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Water Footprint Analysis for Korea Livestock Products with the Concept of Virtual Waterfor Adapting to Climate Change

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Abstract: *As Korea is the 5th largest virtual water importing country and the ratio of imported virtual water to domestic water demand is significant, it is important to examine the impact of virtual water with imported livestock products on the domestic water demand and supply. Therefore, in this study, the amount of virtual water used in the production of the major livestock of Korea was calculated according to the domestic circumstances. In addition,the influence of major livestock products on the livestock water of Korea was also analyzed through the water footprint.The results revealedKorean beef and chicken to be 8% (1,292m^3/tonne) and 11% (417m^3/tonne) lower, respectively, than the world average water footprint value,butpork was9% (436m^3/tonne) higher.The water dependency (WD) on the livestock products was 45.5% and the water self-sufficiency (WSS) was 54.5%. With beef, the WD was highest at 59.1%, and chicken had the highest WSSof 83.4%. In addition, 98% of the virtual water of livestock came from the virtual water of stock feed. The main component of feed was grain, which was raised with agricultural water. As 75% of assorted feed is imported, the imbalance of demand and supply could cause a deficiency in agricultural water. Therefore, virtual water and the water footprint need to be considered when planning the water demand and supply in a changing climate in Korea.*

Keyword: *Water footprint, Virtual water, Livestock product, Water dependency(WD), Water self-sufficiency(WSS)*

I. Introduction

Recently, through the water resources management and global water resources flow in a country, many studies have examined the water footprint with the virtual water concept that presents a new resolution on efficient water resource management and supply around the world(Hoekstra, 2003; Chapagain. et al. 2004; Mekonnen andHoekstra, 2010; Mekonnen, et al, 2012).

Hoekstra et al. (2003, 2004) reported that virtual water is the water required for the production of commodities. For example, the production of 1 kg of beef, pork and chicken requires 15,497, 4,856 and 3,918 liters, respectively. When a country imports 1 tonnesof beef, it may facilitate approximately 15,000m^3 of water resource that it has for other uses.Such a concept can solve the water insufficiency problem with international trade.Many countries have developed interest on virtual water, and such virtual water conceptshas evolved to the water footprint concept to analyze the water flow relationship through international trade (Hoekstra and Hung, 2002; Hoekstra et al., 2011).

Hoekstra (2003) revealed the status of the international virtual water trade from 1995 to 1999, and Hoekstra (2009) calculated the water footprint of crops using the water balance model used in the case of crop growth under optimal conditions. Mekonnen and Hoekstra (2010) examined the total virtual water of a transaction on agricultural and industrial products between countries from 1996 to 2005, and Hoekstra et al. (2011) developed the water footprint process to present the needs of standardizing the evaluation work for countries by producing a water footprint evaluation manual on water mobility for countries as well as the production and consumption based on this procedure. Yoo et al. (2009) used the method proposed by Chapagain et al. (2004) to analyze the virtual water needed to produce 1 tonnesof crops with respect to 44 crops and the virtual water use for agriculture annually in Korea. Lee (2010) proposed the introduction of water footprint and its introduction scheme in Korea by comparing the carbon footprint system on the water footprint system. Kim (2013) performed industry relativity analysis to calculate the water footprint and reported that the ratio of direct water from total water use was 79%, and 82% of the total use in industry consisted of indirect water. On the other hand, although there have been a range of studies on virtual water in recent days, few studies have reported the calculation standard and quantitative evaluation on virtual water with respect to how much livestock products affect agricultural water.

The gross volume of annual water resource of Korea is 129.7 billion tonnes. With the exclusion of the outflow volume at the time of flooding and evaporation, the water resource available for use is 25.5 billion tonnesfor approximately 20%, and within that figure, the agriculture water (paddy field + dry field + livestock) is 15.9 billion tonnes,comprising 62% of the entire available water resource (MOLIT,2011). Water for livestock is 250 million tonnes with only 1.6% of water for paddy fields, but 98% of livestock product has an inflow of virtual water from other food sources. Moreover, the main ingredient of the food source is grain, which has a significant influence on water for paddy field and water for dry fields(Mekonnen and Hoekstra, 2012). Therefore, in this study, virtual water(ℓ/kg) on the major livestock (beef, pork and broiler chicken) of Korea was calculated and the effect of the major livestock products on the livestock water of Korea was analyzed through the water footprint.

II. Data and methods

Data on major livestock consumed in Korea was obtained from the National Statistical Service(www.kostat.go.kr), Rural Development Administration (www.rda.go.kr) and Korea Customs Service (www.customs.go.kr). From the major livestock, beef was set for Korean cattle, pork, and broiler chickens, and the calculation and survey period was applied for 12 years from 2000 to 2011.

The water footprint was classified based on the concept of green, blue and gray, but the three-type water footprint data was not systemized in Korea, meaning that the calculation has certain limitations. Therefore, when calculating the virtual water for major livestock (beef, pork and chicken), the direct consumption-type, the blue water (water used in the process of product production and service) was assumed and calculated for the total water (total water footprint), and when calculating the virtual water for livestock imported from overseas, the value was applied based on the total water.

This study applied two methods to calculate the water footprint of major livestock. The first method was to calculate the virtual water using the data on the use for food and the water of livestock following the feeding management, and the second method was the method to calculate the virtual water using the data for the water use volume and production volume survey for mixed feed.

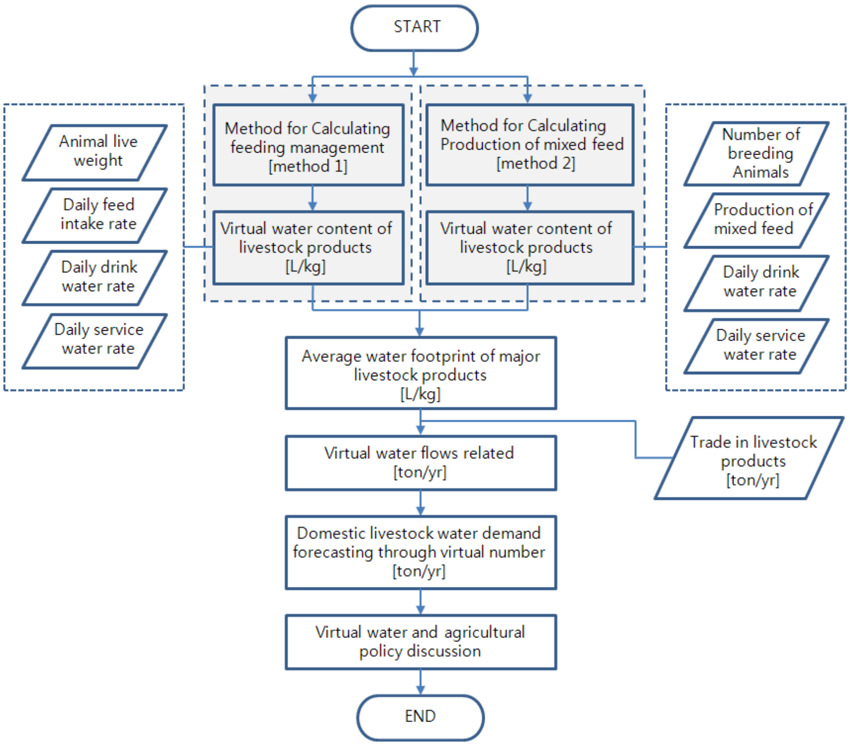

Figure 1. Research process flowchart

Figure 1 shows the flow chart and calculation method of this study and the volume of feed and water applied the specification management data of each livestock,as recommended by Rural Development Administration (RDA) and the ratio data of livestock mixture feed of Japan by Mekonnen et al. (2010). In the case of Korean livestock, the value was calculated by including the virtual water on rice straw separately, and the virtual water included in feed was calculated by applying for each applicable country or global average value as reported by Hoekstra et al. (2010), and the water use volume of livestock was calculated using the use volume data for the livestock water of WAMIS (www.wamis.go.kr). The virtual water value of the livestock calculated using the above two methods was averaged to formulate the virtual water value (ℓ/kg) of domestic livestock and comparative analysis was implemented with the global average virtual water value.

Calculation of the water footprint for livestockwas organized with the indirect water footprint related to feed, water footprint directly consumed, and water footprint consumed for service of the direct water footprint(Mekonnen, et. al., 2012).The water footprint related to one livestock can be expressed as Equation (1).

$$WF[a,c,s] = WF_{feed}[a,c,s] + WF_{drink}[a,c,s] + WF_{serv}[a,c,s]$$

Eq. (1)

where$WF_{feed}[a,c,s]$ means the water footprint related to livestock feed, “a”, whichis included in the production systemin“s” from country “c”, and $WF_{drink}[a,c,s]$ means the water footprint related to water that livestock drinks and $WF_{serv}[a,c,s]$ means the water footprint related to other services required for livestock breeding. The service related water footprint is the water used for the service required to cleaning the farm, wash the livestock or maintain the breeding-related environment.

The water footprint related to the feed is expressed as Equation (2). The water footprint of the feed can be divided into two parts, one is the water footprint of the feed ingredient and the other is the water footprint related to the water used to mix the feed.

$$WF_{feed}[a,c,s] = \frac{\sum_{p=1}^{n}(Feed[a,c,s,p] * WF_{prod}[p]) + WF_{mixing}[a,c,s]}{Pop[a,c,s]}$$

Eq. (2)

WhereFeed[a,c,s, p] means the volume of “p” for the feed ingredient consumed for one year from the production system “s” of country “c” for the “a” group, and $WF^*_{prod}[p]$ is the water footprintof the feed ingredient “ p” (m^3/tonne). $WF_{mixing}[a,c,s]$ is the water footprint related to the water used in a mixture of feed and Pop*[a,c,s] means the heads of livestock slaughtered per year. In this study, the water footprint of water mixed with feed was set to “0” because it was not known and the feed produced was assumed to be fully consumed by the livestock, and $Pop^*[a,c,s]$ was calculated for the virtual water based on the number of livestock bred for a year, not the number of livestock slaughtered. The water footprint of agriculture product(WF*prod[p], m^3/tonne) consumed by major livestock was calculated using the method reported by Hoekstra et al. (2010, 2012).

Livestock bred in a country consumes the crops produced domestically as well as the feeds imported from overseas. Therefore, to calculate the feed related water footprint, it would be effective to use the added-weighted average on the feeds produced domestically and imported, as shown on Equation (3).

$$WF_{prod}[p] = \frac{P[p] * WF_{prod}[p] + \sum_{n_e}(T_i[n_e,p]) * WF_{prod}[n_e,p]}{P[p] + \sum_{n_e} T_i[n_e,p]}$$

Eq. (3)

where P[p] means the total volume of the feed ingredient produced within a country, whereas$T_i[n_e,p]$is the import volume of “p”, which is the feed ingredient imported from the exporting country, “ne”, to the importing country, $WF_{prod}[p]$is the water footprint related to the production of “p”, which is the feed from the applicable country, and $WF_{prod}[ne,p]$ is the water footprint related to the production of “p” (m^3/tonne), which is the feed from the feed exporting country, “ne”.

III. Analysis results

3.1 Analysis of the virtual water for thelivestock product

In this study, two methods were used to calculate the water footprint of major livestock products. The first wasa method to calculate the virtual water based on the data for the volume of water and food of livestock products following the feed management. The feedmanagement is the optimal standardized management method by maintaining a high quality product value and comprehensively describing the food feed volume, feeding temperature, environment, disease management and others in raising cattle until the time of shipment. For each Korean beef, the bulky feed of rice straw and other dried ingredients and the mixed feed containing corn are fed for 4.0~ 11.4kg as for each age with an average of 2~16 liters of water each day. The slaughter age is approximately 30 months with a weight of 800kg. For pork, the mixed feed was made for 0.3~ 3.0kg as appropriate for each age with a mean of 1.3~7.3 liters of water each day. The slaughter age was approximately

27 weeks with a weight of 115kg. With chicken, 0.023~ 0.152kg of mixed feed was fed where appropriate for each age and an average of 0.9 liter of water was given. The slaughter age was approximately 5 weeks and the weight was 1.6kg (RDA, 2013).

The water footprint of the composition ingredient for the feed(WF^*_{prod}[p], m^3/tonne)was calculated on the domestic and imported feed, but the composition ingredient on domestic and import feed is unknown. Therefore, the feed ingredient applied used the world average water footprint value shown for each feed from the data presented by Mekonnen et al. (2010). In particular, the feed composition of Japan, which was considered similar to the feed management of Korea, was applied to the calculation. On the other hand, assuming that the rice straw for feedis solely domestically produced rice straw, it was estimated using the data for the calculation value of domestic virtual water reported by Shin (2010). The marks were determined to be WF_{feed}[a] for Korean beef, WF_{feed}[b] for pork and WF_{feed}[ch] for chicken, and the cattle breeding system was determined based only on the bred meat from the cattle shed through feeding, not grazing. Korean beef consumes feed and rice straw feed as food, and pork and chicken are assumed to depend only on feed.

As a result of the analysis, WF_{feed}[a],WF_{feed}[b] and WF_{feed}[ch] was shown to be 15,612 ℓ/kg, 5,391 ℓ/kg and 3,894 ℓ/kg, respectively. Edible water under the feed management of major livestock products forWF_{drink}[a],WF_{drink}[b] and WF_{drink}[ch] was 9.9ℓ/kg, 4.1ℓ/kg and 0.1ℓ/kg, respectively. The virtual water calculation on service water was calculated by dividing into WF_{serv}[s1] and WF_{serv}[s2]. WF_{serv}[s1] means the cattle raising water (edible water volume required for cattle raising and water required to cleanthe cattle shed and machinery) used in Korea, and WF_{serv}[s2] means the processing water (volume required for basic processing within the livestock farms with the application of 15.6% of cattle raising water). The WAMIS statistical data was used for the cattle raising water of WF_{serv}[s1]. As a result, the service water following the feed management for major livestock products showed WF_{serv}[a],WF_{serv}[b] and WF_{serv}[ch] values of 47.9ℓ/kg, 29.9ℓ/kg and 1.0ℓ/kg, respectively. For each unit of livestock product calculated in showing WF[a,c,s], the total virtual water of the major livestock products, the total virtual water for Korean beef, pork and chicken was 15,678(ℓ/kg), 5,691(ℓ/kg) and 3,938(ℓ/kg), respectively (Table 1).

Table 1. Average water footprint of major livestock products.

Livestock	Beef	Pig	Chicken
WF_{feed} (m^3/cap.yr)	4,995.62	1,239.88	62.35
WF_{drink} (m^3/cap.yr)	3.61	1.50	0.04
WF_{serv} (m^3/cap.yr)	17.48	10.91	0.37
WF (m^3/cap.yr)	5,017	1,252	63
Life time(yr)	2.5	0.5	0.1
Average weight at end of life time(kg)	800	115	1.6
WF (ℓ/kg)	15,678 [a]	5,443 [b]	3,938 [ch]

The second method was to calculate the virtual water by examining the mixed feed production volume and water use volume data. The mixed feed production volume increased or decreased according to the number of cattle bred in farms assuming that the volume of feed consumed by each cattle was calculated by dividing the mixed feed by the number of cattle assuming that the mixed feed produced is consumed completely by the cattle. As a result of calculating by inputting the data of mixed feed and number of cattle produced domestically based on the statistical data provided by KREI (2013), the total virtual water from the food unit of livestock product was 1,661(ℓ/kg), 1,751(ℓ/kg) and 18,98(ℓ/kg) for Korean beef, pork and chicken, respectively. The total virtual water of WF[a,c,s] from the major livestock products determined using the calculation result on the above service water and edible water was 12,731(ℓ/kg),5,140(ℓ/kg) and 3,063(ℓ/kg) for Korean beef, pork and chicken, respectively.If the value calculated using the above two methods is averaged, the values calculated for Korean beef, pork and chickenwere 14,205 (ℓ/kg), 5,292(ℓ/kg) and 3,501(ℓ/kg), respectively.

For each country, the method of feed management of major livestock products (cattle shed, grazing and so forth) and the type for each cattle was diversified, showing that the composition and volume of food should be different. Compared to the water footprint calculation value of the livestock product for each major country, as surveyed by Chapagain and Hoekstra (2004), Korean beef and chicken were 8% (1,292m^3/tonne) and 11% (417m^3/tonne) lower than the world average water footprint value, respectively, but pork was 9% (436m^3/tonne) higher.

3.2 Export and import analysis of the major livestock product

The virtual water value of major livestock products was determined to analyze the export and import flow of major livestock products. The statistical data of the Animal and Plant Quarantine Agency (APQA, 2013;http://www.qia.go.kr) was used to survey the import and export volume of beef, pork and chicken from 2000 to 2011. The virtual water used by livestock products for each country was calculated using the data reported by Chapagain and Hoekstra (2004), and any virtual water of livestock products in a country without this data was calculated using the world average value. The virtual water of major domestic livestock products that are exported was calculated using the virtual water calculation value of major livestock products estimated under this study. The importvolume of APQA and Livestock Distribution Information Center (LDIC, 2013;http://www.ekapepia.com) showed a slight difference. Hence,the statistical import volume of LDIC was determined to be the calculation base.

As a result of calculating the water footprint of major livestock products for each country, the virtual water from 2000 to 2011 was a total of 53,772 million tonnes, which is in accordance with the ratio of virtual water through trading in the order of beef (77.0%), pork (17.2%) and chicken (5.8%)(Figure 2).During the same period, the virtual water exported was 499 million tonnesin the order of chicken (55.3%), pork (42.5%) and beef (2.2%) for the export ratio of virtual water through trading. The virtual water that subtracts the export volume from the import volume was 53,273 million tonnes, and the available cattle raising water use volume for the water resource of Korea during the period, 2000-2011, was 2,500 million tonnes, showing a significant amount of virtual water. The water import dependencycan be obtained from the water footprint throughtrade.

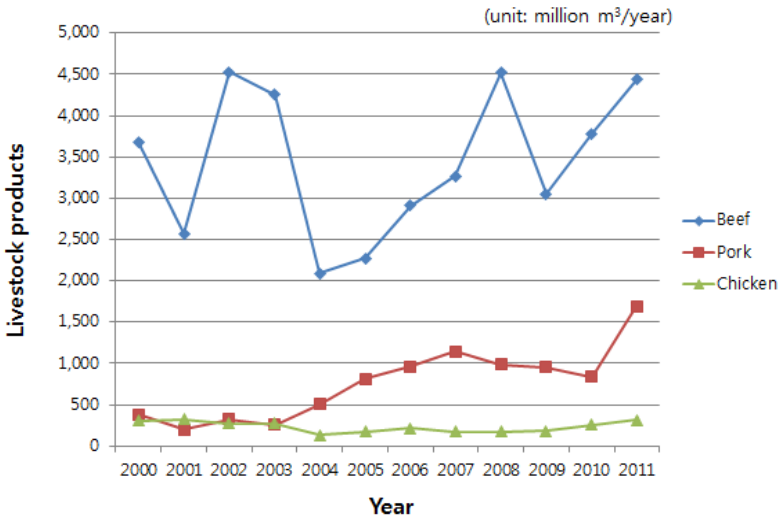

Figure 2. Net Livestock products quarantined imports &exports water footprint from the period 2000 - 2011

The water import dependency (WD) is determined by dividing the External Water Footprint (EWFP)by the total Water Footprint (WFP), and it can be expressed simply as Equation (4).

$$WD = \frac{EWFP}{WFP} \times 100 \qquad \text{Eq. (4)}$$

where the units for WD,EWFP and WFP are %, m^3/year and m^3/year, respectively(Chapagain and Hoekstra, 2004).The WD can be shown from the water footprint. The Water Self-Sufficiency (WSS) is the value dividingthe Internal Water Footprint (IWFP) by WFP and can be expressed simply as Equation (5).

$$WSS = \frac{IWFP}{WFP} \times 100 \qquad \text{Eq. (5)}$$

where the units for WSS,IWFP and WFP are %, m^3/year and m^3/year, respectively(Chapagain and Hoekstra, 2004).

The IWFP of major livestock products of Korea was calculated using the livestock product demand and supply data of the Korea Rural Economic Institute (KREI, 2012). The beef, pork and chicken produced in 2011 were 216,000 tonnes, 576,000 tonnes, and 455,000 tonnes, respectively (Figure 3).

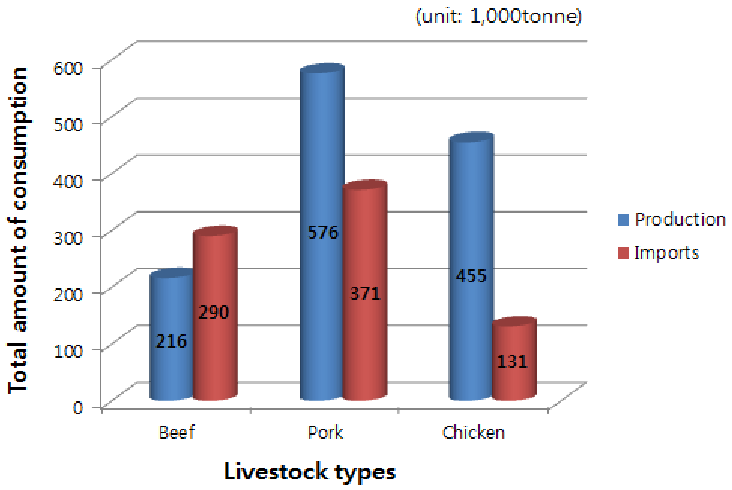

Figure 3. Production and imports of livestock in 2011

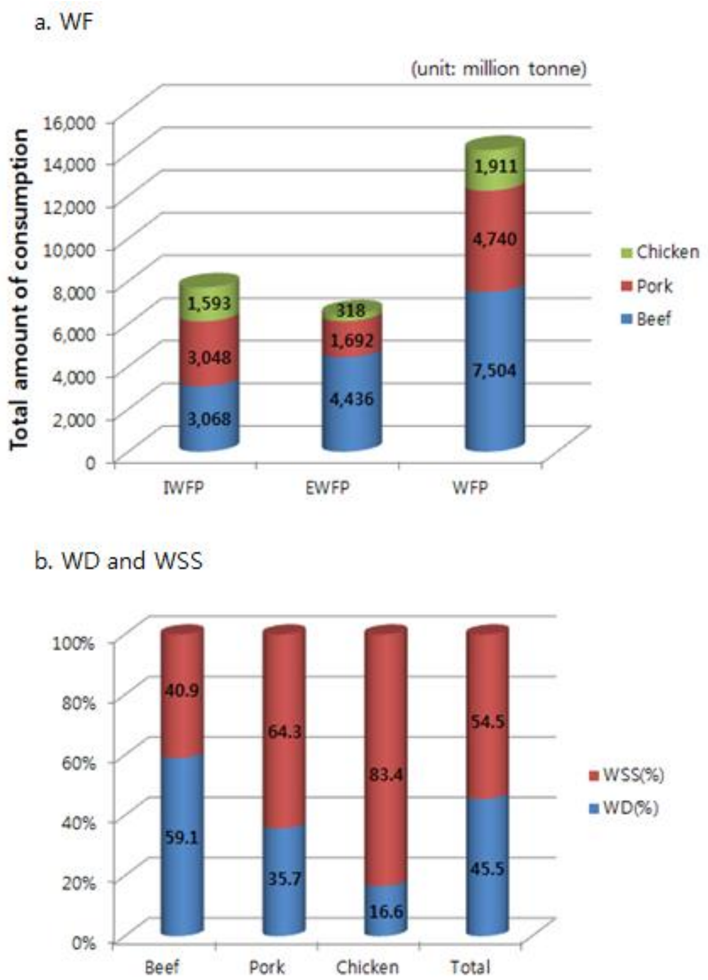

Figure 4.Livestock water import dependency & water self-sufficiency in 2011. a. Water footprint (WF). b. Water import dependency(WD) and Water self-sufficiency (WSS).

By filling in the virtual water value on the major livestock products calculated in this study (Figure 4), the IWFP was 7,709 million tonnes. The EWFP was based on the livestock products imported in 2011. The imported beef,pork and chicken were 290,000 tonnes, 371,000 tonnes, and 131,000 tonnes, respectively, and the exported chicken was 15,000 tonnes.Using the virtual water of the data calculated by the virtual water for each imported country and the global average virtual water, the virtual water value obtained by subtracting the export volume from the import volume was 6,446 million tonnesfor the EWFP. Table 2lists the WD and WSS of major livestock products of Korea. As of 2011, the WDof the livestock products was 45.5% and the WSS was 54.5%. The WD was highest for beef at 59.1% and the WSSfor chicken was highest at 83.4%.

Table 2. Livestock water import dependency & water self-sufficiency

Livestock product		2011 (1,000ton)	IWFP	EWFP	WFP	WD(%)	WSS(%)
Beef	Production	216	3,068	4,436	7,504	59.1	40.9
	Imports	290					
Pork	Production	576	3,048	1,692	4,740	35.7	64.3
	Imports	371					
Chicken	Production	455	1,593	318	1,911	16.6	83.4
	Imports	131					
Total			7,709	6,446	14,155	45.5	54.5

3.3Forecastingthe required volume of domestic livestock water

Figure 5 shows the forecasted result of the prospect in the major livestock product production in Korea along with its consumption value per person from 2013 to 2022. The consumption of major livestock products per person is expected to increase steadily up to 2022, and the production and import are also expected to increase. Based on the data for 2011, the total volume of beef, pork and chickenimported into Korea was calculated to be 15,391m^3/tonnes,4,563m^3/tonnesand 2,887m^3/tonnes, respectively. The virtual water of import livestock products in 2013 was 5,536 million tonnes, which was increased from 882 million tonnesto 6,418 million tonnesin 2022. Among them, beef, pork and chickencomprised4,795 million tonnes, 1,175 million tonnes, and 448 million tonnes, respectively. The virtual water needed for the livestock production volume in Korea for 2013 and 2022 was estimated to be 8,381 million tonnesand 9,131 million tonnes, respectively.

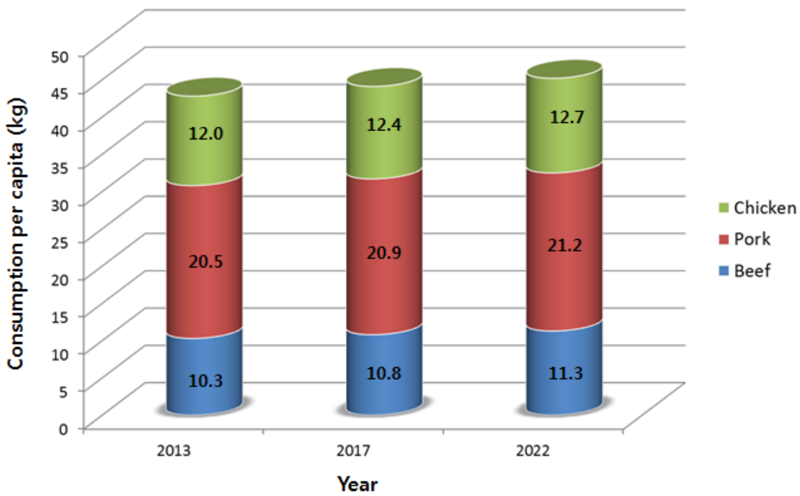

Figure 5. Consumption of major livestock products (2013~2022)

The livestock water of the required water resource in 2022 was estimated to be 247 million tonnes. The virtual water required for domestic livestock product production was estimated to be 9,131 million tonnesand the available water resource for livestock water compared to the livestock product virtual water was 2.7%. According to the Ministry of National Land and Marine Affairs (2011), the agricultural water required volume of Korea in 2020 was calculated to be 15.9 billion tonnes, meaning that the ratio for virtual water of domestic livestock products was 57.4%. This was attributed to the fact that 98% for invisible water was formed by the feed for cattle and most of the feed comes from agricultural products. Therefore, the livestock product virtual water affects the agricultural water in Korea and the policy agenda can be formulated by forecasting the future demand and supply.

According to the report of the Nong-Hyup Economic Research Institute (2012), the import volume of ingredient grain as of 2010 was 17.58 million tonnes, and the imported production was 13.24 million tonnes. Hence, the mixed feed import dependency of Korea has reached 75%. An analysis of the data of the Korea Customs Service (2012) showed that the import for mixed feed each year has increased with increasing domestic livestock product consumption volume, and compared to 10 years ago, the increase has reached 905.3%. Therefore, when the imported mixed feed is calculated for the virtual water based simply on grain(cereals 1,644m^3/tonne), it is equivalent to a virtual water import of approximately 21.7 billion tonnes. This is more than the agricultural water of Korea. Therefore, any problemswith overseas demand and supply of mixed feed (including feed ingredient grain) from problems in international relations and climate change mightaffect the agricultural water volume of Korea where the water import dependency is very high.

IV. Summary and conclusion

This study estimated the water footprints of major livestock inKorea using two methods of feeding management and a production volume survey for mixed feed using the statistical data and virtual water concept from 2000 to 2011. In addition, this study analyzed the flow of the water footprint through trade between countries and calculated the rate of dependence of water imports and the rate of independence of water. The main findings are summarized as follows:

1. An analysis of the virtual amount of water in major livestock products in Korea revealed 14,205(ℓ/kg), 5,292(ℓ/kg) and 3,501(ℓ/kg) for domestic beef, pork and broiler chickens, respectively. When analyzing the main livestock products imported from 2000~2012, the mean virtual amount imported per year was 4,481 million m^3/year.Among them, the virtual amount of beef, pork and broiler chicken was 3,449 million m^3/year, 773 million m^3/year and259 million m^3/year, respectively.
2. The water footprints within the main livestock products in Korea were 77,090,000 m^3/year as of 2011, the outside water footprints were 64,460,000 m^3/year, and the rate of dependence of water imports for major livestock products was 45.5%.
3. In 2022, the virtual water required for the man livestock products in Korea was expected to be 9,131, million tonnes, and the virtual water being imported was estimated to be 6,418 million tonnes.Because the available water resource for stock breeding water will be 247 million tonnesin 2022, the available water resource forlivestock water compared to livestock product virtual water was found to be 2.7%.
4. A shortage problem of agricultural water is expected in the future because the rate of dependence of mixed feed in Korea was found to be 75%, and there is an imbalance of imported feed, which has a higher level of dependence.

Many factors affect the estimation of virtual water, and because the proportion of feed takes up large part in calculating the virtual water for the major livestock product, it will be possible to calculate the accurate virtual water amount for livestock products on feed only after examining the composition of mixed feed produced in Korea and verifying the virtual water for the composition of feed according to domestic circumstances. In doing so, it is important to examine the amount and composition components of the feed used in livestock, farms, seasons and regions, as well as to calculate the amount of water used in transportation and slaughter and the amount of water used in removing contaminants (such as disposal of excreta).Although the absence of domestic statistical data is a limitation, this study calculated the virtual water using the basic data but could not examine the constituents of the domestic feed for each livestock when calculating the virtual water for the major livestock products. Nevertheless, the fact that the study applied livestock farming system through a meticulous examination and interpretation according to standardized feed management, and interpreted the flow of water footprints for the major livestock products by analyzing the production amount and imports means that these results can provideimportant information for estimating the domestic virtual water in the future.

As virtual water is invisible, no one has assumed that there can be water transport between countries through trade. Nevertheless, the reason the concept of virtual water and the theory of water footprints through trade has gained attention these days is that it suggests new approach and solution in the perspective of solving the problem of water shortages. The statistical data concerning water resources in Korea focus mainly on the requirements such as industrial water and development policy, and they are provided as information for supply.

From now on, however, because water can be visualized through virtual water, it is expected that it will induce water savings, analyze the influence on food imports and agriculture, and be used in a close examination of the international food market and decision making on water shortage problems in a changing climate.

Conflict of Interests
The authors declare that there is no conflict of interests regarding the publication of this paper.

V. Acknowledgement

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