0.3
Total[f]	314.3 ± 4.4	636.8 ± 31.1	505.2	22.6
Blue WF[g]	19.2 ± 0.8	54.5 ± 4.0	40.1	2.8

[a] Winter from December to April (151 day), Summer from May to November (214 day). [b] means ± SE (n = 49 observation for each farm, 689 total number of cows). Note: Total or average value could differ due to rounding. [c] Calculated based on IDF (2015). [d] THI_{adj} for summer season only. [e] Measured WI values ($L\ cow^{-1}\ d^{-1}$) of lactating cows along with extrapolated values for the dry cows, heifers and calves. [f] Unit: $L\ cow^{-1}\ d^{-1}$. [g] L water kg^{-1} FPCM; L of water = kg of water. [*] Total spray includes the water used to spray the cows in barns and milking parlour to reduce heat stress during the summer season only. [**] Wash water includes water used for washing of cows, milking parlour, and equipment in milk house.

2.5.4. Milk House Wastewater and the Grey WF

Effluent water on dairy farms consists mainly of rinse water from the milking parlour, spillage of milk residue, urine and manure runoff [58] [59]. The operations in the milking house require systematic cleaning of the dairy cows, floor area and equipment, which generates wastewater. The calculation of the grey WF for dairy farms is based on the assumption that if the actual nutrient concentration is ≤MAC discharge, then no further dilution or treatment for the effluent water is required, and the grey WF is zero.

NO_3-N and PO_4 Concentrations of Milk House Wastewater

The concentration of NO_3-N in effluent water ranged from 4.2 ± 0.7 mg·L^{-1} to 12.3 ± 1.7 mg·L^{-1} with an overall average of 8.8 ± 1.2 mg·L^{-1}. However, it is not a serious problem as its concentration was <10 mg·L^{-1} [30]. Mantovi *et al.* [60] and Morin *et al.* [61] similarly reported that the wastewater generated from the milk house was characterized to have 0.3 to 6.5 mg·L^{-1} NO_3-N, respectively. However, the concentration of PO_4 was found to be a problem in Kuwait's dairy farms. Based on KEPA guidelines, the maximum acceptable level of PO_4 in effluent water is 30 mg·L^{-1}.

The analysis of milk house wastewater showed that the PO_4 concentration was 75.2 ± 25.6 mg·L^{-1} for farm (C), 66.2 ± 17.3 mg·L^{-1} for farm (B) and 105.2 ± 31.5 mg·L^{-1} for farm (A) with an overall average of 82.2 ± 14.3 mg·L^{-1}. The PO_4 content was affected significantly by farm ($P < 0.05$) and the month of sample collection ($P < 0.0001$).

The high concentration of PO_4 is due to the use of different detergents as well as the presence of cow urine, manure and milk in the wash water [62] [63]. Mantovi *et al.* [60] and Morin *et al.* [61] stated that wash water generated from the milk house has a PO_4 content of 61.3 to 306.5 mg·L^{-1}. In addition, Singh *et al.* [24] found different concentrations of PO_4 based on farm size which was 413.3 mg·L^{-1}, 341.1 mg·L^{-1} and 192.9 mg·L^{-1} for large, medium and small farms, respectively. The PO_4 content in milk house wash water in Kuwait was higher than Janni *et al.* [49] for 14 dairy farms, which was 56 mg·L^{-1} due to different weather conditions and management practices.

To estimate the grey WF, the PO_4 concentration in effluent water must be diluted to be within the MAC. The daily effluent water for farms (C), (B) and (A) was 24,501.9 ± 9,503.3 L·d^{-1}, 14,217.3 ± 1,692.6 L·d^{-1}, and 5,648.8 ± 404.8 L·d^{-1}, respectively. Accordingly, the grey WF was calculated to be 50,774.7 ± 20,066.0 L·d^{-1} for farm (C), 34,054.9 ± 11,340.1 L·d^{-1} for farm (B) and 21,126.7 ± 6,820.1 L·d^{-1} for farm (A). Effluent water and grey WF per day were affected significantly by farm (effluent water ($P < 0.0001$); grey WF ($P < 0.01$)) and the period of sample collection ($P < 0.01$).

The effluent water per lactating cow was 208.9 ± 81.4 L cow^{-1} d^{-1}, 29.7 ± 3.5 L cow^{-1} d^{-1} and 55.5 ± 5.8 L cow^{-1} d^{-1} for farm (C), farm (B) and farm (A), respectively. Consequently, the grey WF was calculated to be 432.4 ± 172.0 L cow^{-1} d^{-1} for farm (C), 71.2 ± 23.7 L cow^{-1} d^{-1} for farm (B), and 215.2 ± 76.8 L cow^{-1} d^{-1}

for farm (A). Grey WF per animal basis was affected significantly by farm ($P < 0.0001$) and month of sample collection ($P < 0.1$).

The grey WF per FPCM ($L \cdot kg^{-1}$ FPCM d^{-1}) was estimated to be 52.1 ± 22.4 for farm (C), 3.4 ± 1.3 for farm (B) and 13.6 ± 5.1 for farm (A). The grey WF per FPCM was affected significantly by farm ($P < 0.0001$) and the period of sample collection ($P < 0.01$).

In Kuwait, the variations between farms in the volume and nutrient contents of effluent water (PO_4 concentration was 75.2 ± 25.6 $mg \cdot L^{-1}$, 66.2 ± 17.3, 105.2 ± 31.5 $mg \cdot L^{-1}$ for farm (C), farm (B) and farm (A), respectively) could be due to the variation in the effluent volume and nutrient status between farms along with the type and amount of pipeline chemicals used, washing duration and frequency [64] that influenced by the amount of animal excretions (urine/feces), PPT level and the balance between pipeline wash water and manure runoff. Commonly, as the herd size increases, the volume of effluent water per animal decreases [65]. Nevertheless, sometimes there is no correlation between herd size and the volume of washing water, suggesting that the capacity of milking parlour and PPT level can have a major effect [66].

In general, the grey WF of dairy farms contributes to water depletion and deterioration. The dilution of water to reach the acceptable level is a burden that should be considered by finding alternative solutions to manage water. This can be achieved using various treatment methods including constructed wetlands that are considered to be an effective in allowing for water re-use and treatment as they remove >95% of pollutants [67].

The determination of the compositions of effluent water for dairy farms is critical as there are no previous assessments in Kuwait for the volume and nutrient contents of milk house effluent water. This will enable farmers to plan for strategies to manage wastewater on their farms to reduce the cost and increase the efficiency of water utilization.

3. Conclusions

The determination of the blue and grey WFs for dairy farms in Kuwait reflects the high pressure on water resources and provides an opportunity for farmers to shift towards improving water use efficiency.

Adopting of the WF concept as a sustainability indicator along with best management practices to enhance the livestock performance and the efficiency of water use will reflect positively on the dairy sector. This is critical to ensure the continuous availability of the limited water resources to serve the domestic dairy sector in order to cover the local demand for dairy products.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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