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The water footprint of livestock production system and livestock products: A dark area: A review

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Abstract
The water footprint concept is an indicator of water use in relation to consumer goods. The water footprint of a product is the volume of freshwater used to produce the product measured over the various steps of the production chain. In research showed that about 27% of the water footprint of humanity is related to the production of animal products. Only 4% of the water footprint of humanity related to the water use at home. A water footprint mostly breaks down into 3 components: the blue, green, and grey water footprints. The water footprint of an animal at the end of its life time can be calculated based on the water footprint of all feed consumed during its lifetime and volume of water consumed for drinking and other uses. There are two major determining factors in water footprint of animal product feed conversion efficiency and composition of feed eaten by the animal in different livestock production system such as grazing and industrial system. The water footprint of various feed ingredient are estimated by using a high resolution grid-based crop water use model. The increase in consumption in the consumption of animal product is likely to put further pressure on the world fresh water resources. The average water footprint per calorie for beef is 20 times larger than for cereal. On an average 37% of cereal production in the world were used for animal feed. To meet the rising demand for animal products, the ongoing shift from traditional system, extensive and mixed to industrial farming system is likely to continue. Therefore the issue of wise water governance is a shared responsibility of consumer, government, businesses and investors.

Keywords: Water foot print, requirement, production, ingredients

Introduction
At the global level, about one third of world's agriculture water usages goes indirectly or directly to animal production and livestock takes 70% of all agricultural land and 30% of the planet's land surface (Steinfeld *et al*.,2006) [18].About 92% of humanity's water footprint relate to agriculture thus food production is a key factor in fresh water scarcity. Animal products are responsible for nearly 30% of water footprint of global agriculture sector and 27% of water footprint of humanity is related to production of animal product and only 4% related to water use at home (Mekonnen and Hoekstra, 2011) [14].

Meat and dairy are among the most water intensive consumer products; the increase in the consumption of animal product is likely to pour further pressure on the world's fresh water resources. Global meat production has almost doubled during 1980-2004 (FAO, 2005) [5] and this upward trend will continue given the projected doubling of meat production in the period 2000–2050 (Steinfeld *et al*., 2006) [18]. To fulfill the increase demand for animal products, the on-going shift from traditional extensive and mixed to industrial farming systems is likely to continue (Bouwman and others 2005; Naylor *et al*., 2005; Galloway *et al*., 2007) [1, 16, 8]. Most of the grain cultivated in the world is for both human consumption and animal consumption. In the period from 2001 to 2007, on average 37% of the cereals produced in the world were used for animal feed [Food and Agriculture Organization of the United Nations (FAO), 2011] [7].

Water footprint concept: Water footprint concept is an indicator of water use in relation to consumer goods (Hoekstra *et al*., 2011) [12]. The concept is an analog to the ecological and carbon footprints, but indicates water use instead of land or fossil energy use. The water footprint of a product is the volume of freshwater used to produce the product, measured over the various steps of the production chain.

Water use is measured in terms of water volume consumed (evaporated) or polluted. The water footprint is a geographically explicit indicator that shows not only volumes of water use and pollution, but also the locations. A water footprint generally breaks down into 3 components: the blue, green, and gray water footprint. The blue water footprint is the volume of freshwater that is evaporated from the global blue water resources (surface and groundwater). The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil). The gray water footprint is the volume of polluted water, which is quantified as the volume of water required to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards (Hoekstra and Chapagain, 2008) [11].

The water footprint of an animal: Water footprint definition and methodology as set out in Hoekstra *et al*., (2011) [12] are described here. The blue water footprint refers to consumption of blue water resources (surface and groundwater) along the supply chain of a product. 'Consumption' refers to loss of water from the available ground-surface water body in a catchment area. Losses occur when water evaporates, returns to another catchment area or the sea or is incorporated into a product. The green water footprint refers to consumption of green water resources (rainwater in so far as it does not become runoff). The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards.
The water footprint of a live animal consists of different components: the indirect water footprint of the feed and the direct water footprint related to the drinking water and service water consumed (Chapagain and Hoekstra 2003, 2004) [2, 3]. The water footprint of an animal is expressed as:

WF[a; c; s] =WFfeed [a; c; s]+WF drink [a; c; s]+ WF serv +[a; c; s]

Where, WF feed [a,c,s], WF drink [a,c,s] and WF serv [a,c,s] represent the water footprint of an animal for animal category a in country c in production systems s related to feed, drinking water and service-water consumption, respectively. Service water refers to the water used to clean the farmyard, wash the animal and carry out other services necessary to maintain the environment. The water footprint of an animal and its three components can be expressed in terms of m^3/y/animal, or, when summed over the life time of the animal, in terms of m^3/animal. For beef cattle, pigs, sheep, goats and broiler chickens—animals that provide their products after they have been slaughtered—it is most useful to look at the water footprint of the animal at the end of its lifetime, because it is this total that will be allocated to the various products (for example, meat, leather). For dairy cattle and layer chickens, it is most straight forward to look at the water footprint of the animal per year (averaged over its lifetime), because one can easily relate this annual animal water footprint to its average annual production (milk, eggs).

The relevance of feed conversion efficiency and feed composition: The supply chain of an animal product starts with feed crop cultivation and ends with the consumer. In each step of the chain, there is a direct water footprint, which refers to the water consumption in that step, but also an indirect water footprint, which refers to the water consumption in the previous steps. By far, the largest contribution to the total water footprint of all final animal products comes from the first step: growing the feed. This step is the most far removed from the consumer (Naylor *et al*., 2005) [16]. Furthermore, the feed will often be grown in areas completely different from where the consumption of the final product takes place.
To better understand the water footprint of an animal product, we need to start with the water footprint of feed crops. The combined green and blue water footprint of a crop (m^3/ton) when harvested from the field is equal to the total evapo-transpiration from the crop field during the growing period (m^3/ha) divided by the crop yield (tons/ha). The crop water use depends on the crop water requirement on the one hand and the actual soil water available on the other hand. Soil water is replenished either naturally through rainwater or artificially through irrigation water. The crop water requirement is the total water needed for evapo-transpiration under ideal growth conditions, measured from planting to harvest. It obviously depends on the type of crop and climate. Actual water use by the crop is equal to the crop water requirement if rainwater is sufficient or if shortages are supplemented through irrigation. In the case of rain water deficiency and the absence of irrigation, actual crop water use is equal to effective rainfall. The green water footprint refers to the part of the crop water requirement met through rainfall, whereas the blue water footprint is the part of the crop water requirement met through irrigation. The gray water footprint of a crop is calculated as the load of pollutants (fertilizers, pesticides) that are leached from the field to the groundwater (kg/ha) divided by the ambient water quality for the chemical considered (g/L) and the crop yield (ton/ha).

Factor affecting water footprint: Livestock water productivity for the unit animal product is influenced by 3 factors namely feed conversion efficiency (amount of feed consumed per unit of meat/milk produced), diet composition (roughage to concentrate ratio), and the feed origin (Gerbens-Leenes *et al*., 2013) [9]. To produce the maintenance diet for 1 tropical livestock unit (TLU= 250kg live weight) about 450 m^3 of water is required annually. Feeds have highly variable water productivity, ranging from 0.5 kg above-ground dry matter/m^3 water (US grasslands on 300 mm annual rainfall) to 8 kg/m^3 (irrigated forage sorghum, Sudan (Peden *et al*., 2007) [17]. Livestock industry across the globe uses about 8% of total water used. The major part of it goes to irrigate the feed crops used for livestock feeding. Zimmer and Renault (2003) [20] demonstrated that a survival diet require 1m^3 of water/head/day, whereas an animal product based diet of humans needs some 10 m^3 water/capita/day. Schlink *et al*., (2010) [19] has discussed global position of water requirement for livestock production in detail. The first factor is the feed conversion efficiency, which measures the amount of feed to produce a given amount of meat, eggs, or milk. Because animals are generally able to move more and take longer to reach slaughter weight in grazing systems, they consume a greater proportion of feed to convert to meat. Because of this, the feed conversion efficiency improves from grazing systems through mixed systems to industrial systems and leads to a smaller water footprint in industrial systems.
The second factor works precisely in the other direction, that is, in favour of grazing systems. This second factor is the composition of the feed eaten by the animals in each system.

When the amount of feed concentrates increases, the water footprint will increase as well because feed concentrates have a relatively large water footprint, whereas roughages (grass, crop residues, and fodder crops) have a relatively small water footprint. The increasing fraction of animal feed concentrates and decreasing fraction of roughages from grazing through mixed to industrial systems (Hendy *et al*., 1995) [10] results in a smaller water footprint in grazing and mixed systems compared with industrial systems.

In general, the water footprint of concentrates is 5 times larger than the water footprint of roughages. Although the total mixture of roughages has a water footprint of approximately 200 m^3/tonne (global average), this is about 1,000 m^3/tonne for the package of ingredients contained in the concentrates. Because roughages are mainly rain fed and crops for concentrates are often irrigated and fertilized, the blue and gray water footprints of concentrates are even 43 and 61 times those of roughages, respectively. The water footprint will vary strongly depending on the production region, feed composition, and origin of the feed ingredients. The water footprint of beef from an industrial system may partly refer to irrigation water (blue water) to grow feed in an area remote from where the cow is raised. This can be an area where water is abundantly available, but it may also be an area where water is scarce and where minimum environmental flow requirements are not met because of overdraft. The water footprint of beef from a grazing system will mostly refer to green water used in nearby pastures.

If the pastures used are either dry or wetlands that cannot be used for crop cultivation, the green water flow turned into meat could not have been used to produce food crops instead. If, however, the pastures can be substituted by cropland, the green water allocated to meat production is no longer available for food-crop production. This explains why the water footprint is to be seen as a multidimensional indicator. Not only should one look at the total water footprint as a volumetric value, but one should also consider the green, blue, and gray components separately and look at where each of the water footprint components is located. The social and ecological impacts of water use at a certain location depend on the scarcity and alternative uses of water at that location.

Contribution of animal in water footprint: During the period 1996–2005, the total water footprint for global animal production was 2,422 Gm^3/y (87.2% green, 6.2% blue and 6.6% grey water). The largest water footprint for animal production comes from the feed they consume, which accounts for 98% of the total water footprint. Drinking water, service water and feed-mixing water further account the only for 1.1, 0.8 and 0.03% of the total water footprint, respectively.

Grazing accounts for the largest share (38%), followed by maize (17%) and fodder crops (8%). The global water footprint of feed production is 2,376 Gm^3/y, of which 1,463 Gm^3/y refers to crops and the remainder to grazing. The estimate of green plus blue water footprint of animal feed production is consistent with estimates of earlier studies. The total water footprint of feed crops amounts to 20% of the water footprint of total crop production in the world, which is 7,404 Gm^3/y (Mekonnen and Hoekstra, 2011) [14]. The globally aggregated blue water footprint of feed crop production is 105 Gm^3/y, which is 12% of the blue water footprint of total crop production in the world (Mekonnen and Hoekstra, 2011) [14]. This means that an estimated 12% of the global consumption of groundwater and surface water for irrigation is for feed, not for food, fibers or other crop products.

Globally, the total water footprint of animal production (2,422 Gm^3/y) constitutes 29% of the water footprint of total agricultural production (8,363 Gm^3/y). The latter was calculated as the sum of the global water footprint of crop production (7,404 Gm^3/y, Mekonnen and Hoekstra, 2011) [14], the water footprint of grazing (913 Gm^3/y, this study) and the direct water footprint of livestock (46 Gm^3/y, this study). The total water footprint per animal category, it was found that beef cattle have the largest contribution (33%) to the global water footprint of farm animal production, followed by dairy cattle (19%), pigs (19%) and broiler chickens (11%) (Table.1). Mixed production systems account for the largest share (57.4%) in the global water footprint of animal production. Grazing and industrial production systems account for 20.3 and 22.3%, respectively (table 2). In the grazing system, over 97% of the water footprint related to feed comes from grazing and fodder crops and the water footprint is dominantly (94%) green. In the mixed and industrial production systems, the green water footprint forms 87 and 82% of the total footprint, respectively. The blue water footprint in the grazing system accounts for 3.6% of the total water footprint and about 33% of this comes from the drinking and service-water use. In the industrial system, the blue water footprint accounts for 8% of the total water footprint.

Table 1: The total water footprint per animal category (1996-2005)

Animal category	Global total no. of animals (millions)	Average annual water footprint per animal (m^3/per/animal)	Annual water footprint animal category (Gm^3/yr)	%
Beef	1,267	630	798	33
Dairy cattle	228	2,056	469	19
Pig	880	520	458	19
Broiler chicken	9,923	26	255	11
Horse	112	1,599	180	7
Layer chicken	5,046	33	167	7
Sheep	1,052	68	71	3
Goat	750	32	24	1
Total	19,258		2,422	100

FAO (2009) [6]

The water footprint of animal products versus crop products: Mekonnen and Hoekstra (2011) [14] showed that the water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value (Table 3). Ercin *et al*., (2011) [4] illustrated this by comparing the water footprint of 2 soybean products with 2 equivalent animal products. They calculated that 1 L of soy milk produced in Belgium had a water footprint of approximately 300 L, whereas the water footprint of 1 L of milk from cows was more than 3 times larger. The water footprint of a 150-g soy burger produced in the Netherlands appears to be about 160 L, whereas the water footprint of an average 150-g beef burger is nearly 15 times larger. Global-average water footprint of a number of crop and animal products. The numbers show that the average water footprint per calorie for beef is 20 times larger than that for cereals and starchy roots. The water footprint per gram of protein for milk, eggs, and chicken meat is about 1.5 times larger than that for pulses. For beef, the water footprint per gram of protein is 6 times larger than that for pulses. Butter has a relatively small water footprint per gram of fat, even less than for oilseed crops, but all other animal products have larger water footprints per gram of fat when compared with oilseed crops.

Table 2: Water footprint of selected animal products for selected country under different farming systems (m^3/ton)

Animal product	Farming system	China	India	USA
Beef	Grazing	16,353	26,155	20,217
	Mixed	13,669	16,869	14,040
	Industrial	13,089	14,749	3,856
Sheep meat	Grazing	9,994	11,930	12,240
	Mixed	5,805	8,426	10,234
	Industrial	2,839	5,600	-
Goat Meat	Grazing	5,345	8,455	-
	Mixed	3,048	4,934	-
	Industrial	1,624	2,512	-
Pig meat	Grazing	12077	4448	6878
	Mixed	6209	5351	6612
	Industrial	4940	12271	4601
Chicken	Grazing	6557	14898	3627
	Mixed	4207	9547	2167
	Industrial	2719	4715	2221
Egg	Grazing	5516	13140	2254
	Mixed	3289	7823	1446
	Industrial	2920	4483	1582
Milk	Grazing	1814	1324	1264
	Mixed	1257	1060	729
	Industrial	-	-	605

(Mekonnen and Hoekstra, 2011) [14]

The water footprint of animal products per ton: By combining the feed conversion efficiency—distinguishing between different animals, production systems and countries (Hendy *et al*., 1995) [10] and the water footprint of the various feed ingredients (Mekonnen and Hoekstra 2011) [14], it was estimated the water footprint of different animals and animal products per production systems and per country. The water footprints of animal products vary greatly across countries and production systems. The type of production system is highly relevant for the size, composition and geographic spread of the water footprint of an animal product, because it determines feed conversion efficiency, feed composition and origin of feed. Differences between countries are related to existing country differences in feed conversion efficiencies, but also to the fact that water footprints of feed crops vary across countries as a function of differences in climate and agricultural practice. The USA, in turn, generally shows lower total water footprints for animal products than India.

Due to the specific climate and poor agricultural practices in India, the water footprint per ton, of feed in this country is larger than in the USA. When look at global averages, it was found that the water footprint of meat increases from chicken meat (4,300 m^3/ton), goat meat (5,500m^3/ton), pig meat (6,000 m^3/ton) and sheep meat (10,400 m^3/ton) to beef (15,400 m^3/ton). The differences can be partly explained from the different feed conversion efficiencies of the animals. Beef production, for example, requires 8 times more feed (in dry matter) per kilogram of meat compared to producing pig meat, and 11 times if compared to the case of chicken meat. This is not the only factor, however, that can explain the differences. Another important factor is the feed composition. Particularly the fraction of concentrate feed in the total feed is important, because concentrate feed generally has a larger water footprint than roughages. Chickens are efficient from a total feed conversion efficiency point of view, but have a large fraction of concentrates in their feed. This fraction is 73% for broiler chickens (global average), whereas it is only 5% for beef cattle. For all farm animal products, except dairy products, the total water footprint per unit of product declines from the grazing to the mixed production system and then again to the industrial production system. The reason is that, when moving from grazing to industrial production systems, feed conversion efficiencies get better. Per unit of product, about three to four times more feed is required for grazing systems when compared to industrial systems. More feed implies that more water is needed to produce the feed. The fraction of concentrate feed in the total feed is larger for industrial systems if compared to mixed production systems and larger for mixed systems if compared to grazing systems. The water footprint per kg of concentrate feed is generally larger than for roughages, so that this works to the disadvantage of the total water footprint of animals raised in industrial systems and to the advantage of the total water footprint of animals raised in grazing systems. This effect, however, does not fully compensate for the unfavourable feed conversion efficiencies in grazing systems. In dairy farming, the total water footprint per unit of product is comparable in all three production systems. For dairy products, the water footprint happens to be the smallest when derived from a mixed system and a bit larger but comparable when obtained from a grazing or industrial system.

Table 3: Water footprint of crop and livestock (global average water footprint)

Feed	Litre/kg	Litre/kcal	Litre/gm protein	Litre/gm fat
Cereals	1644	0.51	21	112
Oil crop	2364	0.81	16	11
Pulse	4055	1.19	19	180
Milk	1020	1.82	31	33
Egg	3265	2.29	29	33
Chicken	4325	3.00	34	43
Butter	5553	0.70	0.0	6.4
Pig meat	5988	2.15	57	23
Sheep/goat	8763	4.25	63	54
Bovine meat	15415	10.19	112	153

(Mekonnen and Hoekestra, 2010) [13]

Water requirement at different stage of different stage of beef production: An average of 1,62,59,00 litre of water goes into producing one tonne of cow feed. Crop is grown to be fed to cattle and their cultivation require huge amount of water. Cow and buffaloes eat up to 20 kgs of feed per day, including paddy, jowar, berseem, cottonseed, mustard or groundnut cakes etc. since production of one kg of any of these food uses anywhere between 1,000-2000 litres, it can roughly estimate that in India, about 20,000-40000 litre of water are used daily to feed one beef animal. These animals should directly drink 35-75 litre of water of per day depending on the weather. 28 litres of water is estimate to be used for washing an animal's daily. Approximately 150 litres per cow/buffalo goes into sanitation and manure removal. At the end of its life, when the animal is killed for its meat, about 15000 litre of water are used hourly to clean the blood, and other part, from the slaughterhouse. Washing the meat before packaging and transporting is another burden.

Water footprint of beef: An industrial beef production system takes three years to attained 545 kg animal body weight. The birth weight of cattle is about 25 kg. Suppose that the animal has consumed 920 kg of grains, 4714 kg of roughages, 24 cubic meters of water for drinking and 7 cubic meters of water for servicing etc. total water footprint is about 9611000. It clear that to produce 1 kg of body weight, they have used approximately1.77 kg of grain, 9.06 kg of roughages and 59.6 litres of water (only for drinking and servicing).

Water footprint of cow: for cow production system where, it takes three years to start milk production. The milk production period is approximately 10 years and average milk production in each year is 7397 litre of milk. Suppose that the animal has consumed 5709 kg of grains 9420 kg of roughages then the water footprint is 39075000 followed by 219000 litres of water for drinking and 64290 litres of water for servicing etc.

Water footprint of pig: An industrial pork production system where it takes less than years to produce 118 kg of body wt. Suppose that the animal has consumed 461 kg of grains (wheat, oats, barley, corn, dry peas, soybean meal and other small grain), 2403 of water for drinking and 8367 litre of water for servicing etc. This means that to produce 1 kg of pork, we have used about 3.9 kg of grain and 23litres of water (only for drinking and servicing).

Water footprint of broiler chicken: An industrial broiler production system where it takes 10 wk to produce 2.2 kg of bone less chicken. Suppose that the chicken has consumed 3.46kg of grains (wheat, oats, barley, corn, dry peas, soybean meal and other small grain). The water footprint of feed is 3211 litre followed by drinking water is 19 litres; 9.8litre for servicing etc. the total water footprint is about 3240.4 litres.

Water footprint of layer chicken: An industrial layer chicken production system where it takes 72 weeks years to produce 300 eggs. Suppose that the layer has consumed 62kg of grains (wheat, oats, barley, corn, dry peas, soybean meal and other small grain). The water footprint of feed is 18925 litre water followed 136 litre for drinking, and 70 litre for servicing. The total water footprint is about 19131 litres of water.

Water footprint of sheep: An industrial mutton production system where it takes 1.5 years to produce 53kg of body wt. Suppose that the animal has consumed 51kg of grains (wheat, oats, barley, corn, dry peas, soybean meal and other small grain), 710 kg of roughages (pasture, dry hay, silage and other roughages), 297020l litres water for feed 2176 water for drinking and 1916 of water for servicing etc. this means that to produce 1 kg of chevon, they have used about 963 gm of grain, 13.39 kg of roughages.

Water footprint of goat: An industrial mutton production system where it takes 1 year before the animal is slaughtered to produce 40 kg. Suppose that the animal has consumed 27 kg of grains (wheat, oats, barley, corn, dry peas, soybean meal and other small grain), 166 kg of roughages (pasture, dry hay, silage and other roughages),1522 litre of water for drinking and 1822 litres of water for servicing etc. litres of water.

Reduction of water footprint: In agriculture, the grey water footprint can be reduced to zero by preventing the application of chemicals to the field. It can be lowered substantially by applying less chemicals and employing better techniques and timing of application (so that less chemicals arrive in the water system by runoff from the field or by leaching). Green and blue water footprints (m^3/ton) in agriculture can generally be reduced substantially by increasing water productivity (ton/m^3). Agriculture is often focused on maximizing land productivity (ton/ha), which makes sense when land is scarce and freshwater is abundant, but when water is scarcer than land, maximizing water productivity is more important. This implies applying less irrigation water in a smarter way, in order to give a higher yield per cubic metre of water evaporated. Replacement of animal product by nutritional equivalent local crop product will reduce food related green water footprint by 23% of global and blue water footprint by 16%. A potential overall water footprint reduction of 36% in industry.

Focus on water use efficiency in crop production (more crop per drop), FCR in livestock (more meat with less feed), water use efficiency in food system as a whole (more nutritional value per drop).

Conclusion

Blue and grey water footprint of animal product are the largest for the industrial system (except chicken products).Water footprint of any animal product is larger than the water footprint of crop products with equivalent nutritional value 29% of total water footprint of agriculture sector in the world is related to the production of animal products; one third of global water footprint of animal production is related to beef cattle. Water policies can be focused on sustainable consumption than sustainable production.

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