SUSTAINABILITY OF WATER RESOURCES MANAGEMENT POLICY: TIME FOR A PARADIGM SHIFT FOR ENSURING FUTURE FOOD SECURITY AND WATER RESOURCES

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ABSTRACT

Sustainability of water resources in global food production systems is of utmost priority. The reoccurring and prolonged drought periods, in addition to the accelerated urbanization and changing lifestyle in a water-scarce country like Korea create a daunting challenge onthe availability of freshwater for food production. A common approach to addressing the challenges of agricultural water conservation has been centered on the field during crop production. This method, though very impactful, cannot secure the projected future food demand considering the ecological deficit and other limiting factors associated with food production.The alternative idea to ensuring food availability is therefore indispensable, specifically by exploring the prodigious food loss and waste (FLW) that could have far-reaching benefits in terms of resources conservation and food security. This study quantifies and analyses the FLW of various food groups in each stage of the food supply chain (FSC) for Korean specific food production data (2007 - 2013) using the top-down approach of global FLW mass flow model. Furthermore, the quantity of water inherent in FLW was assessed using the representative water footprint of food types. The results showed that 14.14 million tonnes (0.78 kg/capita/day) equivalent to 54.92% of domestic production were either lost or wasted with only consumer stage responsible for 48.79%. An average of 56.49 Gm^3/year of water resources was associated with the FLW, representing a considerable 44% of the country's total water resources (129.7Gm^3). Among the food wastages, cereals and meats wastages accounted for the most significant depletion of water resources with This study shows that minimizing food wastage, rather than field water conservationalone,can substantially improve available freshwater andmeet the growing food demand while using the resources sustainably.

Keywords: Food loss and waste, water footprint, food production, Republic of Korea

1. INTRODUCTION

Sustainable water resources and food security are the most significant concern of humanity as the two variables are virtually the basic necessity for human survival. The reoccurring and prolonged drought periods in many parts of the world especially in Korean peninsula of East Asia are daunting challenges to agricultural productivity and stringent law governing the use of limited available water resources(Jung et al., 2011; Kwon et al., 2016). Similarly, the growing global demand for food consumption and the increasing competition for water use are expected to increase the susceptibility of food insecurity and scarcity of water resources, predominantly in Asia and Africa (FAO, 2013; Davis et al., 2016). According to the United Nations, the world population is projected to increase from the current 6 billion to about 9.7 billion by 2050, with the majority in Asia and Africa continents (United Nations, 2015). The consequences of feeding the exponential population growth would require six folds of

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current freshwater demands and a 70% increase in global agricultural production (Searchinger et al., 2013).

One of the sustainable ways of ensuring food security and conservation of water resources is reducing FLW across the food supply chain. The global annual estimates of the edible portion of FLW is approximately 1.3 billion tons, which is equivalent to one-third of annual food production (Gustavsson et al., 2011). This prodigious amount of FLW varies across the regions, countries, and among the food groups. For instance, the food loss which occurs mostly at the upstream of the food supply chain (FSC) is very prominent in the developing countries due to the low technology to tackle the food loss during production and post-harvest stages of food production (Parfitt et al., 2010). However, the food wastage in the high income and industrialized countries, particularly at the consumption stage of FSC, is of great concern due to the accumulation of resources along the supply chain in the food production including water and land (Wunderlich & Martinez, 2018). Aside from the social menace of FLW on food security, the loss of resources embedded in FLW is worrisome. In spite of the numerous studies on the quantifications of FLW across the regions and in many countries, and most importantly its impact on water resources (Liu et al., 2013; Sun et al., 2018; Kashyap and Agarwal, 2019), there is still a knowledge gap in many parts of Asia, specifically South Korea. The existence of ecological deficit and persistence water crisis owing to burgeoning climate change impact in this region is of great concern (Hanjra& Qureshi, 2010).This study addresses the country's specific data gap by analyzing FLW across the FSC, including production, post-harvest, processing, distribution, and consumer in South Korea. Besides, the study evaluates the water footprint of food waste in order to access potential water savings.]

2. MATERIALS AND METHOD

2.1 Definition And Scope

There are different definitions attributed to food wastage in the literature.These, most times, depending on the scope and scale of the study. However, there is a consensus food loss occurs at the upstream of the FSC, such as production, post-harvest storage,and processing (Parfitt et al., 2010).Food waste refers to the portion of food that is intended for consumption but got wasted during the retail and consumption stages (Parfitt et al., 2010; Gustavsson et al., 2011; Salihoglu et al., 2018). The definition offood loss and food waste, as defined above,was adopted in this study.The term FLW or food wastage encompasses all the discarded edible portions of food commodities.These include fruits and vegetable peels, uneaten cooked or uncooked meat, and raw egg without shells, which sometimes refer to anything that animal can eat. The eight food groups including cereal crops, starchy roots, pulses and oilcrops, fruits and vegetables, meat, fish and seafood, milk, and egg in all the five stages of FSC as described by Gustavsson et al. (2011), are considered in this study.

2.2 Food Production Data And Quantifying FLW Along FSC

The national food production quantities data for individual food commodities wereobtained from the FAO database (FAOSTAT, 2019). Due tothe annual variations in the production of food commodities, an average recent production values of seven-year data (2007 – 2013) was used. The fraction of FLW across the value chain, starting from the production stage, was estimated using the mass flow model following the Gustavsson et al. (2013) and Dal' Magro & Talamini (2019). The inedible foods that are not intended for human consumption,such as seed, animal feeds, and other utilities were excluded from the estimates. This was carried out using wastage percentage and conversion factors for industrialized Asia, as described byGustavsson et al. (2013). The estimated wastagepercentage in each stage of the FSC for industrialized Asia as, reported by Gustavsson et al. (2011) was used.The quantity of FLW of each food commodities (in aggregated form of food group) at each stage along the FSC was then calculated by multiplying the food commodity value by the wastage percentage and conversion factors in that specific stage. The population data were obtained from the United Nations (2017) to estimate the per capital FLW across the supply chain. The FLW was after tha tclassified into two groups, plant-based, and animal-based foods. Plant-based food commodities comprise cereal crops, starchy roots, pulses and oil crops, and fruits and vegetable while animal-based foods include meat, fish and seafood, milk, and egg.

2.3 Estimation of Water Footprint of FLW

The water footprint assessment of FLW in this study wasbased on the selected representative food items for each food commodity group. The selected food types are the commonly consumed food items which were based on the availability of such data. The estimated values of the water footprint of food items in Korea used in this study are presented in Table 1. The water footprints of commonly produced food items in Korea were obtained from Lee et al. (2015) and Mekonnen and Hoekstra (2012),as compiled by Yoo et al. (2016).

Table 1. Food commodity group and water footprints representative food items

Food commodity group	**Representative food type**	**Water footprint of food item (m^3/tonne)**	**Food commodity group**	**Representative food type**	**Water footprint of food item (m^3/tonne)**
Plant-based			Animal-based		
Cereal crops	Rice	994.8	Meat	Bovine meat	14023.1
	Wheat	1060.2		Pork meat	163.9
	Barley	795.9		Poultry meat	2427.7
	Maize	1039.7		Edible viscera	9041.0
	Others	2298.1			
Starchy roots	Potato	135.8	Milk	Whole milk powder	1893.5
	Sweet potato	370.0		Skim milk powder	4721.3
				Liquid milk	1015.3
Pulses and oil crops	Soybeans	3346.7	Egg	Egg	2932.4
	Red beans	3166.9			
	Pulses, others	2644.0			
	Oil crops, others	4545.0			
Fruits	Fruits	573.1			
Vegetables	Vegetables	137.9			

Source: (Yoo et al., 2016)

The WF_{FLW}, embedded water footprint associated with the wastage of representative food item, was then quantified using equation 1.

$$WF_{FLW} = \sum_{i}^{n} WF_i \times FLW_i$$

whereFLW_i is the total quantified food loss and waste of food commodity n, WF_i is water footprint of common food items in each food commodity n.

3. RESULTS AND DISCUSSION

3.1 FLW Across The Supply Chain

The result of national FLW for the average 7-year period under this study wasestimated at 14.14 million tonnes. On the per capita basis, using the mean population data for 2007 – 2013 from the United Nations (2017), the estimated amount of FLW was 0.78 kg/capita/day. The amountof FLW generated amounts to 54.92% of annual domestic production (25.74 million tonnes) of the same period (Table 2).

Table 2. Annual average FLW generation in Korea (2007 – 2013) in 1000 tonnes

Food commodity Group	Domestic production[a]	Food loss	Food waste	Total FLW
Cereals	4174.71	756.10	3865.41	4621.51
Tuber crops	943.43	399.70	591.95	991.66
Pulses and oil crops	194.57	25.70	90.84	116.54
Fruits and vegetables	13477.00	2699.36	3603.69	6303.05
Meat	1978.14	174.13	404.38	578.51
Fish and seafood	2244.14	564.68	590.80	1155.48
Milk	2115.00	120.74	154.82	275.56
Egg	618.86	40.23	55.99	96.22
Total	25745.86	4780.65	9357.88	14138.52

[a]Average domestic production of food commodity group in 1000 tonnes for 2007 – 2013 periods obtained from FAOSTAT dataset, 2019.

Our estimate of FLW is in contrary to the annual food waste estimate of about 6.2 million tonnes generated in Korea as quoted by Thi et al. (2015) from grey literature. In the reported study, the food waste at the consumption stage was only considered while the annual variations in the quantity of food waste generation were ignored. Compare to other national FLW studies, Liu et al. (2016) calculated 0.81 kg/capita/day (37.81 million tonnes) of food waste in Japan’s FSC for the year 2011. Dal’ Magro and Talamini (2019) estimated about 1.17 kg/inhabitant/ day for Brazil between the year 2007 and 2013 which are however relatively higher than our estimate of 0.78 kg/capita/day. While in South Africa, Oelofse and Nahman (2013) estimated 0.48 kg/capita/day, and also about 0.40 kg/capita/day were reported by National Environmental agency of Singapore (National Environment Agency, 2017). The food losses at the upstream stages of the supply chain were33.81% of the total FLW while the food waste during the consumption stage was48.79%. It is, however, worthy of note that there could be significant variations in the current status of food wastage at the consumption stage of the supply chain. This is due to the recent policy implementation on food waste in the country. The policy requires households to pay a certain amount of money based on the quantity of food waste while disposing of it. The food waste prevention policy has reportedly caused a drastic reduction in food waste generation (Thompson & Rothman, 2017).

Rice is the staple food in Korea, andas a result, the most and frequently consumed food commodityiscereal and cereal products (Park et al., 2018). Similarly, the Korean diets are very rich in vegetables and with growing consumption of fruits among the adults (Choi et al., 2010).The likelihood of wasting more food from the most frequently purchased and consumed food items cannot be ruled out (Lee, 2018).It is not surprising why cereals, fruits and vegetables are the most predominant wasted food commodities at the consumption stage.The level of total FLW in the country is alarming, considering the ecological deficit, limiting available resources including, water resourcesfor food production, and continuous reliance on food importation (Gabriela 2017).

3.2 Water Footprint of FLW

The average annual water footprint of food wastage discarded across the supply chain between 2007 and 2013 was 56.49 Gm^3. The computational contributions of food commodity groups to the water losses due to food wastage is presented in Figure1. There was a relatively high volume of 50.63% water loss due to wastage of cereals and cereal products among the food commodity groups. This can be attributed to the high production and consumption of rice and rice products in the country. Similarly, water loss associated with meat and meat products was 18.93 Gm^3. The high volume of water footprint requires for production of meat and meat products including water use for drinking, servicing, and growing feed crops during the production stage of the animals, as well as excessive water use during processing of meat in slaughterhouses (Lee et al., 2015), is responsible for the relatively high volume of embedded water losses due to meat and meats products.

For fruits and vegetables, however, the water footprint of food wastage was relatively low (7.93%). Despite the high amount offood wastage across the supply chain of fruits and vegetables (Table 2), the little quantity of estimated water footprint associated withfruits and vegetable wastage can be explained by the small amount of water resources required for their productions as compared to other food commodity products investigated in this study.Similarly, water footprints embedded in the wastage of pulses and oilcrops, starchy roots, eggs, and milk were found to be insignificant. These results are not surprising, considering that the majority of these food commodity groups are largely imported into the country.As a result, the depletion of water resources during the production and processing of the food commodities was avoided.For starchy roots, the low water footprint required for the production of potato and sweet potato (Yoo et al., 2016) results in a small volume of water losses due to food wastage.For milk and egg; not surprisingly, since the mass wastage of milk and egg commodity products was relatively low (Table2), the water losses embedded in these food commoditiestend to be in small quantity (Figure 1).However, the high amounts observed in water losses due to milk and milk products as compared to the egg was due to the significant water resources require during the processing of some food items in the milk and milk products such as whole milk, skim milk, and liquid milk (Yoo et al., 2016).

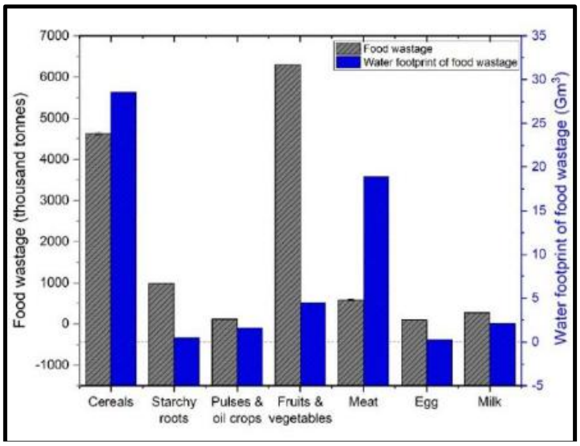

Figure 1. Water loss due to FLW

3.3 Impacts of FLW on Water Resources and Policy Implications

Food wastage is considered as a social and environmental menace, notwithstanding the considerable loss incurred on water resources during food production. Food wastage entails the loss of water resources used in the production of such food. Our study shows the loss of a large volume of water resources due to food wastage, which significantly varies among the food commodity groups. Succinctly, an average of 56.49 Gm^3 of water resources associated with food wastage, which represents 34% higher than the nationally available freshwater for use, was lost during the year 2007 - 2013. Water loss due to animal-based food wastage, specifically meat and meat products, has the most considerablesignificant impacts on water resources. The meat productions are resources intensive since they require a significant additional volume of water to grow their feeds. The per capita consumption rate of meat has continued to increase recently (Kweon & Oh, 2014). Similarly, the wastage of cereals food commodity group showstremendous implication on the loss of water resources. Currently, the country has attained significant self-sufficiency in rice production, whichcome at the expense of depleted water resources. At the same time, about 28.60 Gm^3 was lost through cereal food group wastage in which rice accounts for the largest share. Moreover, significantsources of freshwater for food production and other uses are through the surface and underground reservoirs (blue water), with a combined supplying capacity of 67% of water resources (Korean Statistical Information Service, 2018).

The current water resources management policy is center onthe building of infrastructures for surface water resources such as dams and reservoirs. The topography features, in which about 65% are mountainous area, and the significant variations in annual precipitation with about 70% occurring during the short summer season, make the water management difficult despite the country's average annual rainfall of 1277 mm. The occurrences of severe droughts during the dry seasons of winter and fall have also exacerbated in recent time. The policy adopted to address the challenges of water resources management include the storing of water through the construction of various reservoirs across the country, allocation of water resources among the water users including agriculture, and efficient utilization of allocated water resources to ensure its sustainability.Water resources management is targeted at addressing the concern issues of climate change, persistent drought, water conflicts, and sustainability.

The agriculture water resources in recent time have witnessed a decline in its percentage allocation in the face of stiff competitions among the water users (Korean Statistical Information Service, 2018). Salvaging the enormous food wastage is a feasible alternative to reduce the food demand, sequentially conserve the water resources without adverseeffects on food security. Besides, Yoo et al. (2016) estimated potential water requirement of 1.26 Gm^3 to achieve 55% calorie-based self-sufficiency ratio by 2020. The projected volume of water resources required to meet the calorie demand in the country self-sufficiency is just 2.23% of the total freshwater resources lost through food wastage. The strategy on water resources conservation in the face of water scarcity and persistent drought periods can be actualized through discerning policy planning and implementation, most enotablythrough food wastage reduction. The efforts should intensify more on the cereals and animal-based food commodity wastages, considering their substantialpercentage contribution tothe loss of freshwater resources. Most importantly, there is a need to recognize the fact that food wastage translates to the loss of water resources and other resources used during food production. Furthermore, efforts to achieve target self-sufficiency in food production due to the economic reality of continuous food import-dependent, and impending vulnerability of disruptions in the food supply chain as a result of exponential population growth need an appropriate policy.

4. CONCLUSIONS

The role of freshwater resources on food production is indispensable, and without which the world will cease to exist. The finite water resources are getting depleted, and at the same time, the portions of already produced food are being lost or wasted. This study evaluates the impacts of food wastage along with the embedded water loss on the water resources in Korea. The need for policy intervention on food wastage to sustain the finite water resources was also revealed. The estimate of an average 7-year period (2007-2013) food wastage generation across the supply chain was 14.14 million tonnes (0.78 kg/capita/day), of which the food loss at the upstream stage is 4.78 million tonnes, and the food waste at the downstream stage is 9.36 million tonnes. Cereals and fruits and vegetables accounted for the large proportion of food waste at the consumption stage, while significant portions of tuber crops, fruits and vegetables, and meat are lost during the distribution stage.

Food wastage impacts significantly on water resources. The water footprint associated with food wastage was 56.49 Gm^3, representing34 percent higher than the nationally available freshwater for use. The wastage of meat, which is animal-based food had the most substantial impact on water resources, followed by cereal, a plant-based food group. A considerable percentage of fruits and vegetables were either lost or waste; however, the relative impact on the loss of water resources is quite low.

Although, the estimate of FLW and the loss of water resources associated with the food wastage might not reflect the current situation in the country considering the stringent implementation of “pay as you throw” policy on food waste, however this study indicates that water saving potential and the sustainability of food production are achievable by minimizing food wastage. It is imperative to conduct further studies that reflect the current situation of food waste and the associated resources lost, most notably water resources. This will adequately ensure an appropriate policy to be employed in tackling the food waste issue in addition to the existing policy, under the goal of resources sustainability.

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