Evaluation of Current Freshwater Requirement in Asia Based on Global Food Trade and Food Supply-Demand Balances

Yohei YAMAGUCHI*[1], Naoki YOSHIKAWA*[2], Koji AMANO*[3],
Seiji HASHIMOTO*[4]

Abstract:
This study aims to evaluate the current freshwater requirement in Asia based on global food trade balance and food supply-demand balance matrices. The concept of a water footprint was adopted to estimate both supply and demand side freshwater requirements along with water transportation resulting from food import and export. Rain-fed (green water) and irrigation (blue water) consumption were considered. For blue water, irrigation efficiency was also considered to convert water consumption into water withdrawal because the former did not include irrigation water losses resulting from irrigation technology and management systems. It was concluded that as Eastern Asia mainly imports oil crops and oils (190 km^3), cereals (69 km^3), and meats and eggs (59 km^3), it is Asia's largest importer of imported freshwater volume, with a total volume of 397 km^3, mainly from Asia (117 km^3), North America (129 km^3), and South America (94 km^3). In contrast, South-Eastern Asia is the largest exporting area in Asia, exporting predominantly oil crops and oils (180 km^3), rice (105 km^3), and beverages (53 km^3) with a total exported freshwater volume of 421 km^3. Moreover, an additional analysis of palm oil in Malaysia and Indonesia was implemented to show the utility of our simulation data.

Keywords: *Asia, water footprint, virtual water, food trade balances, food supply-demand balances*

---

*1 Graduate student, Graduate School of Science and Engineering, Ritsumeikan University, Japan
*2, 4 College of Science and Engineering, Ritsumeikan University, Japan
*3 College of Gastronomy Management, Ritsumeikan University, Japan
E-mail: *1 rv0023hs@ed.ritsumei.ac.jp
*2 n-yoshik@fc.ritsumei.ac.jp
*3 amano@se.ritsumei.ac.jp
*4 shashimo@fc.ritsumei.ac.jp

Received on August 29, 2019; accepted after peer reviews on October 30, 2019; published online: November 27, 2019.

©Asia-Japan Research Institute of Ritsumeikan University:

Asia-Japan Research Academic Bulletin, 2019-2020.
ONLINE ISSN 2435-306X, Vol.1, 11.

1. Introduction

(1) Background

Food is indispensable for human life but its production requires massive quantities of freshwater. According to Shen et al. (2008), in 2000, the proportion of freshwater consumed for agriculture, industry, and households was 70% (2,658 km^3/yr), 20% (777 km^3/yr), and 10% (390 km^3/yr) respectively, demonstrating that agricultural freshwater consumption is particularly high. Thus, a quantitative evaluation of the amount of freshwater required for food production is of vital importance.

Both land and freshwater are required for food production. However, in resource-poor countries that lack the resources required to produce sufficient food to meet the national demand, food importation could be an important option to compensate for the shortfall. Thus, water transportation is caused by importing foodstuffs, interpreted as indirect water consumption by the importing countries. Thus, it is essential to evaluate total freshwater resources by considering the water transportation flow created via the import and export of foodstuffs between trading countries, along with their direct water consumption resulting from food production and domestic consumption, both of which are, in general, not equivalent.

(2) Evaluation Index of the Freshwater Resource

The International Organization for Standardization (ISO) put forward the concept of a water footprint (WF) and defined it as an evaluation index “to provide decision makers in industry, government and non-governmental organizations with a means to estimate the potential impact of water use and pollution, based on life-cycle assessment” in a briefing note for ISO 14046. Most manufactured goods and services pass through raw material, processing, distribution and sales stages before reaching the final demand stage where they are consumed by households, businesses, etc., and then finally arrive at an end-of-life stage. WF is calculated by totaling the amount of freshwater consumption related to goods and services, which increases with each of the aforementioned stages. For example, Hoekstra et al. (2011) explained a methodology to estimate WF at a national level. In Hoekstra et al. (2011), WF is separated into three types: green WF, blue WF, and gray WF. The green WF targets “green water,” which is the amount of consumed freshwater that directly originates from precipitation and is not immediately restored to surface water and groundwater. Via a series of water cycle processes, some of the restored water is consumed in the form of irrigation water referred to as “blue water.” This is added up as blue WF. Blue water is artificially supplied as a means of compensating for shortfalls in green water. The gray water footprint is the amount of freshwater required to dilute pollutants to meet current water quality standards.

(3) Research Purpose

Mekonnen and Hoekstra (2011b) globally estimated a consumption-based WF within national and gross virtual water flows in the agricultural, industrial, and domestic water supply sectors. Yamaguchi et al. (2018), our previous research, analyzed only the demand-side freshwater requirement without sufficiently considering the supply-side while focusing on food trade and consumption. In these previous studies, the actual conditions of various countries’ trade and food supply-demand balances are unclear. In fact, as indicated by Kosaka et al. (2012), there are inconsistency problems in trade statistics caused by various factors, causing an uncertainty in the analysis for the unbalances between imports and exports leading to an unintentional deterioration in estimation accuracy. Thus, to improve the estimation accuracy, it is essential to simultaneously specify two balances, namely a food trade balance and a food supply-demand balance, for each country because both imported and exported quantities are determined depending on both supply and demand quantities for products or services interacting with one another. However, it seems that these two balances have tended to be unclear in global analyses of the freshwater requirement.

However, Abdelkader (2018) proposed a virtual water balance equation corresponding to a food balance equation, focusing on 78 crops in Egypt. Han et al. (2017) evaluated the virtual water volume of Mainland China, which is imported from 189 countries and composed of 26 sectors, including one agricultural sector and one food and beverages sector, from both production-based and consumption-based perspectives using the multi-regional input-output (hereafter, "MRIO") table. In this table, trade and supply-demand balances are ensured globally as the total input is equal to the total output, but there are few food categories. Appearing to ensure trade balance or supply-demand balance, the two studies focused on one country as an evaluation target, whose targeted trade partners or items were relatively extensive. In addition to these two studies, there is considerable previous literature focusing on one country but few regional level analyses as described in the following.

In a regional level analysis, White et al. (2018) analyzed the total WF which was one type of seven environmental categories selected using inter-regional input-output analysis focusing on three countries of East Asia (China, Japan, and South Korea). Except for this study, we could not find any other previous literatures integrally evaluating freshwater transportation among Asian countries though the region is among the highest consuming areas. In this sense, specifying individual food supply-demand balance is meaningful. Moreover, during our rapidly internationalizing modern times, importing and exporting of products and services are constantly occurring throughout the world, supporting an incentive to promote exhaustive analysis for inter-regional and intra-regional trade.

In summary, it is important to evaluate the freshwater requirement of Asian regions under circumstances satisfying both the global food trade and food supply-demand balances as there are seemingly few scientific studies focusing on such analysis. This study aims to evaluate the current freshwater requirement in Asia based on global food trade balance and food supply-demand balance matrices. Using these unique matrices is an innovative and helpful means to clarify the actual conditions of various countries' trade and food supply-demand balances. These matrices target only food products but cover more complete food categories than those of the MRIO table. It is expected that this study can be used as a reference to aid in the accumulation of scientific knowledge to arrive at future sustainability in Asia and involving other regions.

(4) Setting the Study Target

In this study, the evaluation target year was 2010. As shown in Table S1, the target countries were the 51 countries in Asia and their trade partner countries, 216 in total, which were extracted from the countries listed in the Food and Agriculture Organization Corporate Statistical Database's (FAOSTAT's) Food Balance Sheets ("FBS") and Detailed Trade Matrix ("DTM"). This study defines the supply-side analysis target as producers and the demand-side analysis target as consumers, and these were applied to all the countries. Furthermore, the products evaluated consisted of 78 food products extracted from the items listed in the FBS table and these products were corresponded to individual food products listed in the DTM table.

2. Development of the Food Trade Balance Matrix

This study used import statistics in the DTM table with trade balance estimates as the foundational data. The trade statistics existed as two types: import and export statistics. The differences between the two were limited to differences in whether the trade transaction data was reported by an importing or an exporting country, both of which publish trade transactional data by year, reporting country, trading partners, and products.

When import and export trade volumes are simultaneously calculated, trade transactions reported by both sides can be double-counted, leading to overestimates of trade. To avoid this, we used import statistics as foundational data to estimate trade balances. Thus, to augment the number of available trade data by a trade partner country, when data was missing from import statistics, the said data was compensated for by using information from export statistics. In other words, using only import statistics was somewhat insufficient because the number of import data replaced by export data accounted for 64% (275,903 samples) of the total trade data analyzed in this study (429,515 samples); thus, concurrently using export statistics was necessary. The RAS method was used to adjust each component of the trade matrices created in this study because of comprising data extracted from import and export statistics.

An FBS table was used as the fundamental data to calculate food supply and demand balances. In the FBS table, domestic product, import, domestic consumption, and export statistical data are reported by year, country, and product. There is no information on a trading partner country breakdown of import and export data in the FBS table. Therefore, the import distribution coefficient was set using the following equation (Eq. 1) based upon DTM table import statistics (Yamaguchi et al., 2018):

$$R_{ijk} = \frac{\sum_{n_l=1}^{N_{l,j}} \left(C_l \cdot IQ_{ijn_kn_l} \right)}{\sum_{n_l=1}^{N_{l,j}} \sum_{n_k=1}^{N_{k,i}} \left(C_l \cdot IQ_{ijn_kn_l} \right)} \qquad \text{(Eq.1)}$$

In this equation, of the several subscripts, i is the targeted country, j is the targeted product item corresponding to food items described in the FBS table, k is the import partner country for the targeted country i, and l is the import items corresponding to food items described in the DTM table. For the Eq. 1, $IQ_{ijn_kn_l}$ is the import volume of import item l composed of product item j in country i from import partner country k, n_k is the number of countries k, n_l is the number of items l, C_l is the raw material conversion factor of import item l, $N_{l,j}$ is the total number of import item l composed of product item j, and $N_{k,i}$ is the total number of import partner countries k.

Here, C_l was used to convert agricultural processed, dairy and dry products, etc. into fresh raw material equivalents. For agricultural processed products, C_l refers to the literature values of a report published by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT, 2004). For dairy products, C_l was made from the percentage of fat content in raw milk and dairy products referring to a handbook published by the United States Department of Agriculture (USDA, 1992). For dry products, C_l was estimated by discard volume and water content of fresh and dry products referring to the Standard Tables of Food Composition in Japan published by the Ministry of Education, Culture, Sports, Science and Technology (MEXT, 2010).

Next, the import volume for each import partner country was estimated by multiplying the import distribution coefficient of the import partner countries defined as Eq. 1 by the FBS table's import volume. A food trade balance matrix was created by placing the exporting countries' names in rows and importing countries' names in columns and the estimated import volume by country formed the matrix components. A food trade matrix was built for each food item. For each food trade balance matrix, to evaluate the trade balance accuracy, total export volume by the exporting country was estimated by summing the matrix column and comparing it to FBS table's export data. As a result, across all the food trade balance matrices, there were countries whose values did not match. In this study, to mitigate these types of inconsistencies in export volume data, the RAS method was applied and we adjusted the components of each food trade balance matrix. To decrease the amount of lacking trade data as much as possible, some lacking data were compensated for by using export statistics to estimate the initial value of the food trade balance matrices before RAS adjustment.

To evaluate the validity of the RAS method, import and export consistencies were defined referring to Kosaka et al. (2012). The more closely these values become 1.0, the higher consistency is.

The maximum and minimum class values of export consistency before adjusting were -4.4 and 4.0, whereas those after adjusting were -2.4 and 2.8. For the export consistencies, the total number of samples is 8,287. For both, the number of classes and class intervals were uniformly set as 23 and 0.4, respectively. These results show an improvement in the export consistency by employing the RAS method. On the other hand, the maximum and minimum class values of import consistency after adjusting were -2.8 and 2.4, while those before adjusting were all 1.0. This result shows the decrease in the import consistencies because of using export statistics with the same number of classes and class intervals in case of export consistencies described as the aforementioned values. However, comparing the change in the import consistencies before and after RAS adjustment, the fluctuation was below approximately 1% of total samples (11,567 samples). This result suggests that the export consistencies were improved drastically by using the RAS method for maintaining high import consistencies.

3. Estimation of Supply and Demand Side Freshwater Requirements

(1) Estimation of Food Supply and Demand Balances

In this study, food supply and demand balances were estimated using the following equation (Eq. 2) by country based on the breakdown of the supply and demand balance in the FBS table. A food supply-demand balance matrix was created using the simulation value of food supply and demand balances obtained using this equation by country.

$$PRD_j + IQ_j + SV_j = DSQ_j + EQ_j \qquad \text{(Eq.2)}$$

In this equation, PRD_j is the production quantity, IQ_j is the import quantity, SD_j is the decrease in stock quantity, DSQ_j is the domestic supply quantity, EQ_j is the export quantity, and SI_j is the increase in stock quantity for item j. IQ_j and EQ_j were estimated using the food trade balance matrix after RAS adjustment as previously described. SD_j and SI_j were defined by whether the changes in the stock quantity of item j expressed as SV_j was positive or negative, defining the former as SD_j and the latter as SI_j, respectively.

In addition, DSQ_j in Eq. 2 consists of six domestic consumption categories: feed, processed materials, food, seed, waste, and other uses according to the FBS table. In this study, feed and processed materials were classified into intermediate demand and food was considered as final demand. Seeds indicate consumption of items used for food reproduction, such as seed and fertile eggs (FAO, 2001). Waste corresponds to the food loss resulting from each stage from production to storage to distribution, but it does not include pre- and post-harvest losses or household edible or inedible waste (FAO, 2001). Other uses correspond to raw material consumption for inedible processing products and food consumption by tourists (FAO, 2001).

(2) Estimation of freshwater requirements

In this study, freshwater requirements were evaluated from both the supply and demand side using the WF concept. The supply-side freshwater requirements composed of PRD_j, IQ_j, and SD_j were calculated by multiplying PRD_j, IQ_j, and SD_j by the WF intensity of the producer countries, respectively. The demand-side freshwater requirements composed of DSQ_j, EQ_j, and SI_j were similarly estimated by multiplying DSQ_j, EQ_j, and SI_j by the WF intensity of consumer countries, respectively. However, only the final demand and waste categories of DSQ_j were evaluated to avoid the likelihood of overestimation of freshwater requirements because of double counting of the WF between the final and intermediate demand.

To estimate all of the aforementioned freshwater requirements, the WF intensities of the producer country and consumer countries were applied to estimate the supply-side freshwater requirements, defined as direct water consumption required by producers, and the demand-side freshwater requirements, defined as direct water consumption by consumers of foodstuffs. The WF intensity was published in Mekonnen and Hoekstra (2011a) by country and item and categorized into green, blue, and gray water. According to Mekonnen and Hoekstra (2010), the contribution to water consumption of feed crops, drinking water for livestock, and water consumption for the maintenance of a rearing environment for livestock are all included in the WF intensity of livestock products and are reflected in estimating the freshwater requirements of livestock products in this study. Here, because gray water was considered as non-existent water consumption according to its definition in Hoekstra et al. (2011a), green and blue water were considered to focus on the direct water consumption of crops or livestock as described in the following.

As the system boundary of the WF estimation, for each agricultural crop, only the direct water consumption during the cultivation stage was included. For livestock products, the direct water consumption during the cultivation stage required for crops used as feed and the direct water consumption during the rearing stage of livestock, such as drinking water for livestock and service water used to maintain a rearing environment, were set as the evaluation range. Other than the aforementioned, no other stage was included in WF estimation.

As previously mentioned, only final demand and waste in DSQ_j were targeted for evaluation. The latter constituted loss of foodstuffs during storage and transportation, which can be seen as the availability loss of food consumption resulting from insufficient management. Thus, the freshwater requirement derived from waste was included. However, the water requirement of seeds was excluded from the evaluation target because we assumed that seeds would be largely consumed after one or two years from the harvest year equal to the reference year. From this perspective, seed cultivation was considered as a type of upstream indirect water consumption for each crop cultivation stage and as not contributing to the demand-side freshwater requirement. Other uses were also excluded from the freshwater requirement evaluation because of the inconsistency of the system boundary in this study.

In the case of blue water, the estimated blue WF value was divided by irrigation efficiency to convert water consumption into water withdrawal because the former did not include irrigation water losses determined by irrigation water use efficiency depending on the irrigation technology and management system. The irrigation efficiency was obtained from Döll and Siebert (2002) by country or area classification categorizing rice and non-rice. In this study, rice was applied to rice products only, while non-rice was uniformly applied to all target items except for rice.

4. Comparison of Freshwater Requirements

(1) Comparing Supply and Demand Side Freshwater Requirements

Figs. 1 and 2 show the breakdown of supply and demand side freshwater requirements in five Asian areas. In Western Asia, the freshwater requirement for domestic production (279 km^3) is less than that for final demand (350 km^3). In contrast, in South-Eastern Asia, domestic production (1,670 km^3) is nearly twice as high as final demand (895 km^3). In Central Asia, the freshwater requirement derived from domestic production is 233 km^3 and the final demand is 138 km^3. Thus, Western Asia should have a relatively high import dependence while Central Asia, Southern Asia, and South-Eastern Asia tend on aggregate to be producing countries. For example, South-Eastern Asia is the largest exporter area, whose total exported freshwater requirement volume corresponds to 421 km^3, accounting for 52% of the total exported freshwater requirement volume in the five Asian areas (812 km^3).

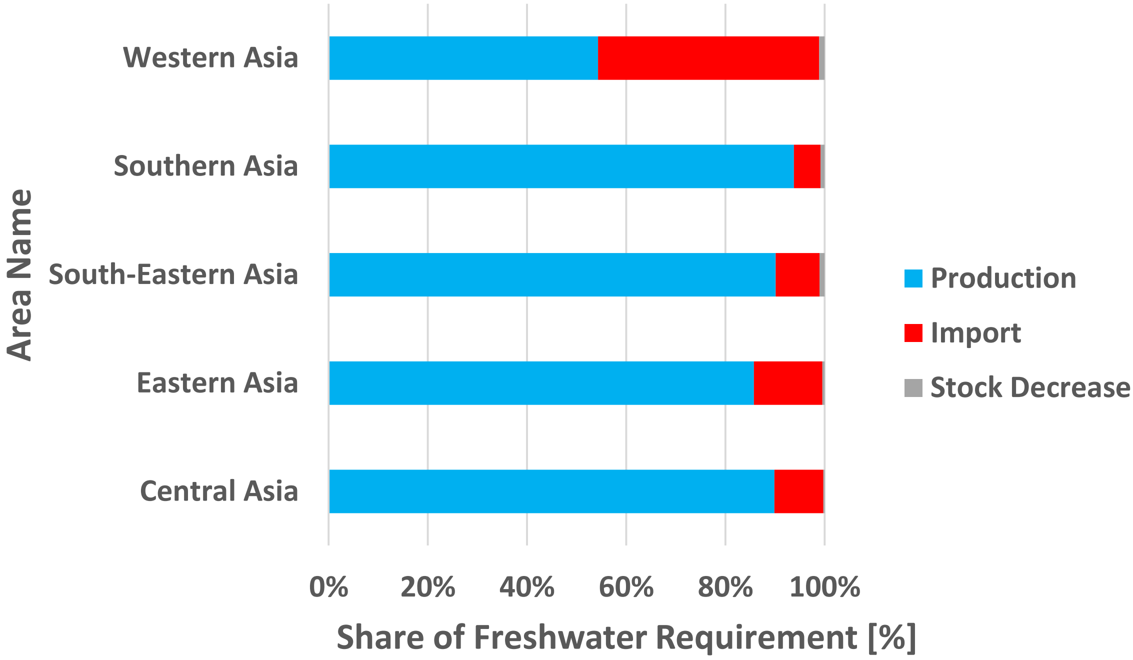

Fig. 1 Breakdown of supply-side freshwater requirements of the five Asian areas.

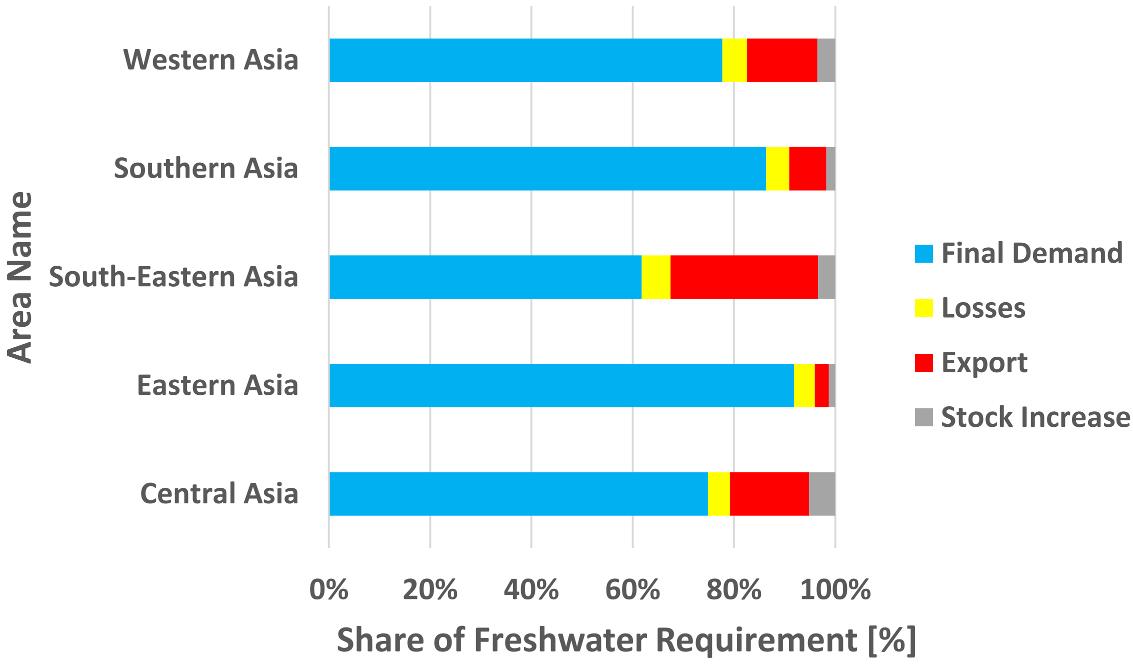

Fig. 2 Breakdown of demand-side freshwater requirements of the five Asian areas.

In Eastern Asia, the freshwater requirement for domestic production and that for final demand are 2,455 km^3 and 1,972 km^3, respectively. Eastern Asia is the highest importer area, whose total imported of freshwater requirement volume is 397 km^3, accounting for 39% of the global total imported of freshwater requirement volume (1,015 km^3). Likewise, in Southern Asia, the freshwater requirement for domestic production and that for final demand are 3,479 km^3 and 2,824 km^3, respectively, while the total exported freshwater requirement volume is 240 km^3. Thus, Eastern Asia and Southern Asia should be major producing and consuming areas because the freshwater requirements of the two are much higher than other areas.

(2) Comparing Imported and Exported Freshwater Requirements

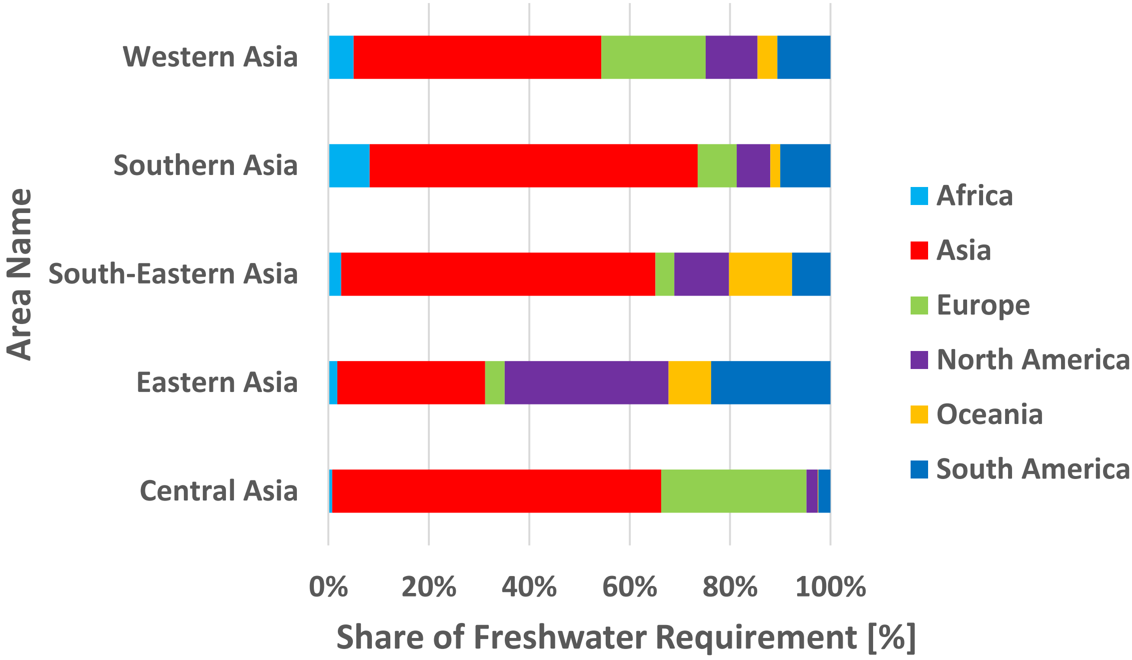

Fig. 3 Importing regions' share of imported freshwater requirements of the five Asian areas.

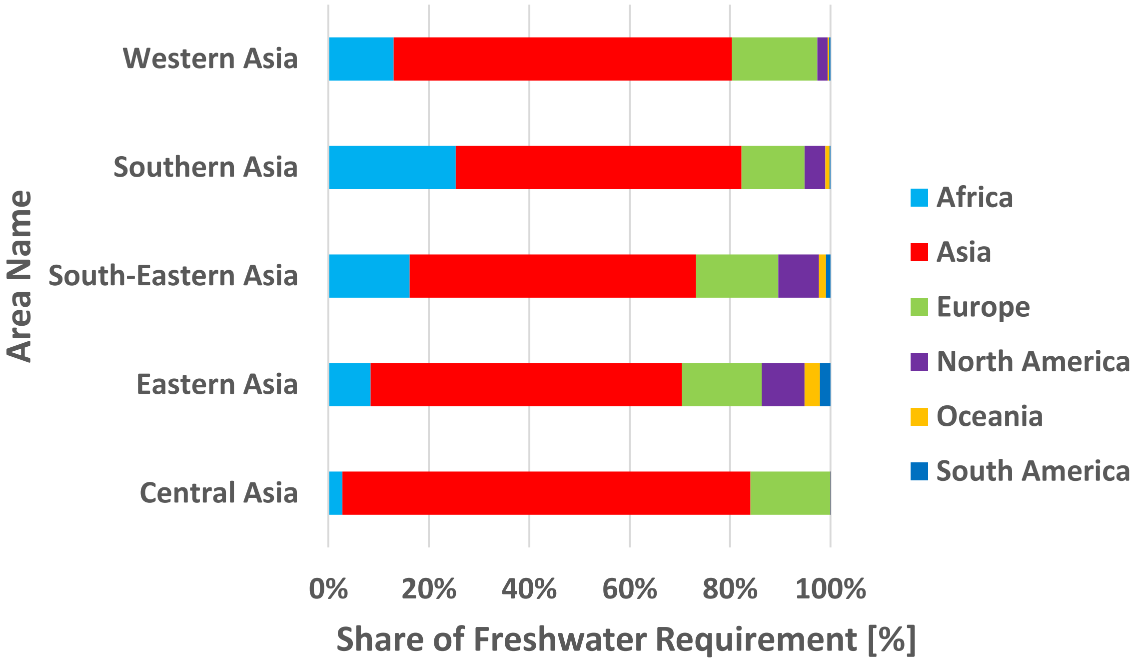

Fig. 4 Exporting regions' share of exported freshwater requirements for the five Asian areas.

Fig. 3 shows the importing region's share of the imported freshwater requirement by the five Asian areas. According to Fig. 3, in the case of Asian areas (except for Eastern Asia), the imported freshwater requirement volumes from Asia are predominant, estimated as 17 km^3 (66% of import share) in Central Asia, 103 km^3 (63%) in South-Eastern Asia, 130 km^3 (65%) in Southern Asia, and 113 km^3 (49%) in Western Asia, respectively. However, Eastern Asia imports freshwater from various areas, such as Asia, North America, and South America. In fact, Eastern Asia imports 117 km^3 (29%) to Asia, 129 km^3 (33%) to North America, and 94 km^3 (24%) to South America, respectively, as imported freshwater requirement volumes. In summary, from the perspective of food importation, Eastern Asia actively utilizes both inter-regional and intra-regional trade, while in other Asian areas intra-regional trade appears to be more dominant than inter-regional trade.

Fig. 4 shows the exporting region's share of exported freshwater requirements for the five Asian areas. Reviewing Fig. 4, the exported freshwater requirement volumes to Asia are dominant in all Asian areas. In fact, the volumes are estimated as 23 km^3 (81% of export share) to Central Asia, 37 km^3 (57%) to Eastern Asia, 240 km^3 (57%) to South-Eastern Asia, 137 km^3 (57%) to Southern Asia, and 42 km^3 (67%) to Western Asia, respectively. From the perspective of food exportation, this tendency shows that intra-regional trade seems to be more prominent than inter-regional trade in all the Asian areas.

Fig. 5 shows the imported item's share of imported freshwater requirements for the five Asian areas. Reviewing Fig. 5, for example, the freshwater requirement of imported oils in Eastern Asia is dominant, estimated as 190 km^3 (48% of import share), followed by 69 km^3 (17%) of cereals and 59 km^3 (15%) of meats and eggs ("meats" hereafter). Eastern Asia is the highest importer, whose total imported freshwater requirement volume is 397 km^3. In contrast, South-Eastern Asia is the largest exporter area, whose total exported freshwater requirement volume is 421 km^3. South-Eastern Asia predominantly exports 180 km^3 (43%) of its oil crops and oils ("oils" hereafter), followed by 105 km^3 (25%) of rice, and 53 km^3 (13%) of beverages. Southern Asia exports 137 km^3 (57%) of its rice. In Central Asia, the freshwater requirement of imported cereals is the largest, estimated as 12 km^3 (48%). In Western Asia, the freshwater requirement of imported rice is nearly the same as that of imported cereals, equivalent to 14 km^3 (22%) and 11 km^3 (18%), respectively.

Fig. 6 shows the exported item's share of exported freshwater requirements for the five Asian areas. As shown in Fig. 6, for example, Central Asia has an extreme preference for cereals at 23 km^3 (79% of export share) for exported freshwater requirement volume. In Southern Asia, the freshwater requirement of exported rice is the largest component of the freshwater requirement estimated at 137 km^3 (57%). In South-Eastern Asia, freshwater requirement of exported oils is 180 km^3 (43%), followed by that of exported rice at 105 km^3 (25%). In Western Asia, the freshwater requirement of exported cereals is estimated as 11 km^3 (18%), similar to that of exported rice at 14 km^3 (22%); both are higher than that of other items. However, Eastern Asia exports various types of items. In Eastern Asia, a major consumer region, the exported freshwater requirement volume of meats is similar to that of sugars and sweeteners ("sugars" hereafter) at 13 km^3 (22%). Both are higher than those of cereal, oils, and rice.

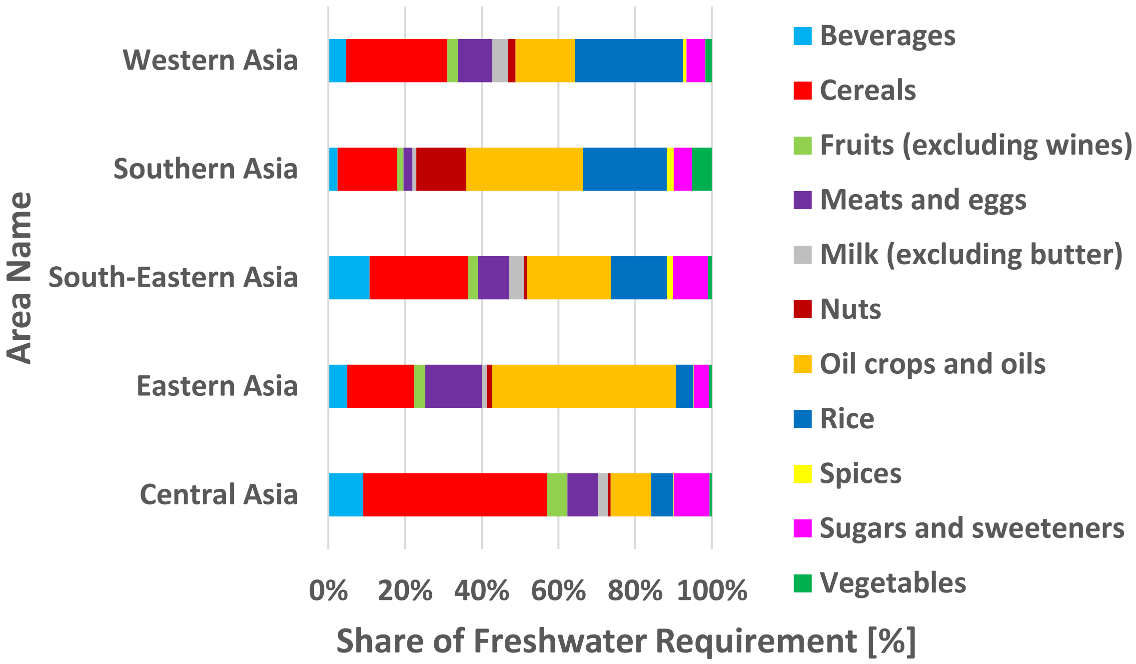

Fig. 5 Imported items' share of imported freshwater requirements of the five Asian areas.

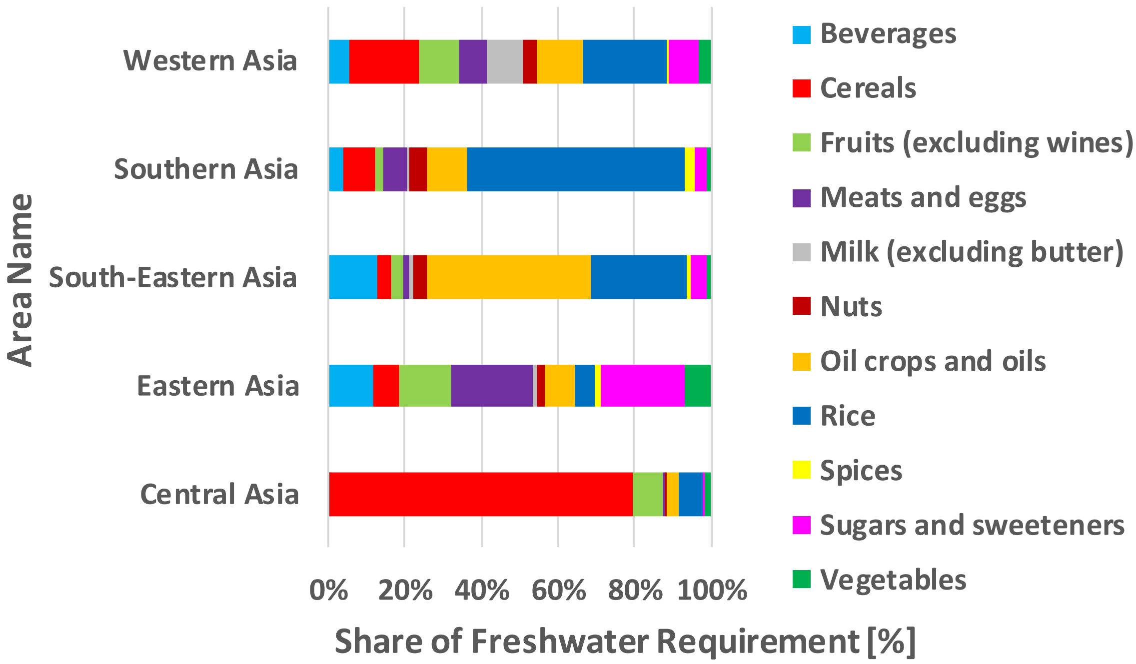

Fig. 6 Exported items' share of exported freshwater requirements of the five Asian areas.

5. Comparison of Country Estimates

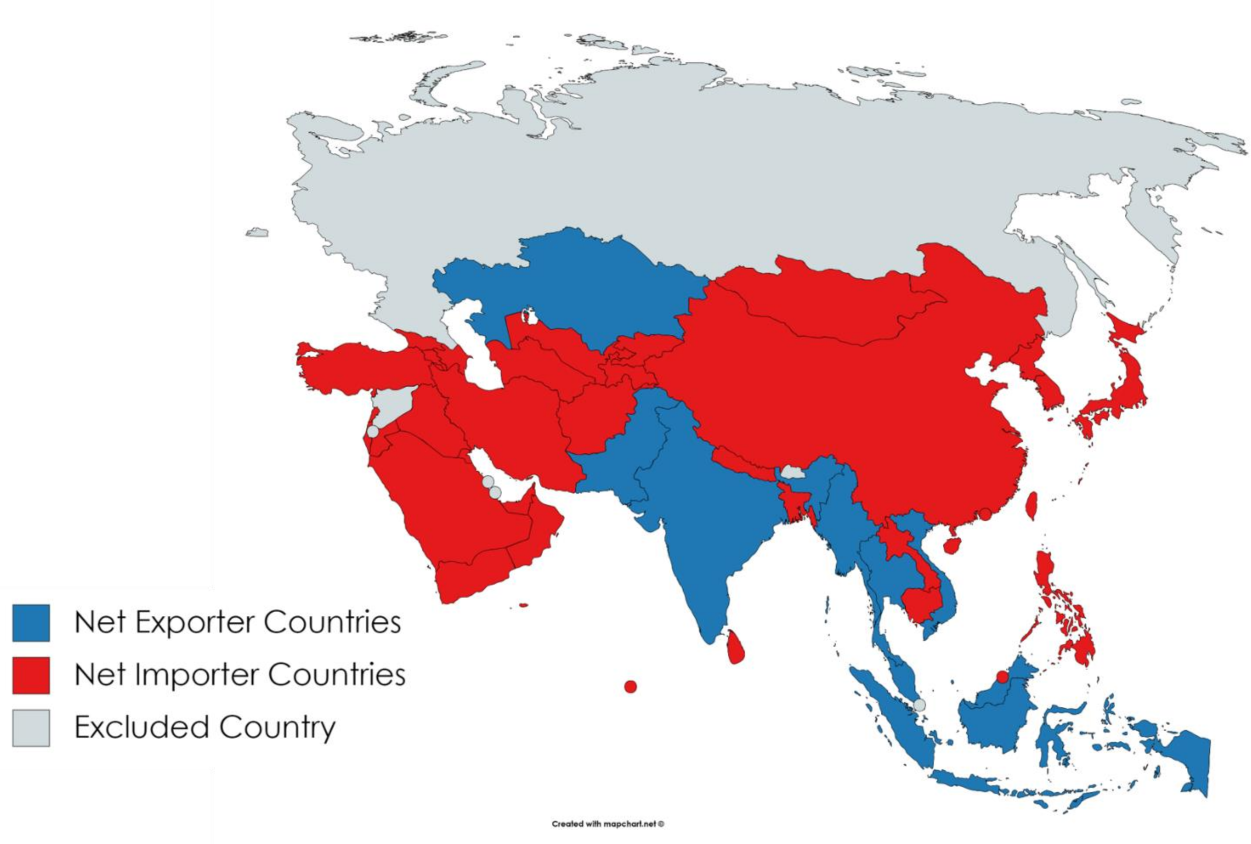

Fig. 7 Distribution map of net importer or exporter countries.

Fig. 7 shows the distribution map of net importer and exporter countries. Net imported volume or net exported volume is distinguished according to whether the difference in imported freshwater requirement volume and exported freshwater requirement volume is negative or positive: the former is defined as net import volume while the latter is defined as net export volume. In addition, supply and demand side freshwater requirements simulated in our study are shown as per capita value (Table 1) or as categorized food item's share (Table 2 and 3). Regarding Table 1, we added the population data for 2010 to help confirm the size of freshwater requirement defined as the sum of green water consumption and blue water withdrawal (hereinafter, this sum is called "freshwater requirement").

Reviewing Fig. 7, nearly all the Central and Western Asian countries are net importer countries. For example, Saudi Arabia is the largest importer in Western Asia, whose imported freshwater requirement volume is 53 km^3 accounting for 23% of the total imported freshwater requirement volumes in Western Asia (229 km^3). Comparing freshwater requirement per capita, Saudi Arabia requires 2,179 m^3/capita for final demand, which is supplied by 987 m^3/capita domestic production and 1,918 m^3/capita imported water. In this country, from the perspective of freshwater requirement, rice (17 km^3) and cereals (15 km^3) are the prominent imported items. For wheat, one type of cereal, this country imports 1.9 million tons (2.8 km^3 as freshwater requirement), which is greater than the 1.2 million tons (2.5 km^3) for domestic production, to meet the 2.6 million tons needed for domestic consumption including 2.4 million tons (4.9 km^3) for final demand and 166 thousand tons (0.34 km^3) for export.

Table 1 Freshwater requirements per capita in each Asian country.

		Population	Supply-Side WR [m³/capita]				Demand-Side WR [m³/capita]				
Area Name	Country Name	[thousand]	WR_PRD	WR_IQ	WR_SD	Total	WR_FD	WR_LS	WR_EQ	WR_SI	Total
Central Asia	Kazakhstan	16	7,154	443	10	7,607	3,029	351	1,574	572	5,526
Central Asia	Kyrgyzstan	5,422	1,858	628	23	2,509	1,489	38	102	4	1,633
Central Asia	Tajikistan	7,642	3,410	617	17	4,044	2,824	58	118	9	3,009
Central Asia	Turkmenistan	5,087	4,827	388	46	5,261	3,216	175	1	0	3,393
Central Asia	Uzbekistan	28,606	1,927	290	2	2,220	1,493	26	54	3	1,577
Eastern Asia	China, Hong Kong SAR	7,025	221	4,221	19	4,462	1,944	21	1,147	128	3,239
Eastern Asia	China, Macao SAR	537	120	1,706	5	1,831	1,593	2	14	20	1,629
Eastern Asia	China, mainland	1,359,755	1,661	146	3	1,810	1,237	60	31	18	1,345
Eastern Asia	China, Taiwan Province of	23,102	912	985	49	1,947	1,280	20	75	14	1,390
Eastern Asia	Democratic People's Republic of Korea	24,592	1,038	82	151	1,271	1,060	58	1	0	1,119
Eastern Asia	Japan	128,552	731	754	13	1,497	1,120	22	13	12	1,167
Eastern Asia	Mongolia	2,713	3,374	424	101	3,899	3,121	20	318	14	3,474
Eastern Asia	Republic of Korea	49,553	912	918	30	1,860	1,362	37	92	5	1,496
South-Eastern Asia	Brunei Darussalam	389	266	2,285	469	3,020	2,733	64	79	9	2,886
South-Eastern Asia	Cambodia	14,309	3,323	128	11	3,462	1,566	434	66	51	2,118
South-Eastern Asia	Indonesia	242,524	2,400	166	30	2,596	1,350	127	551	65	2,093
South-Eastern Asia	Lao People's Democratic Republic	6,246	2,643	144	0	2,788	1,536	123	110	16	1,785
South-Eastern Asia	Malaysia	28,112	4,088	1,771	195	6,054	2,001	87	3,345	255	5,688
South-Eastern Asia	Myanmar	50,156	4,017	75	2	4,094	1,616	109	178	96	1,999
South-Eastern Asia	Philippines	93,727	2,180	330	12	2,522	1,576	68	208	36	1,889
South-Eastern Asia	Thailand	67,209	4,620	230	57	4,907	1,943	270	1,744	214	4,171
South-Eastern Asia	Timor-Leste	1,110	2,321	308	307	2,935	2,092	78	709	47	2,926
South-Eastern Asia	Viet Nam	88,473	2,148	225	8	2,380	1,313	138	510	36	1,997
Southern Asia	Afghanistan	28,803	1,363	381	1	1,745	1,383	119	27	49	1,579
Southern Asia	Bangladesh	152,149	1,377	202	1	1,580	1,191	73	6	155	1,425
Southern Asia	India	1,230,981	1,914	53	16	1,983	1,555	80	82	18	1,735
Southern Asia	Iran (Islamic Republic of)	74,568	3,299	746	34	4,080	3,222	146	152	18	3,539
Southern Asia	Maldives	365	77	2,553	30	2,660	1,877	9	0	137	2,024
Southern Asia	Nepal	27,023	2,031	295	35	2,360	1,702	164	32	16	1,915
Southern Asia	Pakistan	170,560	3,065	110	43	3,219	2,091	100	704	24	2,920
Southern Asia	Sri Lanka	20,198	2,472	441	7	2,921	2,234	117	254	150	2,756
Western Asia	Armenia	2,877	1,616	907	21	2,544	1,926	67	40	40	2,073
Western Asia	Azerbaijan	9,032	1,521	693	15	2,228	1,426	24	157	13	1,619
Western Asia	Cyprus	1,113	1,441	1,310	21	2,772	1,897	81	250	171	2,399
Western Asia	Georgia	4,232	1,202	816	101	2,119	1,870	28	111	18	2,027
Western Asia	Iraq	30,763	562	1,076	5	1,644	1,383	67	18	11	1,479
Western Asia	Israel	7,426	1,496	1,417	107	3,020	2,330	46	236	53	2,664
Western Asia	Jordan	7,182	654	1,349	50	2,053	1,566	55	242	23	1,886
Western Asia	Kuwait	2,998	355	2,723	95	3,172	2,863	104	191	39	3,197
Western Asia	Lebanon	4,337	1,400	1,610	18	3,027	2,292	52	229	61	2,633
Western Asia	Oman	3,041	988	3,485	149	4,622	2,803	97	814	60	3,774
Western Asia	Saudi Arabia	27,426	987	1,918	15	2,920	2,179	41	279	135	2,635
Western Asia	Turkey	72,327	2,228	426	15	2,669	1,505	137	308	111	2,061
Western Asia	United Arab Emirates	8,271	1,067	4,364	170	5,602	3,223	717	2,614	125	6,679
Western Asia	Yemen	23,607	591	718	7	1,316	1,180	25	42	44	1,291

Note: Unit of population is in "thousands," Data is derived from the FAOSTAT database in 2010. "WR" is short for "freshwater requirement" defined as the sum of green water consumption and blue water withdrawal, distinguished by supply and demand side. Blue water withdrawal is calculated by dividing blue water consumption by irrigation efficiency. WR_PRD, WR_IQ, WR_SD, WR_FD, WR_LS, WR_EQ, and WR_SI are freshwater requirements for all targeted food items per capita derived from domestic production, import, stock decrease, final demand, losses, export, and stock increase, respectively. Unit of respective WR is "m^3/capita."

The situation in Central Asia differs from that of Western Asia. Comparing freshwater requirement per capita, the countries of Western Asia except for Kazakhstan are net importers, showing an imported freshwater requirement volume higher than the exported freshwater requirement volume. For example, in Uzbekistan, the second largest consumer in Central Asia, the freshwater requirement for domestic production (1,927 m^3/capita) is higher than that for final demand (1,493 m^3/capita), though the imported freshwater requirement volume (290 m^3/capita) is much higher than the exported freshwater requirement volume (54 m^3/capita). In this country, the imported freshwater requirement of cereals (5.8 km^3) is the greatest. For wheat, Uzbekistan imports 1.7 million tons (5.6 km^3), greater than the 112 thousand tons (0.19 km^3) for export. In this country, the 6.7 million tons (11 km^3) for domestic production of wheat is greater than the 4.7 million tons (7.8 km^3) for final demand.

Table 2 Item's share of supply-side freshwater requirements in each Asian country.

Unit: %

Area Name	Country Name	Item_01	Item_02	Item_03	Item_04	Item_05	Item_06	Item_07	Item_08	Item_09	Item_10	Item_11	Total
Central Asia	Kazakhstan	1.1	39.8	4.7	21.3	13.3	0.2	6.3	8.9	0.0	1.0	3.3	100
Central Asia	Kyrgyzstan	1.1	54.7	1.6	17.2	7.1	0.1	6.6	9.3	0.0	0.7	1.5	100
Central Asia	Tajikistan	2.4	36.7	4.7	28.0	11.8	0.8	4.6	6.3	0.1	1.8	3.0	100
Central Asia	Turkmenistan	0.9	22.3	6.7	23.0	34.2	0.3	2.4	4.6	0.0	1.4	4.1	100
Central Asia	Uzbekistan	1.2	17.7	3.6	30.6	22.1	0.1	6.4	14.1	0.0	1.1	3.0	100
Eastern Asia	China, Hong Kong SAR	0.9	28.9	10.3	23.2	12.0	0.4	7.8	8.5	0.1	1.3	6.6	100
Eastern Asia	China, Macao SAR	1.8	19.5	5.0	24.6	2.5	0.5	14.1	24.6	0.1	2.3	5.0	100
Eastern Asia	China, mainland	2.8	4.0	9.9	57.4	2.3	8.7	3.2	8.1	0.1	2.6	0.8	100
Eastern Asia	China, Taiwan Province of	6.4	7.0	3.7	40.0	5.6	0.8	5.0	16.9	0.2	12.9	1.7	100
Eastern Asia	Democratic People's Republic of Korea	1.3	20.1	5.3	24.1	2.3	0.4	14.2	25.5	0.1	1.4	5.5	100
Eastern Asia	Japan	4.1	18.3	6.3	25.0	2.0	1.3	22.0	13.8	0.4	4.9	2.0	100
Eastern Asia	Mongolia	0.5	19.1	4.4	9.4	0.6	0.4	5.3	52.0	0.0	0.7	7.6	100
Eastern Asia	Republic of Korea	6.8	16.0	2.1	24.3	4.8	0.7	14.9	19.2	0.3	9.4	1.5	100
South-Eastern Asia	Brunei Darussalam	2.2	13.0	0.6	75.5	4.4	0.2	1.4	0.9	0.0	0.9	0.9	100
South-Eastern Asia	Cambodia	3.4	18.0	2.4	27.4	3.2	1.0	12.6	16.9	0.2	12.5	2.5	100
South-Eastern Asia	Indonesia	4.2	7.5	4.3	8.6	0.9	1.6	23.3	43.1	1.2	3.2	2.2	100
South-Eastern Asia	Lao People's Democratic Republic	4.0	4.1	4.3	14.0	14.8	2.2	6.8	34.9	0.6	12.1	2.1	100
South-Eastern Asia	Malaysia	0.3	10.1	1.7	5.5	0.2	0.1	3.0	75.6	0.3	2.3	1.0	100
South-Eastern Asia	Myanmar	6.2	8.4	3.0	5.6	0.9	3.1	28.6	38.1	2.0	2.9	1.3	100
South-Eastern Asia	Philippines	5.0	13.0	4.0	10.5	0.3	0.0	2.4	58.5	0.9	1.3	4.1	100
South-Eastern Asia	Thailand	7.8	5.7	1.2	7.5	0.9	0.5	57.1	15.7	0.7	2.3	0.6	100
South-Eastern Asia	Timor-Leste	0.9	2.4	2.4	12.0	1.5	0.6	22.5	45.6	1.2	1.4	9.4	100
South-Eastern Asia	Viet Nam	1.9	9.5	7.2	11.8	0.6	0.5	31.7	32.7	0.0	2.7	1.5	100
Southern Asia	Afghanistan	2.1	6.6	8.5	6.7	0.7	0.4	5.9	60.8	0.7	6.6	0.9	100
Southern Asia	Bangladesh	28.3	11.6	0.5	34.1	0.7	0.0	1.1	19.2	0.1	1.9	2.5	100
Southern Asia	India	4.9	9.2	3.5	14.5	0.8	2.8	5.2	52.9	1.2	2.2	2.6	100
Southern Asia	Iran (Islamic Republic of)	0.7	20.5	4.4	7.3	6.3	2.1	10.8	38.5	1.0	3.8	4.7	100
Southern Asia	Maldives	0.6	48.2	4.0	12.7	8.7	1.8	4.5	15.9	0.1	1.4	2.1	100
Southern Asia	Nepal	0.3	6.0	2.6	3.2	2.2	1.2	4.1	75.9	1.1	1.5	1.9	100
Southern Asia	Pakistan	0.7	20.0	4.4	5.6	6.3	1.5	13.8	37.0	1.1	4.2	5.4	100
Southern Asia	Sri Lanka	1.6	25.7	10.1	13.7	4.7	9.8	3.9	20.9	0.2	2.0	7.4	100
Western Asia	Armenia	6.1	8.0	4.3	11.0	7.2	4.4	15.2	34.8	1.0	6.6	1.4	100
Western Asia	Azerbaijan	0.5	30.1	2.3	13.5	4.7	6.6	6.9	29.6	1.3	0.9	3.5	100
Western Asia	Cyprus	0.2	24.6	2.5	12.0	9.8	0.2	4.8	39.4	0.5	4.4	1.7	100
Western Asia	Georgia	6.2	4.7	2.2	3.7	1.7	1.1	13.3	59.3	2.7	2.6	2.4	100
Western Asia	Iraq	2.6	29.5	6.7	17.8	7.7	1.9	12.0	14.6	0.5	3.4	3.4	100
Western Asia	Israel	6.4	28.3	9.9	31.6	9.3	0.8	4.1	2.3	0.0	2.7	4.5	100
Western Asia	Jordan	2.8	44.9	6.2	22.4	9.2	1.7	3.6	2.0	0.1	2.3	4.7	100
Western Asia	Kuwait	6.1	23.7	6.7	31.9	11.7	1.8	8.8	2.5	0.1	4.7	2.0	100
Western Asia	Lebanon	7.3	31.2	7.4	23.3	17.2	2.1	5.8	1.2	0.3	2.6	1.6	100
Western Asia	Oman	1.2	30.4	6.5	10.8	3.9	0.1	11.8	29.0	0.0	2.5	3.7	100
Western Asia	Saudi Arabia	4.2	19.7	5.7	36.1	6.3	1.4	12.9	4.4	0.2	6.6	2.5	100
Western Asia	Turkey	3.5	24.2	4.1	23.1	10.1	0.6	12.3	14.3	0.5	4.1	3.1	100
Western Asia	United Arab Emirates	3.2	14.4	5.0	22.1	8.1	1.6	6.2	33.3	0.7	3.4	2.0	100
Western Asia	Yemen	5.2	17.1	6.9	29.6	9.2	4.0	15.1	4.5	0.2	6.0	2.2	100

Note: Item_01, Item_02, Item_03, Item_04, Item_05, Item_06, Item_07, Item_08, Item_09, Item_10, and Item_11 are categorized into freshwater requirement of beverages, cereals, fruits (excluding wines), meats and eggs, milk (excluding butter), nuts, oil crops and oils, rice, spices, sugars and sweeteners, and vegetables, respectively. Freshwater requirement is calculated by the sum of supply-side green water consumption and blue water withdrawal. Unit of respective estimated values is "%."

However, nearly all the South-Eastern and Southern Asian countries are categorized into net exporter countries. For example, Malaysia exports 94 km^3 of freshwater requirement accounting for 22% of the total freshwater requirement in South-Eastern Asia (421 km^3) which is less than that in Indonesia (134 km^3) and Thailand (117 km^3), showing that Malaysia is the third largest exporter in South-Eastern Asia. However, comparing freshwater requirement per capita, Malaysia exports the largest freshwater requirement in South-Eastern Asia (3,345 m^3/capita) while Indonesia and Thailand export 551 m^3/capita and 1,744 m^3/capita, respectively. In Malaysia, freshwater requirement for export is more than that for final demand (2,001 m^3/capita). Both are supplied by domestic production (4,088 m^3/capita) and imported water (1,771 m^3/capita). For this country, palm oil is the predominant exported item because the exported freshwater requirement volume is 63 km^3 accounting for 84% of its exported freshwater requirement of oils (75 km^3). The main export partners of Asian regions for palm oil are in Eastern Asia, such as Mainland China, Japan, and the Republic of Korea.

Table 3 **Item's share of demand-side freshwater requirements in each Asian country.**

Unit: %

Area Name	Country Name	Item_01	Item_02	Item_03	Item_04	Item_05	Item_06	Item_07	Item_08	Item_09	Item_10	Item_11	Total
Central Asia	Kazakhstan	1.5	31.8	6.6	29.2	11.5	0.3	3.2	10.7	0.0	1.2	3.8	100
Central Asia	Kyrgyzstan	1.4	46.2	3.0	23.4	7.7	0.2	4.9	10.5	0.0	1.2	1.6	100
Central Asia	Tajikistan	3.6	25.3	7.6	32.5	15.2	1.2	1.6	5.5	0.1	2.9	4.6	100
Central Asia	Turkmenistan	1.2	15.9	7.8	34.1	28.0	0.4	1.8	5.8	0.0	1.2	3.7	100
Central Asia	Uzbekistan	1.7	10.9	4.7	44.7	11.7	0.1	1.7	19.6	0.0	0.7	4.2	100
Eastern Asia	China, Hong Kong SAR	1.3	20.4	13.8	31.7	10.1	0.5	1.6	11.3	0.1	1.1	8.1	100
Eastern Asia	China, Macao SAR	2.4	13.2	6.2	32.0	3.3	0.6	5.2	28.2	0.1	2.6	6.1	100
Eastern Asia	China, mainland	2.9	5.3	7.5	62.3	3.8	3.8	3.3	7.2	0.1	3.0	1.0	100
Eastern Asia	China, Taiwan Province of	5.8	7.6	3.6	42.6	6.3	0.6	5.2	12.4	0.2	14.1	1.7	100
Eastern Asia	Democratic People's Republic of Korea	1.7	13.9	6.7	31.7	3.2	0.5	4.6	29.5	0.1	1.3	6.7	100
Eastern Asia	Japan	4.4	9.6	8.7	33.1	3.8	1.6	13.0	16.7	0.3	6.4	2.5	100
Eastern Asia	Mongolia	0.5	16.1	5.0	10.7	0.8	0.4	3.2	54.2	0.0	0.9	8.3	100
Eastern Asia	Republic of Korea	8.8	9.5	2.2	29.8	6.4	1.1	8.6	20.1	0.4	11.4	1.7	100
South-Eastern Asia	Brunei Darussalam	2.8	8.6	0.6	78.9	4.6	0.2	1.2	0.8	0.0	1.0	1.3	100
South-Eastern Asia	Cambodia	4.5	8.7	2.4	34.0	2.0	1.0	10.0	18.1	0.1	16.1	3.0	100
South-Eastern Asia	Indonesia	5.4	5.4	5.4	11.0	2.4	2.0	18.0	43.1	1.3	3.6	2.3	100
South-Eastern Asia	Lao People's Democratic Republic	6.0	5.2	4.0	10.7	25.4	1.3	3.8	29.5	0.4	10.4	3.3	100
South-Eastern Asia	Malaysia	0.5	5.4	2.8	9.0	0.4	0.1	3.3	71.2	0.4	5.2	1.7	100
South-Eastern Asia	Myanmar	7.7	6.8	3.6	6.9	1.6	3.9	24.9	38.2	1.7	3.1	1.6	100
South-Eastern Asia	Philippines	8.1	7.5	5.6	16.3	0.6	0.0	2.7	49.5	1.4	1.9	6.4	100
South-Eastern Asia	Thailand	8.7	2.6	1.1	7.8	4.5	0.3	53.1	17.8	0.7	2.8	0.7	100
South-Eastern Asia	Timor-Leste	2.3	2.9	5.0	24.3	3.1	1.2	10.4	38.0	2.4	0.5	9.8	100
South-Eastern Asia	Viet Nam	2.3	5.9	9.0	16.1	5.2	0.6	13.0	42.8	0.0	3.0	2.0	100
Southern Asia	Afghanistan	2.4	5.0	10.2	7.7	1.2	0.5	2.9	60.4	0.8	7.7	1.1	100
Southern Asia	Bangladesh	30.2	10.9	0.5	34.6	0.5	0.0	1.0	17.3	0.0	2.2	2.8	100
Southern Asia	India	5.8	5.3	4.0	18.0	1.9	3.2	3.4	51.6	2.0	1.5	3.3	100
Southern Asia	Iran (Islamic Republic of)	0.8	20.6	5.0	8.2	6.2	2.0	5.6	40.8	1.1	4.5	5.2	100
Southern Asia	Maldives	0.9	47.5	4.1	14.5	9.2	2.0	1.8	15.2	0.2	2.2	2.3	100
Southern Asia	Nepal	0.3	4.9	3.1	3.5	2.2	1.6	2.3	76.9	1.1	1.5	2.6	100
Southern Asia	Pakistan	0.7	20.8	5.0	6.3	6.0	1.4	7.2	40.4	1.3	5.0	5.9	100
Southern Asia	Sri Lanka	2.2	22.3	11.8	16.4	3.8	11.3	2.3	18.0	0.3	3.2	8.4	100
Western Asia	Armenia	6.8	7.3	3.0	15.0	26.7	2.0	3.3	28.9	1.5	3.7	1.9	100
Western Asia	Azerbaijan	0.7	31.7	2.9	16.7	5.0	0.8	4.9	30.5	1.2	1.2	4.3	100
Western Asia	Cyprus	0.2	23.6	2.7	13.3	10.3	0.1	2.0	40.4	0.6	5.0	2.0	100
Western Asia	Georgia	6.4	5.3	2.6	3.8	3.0	0.8	9.9	58.7	3.2	3.0	3.2	100
Western Asia	Iraq	2.9	22.2	6.5	22.3	9.7	1.6	7.2	19.7	0.6	3.7	3.6	100
Western Asia	Israel	6.4	15.0	9.2	40.9	10.0	1.1	3.1	4.8	0.1	4.1	5.2	100
Western Asia	Jordan	4.2	30.4	7.6	29.1	9.6	2.5	2.6	2.9	0.2	4.8	6.1	100
Western Asia	Kuwait	8.1	13.0	7.2	33.3	11.8	8.8	6.8	2.4	0.2	5.7	2.7	100
Western Asia	Lebanon	7.7	28.3	4.5	27.9	17.5	2.2	5.6	1.5	0.3	3.4	1.3	100
Western Asia	Oman	1.3	22.5	6.0	14.4	4.6	0.2	5.9	39.0	0.1	2.5	3.6	100
Western Asia	Saudi Arabia	5.0	11.3	6.5	44.3	7.0	2.3	8.0	6.6	0.2	5.9	2.7	100
Western Asia	Turkey	3.9	16.6	5.2	29.1	10.7	0.4	9.4	15.9	0.7	5.0	3.2	100
Western Asia	United Arab Emirates	3.0	8.3	4.7	20.0	18.4	1.3	4.2	33.7	0.7	3.4	2.3	100
Western Asia	Yemen	5.6	12.9	7.3	38.4	9.5	1.3	10.1	5.8	0.4	6.7	2.1	100

Note: Same as Table 2, but calculating demand-side freshwater requirement.

In fact, each exporting country's share of the total export volume of palm oil to Eastern Asia (5.0 million tons) is 76% (3.8 million tons) in Mainland China, 12% (616 thousand tons) in Japan, and 7.4% (374 thousand tons) in the Republic of Korea, respectively. This volume accounts for 30% of global export volume of palm oil from Malaysia (17 million tons), followed by Southern Asia (3.6 million tons), and Western Asia (1.3 million tons). As freshwater requirement, respective export volumes are equivalent to 19 km^3 in Eastern Asia, 13 km^3 in Southern Asia, and 5.0 km^3 in Western Asia. This fact shows that Malaysia actively produces palm oils exported to other countries, mainly in Eastern Asia. As another example, India is the largest consumer in Southern Asia because the freshwater requirement for domestic production (2,356 km^3) and that for final demand (1,914 km^3) account for 68% of the supply-side total freshwater requirement (3,479 km^3) and 68% of the demand-side total freshwater requirement in Southern Asia (2,824 km^3), respectively. Comparing freshwater requirement per capita, India is a net exporter consuming 53 m^3/capita for import and 82 m^3/capita for export. The largest exported freshwater requirement volume is rice (27 km^3), followed by oils (24 km^3), meats (13 km^3), and cereals (10 km^3). For rice, India exports 2.9 million tons (27 km^3) and consumes 94 million tons for domestic consumption including 86 million tons for final demand (801 km^3), supplied by 97 million tons (904 km^3) for domestic production and 21 thousand tons (0.27 km^3) for import.

As an exception in South-Eastern Asia, the Philippines is a net importer country because 330 m^3/capita is imported while 208 m^3/capita is exported. In the Philippines, the final demand of wheat is 2.0 million tons (4.1 km^3), supplied by 2.8 million tons (5.3 km^3) for import including 49 thousand tons (0.10 km^3) for export because it has no wheat production. Kazakhstan in Central Asia is also another exception. It is a net exporter country because 1,574 m^3/capita is imported whereas 443 m^3/capita is exported. In Kazakhstan, wheat production and import are 16 million tons and 0.14 million tons (56 km^3 and 0.34 km^3), respectively, which are used to meet 6.3 million tons (22 km^3) for export and 1.7 million tons (5.7 km^3) for final demand.

All the countries in Eastern Asia are also grouped as net importers previously described because of their diverse food consumption pattern. For example, Mainland China is the most influential country in determining the food demand and supply of Eastern Asia because its freshwater requirement for domestic production and that for final demand account for 79% (2,259 km^3) of the supply-side total freshwater requirement (2,865 km^3) and 78% (1,682 km^3) of demand-side total freshwater requirement in Eastern Asia (2,146 km^3), respectively. Comparing the freshwater requirement per capita in Mainland China, the freshwater requirement for domestic production (1,661 m^3/capita) is larger than that for final demand (1,237 m^3/capita), while the imported freshwater requirement volume (146 m^3/capita) is higher than the exported freshwater requirement volume (31 m^3/capita). In this country, the imported freshwater requirement of oils (154 km^3) is the greatest source, followed by cereals (16 km^3) and meats (9.7 km^3). This country imports 50 million tons of soybeans, classified into oil crops in this study, corresponding to 98 km^3 of freshwater requirement of imported oils or 64% of its total freshwater requirements of imported oils (154 km^3). Importing soybeans is necessary to meet the 62 million tons for domestic consumption including 5.2 million tons (14 km^3) for final demand, as well as the 281 thousand tons (0.73 km^3) for export because the 15 million tons (39 km^3) for domestic production is less than the domestic consumption. In this country, soybeans are mainly imported from the United States of America (22 million tons) and Brazil (18 million tons), accounting for 45% and 37% of the total imported volume in Mainland China (50 million tons), respectively.

Here, our simulation value of blue water withdrawal for import (11 km^3) and that for export (6.4 km^3) in Mainland China are similar to the 14 km^3 for import and 7.0 km^3 for export estimated by Hun et al. (2017). Zhang and Anadon (2014) estimated national water withdrawal (360 km^3) and consumption (222 km^3) in Mainland China, the former is higher than the blue water withdrawal (669 km^3) in our study, whereas the latter is less than blue water consumption in our study (131 km^3). This difference should be caused by different simulation methods between our study and Zhang and Anadon (2014). Our study applied rice to low irrigation efficiency (0.1) when calculating blue water withdrawal. These two previous studies on MRIO analysis did not refer to green water, with targeted item categories less complete than our study, because both studies targeted only two sectors: the agricultural and food and beverages sectors, and more detailed items of each sector are not clear. This result shows that more extensive item categories than those of MRIO are essential to avoid underestimation in the analysis using coarse item categories.

In addition, comparing freshwater consumption per capita for final demand in Mainland China, our simulation value shows a similar preference to that of Mekonnen and Hoekstra (2011b) as total freshwater consumption of foodstuffs. In our simulation value, the largest item is freshwater consumption of meats (375 m^3/capita), followed by cereals (106 m^3/capita), rice (99 m^3/capita), vegetables (76 m^3/capita), fruit (excluding wines) (“fruits” hereafter) (73 m^3/capita), oils (46 m^3/capita), and milk (excluding butter) (“milk” hereafter) (33 m^3/capita). This tendency is consistent with Mekonnen and Hoekstra (2011b), which showed that freshwater consumption of meats (301 m^3/capita), cereals (138 m^3/capita), rice (109 m^3/capita), vegetables (57 m^3/capita), fruits (48 m^3/capita), oils (43 m^3/capita), and milk (14 m^3/capita), etc. They referred to both green and blue water. Reviewing the sum of green water consumption and blue water requirement per capita considering irrigation efficiency for blue water, in Mainland China, its freshwater requirement of meats for final demand (420 m^3/capita) is the greatest, followed by rice (373 m^3/capita), cereals (161 m^3/capita), vegetables (79 m^3/capita), fruits (78 m^3/capita), oils (50 m^3/capita), and milk (41

m^3/capita). This tendency substantially agrees with that of Mekonnen and Hoekstra (2011b). Comparing freshwater consumption and requirements, rice of the latter case goes up from third to second place in our study because of rice's relatively high irrigation efficiency (0.1).

6. Comparison of Malaysia with Indonesia Focusing on Palm Oil

As previously described, Malaysia actively exports palm oils to Eastern Asia, such as Mainland China (14 km^3), Japan (2.3 km^3), and the Republic of Korea (1.4 km^3) as the freshwater requirement. In Mainland China, the imported freshwater requirement of oils (154 km^3) accounts for 78% of its total imported freshwater requirement (198 km^3). In Malaysia, the exported freshwater requirement of palm oil is 63 km^3 accounting for 84% of that of oils (75 km^3). For domestic production in Malaysia, the freshwater requirement for palm oil is nearly equal to 67 km^3, whereas that for oils is nearly equal to 82 km^3. This fact shows that Malaysia actively produces palm oils for export to other countries, mainly in Eastern Asia.

As an additional consideration, we try to predict the future transition of freshwater requirement for the domestic production of palm oil in Malaysia, along with comparing it to that in Indonesia. In our study, the current freshwater requirement for domestic production of palm oil in Malaysia is estimated at 67 km^3, less than that in Indonesia (88 km^3) in 2010. Then, Malaysia and Indonesia export 63 km^3 and 67 km^3 of palm oil as freshwater requirement, respectively, while Malaysia imports 6.6 km^3 and Indonesia imports 0.30 km^3. When dividing individual freshwater requirement by the population of each country in 2010 (Malaysia approx. 28.1 million and Indonesia approx. 243 million) according to the FAOSTAT database, the freshwater requirement for the domestic production of palm oil is estimated at 2,369 m^3/capita for Malaysia and 362 m^3/capita for Indonesia, respectively, on a country-level average. On the other hand, according to Afriyanti et al. (2016), Sumatra and Kalimantan in Indonesia have 95% of Indonesia's total oil palm plantations. Thus, setting the domestic production of palm oil as 20.4 million tons, which is equivalent to 95% of the total in Indonesia (21.5 million tons) in 2010, the freshwater requirement for the domestic production of palm oil is recalculated at 84 km^3. Dividing this value by the sum of approx. 50.6 million in Sumatra and approx. 14.5 million in Kalimantan in 2010, the freshwater requirement per capita for the domestic production of palm oil is recalculated at 1,296 m^3/capita. Here, the population of Sumatra is the sum of population of its ten provinces while that of Kalimantan is the total population of its five provinces including one province (Kalimantan Utara) with insufficient data in 2010, according to the Badan Pusat Statistk (BPS, 2019).

It is necessary to note that there is a slight difference between Indonesia's population data in 2010 according to the FAOSTAT database (approx. 243 million) and the BPS (approx. 238 million). These results show Malaysians are required to incur a significantly heavier water consumption per capita than Indonesians. According to the ratio of freshwater requirement for domestic production of palm oil to total renewable water requirements according to the AQUASTAT database substituting values in 2010 for those in 2012 because of lacking data, Malaysia and Indonesia are 0.11 and 0.044, respectively. The former has a higher water consumption load than the latter.

When assuming a positive proportional relationship between freshwater requirement and population in the future, all other things being equal, future freshwater requirements for the domestic production of palm oil in Malaysia and Indonesia are calculated by multiplying the individual freshwater requirements per capita described as the aforementioned volumes by the estimated population in 2050 (Malaysia approx. 41 million and Indonesia approx. 331 million) (UNDESA, 2019).

Malaysia and Indonesia are estimated at 96 km^3 and 120 km^3, respectively. In addition, according to Mekonnen and Hoekstra (2011b), Malaysia's palm oil needs a high green water volume

(3,737 m^3/ton) despite no blue water contribution, which is less than Indonesia's green water volume (4,095 m^3/ton) under no blue water consumption. This fact should be a reason that Malaysia is more actively producing palm oil for export than Indonesia, which shows that Malaysia tends to have a heavy load of water consumption to produce palm oil for export. The former is a less water consumptive country than the latter when comparing their freshwater requirements (not per capita volumes) with each other. Thus, from the perspective of freshwater use, Malaysia could decrease the load of freshwater consumption by reducing its export of palm oil. However, domestic production to export palm oil should be an important economic activity for Malaysia because this country produces approximately 39% of the global production of palm oil (46 million tons) according to our simulation values, even though this is not sustainable from the viewpoint of freshwater consumption. It suggests that there is a trade-off relationship between freshwater consumption and economic benefit.

As indicated by Varkkey et al. (2018), Malaysia has implemented "the Malaysian government's voluntary pledge in the late 1990s to keep 50% forest cover" to constrain the deforestation because the land area for palm oil is expanding from year to year. Considering an extreme example, if no future improvement in productivity and technology occurred in Malaysia, it seems that keeping to the no deforestation to expand the cultivation area for palm oil production policy could become difficult and encourage blue water consumption that has never emerged before as well as additional green water consumption. In this extreme case under the assumption described as the aforementioned preconditions, Malaysia needs to decrease by 29 km^3 or 727 m^3/capita of freshwater requirement for domestic production of palm oil in 2050 to keep the level of its current status (67 km^3 or 2,369 m^3/capita) because its future freshwater requirement could reach 96 km^3 in 2050.

This predicted value required to decrease is less than current net trade volume of freshwater requirement of palm oil in Malaysia (56 km^3), calculated by subtracting the imported freshwater requirement volume from the exported freshwater requirement volume. However, it seems to be difficult to reduce the export quantity under market forces because freshwater consumption per production of palm oil in Malaysia is more effective than that in Indonesia due to the aforementioned reason. In fact, in 2010, Malaysia exported 17 million tons or 63 km^3 of palm oil around the world while its main export partner was Mainland China (3.8 million tons or 14 km^3) accounting for 23% of its total exported volumes of palm oil, followed by Pakistan (1.7 million tons or 8.4 km^3), and India (1.2 million tons or 4.3 km^3). On the other hand, Indonesia globally exports 16 million tons or 67 km^3 of palm oil partly exported to Malaysia (1.5 million tons or 6.2 km^3) accounting for 9.2% of its total exported volumes, which is less than to India (4.3 million tons or 18 km^3), and to Mainland China (2.5 million tons or 10 km^3). The total exported volumes of palm oil from Malaysia are higher than those from Indonesia.

Thus, as long as no improvement in water consumption efficiency is expected in Indonesia, this tendency could push up Malaysia's exports of palm oil in the future. As an alternative plan to control production, if Indonesia reduces its freshwater requirement for the domestic production of palm oil to the same level as Malaysia (3,737 m^3/ton), Indonesia can additionally produce 2.8 million tons (10 km^3) in 2050 more than its current status under the same situation as the aforementioned preconditions previously described. Thus, if only Malaysia could import all of the 10 km^3 of palm oil from Indonesia, Malaysia can save as much freshwater requirement as they can import. For the next step, technological improvements in food production, water use management, and resource management are important to arrive at future sustainability in both countries.

Comparing green water consumption volume per production of palm oil in Malaysia and that in Indonesia, the former (3,737 m^3/ton) is more effective than the latter (4,095 m^3/ton) as previously described. Blue water is not consumed to produce palm oil in both countries. Thus, if Indonesia's green water consumption is not improved, the export volume of palm oil from Malaysia is expected to continue to increase for the future under market forces, which could lead to additional deforestation in Malaysia. In this case, the rational next step to save Malaysia's decreasing forest area would be to improve the water consumption efficiency of palm oil production in Indonesia. If, as mentioned above, Indonesia can increase its production equal to 2.8 million tons or 10 km^3, as derived from the improvement in water use efficiency by Malaysia's level of green water consumption of palm oil, Malaysia can create an opportunity to import palm oil from Indonesia.

Austin et al. (2017) indicated that, as a national-wide simulation, one-fifth of the palm oil plantations located in Indonesia's peatlands expanded by 619 kha in the 2010-2015 period. This is approximately twice as much as the 305 kha expansion in the 1995-2000 period, not considering the possibility of pervious drainage or degradation for other use when converting peatland into palm oil plantation. Then, Austin et al. reported that deforestation in Indonesia tended to decrease from 788 kha in the 1995-2000 period to 585 kha in the 2010-2015 period, though deforestation in the 2000-2005 period was 357 kha, the minimum value in all the periods, and that of the 2005-2010 period was 616 kha, significant rebound from the 2000-2005 period. Austin et al. also added that the forest clearing for new plantations has occurred in secondary forest (94.9%) more than in primary forest (5.1%).

In addition, according to Afriyanti et al. (2016), Indonesia's palm oil plantations are mostly distributed in Sumatra and Kalimantan occupying 95% of its total palm oil plantation. Afriyanti et al. also indicated that the conversion of peatland into palm oil plantation has increased from 1995 to 2010 in both regions. For example, the conversion of peatland into palm oil plantation in the 2005-2010 period is calculated as approx. 1.4 Mha larger than approx. 0.4 Mha in the 1990-2000 period in Sumatra, which is the largest producing area in the three target regions of Afriyanti et al.'s study (Sumatra, Kalimantan, and Papua). According to Pirker et al. (2016), in Indonesia, poorly drained soils are identical to peatlands and other soils often equated to areas with high levels of organic matters. According to Afriyanti et al. (2016), reviewing the area of palm oil plantations across Indonesia in the 2010-2015 period, palm oil is produced in both non-peat and peat land, such as swamp or swamp scrubland (541 kha overlaid 36% peat soils), forest land (540 kha in the primary forest and 45 kha in the secondary forest, overlaid 33% and 25% peat soils, respectively), and timber plantation (130 kha overlaid 35% peat soils), etc., in descending order of the area of peatlands.

In addition, as previously stated above, Indonesia's palm oil plantation in the peatland tends to increase from the 1995-2000 period to the 2010-2015 whereas that in the deforestation areas tends to decrease during the same period. This fact shows that it seems to be difficult to continue to produce palm oil in the same cultivated land because of the land degradation due to the long-term production of palm oil in the peatland resulting in the surface soil runoff of nutrient salts (Haraguchi, 2014). From this perspective, compared to Malaysia, the efficiency of green water consumption for the production of palm oil in Indonesia could be enhanced by reducing land degradation and thus improving the water retention capacity of the soil. Thus, not only the aforementioned improvements, but also land improvement and land use management could be the meaningful options to reduce the green water consumption of palm oil in Indonesia.

As another option to help, even if only slightly, reduce additional imports of palm oil in Malaysia as the aforementioned previously described, it could be helpful to substitute more environmental-friendly items for palm oils to reduce the respective green water consumption volumes of Malaysia and Indonesia. According to FAO (2002), palm oil fruits are composed of four parts: the exocarp, mesocarp, endocarp, and kernel. Palm oil is extracted from the pulp or mesocarp, whereas palm kernel oil is extracted from the kernel, whose chemical composition and property differ from the palm oil. In the FAOSTAT, the extraction rate for palm oil is defined as from the 17% to 27%, and that for palm kernel oil is defined as from the 4% to 10%, including the variation to a certain extent. In this regard, as palm oil fruits can supply both oils, it is meaningful to review the water consumption for the production of palm oil fruits. Then, maize is set as a compared item to palm oil fruits since it consumes less water in its production than the palm oil fruits in both Malaysia and Indonesia.

Considering maize as a substituted item, Indonesia's domestic production increased from 19 Mtons in 2010 to 28 Mtons in 2017, while Malaysia's domestic production increased from 48 ktons in 2010 to 73 ktons in 2017, according to the FAOSTAT. Reviewing water consumption volume for the production of maize, Indonesia is 1,349 m^3/ton from green water and 36 m^3/ton from blue water, whereas Malaysia is 990 m^3/ton from green water and 33 m^3/ton from blue water. By multiplying domestic production by the sum of green and blue water consumption per production, water consumption volume of maize in Indonesia is estimated at 25 km^3 in 2010 and 39 km^3 in 2017, while that in Malaysia is estimated at 49 million m^3 in 2010 and 74 million m^3 in 2017. On the other hand, the domestic production of palm oil fruits in Indonesia increased from 98 Mtons in 2010 to 158 Mtons in 2017, while that in Malaysia increased from 83 Mtons in 2010 to 102 Mtons in 2017.

Reviewing water consumption volume per production of palm oil fruits, Indonesia is 2,362 m^3/ton from only green water, whereas Malaysia is 2,156 m^3/ton from only green water. Comparing maize to palm oil fruits in each country, maize is a more effective consumer of water than palm oil fruits. This fact shows that maize is an environmental-friendly item for both countries if a shift in production from palm oil fruits to maize occurs in the two countries. However, compared with the changes in yields of maize in 2010 and 2017 in both countries, the yield in Indonesia increased from 4,436 kg/10a in 2010 to 5,200 kg/10a in 2017, while that in Malaysia from 553 kg/10a in 2010 to 692 kg/10a in 2017. Similarly, comparing the changes in yields of palm oil fruits in 2010 and 2017 in both countries, the yield in Indonesia increased from 16,920 kg/10a in 2010 to 17,067 kg/10a in 2017, while that in Malaysia from 17,119 kg/10a in 2010 to 19,907 kg/10a in 2017. All of this data is calculated based on the FAOSTAT. The comparison of these yields shows that the yields of palm oil fruits is much larger than that of maize in both countries, which could show the predominant productivity of palm oil fruits that can be harvested all the year around. Although the production of maize tended to increase from 2010 to 2017 in both countries, substituting the production of maize for that of all palm oil fruits seems to be unrealistic considering the outstanding productivity of palm oil fruits.

Thus, under the predominant productivity of palm oil fruits, it is important to make an effort to continue to make improvements in the productivity of palm oil fruits and gradually replace palm oil fruits with maize, which is seen as a more environmental-friendly item than palm oil fruits in our trial calculation, under suitable managements beyond our study's field.

7. Conclusion

This study evaluated the current freshwater requirement in Asian countries considering the global food trade and food supply-demand balances. Moreover, as an addition analysis, water consumption for domestic production of palm oil in Malaysia was compared with that in Indonesia under a simple future prediction of water consumption by using our estimates to show how to utilize our simulation data.

By comparing supply-side and demand-side freshwater requirements, Western Asia showed a relatively high import dependence while Central Asia, Southern Asia, and South-Eastern Asia tended on aggregate to be producing countries. Eastern Asia and Southern Asia were major producing and consuming areas because the freshwater requirements of the two are much higher than those of the other areas. In Eastern Asia, the freshwater requirement for domestic production and that for final demand are 2,455 km^3 and 1,972 km^3, respectively. Eastern Asia is the highest importer area, whose total imported freshwater requirement volume is 397 km^3, accounting for 39% of the global total imported freshwater requirement volume (1,015 km^3). In Southern Asia, the freshwater requirements for domestic production and for final demand are 3,479 km^3 and 2,824 km^3, respectively, while the total exported freshwater requirement volume is 240 km^3. Thus, Eastern Asia and Southern Asia are major producing and consuming areas because the freshwater requirements of the two are much higher than those of the other areas.

By comparing the imported and exported freshwater requirements, Eastern Asia actively utilizes both inter-regional and intra-regional trade while in other Asian areas intra-regional trade appears to be more dominant than inter-regional trade. It was concluded that as Eastern Asia mainly imports oils (190 km^3), cereals (69 km^3), and meats (59 km^3), it is Asia's largest importer of imported freshwater volume, with a total volume of 397 km^3, mainly from Asia (117 km^3), North America (129 km^3), and South America (94 km^3). In contrast, South-Eastern Asia is the largest exporter area, whose total exported freshwater volume corresponds to 421 km^3. South-Eastern Asia predominantly exports oil crops and oils (180 km^3), rice (105 km^3), and beverages (53 km^3).

Comparing the country estimates, nearly all of the Central and Western Asian countries are net importing countries. All countries in Eastern Asia are also in the same group as previously described because of their diverse food consumption pattern. In contrast, nearly all the South-Eastern and Southern Asian countries are categorized as net exporting countries. For example, Malaysia predominantly exports palm oil because its exported freshwater requirement volume is 63 km^3, accounting for 84% of its total freshwater requirement. The main export partners are Eastern Asian countries, such as Mainland China, Japan, and the Republic of Korea. In fact, each exporting country's share of the total exported volume of palm oil (5.0 million tons) in Malaysia is 76% (3.8 million tons) in Mainland China, 12% (616 thousand tons) in Japan, and 7.4% (374 thousand tons) in the Republic of Korea, respectively.

Comparing green water consumption volume for the production of palm oil in Malaysia and that in Indonesia, the former (3,737 m^3/ton) is more effective than the latter (4,095 m^3/ton) as previously described. Blue water is not consumed to produce palm oil in both countries. Thus, if Indonesia's green water consumption is not improved, the export volume of palm oil from Malaysia is expected to continue to increase for the future under market forces, which could lead to additional deforestation in Malaysia. As an alternative plan to control production, if Indonesia reduces its freshwater requirement for the domestic production of palm oil to the same level as Malaysia (3,737 m^3/ton), Indonesia can additionally produce 2.8 million tons (10 km^3) in 2050 more than its current status when assuming a positive proportional relationship between freshwater requirement and population in the future, all other things being equal. Thus, if only Malaysia could import all of the 10 km^3 of palm oil from Indonesia, Malaysia can save as much freshwater requirement as they can import. For the next step, technological improvements in food production, water use management, and resource management are important to arrive at future sustainability in both countries. Additionally, in the aforementioned preconditions, improvement in the water consumption efficiency of palm oil in Indonesia seems to be rational to save Malaysia's forest area. Thus, not only the aforementioned improvements, but also land improvement and land use management could be the meaningful options to reduce the green water consumption of palm oil in Indonesia. In addition, under the predominant productivity of palm oil fruits, it is important to make an effort to continue to improve the productivity of palm oil fruits and gradually replace palm oil fruits with maize, seen as a more environmental-friendly item than palm oil fruits, in our trial calculation, under suitable managements beyond our study's field.

We believe that our simulation data can be a trigger to find the potential problems by reviewing the current conditions in each country related to food supply and demand through the food supply-demand balance considering food trade balances on the global scale interacting with each other. In addition, we expect that an elaborated future prediction based on these data is also extensible for the next step. As can be seen from our comparison of water consumptions for the production of palm oil between in Malaysia and in Indonesia, this study can be used as a reference to aid in the accumulation of scientific knowledge to arrive at future sustainability in Asia and involving other regions.

Acknowledgment: This research was partially supported by the Program for the Strategic Research Foundation at Private Universities, Ministry of Education, Culture, Sports, Science and Technology (MEXT) Japan (S1411032).

Appendixes:

Table S1 Target Countries

Area Name (8 Areas)	Area Name (24 Areas)	Country Name
Asia	Central Asia	Kazakhstan
Asia	Central Asia	Kyrgyzstan
Asia	Central Asia	Tajikistan
Asia	Central Asia	Turkmenistan
Asia	Central Asia	Uzbekistan
Asia	Eastern Asia	China, Hong Kong SAR
Asia	Eastern Asia	China, Macao SAR
Asia	Eastern Asia	China, mainland
Asia	Eastern Asia	China, Taiwan Province of
Asia	Eastern Asia	Democratic People's Republic of Korea
Asia	Eastern Asia	Japan
Asia	Eastern Asia	Mongolia
Asia	Eastern Asia	Republic of Korea
Asia	South-Eastern Asia	Brunei Darussalam
Asia	South-Eastern Asia	Cambodia
Asia	South-Eastern Asia	Indonesia
Asia	South-Eastern Asia	Lao People's Democratic Republic
Asia	South-Eastern Asia	Malaysia
Asia	South-Eastern Asia	Myanmar
Asia	South-Eastern Asia	Philippines
Asia	South-Eastern Asia	Singapore
Asia	South-Eastern Asia	Thailand
Asia	South-Eastern Asia	Timor-Leste
Asia	South-Eastern Asia	Viet Nam
Asia	Southern Asia	Afghanistan
Asia	Southern Asia	Bangladesh
Asia	Southern Asia	Bhutan
Asia	Southern Asia	India
Asia	Southern Asia	Iran (Islamic Republic of)
Asia	Southern Asia	Maldives
Asia	Southern Asia	Nepal
Asia	Southern Asia	Pakistan
Asia	Southern Asia	Sri Lanka
Asia	Western Asia	Armenia
Asia	Western Asia	Azerbaijan
Asia	Western Asia	Bahrain
Asia	Western Asia	Cyprus
Asia	Western Asia	Georgia
Asia	Western Asia	Iraq
Asia	Western Asia	Israel
Asia	Western Asia	Jordan
Asia	Western Asia	Kuwait
Asia	Western Asia	Lebanon
Asia	Western Asia	Occupied Palestinian Territory
Asia	Western Asia	Oman
Asia	Western Asia	Qatar
Asia	Western Asia	Saudi Arabia
Asia	Western Asia	Syrian Arab Republic
Asia	Western Asia	Turkey
Asia	Western Asia	United Arab Emirates
Asia	Western Asia	Yemen

Table S1 Target Countries (Continued)

Area Name (8 Areas)	Area Name (24 Areas)	Country Name
Africa	Eastern Africa	Burundi
Africa	Eastern Africa	Comoros
Africa	Eastern Africa	Djibouti
Africa	Eastern Africa	Eritrea
Africa	Eastern Africa	Ethiopia
Africa	Eastern Africa	Kenya
Africa	Eastern Africa	Madagascar
Africa	Eastern Africa	Malawi
Africa	Eastern Africa	Mauritius
Africa	Eastern Africa	Mayotte
Africa	Eastern Africa	Mozambique
Africa	Eastern Africa	Rwanda
Africa	Eastern Africa	Seychelles
Africa	Eastern Africa	Somalia
Africa	Eastern Africa	Uganda
Africa	Eastern Africa	United Republic of Tanzania
Africa	Eastern Africa	Zambia
Africa	Eastern Africa	Zimbabwe
Africa	Middle Africa	Angola
Africa	Middle Africa	Cameroon
Africa	Middle Africa	Central African Republic
Africa	Middle Africa	Chad
Africa	Middle Africa	Congo
Africa	Middle Africa	Democratic Republic of the Congo
Africa	Middle Africa	Equatorial Guinea
Africa	Middle Africa	Gabon
Africa	Middle Africa	Sao Tome and Principe
Africa	Northern Africa	Algeria
Africa	Northern Africa	Egypt
Africa	Northern Africa	Libya
Africa	Northern Africa	Morocco
Africa	Northern Africa	Sudan (former)
Africa	Northern Africa	Tunisia
Africa	Southern Africa	Botswana
Africa	Southern Africa	Lesotho
Africa	Southern Africa	Namibia
Africa	Southern Africa	South Africa
Africa	Southern Africa	Swaziland
Africa	Western Africa	Benin
Africa	Western Africa	Burkina Faso
Africa	Western Africa	Cabo Verde
Africa	Western Africa	Cﾃｴte d’Ivoire
Africa	Western Africa	Gambia
Africa	Western Africa	Ghana
Africa	Western Africa	Guinea
Africa	Western Africa	Guinea-Bissau
Africa	Western Africa	Liberia
Africa	Western Africa	Mali
Africa	Western Africa	Mauritania
Africa	Western Africa	Niger
Africa	Western Africa	Nigeria
Africa	Western Africa	Saint Helena, Ascension and Tristan da Cunha
Africa	Western Africa	Senegal
Africa	Western Africa	Sierra Leone
Africa	Western Africa	Togo

Table S1 Target Countries (Continued)

Area Name (8 Areas)	Area Name (24 Areas)	Country Name
Europe	Eastern Europe	Belarus
Europe	Eastern Europe	Bulgaria
Europe	Eastern Europe	Czechia
Europe	Eastern Europe	Hungary
Europe	Eastern Europe	Poland
Europe	Eastern Europe	Republic of Moldova
Europe	Eastern Europe	Romania
Europe	Eastern Europe	Russian Federation
Europe	Eastern Europe	Slovakia
Europe	Eastern Europe	Ukraine
Europe	Northern Europe	Denmark
Europe	Northern Europe	Estonia
Europe	Northern Europe	Faroe Islands
Europe	Northern Europe	Finland
Europe	Northern Europe	Iceland
Europe	Northern Europe	Ireland
Europe	Northern Europe	Latvia
Europe	Northern Europe	Lithuania
Europe	Northern Europe	Norway
Europe	Northern Europe	Sweden
Europe	Northern Europe	United Kingdom
Europe	Southern Europe	Albania
Europe	Southern Europe	Andorra
Europe	Southern Europe	Bosnia and Herzegovina
Europe	Southern Europe	Croatia
Europe	Southern Europe	Greece
Europe	Southern Europe	Italy
Europe	Southern Europe	Malta
Europe	Southern Europe	Montenegro
Europe	Southern Europe	Portugal
Europe	Southern Europe	Serbia
Europe	Southern Europe	Slovenia
Europe	Southern Europe	Spain
Europe	Southern Europe	The former Yugoslav Republic of Macedonia
Europe	Western Europe	Austria
Europe	Western Europe	Belgium
Europe	Western Europe	France
Europe	Western Europe	Germany
Europe	Western Europe	Luxembourg
Europe	Western Europe	Netherlands
Europe	Western Europe	Switzerland
South America	South America	Argentina
South America	South America	Bolivia (Plurinational State of)
South America	South America	Brazil
South America	South America	Chile
South America	South America	Colombia
South America	South America	Ecuador
South America	South America	Falkland Islands (Malvinas)
South America	South America	Guyana
South America	South America	Paraguay
South America	South America	Peru
South America	South America	Suriname
South America	South America	Uruguay
South America	South America	Venezuela (Bolivarian Republic of)

Table S1 Target Countries (Continued)

Area Name (8 Areas)	Area Name (24 Areas)	Country Name
North America	Caribbean	Anguilla
North America	Caribbean	Antigua and Barbuda
North America	Caribbean	Aruba
North America	Caribbean	Bahamas
North America	Caribbean	Barbados
North America	Caribbean	British Virgin Islands
North America	Caribbean	Cayman Islands
North America	Caribbean	Cuba
North America	Caribbean	Dominica
North America	Caribbean	Dominican Republic
North America	Caribbean	Grenada
North America	Caribbean	Haiti
North America	Caribbean	Jamaica
North America	Caribbean	Montserrat
North America	Caribbean	Netherlands Antilles (former)
North America	Caribbean	Saint Kitts and Nevis
North America	Caribbean	Saint Lucia
North America	Caribbean	Saint Vincent and the Grenadines
North America	Caribbean	Trinidad and Tobago
North America	Caribbean	Turks and Caicos Islands
North America	Central America	Belize
North America	Central America	Costa Rica
North America	Central America	El Salvador
North America	Central America	Guatemala
North America	Central America	Honduras
North America	Central America	Mexico
North America	Central America	Nicaragua
North America	Central America	Panama
North America	Northern America	Bermuda
North America	Northern America	Canada
North America	Northern America	Greenland
North America	Northern America	Saint Pierre and Miquelon
North America	Northern America	United States of America
Oceania	Australia & New Zealand	Australia
Oceania	Australia & New Zealand	New Zealand
Oceania	Melanesia	Fiji
Oceania	Melanesia	New Caledonia
Oceania	Melanesia	Papua New Guinea
Oceania	Melanesia	Solomon Islands
Oceania	Melanesia	Vanuatu
Oceania	Micronesia	Guam
Oceania	Micronesia	Kiribati
Oceania	Micronesia	Marshall Islands
Oceania	Micronesia	Micronesia (Federated States of)
Oceania	Micronesia	Nauru
Oceania	Micronesia	Palau
Oceania	Polynesia	American Samoa
Oceania	Polynesia	Cook Islands
Oceania	Polynesia	French Polynesia
Oceania	Polynesia	Niue
Oceania	Polynesia	Samoa
Oceania	Polynesia	Tonga
Oceania	Polynesia	Tuvalu
Oceania	Polynesia	Wallis and Futuna Islands
Antarctic Region	Antarctic Region	French Southern and Antarctic Territories
Unspecified Area	Unspecified Area	Unspecified Area

References

Abdelkader, A., Elshorbagy, A., Tuninetti, M., Laio, F., Ridolfi, L., Fahmy, H. & Hoekstra, Y. A. 2018. *Science of the Total Environment*, Vol.639, pp.485-496.

Afriyanti, D., Kroeze, C. & Saad, A. 2016. *Science of the Total Environment*, Vol.557-558, pp.562-570.

Austin, G. K., Mosnier, A., Pirker, J., McCallum, I., Fritz, S. & Kasibhatla, P. S. 2017. *Land Use Policy*, Vol.69, pp.41-48.

Badan Pusat Statistik (BPS), 2019. *Perkembangan Beberapa Indikator Utama Sosial Ekonomi Indonesia Agustus 2019*. No.03230.1940, pp.13.

Döll, P & Siebert, S. 2002. *Water Resources Research*, Vol.38, No.4, pp.8-1-8-10.

Food and Agriculture Organization of the United Nations (FAO). AQUASTAT, http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en, accessed on July 1, 2019.

Food and Agriculture Organization of the United Nations (FAO). FAOSTAT, http://www.fao.org/faostat/en/#data accessed on August 18, 2019.

Food and Agriculture Organization of the United Nations (FAO). 2001. *Food Balance Sheets a Handbook*, http://www.fao.org/docrep/003/x9892e/x9892e00.htm, accessed on December 17, 2018.

Food and Agriculture Organization of the United Nations (FAO). 2002. *FAO Agricultural Services Bulletin 148*, http://www.fao.org/3/Y4355E/y4355e00.htm, accessed on August 24, 2019.

Han, M., Dunford, M., Chen, G., Liu, W., Liu, Y. & Liu S. 2017. *Journal of Cleaner Production*, Vol.164, pp.188-189.

Haraguchi, A. 2014. *Fire and Environmental Safety*, Vol.3, No.1, pp.2-7 (in Japanese).

Hoekstra, Y. A. & Hung, Q. P. 2002. *Value of Water Research Report Series No.11*. pp.1-120.

Hoekstra, Y. A., Chapagain, K. A., Aldaya M. M. & Mekonnen M. M. 2011. *The Water Footprint Assessment Manual Setting the Global Standard*. Earthscan; London: UK. pp.1-228.

International Organization and Standardization (ISO). ISO 14046 Briefing Note. https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/iso14046_briefing_note.pdf, accessed on April 11, 2019

Kosaka, H., Fuse M. & Kashima S. 2012. *Japan Transport and Tourism Research Institute*, Vol.15, No.2, pp.020-031 (in Japanese).

Ministry of Education, Culture, Sports, Science and Technology (MEXT). 2010. Standard Tables of Food Composition in Japan – 2010 (in Japanese). http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu3/houkoku/1298713.htm, accessed on April 11, 2019.

Mekonnen, M. M. & Hoekstra, Y. A. 2010, *Value of Water Research Report Series No. 48*, Vol.1, pp.1-50.

Mekonnen, M. M. & Hoekstra, Y. A. 2011a, *Value of Water Research Report Series No.50*, Vol.1, pp.1-50.

Mekonnen, M. M. & Hoekstra, Y. A. 2011b, *Value of Water Research Report Series No.50*, Vol.2, pp. VI-1-VI-23.

National and Regional Planning Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). 2004. *"Shizenkai no busshitsujunkan eno huka no shukunai shakai o mezashita shigensyōhisuijun no arikata kentōchousahoukokusho"* [Investigation Report on the Examination into Way of Resource Consumption Level Aimed at Low Load Society on Resource Circulation in Natural World]. Reference 3-1-Reference 3-11 (in Japanese).

Pirker, J., Mosnier A., Kraxner F., Havlik P. & Obersteiner M. 2016. Global Environmental Change, Vol.40, pp.73-81.

Shen, Y., Oki, T., Utsumi, N., Kanae, S. & Hanasaki, N. 2008. *Hydrological Sciences Journal*, Vol.53, No.1, pp.11-33.

United Nations Department of Economic and Social Affairs (UNDESA). 2019. World Population Prospects 2019, https://population.un.org/wpp/Download/Standard/CSV/, accessed on June 29, 2019.
United States Department of Agriculture (USDA). 1992. *Agricultural Handbook*. No.697, Economic Research Service; USA. pp.1-77. https://www.ers.usda.gov/publications/pub-details/?pubid=41881, accessed on April 11, 2019.
Varkkey, H., Tyson, A. & Choiruzzad, B., A., S. 2018. *Forest Policy and Economics*, Vol.92, pp.148-159.
White, J. D, Hubacek, K., Feng, K., Sun, L. & Meng B. 2018. *Applied Energy*, pp.550-567.
Yamaguchi, Y., Tamura, K., Yoshikawa, N., Amano, K. & Hashimoto, S. 2018. *Journal of Life Cycle Assessment*, *Japan*, Vol.14, No.1, pp.21-35 (in Japanese).
Zhang C. & Anadon D. L. 2014, *Ecological Economics*, Vol.100, pp.159-172.